HOUSEHOLD PHYSICS

A TEXTBOOK FOR COLLEGE STUDENTS
IN HOME ECONOMICS

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THIRD EDITION

THE MACMILLAN COMPANY — NEW YORK

PRINTED IN THE UNITED STATES OF AMERICA

Third Printing 1957

PREFACE

The first edition of *Household Physic.* was published in 1
he second in 1946. T is third edition has been writ he
ame group of students — college students in home mics.
Some topics have been omitted, some added, and some rewritten; but in general it covers the same subject matter as the previous editions.

usehold Physics is a text in applied physics in which the applications have been chosen from the daily household life and from the various commercial fields which home-economics students nter. The rapid development of various kinds of equipment for use in the home has made it imperative that the housewife understand the principles underlying their operation. The aim has been to present the fundamentals of physics in a manner which will show their close relationship to the problems of the home, and also to treat the subject in such a way as to form a background for those students who intend to enter the commercial field. Subject matter has been selected which has proved to be valuable and interesting to the thousands of young women who have taken the course at this institution.

The mathematics has been kept as simple as possible. Problems have been included in order that the student may make actual calculations to establish relationships between the theory and the practical applications. The problems have been arranged in pairs; the answers are given for the odd-numbered problems only, with the idea that the teacher may choose the
problems with swers, those without answers, or both sets.
he study nclude those for which the answers may
those for which the student will have
o apply what she has learned.
ork should be accompanied by a
the student may have an oppor-
atory technique, and to study

at first hand the operation of household equipment. As give at Kansas State College the course consists of three credit hour in lecture-recitation and one credit hour in laboratory per wee for one semester.

The author wishes to acknowledge the assistance of all of he colleagues. Many commercial concerns have furnished photographs — these have been acknowledged individually in th text. The line drawings for the previous editions were mad by Mr. Keith Underwood. Additional ones for this editio were made by Mr. Leon Armantrout.

The suggestions and criticisms of those who use the book wil be appreciated by the author.

MADALYN AVERY

Manhattan, Kansas

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INTRODUCTION

Since the beginning of time man has come in contact with the physical world in almost everything he has undertaken to do; and he has been forced to observe physical phenomena and to obey physical laws. For years the study of these phenomena and laws was known as *natural philosophy*, but now we use the name *physics*. At first little thought was given to answering the questions "why" or "how much," but since man is compelled to obey the laws of nature it is only as he can answer these questions that he can intelligently use or oppose the forces of nature.

In early times scientific learning did not advance as rapidly as it might have because the scholars of that time were inclined to theorize as to the probable cause of certain phenomena, and their theories were not subjected to experimental tests. The experimental approach was first introduced by Galileo, a young Italian scientist, about the beginning of the seventeenth century. It was Galileo, supposedly, who first demonstrated that freely falling objects all fall at the same rate. He dropped two metal balls, one of which was much heavier than the other, from the top of the Leaning Tower of Pisa, and the two balls reached the ground at the same time. For hundreds of years it had been supposed that the velocity of a falling body depended upon the mass of the body, but no one had performed an experiment to prove that it did. Even after this demonstration many people did not accept the results; Galileo later was forced to resign his position at the University of Pisa, and during his whole lifetime he was criticized for not accepting the theories which had been handed down since the days of Aristotle. But after the experimental method had been introduced by Galileo, physics developed rapidly. It became a more exact science because the experimental approach required quantitative measurements. In recent years its growth has been remarkable.

A century or more ago most of those who pursued a college education were preparing to enter some one of the professions —

medicine, law, or the ministry. Others who attended college did so chiefly for the satisfaction that came from obtaining a broader knowledge of philosophy, art, or languages, with little or no thought of applying the knowledge in a productive manner. Today, in addition to the satisfaction which always comes with mastery of any subject, more and more value is being attached to training which carries with it some practical applications that help one to use intelligently the inventions of the modern world, and that contributes to one's ability to earn a living.

Edison in referring to the educated housewife once applied to her the term "household engineer." When one considers the number and variety of appliances that have been invented and placed at her control the term is a very apt one. In order that she may use her equipment efficiently, as well as with ease and without fear, the housewife should understand the physical laws which govern the operation of these devices.

Household Physics is a text for a course in applied physics for the "household engineer." The classical divisions of the subject have been retained. The fundamentals are the same as for any course in physics, but they have been applied to the work of the household or to that of institutions doing the work of the household. The course is intended to lay a broad enough and sound enough foundation that any student of home economics may approach with greater confidence some of the problems which arise in home management, institutional management, dietetics, textiles, or any of the other rapidly developing fields of home economics.

As a science, physics has developed a vocabulary which the student must master. The student must also learn to define terms and state laws. These definitions and laws should be stated concisely and accurately. Many of the laws may be expressed as simple mathematical formulas which are but "shorthand" statements of the laws. Formulas aid in solving problems which give concrete illustrations of the laws.

MECHANICS

INTRODUCTION TO MECHANICS

In order to study mechanics certain terms must be understood as the physicist uses them. Matter, force, mass, weight, speed, velocity, and acceleration are words which are a part of our general vocabulary; but in physics, since it is an exact science, these words and many others must be used with greater accuracy than is sometimes necessary in everyday life.

Also if we are to answer the question "how much" we must have systems of measurement with definitely established units. The ancient Chinese, Hebrews, Egyptians, and Romans each had systems of units but there was no correlation between the units of the various nations. When trade began to take place between people who were located at points some distance apart money was used as a medium of exchange, and it became increasingly important for certain units to mean the same quantity to all people; then the need for international units was recognized.

1. Systems of Units. The two chief systems of units in use today are the *English system* which had its beginning in about the thirteenth century and the *metric system* which was devised in the latter part of the eighteenth century.

Among the earliest relationships established by the English people were the following: 3 grains of barleycorn laid end to end, or 8 grains laid side by side, equal 1 inch; 12 inches equal 1 foot; 3 feet equal 1 yard. We have the survival of the 3 barleycorns in our present shoe sizes — a number 6 shoe is 1/3 inch longer than a number 5 shoe. The division of the inch into eighths had its origin in the 8 barleycorns. It is also said that during the reign of King James I the length of his foot was the official standard for length.

Government standards for these units were eventually made and kept in the Parliament buildings. But when the Parliament buildings were burned in 1834, all of the standards were destroyed. In 1855 new standards were constructed and adopted. The standard mass, made of platinum, is known as a *pound*, and the imperial yard is defined as the distance between two marks on a special bronze rod. These standards are kept in the office of the Exchequer in London. The unit of time is the *second;* it is defined as the 1/86,400 part of the mean solar day (24 hr per day × 60 min per hr × 60 sec per min = 86,400 sec per day). The English system is awkward to use when a change from one size of unit to another is necessary, because there are no simple relationships between the units. For example, 231 cubic inches equal 1 gallon, and 16 1/2 feet equal 1 rod. The only reason for its widespread usage is that it is familiar to English-speaking people.

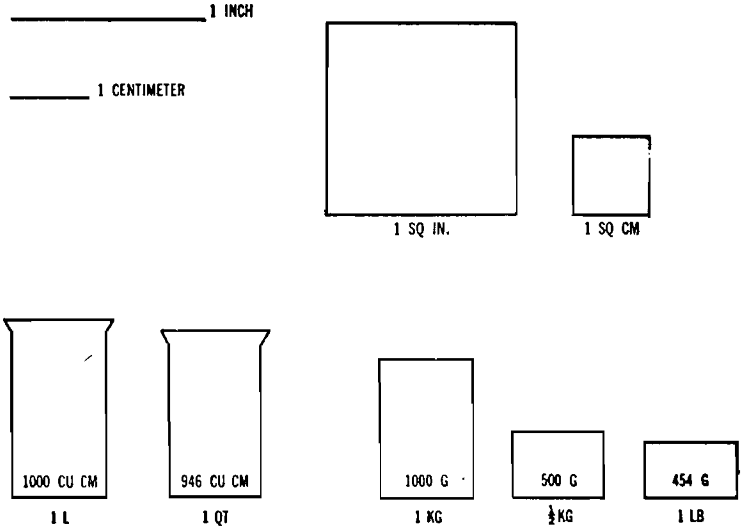

Fig. 1.1. Comparison of English and metric weights and measures.

The metric system was devised about 1791 in France. At that time the weights and measures in use in that country were far from uniform, and the lack of standardization caused more trouble there than in England; so a commission was appointed to devise a new system. The aim of this commission was to devise simple units based on standards which could never be destroyed.

The unit for length was chosen as one ten-millionth of the length of the earth's quadrant from the equator to the pole, and was named a *meter*. It was found later that an error had been made in measuring the earth's quadrant, but it was decided to keep the meter as it had been determined. The standard meter is therefore defined as the distance between two marks on a platinum-iridium bar, which is kept at the International Bureau of Standards at Sèvres, France. The standard mass, made of platinum, is known as a *kilogram*. It has the same mass as 1000 cubic centimeters of water at 4°C. A gram is equal to the mass of 1 cubic centimeter of water at 4°C. The *second* is the unit of time, just as it is in the English system, because all time units in any system are subdivisions of the time required for the earth to make one complete rotation on its axis.

The advantages of the metric system are (1) it is a decimal system, (2) there are simple relations between the units for length, area, volume, and mass, (3) it is used by most of the important nations of the world.[1]

CONVERSION FACTORS FOR ENGLISH AND METRIC UNITS

1 lb = 454 g
2.2 lb = 1 kg
1 in. = 2.54 cm
39.37 in. = 1 m (meter)
1.06 liquid qt = 1 l (liter)
1000 cu cm = 1 l (liter)

Other English and metric units and conversion factors are given in the Appendix.

2. Standardization of Weights and Measures. The Constitution of the United States provides "that Congress shall have the power to fix the standards of weights and measures." Since the states were formerly colonies of England, they adopted the English system of units, and although the system was uniform

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[1] By adding the following prefixes to the metric units (gram, meter, and liter) units of various sizes are obtained.

micro- = one millionth 0.000001
milli- = one thousandth 0.001
centi- = one hundredth 0.01
deci- = one tenth 0.1
deca- = ten 10.
hecto- = one hundred 100.
kilo- = one thousand 1,000.
mega- = one million 1,000,000.

the standards used by the various states differed considerably. It was not until 1830 that the matter received any attention from Congress. At that time standard weights and measures were made and sent to the governor of each state and to the various custom houses. In 1866 the metric system was made legal in the United States.

In 1875, seventeen of the leading countries of the world signed an agreement to establish the International Bureau of Weights and Measures at Sèvres, France. A committee was appointed to provide copies of the international standards for each of the contributing countries. The work was completed in 1889, and the copies which were sent to the United States were adopted in 1893 as the official standards of the United States. They are now kept in Washington, D. C., in the Bureau of Standards, which was established in 1899 as a part of the Department of Commerce. The bureau keeps copies of all standard weights and measures, tests the accuracy of any weights and measures which may be sent to it for inspection, furnishes the states with standards, carries on research of a physical nature, and does much good work in urging all states to adopt uniform requirements in respect to all measurements.

Provision has been made by national law for furnishing each state with standards, but it is the function of each state to enforce the use of accurate weights and measures. Practically all of the states have adopted the standards provided by the national government and a few states have very comprehensive laws in regard to inspection of weights and measures.

For hundreds of years housewives did not use any standard measuring devices. Recipes contained such vague directions as "a pinch of salt," "a dash of pepper," "sweeten to taste," "a handful of flour," or "enough flour for a thick batter." No wonder if two cooks, using the same recipe, made cakes of entirely different size and quality, even though the original ingredients were of the same grade.

Modern recipes read "1/2 teaspoon salt," "1/4 teaspoon pepper," "2/3 cup sugar," or "3/4 cup flour (measured after sifting)." There is also a trend toward replacing the capacity method with the weight method, especially in quantity cookery. The up-to-date housewife considers a measuring cup, a set of meas-

Fig. 1.2. View in the vault at the National Bureau of Standards, showing the standards of length and mass of the United States. (Courtesy National Bureau of Standards, U.S. Department of Commerce)

uring spoons, and a household scale the minimum essentials for standards. Practically everything that comes into the kitchen has been weighed or measured and the amount stamped on the container; the housewife should check these amounts, at least occasionally. The number of liquid ounces, pints, or quarts is stamped on the labels on vinegar bottles, flavoring bottles, and cans of fruit juice. Milk is delivered in standard size bottles. Canned fruits and vegetables are in standard size cans, and the weights are given in pounds and ounces.[1] Not only is the food which is brought into the home measured, but also the quantities of water, gas, and electricity, the temperature of the air, and the temperature of the oven are measured. Recently people have learned to measure the relative humidity and the intensity of illumination in their homes. Each of these measurements will be explained in this book.

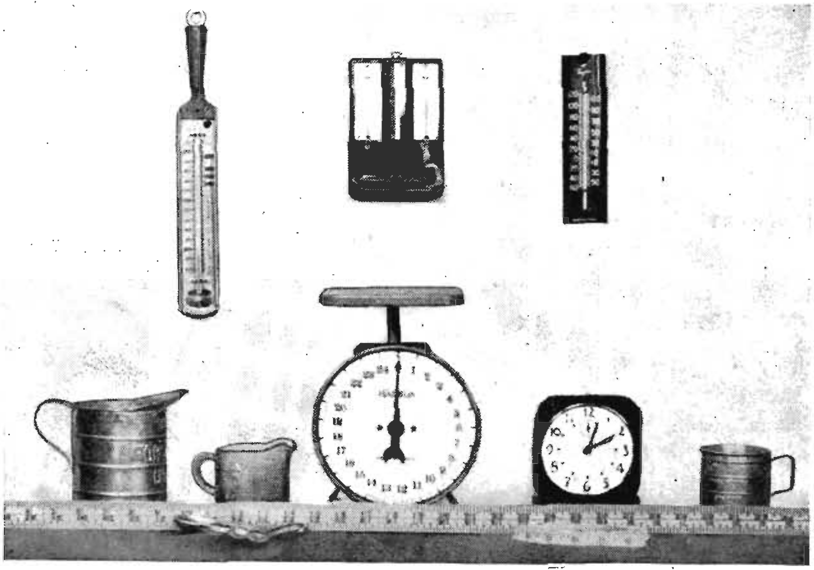

Fig. 1.3. Household measuring devices. (Courtesy Wilma Hilt Crawford, Kansas State College)

3. Fundamental and Derived Units. Some quantities such as length, mass, and time are so fundamental that they cannot be analyzed into more elementary concepts. Therefore length,

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[1] See Appendix for tables of dry and liquid measures, standard sizes of cans, and weights per bushel of foods used in large quantities in the home.

mass, and time are known as the *fundamental quantities*, and all units for these fundamental quantities are known as *fundamental units*. Examples of fundamental units are:

Length — foot, inch, meter, centimeter
Mass — pound, ounce, gram, milligram
Time — second, minute, hour

Other quantities cannot be measured without using two or more fundamental units, or using one fundamental unit more than once. For example, the amount of work required to lift a body a given distance depends upon the weight of the body and upon the distance it is lifted. The density of a body can be calculated if the mass and the volume of the body are known. The speed of a car involves the distance traveled and the time required. If a unit for length is squared or cubed, units for area or for volume are obtained. Units which are obtained by combining fundamental units are known as *derived units*. Examples of derived units are foot-pound, gram-centimeter, pounds per cubic inch, miles per hour, square inch, and cubic centimeter.

4. Matter. All material things are composed of one or more kinds of matter. *Matter is anything which occupies space and offers resistance to change in its condition of rest or motion.* Water, sugar, iron, and cloth are a few kinds of matter. All matter is made up of very small particles — either *atoms* or *molecules*. If the material is an element — such as sodium, chlorine, or iron — it is composed of particles called atoms, all of which are of the same type even though they may differ in mass. There are over ninety elements which occur in nature. Others are produced artificially. If the material is a compound, it is composed of particles called molecules which in turn are composed of atoms. For example, ordinary salt (sodium chloride) is a compound of sodium and chlorine. A molecule of salt may be separated into atoms of sodium and chlorine, but these atoms have entirely different properties from those of the compound sodium chloride.

Matter may occur in three states: *solid*, *liquid*, and *gas*. A solid has a definite volume and shape, and offers resistance to a change in either. A liquid has a definite volume and offers resistance to any change in its volume, but it takes the shape of the containing vessel except at the free surface of the liquid. A gas takes the volume and shape of the container, and offers but slight resistance to a change in either its volume or its shape.

The molecules of which matter is composed do not fill all of the space occupied by the body. The space between the molecules is known as *intermolecular space.* The amount of intermolecular space differs for different materials. In all matter the molecules are thought to be in constant motion. In solids the molecules are held in fixed positions with respect to each other, and the motion is limited to vibrations within the intermolecular space. The molecules in a liquid are in general farther apart than in a solid, and they are free to change their relative positions. Their range is limited only by the walls of the vessel and the surface of the liquid. The molecules in a gas are much farther apart than in a liquid, and their range of motion is limited only by the walls of the containing vessel.

We describe matter in terms of its properties, but many of these properties are changeable. A given kind of matter may be hard at lower temperatures and soft at higher temperatures. For example, a glass rod is brittle at ordinary temperatures and breaks when it is bent, but if it is heated, it becomes quite ductile. Also, even though the temperature of a given mass of gas is held constant, if the pressure on the gas is increased the volume of the gas is decreased. The question arises, "Is there any property of matter which is unchangeable?" At first thought it might be answered that the weight of a given amount of matter does not change, but if the weight is measured at different altitudes, it is found that the weight also changes. (See Sec. 6.)

There is one property of matter, however, which does not change when other properties change — this property is known as *inertia.* To understand more fully the nature of inertia we must realize that matter has no ability within itself to change its state of rest or motion, and that it resists any outside force that tends to change it. If a ball is resting on a table, it will continue to rest there, unless disturbed by some outside force. If a ball is put in motion, it will come to rest, not because of itself, but because friction and gravity are acting on it. *The resistance offered by matter to any change in its condition of rest or motion is called inertia.* The inertia of a given body is proportional to the amount of matter which the body contains.

5. Force. Our first ideas about force come from the muscular efforts we exert in order to move some body or to change its motion. If we lift a rock, throw a ball, or stop a ball which someone else has thrown, we are conscious of exerting a push or a pull. *A force is a push or a pull which tends to cause motion or to change the motion of an object.* A horse exerts a force on a wagon in order to move it. A car is moved by the force exerted by the engine. Sometimes a force does not cause motion. If you try to lift a 200-pound object and can exert a force of only 40 pounds, the object will not move — and while you have exerted a force it only tended to cause motion. Sometimes a force causes a change in the size or shape of a body as when a rubber band is stretched or a spring is compressed. A force which is always acting on us is the force of gravity or the attraction of the earth for bodies on or near its surface.

6. Mass and Weight. It is important to distinguish between the mass and the weight of a body. The *mass* of a body refers to the amount of matter in it and is the same wherever the body may be. If a housewife is ordering groceries she is concerned with the amount of food she will need for dinner. If she orders three pounds of meat she considers whether that much meat will make the required number of servings.

The *weight* of a body is a measure of the pull of the earth on the body. This pull varies from place to place because the attraction of the earth for a body changes when the distance between the body and the center of the earth changes. If the distance is increased the attraction of the earth for the object is decreased. For example, if a body is carried up a mountain it weighs less than at sea level. If it is moved to either the North or the South Pole it weighs more than at the equator because the polar diameter of the earth is less (about 27 miles less) than the equatorial diameter — this increase in weight is about one-third of one per cent. The standard weight of a body is its weight at sea level at 45° latitude. *Therefore one must remember that mass refers to the quantity of matter in a body, while weight refers to a force acting on the body.*

In practice the weight of a body, even though it does vary slightly at different places on the surface of the earth, is used to determine the mass of a body. Various kinds of balances are used. An equal arm balance consists of a bar supported on a knife edge at its mid-point and with a pan at either end. The object which is to be weighed (or for which the mass is to be found) is placed in one pan and standard masses are added to the other pan until a balance is obtained. If this scale is balanced in one place, it will be balanced in any other place. (This weight neglects the buoyant effect of the air which is usually negligible.) An unequal arm balance consists of a bar supported near one end. The object to be weighed is placed on the short arm and the position of a rider is adjusted on the long arm until a balance is obtained. This long arm is graduated and the reading where the rider rests gives the weight of the object.

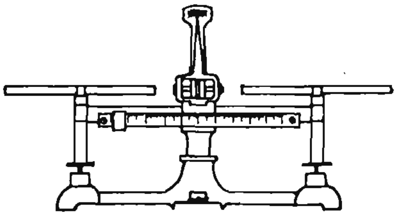


Fig. 1.4. An equal arm balance.

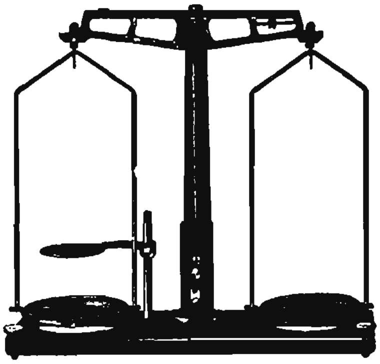


Fig. 1.5. An equal arm balance. (Courtesy Central Scientific Company)

A spring balance consists of a spring mounted in a suitable framework. When the object is placed on the balance the spring stretches and moves a pointer along a graduated scale. Theoretically this balance does not give the same reading at all locations because the pull of the earth varies with altitude and latitude, but the variation is slight for points on the earth's surface and in general is negligible.

It has been found by experiment that the elongation of a spring is directly proportional to the force applied, up to the

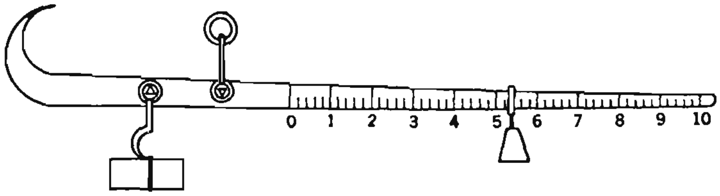


Fig. 1.6. An unequal arm balance.

elastic limit. *The elastic limit of a material is the largest force which may be applied without causing a permanent distortion.* The action of a spring balance is in accord with Hooke's law which states that "*within the elastic limit, all elastic distortions (elongations, compressions, bends, and twists) are proportional to the forces which cause the distortions.*" The stretch of a hair, a thread, or a metal rod, the compression of a pillar which is supporting a load, the bending of a beam which has a load suspended between its supports, and the twist of a drive shaft in a piece of machinery are all distortions which take place in accord with Hooke's law.

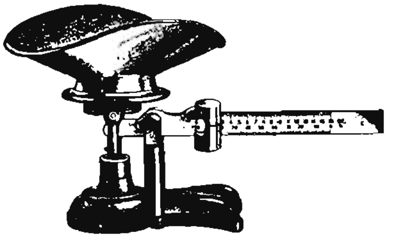


Fig. 1.7. An unequal arm balance. (Courtesy Central Scientific Company)

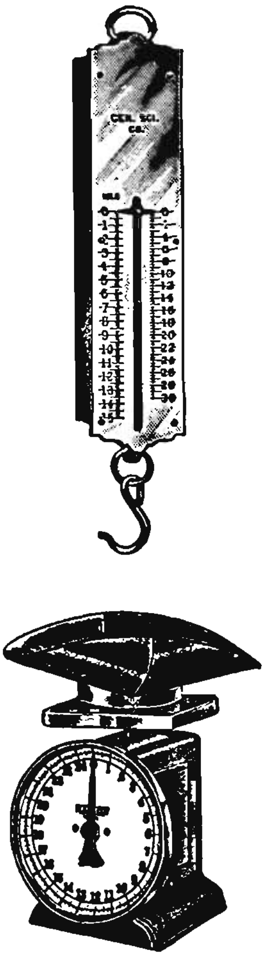


Fig. 1.8. Two types of spring balance. (Courtesy Central Scientific Company)

7. Speed and Velocity. *Speed* and *velocity* are terms often used in conversations about trips in cars. If a car travels 400 miles in 10 hours, the average speed is 40 miles per hour. *Speed is the rate at which a body moves through space.* Velocity differs from speed only in that the *direction* as well as the *rate* of the motion must be known. A speedometer registers the rate of motion but tells nothing of the direction. But if we say a car is traveling 40 miles an hour to the east then we are giving its velocity. *Velocity is the rate of motion in a given direction.* If the velocity varies, the average velocity may be found by

$$\text{Average velocity} = \frac{\text{Distance}}{\text{Time}}$$

$$V_a = \frac{D}{T}$$

or, if there has been a steady increase or decrease in the velocity

$$V_a = \frac{V_{\text{max}} + V_{\text{min}}}{2}$$

where V_{max} = maximum velocity
V_{min} = minimum velocity

Since velocity is distance divided by time suitable units for velocity are feet per second, miles per hour, or centimeters per second.

8. Acceleration. If the velocity of a body is steadily increased or decreased, there is a definite rate of change in the velocity. *Acceleration is the rate of change in the velocity.*

$$\text{Acceleration} = \frac{\text{Change in velocity}}{\text{Time}}$$

$$A = \frac{V_{\text{max}} - V_{\text{min}}}{T}$$

The units for acceleration should be noted carefully. Since acceleration is change in velocity divided by time, suitable units are feet per second per second, or centimeters per second per second. These units are often abbreviated to ft per sec^2 or cm per sec^2.

If a body is allowed to fall freely, it is found that it falls faster and faster, because it is being accelerated by the force of gravity. *The acceleration due to gravity is equal to 32 feet per second per second, or 980 centimeters per second per second.* (These are average values. The actual values vary slightly at different locations.)

If a ball is dropped from a balloon, how fast will it be going at the end of 10 seconds?

$$A = \frac{V_{\text{max}} - V_{\text{min}}}{T}$$

$$32 = \frac{V_{\text{max}} - 0}{10}$$

$$V_{\text{max}} = 320 \text{ ft per sec}$$

What was its average velocity?

$$V_a = \frac{V_{\max} + V_{\min}}{2}$$
$$= \frac{320 + 0}{2}$$
$$= 160 \text{ ft per sec}$$

How far did it fall during the 10 seconds?

$$V_a = \frac{D}{T}$$
$$160 = \frac{D}{10}$$
$$D = 1600 \text{ ft}$$

The ideas of speed and acceleration have various applications in the household, but in general it is not easy to obtain definite data. A car is equipped with a speedometer, and a freely falling body has a known acceleration, but household devices are not provided with speed registering devices, and the acceleration is usually not known. If a vacuum cleaner is pushed across the floor more rapidly or if an egg beater is turned more rapidly one is immediately conscious of the increased force required; but as to how much or at what rate the speed is increased, or how much more force is required, there are few definite data. A greater force will be required to cause a given change of velocity for a large mass than for a small mass; moreover a larger force will be required to cause a given change of velocity in a short time than will be if a longer time is allowed. *Thus we see that the force required is proportional to both the mass and the acceleration.*

STUDY QUESTIONS

1. Which is the older system of weights and measures — the English or the metric?
2. If you are ordering milk in France and want approximately 2 quarts, how do you state your order?
3. If you wish to measure out 50 cubic centimeters of orange juice and have no metric measure, how can you measure it to get approximately the right amount?
4. How many millimeters are equivalent to a kilometer?
5. Which is the larger amount — 100 cubic centimeters or 1/2 cup?

6. In this country we have the ton, which is 2000 pounds and the "long ton," which is 2200 pounds. The latter is used in foreign trade. What is its metric equivalent?
7. What are the three fundamental quantities? m f s g. c s.
8. What are the three states in which matter may exist?
9. What is intermolecular space?
10. What is force?
11. Distinguish between the mass and the weight of a body.
12. If an equal arm balance is balanced at sea level, will it still balance if it is carried to the top of Pike's Peak?
13. If a spring balance reads 10 pounds when a given object is placed on it, will it read more or less as it is carried to a higher altitude? Will it read more or less as it is carried from the equator toward either pole?
14. What is Hooke's law?
15. What is the difference in the meaning of the terms "speed" and "velocity"?
16. Does the speedometer of a car register speed or velocity?
17. If a car travels at a constant speed, does it have an acceleration?
18. How may the acceleration of an object dropped from an airplane be decreased to less than 32 feet per second per second?

PROBLEMS

1. If your waist measure is 24 inches, what is it in centimeters? *Ans.* 61 cm
2. If a girl is 170 centimeters tall, what is her height in feet?
3. If a rug is 3 by 4 meters, what are its approximate dimensions in feet? *Ans.* 9.8 by 13.1 ft
4. If a room is 15 by 22 feet, what are its dimensions in meters?
5. If you buy 5 kilograms of sugar, how many pounds do you have? *Ans.* 11 lb
6. If you weigh 110 pounds, what is your weight in kilograms?
7. If the speed limit is 80 kilometers per hour, what is the approximate speed limit in miles per hour? *Ans.* 50 mph
8. If you drive at a speed of 60 miles per hour, what is your speed in kilometers per hour?
9. In a foods experiment nine 300-gram portions of meat are needed. How many pounds of meat should be purchased? *Ans.* 6 lb
10. If a can contains 795 grams of peaches, how many pounds does it contain?
11. If you want to buy approximately 10 gallons of gasoline in Mexico you will probably ask for 40 liters. How many gallons will you have? *Ans.* 10.6 gal
12. If your pressure saucepan holds 4 quarts, approximately how many liters does it hold?

13. If you are buying drapery material in France and need 16 lengths of material, each one 90 inches long, how many meters do you purchase? *Ans.* 37 m
14. If you buy 4 meters of cloth for a dress in Italy, how many yards do you have?
15. What is the average speed of a car if it travels 400 miles in 8 hours? *Ans.* 50 mph
16. How long will it take to travel 300 miles at an average speed of 40 miles per hour?
17. How far will a plane travel in 6 hours if it has an average speed of 200 miles per hour? *Ans.* 1200 mi
18. What is the average speed of a person who walks a mile in 8 minutes?
19. The speed of a ball changes from 160 feet per second to 90 feet per second in 5 seconds. What is its average speed? What is its acceleration? *Ans.* 125 ft per sec; 14 ft per sec^2
20. A car speeds up from 15 miles per hour (22 feet per second) to 60 miles per hour (88 feet per second) in 12 seconds. What is its average speed? What is its acceleration?
21. A box is dropped from an airplane and strikes the ground 10 seconds later. What is its velocity when it strikes the ground? What is its average velocity? How high is the plane above the earth? (Neglect the friction of the air.) *Ans.* 320 ft per sec; 160 ft per sec; 1600 ft
22. A ball is dropped from the top of a building and strikes the ground 3 seconds later. How high is the building? (Neglect the friction of the air.)
23. How long does it take an object to fall a mile? (Neglect the friction of the air.) *Ans.* 18.2 sec
24. How high will a ball rise if it is thrown up with a velocity of 48 feet per second?

2

FORCE

No one has ever seen a force but everyone has seen and felt the effects of forces. If a body is at rest, a force is required to start it moving or to keep it moving. If the body is already in motion, a force is required to change its motion either in amount or direction. A force may also change the shape of a body — it may stretch, compress, twist, or bend the body. Some forces act on matter constantly — for example, gravity, cohesion, and adhesion. Other forces may be applied by man wherever and whenever he chooses. Moving a table, compressing a spring, stretching a rubber band, and stopping a baseball are examples of forces applied by man according to his wishes at any particular time in order to accomplish some desired result. *A force is a push or a pull which tends either to change the state of rest or motion of a body, or to cause distortion of the body.* (Review Sec. 5.)

Suitable units for measuring force are the *pound* and the *gram*. A force of 1 pound is equal to the pull exerted by the earth on a mass of 1 pound. Likewise a force of 1 gram is equal to the pull exerted by the earth on a mass of 1 gram.

9. Graphical Solutions of Force Problems. A force may be represented graphically by means of an arrow. The length of the arrow is determined by the amount of the force. The line along which the force acts and its direction along that line are indicated by the direction of the arrow. For example, a force

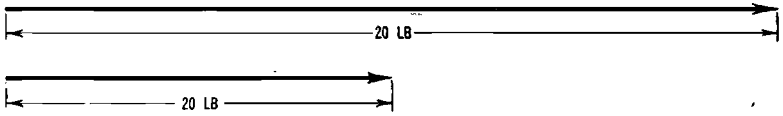


Fig. 2.1. Graphical representation of a force with an arrow.

of 20 pounds acting horizontally to the right may be represented by an arrow as in Figure 2.1. If drawn to a scale of 1 inch = 5 pounds, the arrow will be 4 inches long; if drawn to a scale of 1 inch = 10 pounds, the arrow will be 2 inches long.

Often two or more forces may be replaced by a single force called the *resultant*, which will produce the same effect as the several forces acting together. The original forces are known as the *components* of the resultant. If two forces act along the same line and in the same direction, the resultant is equal to the sum of the components, as shown in Figure 2.2*a*. If two forces act along the same line but in opposite directions, the resultant is equal to the difference between the two forces, and its direction is that of the larger force, as shown in Figure 2.2*b*. If two forces act at an angle with each other, the resultant may be found graphically by completing a parallelogram, the sides of which are proportional to the forces, and drawing the diagonal from the point of application of the forces to the opposite corner of the parallelogram. This line gives both the size and the direction of the resultant force. For example, if forces *AB* and *AC* act

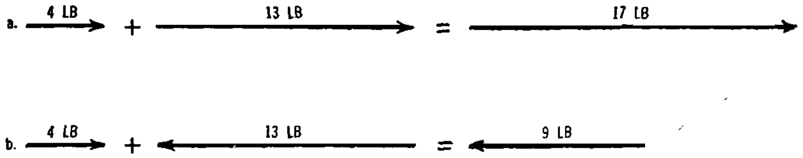


Fig. 2.2. Vector addition of forces.

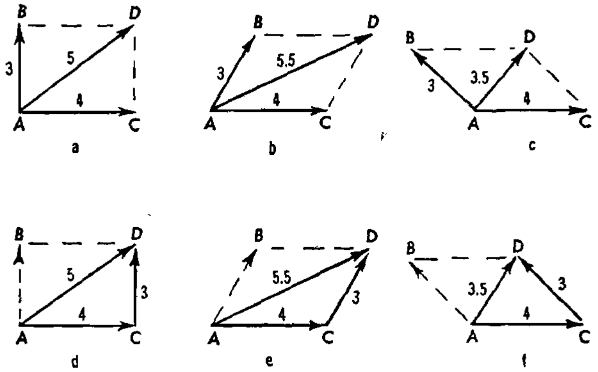


Fig. 2.3. Graphical composition of forces.

at right angles to each other, the resultant will be AD. See Figure 2.3*a*. If forces AB and AC act at some angle other than 90°, the same method is followed. See Figures 2.3*b* and *c*. Figures 2.3*d*, *e*, and *f* show corresponding solutions by the triangle method. After the arrow representing one force has been drawn, an arrow representing the second force is joined to the head of the first arrow. The resultant force is the arrow drawn from the tail of the first arrow to the head of the second arrow. The idea of the triangle method may be extended for more than two forces; the figure then becomes a polygon but the arrow drawn from the tail of the first arrow to the head of the last arrow is the resultant force. Moreover it makes no difference as to the order in which the forces are joined. Figure 2.4 shows two orders of combining a series of the same forces, and the size and direction of the resultant is the same in both cases.

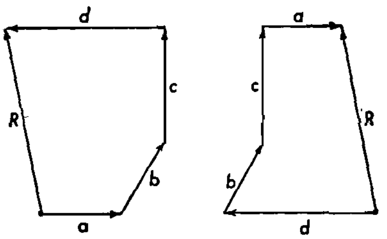


Fig. 2.4. Two orders of combining forces by the polygon method.

A given force may also be resolved into two or more components. The directions of the desired components must be stated. For example, the force on a vacuum-cleaner handle may be resolved into vertical and horizontal components as shown in Figure 2.5. If a force of 8 pounds is applied along the handle it may be represented by an arrow AB drawn parallel to the handle. If then a vertical line is drawn through one end of AB and a horizontal line through the other end of AB, these lines will cross at C. BC represents the vertical component and AC the horizontal component of AB. In this case AC is the useful component of AB which moves the cleaner along the floor, but it is more convenient to apply a larger force AB at an angle than it is to apply a horizontal force AC. The component BC is

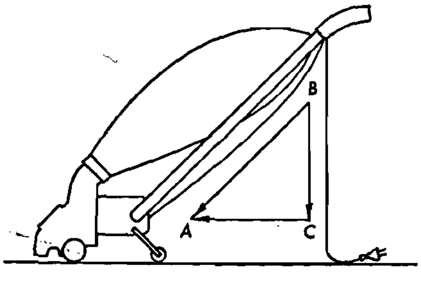


Fig. 2.5. Resolving a force into horizontal and vertical components.

ineffective in moving the cleaner along the floor except that it enters into the force required to overcome friction. (See Sec. 12.)

If an object rests on an inclined plane, the force due to its weight which is a vertical downward force may be resolved into two components — one parallel to the plane and the other normal (at right angles) to the plane. If a car is on an inclined plane (a hill) as shown in Figure 2.6, its weight W may be resolved into the components N, normal to the road and P, parallel to the road. N represents the force which the car exerts on the road and, neglecting friction, P is the force which must be exerted by the brakes to keep the car from rolling down the hill. Neglecting friction, this is also the force which must be exerted by the engine to make the car travel up the hill at constant speed. The actual force which must be exerted by the engine is this force plus the force required to overcome the friction, and if the speed of the car is increased, still more force must be supplied by the engine to cause this acceleration.

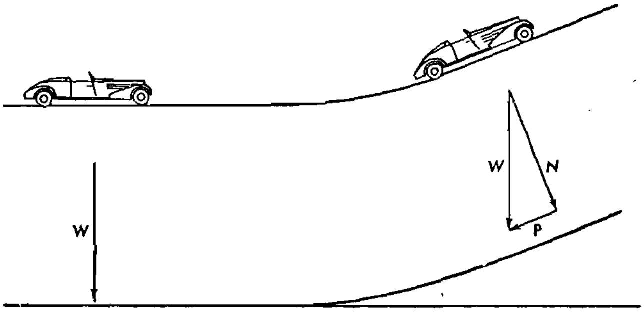


Fig. 2.6. A force may be resolved into components normal to and parallel to an inclined plane.

10. Torque. If a force is used to produce rotation the turning effect of the force depends on two factors — the amount of the force and the perpendicular distance from the line of action of the force to the point about which the force is acting. This perpendicular distance is known as the *lever arm* of the force. *The product of the force F and its lever arm L is the torque of the force.*

$$T = FL$$

The torque exerted by a 75-pound child who sits 4 feet from the pivot of a teeter-totter is

$$\begin{aligned} T &= FL \\ &= 75 \times 4 \\ &= 300 \text{ ft-lb} \end{aligned}$$

The torque exerted by this same child when he sits 6 feet from the pivot is

$$\begin{aligned} T &= FL \\ &= 75 \times 6 \\ &= 450 \text{ ft-lb} \end{aligned}$$

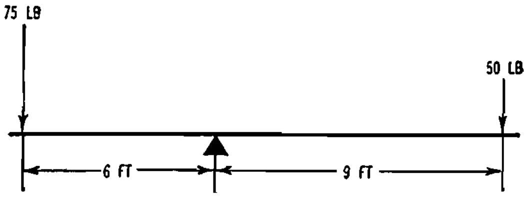


Fig. 2.7. The two torques balance each other.

In this last case how far from the pivot must a 50-pound child sit in order to balance the torque of 450 foot-pounds?

$$\begin{aligned} T &= FL \\ 450 &= 50\,L \\ 9 \text{ ft} &= L \end{aligned}$$

11. Pressure. Often it is important not only to know the force but also to know over how much area that force is distributed so that we may judge the intensity of the force. *Pressure is the force per unit area.* For example, if a force of 20 pounds acts on an area of 5 square inches, the pressure is

$$\begin{aligned} P &= \frac{F}{A} \\ &= \frac{20}{5} \\ &= 4 \text{ lb per sq in.} \end{aligned}$$

But if the same force of 20 pounds acts on an area of 10 square inches, the pressure is

$$\begin{aligned} P &= \frac{F}{A} \\ &= \frac{20}{10} \\ &= 2 \text{ lb per sq in.} \end{aligned}$$

12. Friction. Is friction useful or wasteful? On first thought the answer is "wasteful." The useful work done by the engine of a car is decreased if there is friction in the gears and transmission, or in the engine itself. It takes more force to slide a heavy box on a cement sidewalk than on a waxed floor. A floor is waxed for dancing to decrease friction. But on the other hand, without friction, walking would be impossible. Friction holds the shoe in place on the floor while the body is moved ahead in the next step. It is difficult to walk on an icy sidewalk because the friction is so slight. If the friction between the tires and the wet road is not great enough, the wheels spin and the car will not move ahead. Were it not for friction, nails would not hold boards together, pencils would not write on paper, and brakes on cars would not stop the wheels. There are probably more examples of useful than of wasteful friction.

Friction is the resisting force which opposes any effort to roll or slide one body over or through another. It is a retarding force. If a chair is moved across the floor or a book pushed across the table, the frictional force tends to hinder the motion. The friction is due to irregularities in the surface, and to cohesive and adhesive forces. Two surfaces rubbing together may look smooth to the eye and feel smooth to the hand but still be quite rough if examined microscopically. All surfaces are rough to some extent and, as one surface slides or rolls over the other, the projections on one move up and down over the projections on the other. As the surfaces are smoothed, these projections are decreased and the friction becomes less. Planing, sandpapering, grinding, oiling, and waxing reduce the friction either by removing the projections or by filling the cavities between the projections. Starting friction is always greater than moving friction, and in general sliding friction is greater than rolling friction. It is harder to start a car rolling along a pavement than it is to keep it rolling, because force is required to give the car an acceleration, or as we sometimes say, "to give it a start." Moreover, it is far easier to roll a car than it is to slide it. Probably one man can move a car if the brakes are released so that it can roll, but if the brakes are set, he cannot possibly slide the car. It is also easier to move a piano on rollers than it is to slide it.

The force required to balance or overcome the retarding force of friction depends on the nature of the surfaces in contact and on the magnitude of the force holding the objects together. If the force required to move an object with uniform velocity on a given surface is determined, and then the weight of the object is doubled but all other conditions are kept the same, it will be found that in the second case twice as much force is required to move the object. For any given pair of surfaces there is a constant ratio between the force required to overcome friction and the force holding the two surfaces together. The force holding the surfaces together acts at right angles to the surfaces; that is, it is a normal force. On a horizontal plane the normal force is equal to the weight of the body. If the body is on an inclined plane, the normal force may be determined graphically. (See Fig. 2.6.) *This ratio between the force required to overcome friction and the normal force is known as the coefficient of friction.*

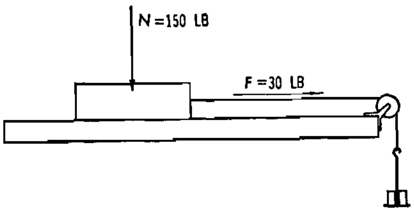


Fig. 2.8. Finding the coefficient of friction.

$$\text{Coefficient of friction} = \frac{\text{force required to overcome friction}}{\text{normal force}}$$

$$C = \frac{F}{N}$$

For example, if a force of 30 pounds is required to move (with uniform velocity) a 150-pound body which is resting on a horizontal surface,

$$C = \frac{30}{150}$$
$$= 0.2$$

If a 300-pound body of the same material is to be moved over the same surface

$$0.2 = \frac{F}{300}$$
$$F = 60 \text{ lb}$$

Within wide limits the coefficient of sliding friction is independent of the areas in contact. For example, the same force is required to move a brick along a horizontal table top, regardless of which of its surfaces the brick is resting on, provided the nature of the surfaces is the same. At first it might seem that the force would be greater when a larger area is in contact, but if the brick is resting on one of its largest surfaces, the amount of force per square inch of bearing surface is less. If it rests on one of its smallest surfaces, the force per square inch is more but there are fewer square inches in contact. Experiments show that the area of the surface does not influence the amount of force required to overcome the friction.

In rolling friction, as the roller moves forward it compresses the surface directly under it. This makes a ridge ahead of the roller or wheel; consequently it is always climbing out of a depression. The smaller the wheel the steeper are the sides of the depression. One piano may be harder to move than another which is no heavier, because the first piano has smaller rollers. The smaller rollers mar the floor more than larger ones do, because the total weight of the piano is supported on the rollers and if they are small, the force per unit area is increased.

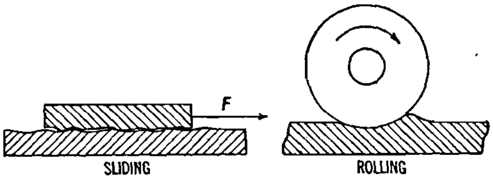


Fig. 2.9. Showing the causes for sliding and for rolling friction.

Oil on metal surfaces decreases friction. Instead of metal moving on metal a film of oil covers the metal surfaces and as a result the moving surfaces become metal on oil or even oil on oil. Friction of solids on solids is independent of the speed within wide limits, but if a solid moves through a liquid or a gas, the friction increases rapidly as the speed increases. The friction of a car moving through air increases approximately as the cube of the speed. That is, if the speed increases from 10 to 20 miles an hour the resistance will be eight times as great. If one tries to increase the speed of a rowboat, the increased effort required is very noticeable. In the case of cars, airplanes, and motorboats, the amount of gasoline required for a given distance, covered at various speeds, is an indication of the varying resistance. This is one of the tests that enter into calculating the most efficient speed at which to drive a car or motorboat. Streamlining decreases the frictional force.

COEFFICIENTS OF FRICTION

Sliding

Oak on oak — fibers parallel	0.4	to 0.5
Oak on oak — fibers crossed	0.3	to 0.4
Leather on metal, lubricated	0.1	to 0.2
Steel on ice	0.02	to 0.03
Rubber on concrete	0.5	to 0.8
Leather on waxed wood	0.2	to 0.4
Rope on wood	0.4	to 0.5
Steel on steel, dry	0.03	to 0.09

Rolling

Steel on steel	0.0004	to 0.008
Wood on wood	0.02	to 0.03

STUDY QUESTIONS

1. How do we know that there are forces?
2. Suggest several things that might happen if the forces of gravity, cohesion, and adhesion ceased to act.
3. What information about a force can be shown with an arrow?
4. How does an arrow which represents a south wind differ from one representing a north wind? An east wind?
5. How would an arrow representing an upward pull of 20 pounds differ from one representing an upward pull of 60 pounds?
6. How may the torque of a given force be increased?
7. What is the difference between pressure and force?
8. What causes sliding friction? Rolling friction?
9. Why do people put glass gliders under pieces of furniture?
10. Why does the engine of a car become too hot if the oil supply is low?
11. Does air, or water, offer the greater resistance to the movement of a body?
12. If a heavy box is dragged along a horizontal sidewalk, and then up an inclined sidewalk, in which case is the greater force required?
13. If a 50-pound box is to be placed at a point 20 feet higher than it now is, would you rather carry it up a vertical ladder or drag it up an inclined plane? Why?
14. What is the purpose of streamlining?

PROBLEMS

1. Solve the following problems graphically and analytically.
   - *a.* If a force of 3 pounds and a force of 4 pounds act along the same line and in the same direction (east), what is the size and direction of the resultant? *Ans.* 7 lb east
   - *b.* If the above forces act along the same line but in opposite directions (3 pounds east and 4 pounds west), what is the size and direction of the resultant? *Ans.* 1 lb west
   - *c.* If the 3-pound force acts to the east and the 4-pound force acts to the north, what is the size and direction of the resultant? *Ans.* 5 lb at an angle 53° north of east

2. Solve the following problems graphically and analytically.
   - *a.* If a force of 6 grams and a force of 8 grams act along the same line and in the same direction (up), what is the size and direction of the resultant?
   - *b.* If the above forces act along the same line but in opposite directions (6 grams up and 8 grams down), what is the size and direction of the resultant?
   - *c.* If the 6-gram force acts horizontally and to the left and the 8-gram force acts vertically downwards, what is the size and direction of the resultant?

3. A force of 4 pounds is applied along the handle of a vacuum cleaner, which makes an angle of 30 degrees with the horizontal. What is the horizontal component of the force? *Ans.* 3.5 lb

4. If a sled is pulled by means of a rope, what force must be exerted on the rope which makes an angle of 30 degrees with the horizontal in order to exert a horizontal force of 26 pounds on the sled?

5. A box which weighs 300 pounds rests on an inclined plane which is 10 feet long and 6 feet high. What is the force parallel to the plane? What is the force normal to the plane? *Ans.* 180 lb; 240 lb

6. A car which weighs 4000 pounds is on a hill which rises 10 feet in a distance of 100 feet along the road. What is the force parallel to the road? What is the force normal to the road?

7. What is the torque of a child who weighs 60 pounds and sits 5 feet from the pivot of a teeter-totter? How far from the pivot must a 50-pound child sit in order to balance the torque of the first child? *Ans.* 300 ft-lb; 6 ft

8. A load of 30 pounds is placed on an unequal arm balance. The lever arm for the load is 4 inches. The counterweight weighs 6 pounds. How far from the pivot must it be placed in order to balance the load?

9. If a 20-pound piece of iron rests on an area which is 2 by 2 inches, what is the resulting pressure? *Ans.* 5 lb per sq in.

10. If a 2000-gram weight rests on an area of 40 square centimeters, what is the resulting pressure?

11. What is the coefficient of friction if a force of 30 pounds is required to slide a 200-pound object across a waxed floor? *Ans.* 0.15

12. What force will be required to slide a box of books weighing 60 pounds across a cement floor if the coefficient of friction is 0.3?

13. What force will be required to roll a 200-pound truck across the floor if the coefficient of friction is 0.04? *Ans.* 8 lb

14. What is the coefficient of rolling friction if a force of 15 pounds will roll a 150-pound washing machine on a cement floor?

15. In Prob. 5 what is the force required to overcome the friction as the box is moved up the plane if the coefficient of friction is 0.05? What is the total force required to move the box up the plane at a constant speed? *Ans.* 12 lb; 192 lb

16. In Prob. 6 what is the force required to overcome the friction as the car is moved up the hill if the coefficient of rolling friction is 0.05? What is the total force required to move the car up the hill at a constant speed?

3

WORK, ENERGY, AND POWER

Work, energy, and power, like force and velocity, are words which are used with various meanings in everyday life. They are often used with reference to mental as well as physical efforts, and we must recognize that they are often used with other than their scientific meanings. But the language of a scientist must be exact and definite, and any term he uses must have only one meaning, so that when he uses that term he will not be misinterpreted or misunderstood.

According to everyday usage, a student works when he sits quietly puzzling over a physics problem. We say that the fire was the work of an incendiary, and that holding a heavy weight all day is hard work. But in the physical sense no work was done in any of these cases. We must, therefore, learn what the scientist means by work; he limits work to processes involving motion or displacement produced by a force.

We say energy is needed to climb a hill, certain foods are rich in energy, the earth receives energy from the sun, some people are "full of energy." But what is energy? Energy is not work — it is ability to do work. You can neither play, see, speak, nor eat without the use of some kind of energy. Energy is one of the most important ideas in physics. In this chapter we shall study mechanical energy but in later chapters we shall study other forms of energy such as heat, electricity, light, and sound; hence we begin to realize the many-sided nature of energy. In our daily lives we are constantly concerned with changing one form of energy into another, and much of our enjoyment of life is due to the fact that energy can be changed from one form to another. For example, the energy in the food we eat keeps our bodies warm and enables us to do work. The electrical energy which we use in our homes may be converted into heat or light, or used to operate the vacuum cleaner, the radio, or the telephone.

We speak of electric power and horsepower, and of a king of great power. We use high-power telescopes and microscopes. We read of a powerful magnet that is used in a factory. But in physics "power" means rate of working. It is often important not only to know the total amount of work done but to know the amount of work done in one second, one minute, or one hour. Some devices can do work faster than others — many machines can work faster than a man. If a load of 500 pounds of paper is to be carried from the basement to the tenth floor of a building a man can carry it up if he is given enough time to make several trips; but it can all be carried up in one trip on an elevator, and in a fraction of the time required by the man.

13. Work. Work has a definite meaning involving two physical concepts which have already been studied — force and distance. *If a force acts on a body and causes the body to move, the amount of work done is equal to the product of the force and the distance through which the force moves.*

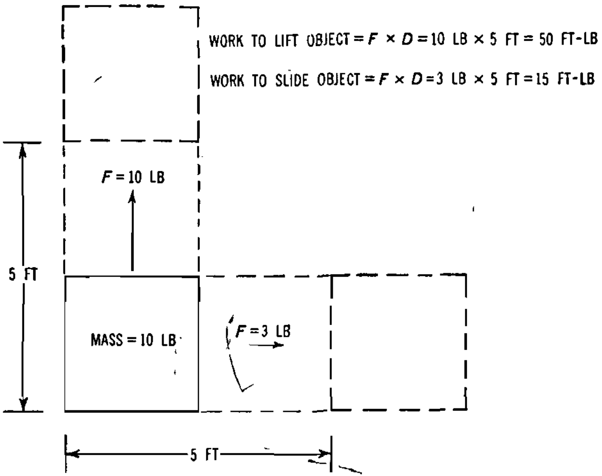


Fig. 3.1. The amount of work is determined by the force and the distance through which it moves.

$$W = FD$$

If the direction of the force is not the same as that of the motion, then only that component of the force which is effective in the direction of the motion is considered in calculating the amount of work done.

Work is done when a book is lifted, when a chair is pushed across a floor, when a spring is stretched, or when a gas is compressed. In each of these cases a force has acted, and has caused a change in the position, tension, or volume of the material on which it acted. If a man lifts one end of a heavy plank from the ground and then stands supporting it for some time, he has done work in lifting it, but is not doing work while he simply supports the plank. He is exerting himself, that is, he is applying force, but he is not causing any change in the position of the plank. If a force is applied to a vacuum-cleaner handle, the force may act at an angle with the floor. But the cleaner moves along the horizontal, and only the horizontal component of the force which acts is used in calculating the amount of work done on the cleaner. If a body is on an inclined plane, the component of the force parallel to the plane is the force which, neglecting friction, enters into the work required to move the object up the plane. The component normal to the plane is used in calculating the force required to overcome friction. The total force required to move the object must also include the force required to overcome the friction.

Since the amount of work is dependent on both the force and the distance through which the body moves, the unit in which work is measured must combine these two factors. The *foot-pound* and the *gram-centimeter* are two common units for work. A foot-pound is the amount of work done when a force of 1 pound acts through a distance of 1 foot. A gram-centimeter of work is the amount of work done when a force of 1 gram acts through a distance of 1 centimeter. It must be remembered that it is the force exerted and not the mass of the object which is used in determining the amount of work done.

14. Energy. *Energy is the ability which a body has to do work.* Inanimate bodies possess energy only because work has been done upon them. If a spring is compressed, a body lifted, or a ball thrown, the amount of work which the object is capable of doing in returning to its original state or position is equal to the work which has been done on it.

Work is done on the spring of a watch when it is wound and as a result the spring is capable of moving the hands of the watch. If a 10-pound body is lifted 5 feet off the ground, 50 foot-pounds of work have been done on it and now because of its position the body has 50 foot-pounds of energy stored in it. *The energy which a body has because of its position is called potential energy.* A body is not necessarily given potential energy just because it is moved to a new position but only when it is able to do more work in its new position. If an object is lifted, it is thereby given potential energy; but if it is just moved along a level surface from one position to another, its potential energy is not increased.

Whenever a body is in motion it is able to exert a force and to do work in coming to rest. For example, when the catcher stops a baseball, the ball does work on his hands. When an automobile runs into a tree, it does work on the tree. A moving body always possesses energy, the amount of which depends on both the mass and the velocity of the body, but the amount of work it can do before coming to rest is exactly equal to the work which has been done upon it. *The energy which a body has because it is in motion is called kinetic energy.*

15. Conservation of Energy. Since the amount of energy which a body possesses is equal to the amount of work which it can do, it is evident that after the body has done some work its supply of energy is decreased. But in doing work the energy which the body loses is transferred to the object on which work is done. When a man does 20 foot-pounds of work in throwing a ball, he gives up that much energy to the ball. As the ball travels through the air, a small part of the energy is used to do work against the friction of the air and is converted into heat. The remaining energy is used to do work on whatever stops the ball — either the catcher's hand or the ground.

Experiments with objects which receive, store, and deliver energy lead to the general law that *energy cannot be created or destroyed but it may be transformed from one form to another.* In our everyday lives we are repeatedly concerned with methods of changing one form of energy into another. For example, the chemical energy in coal is changed into heat energy when the coal is burned and electrical energy is changed into light and heat energy in an electric lamp.

At this time we should also recall the law of conservation of mass. If the masses of several materials which are to enter into a chemical reaction are added, and this total mass compared with the total of the masses of the resulting materials, it will be found that the two totals are equal. That is, in a chemical reaction materials may be recombined, but *the total mass before the reaction is equal to the total mass after the reaction.*

For many years these two laws — conservation of energy and conservation of mass — were regarded as two separate and indisputable laws. But in the twentieth century scientists have learned that under special conditions it is possible to convert mass into energy; in 1945 the whole world became aware of the result of this discovery when the atomic bomb was first used. In an atomic bomb, changes in the nuclei of atoms are made to occur, with the result that small amounts of mass are converted into large amounts of energy. Thus, when measured in suitable units, *the total of the mass and the energy before the reaction is equal to the total of the mass and the energy after the reaction.* Therefore a combination of the two laws is necessary when extraordinary means are used in combining the materials, while each law holds separately under ordinary conditions.

Up to the present time much of the research on nuclear energy has been devoted to its destructive uses. But nuclear energy can be used to benefit mankind. The great quantities of heat liberated in the reactions between nuclei may be used to heat water and produce steam at high pressure, which in turn may be used to heat buildings or to operate turbines to generate electricity. Power plants utilizing nuclear energy are now in use to operate submarines. Other uses are being developed.

Another important use of nuclear energy is in the field of medicine, where radioactive isotopes resulting from nuclear reactions are used in research and in the treatment of patients. These isotopes are also used in plant and animal research, and it is hoped that their use will be the key to the answer for many questions concerning growth and nutrition.

16. Power. When work is done, the amount of work is not the only important consideration, for the time required to do the work is also of interest. Uusually a machine, an engine, or a motor is chosen not on the basis of the total amount of work to be done, but on the basis of the rate at which the work is to be done. *Power is rate of doing work.* The power P may be found by dividing the total amount of work W by the time T required to do the work.

$$P = \frac{W}{T}$$

Since power is obtained by dividing work by time, *units for power may be any work unit divided by any time unit.* Some common units are foot-pounds per second, foot-pounds per minute, and gram-centimeters per second. Power is also frequently expressed in terms of horsepower. The term came into use at the time the first steam engines were made and it was of interest to know how many horses the engine could replace. The accepted numerical values for 1 horsepower are 550 foot-pounds per second or 33,000 foot-pounds per minute.

$$\text{Horsepower} = \frac{\text{Work (ft-lb)}}{550\,\frac{\text{ft-lb}}{\text{sec}} \times T\,(\text{sec})} \quad \text{or} \quad \frac{\text{Work (ft-lb)}}{33{,}000\,\frac{\text{ft-lb}}{\text{min}} \times T\,(\text{min})}$$

A man can work at an average rate of about 1/10 horsepower and a woman at about 1/15 horsepower. For short periods of time these rates may be increased considerably.

STUDY QUESTIONS

1. Define work.
2. If you try for 10 minutes to move a heavy box and cannot move it, how much work have you done on the box?
3. As a clock pendulum swings, what kind of energy does it have when passing through the central position? When it is at the end of a swing?
4. Account for the energy possessed by the water above a dam.
5. What is the law of conservation of energy?
6. What is the law of conservation of mass?
7. What is the law of conservation of mass and energy?
8. What are some peace-time uses for nuclear energy?
9. Name several uses for radioactive isotopes.
10. Is the amount of energy available for use by man increasing or decreasing?
11. What is the origin of the term "horsepower"?
12. Is the power of a car engine greater at 50 miles per hour or at 20 miles per hour? Why?

PROBLEMS

1. How much work is required to lift a load of 120 pounds a vertical distance of 8 feet? *Ans.* 960 ft-lb
2. How much work is required to lift a 500-gram weight a vertical distance of 30 centimeters?
3. How much force is required to slide a 400-gram box along a table top if the coefficient of friction is 0.2? How much work is required to move the box 30 centimeters? *Ans.* 80 g; 2400 g-cm
4. How much work is required to slide a 4-pound book a horizontal distance of 3 feet if the coefficient of friction is 0.2?
5. How much force is required to move a car which weighs 3600 pounds up a road which rises 3 feet in 100 feet along the road if there is no friction? If the normal force is 3598 pounds, how much force is required to overcome friction if the coefficient of friction is 0.3? What is the total force required? How much work is required to move the car at a constant speed for 100 feet? *Ans.* 108 lb; 1079 lb; 1187 lb; 118,700 ft-lb
6. How much force is required to move a 300-pound refrigerator onto a truck if it is pushed up an incline which is 12 feet long and the floor of the truck is 3 feet above the ground? The coefficient of friction is 0.2. How much work is required to put the refrigerator into the truck?
7. A book which weighs 2 pounds is carried to the third floor of a building (elevation 30 feet). How much work is done on it? How much potential energy does it have with respect to the ground? *Ans.* 60 ft-lb
8. An airplane which weighs 3 tons is flying at an altitude of 1 mile. What is its potential energy?
9. A box which weighs 40 pounds is dropped from a plane at an altitude of 5000 feet. How much kinetic energy does it have just as it strikes the ground? *Ans.* 200,000 ft-lb
10. A 2-kilogram weight falls from a table which is 90 centimeters high. How much kinetic energy does it have just as it strikes the floor?
11. What power is required for a 110-pound woman to climb a stairway in her home (elevation 8 feet) in 4 seconds? What horsepower is required? Should she climb the stairs this fast? *Ans.* 220 ft-lb per sec; 0.4 hp
12. A motor has 165,000 foot-pounds of work to do in 10 minutes. What horsepower is required?
13. A 1/4 horsepower motor works for 8 hours. How much work has it done? *Ans.* 3,960,000 ft-lb
14. If a woman can work at the rate of 1/15 horsepower, how much work can she do in 4 hours? (An electric motor could do this work for about 1 cent.)

4

SIMPLE MACHINES

Since so much of the work in homes, on farms, in shops, and in factories is done with machines, it is sometimes said that we are living in the machine age. Some of these machines are quite simple, and others are very complicated; but the complicated machines when studied are always found to be combinations of simple machines. *A machine is a device for transferring or for transforming energy.* In this chapter only the simple machines which are used to *transfer* mechanical energy will be explained. Later some of the devices which are used to *transform* one kind of energy into another will be explained — for example, an electric generator is a machine for changing mechanical energy into electrical energy, and an electric motor is a machine for changing electrical energy into mechanical energy. In a gasoline engine the chemical energy of the gasoline is changed into heat energy which in turn is changed into mechanical energy.

Many examples of simple machines which are used to transfer mechanical energy are familiar to everyone. When force is applied to a pump handle to lift water or to a steering wheel to change the direction of a car, the result is that energy is transferred from one place to another. When force is applied to the treadle of a sewing machine the motion of the treadle causes various levers and wheels to move, and as a result energy is transferred from the treadle to the needle, the shuttle, and the feed. When a key on a typewriter is struck, a system of levers transfers the energy from the key bar to the type bar. If one tries to crack a hard-shelled nut without a nutcracker, open a tin can without a can opener or take the cap off a bottle without a bottle opener he soon decides that it is much easier to do the work if he uses a simple machine. It is easier because the work is done by exerting a smaller force through a larger distance. The force applied to the handle of the nutcracker is much less than the force required to break the nut. The handle of the can opener moves through a greater distance than the cutting blade but the force applied to the handle is less than the force exerted on the can.

Sometimes a machine is used when the chief aim is not to decrease the force required but to increase the speed. The force required to move the blades of a rotary cream whipper through the cream is very small, but the geared wheels which transfer the energy from the drive wheel to the beater blades increase the speed of the blades so that the cream can be whipped in a very short time. However, the force applied to the drive wheel is greater than the force required to move the beater blades through the cream.

17. Laws of Machines. Since a machine is a device for transferring work or energy from one place to another, it is evident that work must be put into the machine and that work will be delivered by the machine. However, the useful output of work is never so large as the input because some work must always be done in overcoming friction. If the frictional force is made as small as possible, the efficiency of the machine is increased. The fundamental principle underlying all machines is

$$\text{Work input} \times \text{efficiency} = \text{work output}$$

$$F_i \times D_i \times \text{efficiency} = F_o \times D_o$$

where

F_i = input force

F_o = useful output force

D_i = distance input force moves

D_o = distance output force moves

From the above equation it is evident that *the efficiency of a machine is the ratio of the useful work output to the work input. Efficiency is expressed as a percentage.*

It might seem, since the work input is greater than the useful work output, that it is a disadvantage to use a machine, but a machine enables one to control the two factors which determine the amount of work — the force and the distance through which the force moves. The force may be applied more advantageously by the machine or a small force put into the machine may make it possible to exert a large output force. Sometimes the only reason for using a machine is to increase the speed of the motion. *It should be recognized that a machine can give either a force advantage or a speed advantage, but not both.* An increase in force results in a decrease in speed; an increase in speed results in a decrease in force; a gain in one is secured at the expense of the other.

Since it is often desirable to know the relationship between the useful output force and the input force, it has been arbitrarily agreed that *the mechanical advantage of a machine is the ratio of the useful output force to the input force.*

$$MA = \frac{F_o}{F_i}$$

If this ratio has a value of more than 1, there is an increase in force but a decrease in speed; if it is less than 1, there is a decrease in the force but an increase in the speed. If this ratio is equal to 1, it indicates that there has been no increase or decrease in either the force or the speed; however, it still may be advantageous to use the machine in order to change the direction of the force and the resulting motion. This method of obtaining the mechanical advantage gives the *actual mechanical advantage* for it involves the actual forces, since the force required to balance the friction is included in F_i. The *theoretical mechanical advantage* may be obtained from the ratio of the distances the forces move, but this value will always be higher than the actual mechanical advantage because measurement of these distances gives no indication of the amount of friction in the machine.

$$\text{Theoretical } MA = \frac{D_i}{D_o}$$

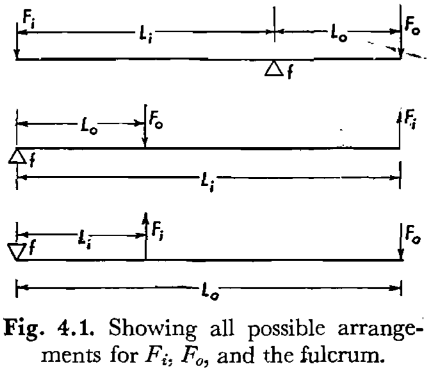


Fig. 4.1. Showing all possible arrangements for F_i, F_o, and the fulcrum.

The simple machines which are used for transferring energy are described in this chapter. These are *(1) the lever, (2) the inclined plane, (3) the wheel and axle, (4) the screw, and (5) the pulley.*

18. The Lever. A lever is a rigid bar on which a force F_i is applied at one point in order to exert a force F_o at some other point. The point about which the lever pivots is the fulcrum, f. The fulcrum may be between the two forces, or it may be at one end of the bar. Figure 4.1 shows all of the possible arrangements for F_i, F_o and the fulcrum. Figure 4.2 shows several simple lever machines.

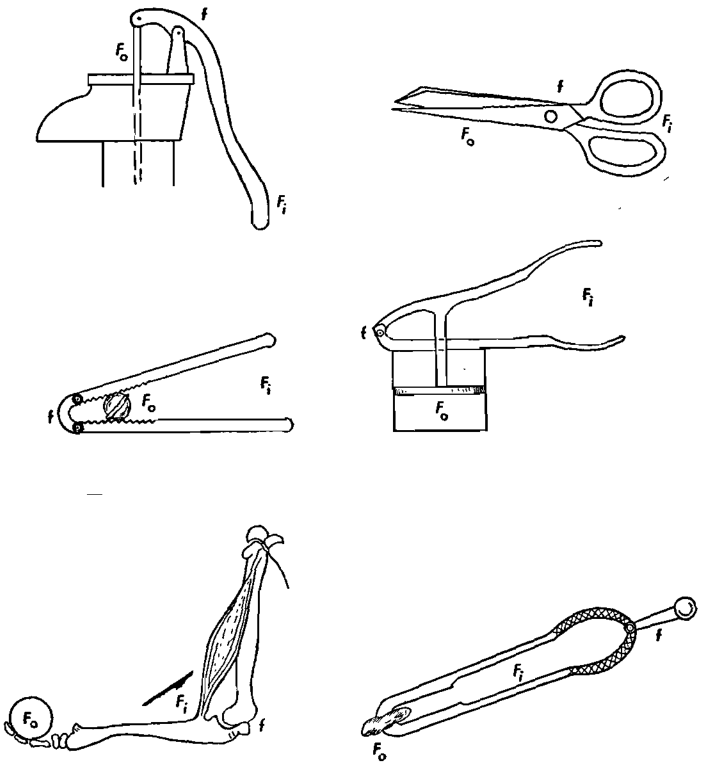


Fig. 4.2. Lever machines.

It is often more convenient to measure the length of the lever arms than to measure the distances the forces move when one is studying a lever machine. If the force and its lever arm L are known, the torque may be calculated. (See Sec. 10.) It is found by experiment that

$$\text{Torque of } F_i \times \text{efficiency} = \text{torque of } F_o$$
$$F_iL_i \times \text{efficiency} = F_oL_o$$

Likewise the theoretical mechanical advantage of a lever machine may be obtained from the ratio of the lever arms.

$$\text{Theoretical } MA = \frac{L_i}{L_o}$$

19. The Inclined Plane. An inclined plane enables one to move an object from one level to another by sliding or rolling it along a surface which gradually rises. A heavy object is often loaded into a truck by sliding it up a plank used as an inclined plane. Any sidewalk or road which is not horizontal is an inclined plane. A road which winds back and forth in climbing a mountain is easier to travel than one which is too steep. In the first case the ratio of the length of the incline to the vertical climb is greater than in the second case, or in other words the mechanical advantage is greater. A good road should not average more than a 6 per cent grade, that is, it should not climb more than 6 feet in a distance of 100 feet. Roads sometimes have a grade of as much as 20 per cent for a short distance but a car could not continue to climb such a sharp grade because the engine soon would become overheated.

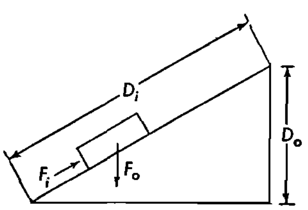


Fig. 4.3. An inclined plane.

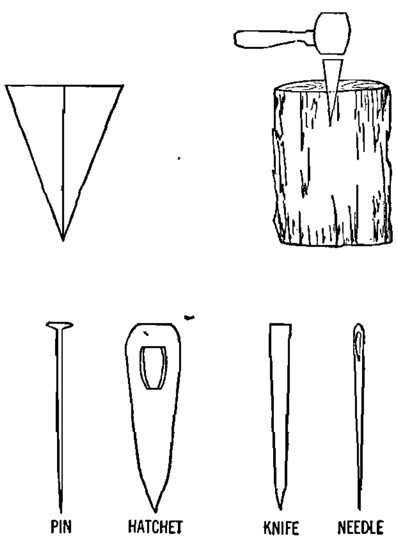
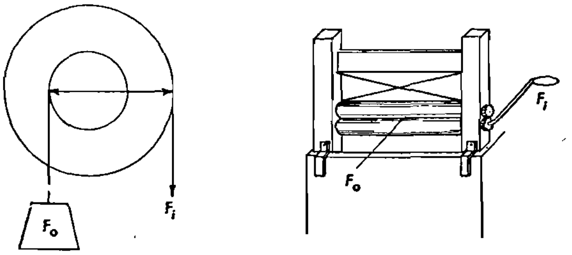


Fig. 4.4. Wedges.

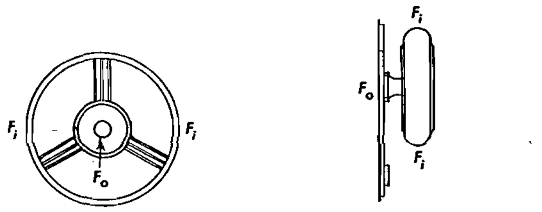
On an inclined plane F_i is the force applied to the object parallel to the incline and F_o is the weight of the object to be lifted. D_i is obtained by measuring the length of the incline and D_o is the vertical distance the object is lifted, or the height of the plane. Figure 4.3 shows an inclined-plane machine. In Figure 4.4 are several double inclined planes or wedges. Knife blades or any sharp cutting edge, pins, and needles are wedges. The sharper the wedge, the greater is its mechanical advantage.

20. The Wheel and Axle. The usual wheel-and-axle machine consists of two wheels on the same axis, or often one wheel is replaced by a crank which is really one of the spokes of the wheel with a handle at the end. Figure 4.5 shows several wheel-and-axle machines. When the wheel or the crank makes one revolution, the axle also makes one revolution. Therefore the distances involved are the circumferences of the two circles.[1] Usually the input force is applied to the wheel or crank and the output force is applied by the axle. In that case the mechanical advantage is more than one, or in other words the force is increased and the speed is decreased. A small force on the rim of the steering wheel of a car results in a large force applied by the steering rod to turn the front wheels of the car. A small force on the handle of the clothes wringer results in a larger force exerted by the rollers on the clothes. But sometimes the input force is applied to the small wheel and the output force is applied by the large wheel. In this case F_o moves rapidly.



WHEEL AND AXLE

CLOTHES WRINGER



STEERING WHEEL

DOORKNOB

Fig. 4.5. Wheel and axle machines.

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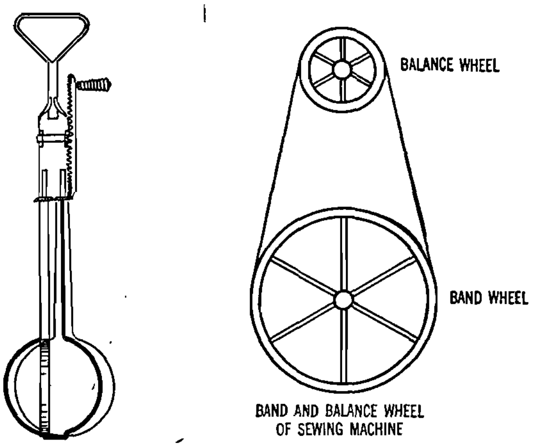
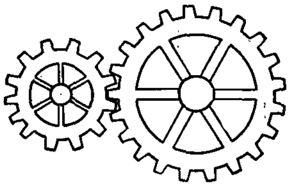
[1] The circumference of a circle is either $\pi \times$ the diameter or $2\pi \times$ the radius. Therefore, either the diameters or the radii may be used for the distances, since the ratio of either the diameters or the radii is the same as the ratio of the circumferences.

In a modified form of the wheel-and-axle machine the two wheels are on separate axes; sometimes they are geared together at their perimeters with cogs and sometimes they are connected by means of an endless chain or belt. Since the wheels differ in size the smaller wheel will rotate more rapidly than the larger wheel. Sometimes this type of machine is used to increase the force and sometimes to increase the speed. In a rotary egg beater the speed is increased. The band and balance wheel of a sewing machine are also designed to increase the speed. Clocks and watches have cogwheels which revolve in the ratios of 60:1 and 12:1. The cogwheels which turn the pointers on the dials of water, gas, and electric meters are made with a 10:1 ratio so that ten revolutions of one wheel will cause one revolution of the next wheel.



EGG BEATER

BAND AND BALANCE WHEEL OF SEWING MACHINE



GEARS

Fig. 4.6. Modified wheel and axle machines.

An important use of geared wheels is found in the automobile. Energy must be transferred from the crank shaft of the engine at the front of the car to the differential at the rear of the car. The transmission case contains gears which make possible three speeds forward and one in reverse. For high speed the engine is connected directly to the drive shaft. Intermediate speed may have a gear ratio of 2:1; that is, the torque is doubled. For low and reverse the ratio may be 4:1. In the differential there is a further speed reduction of from 3:1 to 5:1 in passenger cars.

21. The Screw. A screw machine is used when a large mechanical advantage is needed in order to lift a heavy load. A jackscrew is shown in Figure 4.7. When the handle of a screw machine makes one complete revolution the load is lifted a distance equal to the pitch of the screw, or the distance between the centers of two successive threads. A food grinder is a screw machine, but one in which the pitch is variable. The pitch decreases as the food travels ahead in the grinder so that the food will be cut into smaller and smaller pieces. The average pitch is obtained by dividing the length of the screw by the number of threads. Since, in any screw machine, the distance the input force travels is large compared to the pitch, the theoretical mechanical advantage is very large. The actual mechanical advantage is usually much less because of the large amount of friction, but even after allowing for the loss due to friction, the actual mechanical advantage is still large.

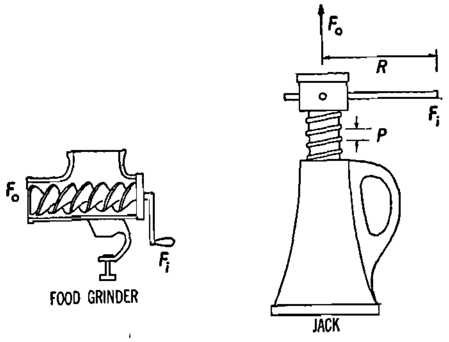


Fig. 4.7. Screw machines.

22. The Pulley. A pulley is a wheel with a grooved rim, which is free to rotate on its axis. The wheel, or *sheave* as it is usually called, is supported in a framework called a *block*. Over this sheave passes a rope, a cable, or a chain, one end of which is attached either directly to the load or else to another block which is attached to the load. The input force is applied at the other end of the rope or cable. If the pulley is attached to a stationary support, it is known as a *fixed pulley*, and if attached to the object which is being moved, it is a *movable pulley*. When heavy loads are to be lifted, combinations of fixed and movable pulleys are used.

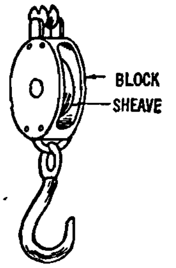
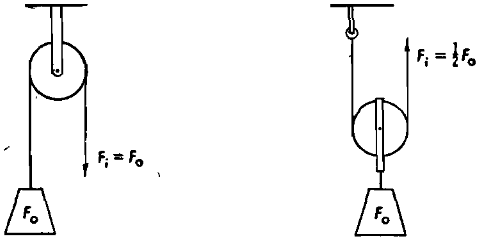


Fig. 4.8. A pulley.

Only simple pulley combinations are used in the home. The cords which connect the window sash to the window weights run over single fixed pulleys. The cords on Venetian blinds also pass over single fixed pulleys; the pulleys simply change the direction of the force — the blind is raised by pulling down on the cord.



A SINGLE FIXED PULLEY A SINGLE MOVABLE PULLEY

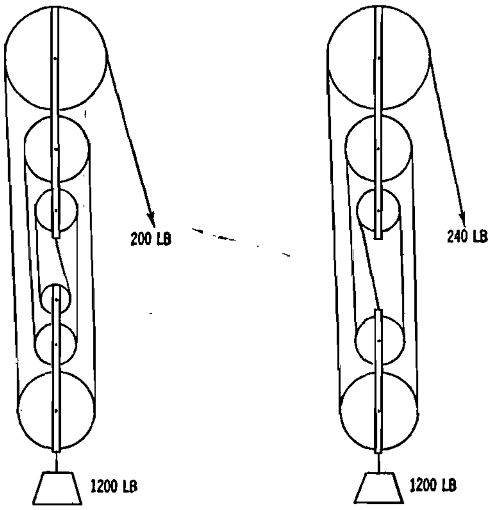


Fig. 4.9. Various pulley combinations.

When heavier loads are to be lifted more pulleys are used. Figure 4.9 shows several combinations which might be used in a factory or in a machine shop. When at rest the tension in all parts of the rope is the same. If six ropes are used to support a load of 1200 pounds, the tension in the rope is 200 pounds. When the load is moved enough extra force must be applied to overcome the friction in the system. As is true in all machines the actual mechanical advantage is F_o/F_i. In general, the easiest way to find the theoretical mechanical advantage is to count the number of ropes which support the load. The theoretical mechanical advantage for a single fixed pulley is 1 and for a single movable pulley is 2.

STUDY QUESTIONS

1. How does the actual mechanical advantage of a machine differ from the theoretical mechanical advantage? Which is larger?
2. If the mechanical advantage of a machine is large, will the output force move rapidly or slowly as compared with the input force? In general, how does the speed advantage of a machine vary with the mechanical advantage?
3. Why do you place something which is hard to cut near the hinge of a pair of scissors?
4. Is it easier to guide a car with a large steering wheel than it would be to guide one with a small wheel?
5. If a workman is trying to lift the corner of a house with a jackscrew and finds he cannot exert enough force, what would you suggest that he do?
6. How does the weight of a window sash compare with the weight of the "weights" in the window casing? Then why do you have to "push" the window up or down?
7. How may the efficiency of a machine be increased?

PROBLEMS

1. If a force of 10 pounds is used to lift the handles of a garden wheelbarrow a distance of 15 inches and the load is lifted 5 inches, how heavy is the load? What is the mechanical advantage? (Neglect friction.) *Ans.* 30 lb; 3
2. If a 50-pound child on one end of a seesaw moves up and down 2 feet, how far does a 40-pound child on the other end move? What is the mechanical advantage? (The second question has 2 answers. Neglect friction.)
3. A force of 40 pounds is needed to pull a large nail. The nail fits into the claws of the hammer 2 inches from the fulcrum and force is applied on the handle 12 inches from the fulcrum. What theoreti-

cal force is required? What is the theoretical mechanical advantage? *Ans.* 6.67 lb; 6

4. If a force of 6 pounds is applied on the handles of a potato ricer 10 inches from the hinge, what theoretical force is exerted on the potatoes which are 2 inches from the hinge? What is the theoretical mechanical advantage?
5. A force of 5 pounds is applied to a pump handle 2 feet from the fulcrum. The piston and water weigh 15 pounds and are 6 inches from the fulcrum. What is the actual mechanical advantage? What is the theoretical mechanical advantage? What is the efficiency of the machine? *Ans.* 3; 4; 75 per cent
6. A force of 2 pounds is applied on the handles of a pair of shears 3 inches from the hinge. If the efficiency is 90 per cent, what force can be exerted to cut a cord at a point 1.5 inches from the hinge?
7. If the forearm is held in a horizontal position, what force in the muscle of the upper arm is required to lift a 2-pound object in the hand? The distance from the elbow to the object is 12 inches and the distance from the elbow to the point where the tendon from the muscle is attached is 1.5 inches. (Assume 100 per cent efficiency.) What is the theoretical mechanical advantage? *Ans.* 16 lb; 1/8
8. Tweezers are used to place weights on a balance. The length of the tweezers is 10 centimeters. Force is applied with the fingers 7 centimeters from the fulcrum. What theoretical force is required to lift a 100-gram weight? (Assume 100 per cent efficiency.) What is the theoretical mechanical advantage?
9. A 300-pound refrigerator is to be moved up an incline which is 2 feet high and 5 feet long. The efficiency of the inclined plane is 80 per cent. What input force is required? Find the actual and the theoretical mechanical advantage. *Ans.* 150 lb; 2; 2½
10. The diameter of a steering wheel is 15 inches and the diameter of the steering rod is 1 inch. If a force of 4 pounds is applied on the rim of the wheel, what force can be exerted with the rod if the efficiency is 90 per cent? Find the actual and the theoretical mechanical advantage.
11. The diameter of a door knob is 2 inches and the diameter of the axle is 0.5 inch. If a force of 0.9 pound is applied on the knob, the force exerted with the axle is 3 pounds. What is the efficiency? Find the actual and the theoretical mechanical advantage? *Ans.* 83.3 per cent; 3.33; 4
12. An inclined plane is 8 feet long and 3 feet high. A force of 50 pounds is required to move a load of 100 pounds up the plane. What is the efficiency? Find the actual and the theoretical mechanical advantage.
13. A jackscrew has a pitch of 0.5 inch and the load to be lifted is 800 pounds. The efficiency is 40 per cent. What force is required

on the turning rod if it is 30 inches long? What is the actual mechanical advantage? What is the theoretical mechanical advantage? *Ans.* 5.31 lb; 151; 377

14. A food grinder has an average pitch of 1 inch and the handle is 10 inches long. What is the theoretical force on the food if the force on the handle is 6 pounds? What is the theoretical mechanical advantage?

15. A load of 225 pounds is to be lifted with a system of pulleys. The tension in the rope is not to exceed 60 pounds. The efficiency is 75 per cent. How many ropes are required? Make a sketch of the pulley system. What is the actual mechanical advantage? What is the theoretical mechanical advantage? *Ans.* 5; 3.75; 5

16. A load is to be lifted with a system of pulleys which has 3 supporting ropes in which the tension is not to exceed 40 pounds. The efficiency is 90 per cent. Make a sketch of the pulley system. What is the theoretical mechanical advantage? What is the actual mechanical advantage? How large is the load?

17. The diameter of the band wheel on a treadle sewing machine is 12 inches, and the diameter of the balance sheel is 3 inches. What is the speed advantage? *Ans.* 4

18. The crank of a rotary can opener is 6 inches long and the wheel which rotates the can has a radius of 1/4 inch. What is the mechanical advantage?

19. A radio tuning knob has a diameter of 1 inch and the spindle has a diameter of 1/4 inch. What is the mechanical advantage? *Ans.* 4

20. If a rotary egg beater has 72 cogs on the large wheel and 9 cogs on the small wheel, how many revolutions of the blades occur when the operator's hand makes one revolution?

5

DENSITY AND SPECIFIC GRAVITY

If asked to explain the chief difference between iron and cork, many people would reply that iron is heavier than cork. But when they are reminded that a large cork is much heavier than a small nail, then these people may qualify their statements by saying that iron is heavier than cork "according to its size." It is true that one of the most obvious differences between substances is that for equal volumes some are heavier than others. But this statement is not definite or exact and therefore does not satisfy the scientist.

23. Density. *The density of a substance is the mass per unit volume.*

$$D = \frac{M}{V}$$

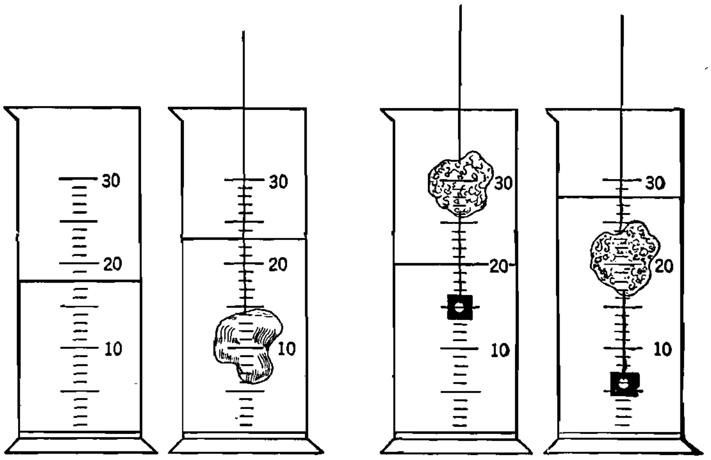
The units for expressing density depend upon the units in which the mass and the volume are measured. Among the units which may be used for density are pounds per cubic foot, pounds per cubic inch, and grams per cubic centimeter. The density of water in these units is

62.4 lb per cu ft
0.036 lb per cu in.
1.0 g per cu cm

Since the density of a substance is the mass per unit volume, both the mass and the volume must be known before the density can be calculated. The mass may always be obtained by weighing the material. If the material is in some regular geometric form such as a parallelopiped, a cylinder, or a sphere, the volume may be computed from the linear dimensions. But often the material is irregular in shape and some other method of obtaining the volume must be used.

24. Volume of Irregular Solids. The volume of an irregular body may be found in various ways.

1. If the body is insoluble in a given liquid it may be immersed in that liquid in a graduate which is calibrated either in cubic centimeters or in cubic inches. The liquid level is read before and after the body is immersed. The difference between the two readings is equal to the volume of the object. Water is the liquid generally used. (See Fig. 5.1.)



a. OBJECT HEAVIER THAN WATER
VOLUME = 5 CU CM

b. OBJECT LIGHTER THAN WATER
VOLUME = 8 CU CM

Fig. 5.1. Finding the volume of an irregular solid.

2. The "overflow" method may be used. (See Fig. 5.2.) A container of suitable size, equipped with an overflow spout, is filled with liquid until the container overflows. Then the object is lowered into the liquid, and the overflow caused by the object is caught in a suitable container. If a graduate is used the volume is obtained from the calibration on the graduate, otherwise the liquid must be weighed and its volume calculated. Water is generally used because it is plentiful, and easy to use, but any liquid in which the material will not dissolve may be used.

3. The object may be weighed in air and then when it is suspended in a liquid. It apparently weighs less when suspended in a liquid because of the buoyant effect of the liquid. Archimedes discovered this buoyant effect of liquids about 250 B.C. He was confronted with the problem of determining whether a new crown which had been made for the king of Syracuse was of

pure gold. It was irregular in shape, and the volume was difficult to determine. One day, while bathing, he noticed the buoyant effect of the water on his body, and he suddenly realized that here was the key to his problem. He weighed the crown first in air and then when it was immersed in a liquid, and determined the apparent loss of weight. This apparent loss of weight he knew was due to the weight of the liquid displaced by the crown, and knowing the density of the liquid, he found the volume of the object.

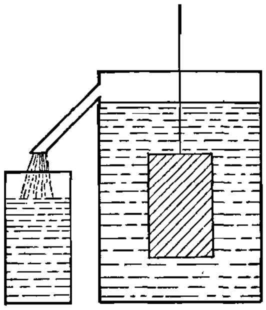


Fig. 5.2. Finding the volume of an object from the liquid which overflows.

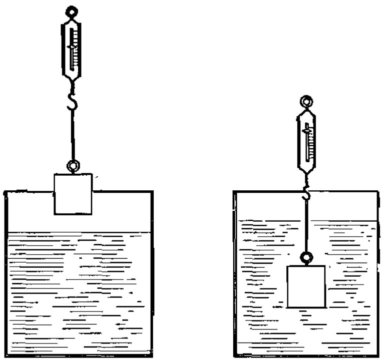


Fig. 5.3. Finding the volume of an object from the buoyant effect of a liquid.

$$\text{Volume of object} = \frac{\text{loss of weight in the liquid}}{\text{density of the liquid}}$$

Then he calculated the density of the crown and compared his result with the value for pure gold. Archimedes' law of buoyancy states that *a body which is wholly or partially immersed in a liquid is buoyed up by a force equal to the weight of the displaced liquid.*

25. Volume of Bodies Lighter Than the Liquid. If the body is lighter than the liquid in which it is suspended it floats, and therefore in order to find its volume a suitable sinker must be attached below the object to pull it into the liquid. Any of the methods explained in the preceding section may then be used to find the volume. In each case only the change caused by the object itself (not the object and the sinker) is considered in calculating the volume of the object.

26. Specific Gravity. It was observed at the beginning of this chapter that some materials are heavier than others. Iron is heavier than cork — it is also heavier than aluminum and heavier than water. Copper is heavier than iron, but not so heavy as silver or gold. Cork is lighter than water. It would seem to be an advantage to have some means of comparing the density of a material with the density of some other material chosen as a standard. Water has been chosen as a standard for comparison, and *the ratio of the density of a material to the density of water is the specific gravity of that material.*

$$\text{Specific gravity} = \frac{\text{density of material}}{\text{density of water}}$$

or, what amounts to the same thing,

$$\text{Specific gravity} = \frac{\text{weight of body}}{\text{weight of an equal volume of water}}$$

If a body is weighed and then is immersed in water and weighed again the apparent loss of weight is, according to Archimedes' law of buoyancy, equal to the weight of the displaced liquid. This liquid has the same volume as the object. Therefore

$$\text{Specific gravity} = \frac{\text{weight of body}}{\text{loss of weight of body in water}}$$

The specific gravity of a body lighter than water can also be found by noting how much of the body sinks into the water. If it sinks half way into the water it is one-half as heavy as water and the specific gravity is 0.5. Likewise if it sinks until three-fourths of the body is below the surface of the water its specific gravity is 0.75.

The specific gravity of a material always has the same numerical value regardless of the units from which it is obtained, and since it is a ratio between two like units it has no unit. For example, the density of mercury is

849 lb per cu ft
0.49 lb per cu in.
13.6 g per cu cm

SPECIFIC GRAVITY TABLE

Solids	Platinum		21.4	
	Gold		19.3	
	Silver		10.5	
	Copper		8.9	
	Iron		7.0	to 7.8
	Tin		7.3	
	Aluminum		2.7	
	Lead		11.3	
	Concrete		2.7	to 3.0
	Glass		2.4	to 2.8
	Diamond		3.0	to 3.5
	Cork		0.24	
	Ice		0.917	
	Sugar		1.6	
	Wood			
	Seasoned oak		0.6	to 0.9
	Walnut		0.64	to 0.7
	Mahogany		0.66	to 0.85
	Bamboo		0.3	to 0.4
	Gumwood		0.52	to 0.56
Liquids at 0°C	Water		1.0	
	Sea water		1.025	
	Mercury		13.6	
	Milk		1.028	to 1.035
	Olive oil		0.92	
	Alcohol		0.81	
	Ether		0.736	
	Turpentine		0.87	
	Kerosene		0.81	
	Gasoline		0.66	to 0.69
	Salt solution	10%	1.07	
		25%	1.9	
	Sugar solution	10%	1.04	
		25%	1.1	
	H_2SO_4	5%	1.03	
		100%	1.83	
	HNO_3	5%	1.03	
		100%	1.51	
Gases at 0°C 760 mm	Air		0.001293	
	Carbon dioxide		0.001977	
	Hydrogen		0.0000899	
	Oxygen		0.001429	
	Ammonia		0.00077	
	Chlorine		0.003214	
	Helium		0.000178	
	Sulphur dioxide		0.002927	

When the ratio of the density of mercury to the density of water is computed in corresponding units we find that

$$\frac{849 \text{ lb per cu ft}}{62.4 \text{ lb per cu ft}} = 13.6$$

$$\frac{0.49 \text{ lb per cu in.}}{0.036 \text{ lb per cu in.}} = 13.6$$

$$\frac{13.6 \text{ g per cu cm}}{1 \text{ g per cu cm}} = 13.6$$

27. Density and Specific Gravity of Liquids. The density and specific gravity of a liquid are found according to the same fundamental principles outlined above. To find the mass the liquid may be weighed in a suitable container and the weight of the container subtracted. If the container is a graduate the volume of the liquid may be read directly. If the container is of a regular geometric shape the volume of the liquid may be calculated from the inside measurements of the container.

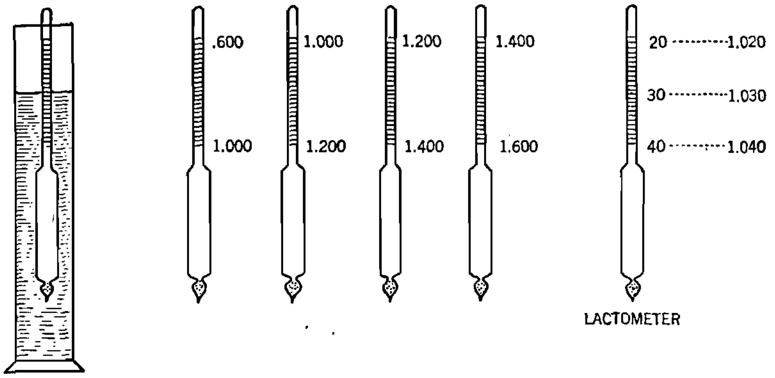


Fig. 5.4. Hydrometers.

The specific gravity of a liquid may be obtained by using a *hydrometer*, which is a cylindrical glass instrument with a weighted bulb to make it float upright, and a calibrated stem. The hydrometer is carefully lowered into the liquid which must be in a container which will allow the hydrometer to float freely. It will sink until it displaces a weight of liquid equal to its own weight. Then the reading at the surface of the liquid is the specific gravity of the liquid. In order to be absolutely accurate the temperature of the liquid must be the same as the calibration temperature of the hydrometer or else a correction must be made for the difference in temperature. Since heavy liquids exert a greater buoyant force than light liquids, and since it is desirable to have a short stem, hydrometers are made in various weights for various purposes. A hydrometer which is suitable for measuring the specific gravity of kerosene or alcohol is not heavy enough for milk, or for solutions of sugar or salt.

Hydrometers are used to test the concentration of sugar syrups, fruit juices, milk, alcohol, vinegar, oils, battery acid, and antifreeze solutions. Often a special calibration is used instead of the regular specific gravity calibration if the hydrometer is to be used for some special purpose. A hydrometer for testing milk is a lactometer, and since the specific gravity of milk ranges from about 1.026 to 1.036 and the variation is in the last two numbers the scale is marked from 20 to 40 meaning 1.020 to 1.040. The specific gravity of the syrup on canned fruits indicates the amount of sugar used and the specific gravity must not be below a given minimum if the label is marked "in heavy syrup" or "in light syrup." When the attendant at the filling station tells you your car battery tests "twelve-fifty" he means the specific gravity of the battery acid is 1.250. (See Sec. 136.)

28. Density and Specific Gravity of Gases. Pressure has only a negligible influence upon the volume of a solid or a liquid, but it has a great effect upon the volume of a gas. Temperature also has a decided effect upon the volume of a gas. Therefore both the pressure and the temperature of the gas must be known. It is customary to find the volume at the existing pressure and temperature and then compute the volume at standard pressure and temperature before determining the density. (See Sec. 35, Boyle's law and Sec. 58, Charles's law.) The specific gravity of a gas is sometimes given in relationship to air or to hydrogen instead of to water.

STUDY QUESTIONS

1. Why does oil float on water?
2. Why does iron not sink in mercury? Name a material that will sink in mercury.
3. Why can a balloon which is filled with hydrogen carry a heavier load than one which is filled with hot air?
4. Where in a room would you expect to find the most carbon dioxide?

5. Why will a ship, which is made of materials that are heavier than water, float?
6. Does chlorine gas stay close to the ground or rise rapidly?
7. Will gumwood sink or float in water?
8. Tomato juice or the syrup on canned fruit is sometimes checked with a hydrometer. Why?
9. What change occurs in the specific gravity of a liquid as its temperature increases?
10. Which is "heavier," aluminum or concrete?

PROBLEMS

1. If 4 cubic feet of aluminum weighs 674 pounds, what is the density of the aluminum? What is its specific gravity? *Ans.* 168.5 lb per cu ft; 2.7
2. If a silver spoon weighs 56 grams and has a volume of 5.3 cubic centimeters, what is its density? What is its specific gravity?
3. What is the weight of a piece of platinum which is 2 by 4 by 5 inches? *Ans.* 30.8 lb
4. What is the volume of a piece of glass which weighs 20 pounds?
5. What is the weight of the air in a room which is 20 by 30 by 10 feet? (Assume standard conditions for temperature and pressure.) *Ans.* 486 lb
6. What is the weight of the water in a swimming pool which is 100 feet long and 40 feet wide, if it is filled to an average depth of 9 feet?
7. The information printed on the side of a boat reads, "Maximum displacement 50 cubic feet." The boat weighs 800 pounds. How large a load may be placed in it? *Ans.* 2320 lb
8. A life preserver has a volume of 2 cubic feet and weighs 20 pounds. What buoyant force may it exert on the person using it?
9. If a girl floats in water with about 77/80 of her volume below the surface of the water, what is her specific gravity? *Ans.* 0.96
10. A bamboo pole floats with about 3/5 of its volume above the water. What is its specific gravity?
11. A piece of gold weighs 300 pounds. Its apparent weight when suspended in water is 284.4 pounds. Find its volume, its specific gravity, and its density. *Ans.* 0.25 cu ft; 19.23; 1200 lb per cu ft
12. A block of iron weighs 44 pounds. Its apparent weight when suspended in water is 38 pounds. Find its volume, its specific gravity, and its density.
13. What is the weight of a gallon of gasoline? *Ans.* 5.7 lb
14. What is the weight of a cubic foot of ice?

6

MECHANICS OF LIQUIDS AND GASES

Many of the conveniences of the modern home involve applications of the laws of liquids and gases. Water and gas are often forced to houses many miles from the source of supply. Water under pressure may be furnished to a house from a lake or from an elevated tank, either of which is above the level of the house. If it is not possible to secure water from an elevated source, water may be pumped into a pneumatic pressure tank and stored for future use; when it is needed it is forced by the compressed air to the level where it is to be used. Pumps operate because a difference in pressure is created by the pumping action. Air rushes into a vacuum cleaner because of the low pressure created in the body of the cleaner by a fan. Gasoline stoves must have air pumped into the fuel tank to force the gasoline to the burner where it is consumed. Liquids may be siphoned from one level to another and cream may be siphoned from the top of a bottle of milk, because of the pressure of the air. A drink may be sipped through a straw because the pressure inside of the straw is decreased below that of the atmosphere by sucking on the upper end of the straw.

It will be remembered that solids offer resistance to change in both form and volume. Liquids offer little resistance to change in form but very great resistance to change in volume. An increase of pressure of 3000 pounds per square inch will decrease the volume of water only about 1 per cent. Gases offer little resistance to change in either form or volume. It will also be remembered that solids exert downward pressures only. Liquids exert downward and lateral pressures, and if enclosed may exert pressures in all directions. Gases always exert pressure in all directions.

29. Pressure Due to Liquids. The downward force and pressure of a liquid may be found in the same way as for solids. (See Sec. 11.) The downward force is equal to the total weight of the liquid. The pressure is obtained by dividing the force by the area on which it acts.

$$P = \frac{F}{A}$$

The pressure may also be calculated if the height and the density of the material are known. Since the force which the liquid exerts on a supporting surface is equal to the product of the volume and the density, then

$$P = \frac{F}{A} = \frac{\text{volume} \times \text{density}}{\text{area}} = \frac{(\text{area} \times \text{height}) \times \text{density}}{\text{area}}$$

or

$$P = HD$$

If a column of water is 10 feet high, the pressure is

$$\begin{aligned} P &= HD \\ &= 10 \times 62.4 \\ &\doteq 624 \text{ lb per sq ft} \end{aligned}$$

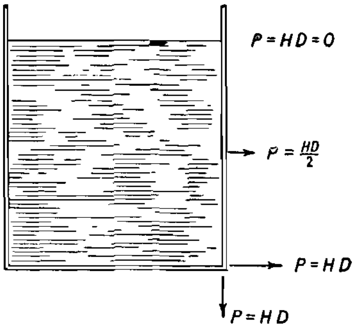


Fig. 6.1. Lateral pressure due to a liquid.

It is apparent, however, since a liquid must be confined in a vessel in order to give it shape, that there are other forces and pressures to be considered — those on the sides of the container. At any given point in a liquid which is at rest the upward, downward, and lateral pressures are equal. If this were not true the liquid would flow from the region of greater pressure to the region of less pressure. At any other point in the liquid at the same depth the pressure is the same as at the first point, but points at different depths are at pressures which vary with the depth. The pressure at any point may be found by $P = HD$. If the downward pressure at the bottom of the container is $P = HD$, then the lateral pressure right at the bottom is also $P = HD$, but the lateral pressure at the top is zero because H is zero. Therefore the pressure increases from zero at the top to a maximum at the bottom of the liquid. The average pressure is

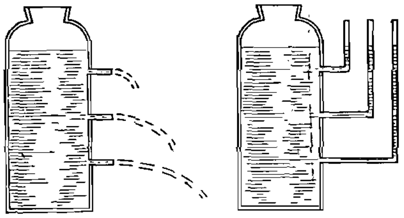


Fig. 6.2. Pressure varies as the depth.

$$P_a = \frac{HD + 0}{2} = \frac{HD}{2}$$

or in other words the average pressure is equal to the pressure half way down.

For example, if a dish 6 inches deep and 12 by 5 inches on the bottom is filled with water, the pressure on the bottom is

$$\begin{aligned} P &= HD \\ &= 6 \times 0.036 \\ &= 0.216 \text{ lb per sq in.} \end{aligned}$$

The average pressure on a vertical wall is

$$\begin{aligned} P_a &= \frac{HD}{2} \\ &= \frac{6 \times 0.036}{2} \\ &= 0.108 \text{ lb per sq in.} \end{aligned}$$

The force on the bottom of the dish is

$$\begin{aligned} F &= PA \\ &= 0.216 \times 12 \times 5 \\ &= 12.96 \text{ lb} \end{aligned}$$

or

$$\begin{aligned} F &= \text{volume} \times \text{density} \\ &= (12 \times 5 \times 6) \times 0.036 \\ &= 12.96 \text{ lb} \end{aligned}$$

The force on one of the 6 by 5-inch sides is

$$\begin{aligned} F &= P_aA \\ &= 0.108 \times 6 \times 5 \\ &= 3.240 \text{ lb} \end{aligned}$$

and on one of the 6 by 12-inch sides is

$$\begin{aligned} &= 0.108 \times 6 \times 12 \\ &= 7.776 \text{ lb} \end{aligned}$$

30. Pascal's Law. Suppose that a vessel fitted with two equal pistons A and B, as shown in Figure 6.3, is filled with some fluid. There is no tendency for either of these pistons to move. But if an extra weight is placed on one piston it will move down and the other piston will move up unless a like weight is placed on the second piston. This experiment illustrates the law discovered experimentally about three hundred years ago, by Pascal, a French scientist, who found that *pressure applied to an enclosed gas or liquid is transmitted undiminished in all directions.* The expansion of a rubber balloon when it is being inflated illustrates this law. The air in an automobile tire exerts the same pressure on all parts of the tire. If force is applied to the piston in Figure 6.4, water is forced through the holes an equal distance in all directions.

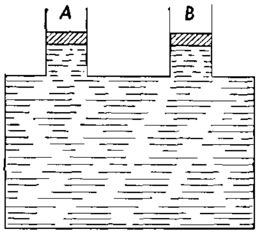


Fig. 6.3. The pistons do not move unless an extra force is applied to one of them; then it will move down and the other one will move up.

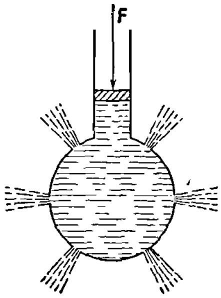


Fig. 6.4. Pressure exerted on any part of an enclosed liquid is transmitted undiminished in all directions.

31. Multiplication of Force by Transmission of Pressure. Now let us consider two cylinders, a small one and a large one, which are connected as shown in Figure 6.5 and which are filled with some liquid — usually either water or oil. Each cylinder is fitted with a piston. If a force is applied to the small piston, the resulting pressure is transmitted to the large piston

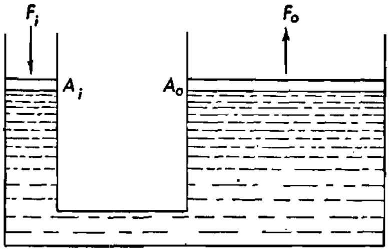


Fig. 6.5. Multiplication of force due to the difference in the areas of the pistons.

in accordance with Pascal's law. Since the input pressure equals the output pressure

$$P_i = P_o$$

then

$$\frac{F_i}{A_i} = \frac{F_o}{A_o}$$

For example, if the area of the small piston is 4 square inches and the area of the large piston is 100 square inches, the force which must be exerted on the small piston in order to lift a load of 1200 pounds is

$$\frac{F_i}{4} = \frac{1200}{100}$$
$$F_i = 48 \text{ lb}$$

Such a device is known as a *hydraulic machine* and as is the case with the simple mechanical machines discussed in Chap. 4, it is not 100 per cent efficient; actually a larger force than that calculated above is required to operate the machine. If the efficiency of the above machine is 80 per cent, then F_i is

$$\frac{F_i \times 0.80}{4} = \frac{1200}{100}$$
$$F_i = 60 \text{ lb}$$

If the small piston moves down 50 inches the volume of liquid pushed out of the small cylinder into the large cylinder is $4 \times 50 = 200$ cubic inches. If 200 cubic inches of liquid enter the large cylinder the piston which has an area of 100 square inches will be pushed up 2 inches.

$$\begin{aligned} \text{Work in} \times \text{efficiency} &= \text{work out} \\ F_iD_i \times \text{efficiency} &= F_oD_o \\ F_i \times 50 \times 0.80 &= 1200 \times 2 \\ F_i &= 60 \text{ lb} \end{aligned}$$

a result which agrees with the answer obtained by use of Pascal's law. A very large mechanical advantage may be obtained with this type of machine. The actual mechanical advantage is

$$MA = \frac{F_o}{F_i} = \frac{1200}{60} = 20$$

The theoretical mechanical advantage is

$$MA = \frac{A_o}{A_i} = \frac{100}{4} = 25$$

or

$$MA = \frac{D_i}{D_o} = \frac{50}{2} = 25$$

Pascal's law is applied in building hydraulic presses which are used for compressing cotton bales, for pressing oils from seeds, and for many other purposes. Hydraulic elevators are used in some places; the chief objection to them is that they operate very slowly. The small piston is connected to the city water main, and the large piston is the platform on which the load is placed. To let the elevator descend, the water in the large cylinder is allowed to run out by turning a stopcock. Most automobiles are equipped with hydraulic brakes. The advantage of hydraulic brakes over mechanical brakes is that all the wheels are retarded with the same force. If mechanical brakes are out of adjustment and one band tightens sooner than another, the car tends to swerve sidewise. Many automobile filling stations are equipped with hydraulic lifts for elevating

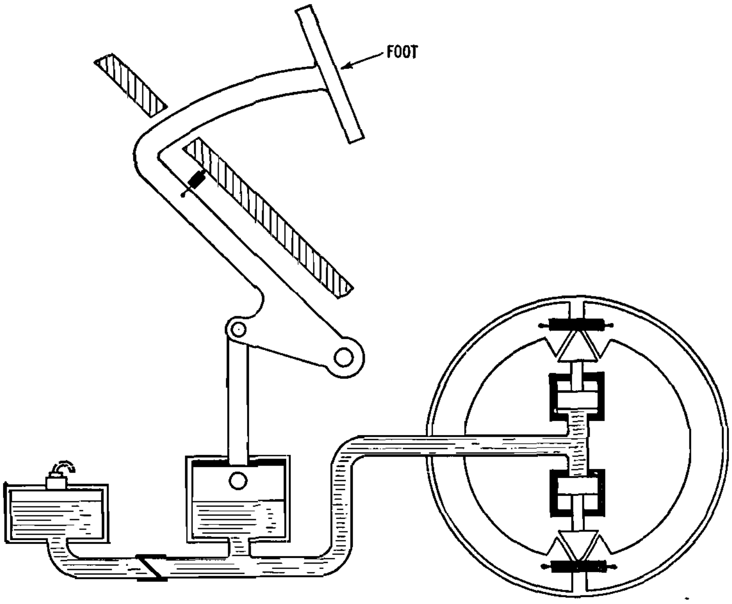


Fig. 6.6. The hydraulic brake system of an automobile.

cars while they are being greased or repaired. A hydraulic press in use by one large steel company is capable of producing a force of 14,000 tons, which is a force equal to the weight of about 250,000 people.

32. Barometers. The air surrounding the earth may be thought of as a sea of gas with the surface of the land and water forming the floor of this sea. People speak of things being as "light as air," and are often surprised when confronted with calculations showing the weights of given volumes of air. The specific gravity of air is 0.001293. A cubic foot of air therefore weighs 62.4 × 0.001293 = 0.08 pound approximately. If an average size room in the home is 14 by 16 by 8 feet it contains 1792 cubic feet of air. The weight of this air is then 1792 × 0.08 = 143.36 pounds.

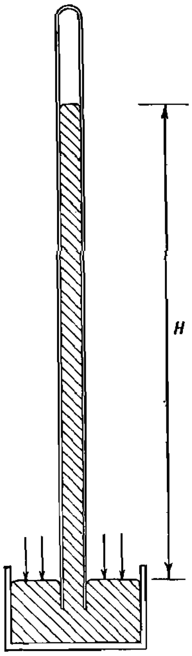


Fig. 6.7. Torricellian barometer.

As early as 1630, in the time of Galileo, it was believed that the air had weight and, as a result, exerted pressure. Galileo weighed a glass bulb full of air, then pumped in more air and weighed again, and he found that the weight of the bulb had increased. Galileo believed that the surface of the earth was subject to the pressure of all the air resting on it. He also believed that the pressure exerted by the air should decrease if one traveled up through it, because he knew from experiments that the pressure in liquids varied with the depth. In 1644 Torricelli, who had been a pupil of Galileo, made the first barometer. *A barometer is a device for measuring the pressure of the air.* Torricelli closed one end of a glass tube, filled the tube with mercury, placed his finger over the open end, and inverted the tube. The open end was then dipped in a dish of mercury and when Torricelli removed his finger the height of the mercury column dropped to 30 inches at sea level and to 29 inches at a higher elevation. Pascal reasoned it should go even lower at still higher altitudes. So he asked a relative who lived near a high mountain to try the experiment at various points up the mountain side. The mercury column fell lower and lower as the altitude increased but rose again to its original height in descending the mountain. In this way it was proved that the air does exert pressure and that the amount of pressure decreases as the altitude increases. The same results can be shown by putting such a tube under a tall glass bell jar and pumping out the air with a vacuum pump. The mercury in the tube falls as the air is pumped out but when the air is turned in again the mercury rises to the original height. This tube of mercury inverted in a dish of mercury is known as a *Torricellian barometer.*

Since there is practically a vacuum above the mercury in the tube, the pressure due to the column of mercury must be the same as the pressure exerted by the air on the surface of the mercury in the dish. If the air pressure increases, more mercury will be forced into the tube; but if the air pressure decreases, the height of the mercury column will decrease.

Since the mercury column stands at a height of 30 inches at sea level, the pressure of the air must be

$$\begin{aligned} P &= HD \\ &= 30 \times 0.49 \\ &= 14.7 \text{ lb per sq in.} \end{aligned}$$

Since this pressure is approximately 15 pounds per square inch, that value may be used for standard atmospheric pressure in order to simplify mathematical calculations. In metric units the pressure of the air at sea level is equivalent to 76 centimeters of mercury, or to 1033.6 grams per square centimeter ($P = HD = 76 \times 13.6 = 1033.6$ g per sq cm).

If water is used in the barometer, the column stands 34 feet high at sea level.

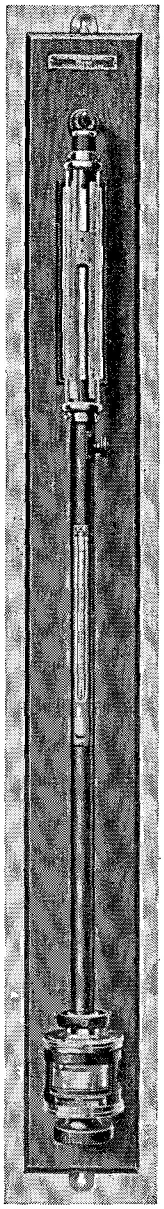


Fig. 6.8. A standard mercury barometer. (Courtesy Taylor Instrument Companies)

$$\text{Feet of water} = \frac{\text{inches of mercury} \times \text{specific gravity of mercury}}{12}$$

$$= \frac{30 \times 13.6}{12}$$

$$= 34 \text{ ft}$$

Water barometers are too long and awkward to be usable, but the fact that the air pressure is sufficient to balance a column of water 34 feet high is of interest in connection with pumps and pressure tanks. (See Secs. 45 and 46.)

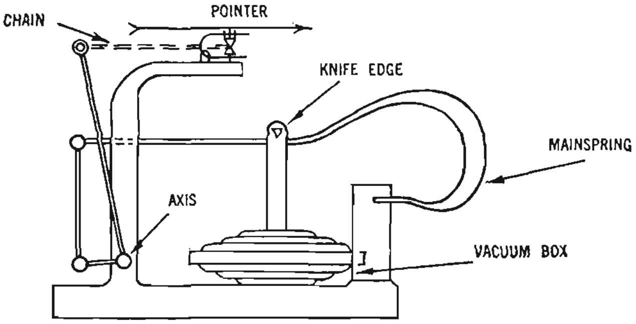


Fig. 6.9. Mechanism of an aneroid barometer.

An *aneroid barometer* is much more convenient than a mercury-in-glass barometer if the device is to be carried about. Aneroid means "without liquid" and the sensitive part of an aneroid barometer is a thin corrugated metal box which is evacuated. This makes it sensitive to changes in pressure on the outside. As the air pressure increases, the box is flattened, but when the air pressure decreases, it expands. This motion is transmitted by a spring and levers to a needle which travels over a scale. The scale may be graduated to correspond to inches or centimeters of mercury, or it may be

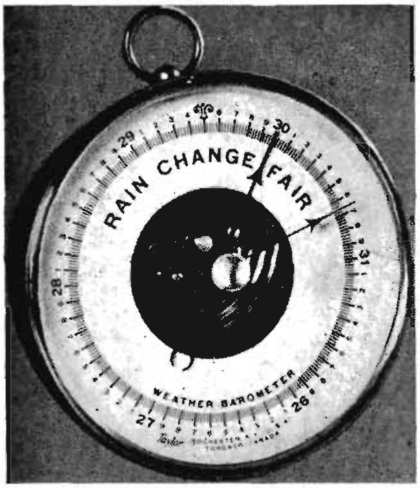


Fig. 6.10. An aneroid barometer. (Courtesy Taylor Instrument Companies)

calibrated to give the approximate elevation in feet or meters. Aneroid barometers are used on airplanes and balloons and by meteorologists, geologists, surveyors, and explorers.

A *barograph* is a recording aneroid barometer. The pointer which moves as the air pressure changes is equipped with a pen which rests against a chart on a revolving cylinder which is turned by means of a clock mechanism. It may revolve once a day or once a week. A special slow-drying ink is used on the pen so that one inking will last for several days.

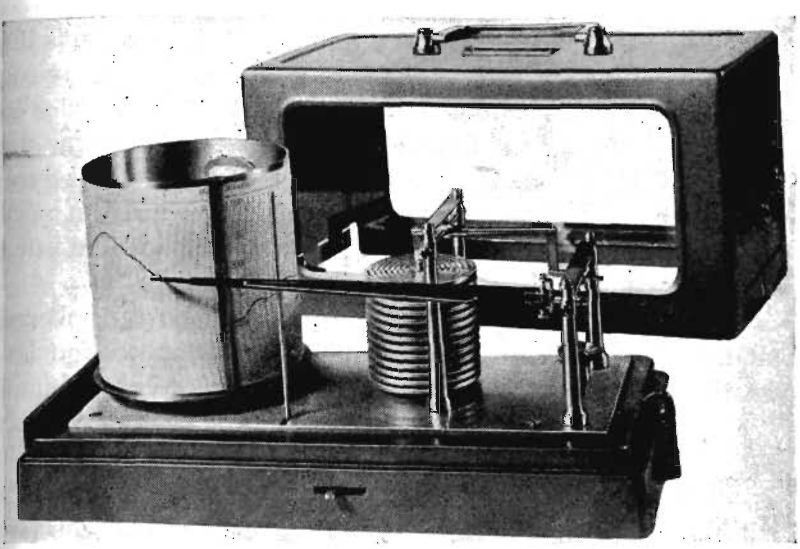


Fig. 6.11. A barograph. (Courtesy Julien P. Friez & Sons, Inc.)

33. Surface Tension. It will be noticed that the top surface of the mercury in the barometer is curved as is shown in Figure 6.7. The mercury surface is convex (curves up) but if the tube contains water the surface is concave (curves down). This curved top surface is called the *meniscus.* If the adhesion (attraction between unlike molecules) between the liquid and the tube is greater than the cohesion (attraction between like molecules) between the molecules of the liquid, the liquid wets the tube and the surface is concave. If the cohesion of the liquid is greater than the adhesion of the liquid for the tube the liquid does not wet the tube and the surface is convex. The curved surfaces of liquids in small tubes are due to surface tension.

In order better to understand the nature of surface tension let us consider a number of familiar illustrations. When a drop of water falls through air it tends to draw itself into a sphere. When water is sprinkled on an oily surface or when mercury is spilled on the floor, the small drops are spherical in shape. In this form the surface area is reduced to a minimum. The liquid acts as if its surface is an elastic membrane which contracts as much as possible. The surface of a liquid in a container acts the same way — as if it were under tension and constantly trying to contract. But it must be remembered that the molecules in the surface layer are no different than the molecules below the surface layer. The surface layer is not a film in the usual sense of the word; for example, the film which is formed on milk when it is heated without being stirred and which can be lifted off with a spoon is a real film.

To explain this apparent elastic film it must be remembered that molecules are so extremely small that the attraction between them is not appreciable unless the molecules are close together and the combined effect of large numbers of molecules is considered. The space around a molecule within which the attractive force of the molecule for other molecules can be detected is known as the *sphere of influence* of the molecule. Let us consider the molecules *a* and *b* in Figure 6.12. Molecule *a* is below the surface and thus is entirely surrounded by like molecules. Each molecule exerts attractive forces upon all of the surrounding molecules, therefore *a* is in a balanced condition because of these forces. But *b*, which is a molecule in the surface layer, is not in a balanced condition because there are no forces tending to pull it up to balance the downward pull of the molecules below it. This unbalanced force which tends to pull a surface molecule into the liquid accounts for the tendency of the surface to contract. Therefore surface tension is due to unbalanced molecular forces in the surface of the liquid.

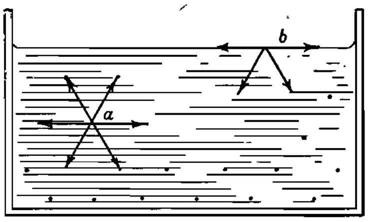


Fig. 6.12. Illustrating the cause of surface tension.

There are many illustrations of surface tensions that we may observe from day to day. A spoon or a cup may be filled a little "more than full" of water and the surface tension film keeps the water from spilling over. A needle or a safety razor blade, if carefully placed on the surface of water, will float even though the steel of which they are made has a greater density than the water. Some insects which have a waxlike coating on their feet can walk on water. However, if they are pushed through the surface film, then the film tends to hold them under, and it is difficult for them to get on top of the film again. The surface tension of oil is less than that of cold water; hence if a drop of oil is placed on the surface of cold water it spreads out in a thin film. However, since the surface tension of hot water is much less than that of cold water, if a drop of oil is placed on the surface of hot water it shows less tendency to spread out. Globules of fat sometimes float on the surface of hot soup, but as the soup cools the fat spreads out over the surface. The spreading behavior of an oil on the surface of water depends on (1) the surface tension of the oil, (2) the surface tension of the water, and (3) the interfacial tension or the tension of the surface between the two liquids.

Surface tension is of importance in beating eggs or cream. If the surface tension is decreased the materials whip better because the films spread thinner, and have less tendency to shrink into droplets; consequently more air can be incorporated. The addition of salt or cream of tartar improves the whipping quality, but sugar decreases the whipping quality. Cold cream whips better than warm cream; this behavior may seem incompatible with the fact that surface tension increases with lower temperature. But viscosity also increases with lower temperature, giving the whipped cream, with its incorporated air bubbles, a more mechanically stable structure.

Often when a solvent is used to remove a grease spot from a dress the spot disappears but a ring is left. This is because the solvent dissolves the grease, and since the surface tension of the solvent is low it spreads rapidly through the cloth, thus distributing the grease spot in a large circle around the original spot.

34. Bourdon Pressure Gauge. A Bourdon pressure gauge contains a curved hollow tube the open end of which is connected to the container in which the pressure is to be measured, and the closed end of which is attached to a lever system which in turn is connected to a cogwheel. When this wheel rotates, it turns the pointer on the face of the scale. When the pressure increases, the tube tends to straighten, and as a result, the pointer is moved to a higher reading. If the gauge is made so that the pointer reads zero at normal atmospheric pressure and moves up or down as the pressure goes either above or below atmospheric pressure, the readings indicate the difference in pressure between the unknown pressure and atmospheric pressure, and such readings are known as *gauge pressures.* The *total or absolute pressure* is obtained by adding the atmospheric pressure to the gauge reading. A gauge reading of 20 pounds per square inch is equivalent to an absolute pressure of 15 + 20 = 35 pounds per square inch. A gauge pressure of − 5 pounds per square inch is equivalent to an absolute pressure of 15 − 5 = 10 pounds per square inch.

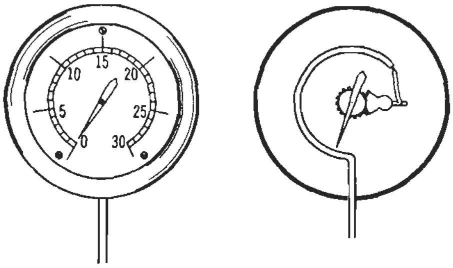


Fig. 6.13. A Bourdon pressure gauge.

35. Boyle's Law. Robert Boyle in 1660 found when experimenting with gases that if he held the temperature of a gas constant while he increased the pressure its volume decreased, but when he decreased the pressure the volume increased. Boyle's law is stated as follows: *if the temperature of a given mass of a gas is held constant, its volume varies inversely with the absolute pressure to which it is subjected.*

$$\frac{P_1}{P_2} = \frac{V_2}{V_1}$$

or

$$P_1V_1 = P_2V_2$$

For example, if the volume of the gas was reduced to one half of its first value, the pressure was doubled, or if the volume was increased to three times its first value the pressure was reduced to one third of what it had been. When air is pumped into a tire until the gauge reads 30 pounds per square inch the absolute pressure of the air has been changed from 15 pounds per square inch atmospheric pressure to 45 pounds per square inch (30 + 15 = 45). When oxygen is stored in tanks for use in hospitals, laboratories, and shops it is often under a gauge pressure of 2200 pounds per square inch or an absolute pressure of 2215 pounds per square inch.

36. Pressure Coffee Makers. Coffee makers of the type shown in Figure 6.14 depend in part on atmospheric pressure for their operation. The water is placed in the lower container, the top part is fitted snugly into the lower part (a rubber gasket makes an airtight joining possible), the filtering device is put in place, and the ground coffee is placed in the top container. Then the coffee maker is placed over a source of heat — or it may have a self-contained electric heating unit as shown in Figure 6.14. As the temperature increases, the air and water vapor in the lower container expand and force the hot water up the tube in to the upper container. In the automatic type all of the water is forced into the upper container; consequently, the temperature in the lower container rises high enough to operate a thermostat which turns the unit to low heat. Then the air and water vapor in the lower part cool and contract, thus reducing the pressure to less than atmospheric pressure, and the liquid (coffee) in the top container is forced back into the lower container.

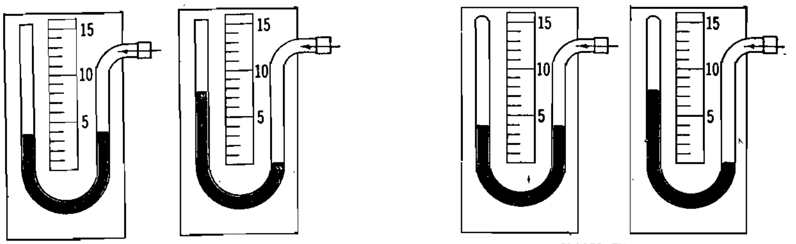
Fig. 6.14. A pressure coffee maker. (Courtesy Sunbeam Corporation)

It is important not to loosen the upper part from the lower part while the liquid is in the upper part because the pull of gravity alone cannot force the liquid through the filter. The extra pressure required results from the difference between atmospheric pressure and the decreased pressure in the lower container.

37. Manometers. *Open Manometers.* If a U-tube is partly filled with a liquid, the liquid will stand at the same level in both arms when the U-tube is exposed to atmospheric pressure only. If, however, one side is subjected to a greater pressure, the liquid will fall on that side and rise on the opposite side. The pressure in excess of atmospheric is found by multiplying the difference in height of the two columns of liquid by the density of the liquid. For example, if one side is connected to a gas cock and if the liquid then stands at 2 inches on one side and at 9 inches on the other side, the gauge pressure of the gas is equivalent to 7 inches of the liquid. If the liquid is water

$$\begin{aligned} P &= HD \\ &= 7 \times 0.036 \\ &= 0.252 \text{ lb per sq in.} \end{aligned}$$

The total or absolute pressure is obtained by adding this amount to the atmospheric pressure. If the pressure to be measured is less than atmospheric — for example, the pressure in a vacuum-cleaner nozzle — the liquid will rise on the side subjected to the decreased pressure. The decrease in pressure is calculated from the difference in the height of the two columns; the absolute pressure is obtained by subtracting this amount from the atmospheric pressure. For small differences in pressure water is the liquid generally used in the tube, but for larger pressures mercury is used — otherwise the tubes would be inconveniently long.



OPEN TUBE CLOSED TUBE

Fig. 6.15. Open and closed manometers.

Closed Manometers. A closed manometer is often used for measuring large pressures. One end of the tube is closed and the space above the liquid is filled with some gas — usually air. The volume and the pressure of this gas are measured when the other side of the manometer is exposed to atmospheric pressure. Also the volume of the enclosed gas and the difference in level of the liquid columns is noted when the manometer is connected to the container in which the unknown pressure is to be measured. The pressure of the gas in the closed arm may be determined by use of Boyle's law. The absolute pressure in the container is then equal to this pressure plus the pressure due to the difference in the two columns of liquid which is calculated by $p = HD$. For example, if, when the manometer is exposed to the unknown pressure, the volume of the gas in the closed arm is reduced to one-quarter of the original amount then the pressure of the gas according to Boyle's law is $4 \times 15 = 60$ pounds per square inch. If the liquid (for example Hg) stands 10 inches higher on one side than on the other side of the manometer, the pressure due to the liquid is $10 \times 0.49 = 4.9$ pounds per square inch. Therefore the total absolute pressure is $60 + 4.9 = 64.9$ pounds per square inch, and the corresponding gauge pressure is $64.9 - 15 = 49.9$ pounds per square inch.

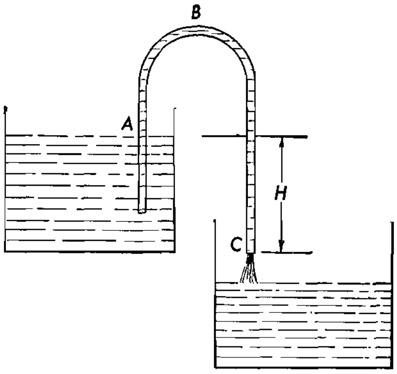


Fig. 6.16. A siphon.

38. The Siphon. A siphon is a bent tube with unequal arms which is used for transferring liquids from a higher to a lower level. If the tube is filled with the liquid and placed as shown in Figure 6.16, the liquid will flow from the upper container into the lower container. Since atmospheric pressure keeps the short arm full, the maximum distance from the top of the liquid at *A* to the top of the bend *B* will be determined by the kind of liquid and by the atmospheric pressure. For standard atmospheric pressure, this distance is limited to 34 feet for water and to 30 inches for mercury. The upper surface of the liquid at *A* and the open end of the siphon at *C* are both subject to atmospheric pressure. The pressure which makes the siphon operate is proportional to the difference in height between the points *A* and *C* and to the density of the liquid; i.e., the pressure is calculated by $P = HD$.

Siphons are used for a variety of purposes. Cream may be siphoned from the top of a bottle of milk, gasoline may be siphoned from the tank of a car, and water may be siphoned from a tank. Sometimes after sediment has settled out of a liquid the clear liquid is siphoned off without disturbing the deposit in the bottom of the container. Water may be siphoned from a fish bowl without disturbing the decorations and water plants which may be in it. In chemical laboratories glass siphons are used in removing liquids from reagent bottles. Siphons are used in aqueducts to carry water over hills; the air bubbles which are carried along in the water tend to collect at the top of the siphon and small air pumps have to be installed to keep the pipe full of water.

39. Vacuum Cleaners. The first vacuum cleaners were made very much like pumps, but they pumped air instead of water. The rush of air through the machine carried dust and litter with it, and the air escaped through a cloth bag which trapped the dirt.

In the vacuum cleaners in use today a decrease in pressure is produced in the body of the cleaner by a fan which is operated by an electric motor. The fan and motor are enclosed in a case; on the intake side of the case is the nozzle which is shaped to fit closely to the surface to be cleaned; on the outlet side the air escapes through a cloth or fiber bag which traps the dirt. This principle has been used for years in removing grain from ships, sawdust from machinery, and ashes from ash pits. It is interesting to note that the process was first used for lifting much heavier amounts of material than are lifted in house cleaning. One of the problems in adapting the principle to vacuum cleaners was to build a machine which would get practically all of the dirt — thoroughness of cleaning was the important point, rather than the mass of material moved.

The general methods of assembling the essential parts of a vacuum cleaner are shown in Figures 6.17, 6.18, and 6.19. These parts include the motor, the fan, the dust bag, and the nozzle. Some machines depend entirely upon the rush of air through the nap of the carpet to do the cleaning. Other machines have brushes to aid in moving the nap and loosening the dirt. In cleaners of the types shown in Figures 6.18 and 6.19 the brushes are always stationary, but in cleaners of the type shown in Figure 6.17 the brushes may be either stationary or revolving. However, they are usually connected by a belt to the drive shaft of the motor and consequently revolve rapidly when the motor is running.

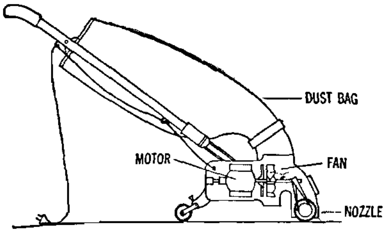


Fig. 6.17. Showing the main parts of an upright-type vacuum cleaner.

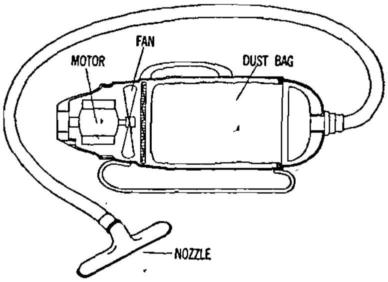


Fig. 6.18. Showing the main parts of a cylinder-type vacuum cleaner.

The material and the weave of the bag are important. If the weave is too open, dirt escapes with the air; and if it is too tight, the air does not escape easily and a back pressure develops which decreases the efficiency of the machine. The bag should be emptied often. It is not made large in order to hold a large amount of dirt, but to provide a large filtering area. If the bag has considerable dirt in it, the filtering area is reduced and the incoming air has to pass through the accumulated dirt, which reduces the efficiency of the cleaner. Merely emptying the bag is not enough; it should be turned wrong side out and brushed or cleaned with the cleaner attachments, because the pores of the cloth become filled with dirt and lint, and ravelings collect on the inner surface, and thus the air cannot escape at the normal rate.

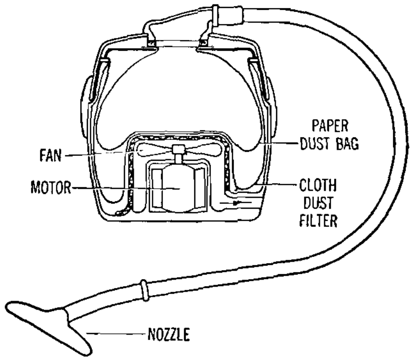


Fig. 6.19. Showing the main parts of a canister-type vacuum cleaner.

At the present time many cleaners are equipped with disposable paper bags. This eliminates the unpleasant task of emptying the bag, but the problem of making a paper bag that will keep the dirt in and let the air out has not been entirely solved. Also some operators let too much dirt accumulate in the bag before it is discarded, and this reduces the efficiency of the machine.

The operator should be careful not to pick up sharp-pointed objects, such as hairpins and tacks, because they may nick the fan blades or puncture the bag. If the machine is to be oiled by the operator, directions are furnished with the machine; but now most machines have the bearings sealed in oil and a periodic checkup and oiling by a service man is all that is necessary.

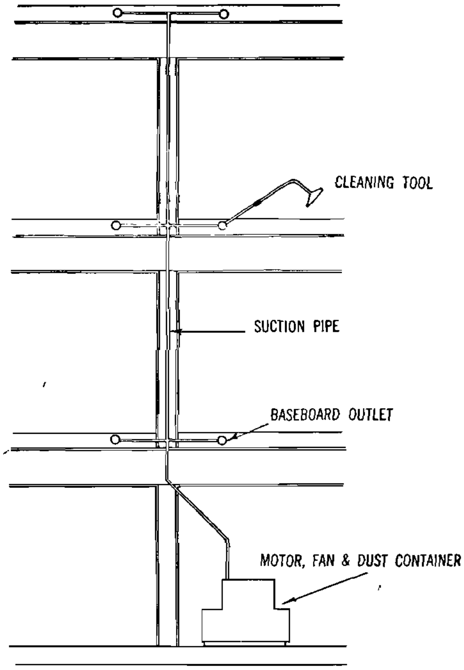


Fig. 6.20. A permanently installed vacuum-cleaning system.

A permanently installed system of vacuum cleaning is especially satisfactory for large buildings, such as hotels, office buildings, hospitals, and libraries. The White House in Washington, D.C., is equipped with this type of cleaning system. In a permanent installation the motor and fan are installed in a cabinet in the basement, and tubes lead from this cabinet to the various rooms in the building where they are closed with tight-fitting caps. When a room is to be cleaned, a flexible tube, equipped with suitable metal extensions and a nozzle or a brush, is attached to one of these openings and the motor is then turned on by means of a conveniently located switch. The dirt is carried to the basement and deposited in a dust trap which is connected to the sewer.

STUDY QUESTIONS

1. Why are gases more compressible than liquids?
2. Why do liquids exert sidewise forces?
3. Name several practical applications of Pascal's law.
4. If you travel up a mountain with a barometer, will its reading increase or decrease?
5. Why does an aviator need an aneroid barometer on his instrument panel?
6. What causes surface tension?
7. Name several instances in which surface tension is of importance in baking.
8. How is a gauge pressure changed to the corresponding absolute pressure?
9. Are gauge or absolute pressures used in Boyle's law?
10. Which is the better choice for measuring a high pressure — an open or a closed manometer?
11. What will happen if a small hole is made in the top of a siphon while it is operating?
12. How is the pressure reduced to less than atmospheric pressure in the nozzle of a vacuum cleaner?
13. What factors must be considered in choosing the cloth from which to make the dust bags for vacuum cleaners?
14. What are the advantages and disadvantages of paper bags for vacuum cleaners?
15. What are the advantages of a permanently installed vacuum cleaning system?

PROBLEMS

1. If olive oil fills a beaker to a depth of 5 centimeters, what is the pressure on the bottom of the beaker? *Ans.* 4.6 g per sq cm
2. If a beaker is filled with mercury to a depth of 10 inches, what is the pressure on the bottom of the beaker?
3. If a hot-water tank is 4 feet high and full of water, what is the pressure on the bottom? What is the average pressure on the side walls? What is the force on the bottom of the tank if the area is 2 square feet? *Ans.* 249.6 lb per sq ft; 124.8 lb per sq ft; 499.2 lb
4. If the water in a swimming pool is 10 feet deep, what is the pressure on the bottom of the pool? What is the average pressure on the sides

of the pool? If the pool is 30 by 50 feet, what is the force on the bottom? What is the force on one end of the pool?

5. A force of 15 pounds is exerted on the small piston of a hydraulic press, which has an area of 2 square inches. If it is assumed that there is no friction, how heavy a load may be lifted by the large piston, which has an area of 24 square inches? What is the mechanical advantage of the press? If the small piston moves down 6 inches, how far will the large piston move up?
Ans. 180 lb; 12; 0.5 in.
6. If a 2000-pound load is to be lifted with a hydraulic press which is 80 per cent efficient, what force will be required? The area of the large piston is 40 square inches and the area of the small piston is 12 square inches.
7. If the barometer reads 28 inches of mercury, find the pressure of the air in pounds per square inch. Find the equivalent water column. What will the barometer read in centimeters of mercury?
Ans. 13.72 lb per sq in.; 31.7 ft; 71.12 cm
8. If the barometer reads 73 centimeters of mercury, find the equivalent number of inches of mercury. Find the equivalent number of feet of water. Find the air pressure in pounds per square inch.
9. Change a gauge reading of 10 pounds per square inch to the corresponding absolute pressure. *Ans.* 25 lb per sq in.
10. Change an absolute pressure of 20 pounds per square inch to the corresponding gauge reading.
11. If 400 cubic feet of gas at a pressure of 28 inches of mercury are allowed to expand to 600 cubic feet, what is the new pressure?
Ans. 18.7 in. of Hg
12. If 2000 cubic centimeters of gas at a pressure of 75 centimeters of mercury are put under a pressure of 300 centimeters of mercury, what will be the resulting volume?
13. When one side of an open manometer is attached to a gas outlet, the difference between the water levels in the two sides is 8 inches. What is the pressure of the gas in excess of the air pressure?
Ans. 0.288 lb per sq in.
14. When a given vacuum-cleaner nozzle is attached to one end of an open manometer, the difference between the water levels in the two sides is 15 inches. What is the decrease in pressure caused by the cleaner?
15. If a tire is flat, how many cubic feet of air at normal pressure must be pumped into the tire to cause the gauge to read 28 pounds per square inch? The volume of the tire when it is pumped up is 1.5 cubic feet. How much does the air in the tire weigh?
Ans. 4.3 cu ft; 0.35 lb
16. If the gauge on an oxygen tank reads 25 pounds per square inch and the volume of the tank is 2 cubic feet, how much space will the oxygen occupy if it expands until the pressure is normal?

7

GAS SUPPLY FOR THE HOUSE

The gas used in the home may be either natural or artificial gas. In either case, pressure forces the gas through a piping system which consists of main lines, branches, and house service pipes. Coming from the mains into a building, the gas passes through a pressure regulator and from there to the gas meter where it is measured. Then it goes to the various gas burners in the house.

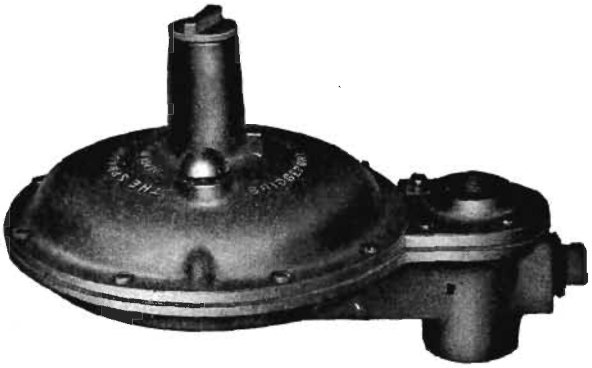


Fig. 7.1. Gas pressure regulator. (Courtesy The Sprague Meter Company)

Fig. 7.2. Cross section of a gas pressure regulator.

40. The Pressure Regulator. As indicated in Figure 7.2, gas from the service pipe enters the regulator at the inlet *I*, passes through valve *V*, and then out tnrough *O* to the gas meter. The valve *V* is controlled by the mechanism at the left. *L* is a leather diaphragm which separates this compartment into two parts.

An iron weight *W* rests on this diaphragm but is partially supported by the spring *S*. As gas enters through the valve *V* it fills the space below the leather diaphragm and, as the pressure increases, the diaphragm *L* and the weight *W* are raised. This mechanism is attached to the left end of the lever *ab* which is pivoted at *c*. This action partially or entirely closes the valve *V* and thus decreases the rate at which gas may enter. As a result the pressure under *L* decreases and the weight *W* pushes the diaphragm down again. Thus the pressure of the gas leaving the regulator at *O* is held constant. Except when sudden changes in pressure occur in the supply line or when gas appliances are turned on or off in the house, there is very little motion in the mechanism of the pressure regulator. The upper side of the diaphragm is exposed to atmospheric pressure through the pipe *A*. If the regulator is installed in the house, this pipe extends out through the wall or foundation so that the small amount of gas which may diffuse through the diaphragm will not escape in the house.

Fig. 7.3. A gas meter. (Courtesy The Sprague Meter Company)

41. The Gas Meter. A gas meter is a mechanical device which is operated by the pressure of the gas passing through it and which measures the number of cubic feet of gas passing through it. The meter receives the gas from the pressure regulator and delivers it to the pipes which distribute it to the burners. The meter contains four gas compartments with flexible walls. (See Fig. 7.5.) Gas enters at *C*, and flows into *B* and *B'* and expands these compartments. At the same time gas is expelled from *A* and *A'* into *O*, which connects to the pipe leading away from the meter. The motions of these walls operate levers which move the sliding valves *V* and *V'* to the positions shown in Figure 7.5b. Then *A* and *A'* fill and *B* and *B'* empty. In order to maintain a constant flow one pair of compartments fills as the other pair empties. The mechanism which operates the valves V and V' also operates a set of geared wheels which in turn operate the pointers on the dials of the meter.

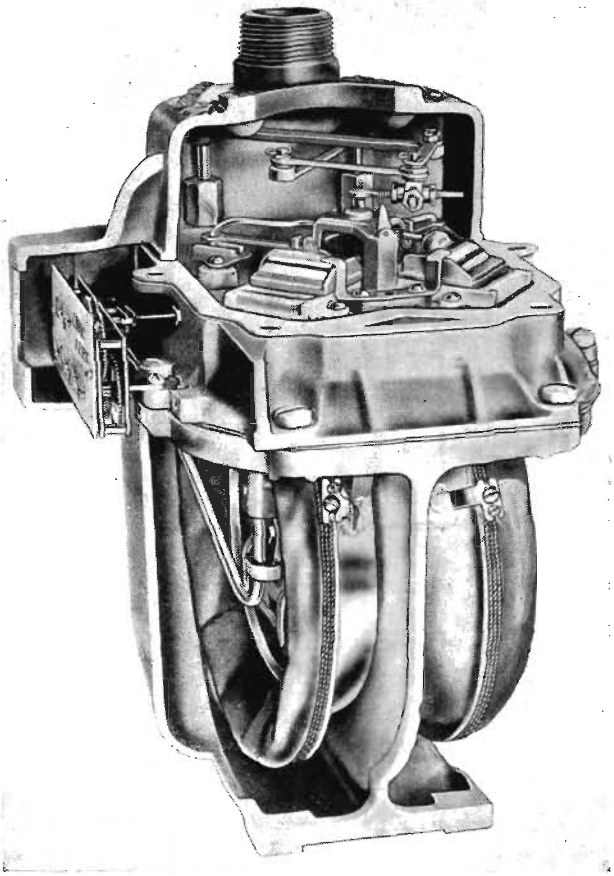
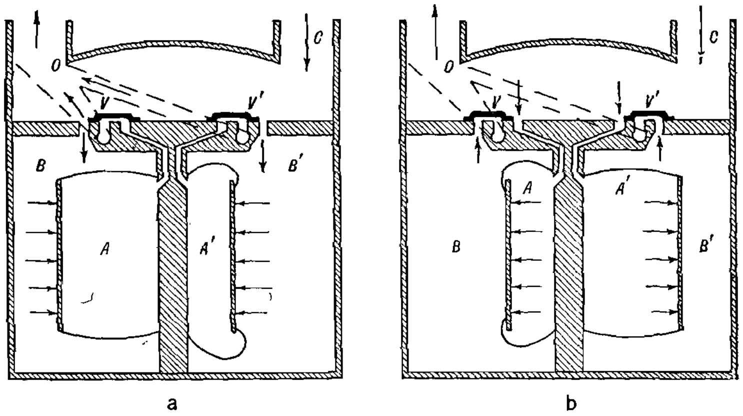


Fig. 7.4. Interior of a gas meter. (Courtesy Pittsburgh Equitable Meter Company)

42. Gas Meter Readings. On some of the dials the numbers read clockwise and on others counterclockwise. This is due to the motion of the geared wheels — when one is driven clockwise the next is driven counterclockwise, the next clockwise, and so on for as many wheels as are geared together. When one pointer has made a complete revolution, the pointer on the next dial has moved from one number to the next; that is, 10 revolutions on one dial result in one revolution on the next. Sometimes it is difficult to tell whether a hand is just reaching a certain number or has just passed it. This reading can always be determined by noting the next dial to the right. Therefore it is usually a saving in time to read the dials from the right to the left. The number below the dial is the number of cubic feet which it records for one complete revolution. In Figure 7.6 the reading is 13,100 cubic feet for the first set of dials. (Record the readings for the other sets.) The 1-cubic-foot dial is for calibration purposes only. Some meters have a recording device like the mileage indicator on a car which gives the reading directly.



a b

Fig. 7.5. Diagrammatic cross section of a gas meter.

The difference between two consecutive readings is the number of cubic feet of gas used during the intervening time. For example, if on January 1, the reading is 168,000 cubic feet and on February 1, it is 187,000 cubic feet, the difference is 19,000 cubic feet. If gas is sold at $1.00 per thousand cubic feet, the bill for the month would be $19.00. In many cities there is a lower rate for all gas used above a certain amount. The rate might be $1.00 per thousand cubic feet for the first thousand and only $0.50 per thousand for all above that amount. There is usually a minimum charge for each month, no matter how little gas is used during that month.

43. Gas Burners. A common type of gas burner is shown in Figure 7.7. The gas enters the burner through a small orifice at a speed of from 100 to 150 feet per second. This rapidly moving stream of gas carries air with it into the mixing tube and, because of atmospheric pressure, more air is forced in through the air shutter. The amount of air which mixes with the gas in the mixing tube may be regulated by changing the size of the opening in the air shutter, and the flow of gas may be regulated by adjusting the size of the gas orifice. The air which mixes with the gas in the mixing tube is known as *primary air*. This air and gas mixture will not burn until it is supplied with more oxygen, but the air which surrounds the burner supplies the required oxygen and is known as *secondary air*. When the ratio

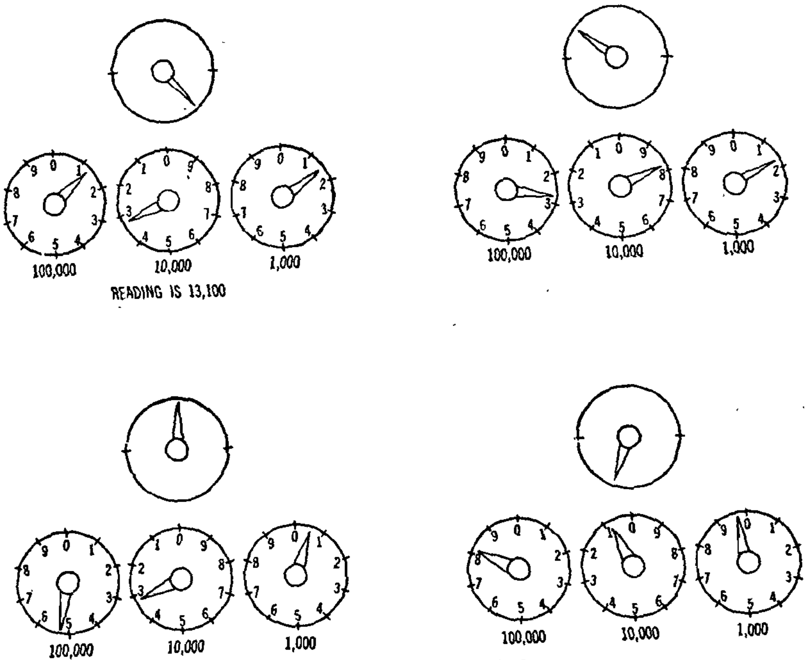


Fig. 7.6. Gas meter dials.

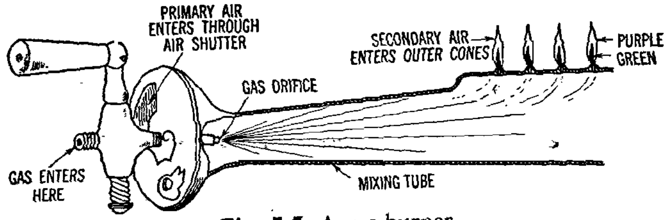


Fig. 7.7. A gas burner.

of gas to air is properly adjusted, the gas flame consists of two cones — an inner green one and an outer purple one. (See Fig. 7.7.)

Most gas-stove burners are lighted from a pilot light centrally located with respect to the surface burners. When a burner is turned on, gas travels from the burner through a tiny tube to the pilot light where it is ignited. The flame travels back through the tube and ignites the burner.

If the burner is to be lighted with a match, one should turn the gas on and then hold the lighted match near the burner. If the lighted match is held near the burner before it is turned on, the burner may "pop" or "flash back" because the burner is full of air when the gas is turned on, and the ratio of air to gas is too great. The flame travels back from the openings in the burner faster than the mixture of gas and air travels toward the burner, and combustion takes place in the mixing tube with a roaring noise; and, since there is not enough air for complete combustion, poisonous carbon monoxide is produced.

A very high flame rising above the grate indicates too much gas. A sputtering, roaring flame indicates too much air. A flame with a yellow tip indicates too little air. When the flame burns with the purple cones just reaching the bottom of the cooking utensil, the gas is being burned efficiently.

To change the amount of air entering through the air shutter, loosen the screw which holds the shutter in place, rotate the shutter the desired amount, and then tighten the screw. Figure 7.7a shows a cross section of a gas valve. To increase the flow of gas, loosen the cap *C* a trifle; and to decrease the flow, tighten *C*. Once adjusted, no further change should be necessary.

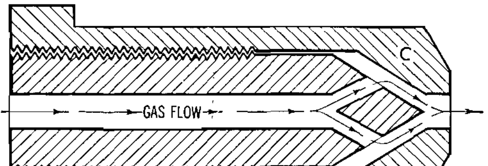


Fig. 7.7a. A cross section of a gas valve.

An oven burner has a mixing tube similar to that of a surface unit. The oven pilot light burns constantly after the oven burner is lighted. If the oven burner goes out accidentally or is turned out by the oven thermostat, the pilot light will relight the gas and thus prevent an explosion.

44. Gas Oven Thermostats. There are two general types of thermostats for gas ovens. One is known as a liquid temperature control and the other is generally referred to as a rod-and-tube control. They differ chiefly in the device which is placed in the oven to respond to the temperature.

The principal parts of the liquid temperature control are shown diagrammatically in Figure 7.8. The tube *T*, which is located in the oven, and the cylinder *L* are filled with a liquid. As the temperature in the oven increases, the liquid in *T* expands and the resulting pressure is transmitted by the liquid to the flexible diaphragm *D*, which exerts a force on the lever *ABC* at *A*. The fulcrum of the lever is at *B*; consequently when *A* is forced to the right, *C* is moved to the left, thus partially or entirely closing the gas valve *V*. As a result the oven cools, the pressure of the liquid decreases, and the force acting on *A* is reduced. A spring in the mechanism of the valve *V* causes it to open whenever the force at *A* is decreased. Thus the temperature in the oven controls the flow of gas to the oven burner.

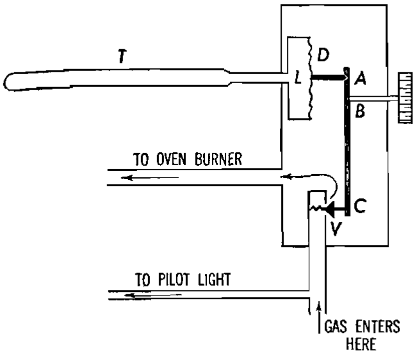


Fig. 7.8. A liquid thermostat.

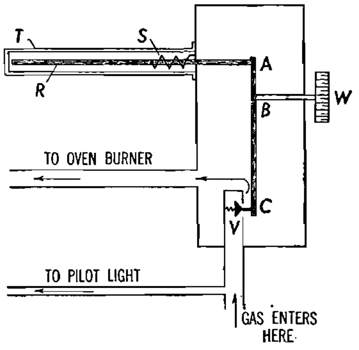


Fig. 7.9. A rod-and-tube thermostat.

The temperature to be maintained in the oven is determined by setting the temperature wheel *W*, which is really the head of a screw, the tip of which serves as the fulcrum for the lever *ABC*. A slight change in the position of the fulcrum at *B* changes the force required at *A* to open or close the gas valve. This change of force results of course from a change of temperature in the oven.

The rod-and-tube control is shown in Figure 7.9. The temperature wheel *W*, the lever *ABC*, the valve *V*, and the outlet to the oven burner are similar to Figure 7.8, but the device for changing the pressure at *A* differs. The porcelain rod *R* is enclosed in a copper tube *T* which is fastened to the oven wall at the right. As the temperature of the oven increases, the copper tube increases in length with the free end moving to the left. A spring *S* keeps the porcelain rod *R* pushed to the left as far as possible. Consequently as the oven temperature increases, the pressure of *R* at *A* decreases. A spring in the mechanism of the gas valve *V* closes the gas valve as the pressure at *A* decreases. Consequently the gas supply to the oven is decreased; then the oven cools slightly, the copper tube contracts, *R* is moved to the right and exerts more force on *A*, which causes the gas valve to open again. This type of temperature control is now used chiefly on heavy-duty equipment.

It is interesting to note that in Figure 7.8 when the temperature in the oven increases, *A* is moved to the right while in Figure 7.9 when the temperature of the oven increases, *A* is moved to the left. Consequently the details of the valve *V* are slightly different.

STUDY QUESTIONS

1. What is the purpose of the gas regulator?
2. Who is responsible for making any needed adjustments on the gas regulator, the gas meter, or the burner in a gas furnace — the consumer or the gas company?
3. What is meant by primary and secondary air in connection with a gas burner?
4. What makes a gas burner pop or flash back?
5. How may a gas burner be adjusted to secure the proper mixture of gas and air?
6. Describe an ideal gas flame.
7. Why should a gas oven be equipped with a pilot light?
8. Explain the liquid temperature control for a gas oven.
9. Explain the rod-and-tube temperature control for a gas oven.

PROBLEMS

1. If on November 1 the gas meter reads 24,300 cubic feet and on December 1 it reads 29,900 cubic feet, what is the gas bill for the month of November according to the following schedule?

First 1000 cu ft	$1.00
All over 1000 cu ft	0.50 per M

Ans. $3.30

2. If on February 1 the gas meter reads 37,600 cubic feet and on March 1 it reads 56,300 cubic feet, what is the gas bill for the month of February according to the above schedule?

8

HOUSEHOLD WATER SUPPLY AND SEWAGE DISPOSAL

Water is so essential to our comfort and health that too much care cannot be devoted to the maintenance of a pure, adequate, and inexpensive supply. Primitive man placed his home near a spring or a river, and depended upon it to supply his needs. Later he learned that a better and more dependable supply might be obtained by digging wells. Ancient wells were usually made in the form of a tunnel, the descent to the water level being by steps. Later the wells were dug vertically and buckets were lowered into the water and then lifted out by hand or by means of a wheel and axle. Naturally, most of these wells made use of water supplies as near the surface of the earth as possible; consequently the water was easily contaminated, and during dry seasons the supply was soon exhausted. The invention of the pump was a decided advance. When better pumps were built, and people came to understand their operation more fully, deeper sources of water were used.

In order to secure an abundant supply of good water, it is often necessary to bring water from a long distance to the point where it is to be used. While water systems are considered a modern invention, many of the ancient cities had rather elaborate systems for furnishing an adequate water supply — water was brought in open ditches or aqueducts from great distances, carried through the streets, and piped into the homes. Our present idea of a central water plant for a community, though not a modern one, has been developed until the service is highly satisfactory.

If the water can be obtained from mountain lakes or from deep wells, it will need very little purification, but if it is obtained from shallow wells or from a river which passes through densely populated areas, it may have to be cleaned and purified before it can be used. Often it is pumped into settling basins, where the dirt settles out, and then it is transferred to other basins where it is aerated, sunned, and treated with chlorine and other chemicals. Sometimes it contains such large quantities of minerals that it has to be "softened" — that is, treated with chemicals to remove these materials before it is satisfactory for use by the community.

45. Pumps. One of the oldest household conveniences is the lift pump — it is known to have been in use in the days of Aristotle about 350 B.C. A simple lift pump consists of a cylinder, a piston, a piston rod, a handle, and two valves — one valve in the piston and another at the bottom of the cylinder where the pipe leading from the water supply enters the cylinder. These valves open upward when the pressure below the valve is greater than that on the top, but if the pressure on the top of the valve is greater than that below, the valve closes. The piston fits the wall of the cylinder tightly because the leather ring, which is placed around the metal part of the piston, swells slightly when it is wet.

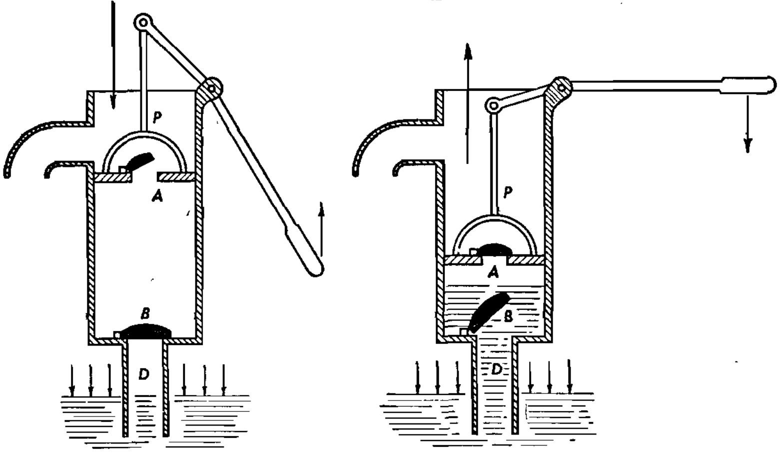


Fig. 8.1. A diagrammatic cross section of a lift pump.

Suppose the handle of the pump in Figure 8.1 is being raised. This results in lowering the piston P and tends to increase the pressure in the cylinder below P. The increased pressure will close valve *B* tightly, but open valve *A* and the air in the cylinder will pass through it. When the handle is lowered, the piston is raised. This tends to decrease the pressure in the cylinder below *P* to less than atmospheric pressure. Therefore valve *A* will close because of the greater pressure on top of it, and valve *B* will open because the pressure on top of it is less than the pressure in pipe *D*, which is equal to the atmospheric pressure on the surface of the water in the well. Possibly, for several strokes, air only will pass through the valves, but soon water will enter the cylinder through valve *B*. Then on the downstroke of the piston the water will be trapped by *B* and will pass through *A*. The water will be lifted by the piston on its upstroke and forced out through the spout.

Since the pressure of the air is equivalent to that of a column of water 34 feet high, this pump could theoretically — if the piston fitted perfectly — be placed 34 feet above the surface of the water supply. Actually, lift pumps are seldom placed more than 20 feet above the water level because the pistons do not fit perfectly. If the pump has not been used for some time, the leather around the piston may have dried until it does not fit the cylinder closely enough to make the pump operate. If so, the pump must be primed; that is, water must be poured in at the top to complete the seal between the piston and the cylinder wall.

If the water is more than about 20 feet (theoretically 34 feet) below the place where the pump is to be located the cylinder, instead of being placed in the pump standard, is placed near or even in the water, and a long delivery pipe connects the cylinder with the pump standard and the spout. The piston rod moves up and down in this pipe and the water is lifted mechanically, from the cylinder to the spout, by the piston on its upstroke.

If the water is to be used at a level above the pump, a force pump must be used. A force pump may be made just like a lift pump except that it is closed at the top with a packing so that water can be forced up a delivery pipe to a level above the pump. Of course as the distance to this level increases, the force required to operate the pump increases.

Another type of force pump has no valve in the piston, but instead there is a valve in the discharge pipe which opens out of the lower part of the cylinder below the piston. (See Fig. 8.2.) On the upstroke of the piston, water enters the cylinder through valve *B* as in the lift pump, but on the downstroke the water is forced out valve *A* into the air chamber *C* and into the delivery pipe *E*. The air chamber helps to furnish a steadier stream of water, because the air in *C* is compressed as the piston forces water through valve *A* — then, when no water is coming through *A*, this air expands and forces the water in *C* up *E*.

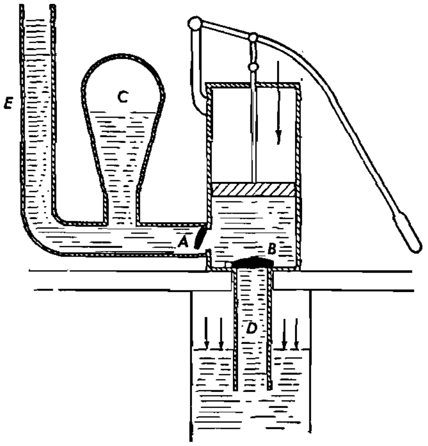


Fig. 8.2. A diagrammatic cross section of a force pump.

46. Water Supply for an Individual House.

Water for an individual house may be piped from a lake or a stream which is at a level higher than the house, or it may be pumped from a lower level. Sometimes it is pumped into an elevated tank or reservoir from which it flows by gravity to the house. Sometimes it is pumped into a pneumatic pressure tank where it is stored until needed, and then it is forced by the compressed air in the tank to the place where it is to be used.

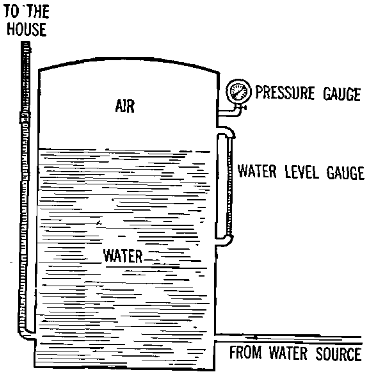


Fig. 8.3. A pneumatic pressure tank.

The pressure on the water in the tank may be computed by means of Boyle's law. For example, if it is assumed that the tank is full of air at normal atmospheric pressure before the water is pumped in, and then water is pumped in until the volume of the air has been reduced to one-third of the original amount the resulting absolute pressure will be three times the original pressure of one atmosphere or 3 × 15 = 45 pounds per square inch.

The gauge pressure will be equal to two times the atmospheric pressure or 2 × 15 = 30 pounds per square inch. (It will be recalled that absolute pressure minus atmospheric pressure equals gauge pressure.) Also since one atmosphere of pressure is equivalent to that of a column of water 34 feet high the pressure in the tank in this case has been increased enough to force water to a point 2 × 34 = 68 feet above the level of the water in the tank.

47. Water Supply for a Community. In general there are two methods of providing water under pressure to groups of homes — the gravity system and the direct-pressure system. The gravity system provides pressure by using water from a supply stored at a level higher than the houses. The water may be pumped from a lake or a running stream, or it may be pumped into an elevated reservoir from which it flows by gravity to the various houses. The direct-pressure system is used where conditions are not adapted to the gravity system. After the water has been cleaned and purified it is pumped directly into the mains, and the engines or motors which drive the pumps are equipped with automatic regulators controlled by the water pressure in the mains. Enough pumps must be installed so that the pressure can be maintained during periods when extra amounts of water are used — during fires or during hot, dry seasons. A combination system provides both for direct pumping and for a stored supply. The direct pumping takes care of the average demand and the elevated reservoirs furnish a uniform pressure and a reserve supply for periods when larger amounts are needed.

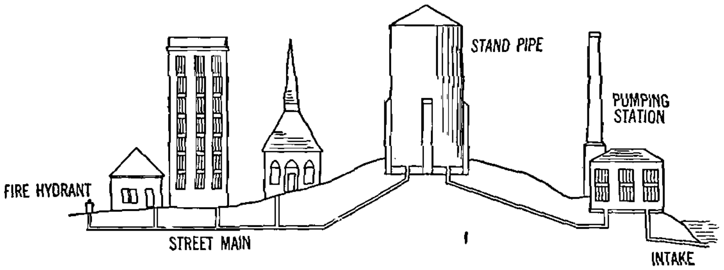


Fig. 8.4. Cross section of a water system for a community.

Regardless of the method of providing the water, it is distributed about town through pipes with branches leading to the houses. These pipes must be placed underground below the frost line. At the curb there is a cutoff valve which is used by the water company employees to turn the water off or on for a particular house. Inside the house is a cutoff valve by means of which the occupant of the house may turn off the water if the house is not to be occupied for some time, or if repairs are to be made on the water system within the house. Sometimes this valve is a cutoff drain valve (see Fig. 8.9*c*) so that the water can be cut off and all of the water pipes drained, or the drain valve may be at some other point in the system. (The individual fixtures in the house may be provided with cutoff valves also, so that repairs may be made without cutting off the water from the whole house.)

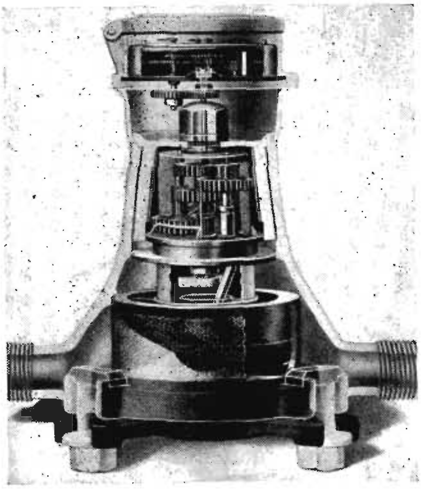


Fig. 8.5. A water meter. (Courtesy Neptune Meter Company)

After the water passes through the cutoff valve it goes through the water meter where it is measured, unless the system does not use meters. Occasionally where an abundant supply is furnished by the gravity method it is cheaper to arrange a monthly or yearly rate for each home, based on the size of the house, the number of persons in the house, or the size of the lot, and the consumer is permitted to use all the water he wants. This plan saves the cost of installing the meter and the expense of monthly or quarterly readings. It encourages the use of plenty of water, but it also encourages the waste of water; if the supply is over-abundant, this does not matter, as the water would otherwise overflow at the reservoir, but if the water has to be pumped, the only equitable method of distributing the cost among the consumers is to measure the water and charge according to the amount used. The rate is usually named at a given amount per thousand gallons or per thousand cubic feet, and usually there is a sliding scale, such as was explained in connection with gas bills.

48. The Water Meter. A disk type of water meter consists of a chamber with inlet and outlet openings, within which is a disk which is moved by the pressure of the water as it passes through. The disk does not rotate but goes through a motion similar to that which a wagon wheel would have if it were placed horizontally on the ground, and someone walked around the rim. This procedure would cause the hub to "nod." First, water from the inlet enters on top of the disk and the pressure of the water causes it to begin this nutating (nodding) motion, and then, as the opposite side of the disk is pushed down, water enters below the disk and the motion continues. When water enters above the disk the water below the disk is forced out, and when it enters below the disk the water above the disk is forced out. A spindle fastened to the hub of the disk causes a small cogwheel to rotate, and this is geared to other wheels which move the pointers on the dials. The method of reading the dials has been explained in connection with gas meters. The small dial marked "1 cu ft," is

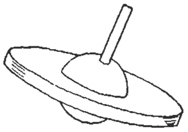


Fig. 8.6. The "nodding" wheel of the water meter.

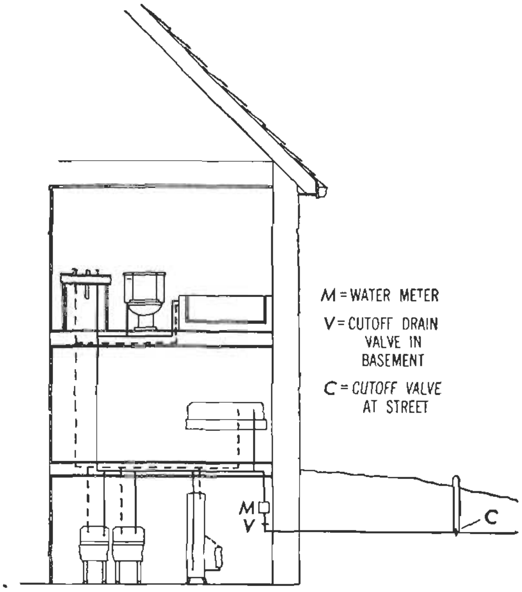


Fig. 8.7. Water supply pipes for a house.

for use in testing the accuracy of the meters. Water is allowed to run from a faucet while the meter registers "1 cu ft," and this water is carefully measured in a cubic foot container. All meters should be tested when installed, and may be rechecked whenever the consumer thinks the meter is inaccurate.

49. Distribution of Water in the House. The term "plumbing" is used to include all pipes and fixtures that carry water into the house and remove waste material from the house in the form of sewage. Rough plumbing includes all the pipes which should be inside the walls or between the floors, and which should be installed while the house is being constructed, after the studding and joists are in place, but before the plaster is put on and the floors are laid. The three chief rooms in a house to be supplied with water are the laundry, the kitchen, and the bathroom. (If the house is heated with hot water or steam, the heating system is also connected with the plumbing system.) There should always be provision for supplying hot water as well as cold water in the laundry, kitchen, and bathroom.

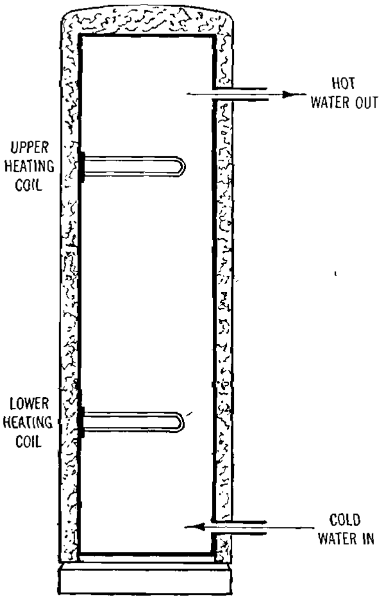
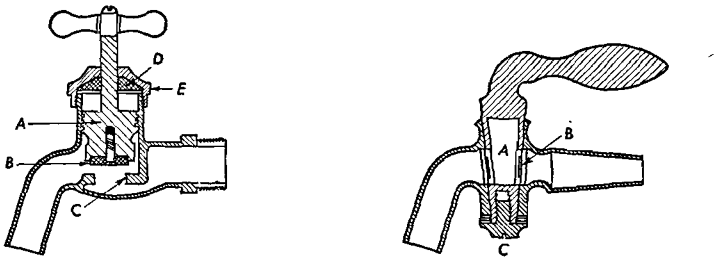


Fig. 8.8. A hot water tank with electric heating coils.

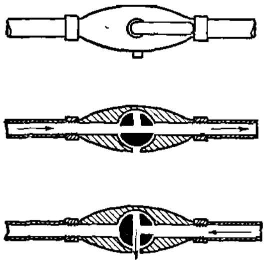
A supply of hot water is provided by means of a hot water tank, which may be heated by either gas or electricity. Figure 8.8 shows a cross section of an electrically heated tank. Cold water enters at the bottom and hot water leaves at the top. The heating unit is controlled by a thermostat.

50. Faucets. The internal construction of an ordinary compression faucet is shown in Figure 8.9a. When the handle is turned to close the faucet a screw forces the disk *A*, which is faced with a fiber washer *B*, against a circular opening or seat *C*. This shuts off the water. When the handle is turned to open the faucet the disk is raised, making an opening for the water to pass through. There are two simple repairs which may sometimes be necessary. The fiber washer *B* or the packing *D* around the handle may wear out; replacements for either may be bought for a few cents. When the faucet is to be repaired the water supply is shut off, the screw cap *E* is removed with a suitable wrench, the valve stem is screwed out, and the old washer *B* is replaced with a new one. If the packing *D* is to be replaced the screw in the top of the handle is taken out, the handle is removed, and the valve stem separated from the cap *E*. A new packing *D* is put in place and then the faucet is reassembled.



a. COMPRESSION FAUCET

b. GROUND KEY FAUCET



c. CUTOFF DRAIN VALVE

Fig. 8.9. Faucets and a cutoff drain valve.

In the ground-key type of faucet shown in Figure 8.9b there is a tapered key *A* which fits into an opening in part *B*. These parts are ground into place with emery and must fit tightly or the faucet will leak. There is a slot in the key which allows the water to flow through when the handle is turned to the proper position. As the faucet wears, the screw *C* is adjusted to keep the joint tight; the joint may be reground if the adjustment of the screw does not stop the leak.

Self-closing faucets are often used to prevent the waste of water where it may be left running because of carelessness. When the handles of the self-closing faucet are squeezed together, the valve is lifted from its seat and a spring is compressed. When the handle is released, the spring pushes the valve back in place.

A cutoff valve is often placed in a pipe in order that the flow of water through it may be stopped or started at will. It may be a cutoff drain valve of the type shown in Figure 8.9c. This valve will cut off the supply and drain the water from the pipe on the delivery side.

51. Removal of Waste Water from the House. At each place where a water supply is provided in the home, provision is made also for removing waste water. As shown in Figure 8.10, the laundry tubs, kitchen sink, lavatories, bathtubs, and closets are connected by pipes to the main stack or soil pipe *SP* which is the large vertical pipe extending from below the basement floor to a point above the roof. At its lower end it joins the drain pipe which leads out to the street sewer *SS*.

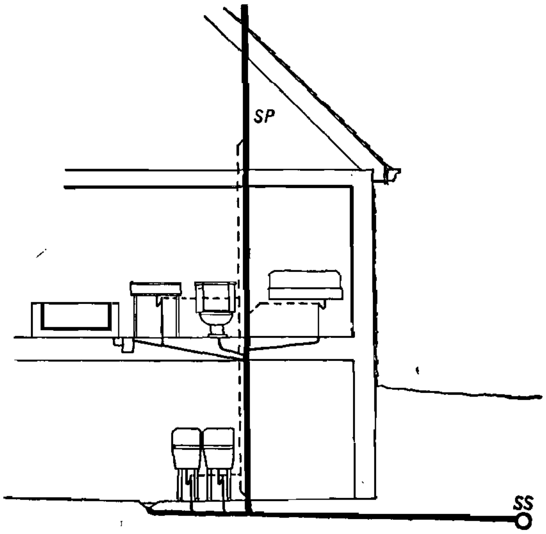


Fig. 8.10. Sewage pipes for a house.

At each place in the house where waste water is to be removed a trap is provided to prevent the escape of sewer gas into the house. One type of trap is an S-shaped tube with one arm of the S connected to the source of impure water and the other arm connected to the waste pipe leading to the soil pipe. From the diagram it may be seen that one bend of the S is filled with water which forms a seal and prevents sewer gas from rising through the pipes into the house. If the trap is made to connect through the wall instead of through the floor it is known as a P-trap. S- and P-traps are used on waste pipes from laundry tubs, kitchen sinks, and lavatories. If one of these traps becomes clogged with sediment and grease it may be cleaned by removing the screw plug in the lower bend of the trap. The cellar drain may be provided with a trap similar to the one shown in Figure 8.11. Bathtubs are usually provided with drum traps. The trap for the water closet is built into the bowl of the closet.

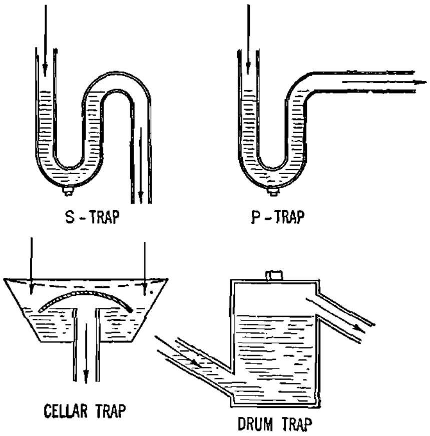


Fig. 8.11. Traps.

In order to prevent the loss of the water seal in the trap due to siphon action it is sometimes necessary to use a vent pipe; this is a pipe connected to the waste-pipe side of the trap, through which air at atmospheric pressure may enter, thus preventing the possibility of siphonage. The vent pipes are all connected to a main vent pipe which is usually connected to the soil pipe just below the point where it passes through the roof. The vent pipes are shown with dotted lines in Figure 8.10. The circulating air in the pipes also oxidizes the decomposing waste material which adheres to the sides of the waste pipes. Any trap may lose its seal through evaporation, and if a drain is used infrequently, it should have water poured into it occasionally. After a house has been closed for some time, it is often found to contain sewer gas unless a caretaker has filled the traps occasionally.

A garbage disposal unit is now an accepted part of the plumbing system of a house. It is essentially a motor-driven grinding device attached to the drain of the kitchen sink in place of the usual trap. Its outlet is connected to the house sewer pipe. (See Fig. 8.12.)

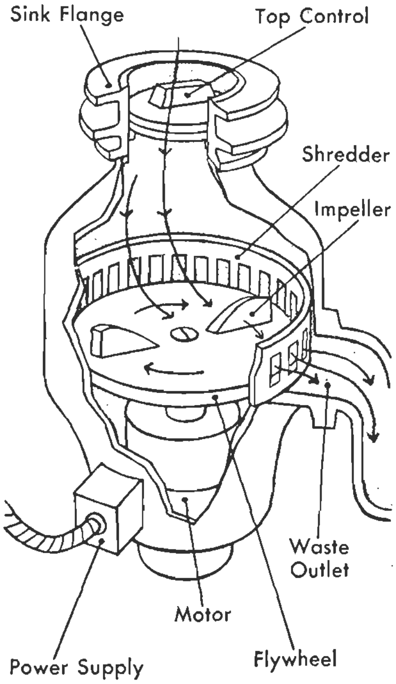


Fig. 8.12. A garbage disposal unit. (Courtesy Consumers' Research, Inc.)

Fruit and vegetable peelings, small bones, and other normal kitchen wastes are dropped into the hopper and are ground into small particles by being whirled rapidly by the impeller blades on the flywheel, and consequently thrown out by centrifugal force (force away from the center) against the shredder blades. Cold water running through the unit while it is in operation washes the ground material down the waste outlet.

There are several types of closets, but in general the siphon-jet shown in Figure 8.13 is considered the most satisfactory because it operates quietly, has a large water surface in the bowl, and hence is easier to keep clean. When the closet is flushed, water enters either from a flush tank or a flush valve. A small part of this water flows through the hollow rim, enters the bowl through small holes distributed around the rim, and thus cleans the sides of the bowl. The greater part of the water enters the bowl through a small opening — called the *jet* which is in the lower part of the bowl. This water starts the siphon action, which empties the bowl quickly. After the siphon action stops, enough water runs into the bowl to fill the trap.

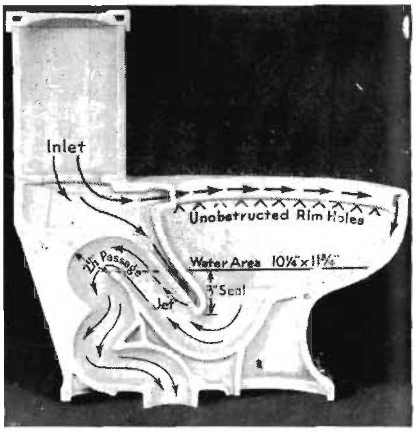
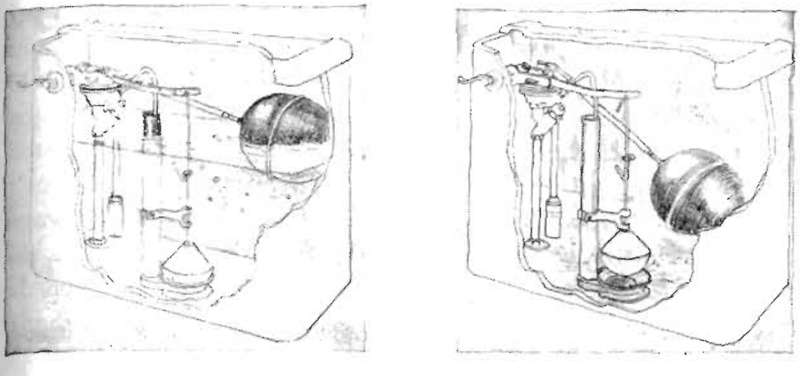


Fig. 8.13. Cross section of a siphon-jet closet. (Courtesy Kohler Co.)



a b

Fig. 8.14. A flush tank. (Courtesy Crane Co.)

The parts of the flush tank are shown in Figure 8.14. There are two lever systems in its mechanism. One controls the inlet valve by means of the float valve, and the other controls the outlet by means of the handle on the outside of the tank and the hollow rubber ball which fits into the outlet. Figure 8.14a shows the tank filled with water. When the handle on the outside of the tank is turned, the lever to which it is attached lifts the hollow rubber ball which has closed the opening to the bowl, and the water rushes into the bowl. Figure 8.14b shows the flush tank in the process of discharging. As the last of the water leaves the tank,

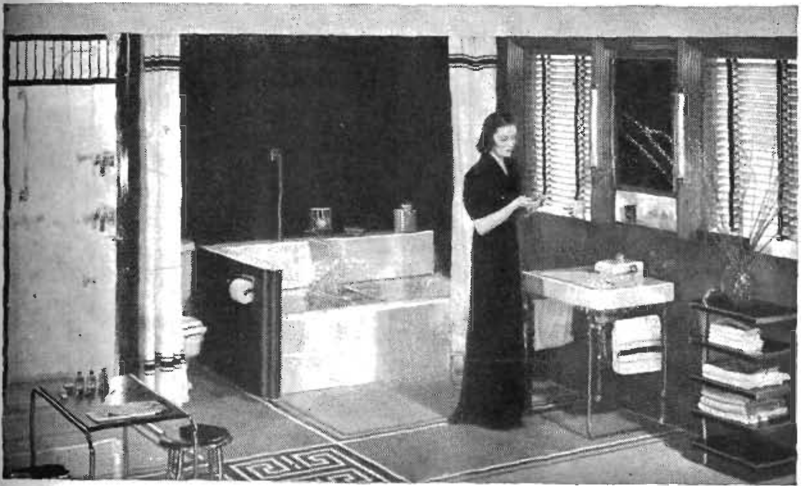


Fig. 8.15. Plumbing fixtures for the bathroom. (Courtesy Crane Co.)

the hollow rubber ball which has been floating in the water just above the outlet is sucked back into position. As the tank empties, the hollow copper or plastic float valve is lowered and the inlet valve at the other end of the lever is opened. The tank now gradually refills, the float valve is lifted, the inlet valve is closed, and the tank is ready for the next flushing action.

A flush valve may be used instead of a flush tank. The water for the flushing action is not stored in the valve, as it is in the flush tank, but enters directly from the source of supply when the handle on the valve is tripped. The valve is so constructed that it automatically closes after a suitable amount of water has passed through the closet. Flush valves sometimes cannot be used in homes because the water pressure is not high enough to make them operate satisfactorily. The pressure may be too low either

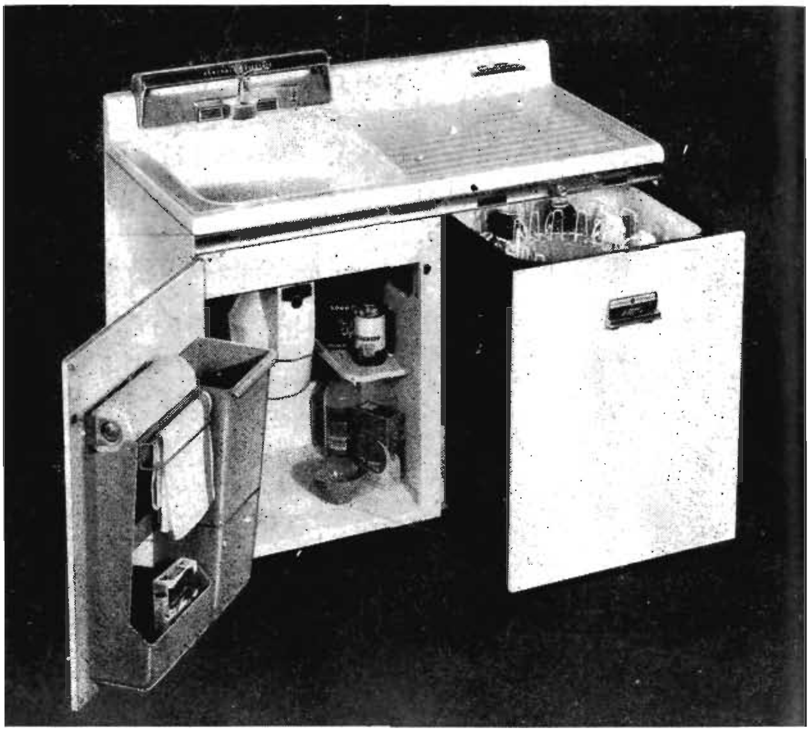


Fig. 8.16. Plumbing fixtures for the kitchen. Water is supplied to the sink, the dishwasher and the garbage disposal unit. (Courtesy General Electric Company)

because the pressure in the mains is too low or because the supply pipes to the house are too small. They are often noisy in operation also. Advantages of the flush valve over the flush tank are that it takes less room and it cannot be opened and tampered with by inexperienced persons.

52. Disposal of Sewage. In some localities sewage flows by gravity to some point where it may be discharged — possibly into a river. In other places, where the contour of the land is such that sewage cannot be taken care of by gravity flow, pumps must be installed. Sewage is chiefly water, but it contains organic matter, and it is a dangerous practice in densely populated areas to discharge it on the surface of the earth or into a stream. Disease germs may be spread, and often epidemics of typhoid, dysentery, and infantile paralysis break out at successive towns down the stream, leaving no doubt as to how the germs were transmitted. If the towns are more scattered, the water may be purified before it reaches the next town, because it is greatly diluted when it mixes with the water in the stream and the solid materials settle to the bed of the stream and gradually decompose. Also, as the

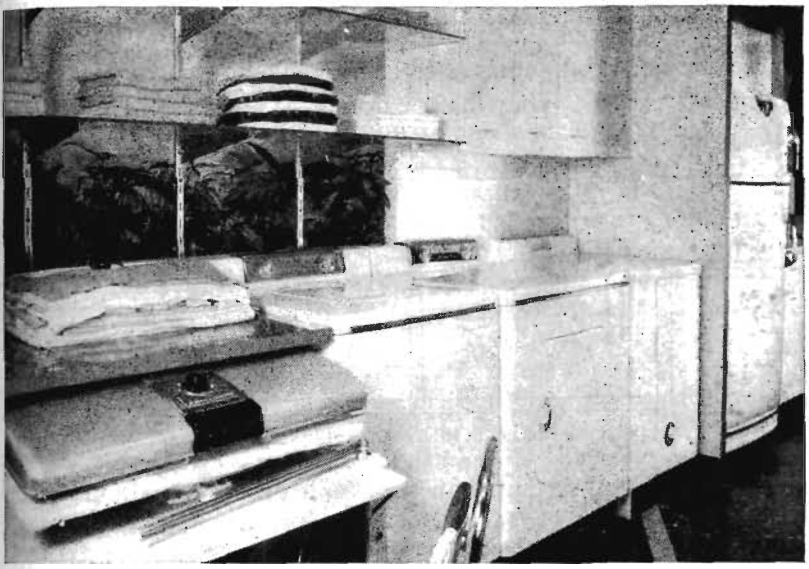


Fig. 8.17. Plumbing fixtures for the laundry include the automatic washer and hot water tank. Note also the dryer and ironer. (Courtesy General Electric Company)

stream flows along, the water is exposed to the sunlight and the air, and the organic materials are gradually reduced to inorganic materials. If a city does not empty its sewage into a stream or lake, it must take care of it with an extensive sewage treatment plant consisting of settling basins, digesters, and drying beds.

If the sewage from a house cannot be emptied into a central sewage system, it may be emptied into a septic tank, which is a tile or cement receptacle placed in the ground. The sewage enters the first compartment at *A* and is acted on by anaerobic (without air) bacteria. Here it is partly oxidized, and most of the solid material is liquefied. Then it flows into the second compartment, where the bacterial action is continued. The outlet of the septic tank connects to a pipe which empties into a stream or into an absorption system.

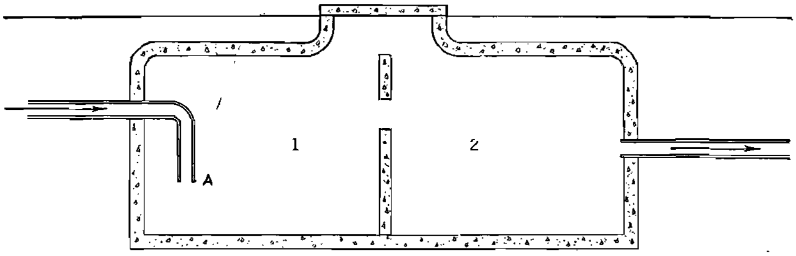


Fig. 8.18. A septic tank.

The absorption system is an area built up of layers of crushed rock and gravel, and covered with a layer of sand. A tile distribution system is installed just below the surface as shown in Figure 8.19. Here aerobic (with air) bacteria further oxidize the

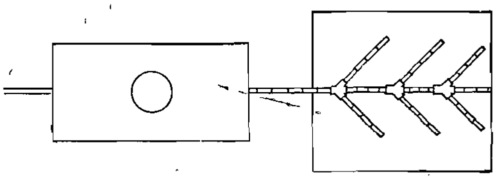


Fig. 8.19. A septic tank and absorption system.

material, and it is finally reduced to water and inorganic material. As the sewage drains away, air circulates through the spaces between the sand and gravel particles, and the aerobic bacteria are resupplied with oxygen and are ready to attack the next flow of sewage from the septic tank.

STUDY QUESTIONS

1. Which valve in a lift pump is open when the piston is descending? When the piston is ascending? Are both valves ever open at the same time?
2. If the water level is 38 feet below the surface of the ground, what kind of pump must be installed?
3. Name several agencies that help to purify water.
4. How may water under pressure be provided for country houses?
5. What are the methods of supplying water to groups of houses? What are the advantages and disadvantages of each method?
6. How does a water meter measure the water which passes through it?
7. When should the rough plumbing be installed in a house?
8. Tell how to repair a compression faucet that drips.
9. What is wrong if the faucet leaks around the valve stem?
10. Where may cutoff drain valves be installed to advantage?
11. What is the purpose of a trap?
12. Tell how a garbage disposal unit operates.
13. Why is a siphon-jet closet considered the best type?
14. What is wrong if the water continues to run from the flush tank after the normal flushing period?
15. Does a flush valve have any advantages or disadvantages over a flush tank?
16. What is the purpose of the soil pipe?
17. Why is the problem of sewage disposal being discussed so widely at present?
18. Will the increase in the use of garbage disposal units increase the sewage disposal problem?
19. What special sewage disposal problems exist in your community?
20. What is being done in your community to improve sewage disposal methods?
21. What changes occur in sewage in the septic tank?
22. What changes occur in sewage in the absorption system?

PROBLEMS

1. If a pneumatic pressure tank which holds 40 gallons is full of air at atmospheric pressure and then water is pumped in until the air volume is reduced to 10 gallons, what is the absolute pressure inside of the tank? What is the gauge pressure in the tank? How far can water be forced up the delivery pipe?

   Ans. 60 lb per sq in.; 45 lb per sq in.; 102 ft
2. If a pressure tank which holds 80 gallons is full of air at atmospheric pressure and then water is pumped in until the air volume is reduced to 20 gallons, what is the absolute pressure inside of the tank? What is the gauge pressure in the tank? How far can water be forced up the delivery pipe?

3. In Prob. 1 above, what is the gauge reading after 15 gallons of water have been drawn from the tank? *Ans.* 9 lb per sq in.
4. In Prob. 2 above, what is the gauge reading after 15 gallons of water have been drawn from the tank?
5. How much pressure is required to force water from a tank in the utility room to the bathroom on the second floor — a distance of 8 feet? *Ans.* 3.53 lb per sq in.
6. How much pressure is required to force water from a tank in the basement to the bathroom on the second floor, which is 17 feet above the tank?

HEAT

9

INTRODUCTION TO HEAT

In prehistoric times man accepted the sun and fire as sources of heat and light. Instead of wondering about what caused heat, he thought of the sun and of fire as gods; "sun worship" and "fire worship" played an important part in several ancient religions. As civilization advanced, however, man began to ponder about the nature of heat, and developed various theories in an attempt to provide an answer.

Until the early part of the nineteenth century, heat was believed to be a fluid. This fluid was thought to have no weight, since the body weighed the same regardless of its temperature. It could not be separated from a body, but it could pass from one body to another the same as any other fluid, and if one body was hotter than another it was because it had more of this fluid in it. When two bodies which contained different amounts of the fluid were placed together, the fluid would flow from the one with the greater amount to the one with the smaller amount, until the two contained equal quantities of *caloric*, as the fluid was called. We see the effect of this theory in the terms we use today in discussing heat. We speak of heat as flowing from one body to another; the term "caloric" survives in our term "calorie"; and the term "latent heat" (the heat involved in changes of state from solid to liquid and from liquid to gas) results from the early theory that the heat involved in these changes was hidden between the molecules and thus did not cause a temperature change.

53. Kinetic Theory of Heat. During the latter part of the eighteenth century, a number of experiments were performed which led to a new theory regarding heat. In 1798 Count Rumford in Germany was engaged in boring a cannon and was much concerned with the large amount of heat which resulted. Water was used to cool the iron, and the faster the boring was done, the faster the water was heated. He decided there was a definite relationship between the amount of work done and the amount of heat developed. Sir Humphry Davy, director of the Royal Institution in England, was so impressed by Rumford's ideas that he tried various experiments of his own. In 1799 he rubbed two pieces of ice together, and they melted, even though the experiment was carried on in a room in which the temperature was below the melting point of ice. All agreed that heat was required to melt the ice, but they did not all agree as to the source of the heat. However, they observed that the faster the pieces were rubbed together, the faster the ice melted; and so they decided there must be some relation between the amount of work done and the amount of heat furnished to the ice. Other investigators in England and in Germany, and later in the United States, arrived at the same conclusion. Joule in 1843 proved definitely by experiment that the amount of heat energy developed was proportional to the amount of work, and calculated the amount of work which was equivalent to one unit of heat.

For over 20 centuries the fluid theory of heat had been accepted, but within the last 150 years scientists have learned far more about heat energy than had been learned in all the time previous to this period. As a result the old fluid theory of heat has been discarded. Now it is known that in addition to mechanical energy there are other forms of energy that can be transformed into heat energy, and also that heat energy can be transformed into other kinds of energy. *Heat is energy which is associated with molecular motion.* One of the fundamental concepts of matter is that it is composed of molecules which are in constant motion. When heat is added to a body the velocity of the molecules is increased or, in other words, the kinetic energy of the molecules is increased. Adding heat to a body may produce one or more of the following physical changes:

1. An increase in temperature which results from an increase in the average kinetic energy of the molecules.
2. Expansion which results from increasing the average distance between molecules.

3. Change of state from solid to liquid (melting), from liquid to vapor (vaporization), or from solid to vapor (sublimation).
4. Change in pressure exerted by an enclosed gas or liquid due to increased bombardment of the container by the molecules.
5. Change in physical characteristics such as hardness, toughness, plasticity, malleability, and ductility.

Heat may also cause or accelerate certain chemical changes, it may cause certain electrical effects, and if a body is heated to a high temperature, light may be given out.

54. Sources of Heat. The sun is the original source of almost all of the energy which is available to man. Energy from the sun warms the earth and its atmosphere. Water is evaporated, clouds are formed, rain falls and soaks into the ground or runs into rivers and lakes. Some of this water may be used to furnish power to operate machinery. Coal and oil represent stored solar energy since they were formed from plant and animal life which in turn were made possible because of the energy received from the sun. The earth is receiving additional energy from the sun every day. The chief sources of heat which man can control and use are (1) chemical reactions, which include the burning of fuels, (2) electrical energy, and (3) mechanical energy.

STUDY QUESTIONS

1. If heat is added to a body, what effect does it have on the motion of the molecules?
2. What is the original source of almost all of the heat available to man?
3. What sources of heat does man have at his control?
4. What physical and chemical changes in a material may result from the addition of heat energy?
5. Who did the experimental work which proved that the amount of heat energy developed is proportional to the amount of work done?
6. How old is the kinetic theory of heat?
7. Explain how the caloric theory of heat still influences our everyday conversation about heat.

10

THERMOMETERS

A thermometer is a device for measuring temperature. This definition then raises a question. What is temperature? In everyday language temperature is a measure of how hot or how cold a body is and usually the comparison is made with the human body. But the temperature sense is not very reliable as the following examples will show. (1) A person may be sitting in a room in which he feels chilly, but to one coming in from outdoors on a cold day the room may seem quite warm. (2) If the right hand is put into hot water and the left hand in cold water, and then both hands are placed in warm water, the water in the third dish will feel cold to the right hand but warm to the left hand, and yet it is at the same temperature for both hands. (3) An outdoor temperature of 70°F feels warm in the winter and cool in the summer. Thus we see that the terms "hot" and "cold" are relative terms and that our judgments of temperatures are influenced by the conditioning which we have just experienced. It is evident that we need some means of measuring temperature which is independent of our temperature sense.

In general, when heat is added to a body its temperature increases, and at the same time its length, its volume, or some other physical property changes. The change in any one of these properties may be used as a means of measuring the change in temperature. The material may be a gas, a liquid, or a solid; but a material must be selected for which this change is great enough that it can be measured easily and accurately.

55. Early History of Thermometers. Galileo is credited with making the first thermometer in 1592. It was a gas thermometer, i.e., he judged the change in temperature by noting the change in volume of an enclosed quantity of gas. Galileo inserted a long glass tube in a cork which was then inserted in the neck of a flask. The flask was inverted and mounted so that the end of the tube dipped into a dish of water. Then the flask was heated, and as the air expanded, part of it was driven out. When the flask cooled, the air contracted, and since the pressure inside of the flask was less than atmospheric pressure, water was forced up the tube. Care was taken not to heat the flask too much; otherwise the water would rise too high in the tube or even into the flask.

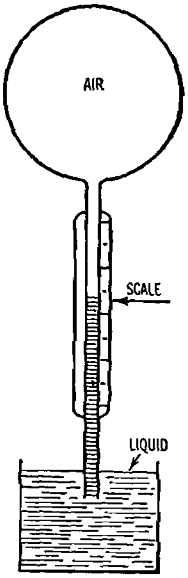


Fig. 10.1. A gas thermometer.

As the temperature of the medium around the flask changed, the air in the flask contracted or expanded, and the water level in the tube rose or fell. A rise indicated a decrease in temperature and a fall an increase in temperature. The greatest difficulty with this thermometer was that it was also a barometer and would respond to changes in atmospheric pressure. Imagine the surprise of a physician using such a thermometer in those early days to find that the temperature of his patient had apparently increased alarmingly when he seemed to be recovering from his illness. The apparent increase in temperature could really have been due to a decrease in atmospheric pressure.

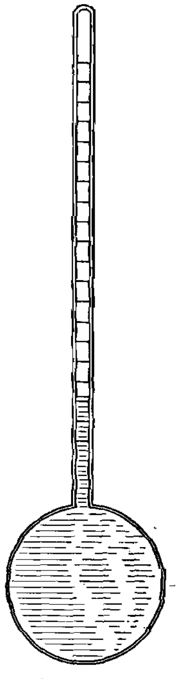


Fig. 10.2. A liquid-in-glass thermometer.

The next improvement in Galileo's thermometer was made in 1632. The flask and tube were placed in an upright position, and the flask was filled with water or wine. This thermometer was more convenient and was not affected by barometric pressure changes, but it was not so sensitive as the gas thermometer because the expansion of a liquid is not so great as that of a gas for a given temperature change. However, this was the first liquid-in-glass thermometer. In 1657 alcohol was used and the tube was sealed at the top. In 1659 mercury was used for the first time.

56. Construction and Calibration of Thermometers. Liquid-in-glass thermometers are used more than any other kind at the present time. The liquid is usually mercury or alcohol — each has some advantages and some disadvantages. Mercury can be heated to a high temperature (357°C) without vaporizing; it expands more uniformly at different temperatures than do most materials; it is a metal, and therefore conducts heat rapidly; its color makes it easily visible; it does not adhere to the tube. It cannot be used for very low temperature measurements because it freezes at about − 39°C. Alcohol is not suitable for high temperature measurements because it vaporizes at 78°C. It does not expand uniformly for all temperature changes. Its greatest advantage is its low freezing point (− 130°C) which makes it suitable for low temperature measurements, for nowhere on the earth does the natural temperature go below the freezing point of alcohol. Since it is transparent it is usually colored red or blue to make it more visible.

A liquid-in-glass thermometer is made by drawing out a glass tube until it has an extremely fine bore, often less than the size of a human hair, and then a bulb is blown on one end of the tube. The thermometer is heated to drive out the air and while still hot the open end is dipped in the liquid. As the thermometer cools the liquid is drawn into the bore and bulb. When it is nearly full, it is held with the bulb end down and heated until the liquid runs out at the top. The end is then sealed off and the thermometer put away to cool and "age." When glass is heated, it expands, and as it cools, most of the contraction will take place by the time it has returned to normal temperature, but it may take weeks, months, or even years for it to return exactly to its original size. High-grade thermometers are never calibrated until they have been "aged"; otherwise, no matter how carefully they are calibrated they will be inaccurate after a period of time.

Thermometers are calibrated by placing them in melting ice and then in steam at known atmospheric pressure, to obtain the fixed points. Intermediate points on cheaper thermometers are obtained by dividing the intervening distance on the stem into equal spaces. This division is based on the assumption that the bore is of uniform cross-sectional area at all points, and this assumption is practically never true. For greater accuracy, thermometers may be tested for intermediate points by placing them in liquids of known boiling points or by heating them slowly in water with another thermometer which is known to be accurate, and marking corresponding points. Care must be taken to do the work slowly, so that, if one thermometer responds more rapidly than the other, the slower one will have time to respond fully. The thermometers must not touch the vessel containing the liquid when readings are being made. The accuracy of a liquid-in-glass thermometer depends upon the evenness of the bore, thorough aging, and the care with which the calibration is made.

Various factors enter into the quickness of response of a liquid-in-glass thermometer. A mercury thermometer will respond more quickly than an alcohol thermometer, because mercury is a better conductor of heat. A thermometer with a long slender bulb will respond more quickly than one with a spherical bulb of the same volume because the surface area is greater and the radius is less. A thermometer which has a long space on the stem for each degree is said to be more sensitive than one which has a shorter space. A long space on the stem for one degree results from using a large bulb, a small bore, and a liquid which expands a great deal for a change in temperature of one degree.

Metals are the chief solids used for thermometers, because they conduct heat rapidly, and because they expand more than most solids when the temperature increases. A metallic thermometer often contains a bimetallic strip which is made of two strips of unlike metals which do not expand the same amount for

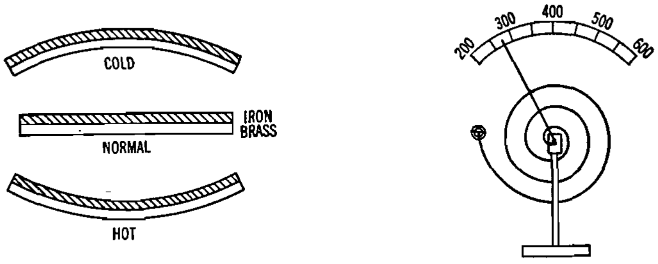
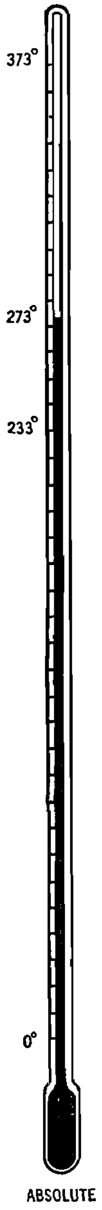


Fig. 10.3. Thermometers made of metals.

a given temperature change — these two pieces of metal are either riveted or welded together and when the temperature changes they curve because of the unequal expansion. This motion moves a pointer which travels over a temperature scale. A metallic thermometer may be made of just one kind of metal wound in a spiral, and the change in length due to a change in temperature will change the tension of the spiral and thus move a pointer over a scale. In general, metallic thermometers do not respond so quickly as do liquid-in-glass thermometers to temperature changes chiefly because of the larger amount of material which must be heated.



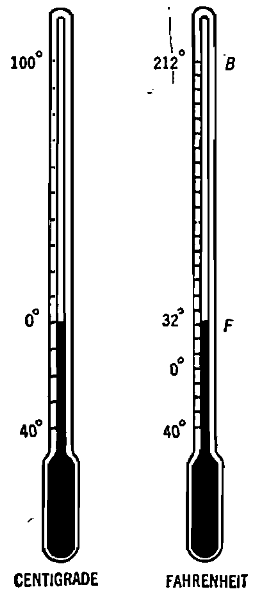


Fig. 10.4. Thermometer scales.

Gas thermometers are not used by the general public, but they are sometimes used in laboratory work. If the bulb of a gas thermometer is large and the bore small a slight change in the temperature and consequently in the volume of the gas will produce a large change in the water level in the bore. They are useful if it is important to measure extremely small changes of temperature. If the experiment extends over a short period of time, the atmospheric pressure may not change; but if the pressure does change during an experiment, corrections may be made if barometric readings for the same period have been recorded.

57. Thermometer Scales. Along with the development of thermometers came the development of thermometer scales. Many scales have been devised but only two of these are in common use today — the *Fahrenheit* devised in 1724 and the *Centigrade* devised in 1742. The latter is used all over the world in scientific work and in many countries for all temperature measurements. The Fahrenheit is used more than the Centigrade by the general public in English-speaking countries.

It has been arbitrarily agreed to use the freezing and the boiling points of water at standard barometric pressure as the fixed points for these scales. The two scales are shown in Figure 10.4. The unit used for measuring temperature is the degree. The Centigrade uses the temperature of melting ice as 0° and the temperature of boiling water as 100°. The Fahrenheit uses the temperature of melting ice as 32° and the temperature of boiling water as 212°.[1] On the Centigrade the difference in temperature between the freezing and the boiling points of water is divided into 100 degrees and on the Fahrenheit the same temperature difference is divided into 180 degrees. (212 − 32 = 180 degrees.) Therefore 1 degree on the Centigrade scale represents a larger temperature change than 1 degree on the Fahrenheit scale.

A given *temperature reading* on one scale may be converted into the corresponding temperature reading on the other scale by

$$\frac{C}{100} = \frac{F - 32}{180}$$

Since the ratio between 100 degrees and 180 degrees is the same as 5 to 9, a *change in temperature* on one scale may be converted into the corresponding *change in temperature* on the other scale by

$$9C = 5F$$

where C is the Centigrade temperature change and F is the Fahrenheit temperature change. For example, if the temperature changes 18 degrees on the Fahrenheit scale, the corresponding change on the Centigrade scale is

$$9C = 5 \times 18 \text{ degrees}$$
$$C = 10 \text{ degrees}$$

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[1] Fahrenheit originally used the temperature of the human body as his upper fixed temperature and called it 96° and he obtained the boiling point of water by calculation. The zero of his thermometer was supposed to be the lowest temperature that could be obtained with a mixture of salt and ice. It is unfortunate that a scale with such poorly chosen numbers for the fixed points is so widely used in English-speaking countries.

58. Absolute Temperature. While the temperature of melting ice had been arbitrarily chosen as the lower fixed point for both the Centigrade and the Fahrenheit scales, yet it was known that lower temperatures could be obtained. Naturally the question arose as to what was the lowest temperature possible, or in other words what temperature could be designated as the *absolute zero*.

Charles, in 1787, found experimentally that if a fixed volume of gas at 0°C was warmed 1 Centigrade degree, its pressure increased 1/273 of its value at 0°C. If the gas was cooled 1 Centigrade degree, its pressure was decreased 1/273 of its value at 0°C. If the gas was cooled 10 Centigrade degrees, its pressure was decreased 10/273 and this proportional change in pressure with change in temperature was found to hold for all "permanent" gases, that is, for gases which liquefy at such low temperatures that their liquefaction was at that time considered impossible.

Likewise if the pressure of the gas was held constant, it was found that the volume decreased 1/273 of the volume at 0°C for each Centigrade degree decrease in temperature. Thus:

$$\frac{P_1}{P_2} = \frac{T_1}{T_2} \quad \text{(Volume held constant)}$$

and

$$\frac{V_1}{V_2} = \frac{T_1}{T_2} \quad \text{(Pressure held constant)}$$

Charles did not publish his results and in 1802 Gay-Lussac performed the same experiments and obtained the same results, and since he published his results he is often given the credit for the discovery.

According to these experiments if a fixed volume of gas were cooled to − 273°C, there would be no pressure exerted by the gas; this would mean that there was no molecular motion or, in other words, that all of the heat energy had been removed from the gas. If the pressure was held constant the volume would theoretically decrease to zero. Temperatures within a fraction of a degree of − 273°C have been obtained experimentally and, while the experimental values for change in pressure or change in volume per degree Centigrade change in temperature depart somewhat from 1/273 for low temperatures, the temperature

– 273°C is the accepted value for absolute zero. The corresponding value on the Fahrenheit scale is – 460°, and that value is used by some engineers who prefer to use the Fahrenheit scale; but in most scientific work the absolute zero based on the Centigrade scale is used. (See Fig. 10.4.)

It will be recalled that Boyle (see Sec. 35) found that if the temperature of a gas was held constant, the volume of the gas varied inversely as the absolute pressure. Therefore these laws may all be combined to give

$$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$$

where P_1 and P_2 are absolute pressures and T_1 and T_2 are absolute temperatures.

59. Household Thermometers. Accurate temperature measurements in the work of the household are just as important as in other work. True, the homemaker learns from experience to judge with some degree of accuracy the temperature of the oven, the "doneness" of a sugar syrup, the temperature of a sick child, or the temperature of the room. But, as we observed earlier, our temperature sense is not very reliable. For a very reasonable cost the homemaker may have a set of thermometers which will give accurate information and which will soon be used as often as the measuring cups and spoons, the tape measure, or the household scale.

Oven thermometers may be either mercury-in-glass or metallic. The mercury-in-glass thermometers are usually made on a base so they can be set upright on the oven shelf. The metallic thermometers are fastened on the oven doors or on the side of the oven. The mercury thermometers are more reliable, but the metallic thermometers are more convenient and are, therefore, more commonly used. Since in general we do not deal with sudden temperature changes in ovens, the slowness of response of the metallic thermometers is not a decided disadvantage. Oven thermometers register from about 150° to 650°F.

Jelly and candy thermometers are mercury-in-glass thermometers. They register from about 40° to 350°F and have such terms as "soft ball," "hard ball," and "hard crack" indicated. This makes it possible to use them with recipes which give the temperatures in degrees, or with recipes which refer to the physical state of the syrup.

Meat thermometers are mercury-in-glass thermometers with pointed bulbs which may be stuck into the center of a roast after an incision has been made with a sharp, pointed instrument.

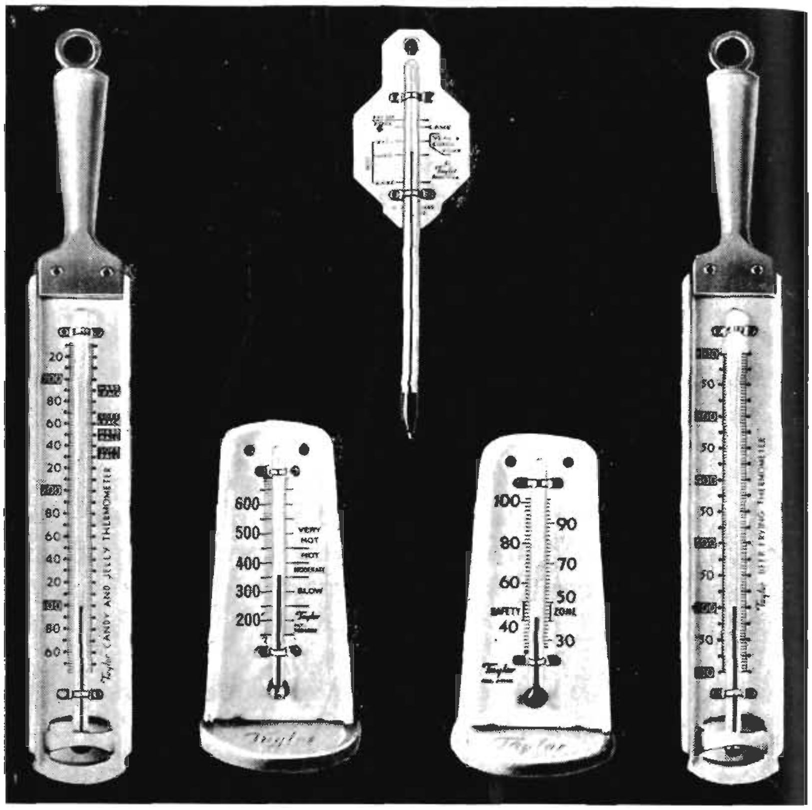

Fig. 10.5. Household thermometers. (Courtesy Taylor Instrument Companies)

They register from about 100° to 215°F, and have the temperatures for rare, medium, and well done indicated. When the center of the roast reaches the indicated temperature, it is cooked the desired amount. This is much more definite than allowing a certain number of minutes per pound, a rule which could hardly hold for all sizes and shapes of roasts.

Dairy thermometers are liquid-in-glass with either mercury or alcohol for the liquid. They register from about 10° to 110°F, and are marked with desirable temperatures for cheese making and churning. Rural housewives find them very useful.

An *incubator thermometer* is an example of a thermometer of very short range, but carefully calibrated, and used for one definite purpose. Its range is from about 95° to 106°F; 100° to 105° is the incubation range, and 103° is especially marked as the temperature at which the eggs are to be kept during most of the incubation period. They are usually mounted so that they will stand among the eggs and so that they can be read without removal from the egg tray.

Fig. 10.6. Clinical thermometer. (Courtesy Taylor Instrument Companies)

The *clinical thermometer* is another thermometer which has a very short range and is intended for only one purpose — that of taking the temperature of the human body. It is calibrated with extreme care, if made by a reliable company. The range is from about 92° to 108°F with the degrees divided into fifths. The average normal temperature of the human body is 98.6°F and this point is specially marked. Not all persons have the same normal temperature, nor does any one person have the same normal at all times. The temperature of a well person varies from day to day and from morning to night. It differs with age, occupation, and food. One should know his average normal temperature as a guide in time of illness. Clinical thermometers have another feature. They belong to the class known as *maximum* thermometers. The reading will increase as the temperature increases, but it does not decrease as the temperature decreases. This makes it possible to read such a thermometer some time after the maximum temperature has occurred. The thermometer is constructed with a narrow place in the bore, just above the bulb, which is known as a *constriction*. It is so small that the mercury will go through only when under pressure due to expansion. As the temperature decreases, the

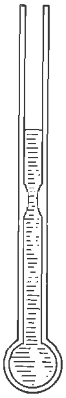

Fig. 10.7. Constriction in the bore of a thermometer.

molecular attraction between the mercury molecules is not great enough to draw the molecules back into the bulb, and so the mercury in the bore remains there. The mercury may be forced back by shaking the thermometer in the arc of a circle with the bulb end out. Larger maximum thermometers are fastened to a framework in which they are whirled to force the mercury back through the constriction. This force due to the circular motion is known as *centrifugal force*, which means literally "to flee from the center." (A force toward the center is a centripetal force — literally "to seek the center.")

Room-temperature thermometers and outdoor-temperature thermometers may be either liquid-in-glass or metallic. They have various ranges depending on the locality in which they are to be used. A common range is from 0° to 120°F. They may be purchased for a variety of prices, but one must not expect too much accuracy in an inexpensive thermometer. A large part of the cost of a thermometer is due to careful workmanship, since the raw materials for an expensive thermometer cost little, if any more, than do those for a less expensive thermometer.

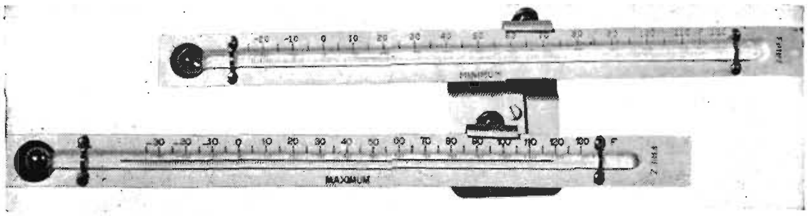

Fig. 10.8. Maximum and minimum thermometers. (Courtesy Julien P. Friez & Sons, Inc.)

60. Maximum and Minimum Thermometers. As the names indicate, these thermometers are for registering the highest and lowest temperatures which have occurred during a given period of time. The construction of one type of maximum thermometer has been explained in connection with clinical thermometers. The minimum thermometer contains a colorless liquid — usually alcohol — in which is floating a small metal marker. As the temperature lowers the alcohol contracts and the surface tension film is strong enough to move the marker down. Then, when the temperature goes up, the alcohol expands and flows around the marker, leaving it to indicate the lowest temperature that had occurred. The end of the marker away from the bulb indicates the minimum temperature since that is the end which was in contact with the surface film. The thermometer is reset by standing it on end with the bulb end up so that gravity can pull the marker to the end of the alcohol column which is indicating the present temperature. This thermometer must be in a horizontal position while it is operating, so that gravity will not move the marker. The chief use of these thermometers is in weather bureau offices, though they may be used any place where maximum and minimum temperatures are of value or interest.

Six's thermometer is a combination maximum and minimum thermometer which is often used in weather bureaus. (See Fig. 10.9.) The bulb *A* and the bore up to *B* contain alcohol. From *B* to *C* the bore is filled with mercury, and from *C* to *D* there is more alcohol. Two small iron indexes are in the bore — one above *B* and the other above *C*. These are held in position by small steel springs. When the temperature rises the alcohol in *A* expands and pushes the mercury along the tube. The mercury pushes the index *c* up the tube and later when the temperature falls it remains to indicate the highest temperature that occurred. Also when the temperature falls the alcohol in *A* contracts, the mercury at *B* rises, and the index *b* is pushed up to the lowest temperature. Consequently the lower ends of *c* and *b* indicate the highest and lowest temperatures which occurred. The thermometer is reset by drawing the indexes down to the mercury with a small horseshoe magnet.

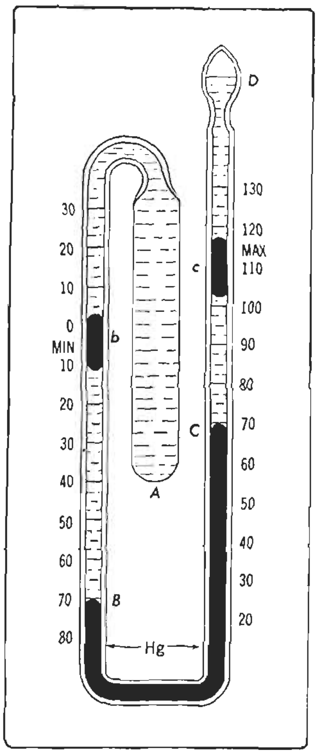

Fig. 10.9. A Six maximum and minimum thermometer.

61. Thermograph. The name indicates that this is a *recording thermometer* since "thermograph" means literally "to write the temperature." The sensitive part of the instrument is either (1) a curved tube, filled with a liquid, which straightens when the temperature, and consequently the pressure, increases, or (2) a curved strip made of two kinds of metal, one of which expands more than the other for a given temperature change and thus changes the curvature of the strip. The motion of the curved piece moves a pointer which has an inked pen on the end. The pen rests against a chart which is on a revolving cylinder. The chart is marked with the days and hours, and temperatures, and furnishes a continuous record of the temperature for the period it covers. A special ink which does not dry quickly is used on the pen and one inking will last for several days. The cylinder on which the chart is placed is driven by a clocklike mechanism.

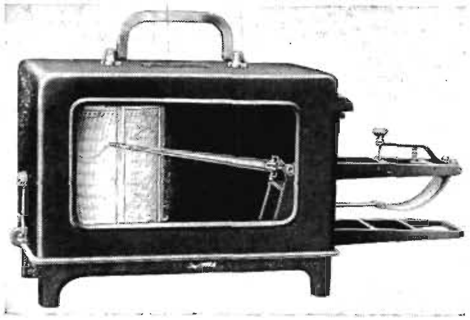

Fig. 10.10. A thermograph. (Courtesy Julien P. Friez & Sons, Inc.)

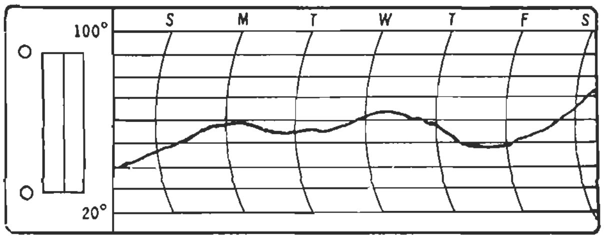

Fig. 10.11. A thermograph chart.

Thermographs are used in many places. Those intended for weather bureau use have charts covering a period of one week and a set of fifty-two makes a complete record for one year. Others are made to record the temperatures for any desired number of days and for any desired temperature range. They may be used in hospitals, nurseries, greenhouses, and schoolrooms; or they may be used in testing refrigerators, ovens, hotbeds, and cold storage plants.

STUDY QUESTIONS

1. When was the first thermometer made? By whom?
2. Why is mercury a suitable liquid for use in thermometers?
3. Does the temperature of a body indicate in any way how much heat is in the body?
4. Why is the Centigrade scale to be preferred to the Fahrenheit scale?
5. Why are recording thermometers of value?
6. What failures in cooking may be eliminated by the use of thermometers?
7. Why should thermometers be aged?
8. Why are clinical thermometers made with cylindrical bulbs?
9. What causes surface tension? In what thermometer is surface tension of importance?
10. What is the purpose of a constriction in a thermometer bore?
11. Is the cost of a thermometer due chiefly to the materials used in its construction or to the care with which it has been made and calibrated?
12. What factors influence the quickness of response of a thermometer?
13. What is meant by the sensitivity of a thermometer? What details of construction determine the sensitivity of a thermometer?
14. Explain how "absolute zero" was determined.

PROBLEMS

1. If the temperature changes 45 degrees on a Fahrenheit thermometer, what is the corresponding change on a Centigrade thermometer? *Ans.* 25 deg
2. If the temperature changes 45 degrees on a Centigrade thermometer, what is the corresponding change on a Fahrenheit thermometer?
3. What temperature on a Fahrenheit scale corresponds to 20°C? *Ans.* 68°F
4. What temperature on a Centigrade scale corresponds to 98.6°F?
5. A candy thermometer has "soft ball" at 240°F. What is the corresponding temperature on a Centigrade thermometer? *Ans.* 115.6°C
6. Ice cream has a temperature of about − 8°C. What is the corresponding Fahrenheit temperature?

7. A temperature of 27°C corresponds to what absolute temperature? *Ans.* 300°A
8. A temperature of 373°A corresponds to what temperature on the Centigrade scale?
9. What temperature has the same value on both the Centigrade and Fahrenheit scales? *Ans.* −40°
10. What temperature is half way between the freezing and the boiling points of water on the Fahrenheit scale?
11. If the temperature of 200 cubic centimeters of gas at 27°C is increased to 57°C, what is the new volume if the pressure is held constant? *Ans.* 220 cu cm
12. The pressure of a given volume of gas at 27°C is 80 centimeters of mercury. If the volume remains constant, what will the pressure be when the temperature increases to 127°C?
13. An oxygen tank which has a volume of 2 cubic feet is full of oxygen at a gauge pressure of 2085 pounds per square inch and at a temperature of 7°C. What volume will the oxygen occupy if it is changed to normal atmospheric pressure and a temperature of 27°C? *Ans.* 300 cu ft
14. If 5 cubic feet of air at normal atmospheric pressure and at a temperature of 27°C are pumped into a tire, what is the gauge pressure after the tire is placed in a garage where the temperature is 17°C? The volume of the tire is 1.5 cubic feet.

11

EXPANSION

The expansion of a material due to a rise in temperature has been mentioned several times in the previous chapter. Expansion is due to increased molecular activity and the increase in distance between molecules resulting from the addition of heat energy. Bread rises more rapidly if placed in a warm place because the carbon dioxide gas given off by the yeast plants expands and increases the size of the tiny gas pockets in the dough. When the bread is baked, the yeast plants are killed, but the carbon dioxide, which is in the dough when it is placed in the oven, expands still more because of the high temperature in the oven. If the oven is too hot at first, a hard crust will form on the loaves and prevent the maximum expansion of the dough. Sometimes if dough is allowed to rise too much before it is baked, it will "fall" when the pan is moved, because the dough has expanded until the walls of the gas pockets cannot withstand any jar or vibration without collapsing. Baking powder and soda unite with the liquids in a dough or batter to form carbon dioxide, and this gas expands when the food is cooked. In the above instances the expansion is also partly due to the fact that the water in the dough turns into steam and increases in volume many times. When an egg is beaten, air is mixed with it, and when this air is heated, it expands and thus helps to make the food lighter. The fluffiness of an omelet depends largely upon the amount of air beaten into the eggs when it is made. Eggs should be at room temperature when they are beaten, because the surface tension of the egg film decreases when the temperature increases. Consequently more air can be incorporated, and greater expansion results when the food is cooked.

Screw lids on jars will often loosen more easily if they are dipped into hot water for a few minutes, because the metal expands more rapidly than the glass, and then the lid fits more loosely. The steel rails of a railroad track are laid with a small amount of space between adjoining ends to allow for the expansion of the iron. Sidewalks and pavements are built in sections with expansion joints between the sections to prevent cracking and buckling in hot weather. Allowance must be made for expansion and contraction on bridges — often the spans rest on rollers and interlacing projections join the spans. Allowance must be made for the change in length of steam and water pipes in buildings. Enamel on cooking utensils or stoves may crack if there is a sudden change in temperature, because the enamel has a different coefficient of expansion than the iron base on which it is coated. Consequently enameled stoves should not be washed when they are hot, and enameled pans should not be taken from the refrigerator and put over a flame immediately.

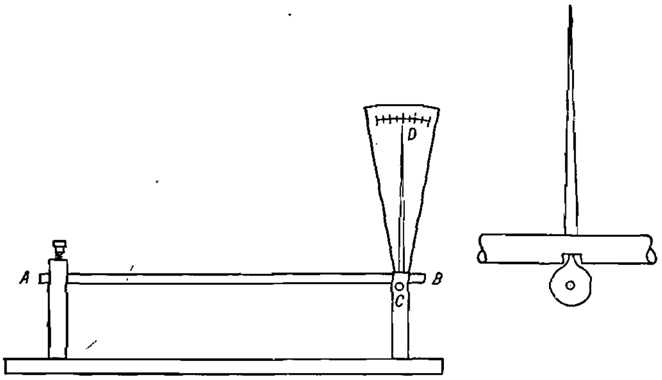

Fig. 11.1. Linear expansion apparatus.

A simple demonstration for showing the increase in length of a rod is shown in Figure 11.1. When *AB* is heated, it increases in length a trifle, but this increase is made more apparent by means of the lever *CD*. In Figure 11.2 the iron ball will just pass through the ring when the ball is cold, but if it is heated, it will not go through the ring. If the ring is heated instead of the ball, the diameter of the opening will increase and the cold ball will go through the hot ring. If both are heated equally, the ball will still go through the ring since the increase in diameter of the ball

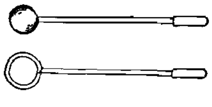

Fig. 11.2. Iron ball and ring.

is the same as the increase in the diameter of the opening in the ring.

62. Factors Affecting Expansion. Experiments have proved that the change in size of an object due to a change in temperature depends on three factors: (1) the coefficient of expansion, which depends on the kind of material, (2) the original size of the object, and (3) the change in temperature. One may be concerned only with the change in length, or the change in area or volume may be the important item to consider.

The coefficient of linear expansion is the change in length of a unit length of the material (measured at 0°C or 32°F) for a change in temperature of one degree. Thus the change in length is equal to the product of the coefficient of expansion a, the original length l, and the temperature change t.

$$\text{Change in length} = alt$$

Likewise the change in area or the change in volume may be calculated. The coefficient of area expansion b is equal to approximately two times the linear coefficient, and the volume coefficient c is equal to approximately three times the linear coefficient. In the case of liquids and gases the volume coefficient is the only one possible.

TABLE OF EXPANSION COEFFICIENTS PER DEGREE C

MATERIAL	LINEAR	AREA	VOLUME
Aluminum	0.000023	0.000047	0.000071
Brass	0.000019	0.000038	0.000057
Concrete	0.000012	0.000024	0.000036
Copper	0.000016	0.000032	0.000048
Glass	0.000009	0.000018	0.000026
Glass (Pyrex)	0.000003	0.000006	0.000009
Ice	0.000052	0.000104	0.000155
Iron	0.000011	0.000022	0.000033
Platinum	0.000009	0.000018	0.000027
Porcelain	0.000004	0.000008	0.000012
Silver	0.000019	0.000039	0.000058
Mercury			0.00018
Water			0.00043
Gases			0.00366 (1/273)

The coefficients were obtained experimentally by measuring the change in size and dividing this change by the original size and by the number of degrees' change in temperature. The coefficients are usually given for a change in temperature of one Centigrade degree and the corresponding Fahrenheit coefficients may be obtained by multiplying the Centigrade coefficient by 5/9 since a Fahrenheit degree is only 5/9 as large as a Centigrade degree. The coefficients are independent of the length, area, or volume units used in determining the coefficients.

It will be noted that Pyrex glass has a much smaller coefficient of expansion than ordinary glass so that when it is subjected to sudden temperature changes the change in size between adjacent layers is usually not enough to cause cracking. For this reason Pyrex glass dishes may be made much thicker than those made from ordinary glass and are less likely to be broken in general kitchen use. It will also be noted that platinum has the same coefficient as glass; hence platinum is often used when it is necessary to fuse a metal into glass since a metal with a different coefficient would cause cracks to form around the seal when it cooled. But because platinum is expensive, an inexpensive alloy called *kovar*, or else a copper-clad steel wire, is now used in the manufacture of electric light bulbs to seal the wires into the glass.

63. Thermostats. *A thermostat is a device for maintaining a constant temperature.* The type which is generally used in connection with a house-heating system consists of a bimetallic strip which curls and straightens with changes in temperature and in so doing

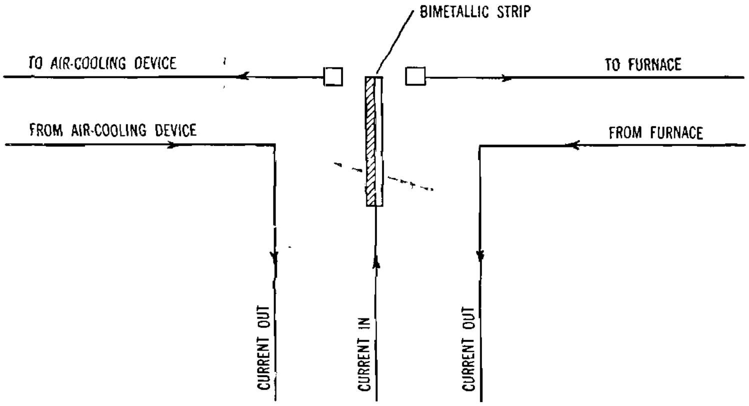

Fig. 11.3. Diagrammatic sketch of a thermostat and the electric connections for an air conditioning system.

opens or closes an electric circuit to a motor which opens or closes a draft or a fuel valve, or which operates a stoker. The temperature at which the thermostat operates is controlled by turning a temperature indicator which is really a device for regulating the pressure on the bimetallic strip. The thermostat may be connected to turn on the heating system if the temperature is too low or to turn on the cooling system if it is too warm. (See Fig. 11.3.) The thermostat in a refrigerator, an electric iron, or a heating pad may operate in exactly the same way.

In another type of thermostat an electrical circuit is made or broken as the mercury level in a tube rises or falls because of temperature changes. (See Fig. 11.4.) The circuit is complete when the mercury expands enough to make contact at *C*. This contact may cause a warning bell to ring or a motor to start. The disadvantage of this type is that the temperature at which it operates cannot be adjusted. This is essentially the type of thermostat used in a sunshine-duration recorder. (See Sec. 115.)

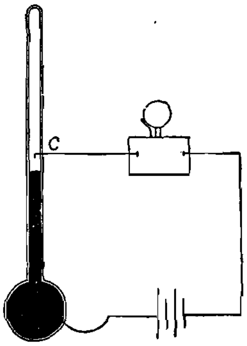

Fig. 11.4. A thermostat which operates at one temperature only.

One type of electric-oven thermostat has a bimetallic strip under one end of a tube of mercury. As the temperature increases, the strip curls and tips the mercury tube, causing all the mercury to run to one end. This breaks the electric circuit. As the oven cools, the strip straightens and allows the tube to lie horizontally, and this straightening completes the circuit again.

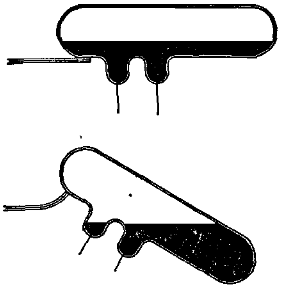

Fig. 11.5. Electric-oven temperature regulator.

64. Change of Size Due to Change of State. When a vapor changes to a liquid it decreases decidedly in volume. The molecules are far apart in the vapor state, but when energy is removed from the gas, the molecules move more slowly in shorter paths and consequently fill less space. It has been found by experiment that 1 gram of water in the vapor state at 100°C occupies about 1750 cubic centimeters but in the liquid state it occupies only 1 cubic centimeter. When liquids change into solids most of them show a decrease in volume — a pan of melted paraffin or lard usually has a depression in the surface when it solidifies.

But water behaves in an entirely different manner. It contracts as it cools just as other liquids do until it reaches 4°C — then it expands as the temperature continues to decrease to 0°C. When water freezes it expands about one-eleventh in volume. Thus the ice is considerably lighter than the water, and it floats. This expansion of water as it freezes is of importance in nature. When lakes and rivers freeze over the ice stays on top and acts as an insulator to prevent further loss of heat from the water below the ice. Thus fish and other water life are protected from extremely cold temperatures. If the ice were denser than water it would sink to the bottom as it froze, more ice would form and sink, and soon the river would be frozen solid. The next summer it would begin to melt at the top, but, since water is a poor conductor of heat, possibly only a relatively thin layer would melt. It is fortunate that icebergs float with about one-ninth of their volume above water, and consequently give warning of their presence. Rocks are weathered and soil is loosened as the water in them freezes and expands. So far only the advantages of this expansion have been mentioned, but there are some disadvantages. Water pipes and car radiators freeze and burst; plant cells, which contain a great deal of water, freeze, and the resulting expansion breaks the cell walls.

There are a few other substances which expand when they solidify. Type metal which is an alloy of antimony, lead, and tin expands, and this property causes the letters to be sharp and well formed. If a material were used which contracted as it cooled, it is easy to see that an E might print as an F or e as c, and the fine points on the type letters, which aid in making the print easy to read, would be missing. Cast iron is another material which expands on solidifying and fills the mold completely — in fact allowance is made for the expansion, otherwise the mold would burst. Consequently odd-shaped pieces for machinery can be cast and the cost of production is decidedly less than it would be if each piece had to be shaped from the solid metal, or ground down from a casting made in approximately the correct shape but larger than the finished article to allow for uneven shrinkage as the material solidified.

Copper, gold, silver, and nickel contract as they solidify; therefore coins cannot be cast, but must be stamped with a heavy die.

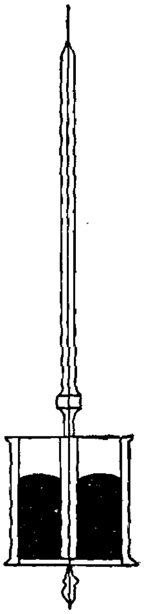

Fig. 11.6. A clock pendulum.

65. Pendulums and Balance Wheels. Pendulums are used to regulate the speed of clocks — the longer the pendulum the slower the clock runs. If the pendulum is made of metal, the length changes as the temperature changes, and the accuracy of the clock is affected. If wood is used instead of a metal, it changes length because of changes in the humidity. One way of compensating for the change in length of a metal pendulum is shown in Figure 11.6. Two containers of mercury are mounted at the lower end of the pendulum rod. Since the expansion of mercury is considerably greater than that of the brass or steel which is used for the rod, the increase in length of the pendulum due to the rod is counterbalanced by the rise in the center of gravity of the mercury.

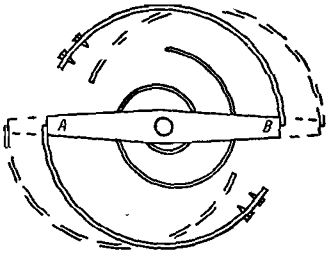

Fig. 11.7. Balance wheel of a watch.

The balance wheel in a watch is made as shown in Figure 11.7. The rim of the wheel is bimetallic, and as the temperature increases, the free ends of the sections of the rim curl in. This decrease in the size of the wheel is offset by the increase in the length of the spokes.

STUDY QUESTIONS

1. Why does ice float?
2. Why may the mercury thread in a thermometer fall a little when the thermometer is first put in hot water?
3. Should an oven rack or the grate in a furnace fit tightly when it is cold?

4. Is any provision made in hot-water and steam pipes for the change in length due to changes in temperature?
5. Why are sidewalks and paved roads made in small sections? Why is the material between the sections of a paved road more noticeable in the summertime?
6. Why will a metal can cover come off easier after it has been dipped in hot water a few seconds?
7. Why will a drop of cold water on a hot glass dish usually break it?
8. Why does a fireplace sometimes smoke at first but does not after the fire has burned a few minutes? Often the smoking can be stopped by holding a flaming paper under the flue. Why?
9. Enameled stoves should not be washed when hot. Why?
10. Why is a Pyrex glass dish less likely to break than one made of ordinary glass?

PROBLEMS

1. If a Pyrex dish is 9 inches long at 70°F, how long is it at 270°F? Work the same problem assuming that the dish is made of ordinary glass. *Ans.* 9.003 in.; 9.009 in.
2. How much will an 18-inch iron oven rack increase in length if the oven temperature changes from 70°F to 470°F?
3. How much will the volume of 4 cubic feet of water change if the temperature is changed 30 Centigrade degrees? *Ans.* 0.0516 cu ft
4. If 3000 cubic feet of air are heated from 15°C to 20°C, what is the resulting volume?
5. A piece of material is 10 inches long at 20°C. At 100°C it is 10.0152 inches long. What kind of material is it? *Ans.* Silver
6. A piece of material which has a volume of 10 cubic feet is warmed from 43°F to 70°F. It then has a volume of 10.0107 cubic feet. What is the material?
7. If one gallon (231 cubic inches) of water freezes, how many cubic inches will it increase in size? What is the total volume of the ice? *Ans.* 21 cu in.; 252 cu in.
8. If 1 gallon of water is turned into steam at atmospheric pressure, how much space does it occupy?
9. If an iron bridge increases 1.65 inches in length from a winter day when the temperature is 20°F to a summer day when the temperature is 110°F, how long is the bridge? *Ans.* 250 ft
10. How much must the temperature of 3000 cubic feet of air be increased in order to increase the volume of the air 10 cubic feet?

12

QUANTITY OF HEAT

Adding heat to a body may change its temperature, its state, its size, or its physical characteristics, but whatever change takes place, the amount of the change will depend on the quantity of heat energy added to the body. Heat is a form of energy and may be measured in the usual energy units, such as foot-pound and gram-centimeter, but for a good many purposes it is more convenient to use units which are based upon the amount of heat required to change the temperature of a unit mass of water.

66. Heat Units. Two standard units for measuring quantity of heat are the *calorie* and the *British thermal unit. A calorie is the amount of heat required to change the temperature of 1 gram of water 1 degree Centigrade. A British thermal unit (Btu) is the amount of heat required to change the temperature of 1 pound of water 1 degree Fahrenheit.* The relation between the calorie and the British thermal unit may be determined as follows: 1 pound of water is equivalent to 454 grams of water but 1 degree Fahrenheit is only 5/9 of a degree Centigrade; therefore 1 Btu is equivalent to $454 \times 5/9 = 252$ calories. The calorie as defined above is the gram-calorie (g-cal); however, a larger unit called the *kilogram-calorie* (kg-cal) is used in some measurements, especially in foods work. The kilogram-calorie is equivalent to 1000 gram-calories. In this book the term "calorie" will always refer to the gram-calorie. A very exact definition of a calorie or a British thermal unit states a definite temperature interval — from 15° to 16°C for a calorie and from 59° to 60°F for a British thermal unit — since the amount of heat needed to change the temperature of a unit mass of water 1 degree is found to change slightly as the temperature of the water changes. However, this variation is so small that for all practical purposes the definition as given above will hold from 0° to 100°C or from 32° to 212°F.

Not all substances require the same amount of heat to produce a given temperature change. These variations may be accounted for by the differences in molecular structure — different amounts of internal work are required to produce a given change in temperature as well as to produce the accompanying change in size. *The specific heat of a material is the amount of heat required to change the temperature of a unit mass of a material 1 degree.*[1] In the following table we see that the specific heat of aluminum is 0.22; this means that 0.22 of a calorie will heat 1 gram of aluminum 1 Centigrade degree, or that 0.22 of a British thermal unit will heat 1 pound of aluminum 1 Fahrenheit degree.

SPECIFIC HEATS

(*Cal per g-°C or Btu per lb-°F*)

Water	1.00	Porcelain	0.26
Steam	0.48	Tin	0.05
Ice	0.50	Glass	0.19
Air	0.24	Mercury	0.03
Aluminum	0.22	Crockery	0.20
Copper	0.09	Brick	0.20
Iron	0.12	Asbestos	0.19
Chromium	0.11	Sugar	0.27
Silver	0.06	Olive oil	0.47

The specific heat of tea or coffee is approximately the same as that of water. Milk contains some solid material and has a specific heat of about 0.92 and the specific heat of 30 per cent cream is about 0.7 at 40°F. Meat, potatoes, eggs, and the human body average about 0.8. In general, as the per cent of water decreases, the specific heat decreases. It is interesting to note the differences between the specific heats of ice, water, and steam, which all have the same chemical composition but differ physically. The *thermal capacity* of a body is the amount of heat required to change the temperature of the body 1 degree. The *water equivalent* of a body is the amount of water which has the same thermal capacity as the body.

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[1] Specific heat may also be defined as the ratio of the quantity of heat required to raise the temperature of a body 1 degree to that required to raise the temperature of an equal mass of water 1 degree.

67. Heat Involved in Change of Temperature. It has been found by experiment that the amount of heat involved in changing the temperature of a given amount of material depends on the mass of the material m, the specific heat of the material s, and the temperature change of the material in degrees t.

$$H = mst$$

For example:

1. The amount of heat required to warm 8 pounds of water (nearly one gallon) from 70° to 80°F is

$$H = mst$$
$$H = 8 \times 1 \times (80 - 70)$$
$$H = 80 \text{ Btu}$$

2. The amount of heat required to warm 12 grams of steam from 100° to 110°C is

$$H = mst$$
$$H = 12 \times 0.48 \times (110 - 100)$$
$$H = 57.6 \text{ cal}$$

3. The amount of heat required to warm 2 pounds of copper from 90° to 120°F is

$$H = mst$$
$$H = 2 \times 0.09 \times (120 - 90)$$
$$H = 5.4 \text{ Btu}$$

68. Heat Involved in Change of State. When heat is added to a material, it does not always cause a change in temperature. For example, if heat is added to ice at 0°C or 32°F, it melts the ice instead of increasing the temperature. If more heat is added after the ice is all melted, the temperature of the water will then begin to increase. When heat is removed from water, the temperature decreases to 0°C or 32°F, and then, if more heat is removed, the water begins to freeze. The temperature remains constant until the material is all frozen, and then the temperature begins to decrease again. The same situation exists at the boiling point. Water may be warmed to 100°C or 212°F (standard pressure); then if more heat is added, the temperature does not increase, but the water begins to vaporize. After it is all vaporized, the temperature of the vapor begins to increase if more heat is added. When heat is removed from water vapor, the temperature decreases to 100°C or 212°F; then if more heat is removed the vapor condenses into water at the same temperature. After all of the vapor is condensed, the temperature of the water begins to decrease if more heat is removed.

The heat involved in the change of state from a solid to a liquid, or vice versa, is the *heat of fusion*, and that involved in the change from a liquid to a gas, or vice versa, is the *heat of vaporization*. *The heat of fusion of a material is the amount of heat required to change the state of a unit mass of the material from a solid to a liquid at the same temperature. The heat of vaporization of a material is the amount of heat required to change the state of a unit mass of the material from a liquid to a vapor at the same temperature.* The heat of fusion for water is 80 calories per gram or 144 British thermal units per pound. The heat of vaporization for water is 539 calories per gram or 970 British thermal units per pound. This heat energy is used to do work against molecular forces which results in changing the molecular arrangement. Consequently the potential energy is increased. These changes account for the differences in the three physical states — solid, liquid, and gaseous.

It has been found by experiment that the amount of heat involved in a change of state depends on (1) the mass of the material m and (2) either heat of fusion f or heat of vaporization v.

$$H = mf \quad \text{or} \quad H = mv$$

For example:

1. The amount of heat required to melt 10 pounds of ice at 32°F is

$$\begin{aligned} H &= mf \\ &= 10 \times 144 \\ &= 1440 \text{ Btu} \end{aligned}$$

2. The amount of heat required to vaporize 20 grams of water at 100°C is

$$\begin{aligned} H &= mv \\ &= 20 \times 539 \\ &= 10{,}780 \text{ cal} \end{aligned}$$

The changes in state and in temperature for a material, and the amounts of heat involved, may be shown diagrammatically.

Figure 12.1 shows such a diagram for water. A study of this diagram will be helpful in solving the first problem given below.

In each of the two problems which follow, the question "How much heat?" is answered, but it is interesting to contrast the two solutions which differ because of the difference in material. The first problem, which deals with changing ice from below 0°C to steam above 100°C, involves five quantities of heat; the second problem, even though the mass and the temperature change are the same as in the first problem, involves only one quantity of heat since there is no change of state.

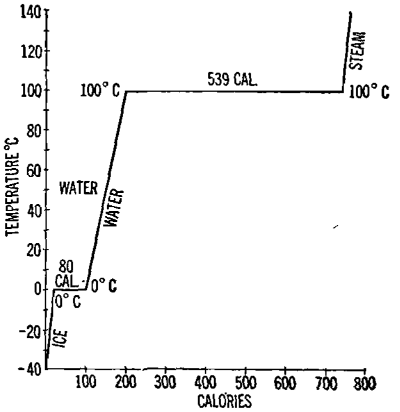

Fig. 12.1. Change of state and change of temperature diagram for water.

1. How much heat is required to change 10 grams of ice at $-20°$C to steam at 140°C?

Amount of heat required = heat to warm the ice to the melting temperature + heat to melt the ice + heat to warm the water from the freezing temperature to the boiling temperature + heat to vaporize the water + heat to warm the steam to the final temperature.

$$\begin{aligned} H &= mst + mf + mst + mv + mst \\ &= (10 \times 0.5 \times 20) + (10 \times 80) + (10 \times 1 \times 100) + \\ &\quad (10 \times 539) + (10 \times 0.48 \times 40) \\ &= 100 + 800 + 1000 + 5390 + 192 \\ &= 7482 \text{ cal} \end{aligned}$$

2. How much heat is required to warm 10 grams of aluminum from $-20°$C to 140°C?

$$\begin{aligned} H &= mst \\ &= 10 \times 0.22 \times 160 \\ &= 352 \text{ cal} \end{aligned}$$

Heat of fusion and heat of vaporization will be discussed more fully in the next chapter on Change of State.

69. Calorimetry. *A calorimeter is an insulated vessel in which heat measurements are made.* It is usually a thin-walled metallic container entirely surrounded by layers of some heat-insulating material, such as felt, bakelite, or hard rubber. (See Sec. 90.) Dead air spaces are often interposed between layers of these materials. If materials at different temperatures are placed in the calorimeter, it may be assumed that, during the short time the experiment is being carried on, no heat is gained by or lost from the calorimeter and its contents. If this ideal situation exists within the calorimeter, *the heat lost by the hot materials is equal to the heat gained by the cold materials.* (The heat involved in warming or cooling the calorimeter must be accounted for.)

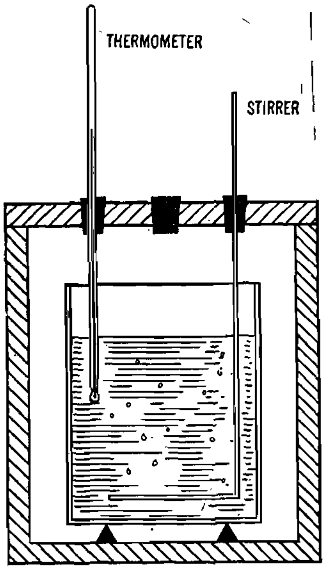

Fig. 12.2. A calorimeter is an insulated container to use in heat experiments.

The following problems illustrate the basic principle of calorimetry.

1. If 10 pounds of water at 190°F are mixed with 4 pounds of water at 50°F what is the final temperature?

Heat lost by hot water = heat gained by cold water.

$$
\begin{aligned}
mst &= mst \\
10 \times 1 \times (190 - T) &= 4 \times 1 \times (T - 50) \\
1900 - 10T &= 4T - 200 \\
14T &= 2100 \\
T &= 150^\circ\text{F}
\end{aligned}
$$

(This problem neglected the effect of the container in which the mixing was done.)

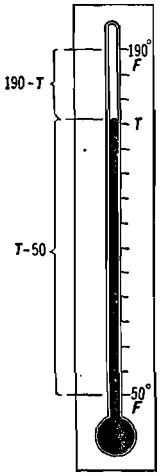

Fig. 12.3. The unknown temperature is between the highest and the lowest temperatures.

2. What is the final temperature if 10 grams of water at 90°C is put into an aluminum calorimeter cup which weighs 30 grams

and which contains 40 grams of water? The temperature of the calorimeter cup, and of the water in it, is 20°C.

Heat lost by hot water = heat gained by calorimeter cup + heat gained by cold water.

$$\begin{aligned} mst &= mst + mst \\ 10 \times 1 \times (90 - T) &= 30 \times 0.22 \times (T - 20) + \\ &\quad 40 \times 1 \times (T - 20) \\ 900 - 10T &= 6.6T - 132 + 40T - 800 \\ 56.6T &= 1832 \\ T &= 32.4^\circ\text{C} \end{aligned}$$

3. If 2 pounds of ice at 32°F are added to 8 pounds of water at 90°F which is in a glass bowl weighing 3 pounds, what is the final temperature?

Heat to melt the ice + heat to warm the cold water = heat lost by the warm water + heat lost by the glass bowl.

$$\begin{aligned} mf + mst &= mst + mst \\ 2 \times 144 + 2 \times 1 \times (T - 32) &= 8 \times 1 \times (90 - T) + 3 \times \\ &\quad 0.19 \times (90 - T) \\ 288 + 2T - 64 &= 720 - 8T + 51.3 - 0.57T \\ 10.57T &= 547.3 \\ T &= 51.8^\circ\text{F} \end{aligned}$$

The problem may not ask for a temperature — perhaps the question concerns a specific heat, or a mass, or the amount of heat to change the state of one of the materials. The formula must be worked out for each individual problem but it must always account for all the quantities of heat involved.

4. What mass of ice at − 12°C must be put into 100 grams of water at 60°C to cool it to 40°C? (Neglect the effect of the container.)

Heat to warm the ice to the melting temperature + heat to melt the ice + heat to warm the cold water = heat lost by the warm water.

$$\begin{aligned} mst + mf + mst &= mst \\ m \times 0.5 \times 12 + m \times 80 + m \times 1 \times 40 &= 100 \times 1 \times 20 \\ 126m &= 2000 \\ m &= 15.9\ \text{g} \end{aligned}$$

While household appliances are not classed as calorimeters, many of our heating and cooking appliances have undergone changes intended to make them more efficient in either retaining or excluding heat. This increased efficiency has decreased the cost of operation and increased the comfort of the operator. Insulated devices found in the home are ovens, refrigerators, hot water heaters and ice cream freezers. Even the house itself is insulated, since one of its purposes is to keep heat in during the wintertime, and out during the summertime. Of course the walls of the devices mentioned above are far from perfect heat insulators.

STUDY QUESTIONS

1. Which is hotter, a cup of boiling water or a gallon of boiling water? Which contains the more heat?
2. What is the distinction between thermal capacity and specific heat?
3. How do you account for the variations in the specific heats of materials?
4. What are the specific heats of ice, water, and steam? Why do they differ?
5. Will 1000 calories of heat always produce the same effect in cooking a food?
6. Can you suggest some uses for water which are probably due to the fact that it has a high specific heat?
7. Does one do any work in calorimetry in the kitchen?
8. What becomes of the heat energy that must be added to a gram of water at 100°C to change it into steam at 100°C?
9. Why does steam at 212°F cause a more serious burn than boiling water at 212°F?
10. Would you expect the heat of vaporization for water at 100°C to be more or less than for water at 98°C?

PROBLEMS

1. How many British thermal units of heat are required to warm 8 pounds (approximately a gallon) of water from 70° to 200°F? *Ans.* 1040 Btu
2. How many calories of heat are required to warm 100 cubic centimeters of water from 20°C to 100°C?
3. How many calories are equivalent to 4 British thermal units? *Ans.* 1008 cal
4. How many British thermal units are equivalent to 5 kilocalories?
5. What is the thermal capacity of 10 pounds of silver? *Ans.* 0.6 Btu
6. What is the thermal capacity of a 150-pound person?
7. How much heat is required to warm 10 pounds of ice from 20°F to 32°F? *Ans.* 60 Btu

8. How much heat is given out when 20 grams of steam cool from 130°C to 100°C?
9. How much heat is required to melt 10 grams of ice at 0°C? *Ans.* 800 cal
10. How much heat must be removed from 10 pounds of water at 32°F in order that it may freeze?
11. How much heat must be removed from 10 pounds of steam at 212°F in order that it may condense? *Ans.* 9700 Btu
12. How much heat must be added to 10 grams of water at 100°C to convert it into steam?
13. How much heat is required to change 10 grams of ice at −20°C to steam at 140°C? *Ans.* 7482 cal
14. How much heat must be removed from 10 pounds of steam at 240°F to change it to ice at −20°F?
15. If 10 pounds of water at 80°F and 15 pounds of water at 50°F are mixed, what is the final temperature? *Ans.* 62°F
16. If 200 grams of water at 70°C are put into a glass beaker which weighs 50 grams and is at a temperature of 20°C, what is the resulting temperature?
17. How much hot water at 90°C must be added to 400 grams of water in a glass beaker weighing 100 grams to increase the temperature from 20°C to 50°C? *Ans.* 314.3 g
18. How much cream at 40°F must be added to 1 cup (0.5 pound) of coffee at 140°F to cool it to 130°F? The coffee is in a glass cup which weighs 0.1 pound.
19. What is the specific heat of copper if a beaker weighing 300 grams and at a temperature of 10°C cools 36 grams of water from 80°C to 50°C when the water is put in the beaker? *Ans.* See specific heat table.
20. When 5 pounds of a material at 160°F is dropped into 2.5 pounds of water at 50°F, the temperature of the water increases to 60°F. What is the material?
21. How much ice at 32°F must be put into 2 pounds (approximately a quart) of fruit juice (specific heat = 1) to cool it from 84°F to 44°F? *Ans.* Approximately 0.5 lb
22. How much steam at 100°C is needed to warm 400 grams of water and 200 grams of aluminum from 20°C to 35°C?

13

CHANGE OF STATE

In the preceding chapter change of state was discussed briefly, and the amounts of heat involved in changing the state of H_2O at the freezing and boiling points were used in problems. In this chapter fusion and vaporization will be discussed more fully and other phenomena connected with changes in state will be explained.

70. Heat of Fusion. Every pure, *crystalline* material has a definite melting temperature and a definite heat of fusion. The heat added during fusion does not increase the temperature of the material, and the heat seems to disappear, but the kinetic theory accounts for its disappearance. It has already been explained that in the solid state the molecules are more rigidly held in position and that the paths through which they vibrate are shorter than in the liquid state. If the molecules are freer to move in the liquid state, work is required to overcome the forces of cohesion which limit the motion of the molecules in a solid. The heat of fusion is utilized in doing this work and is stored in the material as potential energy which is given out again as heat energy if the material changes back to the solid state.

Some materials such as glass, wax, butter, and paraffin do not have definite melting temperatures — they gradually change state as the temperature increases — or in other words they soften. Such materials are called *amorphous* materials; that is they are really mixtures of materials which change state at various temperatures and as one after the other melts the material is gradually changed from a solid to a liquid.

71. Heat of Vaporization. It has been explained before that in the liquid state the molecules have less freedom of motion than in the gaseous state. If the molecules are freer to move in the gaseous state, work is required to overcome the forces which limit the molecular motions in the liquid state. It is the heat of vaporization which is utilized for this work and which is stored in the material as potential energy. If the gas changes back into a liquid, the potential energy is given out again as heat energy.

Liquids may change into the gaseous state at all temperatures. If the change takes place quietly from the surface of the liquid, the process is *evaporation;* but if bubbles of vapor form in the liquid, rise, and break through the surface, the process is *boiling.* Pure liquids such as water, ammonia, and sulphur dioxide have definite boiling temperatures at standard atmospheric pressure. Mixtures of liquids change state gradually because the various materials are vaporizing one after the other. By regulating the temperature a mixture of alcohols may be vaporized one after the other and collected separately. This process is known as *fractional distillation.*

The following table gives freezing and boiling points, heats of fusion and vaporization for various materials. Some of these materials are used in household utensils, some in thermometers, and some in electric refrigerators.

MATERIAL	FREEZING POINT		BOILING POINT		HEAT OF FUSION		HEAT OF VAPORIZATION	
	°C	°F	°C	°F	Cal/g	Btu/lb	Cal/g	Btu/lb
Water	0	32	100	212	80	144	539	970
Mercury	− 40	− 40	357	675	2.8	5	65	117
Alcohol	− 130	− 202	78	172			204	367
Ammonia	− 75.5	− 103.9	− 33.5	− 29			297	534
Sulphur dioxide			− 10	14			95	171
Carbon dioxide (dry ice)	− 56	− 67.2			45.3	81.5		
Aluminum	658	1152	1800	3272	76.8	140		
Iron	1530	2786	2450	4442	8	14.5		
Silver	961	1760	1955	3551	21	38		
Gold	1064	1883			15.8	28.4		
Pewter	280	536						
Milk	− 0.6	31	100.2	212.3				
Salt sol. 5%	− 3.0	26.6	100.5	212.9				
Sugar sol. 5%	− 0.3	31.5	100.1	212.2				

72. Sublimation and Frosting. The change in state from the solid directly into the vapor state is very common, and is known as *sublimation.* Camphor, moth balls, ice, snow, carbon dioxide (dry ice), smelling salts, and nasal inhalants all make this change of state. Ice and snow often disappear during periods of very cold weather when we know they have not melted. Sometimes when laundry is hung outdoors in cold weather it "freezes dry" — that is, the water freezes and then the ice sublimates. When a piece of dry ice is exposed to air at room temperature, it appears to be steaming; but the apparent steam is really tiny drops of water which are formed when the water vapor in the atmosphere is cooled by the dry ice until it condenses.

The reverse change of state — from the vapor to the solid state — is known as *frosting.* Water vapor in the air outdoors often changes directly into frost, which deposits on vegetation, on the ground, or on the windshields of cars. In the house frost may form on cold windows, and in a refrigerator the moisture deposits as frost on the freezing unit.

73. Freezing Mixtures. A mixture of common salt (NaCl) and ice is used to freeze ice cream which has to be cooled to about 17°F or − 8°C to be hard enough to hold its shape. When the salt is added to the ice it causes the ice to melt rapidly, and there is a decrease in the temperature of the mixture. The decrease in temperature is explained as follows: In order that a molecule of H_2O may escape from the surface of the ice and become a molecule in the liquid state, a certain amount of energy is required, but there is an attraction between the ice molecules and the salt molecules which decreases the amount of energy required. Therefore the ice can melt at a lower than normal temperature when salt is present. The freezing point of the solution is lowered as salt is dissolved in it, hence heat can be taken from the solution to melt the ice, and the temperature of the solution decreases until the ice and the solution are in thermal equilibrium. The lowest possible temperature obtainable with a mixture of salt and ice is − 22°C or − 7.6°F, which is the freezing point of a saturated salt solution. One part of salt to three parts of ice (by weight) is roughly the proportion for saturation. However less salt — about one part of salt to six or eight of ice — is a better proportion for freezing ice cream, because if ice cream is frozen too rapidly it is crystalline instead of smooth and velvety. More salt than the 1:3 ratio of salt to ice causes more rapid freezing but does not produce a lower temperature than the 1:3 ratio.

74. Heat of Solution and Heat of Hydration. When a crystalline salt is dissolved in water, energy is taken from the water to separate the atoms or ions which are arranged in a definite pattern in the crystal. This energy is the *heat of solution.* But combinations between these atoms or ions and the solvent may evolve heat. This heat is known as *heat of hydration.* If the heat of solution is greater than the heat of hydration, the temperature of the solution decreases; but if the heat of hydration is the greater, then the temperature of the solution increases. When salt (NaCl) is added to water the temperature is lowered slightly because the heat of solution is greater than the heat of hydration, but if sodium hydroxide (NaOH) is added to water the temperature increases considerably because the heat of hydration is greater than the heat of solution.

75. Evaporation. If water is placed in an open dish, it will all disappear if left long enough. If the hands are dipped in water but not dried with a towel, they soon dry in the air. If a perfume bottle is left unstoppered, it is soon empty. In each case a liquid has evaporated.

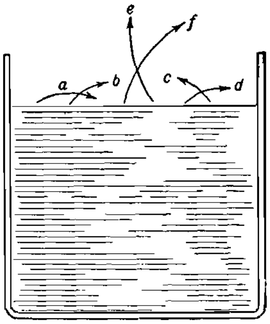

Fig. 13.1. Evaporation of a liquid.

Since the molecules of a liquid are in constant motion, it is reasonable to suppose that some are moving faster than others, and as they dart to and fro, it is quite possible that some of these molecules will dart out far enough from the surface of the liquid to escape — or in other words some of the molecules have evaporated. However, there is an attraction between the molecules which tends to draw back into the liquid those that dart out, and if they are not going too fast when they leave the surface, they will be drawn back into the liquid as at *a*, *b*, *c*, and *d* in Figure 13.1. But some molecules, like *e* and *f*, will have enough kinetic energy to carry them away from the surface, and they are then in the vapor state. Since the molecules with the most kinetic energy escape, the average energy of the remaining molecules becomes less or, in other words, the temperature of the remaining liquid is decreased slightly.

Liquids vary decidedly in rate of evaporation — some like gasoline and ether evaporate rapidly; water evaporates more slowly; mercury evaporates very slowly. The rate of evaporation always increases as the temperature of the liquid increases because heating the liquid furnishes the energy necessary for the escape of the molecules. Since evaporation takes place at temperatures below the boiling point, the heat absorbed per unit mass of material is slightly more than the heat of vaporization at the boiling point. The amount of heat required at various temperatures to evaporate a unit mass of water is shown in the following table.

TEMPERATURE	HEAT OF VAPORIZATION
°C	Cal per g
10	590
20	585
30	580
40	574
50	568
60	563
70	557
80	551
90	545
100	539
°F	Btu per lb
32	1072
70	1052
100	1036
150	1007
212	970

The greater the pressure over the surface of the liquid the harder it is for the molecules to escape. For this reason liquids are kept in closed containers to prevent evaporation — the region above the liquid then becomes saturated, and molecules return to the liquid at the same rate that others leave the liquid, or a state of equilibrium exists. When a bottle of perfume is opened, the vapor escapes, and we smell the perfume. When the bottle is corked again, evaporation takes place until the space above the liquid is saturated; then there is no more evaporation until the bottle is opened again. Water evaporates faster on a day when there is little moisture in the atmosphere, and it evaporates faster when the wind is blowing so that the vapor is blown away as fast as it forms.

76. Boiling. When a liquid is heated the liquid in the bottom of the dish where the heat is applied increases in temperature and soon becomes hot enough to turn into a vapor. These bubbles of vapor rise and break through the surface when the vapor pressure in the bubbles just exceeds the pressure on the surface of the liquid. If they break below the surface, the liquid is simmering. The temperature at which boiling occurs depends chiefly on the kind of liquid and the pressure over the liquid. While the boiling point of water is usually said to be 100°C or 212°F, that is the correct temperature only when the atmospheric pressure is equal to 76 centimeters or 30 inches of mercury. The following table shows the temperatures at which water boils for various pressures, and this information also is shown graphically in Figure 13.3.

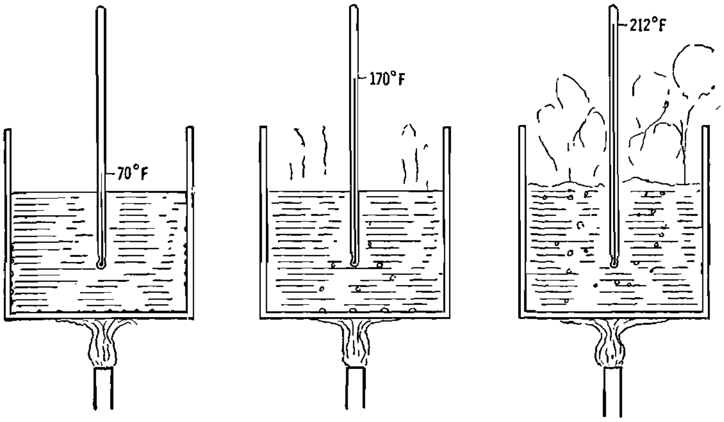

Fig. 13.2. Simmering and boiling.

Other factors sometimes change the boiling point slightly. When salt is added to water, the boiling point is increased because the salt decreases

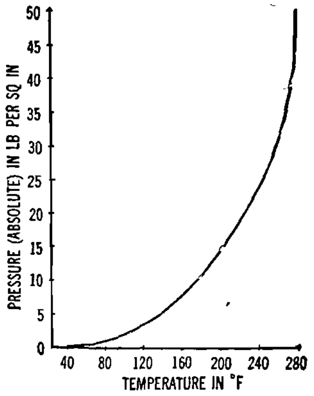

Fig. 13.3. Pressure-temperature curve for water vapor.

the vapor pressure within the bubbles so that the solution must be heated to a higher temperature before the vapor pressure exceeds the pressure on the surface of the liquid. The shape and material of the container influence the boiling point also. Water may boil in a metal dish at a temperature several degrees below that in a glass dish because the force of adhesion between water and glass is high. If water is boiled in a container which has a curved bottom such as a round-bottomed flask, the boiling point tends to be higher than it is in a flat-bottomed container. If beads, tacks, or pebbles are put in the rounded container the boiling point is lowered — probably to normal.

TEMPERATURE	PRESSURE		TEMPERATURE
°F	Lb per Sq In.	Cm of Mercury	°C
32	0.1	0.5	0
50	0.2	0.9	10
68	0.3	1.8	20
86	0.6	3.2	30
104	1.1	5.5	40
122	1.8	9.3	50
140	2.9	14.9	60
158	4.6	23.4	70
176	7.0	35.5	80
194	10.4	52.6	90
212	14.7	76.0	100
230	20.8	107.5	110
248	28.8	148.9	120
266	39.2	202.6	130
284	52.4	271.0	140

77. Vacuum Pans. The fact that lowering the pressure over the surface of a liquid decreases its boiling point may be demonstrated in two ways. (1) If some water is placed in a flask and boiled, the air above the water will be driven from the flask. If the flask is removed from the fire, corked tightly, inverted, and then cold water is poured over it, the water will again begin to boil. This is because the steam is condensed, the pressure reduced, and the water is hot enough to boil at this reduced pressure. If the experiment is continued, the water will still be boiling when the flask is cool enough to hold in the hand. (2) If some hot water is placed in a dish under a bell jar which is connected to a vacuum pump so that the air can be pumped out, the water will begin to boil when the pressure is reduced to just less than the vapor pressure in the liquid.

The fact that water will boil at a lower temperature if the pressure is reduced is made use of in vacuum pans. These are devices for preparing foods in which the water content should be decreased but at a temperature which will not change the chemical composition of the food. In sugar refineries the syrup must be boiled to reduce the water content in order to obtain granulated sugar. If this is done at normal pressure, the temperature is high enough to scorch the sugar, but in a vacuum pan the pressure is reduced by means of a pump and the water evaporates at a much lower temperature. Evaporated milk, dried eggs, dried fruits, candies, jellies, and preserves are prepared in vacuum pans. It should be noted that evaporation is the chief aim and cooking is secondary. In fact the decrease in temperature would only increase the cooking time. When our grandmothers made preserves, they cooked them all day over a low heat, stirring frequently to prevent scorching. This was not done because the strawberries or cherries needed so much cooking — it was done to evaporate the liquid. Vacuum pans for home use are not on the market but in commercial food preparation they are very important.

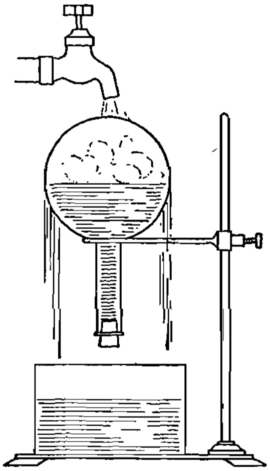
Fig. 13.4. Boiling at reduced pressure.

78. Steam Cooking Devices. There are a number of cooking devices which use steam at normal or above normal temperatures, and often the operator does not fully understand why different amounts of time are required for the same cooking process because of the differences in temperature.

The most common of these devices is the double boiler. Water is placed in the lower pan and the food in the upper pan, which fits tightly into the lower one. The water boils in the lower pan at a temperature depending on the atmospheric pressure, or at a temperature slightly higher, since, if the two pans fit together very well, there may be a slight increase in pressure. But the cooking may be considered as being done at the normal boiling temperature of water, and the temperature in the food container will not go above the boiling point of water no matter how fast the water boils. This cooker is suitable for making cream sauces and custards which would scorch or curdle if the temperature were higher. The inner container may be perforated, and the steam then rises around and through the food and cooks it in about the same time that it would cook in boiling water, but it is an advantage to cook some foods in steam rather than in boiling water, because the mineral content of the food is not reduced and the foods retain their shape better.

Fig. 13.5. Steam-jacketed kettle. (Courtesy The Aluminum Cooking Utensil Co.)

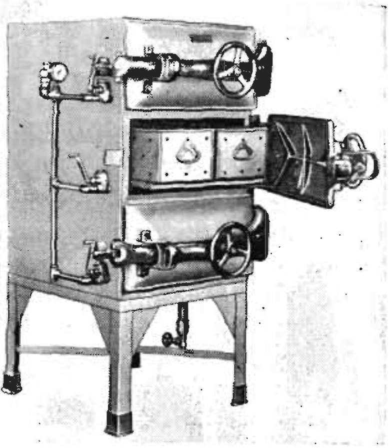

Fig. 13.6. A steamer of the type used in an institutional kitchen. (Courtesy Cleveland Range Co.)

In hospitals, cafeterias, hotels, and other places where steam under pressure is available, cooking devices similar to the two just discussed are used, but the temperatures are higher, because the pressure used is above normal. The *steam-jacketed kettle* is one of these devices. It is similar to the double boiler except that it is larger, and the top is fitted into the lower part with a steam-tight joining. Steam is introduced into the lower section, and the condensed steam is removed through a drain valve. The *steamer* is a device similar to a large oven. The food is placed in either open or closed pans on the shelves, and when the door is closed, the steam under pressure is turned into the food compartment. When the door is to be opened, the steam must be turned off. On some steamers the closing or the opening of the door automatically turns the steam on or off. Of course the steam which is already in the food compartment escapes; therefore the person opening the door should be careful to avoid being burned. These devices are generally used with steam at, or slightly above, normal pressure, depending on the kind of food which is to be cooked.

Pressure cookers are cooking devices which are generally used at pressures and temperatures considerably above normal. The food and a suitable amount of water are placed in the cooker and a tight-fitting lid is clamped on, so that the joining is steamtight. The lid is provided with several attachments — a pressure gauge, a pet cock, and a safety valve. The pressure gauge registers the pressure in pounds per square inch, and may have the corresponding temperatures on the dial. Of course these temperatures are based on 100°C or 212°F as the boiling point of water, and would not be quite accurate for other starting temperatures. A thermometer would be a more accurate and a more sensitive indicator than a pressure gauge, but is not so convenient, and is more easily broken. The pet cock is an outlet for air or steam — it is simply a cutoff valve which may be used to open or close an opening into the cooker. The safety valve is, as its name suggests, a device for preventing the pressure from going too high — the construction varies but the details are always given in the instruction book which accompanies the cooker. When the safety valve is forced open, the escaping steam makes enough noise to warn the person who is using the cooker.

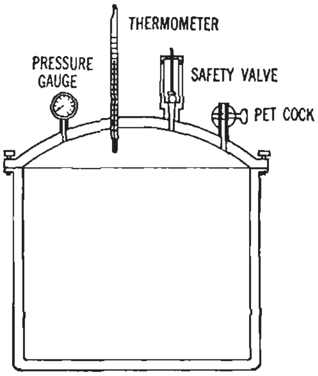

Fig. 13.7. Cross-section of a pressure cooker.

After the food and water have been put into the cooker and the lid properly adjusted, the cooker is put on the stove with the pet cock open. When steam forms, first the air is driven out, and then steam begins to escape. When steam has escaped for several minutes — long enough to be sure all of the air is out — the pet cock is closed and then the pressure and the temperature begin to increase. When the desired pressure has been reached, it may be held constant by regulating the source of heat. When the food has cooked for the required time, the cooker is removed from the fire and the pet cock opened to allow the pressure to go down to normal. Then the lid may be removed. The lid must never be removed while there is any pressure. Serious burns have resulted when, through ignorance or carelessness, the operator has loosened the lid while there is still steam under pressure in the cooker. All parts of the cooker should be cleaned and dried each time after the cooker is used. The safety valve should be taken apart to make sure it does not rust and stick and thus fail to be a safety device.

The above procedure is the general plan — variations are made according to the type of food being cooked. The pet cock is opened when the cooking period is ended if the food should be dry and flaky — for example, potatoes; but if the steam should condense on the food to make it moist, as in the case of a pot roast or chicken, the pet cock is left closed until the pressure has gone down to zero. Then there is less than normal pressure in the cooker because of the condensation of the steam, and the pet cock must be opened to allow air to enter before the lid can be removed. If glass containers of food are processed in the cooker, the pressure should be allowed to go down to zero before the pet cock is opened. Otherwise since food in the containers does not cool at a rate corresponding to the decrease in pressure, the liquid in the containers tends to vaporize. Since water increases in volume about 1750 times when it turns into steam at normal pressure, the pressure may even be great enough to burst the can. In any case all of the vapor cannot remain in the container, and therefore the containers are not full when taken from the cooker. If tin cans are used, they are sealed before they are put in the cooker, and since the tin will stand the sudden increase in pressure, the pet cock may be opened as soon as the cooking time has elapsed.

Pressure saucepans are used extensively in homes. They are simply small pressure cookers, but they are convenient to handle both because of their small size and because the attachments are easy to use. The lids are usually equipped with a rubber gasket, and all that is required to adjust the lid is to place it on the cooker in the proper position and rotate it slightly until it is locked in place. The steam vent is left open until the air is driven out, and then it is closed by putting a pressure regulator over the vent pipe. The pressure regulators are made in a variety of ways, but in general provide a means of regulating the pressure to 5, 10, or 15 pounds per square inch (gauge pressure). When the cooking time has elapsed and the pressure has been reduced to normal, the pressure regulator is removed, and it is then safe to take off the lid. An over-pressure plug is provided which will allow the steam to escape before the pressure becomes dangerously high in case the steam vent becomes clogged and does not let the pressure regulator operate as it should.

Fig. 13.8. A pressure saucepan. (Courtesy Aluminum Goods Manufacturing Company)

STUDY QUESTIONS

1. How does a crystalline material differ from an amorphous material?
2. When a material changes from a liquid to a solid, does it absorb heat or give out heat?
3. Distinguish between evaporation and boiling.
4. What is distillation?
5. What is sublimation? Frosting?
6. What is the most common freezing mixture?
7. Distinguish between heat of solution and heat of hydration.
8. What is the chief function of a vacuum pan?
9. How does a steamer differ from a steam-jacketed kettle?
10. Is the temperature in a steamer necessarily much higher than that in boiling water? Why?
11. In general, is the temperature in a pressure cooker higher than that in a steamer?

14

FUELS

As far back as the history of man goes, there is no record of a people that did not use fire. As civilization progressed more uses for it were discovered. Fires are used to warm the home, to cook food, and to furnish energy for operating various kinds of machinery.

In order to have a fire there must be something to burn, and the material which is consumed is the fuel. Since ancient times wood and oil have been used as sources of heat energy. Natural gas was used by the Chinese for light, but not for heat. Coal has been used as a fuel for hundreds of years. Stories are told of coal beds that have burned continuously for years with the flames eating deeper and deeper into the earth. Uncivilized people were awed by these spectacles, and many legends have resulted from real or supposed happenings in connection with these fires. Sometimes people thought the whole earth would finally be consumed.

A fuel is a material which, when burned, will furnish heat energy at a reasonable cost. All substances give off some heat energy when burned or oxidized but in many cases at such a high cost per British thermal unit that they could not economically be used as fuels. A material which once may have been classed as a fuel may now be too expensive because of scarcity or the discovery of other uses for the material. For example, in the early days of this country wood was the chief fuel, and it was not uncommon for people to burn huge walnut logs. Now the supply is limited, and walnut is considered far too valuable to burn. In rural districts corncobs are sometimes used for fuel, but fifty or sixty years ago, when corn was plentiful and very cheap, ears of corn were also burned.

Fuels may be solids such as coal or wood, liquids such as oil or kerosene, or gases — either natural or artificial. While electricity is a source of heat energy, it is not a fuel because it is not "a material," and it is not "burned."

79. The Origin of Fuels. The origin of wood is known to all. People see trees grow, and know they are cut down, sawed into short lengths, and burned in a stove or furnace, but the origin of the other fuels mentioned is not so obvious. It is believed that in early geological ages parts of the earth were covered with dense tropical forests. Season after season some of the timber growth died and fell to the ground. After a thick layer had accumulated, changes in the earth's crust occurred which caused large areas of the earth's surface to sink, and become covered with water. The decay of the vegetable matter continued, and because of various pressure and temperature conditions coal was formed. Sometimes there are several layers of coal at different depths, showing that the process was repeated. In some places the layers lie at an angle, showing that, after the layers were formed, some internal change in the earth caused changes in the outer layers. The hardness of the coal depends on the pressure to which the material was subjected. Soft coal is known as *bituminous* coal, and hard coal is called *anthracite*. Anthracite is usually found in mountainous regions where much tilting and crumpling of strata have occurred.

Oils and gases are found sometimes with coal and sometimes quite separate from coal beds. It seems probable that they were formed from plant and animal life in about the same way that coal was formed.

✓ **80. Chemical Composition of Fuels.** Fuels are all alike in that they contain hydrocarbons, that is, compounds of hydrogen and carbon, and there may also be free hydrogen and carbon. These are the combustible materials. A good fuel has a high percentage of combustible materials and a low percentage of noncombustible materials, such as inorganic salts (ash), water, nitrogen, and carbon dioxide.

✓ **81. Choice of a Fuel.** The cost of a fuel depends upon the kind of fuel, the cost of obtaining it, i.e., cutting the trees, mining the coal, or drilling the gas well, the amount available, and the distance from the producer to the consumer.

The consumer must also consider the efficiency of his burner, i.e., what percentage of the energy in the fuel can be made available. The amount of energy in the fuel may be determined from a calorimeter test. In a calorimeter, however, the fuel is burned under ideal conditions and consequently gives higher values than will be obtained in the home. The test may prove, though, that a certain fuel at \$10 per ton is cheaper than another at \$6 per ton because of the greater amount of combustible material in the former.

Fuels differ so decidedly in the ease of handling, the degree of cleanliness possible, and the labor involved in removing ashes and clinkers, that the consumer must realize that the first cost is not the only cost. There is a wide difference between (1) shoveling coal into the furnace, cleaning up the coal dust, and carrying out the ashes, and (2) setting a thermostat which automatically controls the flow of gas or oil. The relative convenience of storing the fuel in the basement or of having it delivered through a small pipe as it is needed is another consideration. Someone has said that, as the fuel room goes out of the basement, the game room comes in.

In the United States coal is very widely used as a source of heat and power. The cost per ton is often very low for cheaper grades, but coal burners are not very efficient, and of the possible number of heat units, a low percentage is delivered as useful heat. If the coal is not completely oxidized, the unconsumed gases are lost through the chimney. Unless automatic stokers are used, it is difficult to supply fuel to the furnace at an ideal rate.

Kerosene and gasoline are used considerably for summer fuels in regions where gas is not available. Since in the use of these fuels the heat is localized, less heat is given off into the kitchen than if wood or coal is used. When the flame is turned out the stove cools quickly.

Either natural or artificial gas may be obtained almost anywhere in the United States. In some localities gas is delivered in large tanks rather than through a pipe line. Other fuels commonly used are peat, charcoal, and coke. Peat is formed from the roots and stems of plants, and it is chemically very much like wood. Charcoal is partly burned wood, and coke is a by-product from coal which has been used in producing artificial gas.

82. Fuel Value of Solid and Liquid Fuels. There are a number of calorimeters in use for finding the fuel value of solid and liquid fuels. They are alike fundamentally in that a known mass of fuel is burned and that the heat liberated is absorbed by materials for which the mass, specific heat, and temperature change are either known or can be measured; thus the heat furnished by the fuel can be calculated.

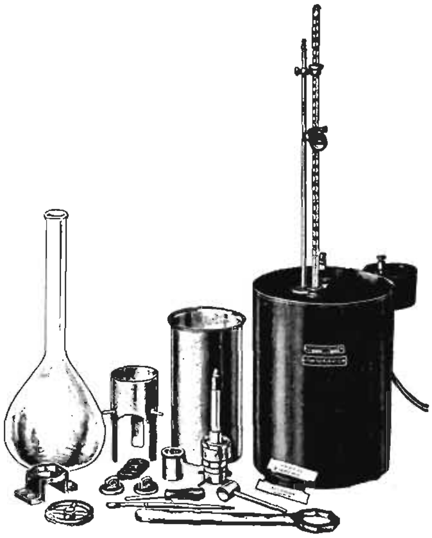

Fig. 14.1. Parr or bomb calorimeter assembly. (Courtesy Parr Instrument Co., Inc.)

The Parr or bomb calorimeter is an example of the type of calorimeter used for solid fuels. The fuel to be tested must be dry and finely powdered. A carefully weighed sample (1/2 gram) is placed in the inner cup of the bomb, which is known as the *fusion cup*. Suitable oxidizing agents are added — for coal, 1 gram of potassium perchlorate ($KClO_4$) and 10 cubic centimeters of sodium peroxide (Na_2O_2) are used. These materials must be thoroughly mixed. A fuse wire is attached to the lid of the bomb, and the bomb is assembled — it must be watertight, since water and Na_2O_2 unite explosively. The bomb is placed on a stand in the water container of the calorimeter, and a thermometer is inserted in the water. The water container is surrounded by two walls of insulating material and two layers of air. The bomb has stirring vanes attached to it, and it is rotated in order to stir the water so that all of the water will heat uniformly. When the thermometer shows a constant reading the temperature is recorded, and then a current is sent through the fuse wire which heats it red hot, melts it, and ignites the fuel. As the fuel burns, the heat given out warms the metal parts of the calorimeter and the water. When the thermometer shows no further increase in temperature the reading is noted and the apparatus dismantled.

The fusion cup then contains a hard, salty residue composed of the ash of the fuel and the unused chemicals. This residue is soluble in water.

There are various corrections to be made to account for the heat furnished by burning the fuse wire and the chemicals other than the coal. In all, these amount to about 27 per cent of the total heat furnished — therefore about 73 per cent of the heat is furnished by the fuel itself. Calculations are made as follows — if 1/2 gram of coal warms 2000 grams of water and 1400 grams of metal ($s = 0.1$) from 21° to 23.4°C the amount of heat given out by the coal is

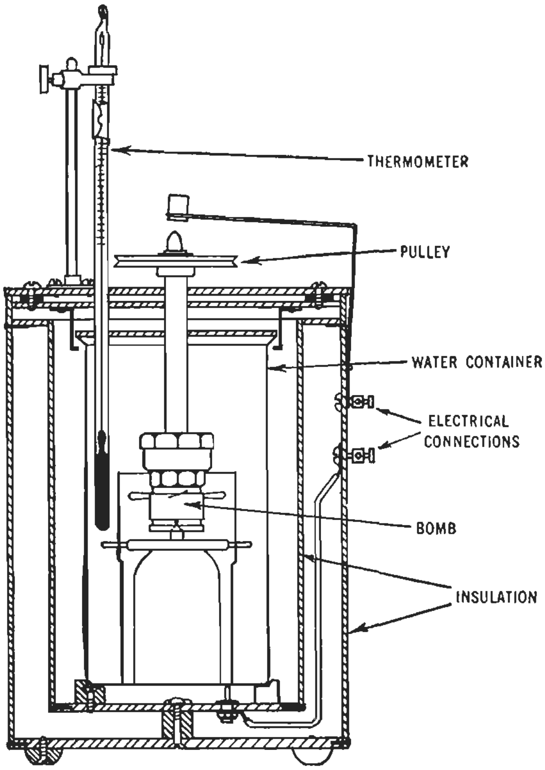

Fig. 14.2. Cross-section of a bomb calorimeter.

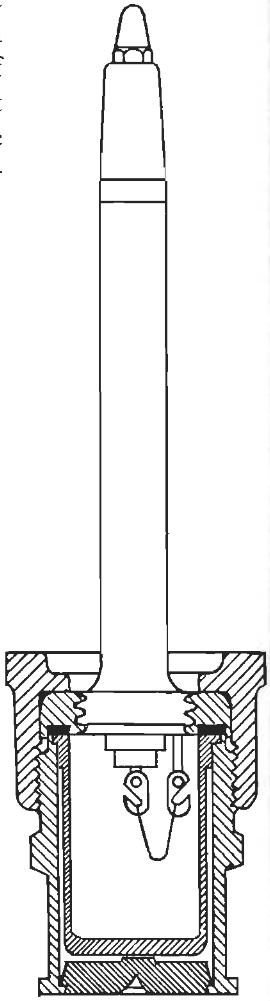

Fig. 14.3. Detail of the bomb.

$$
\begin{aligned}
H &= 0.73[mst + mst] \\
&= 0.73[(2000 \times 1 \times 2.4) + (1400 \times 0.1 \times 2.4)] \\
&= 0.73[4800 + 336] \\
&= 3750 \text{ calories per } 1/2 \text{ g} \\
&= 7500 \text{ calories per } 1 \text{ g} \\
&= \frac{7500 \text{ cal/gm} \times 454 \text{ gm/lb}}{252 \text{ cal/Btu}} = 13{,}512 \text{ Btu/lb}
\end{aligned}
$$

TABLE OF AVERAGE FUEL VALUES FOR SOLID AND LIQUID FUELS

Wood (air-dried)	7,500 Btu per lb
Coal	14,000
Fuel oil	18,500
Kerosene	20,000
Gasoline	21,000

83. Fuel Value of Gaseous Fuels. Because of the physical properties of a gas an entirely different kind of calorimeter is used in testing it. Instead of first separating a given volume of gas for a test sample, gas is used from the supply, but it passes through a meter as it goes to the burner so that the amount used in the test is known. The heat furnished by the gas is used to heat water which flows through the calorimeter and is weighed. From the mass and temperature change of the water the amount of heat obtained from the gas may be determined.

The Sargent calorimeter (see Fig. 14.4) is representative of the type of calorimeter used for testing the fuel value of gases. Figure 14.5 shows a cross section of the calorimeter. Water is run into a small elevated tank A, preferably from a supply at constant temperature, and at a rate which will keep water running through the overflow pipe. This method ensures that the water entering the calorimeter is from a source at constant pressure and therefore that it will flow through the calorimeter at a constant rate. The temperature of the inlet water is taken at T_i; the water, which enters the body of the calorimeter at B, is heated by the gas flame C as it flows through; the outlet temperature is noted at T_o as the water leaves the calorimeter. The water is collected at D.

When the calorimeter is first started some of the heat from the gas is used to heat the metal parts of the calorimeter; therefore no data are taken until the thermometer at the outlet indicates a

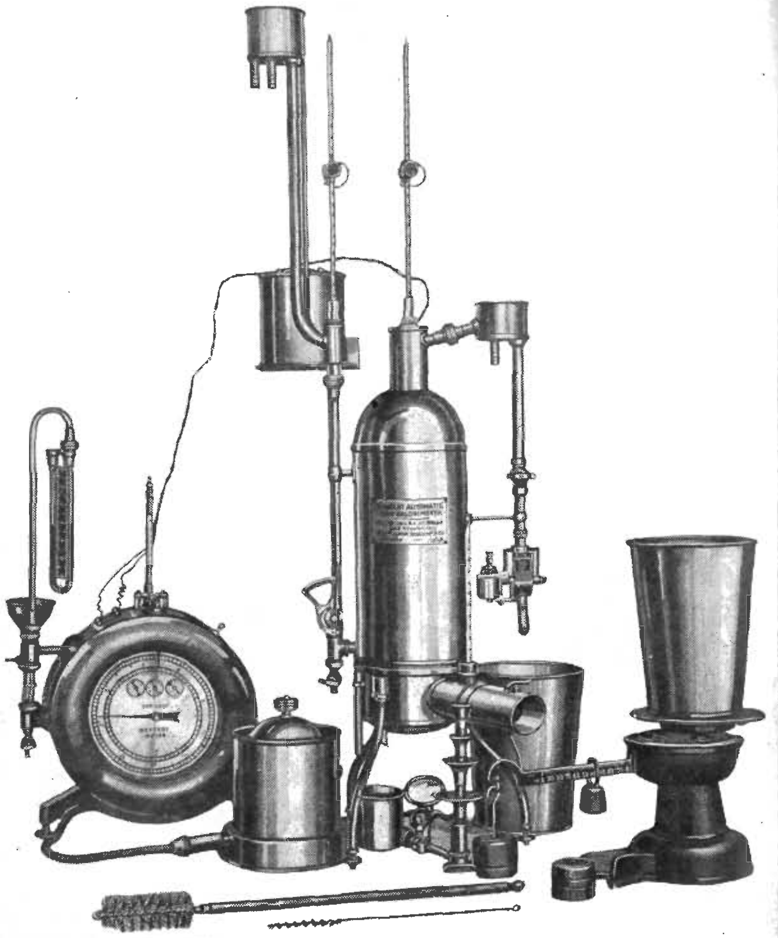

Fig. 14.4. A Sargent gas calorimeter and wet test meter. (Courtesy E. H. Sargent and Co.)

constant outlet temperature. Then while a given volume of gas is burned the water is collected at *D*, and weighed.

For example, if 0.1 cubic foot of gas heats 4 pounds of water from 70°F to 95°F the amount of heat given out by the gas is

$$\begin{aligned} H &= mst \\ &= 4 \times 1 \times (95 - 70) \\ &= 100 \text{ Btu per } 0.1 \text{ cu ft} \\ &= 1000 \text{ Btu per cu ft} \end{aligned}$$

There are various corrections for air temperature, for barometric pressure, and for the temperature of the gas which must be made in a commercial test, but which need not be made in order to understand the general principle of the calorimeter.

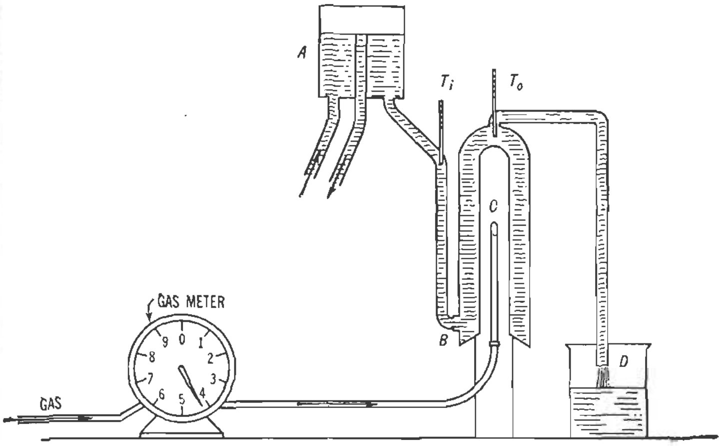

Fig. 14.5. Cross-section of a gas calorimeter.

TABLE OF FUEL VALUES FOR GASES

Natural gas	1000 Btu per cu ft
Artificial gas	500
Butane	3000

84. Commercial Use of Calorimeters. Both of the calorimeters described above are used for commercial tests as well as for laboratory tests. Concerns buying large quantities of a fuel nearly always ask for a calorimeter test. Gas companies usually have contracts with the cities they serve which require that the gas furnish not less than a given number of British thermal units per cubic foot — tests are made at required intervals and the pressure adjusted to assure the required fuel value.

85. Electricity as a Source of Heat. Electricity as a source of heat will be discussed more fully in Chap. 27. Electricity is the cleanest and most convenient source of heat, but in most localities it is too expensive for house heating or even for heating the household water supply. But for heating one or two rooms when the weather is chilly, or for cooking, the cost is reasonable. Electrical energy is furnished at a given rate per kilowatt-hour (kw-hr). An average cost is about $0.05 per kilowatt-hour, but rates in the United States vary from less than $0.01 to as much as $0.18. One kilowatt-hour of electrical energy is equivalent to 3412 British thermal units of heat energy.

86. Mechanical Equivalent of Heat. It has already been explained (Sec. 53) that experiments performed in the latter part of the eighteenth century proved that there is a definite relationship between the amount of work done and the amount of heat energy resulting from that work. *The number of units of mechanical work which are equivalent to one unit of heat is called the mechanical equivalent of heat,* and is usually designated by *J* in honor of Joule who was one of the first to make a determination of its value. Two numerical values for *J* are

778 ft-lb per Btu

and 42,700 g-cm per cal

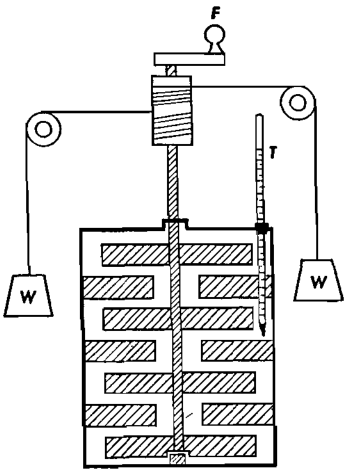

Fig. 14.6. Apparatus for finding the mechanical equivalent of heat. The water in the calorimeter is stirred rapidly by the rotating vanes.

These numbers were obtained by measuring the work done in warming water by stirring it rapidly in a well-insulated calorimeter and then calculating the number of work units equivalent to one heat unit. For example: if a force of 12 pounds is exerted on the handle of the stirring apparatus and the handle moves 389 feet in order to warm 3 pounds of water 2 Fahrenheit degrees, how much work is required for 1 British thermal unit?

$$J = \frac{W}{H} = \frac{12 \text{ lb} \times 389 \text{ ft}}{3 \text{ lb} \times 1 \text{ Btu/lb-°F} \times 2\text{°F}} = 778 \text{ ft-lb/Btu}$$

Also if the value of *J* is known the amount of work equivalent to the heat required to melt 10 pounds of ice may be calculated.

$$J = \frac{W}{H}$$

$$778 \text{ ft-lb/Btu} = \frac{W}{10 \text{ lb} \times 144 \text{ Btu/lb}}$$

$$W = 1{,}120{,}320 \text{ ft-lb}$$

Other everyday examples of work energy being converted into heat energy are the following: the heat that results when the hands are rubbed together, when wood is rubbed with sandpaper, and when a machine is operated without oil.

✓**87. Foods as Fuels.** *A food is a material which when oxidized in the human body builds or maintains body tissue, regulates body processes, or furnishes energy.* The fuel value of a food may be measured in a bomb calorimeter but an oxycalorimeter is more frequently used. The apparatus shown in Figure 14.7 consists of a combustion chamber *A* in which a weighed sample of the food is burned, a soda-lime absorber for carbon dioxide *B*, a device for measuring the oxygen used *C*, and a blower unit for circulating the gas mixture *D*. Tables are used for converting liters of oxygen consumed in the burning process to calories of heat furnished by the food.

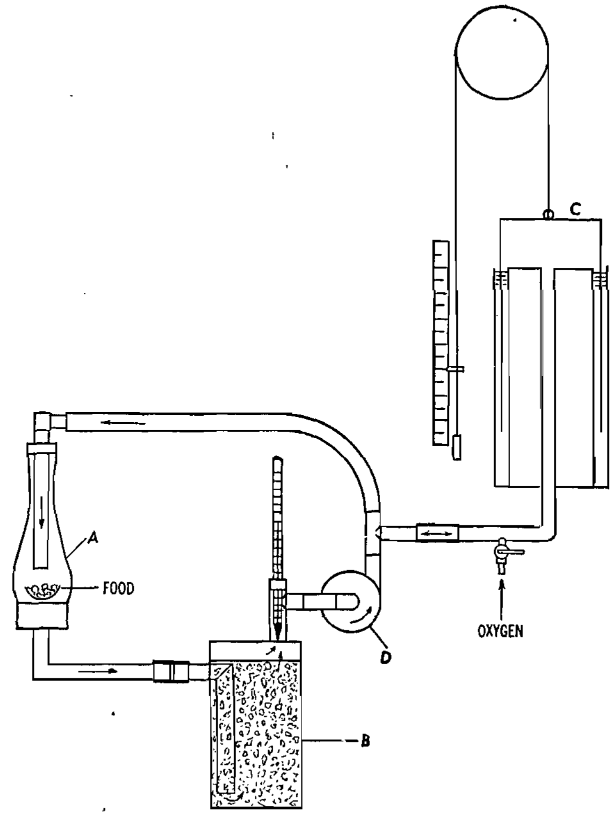

Fig. 14.7. An oxycalorimeter.

When completely oxidized in a calorimeter the following average fuel values are obtained:

Carbohydrates	4.1 kilocalories per gram *
Protein	5.65
Fats	9.45

* 1 kilocalorie = 1 Calorie as used in foods and nutrition.

The energy used in the body is obtained from the oxidation of the same kinds of compounds that are found in foods, but the oxidation is less complete. In the body, carbohydrates and fats are oxidized to the same products as in the calorimeter, but protein is less completely oxidized and about 1.3 kilocalories per gram of combustible protein material is excreted. Hence when the body burns material which it has previously absorbed it obtains:

Carbohydrates	4.1 kilocalories per gram
Proteins	4.35
Fats	9.45

However, allowance must be made also for the fact that the body does not usually absorb 100 per cent of the digestible material in the food. When the fuel values are corrected for this loss the physiological fuel values obtained are then

Carbohydrates	4 kilocalories per gram
Proteins	4
Fats	9

The following table gives some average physiological fuel values.

FOOD	KCAL PER GRAM	BTU PER POUND
Apples	0.6	1,080
Bananas	1.0	1,800
Beef	3.0	5,400
Bread	2.6	4,680
Butter	7.3	13,140
Carrots	0.4	720
Chicken	1.1	1,980
Cheese	4.0	7,200
Crackers	4.2	7,560
Cream, 20%	2.1	3,780
Eggs	1.6	2,880
Fudge	4.0	7,200
Flour	4.0	7,200
Ice cream	2.1	3,780
Milk	0.7	1,260
Olives	1.4	2,520
Oranges	0.5	900
Peanuts	6.0	10,800
Potatoes	0.9	1,620
Sugar	4.0	7,200
Walnuts	6.9	12,420

If the food intake of the body is greater than the amount needed for "repair, growth, body processes, and energy" the weight of the body increases. If a person wishes to reduce by exercising, enough work must be done to burn up the stored energy. When the body loses 1 pound of fat possibly 85 per cent of the energy is converted into heat and the remaining 15 per cent is used for lifting the body if climbing a hill or for lifting weights or working on a machine. Considered as a machine the human body is not very efficient. For short periods of time or for work which the person does efficiently (with a minimum of wasted motion) the efficiency might be increased to perhaps 25 per cent, but 15 per cent is a fair average. Since 1 pound of fat will furnish about 16,000 British thermal units the amount of energy available for doing work is

$$16{,}000 \times 0.15 = 2400 \text{ Btu}$$

or this is equivalent to

$$2400 \times 778 = 1{,}867{,}200 \text{ ft-lb}$$

This is enough work to lift a 100-pound girl 18,672 feet (over 3 miles) or enough work to lift a 3000-pound car over 600 feet. It is equivalent to the work done by a 100-pound girl in climbing a flight of stairs in her home about 2200 times. The girl may avoid any necessity for doing this work if she regulates her food intake to meet her energy expenditure and consequently avoids gaining the extra weight.

88. Energy Requirements of the Human Body. The food intake of the human body necessary to maintain a constant weight depends upon a large number of factors. It varies with size, shape, body composition, age, growth, kind and amount of work, climate, sex, and upon the individual characteristics of the person. Various experiments have been carried on to determine the average energy requirements for various types of people.

The total energy expenditure of the body in the form of heat and mechanical work may be determined by confining the person in a small room known as a *respiration calorimeter*, which is well insulated and arranged so that the heat generated by the body can be absorbed by a known amount of water passing through it. The amount of heat given off is calculated from the mass and rise in temperature of the water. The person may live in this calorimeter for several days. Records are kept of everything which enters or leaves the calorimeter during the test period. The person may be instructed to lie in bed all of the time, or to sleep a normal amount and to do various types of work for stated lengths of time. After all corrections for gains or losses of heat due to materials which were put into or taken from the calorimeter during the experiment have been made, the amount of heat energy given out by the person may be determined. By comparing data for a period of rest with a period of walking or of other work the extra energy required for the particular type of work may be determined.

Later it was found by experiment that practically the same results could be obtained by measuring the amount of oxygen consumed during one of these test periods. One type of apparatus used consists of an airtight mask which is fitted over the mouth and nose and connected by tubes with a device for measuring the volume of oxygen which is consumed in the body. From the volume of oxygen used the number of calories of energy expended may be calculated. This method makes it possible to do experiments quickly and is especially useful for measuring the energy used in short periods of time — for example, in eating a meal, in walking up a flight of stairs, or in cleaning a room. This apparatus is used in measuring the "basal metabolism," i.e., the rate at which the energy is used when the body is at complete rest both mentally and physically, 12 to 18 hours after the last intake of food in a room at comfortable temperature and with the body temperature within its normal range. This gives a measure of the energy required to carry on the involuntary body processes.

STUDY QUESTIONS

1. What does dense black smoke coming from a chimney indicate?
2. Why does increasing the draft help a slow fire to burn faster?
3. Why does a fire sometimes burn better if the fuel in the firebox is stirred?
4. If a gas flame smokes the cooking utensils, what is the cause?
5. Why does the air valve on a gas stove sometimes need adjustment?
6. What are the combustible materials in a fuel?
7. Why is wet wood less efficient as a fuel than dry wood?
8. Why is electricity not classified as a fuel?

9. What fuels are used in your community? What factors entered into determining the choice of fuels?
10. Does a 10-horsepower engine require more fuel than a 2-horsepower engine? Why?
11. Does a man doing heavy physical work require more food than a man doing office work?
12. Will a girl require more food on a day when she climbs a mountain than on a day when she is reading most of the time?
13. If the amount of heat energy per unit mass of a food is known, can the amount of that food required for doing a certain amount of mechanical work be calculated?
14. Can you suggest some of the factors that have entered into calculating diets for laborers, office workers, housewives, school children, and overweight and underweight individuals?

PROBLEMS

1. Calculate the approximate cost per British thermal unit for each of the following fuels:
   Coal at $16.00 per ton, 14,000 British thermal units per pound.
   Gas at $0.50 per thousand cubic feet, 1000 British thermal units per cubic foot.
   Ans. $0.000,000,6 per Btu; $0.000,000,5 per Btu
2. Calculate the cost per British thermal unit for each of the following fuels:
   Gasoline at $0.25 per gallon, 21,000 British thermal units per pound (5.5 pounds = 1 gallon).
   Sugar at $0.09 per pound, 7200 British thermal units per pound.
3. How many kilocalories are furnished by a 100-gram serving of ice cream? *Ans.* 210 kcal
4. How much heat results when a 50-pound log of wood is burned?
5. How many foot-pounds of work can be done with the heat energy required to melt 2 pounds of ice? *Ans.* 224,064 ft-lb
6. If a 4270-gram mass is lifted 600 centimeters, how much work is required? If this work is converted into heat energy, how much will it warm 10 grams of water?
7. If a person eats 30 grams of sugar, how many kilocalories of heat may be furnished to the body? *Ans.* 120 kcal
8. If one pat of butter furnishes 100 kilocalories, how much is 1 liter of water warmed if all the heat energy of the butter is transferred to the water?
9. If a girl eats 1/2 pound of fudge, how many foot-pounds of work should she be able to do, assuming that 15 per cent of the energy of the fudge is utilized for mechanical work? (See table for fuel value of fudge.) *Ans.* 420,120 ft-lb

10. If you are to carry a 20-pound vacuum cleaner upstairs (8 feet), how much work will be done on the cleaner? How much bread will be required to provide this amount of energy if 20 per cent of the energy of the bread is available for mechanical work? (See table for fuel value of bread.)

11. If a 125-pound girl drinks a coke (75 kcal) each afternoon, how many times will she have to climb an 8-foot flight of stairs each day in order to do an amount of work equivalent to the energy in the coke? *Ans.* 232 times

12. A 125-pound girl eats an apple which furnishes 250 Btu. How high can she climb a mountain in using this energy?

15

HEAT TRANSFER

Whenever heat energy is at a higher temperature level at one place than at another, it tends to go from the region of higher temperature to the region of lower temperature. Most of our modern heating systems are arranged so that the fuel is burned in the furnace room and the heat is transferred to the living quarters of the house by various mediums. The heat in a pressure cooker is transferred to the surrounding air through the metal wall. The heat in one's hand is quickly carried away if the hand is placed on a cold metal pipe. The sun, which is estimated to be at a temperature of 5000°C, is constantly emitting energy, a small portion of which is transferred to the earth.

This tendency of heat to flow from one place to another is sometimes an advantage and sometimes a disadvantage. In the case of transferring heat from the furnace to the living room, it is an advantage, but when the same heat energy tends to escape through the walls of the house, we try to stop it by making the walls of materials which will prevent its escape as much as possible. We are glad that heat passes readily through the wall of a steam radiator but regret that it passes even slowly through the wall of the refrigerator.

Heat energy may be transferred from a region of higher temperature to one of lower temperature by three methods — *convection, conduction, and radiation.*

89. Convection. *Convection is the transfer of heat which occurs when movement of a material from one place to another is caused by differences in density.* If heat is applied to the lower part of a fluid, that part of the fluid expands and its density is decreased. The colder, heavier part of the fluid falls and forces the warmer, lighter fluid to rise. During this fall and rise, the intermingling of hot and cold molecules tends to equalize the distribution of heat energy, and the fluid as a whole is warmed. The heat from a hot-air furnace is transferred to the living quarters of a house by means of convection currents of air. The heated air is pushed up through one pipe as the colder air returns to the furnace jacket through another pipe.

Convection currents occur in fluids (liquids and gases) but not in solids, because the molecules in fluids are quite free to move about, but those in solids are held within their own intermolecular spaces. Actual computations of amounts of heat transferred by convection are rather complicated and will not be taken up in this text. Some of the factors which influence the amount of heat transferred by this method are difference in temperature between the source of heat and the place to which it is being transferred, specific heat of the medium, viscosity of the medium, coefficient of expansion of the medium, and size, smoothness, and straightness of the channel through which the material passes. Heat transfer by convection has many applications in the home — in refrigeration, ventilation, and heating. These subjects will be discussed more fully in later chapters.

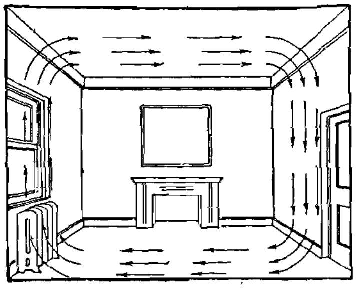
Fig. 15.1. Convection currents in the air in a room heated by a radiator.

90. Conduction. *Conduction is the transfer of heat from particle to particle in a material, with no perceptible motion of the heated material.* When a material is heated the kinetic energy of the molecules is increased. When a molecule with high kinetic energy comes in contact with a molecule with less energy, some of the energy of the first is transferred to the second, and thus the temperature of the second molecule is increased. It in turn will transfer energy to another molecule and thus the heat energy is conducted through the material, but none of the material has been transferred from one place to another.

Materials vary decidedly in their ability to conduct heat. Some solids, especially metals, are good conductors, while other solids, like glass and wood, are poor conductors. Some very poor conductors, called *insulators*, such as asbestos, sawdust, cork, and commercial insulation materials contain many small air pockets. These "dead" air spaces account for a large part of the insulating ability of the material. In general, liquids and gases are poor conductors of heat.

The coefficient of thermal conductivity of a material is (in metric units) the number of calories of heat transferred through a centimeter cube of the material in 1 second if the temperature difference between the two opposite surfaces is 1 Centigrade degree. The coefficient may be calculated for use with English units, and it is sometimes so used in refrigeration calculations and by heating engineers. Usually the amount of heat is calculated in metric units and then converted into British thermal units by dividing the number of calories by 252 — the number of calories in 1 British thermal unit.

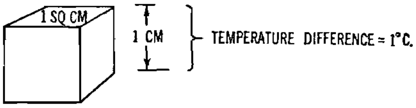

Fig. 15.2. Coëfficient of conductivity.

The amount of heat transferred by conduction may be calculated by

$$H = \frac{KAT(t_2 - t_1)}{L}$$

where H = heat in calories
K = coefficient of conductivity
A = area in cm^2
T = time in sec
$t_2 - t_1$ = temperature difference between the two surfaces of the conductor in C degrees
L = length of path through the conductor in cm

Conduction has many applications in the home in refrigeration, in heating systems, transfer of heat through cooking utensils, and various types of insulation such as in oven walls and in the walls of houses. These will be discussed more fully in some of the following chapters.

COEFFICIENTS OF CONDUCTIVITY

(In cal per cm cube per degree C per sec)

GOOD CONDUCTORS	
Silver	0.99
Copper	0.91
Aluminum	0.49
Tin	0.14
Iron	0.16
Nickel	0.14
Mercury	0.19
POOR CONDUCTORS	
Ice	0.005
Earth s crust (avg.)	0.004
Glass	0.0024
Porcelain	0.0022
Concrete	0.0022
Mica	0.0018
Plaster	0.0015
Brick	0.0015
Water	0.0014
INSULATORS	
Asbestos paper	0.0005
Snow	0.0005
Rubber	0.00045
Alcohol	0.00043
Wood (avg.)	0.0004
Soil	0.0004
Linoleum	0.00036
Paper	0.0003
Linen	0.00021
Cork board	0.00013
Sawdust	0.00012
Wool flannel	0.00012
Silk	0.00009
Felt	0.00008
Air	0.00005
Cotton batting	0.00004

91. Radiation. It will be noted that a material medium is required for heat transfer by either convection or conduction. However, energy can be transferred through a material or through a vacuum by means of radiation, but part of the energy is always absorbed if it passes through a material medium. For example, the earth receives energy — both heat and light — from the sun through 93,000,000 miles of space which is empty except for the layer of atmosphere around the earth. The thickness of this atmospheric layer is extremely small compared with the distance from the sun to the earth. Radiant energy from the sun does not affect the empty space through which it is transferred and it is not evident as heat energy until it enters the earth's atmosphere. Here it is absorbed — to a slight extent by the atmosphere but chiefly by the earth itself — and converted into heat energy.

An evacuated light bulb gives out heat and light, but the energy cannot be transferred to the glass bulb and the surrounding air by convection because the bulb has been evacuated and it cannot be transferred by conduction because the filament does not touch the glass. In some way however the energy is transferred through the evacuated space.

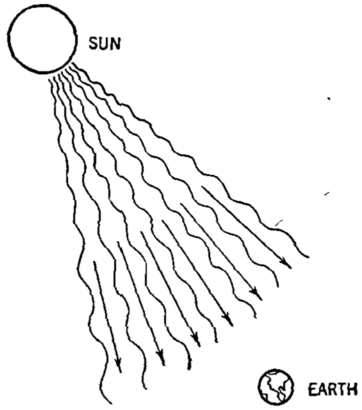

Fig. 15.3. The sun radiates energy to the earth.

Radiant energy can also pass through some materials, but a part of it is always absorbed. In the case of the energy from the sun, some is absorbed as it passes through the earth's atmosphere — the amount absorbed depends on the amount of moisture, smoke, and dirt in the air, and on the distance the energy has to travel through the air. This distance varies with the time of year and the time of day.

Since early times people have pondered about how this radiant energy is transferred. At first it was thought the heat and the light received from the sun were two entirely different things, but now we know they are transferred in exactly the same way. Some of the first theories about this transfer of energy attempted to explain the phenomenon of light, but they apply equally well to the transfer of heat.

One of the first theories was that the radiation consisted of little bundles or corpuscles of energy sent out by the radiating body, but later discoveries, especially in the field of light, could not be explained by this corpuscular theory.

There are at the present time two theories concerning the nature of radiation — the *wave theory* and the *quantum theory*. The *wave theory* was first definitely formulated in 1678 by Huygens, a Dutch physicist, as a result of his study of light. He believed that when a body radiated energy, the energy was given out as waves. His theory explained many of the phenomena of light which had been observed at that time. Later, experiments on the polarization of light indicated that the waves are transverse waves as shown in Figure 15.4.

Fig. 15.4. Radiant energy wave.

According to this theory bodies radiate energy of various wave lengths, but these waves all travel at the same velocity (in empty space or in air); therefore the greater the wave length the less the frequency (number of vibrations per second). The relationship is

$$V = \lambda\nu$$

where
V = velocity
λ = wave length
ν = frequency

But during the latter part of the nineteenth century still other discoveries were made which seemed to indicate that energy after all was radiated in definite bundles. In 1900 Planck, a German physicist, formulated the *quantum theory.* According to this theory energy is not given out in a continuous wave but in definite amounts or quanta; however, each quantum is associated with a given frequency, and the amount of energy it possesses is proportional to this frequency. The energy of a quantum may be found by

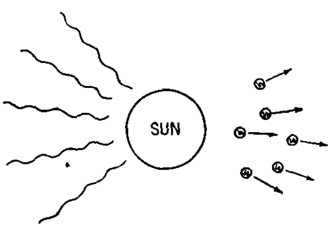

Fig. 15.5. Is energy given out in particles or in waves?

$$E = h\nu$$

where
E = energy
h = Planck's constant
ν = frequency of vibration

This relationship shows that a high-frequency quantum carries a larger amount of energy than a low-frequency quantum. High-frequency quanta correspond to the high-frequency waves of the wave theory.

Some radiation phenomena are best explained by the wave theory and some by the quantum theory — perhaps the real truth lies in a combination of the two theories. At least it is a help to have a theory which aids in forming a mental picture of how energy is transferred by radiation. This comparison has been made — radiant energy according to the wave theory is comparable to a rippling stream of water, but according to the quantum theory it is comparable to rain — the drops corresponding to the quanta, and just as the drops vary in size so do the quanta vary in energy.

While the explanation as to how energy is transferred by radiation is still a theory, there are many facts concerning radiation phenomena which have been definitely established by experiment. The intensity of the radiation depends upon the character of the radiating surface — a light-colored, polished surface radiates slowly, but a dark, dull surface is a good radiator. A good radiator is also a good absorber of radiant energy. The intensity of radiation also depends on the absolute temperature of a body, and in the case of a perfect radiator (a dull, black body)

$$I = CT^4$$

where I = intensity of radiation
C = a constant depending on the units for I and T
T = absolute temperature

Thus if the absolute temperature of a body is doubled, the radiation will increase sixteenfold ($2^4 = 16$).

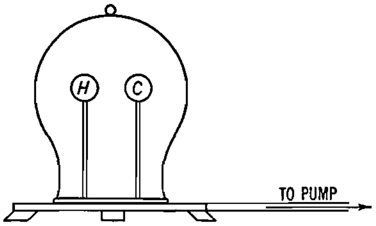

Fig. 15.6. When hot and cold bodies are placed in a vacuum they soon reach the same intermediate temperature.

Since the intensity of radiation depends upon the absolute temperature, it follows that all bodies at temperatures above absolute zero are radiating energy. Thus a cake of ice may be said to radiate heat to a red-hot stove, but the stove radiates heat to the ice at a faster rate. The result is that the stove loses heat and the ice gains heat; therefore the effective rate at which a body radiates heat depends upon the difference in temperature between the radiating body and its surroundings.

The energy radiated by a hot body is made up of various frequencies, their distribution depending upon the temperature of the radiating body. As the temperature increases, the frequencies increase, and if the temperature becomes high enough, the radiation may be in the visible region. When a body is heated, at first it does not glow at all; then it begins to glow with a dull red color; finally the color gradually becomes brighter and shifts through various tones of red and orange to white. ✓

It is possible to separate the radiation of a body into its component frequencies and measure the energy of each. When this is done, the energy is said to form a radiation spectrum. The curves of Figure 15.7 show the energy distributions for various temperatures. The x-axis gives the wave lengths from zero to infinity, and the y-axis indicates the amount of energy. It will be observed that (1) the radiant energy increases as the temperature increases, (2) the energy increases relatively much faster in the short wave lengths as the temperature increases, and (3) for each temperature there is a maximum, characteristic of that temperature. It has been found that, if the wave length of this maximum is multiplied by the absolute temperature, the result is a constant.

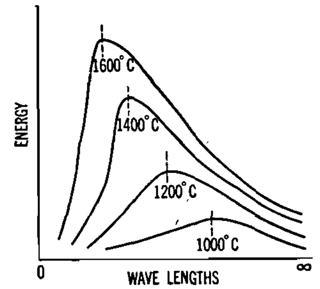

Fig. 15.7. Radiant energy distribution curves.

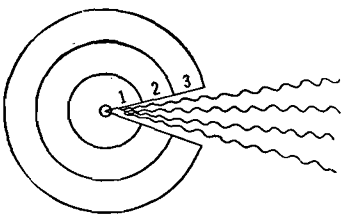

Fig. 15.8. The intensity of the radiation varies inversely as the square of the distance from the source.

$$\lambda_{\max} T = \text{a constant}$$

The fact that the energy in the short wave lengths increases as the temperature increases is of importance in illumination because these short wave lengths are the ones to which the eye is sensitive — that is, they are light waves. A red-hot body (1000°C) does not give out much light, but a white-hot body (2800°C — the temperature of the filament in a gas-filled tungsten lamp) radiates a great deal of light.

The amount of energy intercepted by any given body depends upon the distance between the radiator and the absorber. It has been found by experiment that for a point source the intensity of radiation varies inversely as the square of the distance between the radiator and the absorber. This situation exists because energy is given out in all directions from the radiator. Since the area over which it is distributed is that of the surface of a sphere ($4\pi r^2$), the area is increasing as the square of the radius; therefore the amount of energy per unit area is decreasing as the square of the radius. The amount which is intercepted by the absorber, which may be thought of as part of the bounding sphere, is inversely proportional to the square of the distance between it and the radiator. A surface which is 2 feet away from a point source of radiation will receive only one-fourth as much energy as a surface which is 1 foot away from the source.

We have spoken before of the radiant energy being absorbed when it meets a material medium, but it is not necessarily all absorbed. It may be reflected, absorbed, or transmitted, the same as light; the relative amounts will depend upon the physical properties of the material which the radiant energy meets. If a piece of white cloth and a piece of black cloth are spread on snow on a sunshiny day when the temperature of the air is below freezing, it will be found that the snow melts more rapidly under the black cloth. It will also be noted that if snow is spattered with mud, it melts faster under the dirty spots.

Materials differ widely in their ability to transmit radiant energy. Some transmit a large percentage, some a small percentage, and some are selective, allowing only certain wave lengths to pass through. Light and heat pass readily through clean dry air, but water vapor and smoke in the air cause considerable absorption. Glass is selective in that it transmits the visible waves readily, but cuts out the longer heat waves and the shorter ultraviolet waves.

If E is the total energy falling on a surface,

$$E = r + a + t$$

where
r = reflected energy
a = absorbed energy
t = transmitted energy

92. Household Applications of Heat Transfer. Most cases of heat transfer are the result of a combination of two or even all three of the above methods. When a fuel is burned, the heat may be radiated to a utensil on the stove, it may be carried to the utensil by convection currents, or it may be conducted through the top of the stove. Regardless of the method by which the heat reaches the outer surface of the dish, it is conducted through the dish. Then it may be distributed through the food by convection if it is a fluid, or by conduction if it is a solid. Heat is lost from the sides and top of the dish by conduction through the walls and then carried away by convection and radiation — there is a large loss by convection if the dish is not covered. It is not easy to determine the loss due to each method.

Some cooking utensils have wooden handles, and because the wood is a poor conductor, they do not carry heat to the hand as rapidly as metal does. Some utensils have twisted wire handles which have a good deal of exposed surface, therefore they lose heat rapidly, and so do not get too hot to touch.

In an oven, the heat is distributed by convection currents. Losses through the sides and top are reduced by putting layers of asbestos or mineral wool in the walls for insulation, and by making the outside surface smooth and light-colored so that it is a poor radiator of energy. The old-time, dull, black oven, with no insulation, lost heat so rapidly that much more fuel was required to heat it and to keep it at the desired temperature than is required for the modern oven. Besides, the heat that was lost often made the kitchen uncomfortably hot in the summertime.

Fireless cookers are based on the idea that if hot, partly cooked food is placed in a closed, well-insulated container, the stored heat will finish the cooking process. The early fireless cookers were called *hay cookers* since the space between the outer wall and the food compartment was filled with hay. At the present time, felt, mineral wool, or asbestos is used. Some cookers have a plate made of a composition material which is heated and placed in the bottom of the food compartment under the food container. In some cookers a small electric hot plate is built into the bottom of the food compartment — the current is turned on for a short time and then the food finishes cooking by means of the stored heat. This method is convenient because it eliminates heating the composition plate and preheating the food.

A vacuum bottle (Dewar flask) is a container designed to keep food either hot or cold, depending on the temperature at which it was placed in the bottle. It is a double-walled bottle with the air removed from the space between the two walls and with the surfaces facing on this space silvered. Since the space between the walls is evacuated, little heat is lost by convection or conduction, and since the polished surfaces are poor radiators, little heat is lost by radiation. The bottle is placed in an outside container for protection, and a spring support at the bottom acts as a shock absorber. The bottle is stoppered with a large cork,

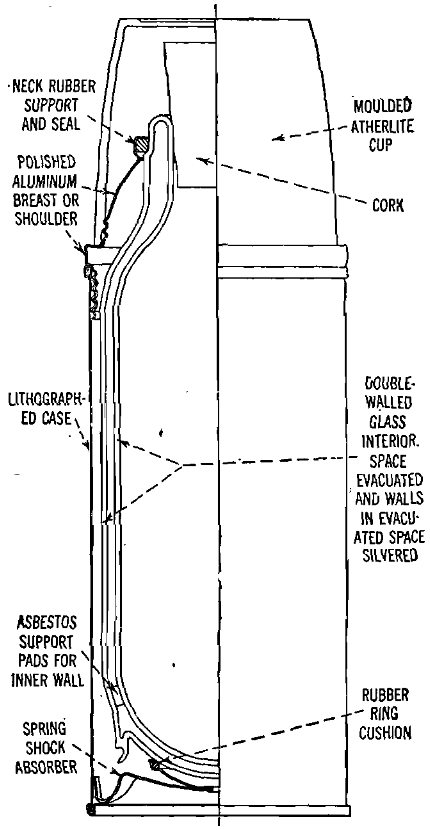

Fig. 15.9. A vacuum bottle. (Courtesy American Thermos Bottle Company)

which is a poor conductor of heat, and a cap screws on over the cork. Very hot food remains reasonably hot, or very cold food reasonably cold after several hours if the vacuum bottle has been well constructed; preheating or precooling the flask by letting it stand for a short time, filled either with hot or with cold water, aids in keeping the food at the desired temperature.

Foods and drinks can be kept warm or cool for short periods of time by placing them in large crockery bottles made specially for that purpose. They are sometimes referred to as vacuum jugs, but there is no evacuated space in the wall — they depend upon the poor conductivity of the crockery to keep the food near the original temperature. Again, preheating or precooling the jug aids in maintaining the desired temperature.

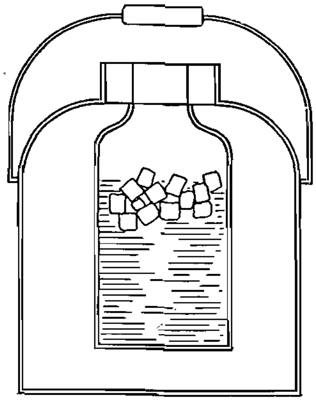

Fig. 15.10. Insulated water jug.

The food container of an ice-cream freezer is made of metal so that the heat may be removed from the ice cream quickly, but the outside container is usually made of wood so that heat from the surrounding air will not be conducted to the ice. Some of the less expensive models have metal outside containers and therefore not only are inefficient, but soon rust through. The inner container is generally better tinned and does not rust so easily.

Table covers are made of fiber board, felt, or pressed cork, i.e., materials which do not conduct heat readily and thus keep hot dishes of food from harming the finish of the table. Hot dishes are handled with cloth pads to prevent burning the hands. If one steps on a rug and then on the bare floor in a cold room the floor seems colder than the rug because the floor is a better conductor of heat. Metals, when hot, feel hotter than they really are because they are good conductors and carry heat to the hand quickly. A pressing iron loses heat by all three methods — heat is conducted from the iron to the air molecules in contact with it, and these molecules are carried away by convection currents; the iron also radiates heat in all directions.

People are concerned with the methods of heat transfer in connection with their clothing. In winter they wear heavier, thicker clothing to decrease the amount of heat which will be conducted away from their bodies. Some kinds of cloth are better insulators than others; the variation depends partly upon the kind of fiber, and a great deal upon the thickness of the material and the kind of weave. Fabrics which have a great deal of air enmeshed are good insulators because air is a poor conductor. Several layers of thin cloth afford more protection than one layer of heavier material because of the enmeshed air. Wool fibers, because of their rough, scaly surface, trap considerably more air than silk or linen fibers, which are smooth. Fur and feathers protect animals because of the air enmeshed in them. However, it should be remembered that fabrics which are too loosely woven do not aid in preventing heat losses by convection. Dark-colored fabrics are better absorbers of radiant energy than are light-colored fabrics.

STUDY QUESTIONS

1. Which is the better heat insulator — one layer of heavy cloth or several layers of thinner cloth?
2. Have you ever heard that a vacuum bottle "keeps cold things cold" better than it "keeps hot things hot"? Why?
3. Why do we wrap papers or cloth around ice to keep it from melting?
4. If paper or cloth is wrapped around a jug of hot coffee, does it keep hot for a longer time?
5. Why does an aluminum pan melt if it is put over a flame with no water in the pan?
6. Why does a dish of food cool quickly if it is put in an open window?
7. Why does touching a hot pan burn worse than touching the hot rolls in the pan?
8. Since air is a poor conductor of heat, why is a thick layer of air poor insulation for an oven wall?
9. Why do icicles melt on the south side of a house before they do on the north side?
10. Why does a person sitting in front of a fireplace complain, "My face is scorching, but my back is cold"?
11. How does the energy of a quantum vary with the frequency?
12. How does the intensity of radiation vary with the temperature?
13. How has a study of radiant-energy distribution curves helped in improving incandescent lights?

14. In a vacuum bottle the space between the two walls is evacuated and the surfaces facing this space are silvered. What heat losses are reduced by evacuating this space? What heat losses are reduced by silvering the surfaces? Which is more important — evacuating the space between the walls or silvering the walls?

PROBLEMS

1. How much heat is lost per hour through a windowpane which is 100 by 70 centimeters, if the temperature inside is 15°C and outdoors is 5°C? The glass is 0.4 centimeters thick. *Ans.* 1,512,000 cal
2. How much heat is conducted through the bottom of an aluminum pan in 30 minutes if the area is 300 square centimeters, the difference in temperature between the inside and outside is 50 Centigrade degrees, and the aluminum is 2 millimeters thick?
3. How long does it take for 100 kilocalories of heat to pass through 1 square meter of aluminum if the temperature difference is 5 Centigrade degrees and the aluminum is 2 centimeters thick? *Ans.* 8.16 sec
4. How long does it take for 100 kilocalories of heat to pass through 1 square meter of plaster if the temperature on one side is 30°C, on the other side 35°C, and the plaster is 2 centimeters thick?
5. How much heat will be conducted through 20 square feet of window glass in 10 hours if the temperature on one side is 80°F and on the other side is 110°F. The glass is 0.25 inches thick and its coefficient of conductivity is $7\,\frac{\text{Btu-in.}}{\text{ft}^2\text{-hr-}^\circ\text{F}}$. *Ans.* 168,000 Btu
6. How much heat will be conducted through a wall made of brick in 24 hours if the area is 400 square feet, the temperature on one side is 30°F and on the other side 70°F? The wall is 8 inches thick and the coefficient of conductivity for brick is $5\,\frac{\text{Btu-in.}}{\text{ft}^2\text{-hr-}^\circ\text{F}}$.

16

REFRIGERATION

Except in the frigid zones of the earth, the preservation of food has always been a problem. In early days people migrated from region to region as the weather changed, and if food was plentiful they used what they wanted of the supply at hand and trusted to Providence to provide for the next day. Gradually they learned to preserve some foods by drying them in the summer or freezing them in the winter, and thus they could store what was not needed for immediate use. This made possible a greater variety in their food as well as being a provision against famine. Gradually people learned that foods would keep longer if placed in a cool cave or in a cold stream of water.

We now know that low temperatures hinder the growth of bacteria and thus help to preserve foods. If food could be stored in an absolutely sterile condition, it would keep for a long time even at higher temperatures; but at the higher temperatures the texture or flavor of the food may not be what is desired. Gelatine dishes must be chilled in order to set, and milk and fruit juices have a better flavor when cool. The humidity of the air in the food storage space is also important. Celery, lettuce, and other foods which have a high water content remain crisp and fresh only if stored in an atmosphere which will not evaporate the water from the food.

93. Refrigerator Walls. The early ice refrigerators were simply well-built wooden boxes with shelves for the food and a space for the ice. The heat absorbed by the ice in melting was taken from the food and the air in the box. Since the boxes were poorly insulated, a considerable amount of heat was conducted through the walls, thus increasing the amount of ice required.

A refrigerator should be made with well-insulated walls and well-fitted doors. Otherwise the amount of ice, electricity, or gas required to keep the food compartment at the desired temperature will increase the cost of operation. The outer and inner surfaces of the walls should be smooth, stainproof, waterproof, and vapor proof. This provides surfaces which are easy to clean and which will not absorb spilled foods or food odors. The doors must fit tightly—a rubber gasket around the door is compressed when the door is closed to insure an air-tight closing.

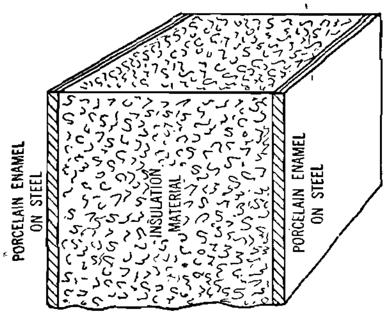

Fig. 16.1. Section of refrigerator wall.

The insulation material which is between the outer and inner walls should be a material with a low coefficient of heat conductivity and one which is dimensionally stable — i.e., one which does not settle. It should be fire resistant, moisture resistant, and durable. The thickness of the insulation material is about 3 to 3½ inches. Fiberglas, mineral wool, and various other commercial insulation materials are used.

Even though the door of the refrigerator is not opened and no food is placed in the refrigerator, some heat is constantly entering through the walls. The amount of heat entering the food compartment may be computed by use of the conductivity formula:

$$H = \frac{KAT(t_2 - t_1)}{L}$$

Average values of K in Btu per square inch-hr-°F per inch of thickness vary from 0.002 to 0.003.

The amount of heat to be removed from the food space also depends upon the amount and temperature of the food put into the refrigerator and the amount of time the door is open. Both of these factors are decidedly variable. The first may be reduced by letting foods cool to room temperature before they are put into the refrigerator, and the second by a little forethought before the door is opened.

94. Types of Refrigeration. ***1. Ice Refrigeration.*** While ice refrigeration has largely been replaced by some type of mechanical refrigeration in the home, a consideration of this method does enter into the background of refrigeration. The heat from the food and that conducted through the walls is absorbed by the ice as it melts. Since the air circulates over the melting ice, its relative humidity remains fairly high; and, consequently, foods are not dehydrated as rapidly as they are in air which is circulated over the coils of a mechanical refrigerator where it is cooled until a large part of the moisture is frozen onto the coils. But the food is not kept as cold in an ice refrigerator as it is in a mechanical refrigerator, and if the supply of ice runs low the refrigerator temperature may be considerably above the desired amount.

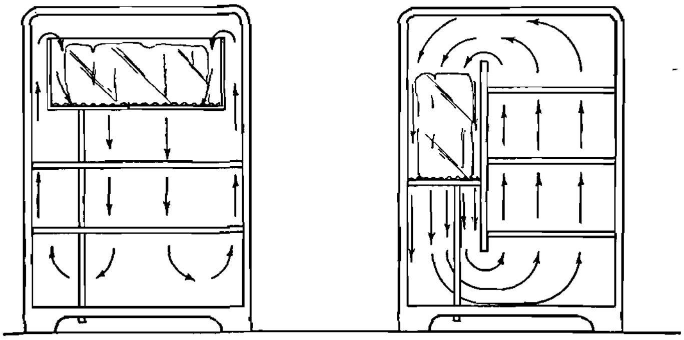
Fig. 16.2. Ice refrigerators — top and side icing.

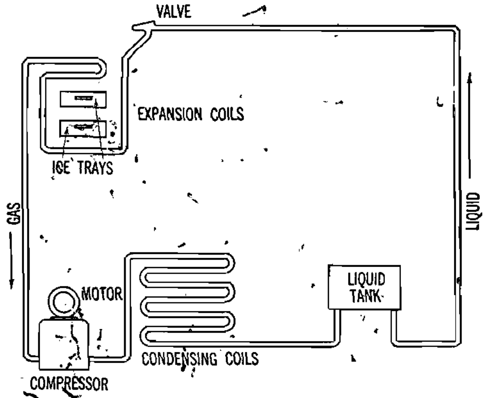

Fig. 16.3. Electrical refrigeration cycle.

2. ***Electrical Refrigeration.*** One of the most satisfactory methods of refrigeration is electrical refrigeration. The electricity does not cool the food space directly; but an electric motor is used to operate the mechanism, and the cooling of the food compartment results from a change in the state of a refrigerating fluid. This fluid is always one which exists as a gas at ordinary temperatures and pressures, but one which will liquefy when subjected to a moderate increase in pressure followed by cooling to room temperature. Freon 12 (dichlorodifluoromethane) is used in many household refrigerators.

The liquid refrigerant is stored under pressure in a small tank. At a given temperature in the food compartment (which is determined by the setting of the thermostat), the motor starts and the pump forces some of this liquid into the expansion coils which make up the cooling unit in the food compartment. The refrigerant is under less pressure in these coils; hence, it absorbs heat of vaporization from the air and food in the refrigerator and changes into a gas. This gas expands rapidly and consequently its temperature drops decidedly. This decrease in temperature causes the thermostat to stop the motor. As the gas absorbs heat, its temperature gradually increases; and when it reaches the temperature for which the thermostat is set, the motor starts again. As more liquid is forced into the expansion coils the gas is pumped out. The pump, or *compressor*, as it is usually called, compresses the gas and as a result its temperature rises considerably. This hot gas from the compressor is then forced through the condensing coils, which are cooled either with water or with air — usually air in the home. As a result of both compressing and cooling the gas, it liquefies, and the liquid is then returned to the tank ready for another trip around the system. The automatic temperature control is a thermostat which makes or breaks the electric circuit to the motor and thus regulates indirectly the amount of liquid that evaporates in the expansion coils. Since electrical refrigeration makes use of a compressor, it is sometimes referred to as a compression system. The compressor and motor are usually in a sealed unit and do not require oiling.

As the air circulates over the expansion coils, it is cooled and part of the moisture in it freezes on the coils. The thicker the ice is on the coils, the less efficient is the system (since ice is a poor conductor of heat), and as a result the motor has to run more of the time to keep the refrigerator cold. This deposit of ice can be minimized by keeping food containers covered. In most refrigerators defrosting is now taken care of automatically. A timing device may turn a heater coil on for a short time during each 24-hour period, or a heater coil may operate for a short time when the door has been opened a predetermined number of times. The melted ice drains into a tube which leads to an evaporating pan in the base of the refrigerator.

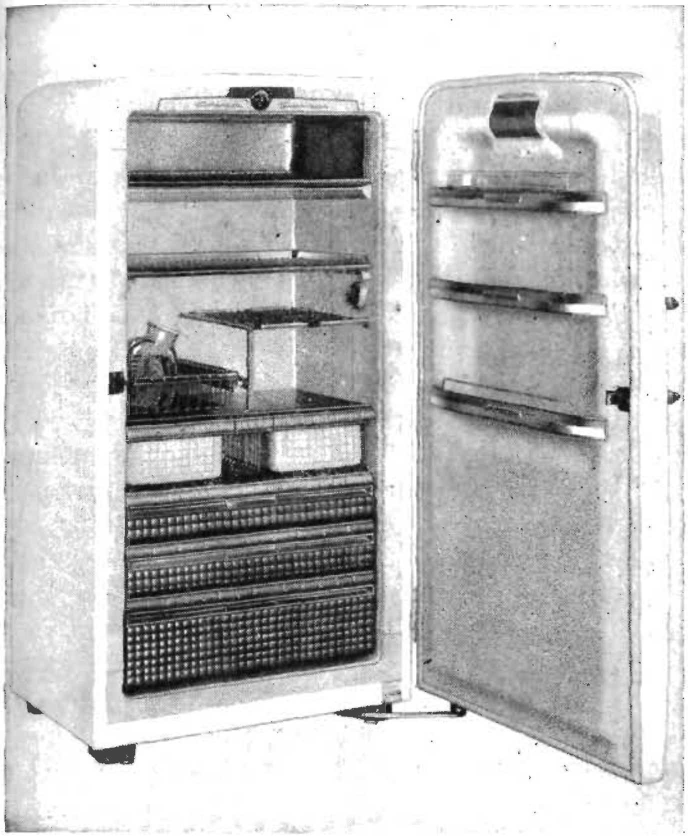

Fig. 16.4. An electric refrigerator with a freezer chest across the bottom. (Courtesy Sears, Roebuck and Co.)

Most refrigerators now have a storage space for frozen foods, as shown in Figure 16.4, which is kept much colder than the remainder of the food compartment. This is accomplished in various ways. The expansion coils of the main system may be placed around the freezer unit and a second sealed coil which is partly filled with refrigerant is operated from the main expansion coils by means of a set of transfer plates. Or the temperature in the warmer compartment may be regulated by adjusting a baffle plate which controls the circulation of air between the two compartments. This adjustment is made by turning a dial calibrated as a thermostat.

3. *Gas refrigeration.* In contrast to electric refrigeration, which is a compression system, gas refrigeration is an absorption system. Since the gas refrigerator has no moving parts, it operates very quietly. The source of energy is a small gas flame. The gas may be either natural gas or some type of bottled gas. The cycle of operation is shown schematically in Figure 16.5. The refrigerant is ammonia, which is liberated from a solution of ammonia in water when the solution is heated. The ammonia is transferred from one part of the system to another through an atmosphere of hydrogen. The total pressure, which is made up of the pressure of the ammonia plus the pressure of the hydrogen, is the same in all parts of the system.

The operation of this system is explained best by noting that there are three distinct complete circuits – the ammonia, the hydrogen, the water — all operating at the same time.

A. The ammonia circuit. When heat is added to the generator, droplets of water, in which ammonia is dissolved, and ammonia vapor are raised in the liquid lift which operates in the same way as a coffee percolator – to the vapor and liquid separator. The ammonia vapor then goes up to the condenser, where it is cooled either by air or by water and condensed into pure liquid ammonia, which drips down into the evaporator located in the food compartment. A stream of hydrogen also enters the evaporator. The ammonia, evaporating in this atmosphere of hydrogen, produces the desired refrigeration. This mixture of ammonia vapor and hydrogen then goes to the absorber, where the ammonia dissolves in the water and returns to the generator.

B. The hydrogen circuit. The hydrogen, which is not soluble in water, passes through the absorber, and rises to the evaporator where it aids in vaporizing the ammonia. Then, mixed with ammonia vapor, it passes back to the absorber where the ammonia dissolves in the water and the hydrogen continues on through the absorber. The absorber is either air- or water-cooled.

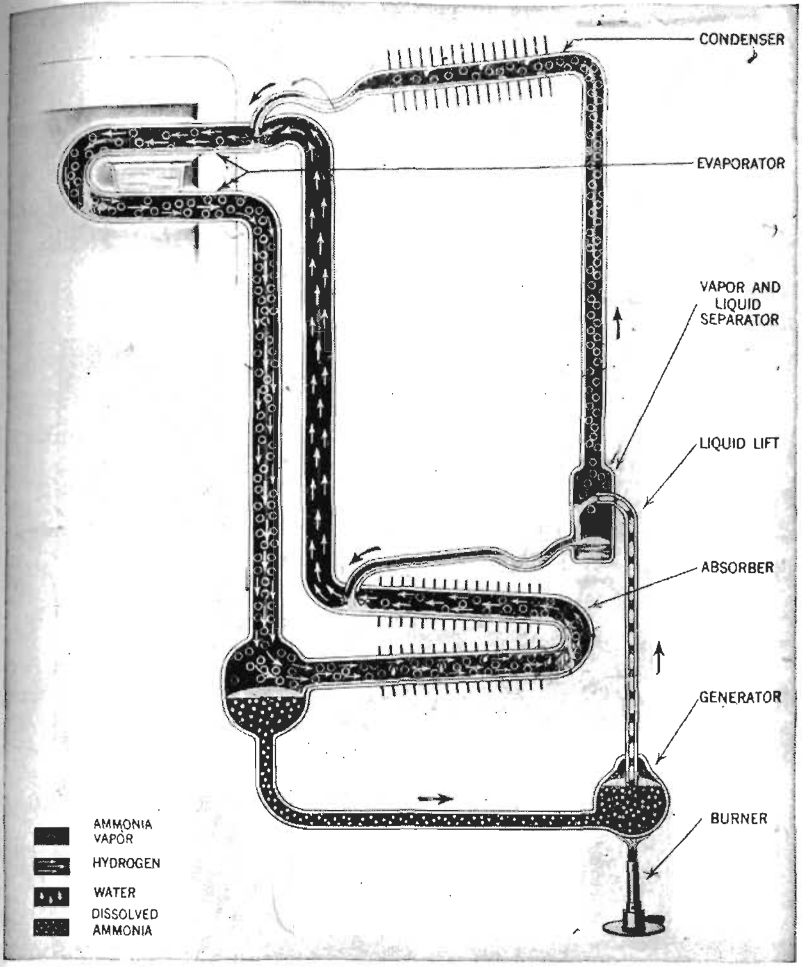

Fig. 16.5. Gas refrigeration cycle. (Copyrighted by Servel, Inc. Reproduced by permission)

C. The water circuit. The water which was driven from the generator to the vapor and liquid separator flows from the separator into the absorber where the ammonia vapor dissolves in it, and this solution returns to the generator. As more heat is added to it, the cycle is repeated.

95. Food Freezers. During the last twenty years the freezing of foods at very low temperatures has become an increasingly popular method of food preservation. For the method to be successful, the foods must be frozen quickly. If the freezing takes place slowly, large ice crystals are formed within the tissues, proteins may be altered, and, when the food is thawed, it is undesirable in texture and may have a poor flavor. But if the food is frozen quickly — at temperatures from −25° to −30°F — much smaller ice crystals are formed, the proteins are not altered, the vitamins are not destroyed, and in general the quality of the product compares favorably with that of fresh meat, fruit, or vegetables.

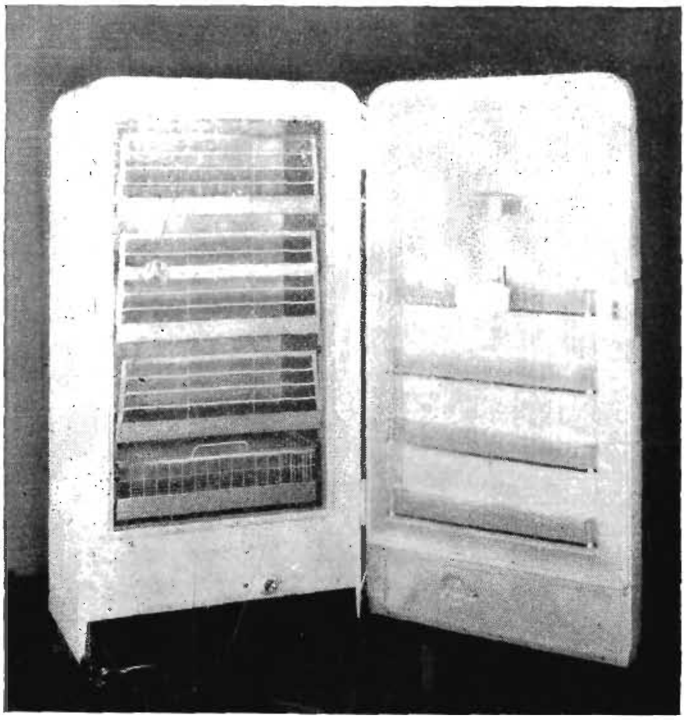

Fig. 16.6. A food freezer of the upright type. (Courtesy Frigidaire Division, General Motors Corporation)

Food freezers in the home are proving to be decidedly popular. They may be purchased in almost any size in accord with the size of the family and the extent to which the housekeeper wishes to make use of frozen foods. They are especially convenient in rural homes because the food which is produced on the farm can be preserved most conveniently by freezing, and because they eliminate the trips to town to take the food to the central freezing and storage lockers. Also the food is at hand whenever it is wanted. The food freezers may be either the chest or the upright type. The insulation material is similar to that used in refrigerators, but is 4 to 5 inches thick.

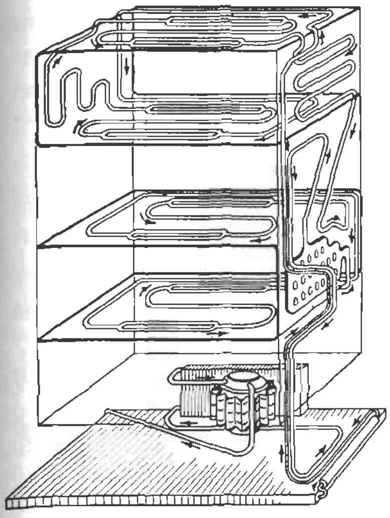

Fig. 16.7. Diagram of the refrigeration system for a food freezer of the upright type. (Courtesy Frigidaire Division, General Motors Corporation)

96. Cold Storage Plants and Ice Plants. Long before food freezers for the home were available, ice plants were using mechanical refrigeration to make huge quantities of ice for both home and commercial use. These plants still have an important place in the refrigeration field. The refrigerant is ammonia and it is often used to cool brine which in turn is used to freeze the tanks of water which become the blocks of ice.

Meat-packing firms are using mechanically refrigerated rooms for storing meat and refrigerated cars for transporting meat. Vegetables and fruits are transported in refrigerated cars. Large central freezing and food locker plants freeze meat, fruit, and vegetables from the farm and garden and store the food until it is wanted by the owner. Now we have refrigerated trucks carrying frozen foods all over the country. Many foods which used to be available only at certain seasons are now available almost any time of the year.

97. Other Uses for Mechanical Refrigeration. In the last few years there has been a tremendous increase in the use of refrigeration systems for air cooling in the home. The units vary from small ones suitable for cooling one room to large units for cooling the whole house. The small units are usually installed in a window, with the expansion coils located so that the air in the room can be circulated over them by means of a fan. The condensing coils deliver the heat to the outdoors. The larger units are installed in the basement or the utility room and often make use of the ducts of a hot-air heating system for distribution. Still larger units are used to cool theaters, hotels, and office buildings.

Skating rinks use refrigeration systems to cool brine which is circulated through pipes to freeze the water. Photographic film keeps much longer if kept cool. Bacteriologists control rate of growth of bacteria by refrigeration. Pathologists freeze specimens of tissues so that they may cut them into thin slices for examination. Blood banks depend upon refrigeration to preserve blood so that it is available when needed.

STUDY QUESTIONS

1. Why must food be refrigerated?
2. What are the requirements for a good refrigerator wall?
3. What is the distinction between a compression system and an absorption system of refrigeration?
4. What factors enter into the cost of mechanical refrigeration?
5. Why should meat, fruits, and vegetables be frozen quickly?
6. Name several uses for mechanical refrigeration in addition to that of cooling food.

PROBLEMS

1. Calculate the amount of heat that enters the food compartment of an ice refrigerator, 24 by 40 by 15 inches, in 24 hours, if the room temperature is 70°F, the average temperature inside of the box is 50°F, and the walls are 3 inches thick. $K = 0.002 \frac{\text{Btu-in.}}{\text{in.}^2\text{-hr-}^\circ\text{F}}$. How much ice is melted? *Ans.* 1229 Btu; 8.5 lb
2. How much heat enters the food compartment of a refrigerator, 20 by 30 by 15 inches, in 24 hours if the room temperature is 110°F, the average temperature inside of the box is 50°F, and the walls are 3 inches thick. $K = 0.003 \frac{\text{Btu-in.}}{\text{in.}^2\text{-hr-}^\circ\text{F}}$. How much ice is melted?
3. How much heat is introduced into a refrigerator unnecessarily if 1 pound of hot food is placed in the refrigerator at a temperature of 150°F instead of waiting until it has cooled to 80°F? (Specific heat of food may be assumed to be 0.9.) *Ans.* 63 Btu
4. How much heat enters a refrigerator if the door is left open a few minutes so that all of the air in the refrigerator is replaced by room air? Assume the volume of the food compartment is 8 cubic feet, room temperature is 100°F, and the refrigerator temperature is 40°F.

17

ATMOSPHERIC HUMIDITY

Water vapor is by weight a relatively small part of the atmosphere, varying from less than 1 per cent in cold, arid regions to about 5 per cent in warm, humid regions. Water vapor is transparent to light, but absorbs a considerable part of the longer heat waves. It is lighter than air, saturated water vapor having a density of about 0.62 that of air at the same temperature and pressure. Most of the water vapor in the atmosphere is within 5 miles of the earth's surface. All plants and animals and many nonliving materials are affected by the water vapor in the atmosphere.

98. Measurement of Atmospheric Humidity. Humidity refers to the general moisture content of the atmosphere but it is not a definite term for which numerical values can be obtained. Therefore the terms "absolute humidity," "relative humidity," and "dew point" are used when definite measurements are to be made. *The absolute humidity is the mass of water vapor per unit volume in the atmosphere.* It is usually measured in grains per cubic foot (7000 grains = 1 pound). The atmosphere may or may not be saturated with water vapor — usually it is not saturated — and the degree of saturation or the relative humidity is generally the information which is of most importance. *The relative humidity is the ratio between the mass of moisture which is in a given volume of the atmosphere and the mass required for saturation of the same volume at the same temperature.* Relative humidity is almost always expressed in per cent. Atmosphere which is not saturated may become saturated if it is cooled because the mass of moisture which can exist in the vapor state in the atmosphere varies with the temperature. *The dew point is the temperature at which the atmosphere becomes saturated.*

The table on page 193 shows the mass of water vapor in grains per cubic foot required for saturation at various temperatures. For example, at 68°F the mass of moisture required for saturation is 7.480 grains per cubic foot. If the air contains only 3.414 grains per cubic foot, that amount is the absolute humidity. The relative humidity is

$$\frac{\text{absolute humidity}}{\text{amount for saturation}} = \frac{3.414}{7.480} = 47 \text{ per cent}$$

One method of determining the amount of moisture in a unit volume of the atmosphere is to find the dew point and then by referring to the table on page 193 the amount of moisture required for saturation at that temperature may be determined. The dew point is found by slowly adding ice to water in a bright-surfaced beaker and noting the temperature of the water when dew first appears on the outside of the beaker. The dew indicates that the water vapor which came in contact with the beaker was cooled to the dew point so that the vapor started to condense. In the above example the dew point must have been 45°F since at that temperature the amount of moisture required for saturation is 3.414 grains per cubic foot.

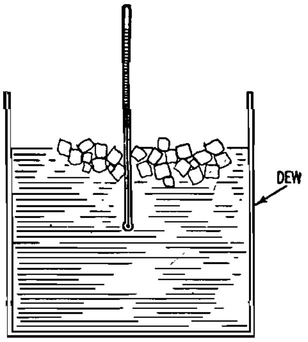

Fig. 17.1. Finding the dew point.

99. Hygrometers. *A hygrometer is a device for determing the relative humidity of the atmosphere.* There are two general types of instruments which are used in making humidity measurements: (1) wet- and dry-bulb hygrometers and (2) hygrometers using hygroscopic materials. A wet- and dry-bulb hygrometer consists of two thermometers with a tubular wick around the bulb of one. The wick either dips into a small cup of water continuously or else it is dipped into water just before making a reading. Water rises in the wick and evaporates at a rate depending on the amount of moisture already in the atmosphere. The evaporation cools the bulb of this thermometer so that it reads less than the dry-bulb thermometer. If the atmosphere is quite

WATER VAPOR REQUIRED FOR SATURATION AT VARIOUS TEMPERATURES

TEMPERATURE °F	GRAINS PER CU FT	TEMPERATURE °F	GRAINS PER CU FT
20	1.235	65	6.782
21	1.294	66	7.009
22	1.355	67	7.241
23	1.418	68	7.480
24	1.483	69	7.726
25	1.551	70	7.980
26	1.623	71	8.240
27	1.697	72	8.508
28	1.773	73	8.782
29	1.853	74	9.066
30	1.935	75	9.356
31	2.022	76	9.655
32	2.113	77	9.962
33	2.194	78	10.277
34	2.279	79	10.601
35	2.366	80	10.934
36	2.457	81	11.275
37	2.550	82	11.626
38	2.646	83	11.987
39	2.746	84	12.356
40	2.849	85	12.736
41	2.955	86	13.127
42	3.064	87	13.526
43	3.177	88	13.937
44	3.294	89	14.359
45	3.414	90	14.790
46	3.539	91	15.234
47	3.667	92	15.689
48	3.800	93	16.155
49	3.936	94	16.634
50	4.076	95	17.124
51	4.222	96	17.626
52	4.372	97	18.142
53	4.526	98	18.671
54	4.685	99	19.212
55	4.849	100	19.766
56	5.016	101	20.335
57	5.191	102	20.917
58	5.370	103	21.514
59	5.555	104	22.125
60	5.745	105	22.750
61	5.941	106	23.392
62	6.142	107	24.048
63	6.349	108	24.720
64	6.563	109	25.408
		110	26.112

moist, there will be little evaporation of water from the wick and little cooling of the wet bulb. A small difference in the readings of the two thermometers indicates high relative humidity. But if the atmosphere is relatively dry, there will be rapid evaporation of water from the wick and considerable cooling of the wet bulb. Therefore a large difference in the readings of the two thermometers indicates low relative humidity. In order to obtain accurate data the air must be in motion about the thermometers, since in still air the moisture content of the space around the wet bulb soon becomes greater than that of the atmosphere in general, and the readings are not a true indication of the moisture content of the atmosphere. Therefore the

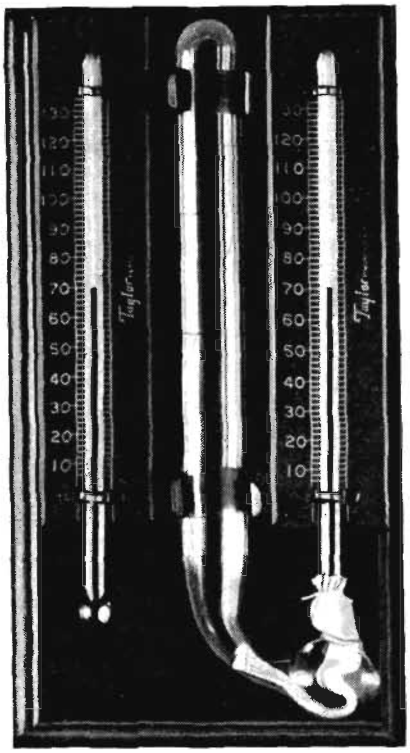

Fig. 17.2. Stationary wet- and dry-bulb hygrometer. (Courtesy Taylor Instrument Companies)

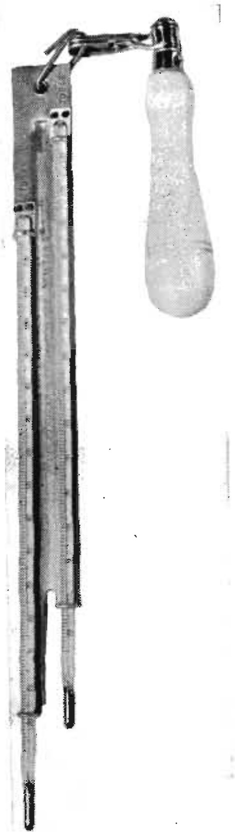

Fig. 17.3. Sling hygrometer. (Courtesy Julien P. Friez & Sons, Inc.)

hygrometer should either be placed where there are air currents or else be mounted so that it can be rotated before taking readings. If it is mounted so it can be rotated it is known as a *sling hygrometer.* Distilled water should be used to wet the wicks because the usual tap water will leave a mineral deposit in the wick which causes it to harden and reduces its capillary action,

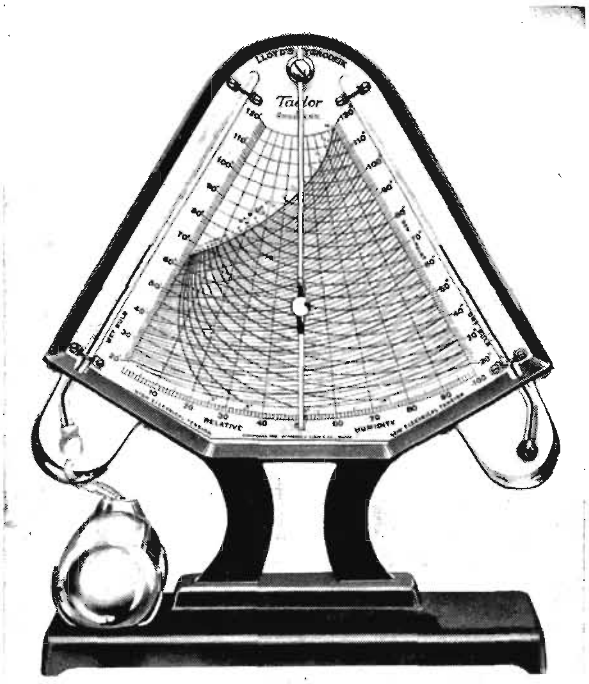

Fig. 17.4. A hygrodeik. (Courtesy Taylor Instrument Companies)

thus reducing the rate of evaporation below normal. Figures 17.2, 17.3, and 17.4 show various wet- and dry-bulb hygrometers.

The numerical value for the relative humidity or for the dew point may be obtained from the tables on pages 196–199. For example, if the dry-bulb reads 65°F and the wet-bulb 53°F, the difference is 12 degrees, or 12 is the depression of the wet-bulb thermometer. In the relative humidity table locate the dry-bulb reading, 65°F, in the first column and follow across the page to the column headed 12. The number thus located is the relative

RELATIVE HUMIDITY, PER CENT — FAHRENHEIT TEMPERATURES[1]

Pressure = 30.0 inches of mercury

AIR TEMP.	DEPRESSION OF WET-BULB THERMOMETER (t–t')																																						
t	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40
0	67	33	1																																					
+1	68	36	5																																					
2	70	39	9																																					
3	71	42	13																																					
4	72	44	17																																					
5	73	46	20																																					
6	74	49	23																																					
7	75	51	26	2																																				
8	76	53	29	6																																				
9	77	55	32	10																																				
10	78	56	34	13																																				
11	79	58	37	16																																				
12	80	59	39	19	0																																			
13	80	61	41	23	4																																			
14	81	62	44	26	8																																			
15	82	64	46	29	11																																			
16	82	65	48	31	14																																			
17	83	66	50	34	17	1																																		
18	84	68	52	36	20	5																																		
19	84	69	53	38	23	8																																		
20	85	70	55	40	26	12																																		
21	85	71	56	42	28	15	1																																	
22	86	71	58	44	31	17	4																																	
23	86	72	59	46	33	20	7																																	
24	87	73	60	47	35	22	10																																	
25	87	74	62	49	37	25	13	1																															
26	87	75	63	51	39	27	16	4																															
27	88	76	64	52	41	29	18	7																															
28	88	76	65	54	43	32	21	10																															
29	88	77	66	55	44	34	23	13	3																														
30	89	78	67	56	46	36	26	16	6																														
31	89	78	68	58	47	37	28	18	8																														
32	89	79	69	59	49	39	30	20	11	2																													
33	90	80	70	60	51	41	32	23	14	5																													
34	90	81	71	62	52	43	34	25	16	8																													
35	91	81	72	63	54	45	36	27	19	10	2																												
36	91	82	73	64	55	46	38	29	21	13	5																												
37	91	83	74	65	57	48	40	31	23	15	7																												
38	91	83	75	66	58	50	42	33	25	17	10	2																											
39	92	83	75	67	59	51	43	35	27	20	12	5																											
40	92	83	75	68	60	52	45	37	29	22	15	7	0																										
41	92	84	76	69	61	54	46	39	31	24	17	10	3																										
42	92	85	77	69	62	55	47	40	33	26	19	12	5																										
43	92	85	77	70	63	55	48	42	35	28	21	14	8	1																									
44	93	85	78	71	63	56	49	43	36	30	23	16	10	4																									
45	93	86	78	71	64	57	51	44	38	31	25	18	12	6																									

AIR TEMP. *t*	DEPRESSION OF WET-BULB THERMOMETER (t-t′)																																							
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40
46	93	86	79	72	65	58	52	45	39	32	26	20	14	8	2																									
47	93	86	79	72	66	59	53	46	40	34	28	22	16	10	5																									
48	93	86	79	73	66	60	54	47	41	35	29	23	18	12	7	1																								
49	93	86	80	73	67	61	54	48	42	36	31	25	19	14	9	3																								
50	93	87	80	74	67	61	55	49	43	38	32	27	21	16	10	5	0																							
51	94	87	81	75	68	62	56	50	45	39	34	28	23	17	12	7	2																							
52	94	87	81	75	69	63	57	51	46	40	35	29	24	19	14	9	4																							
53	94	87	81	75	69	63	58	52	47	41	36	31	26	20	16	10	6	1																						
54	94	88	82	76	70	64	59	53	48	42	37	32	27	22	17	12	8	3																						
55	94	88	82	76	70	65	59	54	49	43	38	33	28	23	19	14	9	5	0																					
56	94	88	82	76	71	65	60	55	50	44	39	34	30	25	20	15	11	7	2																					
57	94	88	82	77	71	66	61	56	50	45	40	35	31	26	22	17	13	8	4																					
58	94	88	83	77	72	66	61	56	51	46	41	37	32	27	23	18	14	10	6	1																				
59	94	89	83	78	72	67	62	57	52	47	42	38	33	29	24	20	16	11	7	3																				
60	94	89	83	78	73	68	63	58	53	48	43	39	34	30	25	21	17	13	9	5	1																			
61	94	89	84	78	73	68	63	58	54	49	44	40	35	31	27	22	18	14	10	7	3																			
62	94	89	84	79	74	69	64	59	54	50	45	41	36	32	28	24	20	16	12	8	4	1																		
63	95	89	84	79	74	69	64	60	55	50	46	42	37	33	29	25	21	17	13	10	6	2																		
64	95	90	84	79	74	70	65	60	56	51	47	43	38	34	30	26	22	18	15	11	7	4	0																	
65	95	90	85	80	75	70	66	61	56	52	48	44	39	35	31	27	24	20	16	12	9	5	2																	
66	95	90	85	80	75	71	66	61	57	53	48	44	40	36	32	29	25	21	17	14	10	7	3	0																
67	95	90	85	80	75	71	66	62	58	53	49	45	41	37	33	20	26	22	19	15	12	8	5	2																
68	95	90	85	80	76	71	67	62	58	54	50	46	42	38	34	31	27	23	20	16	13	10	6	3																
69	95	90	85	81	76	72	67	63	59	55	51	47	43	39	35	32	28	24	21	18	14	11	8	5	1															
70	95	90	86	81	77	72	68	64	59	55	51	48	44	40	36	33	29	25	22	19	15	12	9	6	3															
71	95	90	86	81	77	72	68	64	60	56	52	48	45	41	37	33	30	27	23	20	17	13	10	7	4	1														
72	95	91	86	82	77	73	69	65	61	57	53	49	45	42	38	34	31	28	24	21	18	15	12	9	6	3														
73	95	91	86	82	78	73	69	65	61	57	53	50	46	42	39	35	32	29	25	22	19	16	13	10	7	4	1													
74	95	91	86	82	78	74	69	65	61	58	54	50	47	43	39	36	33	29	26	23	20	17	14	11	8	5	3													
75	96	91	86	82	78	74	70	66	62	58	54	51	47	44	40	37	34	30	27	24	21	17	15	12	9	7	4	1												
76	96	91	87	82	78	74	70	66	62	59	55	51	48	44	41	38	34	31	28	25	22	19	16	13	11	8	5	3												
77	96	91	87	83	79	74	71	67	63	59	56	52	48	45	42	39	35	32	29	26	23	20	17	14	12	9	6	4												
78	96	91	87	83	79	75	71	67	63	60	56	53	49	46	43	39	36	33	30	27	24	21	18	16	13	10	8	5												
79	96	91	87	83	79	75	71	68	64	60	57	53	50	46	43	40	37	34	31	28	25	22	19	17	14	11	9	6												
80	96	91	87	83	79	75	72	68	64	61	57	54	50	47	44	41	38	35	32	29	26	23	20	18	15	12	10	7	5	3	0									
82	96	92	88	84	80	76	72	69	65	61	58	55	51	48	45	42	39	36	33	30	28	25	22	20	17	14	12	10	7	5	2	0								
84	96	92	88	84	80	76	73	69	65	62	59	56	52	49	46	43	40	37	35	32	29	26	24	21	19	16	14	12	9	7	5	3	0							
86	96	92	88	84	81	77	73	70	66	63	60	57	53	50	47	44	42	39	36	33	31	28	25	23	21	18	16	14	11	9	7	5	3	1						
88	96	92	88	85	81	77	74	70	67	64	61	57	54	51	48	46	43	40	37	35	32	30	27	25	22	20	18	15	13	11	9	7	5	3	1					
90	96	92	89	85	81	78	74	71	68	65	61	58	55	52	49	47	44	41	39	36	34	31	29	26	24	22	19	17	15	13	11	9	7	5	3	1				
92	96	92	89	85	82	78	75	72	68	65	62	59	56	53	50	48	45	42	40	37	35	32	30	28	26	23	21	19	17	15	13	11	9	7	5	3	1			
94	96	93	89	85	82	79	75	72	69	66	63	60	57	54	51	49	46	43	41	38	36	33	31	29	27	24	22	20	18	16	14	12	10	9	7	5	3	1		
96	96	93	89	86	82	79	76	73	69	66	63	61	58	55	52	50	47	44	42	39	37	35	32	30	28	26	24	22	20	18	16	14	12	10	8	7	5	3	2	0
98	96	93	89	86	83	79	76	73	70	67	64	61	58	56	53	50	48	45	43	40	38	36	34	32	29	27	25	23	21	19	17	15	14	12	10	8	7	5	3	2
100	96	93	89	86	83	80	77	73	70	68	65	62	59	56	54	51	49	46	44	41	39	37	35	33	30	28	26	24	22	21	19	17	15	13	12	10	8	7	5	4
102	96	93	90	86	83	80	77	74	71	68	65	62	60	57	55	52	49	47	45	42	40	38	36	34	32	30	28	26	24	22	20	18	16	15	13	11	10	8	7	5
104	97	93	90	87	83	80	77	74	71	69	66	63	60	58	55	53	50	48	46	43	41	39	37	35	33	31	29	27	25	23	21	20	18	16	14	13	11	10	8	7
106	97	93	90	87	84	81	78	75	72	69	66	64	61	58	56	53	51	49	46	44	42	40	38	36	34	32	30	28	26	24	23	21	19	17	16	14	13	11	10	8
108	97	93	90	87	84	81	78	75	72	70	67	64	62	59	57	54	52	49	47	45	43	41	39	37	35	33	31	29	27	25	24	22	20	19	17	16	14	12	11	10
110	97	93	90	87	84	81	78	75	73	70	67	65	62	60	57	55	52	50	48	46	44	42	40	38	36	34	32	30	28	26	25	23	21	20	18	17	15	14	12	11

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[1] Courtesy The Weather Bureau, U. S. Department of Commerce.

TEMPERATURE OF DEW POINT IN DEGREES FAHRENHEIT[1]

Pressure = 30.0 inches of mercury

AIR TEMP. t	DEPRESSION OF WET-BULB THERMOMETER $(t-t')$																																						
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40
0	−7																																						
+1	−6																																						
2	−5																																						
3	−4																																						
4	−2																																						
5	−1	−9																																					
6	[illegible]	−8																																					
7	+1	−6																																					
8	3	−5																																					
9	4	−3																																					
10	5	−2																																					
11	6	0	−8																																				
12	7	+2	−6																																				
13	9	3	−4																																				
14	10	5	−2																																				
15	11	6	0	−9																																			
16	12	7	+1	−7																																			
17	13	9	3	−4																																			
18	14	10	5	−2																																			
19	15	11	6	0																																			
20	16	12	8	+2	−7																																		
21	18	14	9	3	−4																																		
22	19	15	11	5	−2																																		
23	20	16	12	7	0	−9																																	
24	21	17	13	9	+2	−6																																	
25	22	19	15	10	5	−3																																	
26	23	20	16	12	7	−1																																	
27	24	21	18	13	8	+2																																	
28	25	22	19	15	10	4																																	
29	26	23	20	16	12	6	−1																																
30	27	25	21	18	14	8	+2	−7																															
31	28	26	23	19	15	10	4	−4																															
32	30	27	24	21	17	12	7	−1																															
33	31	28	25	22	18	14	9	+2																															
34	32	29	26	23	20	16	11	5	−3																														
35	33	30	28	25	21	17	13	7	0																														
36	34	31	29	26	23	19	15	10	+3	−6																													
37	35	32	30	27	24	21	17	12	6	−3																													
38	36	33	31	28	25	22	18	14	8	+1																													
39	37	34	32	29	27	23	20	16	11	4	−5																												
40	38	35	33	30	28	25	21	18	13	7	−1																												
41	39	36	34	31	29	26	23	19	15	10	+2	−8																											
42	40	38	35	33	30	27	24	21	17	12	6	−3																											
43	41	39	36	34	31	28	25	22	19	14	9	+1																											
44	42	40	37	35	32	30	27	24	20	16	11	4	−5																										
45	43	41	38	36	34	31	28	25	22	18	13	7	−1																										

AIR TEMP. *t*	DEPRESSION OF WET-BULB THERMOMETER (*t*–*t*′)																																							
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40
46	44	42	40	37	35	32	29	27	23	20	15	10	+3	−7																										
47	45	43	41	38	36	33	31	28	25	21	17	12	6	−3																										
48	46	44	42	40	37	35	32	29	26	23	19	14	9	+1																										
49	47	45	43	41	38	36	33	30	28	24	21	16	11	5	−5																									
50	48	46	44	42	40	37	34	32	29	26	22	18	13	8	0																									
51	49	47	45	43	41	38	36	33	30	27	24	20	16	10	+3	−7																								
52	50	48	46	44	42	40	37	34	32	29	26	22	18	13	7	−2																								
53	51	49	47	45	43	41	38	36	33	30	27	24	20	15	10	+2	−9																							
54	52	50	48	46	44	42	40	37	34	32	29	25	22	18	12	6	−4																							
55	53	51	50	48	45	43	41	38	36	33	30	27	24	20	15	9	+1																							
56	54	53	51	49	47	44	42	40	37	34	32	29	25	22	17	12	5	−5																						
57	55	54	52	50	48	46	43	41	39	36	33	30	27	24	19	14	9	0																						
58	56	55	53	51	49	47	45	42	40	37	35	32	29	25	21	17	11	+4	−6																					
59	57	56	54	52	50	48	46	44	41	39	36	33	30	27	23	19	14	8	−1																					
60	58	57	55	53	51	49	47	45	43	40	38	35	32	29	25	21	17	11	+4	−8																				
61	59	58	56	54	52	50	48	46	44	42	39	36	33	30	27	23	19	14	8	−2																				
62	60	59	57	55	53	52	50	47	45	43	40	38	35	32	29	25	21	16	11	−3	−9																			
63	61	60	58	56	55	53	51	49	47	44	42	39	36	34	30	27	23	19	14	+7	−2																			
64	62	61	59	57	56	54	52	50	48	46	43	41	38	35	32	29	25	21	17	11	+3																			
65	63	62	60	59	57	55	53	51	49	47	45	42	40	37	34	31	27	24	19	14	7	−3																		
66	64	63	61	60	58	56	54	52	50	48	46	44	41	38	35	32	29	26	22	17	11	+2																		
67	65	64	62	61	59	57	55	53	52	49	47	45	43	40	37	34	31	28	24	19	14	7	−3																	
68	67	65	63	62	60	58	57	55	53	51	49	46	44	42	39	36	33	29	26	22	17	11	+2																	
69	68	66	64	63	61	59	58	56	54	52	50	48	45	43	40	37	34	31	28	24	19	14	7	−3																
70	69	67	65	64	62	61	59	57	55	53	51	49	47	44	42	39	36	33	30	26	22	17	11	+2																
71	70	68	67	65	63	62	60	58	56	54	52	50	48	46	43	41	38	35	31	28	24	20	14	7	−3															
72	71	69	68	66	64	63	61	59	58	56	54	52	50	47	45	42	40	37	33	30	26	22	17	11	+3															
73	72	70	69	67	66	64	62	60	59	57	55	53	51	49	46	44	41	38	35	32	28	25	20	15	8	−3														
74	73	71	70	68	67	65	63	62	60	58	56	54	52	50	48	45	43	40	37	34	30	27	23	18	12	+3														
75	74	72	71	69	68	66	64	63	61	59	57	55	54	51	49	47	44	42	39	36	32	29	25	21	15	8	−2													
76	75	73	72	70	69	67	66	64	62	60	59	57	55	53	51	48	46	43	41	38	34	31	27	23	18	12	+4													
77	76	74	73	71	70	68	67	65	63	62	60	58	56	54	52	50	48	45	42	39	36	33	29	26	21	16	9	−2												
78	77	75	74	72	71	69	68	66	64	63	61	59	57	55	53	51	49	46	44	41	38	35	31	28	24	19	13	+5	−9											
79	78	76	75	73	72	70	69	67	66	64	62	60	59	57	55	53	50	48	46	43	40	37	34	30	26	22	16	10	−1											
80	79	77	76	74	73	72	70	68	67	65	63	62	60	58	56	54	52	50	47	44	42	39	36	32	28	24	20	13	+6	−7										
82	81	79	78	77	75	74	72	71	69	67	66	64	62	60	59	57	55	52	50	48	45	42	39	36	33	29	25	20	14	+7	−6									
84	83	81	80	79	77	76	74	73	71	70	68	66	65	63	61	59	57	55	53	51	48	46	43	40	37	34	30	26	21	15	+8	−4								
86	85	83	82	81	79	78	76	75	73	72	70	69	67	65	64	62	60	58	56	54	52	49	47	44	41	38	34	31	27	22	16	+9	−2							
88	87	85	84	83	81	80	79	77	76	74	73	71	69	68	66	64	62	61	59	57	55	52	50	47	45	42	38	35	31	27	23	17	+10							
90	89	87	86	85	83	82	81	79	78	76	75	73	72	70	69	67	65	63	61	59	57	55	53	51	48	45	43	39	36	32	28	24	19	+11	+1					
92	91	89	88	87	86	84	83	81	80	79	77	76	74	73	71	69	68	66	64	62	60	58	56	54	51	49	46	43	40	38	33	29	25	20	13	+4				
94	93	92	90	89	88	86	85	84	82	81	79	78	76	75	73	72	70	68	67	65	63	61	59	57	55	52	50	47	44	41	38	34	30	26	21	14	+6	−9		
96	95	94	92	91	90	88	87	86	84	83	82	80	79	77	76	74	72	71	69	67	66	64	62	60	58	55	53	51	48	45	42	39	35	31	27	22	16	+8	−5	
98	97	96	94	93	92	90	89	88	87	85	84	82	81	79	78	76	75	73	72	70	68	66	64	63	61	58	56	54	52	49	46	43	40	36	32	28	23	17	+10	−2
100	99	98	96	95	94	93	91	90	89	87	86	85	83	82	80	79	77	76	74	72	71	69	67	65	63	61	59	57	55	52	50	47	44	41	37	33	29	25	19	+12
102	101	100	98	97	96	95	93	92	91	89	88	87	85	84	83	81	80	78	76	75	73	72	70	68	66	64	62	60	58	56	53	51	48	45	42	38	35	31	26	21
104	103	102	100	99	98	97	95	94	93	92	90	89	88	86	85	83	82	80	79	77	76	74	72	71	69	67	65	63	61	59	57	54	52	49	46	43	40	36	32	27
106	105	104	102	101	100	99	98	96	95	94	92	91	90	88	87	86	84	83	81	80	78	77	75	73	72	70	68	66	64	62	60	58	55	53	50	47	44	41	37	33
108	107	106	104	103	102	101	100	98	97	96	95	93	92	91	89	88	86	85	84	82	81	79	77	76	74	72	71	69	67	65	63	61	59	56	54	51	48	45	42	39
110	109	108	106	105	104	103	102	100	99	98	97	95	94	93	91	90	89	87	86	84	83	81	80	78	77	75	73	72	70	68	66	64	62	60	57	55	52	50	47	43

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[1] Courtesy The Weather Bureau, U. S. Department of Commerce.

humidity, which in this example is 44 per cent. Use the dew-point table in the same way; for this example the dew point is found to be 42°F.

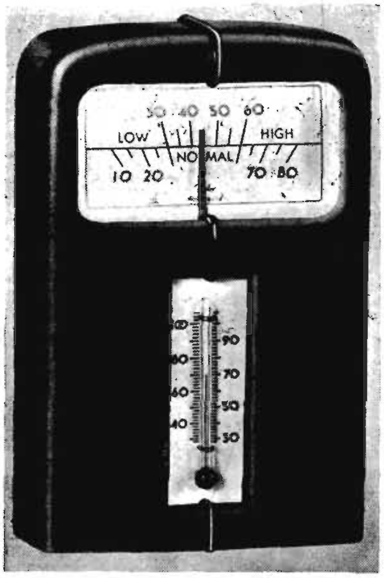

Fig. 17.5. This hygrometer contains a piece of chemically treated cellulose which is hygroscopic. (Courtesy Taylor Instrument Companies)

A hygroscopic material is one which has an affinity for water and will absorb it from the vapor which comes in contact with it. The moisture which is absorbed changes some physical characteristic of the material — its shape, length, or color — and since this change is usually proportional to the degree of saturation of the water vapor it can be used as a measure of the relative humidity. Some materials which are hygroscopic are hair, wool, cotton, and catgut. Fine human hair when carefully cleaned and processed will increase in length about 2.5 per cent when it is placed in saturated water vapor. Twisted catgut tends to untwist as it absorbs moisture, but its response is rather slow. Fine hair responds more quickly and is sensitive to small changes in relative humidity. In general, hygrometers which contain hygroscopic materials are not so sensitive as the wet- and dry-bulb hygrometers, and they also need some mechanical adjustments if the temperature range changes. For example, if one of these instruments is accurate in summer temperatures, it usually is not accurate in winter temperatures unless it has been adjusted. A hygrograph is a recording hair hygrometer. The change in length of the hairs causes an inked pointer to record on a chart. The chart is on a revolving cylinder which is driven by a clocklike mechanism. A hygrograph may be used whenever a record of the relative humidity is of value. The change in length of other

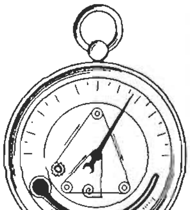

Fig. 17.6. A hair hygrometer

materials than hair may be used to move a pointer over a scale, but in general these other materials are less sensitive to changes in relative humidity.

Instruments which are designed to indicate that the humidity is high or low without giving any quantitative values are called *hygroscopes*. A Swiss "weather house" contains two figures mounted on a crossarm that is suspended at its mid-point by a piece of twisted catgut. The catgut winds and unwinds with changes of humidity and rotates the crossarm so as to bring one or the other figure out of the house. Since the catgut is slow to respond to changes in humidity, the instrument often lags in indicating sudden changes in humidity.

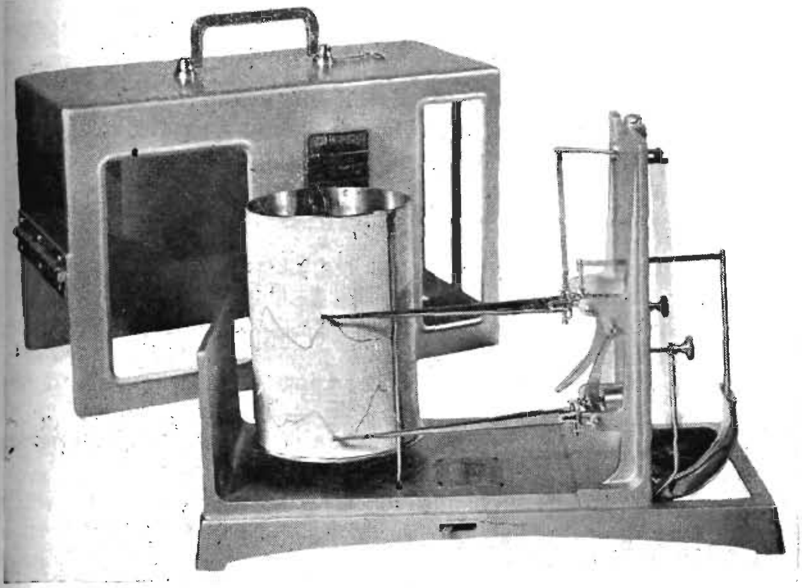

Fig. 17.7. A combination hygrograph and thermograph. (Courtesy Julien P. Friez & Sons, Inc.)

The change in color of a strip of paper or cloth which has been soaked in a solution of cobalt chloride and dried may be used to indicate roughly whether the humidity is high or low. When the humidity is high the color is pink and when low the color is blue.

100. Choice of a Humidity Indicator. A relative humidity of 40 to 50 per cent is usually desirable, but since the human body is less sensitive to deviations from ideal relative humidity than it is to deviations from ideal temperature, the relative humidity may go considerably above or below the desirable range, and people will not be conscious of the change. Therefore, if the humidity is to be kept within the desired range, a device for measuring the relative humidity is even more necessary than a device for measuring the temperature. Some of the advantages and disadvantages of various devices have been discussed above. However, devices are available at a moderate cost which give reasonably accurate measurements for home, schoolroom, or office use.

Devices for controlling the relative humidity in buildings will be discussed in the next chapter on air conditioning.

STUDY QUESTIONS

1. What is the most healthful relative humidity?
2. During what seasons of the year do we usually need to add moisture to the air? During what seasons do we probably need to remove moisture? Is the answer the same for all localities?
3. Why does furniture get loose in the joints in some homes and not in others?
4. Why does water collect on the outside of a pitcher containing ice water?
5. Why is the amount of perspiration more noticeable on a day when the temperature and relative humidity are both high, than on a day when the temperature is high but the relative humidity is low?
6. If a cake of ice is allowed to melt in a room in order to cool the air, what is the effect on the relative humidity?
7. What type of relative humidity indicator do you prefer for your home? Why?
8. What are some of the effects of living in an atmosphere of low relative humidity? Of high relative humidity?

PROBLEMS

1. If the room temperature is 70°F and the dew point is found to be 55°F,what is the relative humidity? *Ans.* 61 per cent
2. If the room temperature is 80°F and the relative humidity is 50 per cent, what is the dew point?
3. If a container which is full of air at a temperature of 20°F and a relative humidity of 80 per cent is tightly closed and brought into a room where the temperature is 70°F, what is the resulting relative humidity in the container? *Ans.* 12.4 per cent
4. If 100 cubic feet of air at a temperature of 25°F and a relative

humidity of 80 per cent is warmed to 70°F, what volume does it then occupy? What is the resulting relative humidity?

5. If the room temperature is 70°F and the wet-bulb thermometer reads 55°F, what is the relative humidity? What is the dew point? *Ans.* 35 per cent; 42°F
6. If the room temperature is 70°F and the wet-bulb thermometer reads 46°F, what is the relative humidity? What is the dew point?
7. If the room temperature is 90°F and the wet-bulb thermometer reads 70°F, what is the relative humidity? What is the dew point? *Ans.* 36 per cent; 59°F
8. If the room temperature is 80°F and the wet-bulb thermometer reads 76°F, what is the relative humidity? What is the dew point?
9. If a school room is 20 by 50 by 10 feet and the relative humidity is found to be 20 per cent, how much water must be evaporated to increase the relative humidity to 50 per cent? The temperature of the room is 70°F. *Ans.* 3.4 lb
10. In a room which is 18 by 20 by 8 feet, the temperature is 70°F and the relative humidity is 30 per cent. How much water must be evaporated to bring the relative humidity up to 50 per cent? How much is required for a house containing 5 rooms of this size? Change this last amount to quarts.

18

AIR CONDITIONING THE HOME

To many people "air conditioning" means cooling the air, but the term is used here in a broader sense to include all of the factors which affect the temperature, the motion, the cleanliness, or the moisture content of the air. For years we have heated our homes when necessary and have given considerable attention to the supply of fresh air; the ideal temperature was thought to be about 70°F, and the amount of fresh air was gauged chiefly by the comfort of the people in the home. Some of the results of poor air conditioning are headache, dullness, oppressive breathing, and general body discomfort. For a long time it was thought that headaches and sleepiness were due to a low oxygen supply or a high percentage of carbon dioxide in the air. But experiments have shown that these reactions may also be due to lack of circulation of the air or to too high or too low a moisture content as well as to the chemical composition of the air.

A few of these experiments will be described briefly. A group of people were placed in a small closed room in which the temperature was kept at 70°F. After a time the people felt much too warm and became very drowsy. When fans were started they felt both cooler and more alert. The room had not been cooled, and no new air had been introduced, but the air had been put in motion. This proved that air motion was important as well as temperature and chemical composition. In another experiment the same air was used over and over and held at 70°F, but the moisture content of the air which had been increased by the breathing of the people was decreased by drying the air, and the people were comfortable much longer than when the air was not dried. In another experiment people were put in a room at 70°F with a very low moisture content and then in another room at 65°F with higher moisture content. The people were more comfortable in the second room. In the first room they were chilly because the air was too dry and moisture from the body was evaporated too rapidly. In the second room, even though the temperature was lower, the evaporation was normal and the people were comfortable. These experiments bring out two points. There is an optimum amount of moisture for the air — if the moisture content of the air is too high or too low, people are not comfortable. Also the 70°F, which had for a long time been considered an ideal temperature, is a little higher than is necessary if the moisture content and circulation of the air are properly regulated. A study of air conditioning, then, includes a study of heating and cooling systems, ventilating systems, air-cleaning devices, and moisture control devices. These are all closely related in their operation.

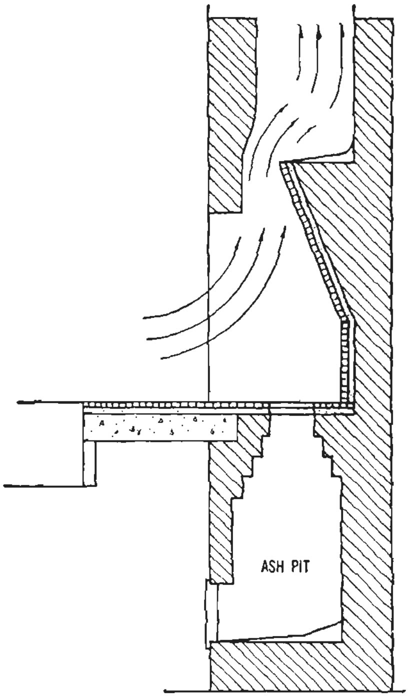

Fig. 18.1. Cross-section of a fireplace.

101. Heating Systems. Heating the home has gone through many stages of development since the days when a burning log in a cave was the complete system. At first there was not even a chimney to carry off the smoke. Later, fireplaces which provided an outlet for smoke were built. They also served as the ventilating system for the cave or cabin — in fact, they provided too much ventilation, and a large part of the heat from the fuel was carried out the chimney. The people of that age did not concern themselves with the question of moisture control, and the amount of moisture present was whatever atmospheric conditions happened to provide.

Heating stoves were first used in 1744. In a stove the draft could be controlled much better than in a fireplace, and since less air went up the chimney and the heated gases were held in the stove long enough to give out the heat to the room air, the amount of fuel consumed was much less, and the rooms were more uniformly heated. The fireplace heated chiefly by radiation; however, a great deal of the heat from a stove is distributed by convection currents. The heat is conducted through the wall of the stove to the surrounding air and heats it. The cold air, which is heavier, settles to the lower part of the room and forces the warm air up. Some heat is radiated by the stove — the amount varies decidedly, depending on the temperature of the stove.

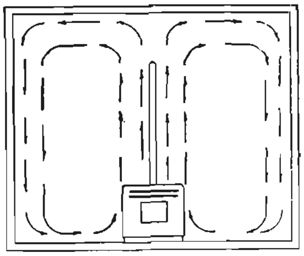

Fig. 18.2. Convection currents caused by a stove.

Three common methods of house heating are hot air, hot water, and steam. These systems are alike in that they all have a firebox from which heat is conducted to some fluid medium, which is circulated through pipes to the living quarters of the house. They differ, as their names indicate, in the medium by which the heat is transferred from the furnace to the rooms. They also differ in the type of pipe used and in the device by which heat is transferred from the heating medium to the room.

A hot-air heating system consists of a firebox enclosed in a jacket; pipes lead from this jacket to the rooms of the house, and return pipes lead from the rooms to the furnace jacket. The hot air is pushed up through the pipes, and circulates around the rooms by convection. The return pipes carry the cooled heavier air back to the furnace. The system may be adjusted to provide for total recirculation, partial recirculation, or all new air. Partial recirculation is the most satisfactory. Total recirculation makes no provision for fresh air (except for what creeps in around windows and doors or what comes in when they are opened). However, all new air furnishes more fresh air than is needed, and it is too expensive to heat so much cold air.

The hot-air pipes practically always enter the rooms at an inside wall as nearly over the furnace as possible. This is to avoid long horizontal pipes which would not provide good convection channels. If a forced-air system is used, with a fan to force the air along the pipes, the furnace may be placed on the first floor. The registers are placed on the inside walls and may be located in the floor, or either low or high in the sidewall. Usually the system is designed for year around operation of the fan for ventilation.

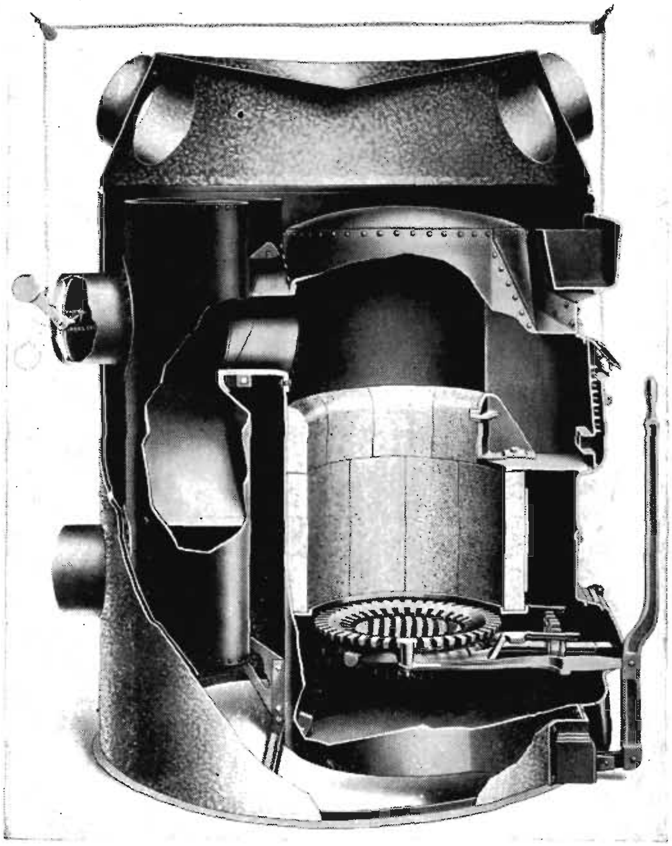

Fig. 18.3. A hot-air furnace. (Courtesy The Fox Furnace Company)

A hot-air register should have an area equal to or larger than the area of the pipe that supplies it, and the cold-air ducts should have a total area equal to the total area of all the hot-air pipes. In some installations only one cold-air duct is provided, but the house will be much more uniformly heated if several small return paths are provided instead of one large one. Cold-air ducts should be placed at the outside walls near windows, and the fresh-air duct from outdoors connects with one of the return pipes, near the furnace. It is provided with a damper so that the amount of new air may be regulated.

Hot-air systems provide for plenty of air movement and for the addition of fresh air. A water pan is always installed in the furnace jacket in an attempt to provide enough moisture for the air, but at best it probably does not provide as much as is needed. Some people think that if the pan has water in it at all times the air is absorbing as much moisture as is needed, but this is not true. In the study of evaporation, it is found that the area of the exposed surface is one of the factors which controls the amount of water evaporated. In the hot-air furnace water is evaporated as fast as possible from the given area, but this may not be as much as is needed. Sometimes pans of water are placed beneath the floor registers where the air will pass over them as it enters the room. Other methods of providing moisture

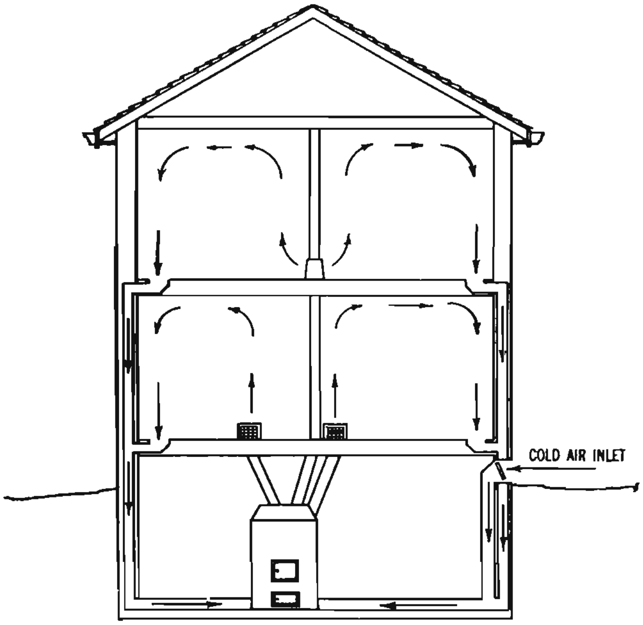

Fig. 18.4. A hot-air heating system.

will be discussed later. Removal of moisture from the air has not been mentioned in connection with heating, because for comfort it is usually not necessary to dry air which needs to be heated.

Hot-water systems have a firebox surrounded on the sides and top with a water tank or boiler. The heated water circulates from the top of the boiler through pipes to radiators placed at the outside walls of the rooms, and the cooled water returns through another set of pipes to the bottom of the boiler. The boiler, pipes, and radiators are entirely filled with water. When the water is heated, it expands, and provision is made for this expansion by one of two methods: (1) A tank which holds several gallons may be installed at some point higher than the highest radiator; an overflow pipe is connected to the sewer to take care of the overflow in case the expansion is more than the

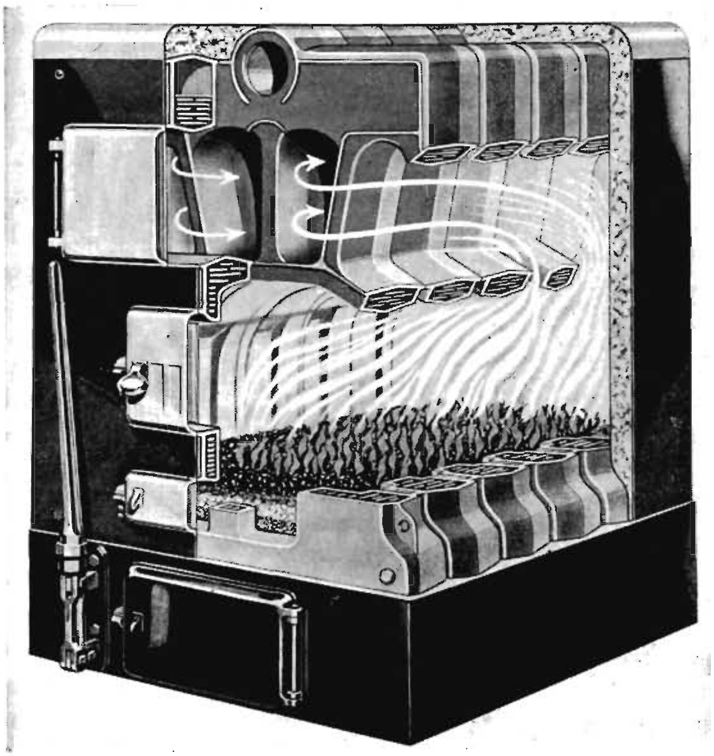

Fig. 18.5. A hot-water boiler. (Courtesy United States Radiator Corporation)

capacity of the tank. The tank must be placed where it will not freeze in the wintertime. (2) The system may be closed and a relief valve installed which will release some of the water, through a pipe connected to the sewer, in case the pressure becomes too high.

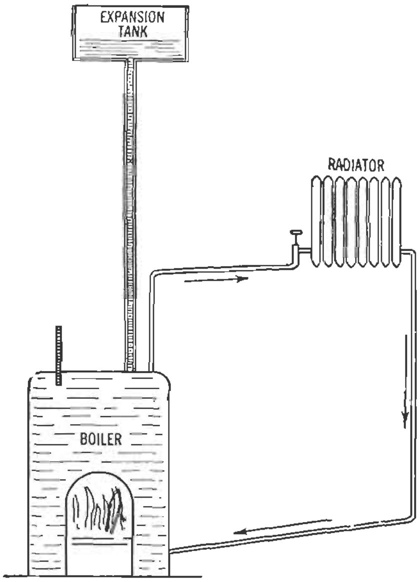

Fig. 18.6. A hot-water heating system.

In a forced hot-water heating system a pump is used to maintain circulation. Either a two-pipe or a one-pipe system may be used. In a two-pipe system the hot water is supplied to the radiators by one pipe and the cooled water is returned to the boiler by another pipe, just as it is in a gravity system. In a one-pipe system a single main pipe serves both to supply the heated water to the radiators and to return the cooled water to the boiler. At each radiator some of the hot water is diverted, by means of a special T, through a small branch pipe to the radiator and another small pipe returns the cooled water to the main pipe.

The heat which has been carried to the radiators by convection is conducted through the walls of the radiators and then is distributed around the room by convection currents and by direct radiation. The finish of the radiator is an important factor in determining the amount of radiation. Bright metallic paint reduces the amount of radiation and dull paint increases the radiating ability. Long, low radiators are better than tall radiators because they furnish the heat to the room at the place where it is needed.

A hot-water heating system provides no ventilation by means of the heating system itself. There is motion of the air in the room because of convection currents, but no new air is brought in. Sometimes air vents are placed in the walls behind the radiators so that the cold, fresh air coming in will be warmed as it passes over the hot radiators. The system provides no moisture conditioning either. Pans of water hung on the radiators help some but seldom provide enough water vapor. Humidifiers designed for the tops of radiators are better because they have a larger evaporating surface.

A steam heating system is similar in construction to a hot-water system but it is not completely filled with water — only enough is used to ensure having water over the top of the firebox at all times. Steam under a pressure of 2 to 5 pounds per square inch is used for small systems; higher pressures are necessary for larger systems. Some systems, called *vacuum-steam systems* operate at a pressure slightly below normal; therefore the steam forms at a temperature below the normal boiling temperature. A safety valve is provided for protection if the pressure should run too high, and a water-level gauge shows the level of the water in the boiler. A steam system may be installed with only one set of pipes — the steam goes to the radiator and the condensed water returns to the boiler through the same

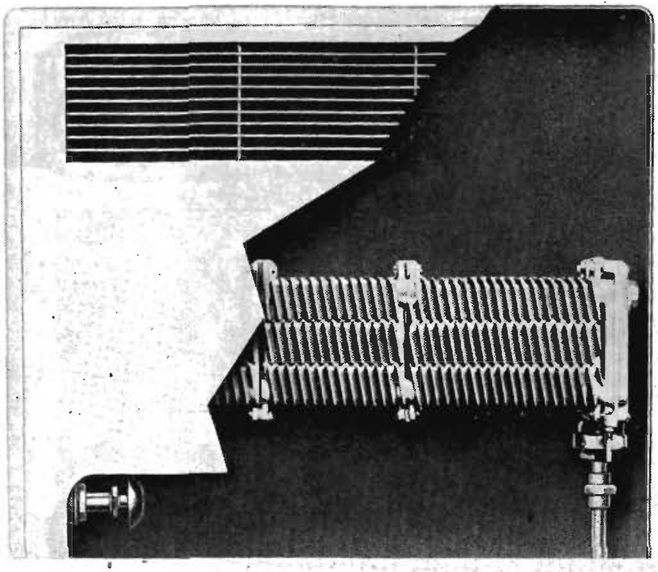

Fig. 18.7. The radiators may be installed behind grills which are flush with the wall. (Courtesy American Radiator Company)

pipe — but separate return pipes are far more satisfactory. The same difficulties regarding ventilation and moisture control are encountered in steam heating that were discussed under hot-water heating, and are provided for in the same manner.

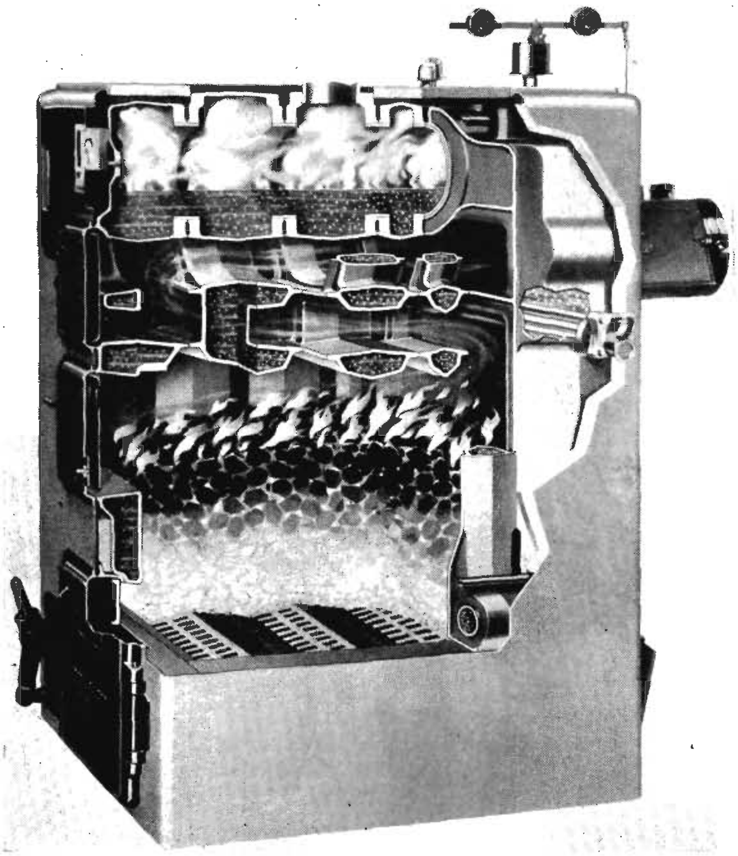

Fig. 18.8. A steam boiler. (Courtesy American Radiator Company)

Any of the above heating systems may be used for panel heating, in which the building structure itself is heated directly either by means of warm air ducts or by hot-water or steam coils located beneath the surfaces of the floors, walls, or ceilings. These heated surfaces, in turn, warm the air and objects in the rooms. This method of heating eliminates registers and radiators in the living quarters of a house. In general, the installations are designed to provide sufficient heat with maximum floor temperatures of approximately 85°F and wall temperatures of approximately 115°F.

The general air temperature may be maintained well below 70°F and yet people will be comfortable if the heating panels have been well designed.

There is no one best heating system. For each individual installation there are various factors to be considered, and then a choice may be made. Some of the factors which must be considered are the following:

1. Initial cost
2. Operating expense — fuel, repairs, and labor
3. Prevailing type of weather
4. Flexibility of system to varying weather conditions
5. Size and construction of house
6. Simplicity of operation
7. Automatic features
8. Cleanliness of operation

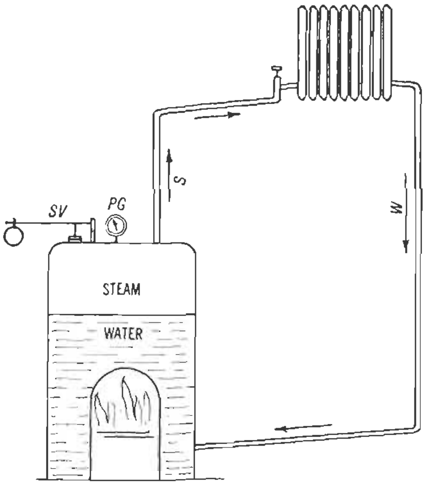

Fig. 18.8a. A steam heating system.

Hot air is usually less expensive to install than hot water or steam, and is the most flexible of the three systems. The warm air circulates soon after the fire starts. In a hot-water system there is a large amount of water to be heated, but it will begin to circulate with only a few degrees increase in temperature. A hot-water radiator will furnish heat for some time after it is turned off because of the high specific heat of water and because there is a large amount of water in the radiator. A steam system will supply heat in a reasonably short time after the fire is started, because the amount of water to be heated to the boiling point is small, but no heat will come to the radiators until after the water has reached the boiling point. A steam radiator will cool quickly after it is turned off, since there is a small mass of material in the radiator to furnish heat. A very much exposed house must be provided with a more adequate heating system than a house which is protected by trees, hills, or other houses. If automatic controls are provided, there is really very little difference in the simplicity of operation between the different systems, but the caretaker must understand the particular system which he is operating. The problem of cleanliness is solved to a large extent by the choice of fuels.

A fireplace, while not considered as a house-heating system, is a very desirable addition to any of the systems discussed above. It is usually installed for the cozy atmosphere it lends to a room rather than as part of the heating system, but that factor does not detract from its further usefulness. It also provides ventilation, which is especially needed with hot-water and steam-heating systems. Small gas heaters and electric heaters are also useful as auxiliary heating units, and they may be installed in the fireplace instead of a coal or wood grate.

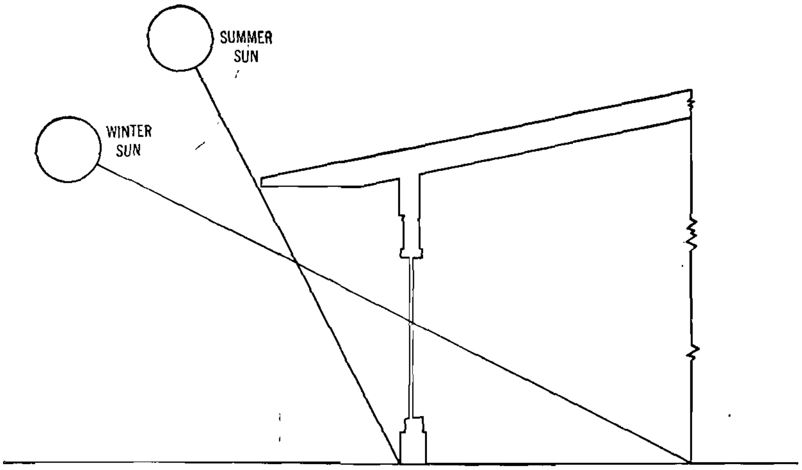

Fig. 18.9. If a house is to be heated by the sun, the pitch and overhang of the roof must be carefully planned to admit the sun's rays in the winter but to keep them from entering in the summer.

102. Solar Heating. If a house is to be heated with energy from the sun, the house must be specially designed to permit a maximum of sunlight to enter as many rooms as possible in the winter. This requires careful orientation with reference to the compass points, consideration of neighboring buildings, and scientific location of the windows with respect to the sun. Several times the usual window area is provided on the south side of the house. In general, large east and west windows are to be avoided because they provide very little more heat in winter and permit a great deal of heat to enter in the summer when the sun rises and sets farther north. Overhanging eaves and awnings keep the sun's rays from entering the south windows in the summer when the sun is high.

Glass areas may be ordinary glass, plate glass, or structural glass. For large areas a special type of glass is used. Two sheets of glass are mounted in metal so that they are separated by a sealed layer of dehydrated air. Frost and water vapor never collect on these windows and little heat is lost by conduction.

The infra-red rays from the sun enter as short waves which are absorbed by the objects in the room. These objects in turn reradiate energy of a longer wavelength to which the glass is impervious. Thus the large glass areas form a heat trap for the sun's radiant energy. In most climates solar heating must be supplemented with a fuel heating system.

103. Heating by Reverse Refrigeration. It will be recalled that a mechanical refrigeration system removed heat from the food compartment of a refrigerator and this heat was released from the system into the kitchen air by the condensing coils. Unlikely as it sounds, outdoor air in winter is a good source of heat, because its temperature is decidedly above absolute zero. (Air at 0°F has about 85 per cent as much heat in it as air at 70°F.) Figure 18.10 shows how a refrigeration unit may be used to heat the air in a building. Cold air enters as shown in the diagram and is then ejected at a still lower temperature. The heat which is removed from the air is absorbed by the refrigerant as it changes from a liquid to a gas in the expansion coils. This gas is compressed and its temperature rises. It then passes through the condensing coils where it gives out heat and gradually changes back into a liquid ready for another cycle. The heat which is given out as the gas passes through the condensing coils is absorbed by the air which is circulated through the house. But this heat was obtained from the cold outdoor air. The only expense for operation is for the electricity to run the system, but in places where the rate is from 1 to 2 cents per kilowatt-hour the cost of operation becomes reasonable. However, the initial cost of the apparatus is still quite high. Another possibility is to use water pumped from the ground, instead of outdoor air, as the source of the heat. The same system, by making minor adjustments, may be used to cool the air in summer.

✓ **104. Air-Cooling Systems.** One of the most satisfactory methods of cooling the air in a building is to force the air over the expansion coils of a refrigeration system. Forced circulation is necessary to make the colder denser air rise if the cooling system is in the basement or to make it circulate if the cooling unit is on the same level as the rooms to be cooled. Instead of using a refrigeration system the air may be forced over pipes through which very cold water is flowing. This method of course is limited to localities where it is possible to pump very cold water from a well. The air may be cooled and cleaned by forcing it through a spray of cold water, but unless the temperature of the water is quite low the relative humidity may be increased above a desirable amount by this method. If the house is heated by a hot-air furnace, the cooled air is circulated through the

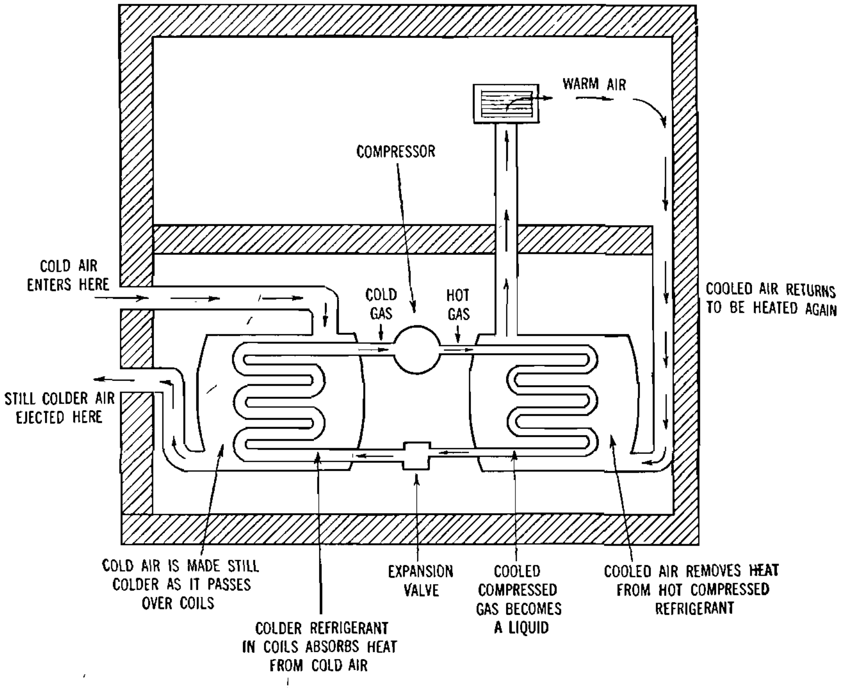

Fig. 18.10. Heating by reverse refrigeration.

ducts of the heating system, but if the house is heated by steam or hot water, ducts for the circulation of the cooled air must be provided.

A less satisfactory cooling unit consists of a box filled with excelsior which is kept damp by water which drips into the top of the box. A fan forces air through the damp excelsior, and heat is removed from the air to evaporate the water. But as a result of this evaporation the air may be too damp for comfort.

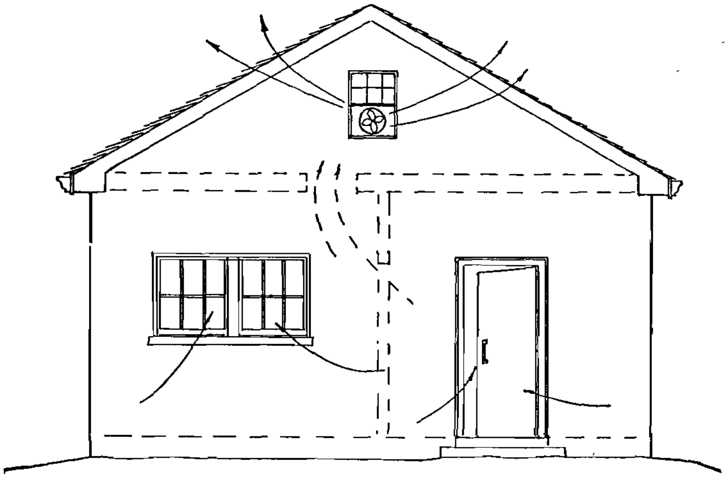

Fig. 18.11. Use of exhaust fans in the attic windows to remove hot air from the house.

The hot air may be removed from the house during the night by opening the house and turning on large exhaust fans installed in the attic. The less dense, hot air is removed, and the heavier, cooler air enters the house.

105. Air-Cleaning Devices. One of the important phases of air conditioning is that of dust, pollen, bacteria, and smoke removal. Air may be cleaned by passing it through a spray of water, or through a filter of felt, spun glass, or steel wool. It is surprising how much dust and dirt is collected in these filters, and as a result of their use the air we breath is much cleaner. Also the need for house cleaning, dusting, and redecorating is decreased if air is filtered.

106. Humidity Control. If the moisture content of the atmosphere is low, rapid evaporation of moisture from the skin may cause a person to feel chilly when, so far as the temperature is concerned, he should be comfortable. If this situation exists, it is better to increase the relative humidity rather than the temperature. Also if the air entering the lungs has very little moisture in it, the membranes of the respiratory organs may become dry and inflamed. A low relative humidity often makes people feel sleepy, and they are not able to work efficiently. On the other hand if the humidity is too high, there is less than normal evaporation from the skin, and the person feels too warm when the temperature is not high enough to cause discomfort. Because he is uncomfortable he will not accomplish as much as he would if he were in a comfortable atmosphere.

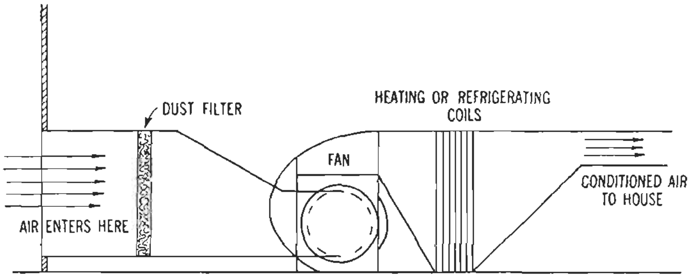

Fig. 18.12. Diagrammatic cross section of an air-conditioning system.

Various ways of increasing the relative humidity have already been mentioned. The water jacket in a hot-air furnace and pans of water under registers or on radiators all help. Usually a low relative humidity exists when the air has been heated; but if the warm, dry air is passed through a spray of warm water or through a wet filter the amount of moisture will be increased. If the air is too damp, it is often due to the fact that the air has been cooled; however, if the air is cooled by passing it over refrigeration coils or pipes through which cold water circulates, the water vapor will be cooled below its dew point, and the excess moisture will be condensed on the pipes.

107. Coordination of Controls. Several times in the preceding discussion it has been pointed out that control of only one of the factors in air conditioning may result in a most undesirable combination of atmospheric conditions — for example, a change of temperature immediately influences the relative humidity, and often low relative humidity results from heating the air and high relative humidity from cooling the air. Sometimes in our zeal to secure temperature and moisture control, we have entirely neglected ventilation, and seldom have we cleaned the air. Successful air conditioning results from coordinating all of the controls for temperature, relative humidity, cleaning, and ventilation.

108. Air Conditioning in Industry. Some materials are very difficult to handle if atmospheric conditions are not right. In paper mills, textile mills — silk and rayon especially — and flour mills the humidity is regulated to improve the quality of the product and to decrease the danger of fires or dust explosions. Food industries realize the importance of humidity control, and of air cleaning to remove dust and bacteria, both in the production and storage of foods. Candy companies are much concerned with temperature and moisture control. In furniture factories and in automobile plants humidity and air-cleaning controls make it easier to apply and to dry lacquers and varnishes. The manufacture of gelatine products including photographic films is especially affected by the temperature and moisture content of the air. Many other examples of the importance of air conditioning in industries might be mentioned. Since the employees work more efficiently in a conditioned atmosphere, the improve-

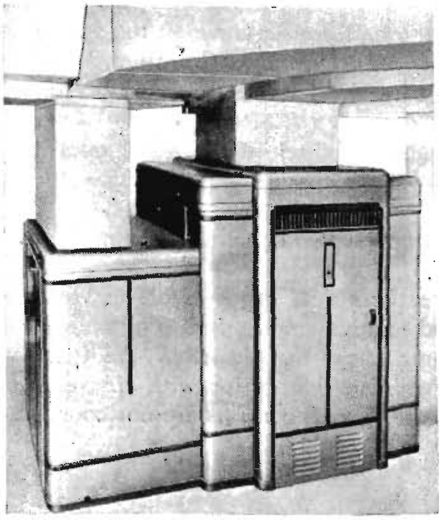

Fig. 18.13. An air-conditioning unit. (Courtesy The Fox Furnace Company)

ment in the product and in the efficiency of operation have justified the cost of the air conditioning.

STUDY QUESTIONS

1. What is included in air conditioning?
2. Describe a situation in which you think a hot-air heating system would not be satisfactory. What type of heating system do you think would be satisfactory?
3. Explain how a house may be heated by reverse refrigeration.
4. What are the reasons for installing fireplaces in modern homes?
5. What effect does a fireplace have on the ventilation of a room?
6. What attention must be given to either a steam or a hot-water heating system if the furnace is not to be operated during cold weather?
7. If a given hot-air register in the home does not furnish enough hot air, what is the reason, and how may the difficulty be corrected?
8. What are some of the benefits resulting from an air-cleaning system?
9. Mention several unusual types of places where air conditioning has been used to advantage.
10. What are some of the unsatisfactory conditions which are sometimes encountered in connection with air conditioning because of the fact that the various controls are not coordinated?

19

THE WEATHER

It is sometimes said that we constantly talk about the weather but never do anything about it. But since methods of air conditioning have become more practical someone has said that we are at last doing something about the weather. However, air conditioning can hardly be called changing the weather — we are only changing some of those factors which also enter into the weather, and we are changing them in very limited spaces. In this chapter we are concerned with the conditions that make up the weather in the great outdoors where, it is true, we cannot do anything about it.

Weather is the result of many atmospheric conditions such as temperature, rainfall, humidity, wind direction and velocity, air pressure, and sunshine. We describe the weather by saying it is hot, cold, dry, damp, foggy, clear, calm, or stormy. The weather varies from day to day, from season to season, and from one locality to another. *Weather is the condition of the atmosphere for an area at a given time while the climate is the summation of the weather conditions for an area over a period of many years.*

109. The Atmosphere. *The atmosphere is the gaseous layer which surrounds the whole earth.* Since it is odorless, colorless, and tasteless we are not usually conscious of it unless it is in motion or we are moving rapidly through it. The atmosphere is composed chiefly of air with small amounts of water vapor and dust. Air is a mixture of gases. About 78 per cent (by volume) of the air is nitrogen and about 21 per cent is oxygen; the remaining 1 per cent is chiefly argon, with a small amount of carbon dioxide and traces of several other gases. These proportions are remarkably constant over the earth's surface and at all seasons of the year. At great elevations (above 10 to 12 miles) the proportions may be different on account of the different densities of the various components. If the air had a constant density equal to that which it has near the earth's surface, the layer of atmosphere would be about 5 miles deep. But since density decreases with altitude about 50 per cent of the air is within 3.5 miles of the earth's surface and about 97 per cent is within 18 miles.

To man, oxygen is the most important gas in the air. It is necessary for all plant and animal life, and for combustion. Aviators must sometimes use oxygen masks because at high altitudes the lungs cannot absorb enough oxygen from the air to support life. The chief function of nitrogen is to furnish food for plant life; carbon dioxide is also an important plant food. The amount of water vapor in the atmosphere depends in part upon the temperature and in part upon whether it is over land or water — the amount varies from a trace to as much as 4 per cent by volume.

110. Temperature. Temperature is an important weather factor, not only because of the effect of temperature directly, but because of the effect it has on other factors. The sun is the chief source of the earth's heat energy. The enormous amount of energy radiated by the sun travels out in all directions, and while the amount which is intercepted by the earth is a very small part of the total emission, that which is directed toward the earth comes through interplanetary space with practically no loss until it reaches the earth's atmosphere. However, as it passes down through the increasingly denser atmosphere, some of the energy is absorbed by water vapor (including clouds) and by dust particles. The amount absorbed depends upon the amount of moisture and dust in the air and the distance the waves have to pass through the air. Thus, when the sun is directly overhead, as in the summertime, the distance the waves travel through the atmosphere is less than when the waves come at an angle as they do in the winter. This explains in part the difference in the amount of heat received from the sun at different seasons. People are sometimes surprised to find on a cool day in summer that "the sun is just as hot" as it was the day before when the temperature was much higher. The sun is sending energy to the earth at almost exactly the same rate on the two succeeding days, but other factors have made the temperature different on the two days. Another example showing the same situation is that of discovering a reasonably warm place on the south side of a building in the winter on a day when the temperature is very low. Icicles may be melting because of the radiant energy received, even though the temperature of the atmosphere in general is below the freezing point of water.

Some of the energy which reaches the earth from the sun is reflected into the air, but much of it is absorbed so that the temperature of the earth is raised. At night, when no energy is being received from the sun, this heat is reradiated and keeps the air from becoming as cold as it otherwise would. The rate at which heat is lost from the earth is determined to a great extent by the presence or absence of clouds above the earth. One often hears the remark, "If it clears off tonight, it will frost." This simply means that if there are no clouds to hold the heat in it will be lost so rapidly that the temperature will drop below the freezing point.

Fruitgrowers sometimes build smudges in their orchards when there is danger of frost harming the flowers or the fruit. The smoke collects above the orchards and acts as a blanket to hold the heat close to the earth. The heat radiated by the earth is thus retained.

111. Atmospheric Circulation. As has been mentioned before, the amount of heat received by various parts of the earth varies decidedly. More is received in the equatorial regions and less in the polar regions; since the equatorial and polar regions are at quite different temperatures, there is a general tendency for the warm air at the equator to be pushed up and flow either way to the poles while cold polar air flows toward the equator next to the earth. Consequently, air masses move from one region to another. When the movement of these air masses is horizontal it is known as a *wind;* all other motions of the air are called *currents* (up currents and down currents). This general motion of air masses is modified by several factors such as the rotation of the earth, the irregular distribution of land and water areas, and the unequal amounts of heat absorbed by the different layers of air. The layer next to the earth always absorbs the most heat. As a result atmospheric circulation becomes very complex.

112. Precipitation. When warm air is pushed up it carries with it water vapor which has evaporated from oceans, lakes, rivers, the ground, and from plants. As the air rises it expands and the air and water vapor are cooled. If the water vapor is cooled below its dew point some condenses into tiny drops which form *clouds*. If conditions cause these tiny drops to form into larger drops *rain* may fall. If the temperature is below the freezing point, the precipitation may be in the form of *snow*, *sleet*, or *hail*. If a cloud forms near the ground, it is called a *fog*. Fogs are often formed also when warm, moist air is blown over a colder region — for example, when warm, moist air blows over a cold land area or over a cold ocean current.

If the water vapor in the atmosphere is cooled until it becomes saturated, condensation occurs and *dew* is formed. If the saturation temperature is below 32°F the water vapor freezes and *frost* is formed. Since the earth and objects close to it cool faster than the surrounding atmosphere the water vapor closest to the earth is the first to condense. Hence dew or frost forms first on objects close to the earth and, as the cooling proceeds, it forms on higher objects. For example, dew or frost is formed on grass and plants, especially in low places, before it is formed on the roofs of buildings. Dew or frost forms on objects which are poor conductors of heat before it forms on those which are good conductors; the amount of heat lost by radiation is practically the same for all objects, but those that are good conductors receive additional heat from the earth to replace this loss, while the poor conductors do not receive more heat so readily.

113. Air Masses and the Weather. *An air mass is a widespread body of air which is approximately homogeneous horizontally, but not vertically because the temperature and the pressure decrease with an increase in altitude.* Air masses are classified as polar continental, polar maritime, tropical continental, and tropical maritime. In general the polar masses are cold and the tropical masses are warm. Since land masses change temperature more rapidly than water masses, the continental air masses vary more in temperature and humidity than do the maritime air masses. Consequently the characteristics of the air masses are modified as they flow along. In making forecasts the Weather Bureau studies the source of the air mass, together with the surface influences to which it has been exposed. The lower layers of an air mass are changed more than the upper layers.

When warm tropical air masses meet cold polar air masses the two do not mix to form a gradual transition from one to the other — instead a definite surface separates the two. This surface is called a *front.* At a front there are sudden changes in temperature, atmospheric pressure, and relative humidity. Fronts are neither horizontal nor vertical but are sloping. If warm air is replacing cold air, it is a *warm front;* but if cold air is replacing warm air, it is a *cold front.* Warm fronts tend to flow up over cold masses, but cold fronts flow in under warm masses of air. As a result, areas which are known as *high- and low-pressure areas* develop. These areas move in more or less regular paths over the surface of the earth. Figure 19.1 shows some of the general paths of these areas in the United States. Lows are generally associated with stormy weather and precipitation, while highs are associated with light breezes and clear skies.

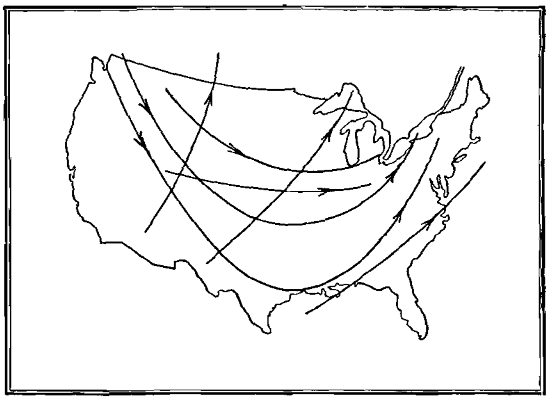

Fig. 19.1. Storm paths across the United States.

114. Work of the Weather Bureau. While it is true that men cannot change the weather, they can profit by studying it, and by learning as much as possible about the weather conditions which will probably exist in the next few hours or the next few days. The general trends of changes in the weather for a given area are known from a study of the weather records; that is, about how cold it will be in the winter, about how hot in the summer, when it will be safe to plant certain crops in the spring, and when they will have to mature in the fall in order to avoid injury by frost. Of course these conditions vary from year to year, but they are a guide by which to carry on our lives. But in addition much more exact information from day to day is needed. The health and comfort and even the lives of plants and animals often depend on knowing, even a few hours in advance, the important weather changes which are expected to occur. The weather forecast is often the deciding factor as to whether a plane starts on a certain trip, whether a vessel leaves port, or whether it is advisable to go on a camping or a hunting trip. The forecast warns the farmer in time to make extra provision for the comfort of his livestock. School children are often started home early in rural districts if a blizzard is due to arrive before night.

Men of all ages have scanned the heavens, searching for weather indications which would enable them to plan a little farther ahead. As certain phenomena were observed to recur, many weather proverbs were formulated, such as:

"Moonlight nights have the heaviest frosts."

"Heavy frosts generally are followed by fine clear weather."

"Every wind has its weather."

> "Sky red in the morning,
> Is a sailor's sure warning.
> Sky red at night
> Is the sailor's delight."
>
> "Curls that kink and cords that bind
> Signs of rain and heavy wind."
>
> "Men judge by the complexion of the sky
> The state and inclination of the day." — Shakespeare

There is a good deal of truth in these old sayings, and from this simple beginning the science of meteorology has developed. *Meteorology is the study of the atmospheric conditions that affect the weather.* Weather is dependent on many factors, and if the resulting conditions always recurred in exactly the same combination, weather forecasting would be relatively simple. But since there are so many variables in any one combination of weather conditions which may occur in any one locality, the difficulty of forecasting is obvious.

The United States government, seeing the great possibilities in working out the relations of the factors that control weather, and also the great benefit that would be derived by the public from the results of weather study, provided by a special act of Congress in 1870 that the Secretary of War should direct the organization of weather observations and provide for issuing storm warnings by means of suitable signals along the seacoast and the Great Lakes region.

Prior to this time, the army had kept for its own use fairly accurate weather data taken at different military posts over the country, but the constant shifting of troops and the insufficient training of the observers created a demand for an independent service. In addition to the records kept at the military posts, many institutions of learning, and many individuals who became interested, cooperated with the Smithsonian Institution as early as 1847 in keeping daily records or records of unusual weather phenomena. The signal service established in 1870 by the army proved so valuable to navigation and marine interests that, because of the demand of the general public, Congress in 1872 extended the service to include all commerce and agriculture. The value of the service was so evident that in 1891 the Weather Bureau was established and was made a part of the Department of Agriculture. Since that time liberal provision has been made for the work of the Bureau, and the system of making observations and of distributing the forecasts has been greatly improved and extended. In 1940 the Weather Bureau was transferred to the Department of Commerce.

The Weather Bureau organization consists of a central administrative and scientific office in Washington, D. C., and many offices and stations of various grades throughout the United States and in Alaska, Hawaii, and Puerto Rico. For forecast purposes the United States is divided into forecast districts. In each district forecasts are made several times daily for each of the states in the district. These forecasts are made up from the information sent to the center by some observers in the district who report at 6 A.M., noon, 6 P.M., and midnight, and by other observers who report only once or twice a day. Forecasts in normal times are published in the newspapers, announced over the radio, and in some cases over the telephone. The morning forecast is telegraphed from the forecasting station to many of the observation stations in the district. Special forecasts are made if storms or hazardous weather conditions are expected.

The Weather Bureau not only prepares weather forecasts but accumulates and publishes information concerning existing weather conditions and climatic characteristics of a region. A partial list of the Bureau's services gives some idea of the scope of the work. These include the agricultural, marine, airways, forest fire, rivers and flood, and aerological (upper air) services.

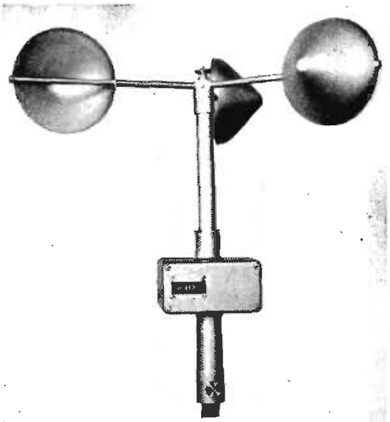

Fig. 19.2. An anemometer. (Courtesy Julien P. Friez & Sons, Inc.)

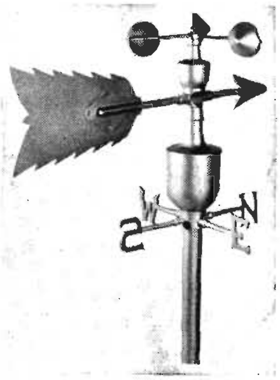

Fig. 19.3. A combination anemometer and wind-direction apparatus. (Courtesy Julien P. Friez & Sons, Inc.)

115. Instruments Used by the Observer. The instruments used in the larger weather stations include maximum and minimum thermometers, a thermograph, a barometer, an anemometer, a wind-direction recorder, a sunshine-duration recorder, and a rain gauge. A few stations use radiosondes.

Maximum and minimum thermometers, the thermograph, and barometer have already been discussed. The thermometers are kept in an instrument shelter house, which should stand well out in the open, over sod, and where air currents can circulate freely about it. If not kept in a shelter house, the thermometers should be kept on the north side of a building, fastened so as to stand out a little from the building.

An *anemometer* has three hemispherical cups placed on rods at 120° angles with each other. The cups "catch the wind" and cause the central spindle to rotate; the rate of wind flow is recorded in terms of miles per hour.

The *wind-direction apparatus* is an automatic recording device operated by a weather vane. As the wind turns the weather vane, dots are recorded by an electrical mechanism on a revolving chart, the location of the dot showing the wind direction. The vane should be placed on top of a building which is high enough that wind currents will not be disturbed by surrounding buildings and trees.

The *sunshine recorder* is a thermostatically operated device. If the sun shines, a mercury thermostat responds to the radiant energy received, and closes an electric circuit which causes a pen to record on a revolving chart. The thermostat is enclosed in a glass tube from which the air has been extracted, therefore the only heat which reaches the mercury is transferred by radiation. The bulb of the thermostat is coated with lampblack to make it a good absorber of radiant energy. When the sun does not shine the black bulb radiates heat rapidly, so it cools, the mercury contracts, and the circuit is opened.

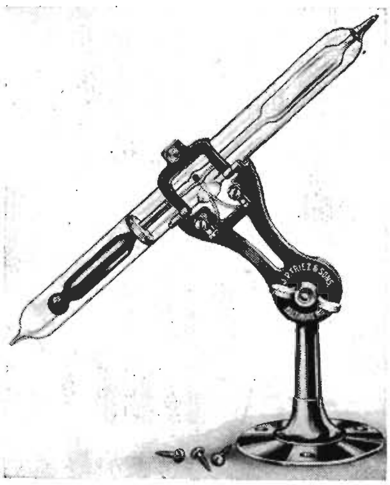

Fig. 19.4. A sunshine-duration transmitter. (Courtesy Julien P. Friez & Sons, Inc.)

The *rain gauge* is constructed of sheet metal. It is a cylindrical container with a funnel-shaped top, the area of which is ten times the cross section of a brass tube placed under it in which the rain is collected. Hence 1 inch of water measured in the brass tube represents only 0.1 inch of actual rainfall. The depth of the water is measured with a special scale on which the units are ten times the normal lengths of the units. Thus the rainfall can be measured accurately to hundredths of inches. The rain gauge should be placed out in the open, securely staked to the ground.

Its distance from any higher object should be at least equal to the height of that object. The reason for this is that disturbed wind currents prevent a representative fall of rain in the gauge.

In order that the forecaster may obtain information about the upper atmosphere, *radiosondes* are used at some stations. A radiosonde is attached to a small balloon and released. It may travel to an altitude of 10 to 15 miles before the balloon bursts. A small parachute then opens to retard the fall of the apparatus. If found, the radiosonde should be returned to the Weather Bureau because some of the parts can be used again. Radiosondes are equipped with a radio transmitter, a battery, an electrical resistance thermometer, an aneroid barometer, and a hair hygrometer. The signals which are sent out are controlled by the temperature, the pressure, and the relative humidity of the atmosphere. These signals are received at a ground station where they are interpreted.

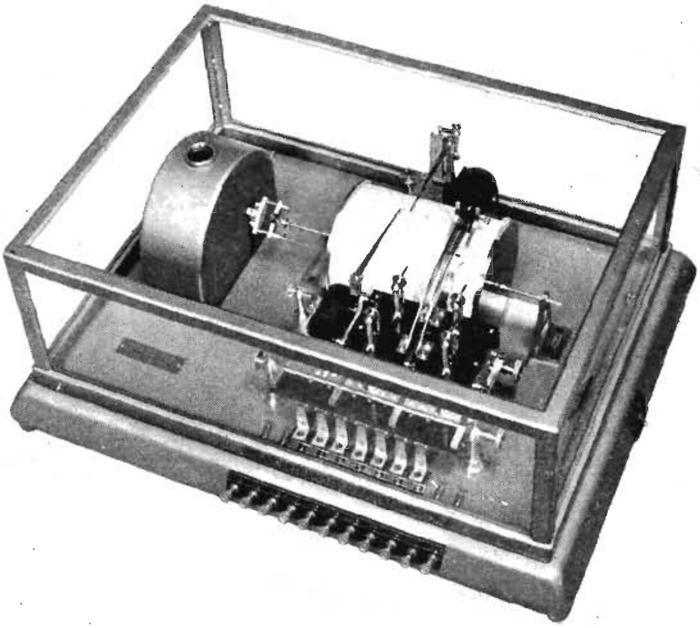

Fig. 19.5. Registering device for recording rainfall, sunshine duration, wind direction, and wind velocity. (Courtesy Friez Instrument Division, Bendix Aviation Corporation)

Not all weather observers have all of these instruments. Some are provided only with maximum and minimum thermometers and a rain gauge. While the observer may be required to read the rain gauge only once every 24 hours, he may obtain interesting and valuable data for local drainage problems by reading the rain gauge for a particular rain, and noting the time it took

Fig. 19.6. Rain gauges. (Courtesy Taylor Instrument Companies)

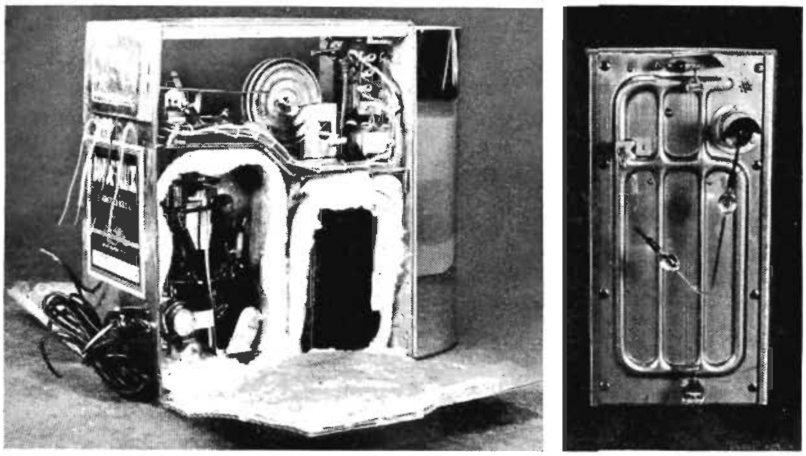

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Fig. 19.7. (a) A radiosonde opened to show placement of parts. The pressure unit is in the top, the radio transmitter at the lower left, and the battery at the lower right. (b) The humidity and temperature units of a radiosonde. (Courtesy U. S. Weather Bureau)

for the rain to fall, and the time it took for it to drain off. He may also note the height to which the water rises in the existing drainage ditches. In towns, note should be made as to whether the storm-sewer system is able to take care of the drainage.

Fig. 19.8. Observer is ready to release balloon with parachute and radiosonde attached. (Courtesy U. S. Weather Bureau)

STUDY QUESTIONS

1. What is the difference between weather and climate? Do they both change?
2. What gas is most abundant in the atmosphere?
3. Approximately what per cent of the air is oxygen?
4. What is the chief factor that determines the temperature of a region? What are other important factors that enter into determining the temperature?
5. Describe the general circulation of the atmosphere of the earth.
6. What is a wind? What is an air current?
7. What is the difference between a fog and a cloud? Between dew and frost?

8. What is an air mass?
9. Name the four main types of air masses.
10. What is a frost?
11. How does a warm front displace cold air?
12. How does a cold front displace warm air?
13. What are the characteristics of a low-pressure area?
14. What are the characteristics of a high-pressure area?
15. Define meteorology.
16. Of what value are continuous weather records?
17. What factors does the forecaster need to know in order to make a forecast?
18. How is the information collected for making forecasts?
19. How are the weather forecasts distributed?
20. What other work does the Weather Bureau carry on in addition to making forecasts?
21. Describe the various "weather" instruments.

ELECTRICITY

20

SOURCES AND USES OF ELECTRICITY

In ancient times a few isolated bits of information constituted all that was known about electricity — the ancients were not aware of the slightest connection between the few peculiar phenomena which they had observed. They had found some pieces of magnetic ores and were puzzled at the attraction these pieces of material had for each other and for small bits of iron. They knew that if a piece of amber was rubbed with silk that the amber acquired the ability to attract the silk to it. The ancients had seen flashes of lightning and knew some of the effects of lightning. They had seen the "northern lights," and the glowing discharge that frequently appeared around the metal tips on a ship's mast and which was called *St. Elmo's fire.* All of these phenomena were attributed to the gods — the gods were showing either pleasure or wrath as the occasion required. Some had experienced the sting of the electric eel. But these few bits of information constituted the sum total of their information about electricity. For centuries after that, even after some other discoveries had been made, electricity was only something to play with — something peculiar and interesting, but not of any practical value.

116. Significant Electrical Discoveries. In 1752 Franklin performed his kite experiment and learned several things about lightning. He was the first to advocate the use of lightning rods for protecting houses during electrical storms. Volta in 1793 found that a continuous current of electricity could be obtained by chemical methods, and currents generated in this way have been very useful. However, as a source of energy for operating electrical machinery as we know it now, batteries would be quite inadequate and very expensive.

In 1819 Oersted found that a wire which had a current flowing through it had some of the same properties as a magnet. Faraday reasoned that, if a wire which was carrying a current had magnetic properties, he should be able to use a magnet to produce a current in a wire. He experimented along this line for several years, and in 1831 made the first simple electromagnetic generator. But Faraday was not interested in the development of generators for producing electrical energy for commercial purposes and it was about thirty years later before the first successful commercial generator was built. It was later used to supply current for carbon arc lights. Edison, in 1879, was successful in making incandescent lamps. Since 1880 there has been rapid progress in the development of the theory and use of electricity.

Electricity has changed our mode of living decidedly. It offers a clean, convenient way of transferring energy, and has made it possible for machines to do huge amounts of work which were formerly done by people. One electric motor can do the work that required thousands of slaves in ancient times. We are so accustomed to having electricity furnish light and heat and operate motors that we look upon it as a necessity. Many people today can scarcely realize what living conditions would be without electricity; yet, while something has been known of electricity for over 2500 years, most of the development in electricity for the home has taken place within the last 60 years.

Electric lights were installed in a few homes soon after 1880, but electrical heating devices and motors for use in the home have been developed chiefly since 1915. The housewife now uses electricity for lighting, cooking, sewing, washing, ironing, cleaning, and refrigeration. Electricity does all of these things quietly, efficiently, and safely. An endless supply of energy comes through wires hidden in the walls where they are out of sight and out of the way. In fact, so many things are done with the aid of electrical energy that this is sometimes spoken of as the "electrical age," and a housewife is now expected to know what was formerly deemed necessary only for a scientist.

But for all the great progress which has been made we have probably just begun to realize the possibilities of electricity. In the total consumption of electrical energy of all kinds the United States now leads the world. We use 1 1/2 times as much per capita as is used in Great Britain. We use 150 times as much per capita as is used in China.

This great expansion has been possible only because efficient generators have been built and efficient methods of distribution have been worked out. The transformer has made long-distance transmission of electrical energy practical. When we pay for electricity we are paying for the electrical energy which has been delivered to us at our homes or in our places of business.

117. A Current of Electricity. What is a current of electricity? Our present concept of matter is that it is made up of atoms which in turn are composed of various kinds of particles, including tiny negatively charged particles called *electrons*. In some materials, notably metals, some of these electrons are relatively free to migrate through the material if a force is applied to cause them to move. When the electrons move the result is a current of electricity. For years a current of electricity was a mystery — now we know it is a *stream of electrons*. We use it dozens of times a day, and even cease to be amazed when we hear of some new electrical discovery.

Before the real nature of an electric current was known, it was customary to say that the current flowed from the positive to the negative; the current is really a stream of negatively charged particles flowing from the negative to the positive. But since so much has been written about electricity according to the old convention, and since most electrical measuring instruments still are marked accordingly, the direction of the current will be spoken of in this text as being from positive to negative.

While the human body has no sense organ especially adapted to respond to electrical energy, we can see the light from an electric lamp, feel the warmth of an electric heater, and feel the breeze from an electric fan. We can hear sounds, which occurred thousands of miles away, by means of the radio or telephone. We can sometimes smell the ozone (free oxygen) which results when an electric discharge takes place through air. If wires leading from the terminals of a small electric cell are placed on the tongue, the resulting taste is slightly sour.

118. Transformations of Energy. Some of the devices which may be used to produce electric currents are *batteries* which transform chemical energy into electrical energy, *generators* which transform mechanical energy into electrical energy, *thermocouples* which change heat energy into electrical energy, *photoelectric cells* which convert light energy into electrical energy, and *microphones* which convert sound energy into electrical energy.

Electrical energy may in turn be transformed into *chemical, mechanical, heat, light, and sound energy.* If current is sent through a solution of some compound, decomposition takes place, which may result in some kind of electroplating, such as silver or copper plating, or which may leave the chemicals in a form capable of furnishing a current again, as in a storage battery. If an electric current is sent through a washing-machine motor, the final result is mechanical agitation of the clothes through the water in the tub of the machine. If current is sent through a toaster, heat is the result, or if it is sent through the filament of a light bulb, the resulting temperature is so high that part of the electrical energy is converted into light energy. If an electric current is furnished to a telephone receiver, a record player, or a loud speaker, sound energy is the result.

Each of the methods of producing an electrical current, and the various effects caused by a current, will be explained. Since practically all of the current used in the home comes from generators, the first question to be asked might be: What is a generator, and how is a current of electricity obtained from a generator? Other questions might be: How is a current transmitted from the generator to the place where it is to be used? Why does a current cause a motor to rotate? How does electricity produce heat and light? How does it cause chemical changes? Before these questions can be answered some of the interesting properties of magnets must be demonstrated because magnets are used in generators. Other methods of producing currents will be studied also, as well as static electricity or "electricity at rest." Then we will have a background for studying the generators which produce the electricity which is used in our homes, the method which consequently is of greatest interest to the student of home economics.

STUDY QUESTIONS

1. What phenomena of an electrical nature were known to the ancients?
2. What date marks the beginning of the rapid increase in the development of electrical power and the use of electrical equipment?

3. What date marks the beginning of the widespread development of electrical equipment for the home?
4. What is a current of electricity?
5. What types of energy may be transformed into electrical energy?
6. What forms of energy may result from an electric current?
7. Why are we especially interested in the currents produced by generators?

21

MAGNETISM

Natural magnets were discovered by the ancients near Magnesia in Asia Minor. Many mythical tales have been handed down through the ages concerning the strange properties of these magnets. Shepherds, who carried staffs with iron crooks at one end, often noticed that small pieces of black stone became attached to their crooks, and that it required a certain amount of force to remove these pieces of material. They also noticed that their crooks seemed to be attracted to larger pieces of this material. Stories were told of people who could not walk away from certain places on the earth because of the attraction of some material in the earth for the nails used in their shoes. It was believed that ships sometimes had fallen apart because they had sailed too near to certain mountains, and the nails had been pulled out by a force emanating from this mysterious material. This material was called *lodestone* (leading stone); it is now known that it was iron oxide (Fe_3O_4) or magnetite, and it has since been found in various parts of the world, especially in Norway and Sweden, and in the United States around the Great Lakes.

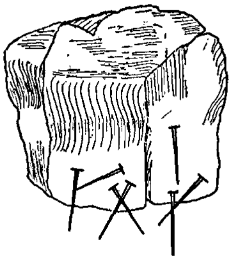


Fig. 21.1. A natural magnet.

119. Early Experiments with Magnets. It was known in ancient times that pieces of lodestone would pick up iron filings or other small pieces of iron and that the effect was especially noticeable at certain places on the lodestone which were called *poles. A pole is a region on a magnet from which the magnetic force seems to emanate.* It was also discovered that if a piece of iron was stroked with a lodestone that the iron then had a pole at each end, and that it would pick up other small pieces of iron. If a long slender piece of lodestone, or of magnetized iron, was suspended so that it was free to turn in a horizontal plane it would always come to rest in a north and south position. Moreover, when the experiment was repeated, it was always the same end that pointed to the north; hence it was called a *north-seeking* pole, and the other end was called a *south-seeking* pole.

These experiments also indicated that the earth had magnetic properties, but it was not until 1600 that Dr. William Gilbert, who was Queen Elizabeth's physician, fashioned a piece of lodestone into a small sphere which he called a *terrella*, and with which he proved that the earth does act as a huge magnet. Further experiments showed that if a north-seeking pole and a south-seeking pole were brought close together they were attracted to each other, but if two north poles or two south poles were brought together they repelled each other. *It is therefore evident that there are two kinds of poles and that unlike poles attract each other, but like poles repel each other.*

120. Theory of Magnetism. Questions which naturally arise in anyone's mind are the following: (1) Are there other magnetic materials? (2) What causes these magnetic effects? (3) How may the force of attraction or repulsion be measured? The most important magnetic materials are iron and its alloys. Cobalt and nickel also are somewhat magnetic, and many other materials are slightly magnetic under certain conditions. Some alloys which are made of nonmagnetic materials are decidedly magnetic.

It is believed that each atom of a magnetic substance is itself a tiny permanent magnet because of the arrangement and the motion of the electrons in the atom. These atoms are combined in the molecules in such a manner that the molecules are also tiny magnets. Under ordinary circumstances the molecular magnets lie in a haphazard order or in small closed groups, and when they are in this condition the material shows no external magnetic effects. But when the material is magnetized the molecular magnets tend to line up in straight rows with all of the north poles pointing in one direction and all of the south poles pointing in the opposite direction. (See Fig. 21.2.)

Many experimentally determined facts confirm this theory.

When a permanent magnet is broken, two new poles appear which are equal in strength to the original poles, and each piece has a north and a south pole. Examination of Figure 21.2 indicates why this is true and shows the arrangement of the poles. This theory also explains why there are poles at the ends of the magnet. At any cross section throughout the length of the magnet north poles are balanced by south poles except at the ends. The north pole is a group of unbalanced north-seeking molecular poles and the south pole is a group of unbalanced south-seeking molecular poles.

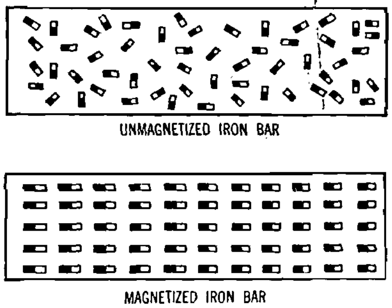


Fig. 21.2. Diagrams showing the change which takes place in a piece of iron when it is magnetized.

It may be shown experimentally that the force of attraction or repulsion between two magnetic poles may be calculated by

$$F = \frac{m_1 m_2}{kd^2}$$

where F = force
m_1 = strength of one pole
m_2 = strength of other pole
k = constant depending on medium in which poles are located
d = distance between the poles

The unit in which the force is measured will depend upon the units chosen for m_1, m_2, and d, but it is important to note that the force is directly proportional to the strengths of the poles and inversely proportional to the square of the distance between the poles.

121. Magnetic Fields. *The magnetic field of force of a magnet is the region around the magnet in which the effect of the magnet can be detected.* If a piece of glass or paper is placed over a bar magnet, and iron filings are then sprinkled over it, the filings tend to form

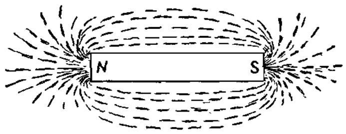


Fig. 21.3. Magnetic field around a magnet.

in lines as shown in Figure 21.3. This lining up of the iron filings occurs because the small particles of iron become magnetized and line up with unlike poles together. The iron filings do not indicate that the field is any different around the north pole than it is around the south pole, but if many small compasses are substituted for the iron filings as in Figure 21.4 it is then found that the compass needles not only form in lines but that at the north pole of the magnet the compass needles all point away from the magnet and at the south pole the compass needles all point toward the magnet. This indicates that the field is directed away from the north pole and toward the south pole. The position of the compass needle at any point indicates the direction of the field at that point.

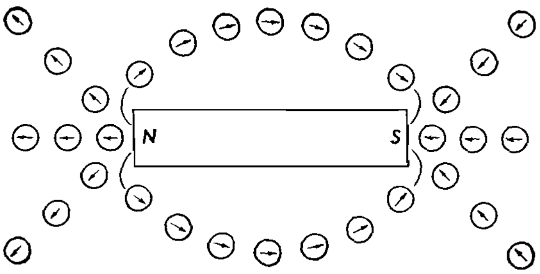


Fig. 21.4. Small compass needles line up in the magnetic field and show the directions of the lines of force.

The diagrams in Figures 21.5 and 21.6 show the fields resulting from various arrangements of magnets. The field between unlike poles shows the lines of force reaching across from the north pole to the south pole, a result which indicates attraction, while the field between two north poles shows the lines of force leaving the poles and then turning aside, a result which indicates repulsion. The field between two south poles would appear the same as that between two north poles except that the lines of force would be reversed in direction.

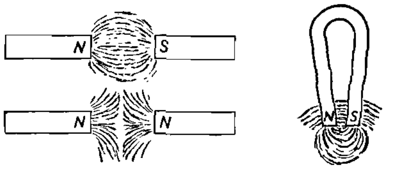


Fig. 21.5. Magnetic fields between like and unlike poles.

122. The Earth as a Magnet. It has been mentioned previously that Gilbert in 1600 first explained that the earth itself acts as a huge magnet with two poles. It is interesting to know that the magnetic and geographic poles of the earth do not coincide. The earth rotates about its geographic axis, and when we speak of the directions "north" or "south," we are speaking with reference to the geographic poles. However the compass needles do not point to these geographic poles but, instead, to the magnetic poles. The magnetic axis of the earth makes an angle of approximately 17 degrees with the geographic axis. Since the north magnetic pole is in the region of Baffin's Bay, a compass needle in the northeastern part of the United States turns to the west of north. Through Georgia, Ohio, and Michigan it points to true north since a straight line can be drawn on the earth connecting places in this region, the magnetic pole, and the geographic pole. At places farther west in the United States the compass needle points to the east of north. The angle through which the compass needle turns from true north is known as the *angle of declination.* The lines across the map of the United States

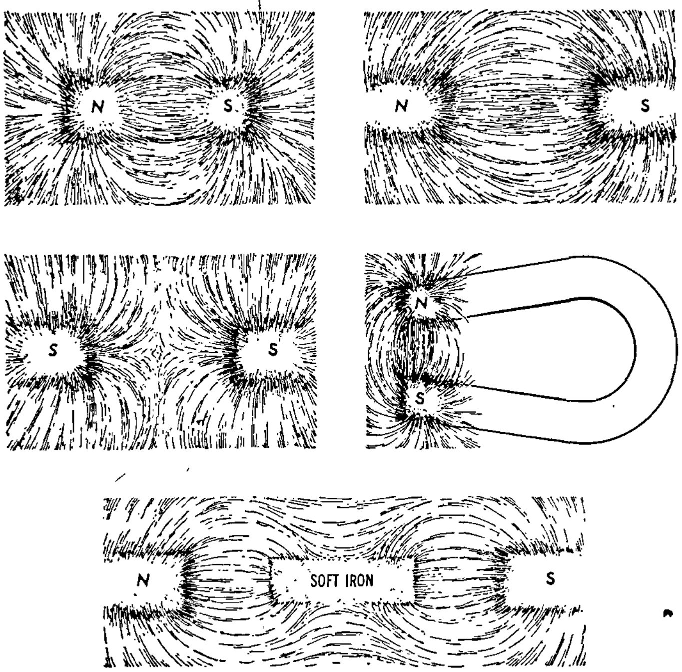


Fig. 21.6. Iron filings have been used to show the lines of force in the magnetic fields.

in Figure 21.8 connect places of equal declination, and the line of zero declination is indicated.

If a compass needle is mounted so that it is free to turn in a vertical plane, it does not lie in a horizontal position except near the equator. In the Northern Hemisphere the north-seeking pole dips down, the angle of dip becoming larger as the magnet is moved from the equator to the pole. The dip at the north magnetic pole is 90 degrees, or in other words at the north magnetic pole the compass needle stands on end with its north-seeking pole toward the earth. At the south magnetic pole the dip is also 90 degrees, and the compass needle stands on end, but it is the south-seeking pole which is toward the earth. Figure 21.9 shows the dip of the compass needle in the central part of the United States.

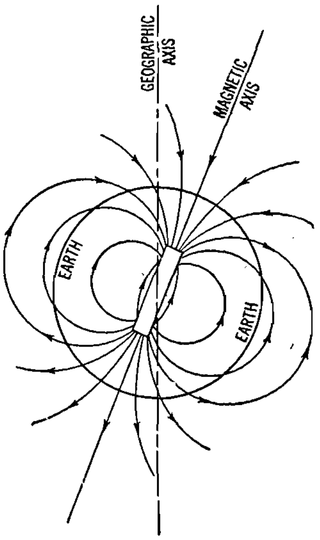


Fig. 21.7. The earth's magnetic field.

123. Magnetic Field around a Conductor. In 1819, Oersted, a Danish physicist, performed an experiment which gave the first evidence of the relationship between magnetism and electricity. He found that there is a magnetic field around a wire which has a current flowing in it. It is now realized that this is

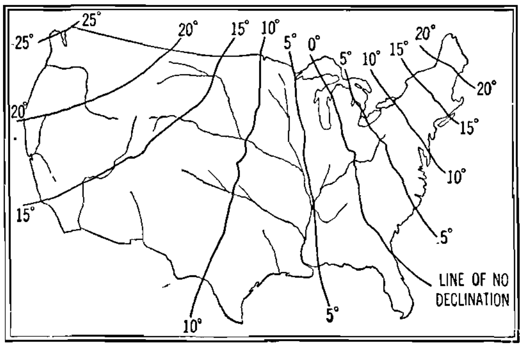


Fig. 21.8. The lines connect points of equal declination.

one of the most fundamental and important discoveries in the study of magnetism and electricity. The apparatus shown in Figure 21.10 can be used to show that there is a magnetic field around a conductor of electricity. A wire is put through a small hole in a piece of glass and the ends of the wire are connected to some source of electrical energy so that a current will flow through the wire. If iron filings are sprinkled on the glass they will collect in concentric rings around the wire. If small compasses are placed around the wire the needles will indicate the direction of the field around the wire. This proves that there is a circular magnetic field around the wire. *A convenient rule for determining the direction of the field in case a compass cannot be used is to hold the wire in the right hand with the thumb pointing in the direction the current is flowing, and then the fingers will curve around the wire in the direction of the magnetic field.*

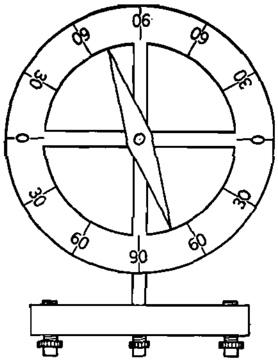


Fig. 21.9. The needle shows the magnetic dip.

If a magnet which is free to turn in a horizontal plane is placed at the center of a coil of wire it will be found that when the current is turned on the magnet will turn until it is parallel to the axis of the coil. If the direction of the field around the wire of the coil is determined by the right-hand rule, it will be found that

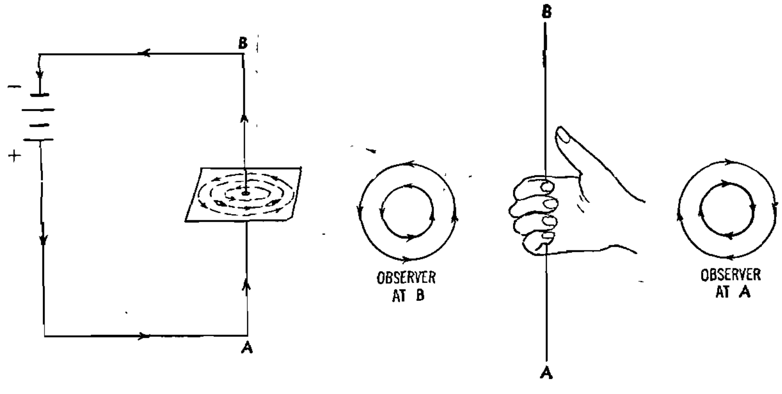


Fig. 21.10. There is a magnetic field around a wire which has a current flowing in it.

the north pole of the compass is pointing in the direction of the magnetic field on the inside of the coil.

124. Electromagnets. In modern times electromagnets are used far more frequently than are permanent magnets. *An electromagnet is a coil of wire with a current flowing in the wire. The wire may or may not be wound on an iron core but in practice an iron core is generally used.* Electromagnets are of great value in the electrical industries because they can be built in almost any desired form or size, and the pole strength can be controlled by the physical properties of the iron used for the core, the number of turns of wire in the coil, and the strength of the current sent through the wire. Since soft iron is more easily magnetized than hard steel and since it also loses its magnetism almost entirely when the current is turned off, electromagnets usually have soft iron cores. If the polarity of the magnet is to be reversed rapidly, a result which is accomplished by reversing the current, there is less heating effect due to internal friction as the tiny magnets reverse their positions. If it is desired to magnetize a piece of iron for use as a *permanent magnet*, a piece of hard steel is placed in the coil, and while it will be hard to magnetize it, it will retain its magnetism after the current is turned off. Tapping the steel while it is in the magnetic field will help to break up the closed groups of molecular magnets and will hasten the magnetization. The right-hand rule for indicating the direction of the field around a conductor may be used to determine the polarity of electromagnets.

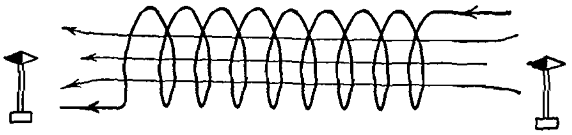


Fig. 21.11. A coil of wire without an iron core acts as a magnet.

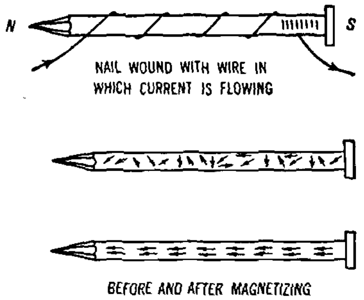


Fig. 21.12. Magnetizing a nail.

125. Doorbells and Buzzers. Electromagnets are used to move the tapper on an electric doorbell or buzzer. The circuit is shown in Figure 21.13. The current is furnished by the battery *B*. When the push button is pressed, it closes the circuit and the current flows through the coils of the electromagnets m_1 and m_2. They attract the soft iron armature *A* to which the bell tapper *T* is attached. As the armature is drawn toward the magnet, the circuit is broken at *C*, and the magnets lose their magnetism. The armature is mounted on a spring *S*, which causes it to fly back and make contact at *C*. The circuit is again completed, and the process is repeated for as long a time as the push-button switch is kept closed.

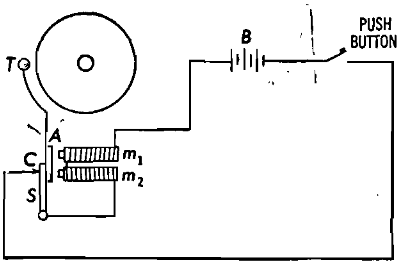


Fig. 21.13. Doorbell circuit.

Doorbells and buzzers may also be operated on the regular house current if the voltage is reduced by means of a small step-down transformer.

STUDY QUESTIONS

1. When were magnets first discovered?
2. What is a magnetic pole?
3. What is the theory as to what happens to a piece of iron when it is magnetized?
4. How many poles does a magnet generally have?
5. Why do iron filings form in lines when sprinkled around a magnet?
6. What is a magnetic field?
7. Explain how the earth is like a magnet.
8. Why does the magnetic needle "dip"? How much does it dip in your locality?
9. Where is the north magnetic pole in relationship to the north geographic pole?
10. How may a piece of iron be magnetized?
11. If you hold a wire in your right hand with the current coming toward you, will the field be in a clockwise or counterclockwise direction?
12. How can you determine which end of an electromagnet is the north pole?
13. Which makes the better permanent magnet — a piece of hard steel or a piece of soft iron? Which makes the better core for an electromagnet?
14. Explain how electromagnets are used in the mechanism of an electric buzzer.

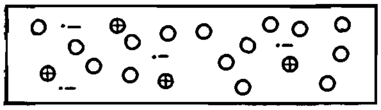
22

ELECTROSTATICS

The earliest record of any knowledge of static electricity dates back to about 600 B.C., when Thales, one of the seven wise men of Greece, recorded his observations concerning a peculiar property of amber. He observed that if the amber was rubbed with silk, it then had an attraction for the silk or for small bits of paper or straw. It is probable that the discovery of this property was quite accidental, for the people of that time often wore strings of amber beads which they rubbed with silk to restore their luster. This property of amber was attributed to a spirit which slept in the amber and was believed to be awakened by the friction or rubbing. Several centuries elapsed before there is any record that other materials had been discovered to have this property. The first serious discussion of the subject was published about 1600 by Dr. William Gilbert, who was the first person to approach the problem in a scientific manner. He knew that many substances could be given a static charge by rubbing them with some other material, and he listed those which he knew could be charged and those which he thought could not be charged. What Gilbert did not know was that he had discovered that some materials are conductors and some are nonconductors, or insulators, and that the materials which he thought could not be charged were really conductors and lost their charge as fast as it was acquired. It was 129 years later, in 1729, that Stephen Gray proved that conductors can be given a charge if they are insulated by means of some nonconductor.

We are all familiar with examples of static charges in our everyday lives. If a cat's fur is rubbed with a dry hand, one hears a faint crackle, or if it is dark one can see tiny sparks. Sometimes when a person combs his hair the individual hairs repel each other but are attracted to the comb. A silk slip under a wool dress sticks tightly to the dress after the two have been worn for a short time. Often children scuff their shoes across a wool rug and then touch their fingers to the tip of some person's ear to see the person jump as the discharge takes place.

126. Conductors and Insulators. There is no sharp dividing line between conductors and nonconductors or insulators. Materials vary widely in their ability to conduct, and those which are extremely poor conductors are classed as insulators. According to our present theory we now believe that each atom of any element consists of a nucleus around which electrons are rotating in various orbits. All of the atoms of any particular element are alike; an atom of one element differs from an atom of another element only in the quantity of charge on the nucleus and in the number and arrangement of the electrons around this nucleus. In some materials part of the electrons are so loosely bound to the atom that they are quite free to move about in the interatomic space. In other materials the electrons are closely bound in the atom and are not free to move about. Substances which possess so-called free electrons are called *conductors* but those in which the electrons are tightly bound are called *nonconductors* or *insulators*.



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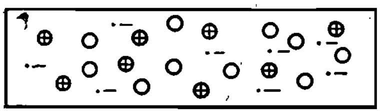

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Fig. 22.1. Diagrams showing the variation in the number of free electrons in different conductors.

127. Positive and Negative Charges. In its normal state any atom is neutral, i.e., the sum of the negative charges of the electrons surrounding the nucleus is equal to the positive charge of the nucleus. However, the atoms of some materials lose their electrons more readily than others, and when any two dissimilar substances are rubbed together the normal state is disturbed. When the materials are separated, one is found to have an excess of electrons and hence is negatively charged, while the other has less than the normal number of electrons and is positively charged. When glass is rubbed with silk the glass receives a positive charge and the silk a negative charge. When hard rubber is rubbed with fur the rubber becomes negatively charged and the fur is positively charged. It has been found by experiment that if either two positively charged bodies or two negatively charged bodies are brought close together, they repel each other;

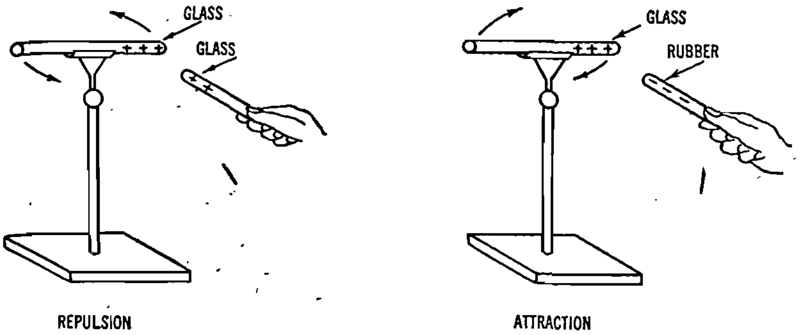

Fig. 22.2. Showing the repulsion and attraction of charged bodies.

but if a positively charged body and a negatively charged body are brought close together, they attract each other. *Thus it is proved that like charges repel each other, but unlike charges attract each other.*

This force of attraction or repulsion between two charged bodies may be calculated by

$$F = \frac{q_1 q_2}{kd^2}$$

where F = force
q_1 = size of charge on one body
q_2 = size of charge on other body
k = constant depending on intervening medium
d = distance between the charged bodies

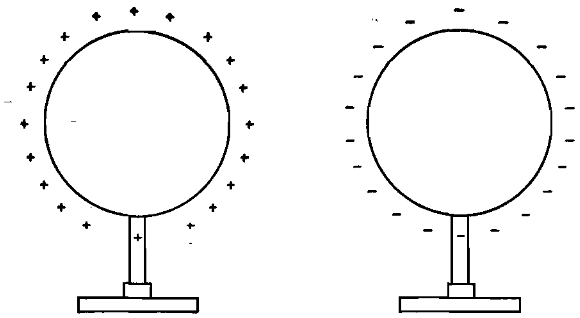

Fig. 22.3. The charge is distributed uniformly over the surface of a sphere.

The unit in which the force is given will depend upon the units chosen for q_1, q_2, and d, but it is important to note that the force is directly proportional to the sizes of the charges and inversely proportional to the square of the distance between the charges.

The static charge on a body is always on the surface because, since like charges repel each other, the charges get as far away from each other as possible. If a body is spherical in shape, the charge is uniformly distributed over the surface, but if the body is irregular in shape, the charge is found to be more concentrated at the edges and points. Bodies which have edges, corners, and sharp points lose their charges more rapidly than smoothly curved bodies.

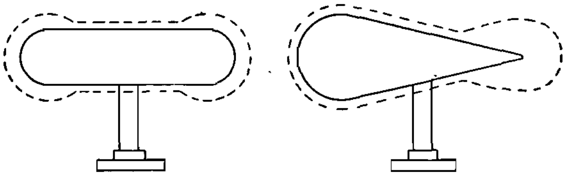

Fig. 22.4. Distribution of charge on irregularly curved bodies.

128. Electrostatic Fields. It has been found by experiment that an electrical field exists around a charged body. If the body is positively charged, the field around it is found to be in the opposite direction to the field around a negatively charged body; so it has been agreed that the field around a positively charged body shall be indicated by arrows pointing away from the body, while that around a negatively charged body shall be indicated with arrows pointing toward the body. The strength of the field E at any point is directly proportional to the size of the charge q

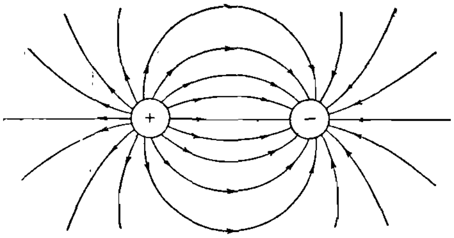

Fig. 22.5. Lines of force between unlike charges.

and inversely proportional to the square of the distance from that point to the charged body.

$$E = \frac{q}{kd^2}$$

The field includes all of the space about the charged body in which the effect of the charge can be detected.

129. Electrostatic Induction. If a charged body is brought near an uncharged conductor, the uncharged body will be charged by induction. Figure 22.6 shows that if the negatively charged rod *B* is brought near the uncharged metal ball *A*, there is a positive charge induced on *A* on the side next to *B*, and a negative charge is induced on the opposite side of *A*. This condition results because the positive charges of *A* are attracted by the negative charges on *B* while the negative charges of *A* are repelled. If *B* is now moved away from *A*, the charged condition of *A* disappears because the charges go back to their normal positions. But if, while *B* is near to *A*, the latter is touched with a grounded conductor the negative charge will be conducted away. If first the conductor is removed, and then *B* is removed, *A* will be left with a positive charge. Thus *A* has been charged by induction.

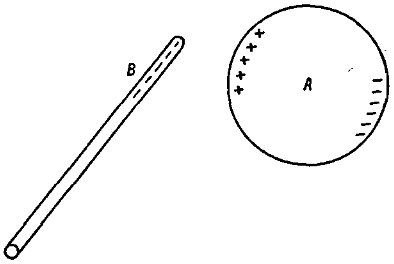

Fig. 22.6. Effect of a charged body on an uncharged body.

If this experiment is done using for *A* a light pith ball suspended on a silk thread, the pith ball will first be attracted to *B* because of the positive charges on the side next to *B*; but if the pith ball touches *B* some of the negative charges of *B* will be transferred to *A*, neutralizing its positive charges and leaving it with a negative charge. Then *A* and *B* will repel each other.

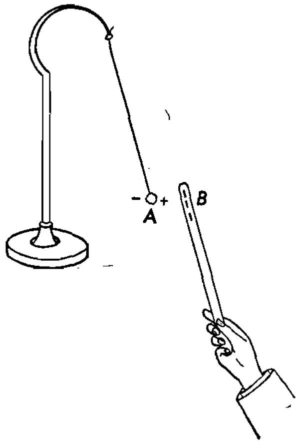

Fig. 22.7. A pith-ball electroscope.

130. Electroscopes. *An electroscope is any device that enables one to determine whether or not a body is charged.* The gold-leaf electroscope, Figure 22.8, is often used for this purpose. It consists of a metal ball A at the top, attached to an insulated metal rod B, which has a piece of gold foil C attached at its lower end. When the electroscope is not charged, the leaves hang down; but if a charged body is brought near A, the leaves at C stand out at an angle from each other. For example, if D has a negative charge, then the negative charges on A–B–C will travel down to C and the leaves will repel each other.

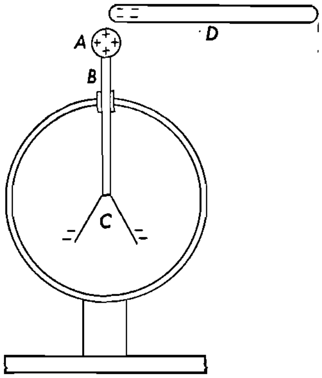

Fig. 22.8. A gold-leaf electroscope.

131. Lightning. Lightning, which is a huge electrical discharge, is in no sense the cause of a thunderstorm but is simply a release of the static charges built up by the storm. In the process of cloud formation some parts of the clouds become positively charged and other parts negatively charged. Other clouds and the earth below the clouds become charged by induction, and when the charges become great enough, a discharge takes place. This discharge may be between clouds, or between a cloud and the earth, depending on the distribution of the charges and the distances between the charged bodies. It has been estimated with some degree of accuracy that perhaps 95 per cent of all lightning discharges take place between clouds, and only 5 per cent between clouds and the earth, and of this 5 per cent a large proportion strike where no damage results. The loud noise called *thunder*, which is heard after the discharge, is due to vibrations in the air caused by the sudden expansion of the air that is heated by the discharge.

The function of lightning rods is to prevent a building from being struck by lightning — not merely to protect it in case a sudden discharge takes place. They are made of a metal which does not corrode easily, must extend into the ground far enough to reach moist earth, and should extend above the highest point of the building on which they are placed. Then if a charged cloud floats over the building, the charge which is induced on the building and the surrounding earth will gradually be discharged instead of being built up in intensity until a violent discharge takes place. Protection by lightning rods is probably more important for isolated buildings and very high structures such as towers and steeples than it is for buildings which are in groups or which are surrounded by trees.

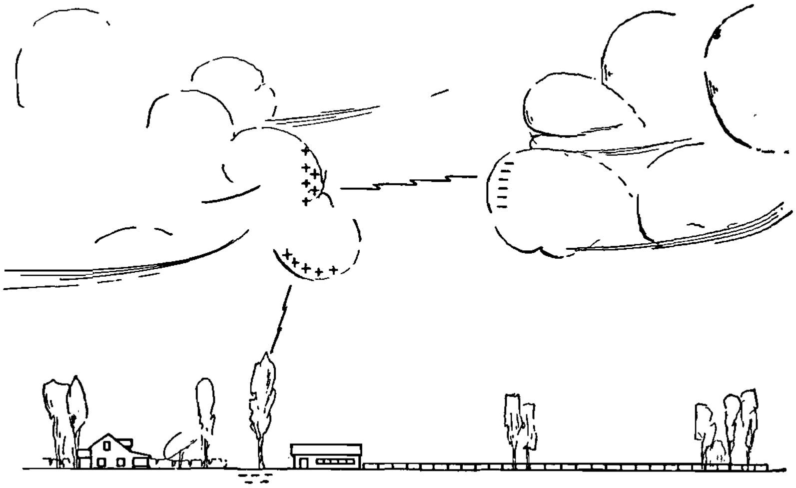

Fig. 22.9. Lightning discharges may be between clouds or between a cloud and the earth.

A person should not seek shelter under a lone tree, and if he is on a golf links or in an open field when an electrical storm occurs, he will be in less danger if he lies down instead of standing up. Livestock may be killed if they stand against a wire fence, for even though the lightning strikes some distance away, it may travel in the wire to the place where the animals are against the fence and pass into the ground there.

132. The Aurora. The aurora is a discharge in the upper stratosphere and is frequently visible as glowing streamers which seem to diverge from the poles. It is probably caused by electrons which come from the sun and are trapped by the earth's magnetic field. These displays are often associated with sun spots, an association which indicates their solar origin. The more brilliant displays are accompanied by magnetic storms and heavy earth currents which seriously disturb telegraph and telephone lines and radio reception. This phenomenon in the Northern Hemisphere is the aurora borealis and in the Southern Hemisphere is the aurora australis.

133. St. Elmo's Fire. St. Elmo's fire is a glowing discharge sometimes seen on masts of ships, the wing-tips of planes, the tops of steeples or spires, the points of lightning rods, or other high, pointed objects. As has been mentioned before, it was one of the few electrical phenomena familiar to the ancients.

STUDY QUESTIONS

1. How are static charges produced?
2. Who published the first serious discussion of electrostatics? When?
3. What are the characteristics of a conductor? Of an insulator?
4. What is the difference between a neutral body and a positively charged body?
5. If a body is negatively charged has it gained negative charges or lost positive charges?
6. What determines the force of attraction or repulsion between two charged bodies?
7. What is an electrostatic field?
8. How may a body be charged by induction?
9. How must a metal object be mounted in order to retain a charge?
10. Describe an electroscope.
11. What is a flash of lightning? Why is it visible?
12. About what per cent of lightning discharges take place between the clouds and the earth?
13. How do lightning rods protect buildings?
14. What precautions should a person observe during an electrical storm?
15. What is the aurora?

23

SOURCES OF ELECTRICAL ENERGY

As has already been pointed out, according to the law of conservation of energy, energy cannot be created or destroyed, but can be changed from one form into another. In this chapter some of the devices which are used for changing other kinds of energy into electrical energy will be discussed. They will be explained in the order in which it was discovered that these transformations of energy were possible:

1. Chemical cells for changing chemical energy to electrical energy
2. Thermocouples for changing heat energy to electrical energy
3. Generators for changing mechanical energy to electrical energy
4. Photoelectric cells for changing light energy to electrical energy.

134. Chemical Cells. In 1786 Galvani, an Italian professor of anatomy, observed that the frog legs which he was dissecting twitched whenever his electrostatic machine discharged and, since he was interested in the physiological effects of electric sparks, he continued his experiments. He found also that there was a pronounced twitching in a frog leg when he touched a nerve with a strip of copper, the muscle with a strip of iron, and then brought the two free ends of the metals together. Since he could usually produce a twitching effect when only one metal was connected between the nerve and the muscle, Galvani decided that the source of the current was in the two unlike animal tissues rather than in the two unlike metals.

Volta, an Italian professor of physics, in 1796 decided that the source of the current was in the unlike metals because he could cause a muscle to contract if he connected two unlike metals and then touched the free ends to two points on the same muscle. To prove that the muscle tissue was not essential, in 1800 he experimented with plates of dissimilar metals stacked with pieces of cloth or paper which had been soaked in brine or in dilute acid. He found that if he then connected the top and bottom plates to the terminals of a galvanometer,[1] there was a current and the size of the current varied with the number of plates used, the kind of plates, and the material with which the intervening cloth or paper was soaked. Then he tried putting strips of copper and zinc in jars of dilute sulphuric acid, and when he connected the ends of the strips to a galvanometer he found there was a current flowing through the external circuit from the copper to the zinc.

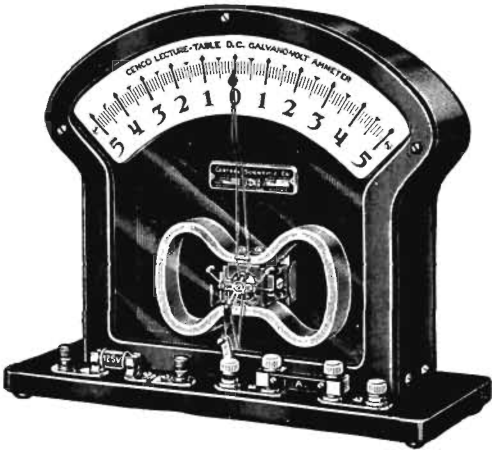

Fig. 23.1. A galvanometer. (Courtesy Central Scientific Company)

A cell made up in the manner just described is called a *simple voltaic cell*, in honor of Volta, and is a *device for transforming chem-*

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[1] A galvanometer is a device which may be included in an electric circuit to show (1) whether there is a current, (2) changes in the size of the current, and (3) the direction of the current. Notice that the device has been named in honor of Galvani. One form of galvanometer consists of a small, light-weight coil of wire mounted between the poles of a horseshoe magnet. If a current flows through the coil it turns and the pointer which is attached to it is moved over a scale, thus indicating that there is a current. The larger the current the farther the pointer moves. Since the coil is free to turn in either direction, its motion indicates the direction of the current, and if the current is reversed, the motion of the coil is also reversed. The reason why a wire, which is in a magnetic field, moves when a current is sent through it will be more fully explained in Sec. 155 and 173.

ical energy into electrical energy. The two metal plates are called *electrodes,* and the liquid is the *electrolyte.* The chemical action which occurs is shown by the equation

$$Zn + H_2SO_4 = ZnSO_4 + H_2 + \text{heat}$$

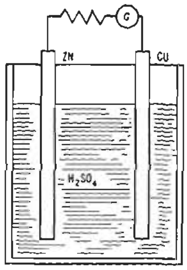


Fig. 23.2. A simple cell converts chemical energy into electrical energy.

The $ZnSO_4$ is formed at the zinc electrode and the hydrogen appears as a gas at the copper electrode.

If one metal, copper for instance, is used as one electrode in an electrolyte and then various other metals are used as the second electrode, it is found that the copper is positive with respect to some and negative with respect to others. The various metals may be arranged in a series starting with the one which is most positive with respect to copper and continuing to the one which is most negative. If another metal is chosen for the reference metal or if another electrolyte is used, the series will still be arranged in the same order. The following list of metals is so arranged that each metal is positive to each of those listed below it.

Carbon
Gold
Platinum
Silver
Mercury
Copper
Lead
Tin
Nickel
Iron
Zinc
Sodium

The farther apart the two metals are in the series the greater is the voltage furnished by the cell, and the voltage of the cell is a measure of the work which the cell will do in sending a unit quantity of electricity through the outside circuit.

Many types of cells have been developed since Volta made his first cell in 1800, and for years currents from cells were the chief sources of electrical energy. Electrical energy obtained in this way is expensive, and the use of electricity could never have developed to its present stage if chemical cells had been the only source of electrical energy. However we still use cells for some purposes. The two types of cells used by the average person are (1) the dry cell used to operate flashlights, doorbells, and country telephones, and (2) the storage battery used to furnish current for the ignition system, the lights and the self-starter on a motor car, and for farm electric plants.

135. Dry Cells. A dry cell is dry only in that the liquid is absorbed by some material to form a porous paste, so that the liquid does not run out when the cell is tipped. There must be two unlike electrodes and an electrolyte which acts on one electrode in a different way than on the other electrode. Zinc and carbon electrodes are most commonly used — the zinc forms the negative electrode and is in the form of a cylindrical cup, while the positive electrode is a carbon rod placed in the center of the cup. The space between the zinc and the carbon is filled with a paste mixture of granulated carbon, manganese dioxide, saturated ammonium chloride, and a filler such as sawdust. The cell is then sealed with wax to prevent evaporation. Such a cell furnishes 1.5 volts.

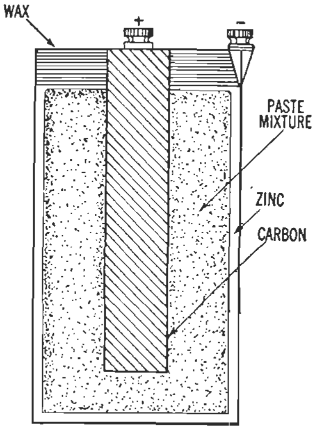


Fig. 23.3. A dry cell.

When the terminals of the cell are connected to an external resistance the current may gradually decrease, because the hydrogen which is set free during the chemical action collects around the carbon electrode forming a gaseous layer which interferes with the action of the cell. This process is known as *polarization*. But the manganese dioxide continually combines with the hydrogen to form water and thus the cell is depolarized. If a large current has been used from the cell, it may have to be left on open circuit for a time to become completely depolarized. This is the reason that dry cells are not suitable for continuous use or where large currents are needed.

136. Storage Batteries. A battery is simply a group of two or more cells — a car battery for example is a group of three cells connected in series. A storage cell is one in which the chemical actions are reversible. The materials which undergo chemical changes when the cell is furnishing a current can be restored to their original forms when a current is sent into the cell in the opposite direction. While there are many kinds of storage cells, the lead cell is the one most commonly used. It has two sets of plates — the positive plates are lead peroxide (PbO_2) and the negative plates are a spongy form of lead (Pb). These plates are arranged alternately and are separated by insulators. The electrolyte is dilute sulphuric acid. When the cell is furnishing a current both sets of plates change to lead sulphate ($PbSO_4$) and the electrolyte changes from a relatively strong acid to a relatively weak acid because of dilution due to the formation of water in the chemical reactions which take place during discharge. When the battery is charged all of the reactions are reversed and the cell is restored to its original state so it can again send out a current. Such a cell furnishes 2 volts when it is fully charged. A car battery consists of three such cells connected in series (so that the voltages add up); therefore a car battery furnishes 6 volts.

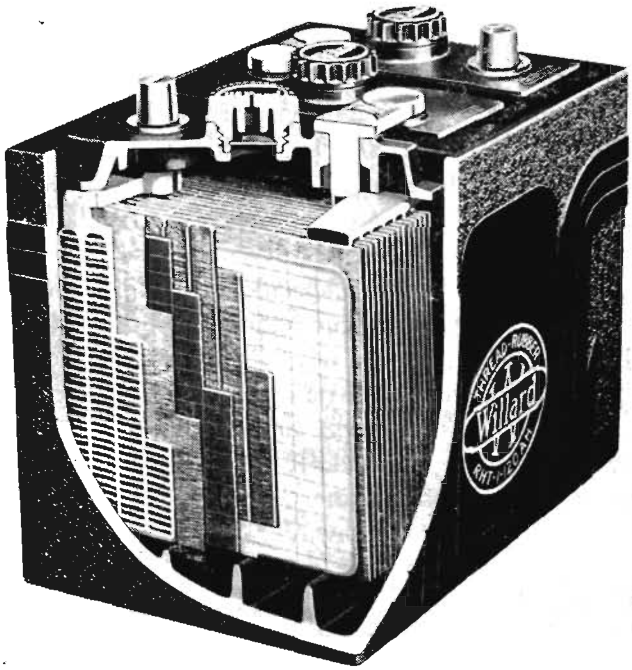


Fig. 23.4. A sectioned storage battery. (Courtesy Willard Storage Battery Co.)

In order that a storage battery may give its best service and have a maximum life, it must have proper care. When a cell is given very little care or is badly misused, it may become sulphated even though it is comparatively new, i.e., the materials change into a hard insoluble white sulphate which will not break down when a current is sent into the cell or, even if it is broken down, the plates have been permanently damaged. Sulphating may be caused by failure to keep enough water in the cell, by allowing the plates to stand in the acid when the cell is discharged, by letting the cell stand too long without having current either sent into it or taken from it, or by charging at more or less than the normal rate. The specific gravity of the electrolyte should be kept at about 1.250 to 1.200. It should never go below 1.150. The electrolyte should cover the plates and if it is decreased in volume by evaporation, distilled water should be added rather than more electrolyte (dilute H_2SO_4) because only water has evaporated. Then when the specific gravity is tested with a hydrometer the reading is a true indication of the state of charge or discharge. The cell should never be allowed to freeze, and if it is fully charged, there is little danger of freezing; but if it is partly discharged, it may freeze and the life of the battery will be shortened if not terminated. The terminals of the cell should be kept free from corrosion, otherwise the binding posts and connecting cables may be eaten away.

The battery should not be overcharged and should not be charged or discharged too rapidly or the life of the battery may be shortened. Most cars have both an adjustment on the generator so that the rate of charging can be regulated, and an automatic cutoff that stops the current to the battery when it is fully charged.

The capacity of a storage battery depends on the size and the number of the plates since an increase in either of these factors will increase the amount of active material. Most car batteries have from eleven to seventeen plates per cell. The larger number of plates is desirable for heavy duty, i.e., if the starter is used many times in comparison with the total number of miles the car is driven, or if the heater, radio, and lights are used considerably. Tests show that about 85 to 90 per cent of the energy put into a battery is available for use.

137. Farm Electric Plants. Complete electric plants of a suitable size to supply energy for an individual home are sometimes installed for farm homes located so far from a transmission line that it is not practical to build an extension line. In many of these plants the current is furnished to the house circuit by a group of storage cells — either 16 cells which furnish 32 volts or 56 cells which furnish 112 volts. The batteries are charged by a generator which may be operated by a gasoline engine, by water power, or by wind power. Some radios are operated from a 6- or 12-volt battery that is kept charged by a wind charger — a generator run by wind power.

138. Thermocouples. In 1821 Seebeck discovered that when two wires, made of different materials, are joined together at their ends to form a closed circuit a current flows in the wires if the two junctions are at different temperatures. If a sensitive galvanometer is included in the circuit, the size and direction of the current can be determined. The size of the current depends on the materials used for the wires and on the difference in temperature between the two junctions; the direction of the current depends on which junction is at the higher temperature, and the direction of the current is reversed when the other junction is at the higher temperature. *Such a device for changing heat energy into electrical energy is a thermocouple.*

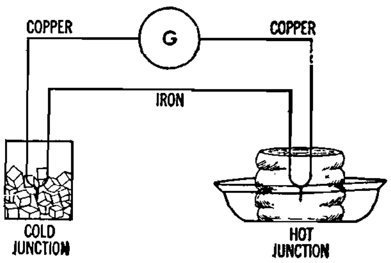


Fig. 23.5. A thermocouple converts heat energy into electrical energy.

While thermocouples do not provide an economical means for transforming heat energy into electrical energy on a commercial scale, they do provide a very convenient means of measuring temperatures which are too high to measure with ordinary thermometers, or to measure temperatures in places where it would be difficult to place an ordinary thermometer. For example, if the hot junction of a thermocouple is placed in a roast, or in a cake, during the baking period, the wires can be led out of the oven through a small hole in the oven wall to the cold junction which, since it must be kept at some constant temperature, is usually placed in melting ice. The galvanometer may be calibrated to read temperatures directly, or the galvanometer deflections may be converted into the corresponding temperature readings by means of a previously made calibration chart. This method of measuring the temperature eliminates opening the oven door at different times during the cooking period. If several thermocouples are placed at various points in the oven, data can be taken to show whether the oven heats uniformly. If a number of thermocouples are inserted in the sole plate of a pressing iron the temperatures of various parts of the plate can be determined under actual ironing conditions.

139. Electromagnetic Generators.—Until the early part of the nineteenth century the chief sources of electrical currents were batteries. Electrical energy obtained in this way was expensive, the equipment was cumbersome, and as a result its use was very limited. About 1831 a young English physicist and chemist Michael Faraday, who was interested in the connection between electricity and magnetism, began experimenting with the possibility of producing a current by moving a wire in a magnetic field, and soon he discovered that a current does flow in a closed conductor if it is moved across a magnetic field. Thus we realize that the mechanical energy which is used to move the wire is being transformed into electrical energy. A mechanical force is used to move the wire in a magnetic field and as a result there is a force which causes the electrons to move in the wire, but when the electrons move in the wire, that is a current of electricity.

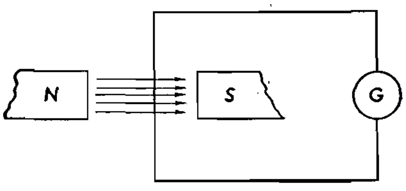


Fig. 23.6. When a wire is moved across the lines of force of a magnetic field, a current of electricity is generated.

If a heavy piece of copper wire is connected to the terminals of a sensitive galvanometer and then the wire is moved across the lines of force of a magnetic field, the galvanometer needle will move. The direction in which the needle moves depends on the direction of the field and on the direction in which the wire is moved across the field. Reversing either the field or the motion of the wire across the field will reverse the galvanometer deflections. If the wire is moved at right angles to a given field — first one way and then the opposite way — the galvanometer needle deflects first one way and then the other. *It is evident that an alternating current is being generated, for if a current of electricity is a stream of electrons an alternating current must be one in which the electrons flow one way and then reverse and flow the other way.* The rate at which the current alternates will depend upon the rate at which the motion of the conductor in the field is reversed.

In Faraday's discovery lies the beginning of the production of electric currents by electromagnetic generators. Because of the importance of this method of obtaining a current of electricity some of the devices which have been developed for this purpose will be more fully discussed in the next chapter.

140. Photoelectric Cells. It was known as early as 1886 by Hertz that under certain conditions electrons are liberated from a metal surface when light falls on it. The metals vary widely in their response, and the alkali metals — potassium, sodium, caesium, and lithium — are the ones from which electrons are liberated most abundantly. Some metals show a greater response to ultraviolet or X rays than to visible light, but some metals in which the outer electrons of the atoms are less firmly held in the atom respond to visible light. The number of electrons liberated in a given time depends on the intensity of the light falling on the surface, but the velocity at which the electrons leave the metal depends on the wave length, or the color, of the light.

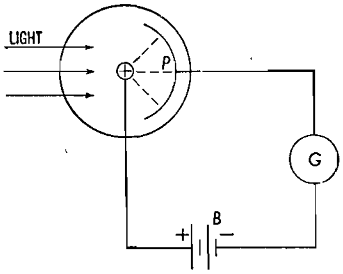


Fig. 23.7. A photoelectric cell.

This emission of electrons from a metal when light falls on it is known as the *photoelectric effect* and the device which is used to change the light energy into electrical energy is called a *photoelectric cell* or an "*electric eye*." Figure 23.7 shows one form of photoelectric cell. It may be evacuated or filled with an inert gas at low pressure. It is connected in series with a battery *B* and a galvanometer *G*. When light falls on the metallic plate *P*, which is made of a photosensitive material, the electrons which are emitted are attracted to the positive plate and the rate of emission is measured by the galvanometer. Since the response of the cell to changes in light intensity is practically instantaneous, various forms have been adapted for use in television, sound recording, burglar alarms, fire alarms, automatic controls for turning lights off and on, electric counting devices, and many other purposes.

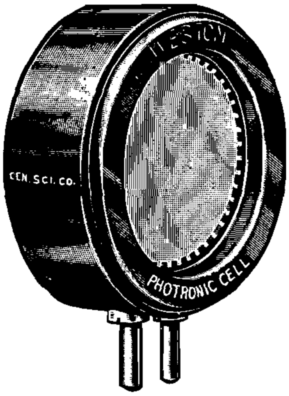


Fig. 23.8. A photronic cell. (Courtesy Central Scientific Company)

Figure 23.8 shows a second type of cell which responds to light and which is known as a *photronic cell.* This cell is not highly evacuated and requires no battery. One cell of this general type which has practically the same response as the human eye to the visible spectrum may be connected with a galvanometer calibrated to read directly the intensity of illumination, and the assembly is known as a *light meter.* (See Sec. 231.) A modification of this assembly is used by photographers as an "exposure meter."

STUDY QUESTIONS

1. What is the purpose of a galvanometer? What causes the needle to move?
2. Describe a simple voltaic cell.
3. What uses are found for dry cells around the house?
4. Name several uses for storage batteries.
5. Give several rules to be observed in caring for a car battery.
6. Suggest some uses for thermocouples in research work in home economics.
7. Who first discovered that, if a closed wire is moved across a magnetic field, a current flows in the wire?
8. What is the importance of this discovery?
9. What is an alternating current?
10. Where have you noticed photoelectric cells in use?
11. What determines the number of electrons emitted in a given time from a photosensitive material?
12. What is a photronic cell?

24

SIMPLE ELECTROMAGNETIC GENERATORS

Faraday's discovery in 1831 that a current flows in a closed conductor when it is moved across a magnetic field was discussed briefly in the last chapter. How little did Faraday realize that his discovery would open up a whole new era in the development of electricity. Starting from his simple experiments performed only a little over one hundred years ago, physicists, electricians, and engineers have developed huge generators furnishing energy to thousands of people all over the world. This energy is used to operate lights, heating devices, motors and other devices in our homes, and to furnish energy for countless industrial processes from which we benefit. The amount of energy used by all of these devices could never have been furnished by batteries, and if generators had not been developed, we could never have enjoyed the widespread use of electricity which we have today. How much we owe to Faraday and his interest in what he could do with a magnet and a few pieces of wire!

141. A Simple Demonstration Generator. A simple demonstration generator can be made by winding a long insulated wire on a pasteboard tube (making the turns of wire much closer on one end of the tube than on the other) and then connecting the ends of the wire to a galvanometer. (See Fig. 24.1.) If either a permanent magnet or an electromagnet is inserted in the coil,

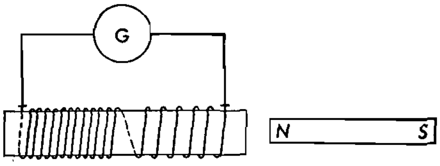


Fig. 24.1. A simple electromagnetic generator.

and then the coil and the magnet are moved with respect to each other, the galvanometer needle moves, indicating that there is a current. Since the galvanometer needle reverses its movement when the motion between the coil and the magnet is reversed, it is evident that an alternating current is being generated.

If the end of the coil having many turns of wire is used, the deflections of the galvanometer needle are greater than if the end with few turns is used, provided that the speed of the motion is the same in both cases. The deflections are greater also if a strong magnet is used instead of a weak magnet, provided that the speed of the motion is the same for each magnet. But if the speed of the motion is changed, it is found that the deflections are smaller when more time is used to move the wires and the magnetic field with respect to each other.

Thus we conclude that the size of the deflections varies directly with the number of turns of wire, and with the strength of the field, but inversely as the time involved. Hence the size of the deflections is proportional to NL/T

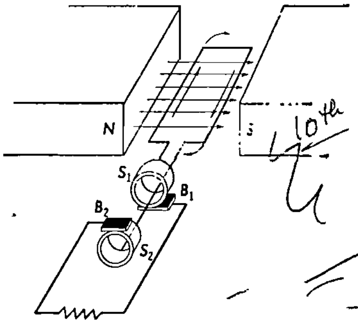
where N = number of wires cutting the lines of force
L = number of lines of force cut by each wire
T = time (in seconds)

It is also found by experiment that the work required to operate the generator is proportional to NL/T so we realize that the deflections of the galvanometer are proportional to the work put into the generator.

If the circuit is broken at any point or if the coil is moved without having a magnet in it or near it there is no indication of current through the galvanometer. Also, even though the magnet is in the coil, and the circuit is closed, if neither the magnet nor the coil is moved or if both are moved but with no relative motion between the two there is no current. These tests prove that mechanical energy must be supplied to the generator before it can supply electrical energy, and that no current will be generated unless there is (1) a closed conductor, (2) a magnetic field, and (3) relative motion between the conductor and the magnetic field. Since the wires cut across the field first in one direction and then in the opposite direction, the current which is generated is an alternating current.

142. Motion of a Wire in the Earth's Magnetic Field. While it is not a practical method of obtaining a current of electricity, it is an interesting experiment to move a wire in the earth's magnetic field and to observe that as a result a current flows in the wire. If a long heavy piece of copper or aluminum wire is connected to the terminals of a sensitive galvanometer and then a section of the wire is swung around and around like a jumping rope, at right angles to the earth's field, a small alternating current results as the wire cuts across the field first one way and then the other way.

143. Alternating-Current Generators. Many commercial generators or dynamos have been developed based on the ideas developed above. In one type the *armature*, which is the moving part of the generator, consists of wires wound on an iron framework. The armature is rotated in the *magnetic field* which may be furnished by permanent magnets but which is usually furnished by electromagnets referred to as the field coils. (See Fig. 24.2.) The ends of the armature wires are fastened to two rings S_1 and S_2 called *slip rings* which are mounted on the armature framework and rotate with it. Connection is made from these rings to the outside circuit through stationary pieces of carbon B_1 and B_2 called *brushes* which are always in contact with the rotating rings. Since the wires on the armature cut through the field first in one direction and then in the opposite direction an alternating current is generated and sent out through the slip rings and brushes to the outside circuit.



10th

Fig. 24.2. An alternating-current generator.

If the armature in Figure 24.3, which consists of only one turn of wire, is rotated at constant speed in the magnetic field, it is evident that it will be cutting lines of force most rapidly when moving at right angles to the field as in B and D. The current will then be a maximum. In A and C the wires are not cutting any lines of force since momentarily they are moving parallel to the field, and so for an instant no current is generated. Also, as the armature is moving from the position shown in *A* through *B* to the position shown in *C* the black side of the loop is moving up through the field and the direction of the current in it is shown by the arrow, but at the same time the white side of the loop is moving down through the field and the current in it is also indicated by an arrow. It will be noted that at any given time the arrows follow each other around the armature indicating that

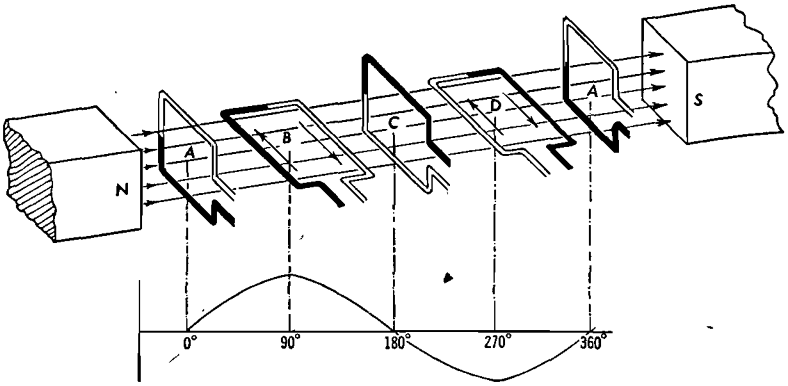


Fig. 24.3. Showing how the current changes in size and direction as the armature makes one complete revolution.

for one-half revolution the current is flowing around the armature in one direction. But as the armature continues its motion from the position shown in *C* through *D* to the position shown in *A* the black side of the loop is moving down through the field and the white side is moving up through the field. The direction of the current is again indicated by arrows and, as indicated, the current in the wire has reversed. Therefore during one half turn of the armature current will leave the generator through one ring and brush, travel around the outside circuit, and return to the generator through the other brush and ring. During the next half turn of the armature the current in the whole circuit is reversed. The curved line in Figure 24.3 is a diagrammatic way of showing the changes in the size and in the direction of the current resulting from one complete rotation of the armature in the field. So we realize that an alternating current is not a steady current but one which gradually increases to a maximum and then gradually decreases to zero, with the current in first one and then the other direction. The current resulting from one complete revolution of the armature is known as one *cycle* of alternating current. The number of complete revolutions per second gives the *frequency* or the number of *cycles per second* furnished by the generator.

144. Direct-Current Generators. If a direct current is desired in the outside circuit, the slip rings are removed and a divided ring called a *commutator* is used. If Figure 24.4 is compared with Figure 24.2 the essential difference between an alternating-current and a direct-current generator is evident. One end of the armature wire is fastened to one segment of the commutator and the other end to the opposite segment. The brushes are in contact with the commutator and are so placed that just as the current reverses in the armature the next section of the commutator comes in contact with a given brush. Therefore the current always leaves through one brush, travels around the outside circuit, and returns to the generator through the other brush. The current resulting from one turn of wire on the armature is shown in Figure 24.5. It is not a steady current, but it is always in the same direction. It can be made steadier by putting more wires on the armature and having more segments in the commutator.

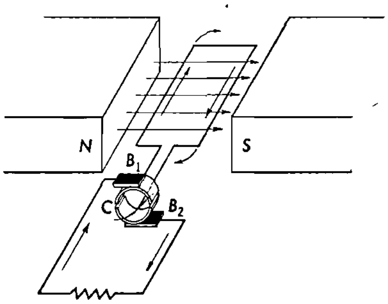


Fig. 24.4. A direct-current generator.

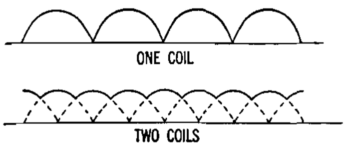


Fig. 24.5. Current from a direct-current generator.

145. Sources of Energy for Generators. Various means are used to furnish mechanical energy to the generator. The armature may be turned by a gasoline or a steam engine, or by water power; small direct-current generators called *wind chargers* are, as the name indicates, operated by wind power. In any case *some form of mechanical energy is put into the generator and transformed into electrical energy. The generator does not make or create energy—it changes one form of energy into another form.*

Experience has shown that sometimes generators which differ considerably in construction from the ones described above are more efficient in commercial installations; therefore various types of generators have been developed, but the basic principle is the same in all types.

STUDY QUESTIONS

1. Why is a galvanometer included in the circuit of the demonstration generator? Would a lamp be a suitable substitute for the galvanometer?
2. What is the purpose of an electric generator?
3. What factors influence the size of the galvanometer deflections?
4. What are the necessary conditions for transforming mechanical energy into electrical energy?
5. What is an armature?
6. What are slip rings? What is their purpose?
7. What are brushes? What is their purpose?
8. What is an alternating current?
9. What causes an alternating current?
10. What is a commutator? What is its purpose?

25

ELECTRICAL MEASUREMENTS

Many of the names of units used in electricity are more or less familiar words but often the exact meaning of the words is not definitely known. In our everyday conversation we may talk about the voltage of the power line, the number of amperes used by a toaster, or the resistance of a hot plate. Whenever we buy new light bulbs, we indicate the size we want by stating the number of watts, and we pay the electric bill at the end of the month by paying for a given number of kilowatt-hours of electrical energy at a certain rate per kilowatt-hour.

It is well to recognize in the first place that most of the terms used in electricity are simply the names of scientists who were interested in electricity and who tried to learn something about it. When definite units for measuring electrical quantities were decided upon they were named to honor these scientists.

Scientists first began to work out a definite terminology for electricity about 1820. For the next forty years there was considerable confusion because many new discoveries were made and still units were not definitely established. In 1863 the British Association for the Advancement of Science tried to organize the information available at that time and made an effort to establish units, but much revision of this work was necessary, and many units were not internationally defined until near the end of the nineteenth century.

146. Quantity of Electricity. *The unit for quantity of electricity is the coulomb*, named for the French scientist, Coulomb, and the symbol Q is used to indicate this quantity. The coulomb was originally defined in terms of electrolysis,[1] but scientists gradually

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[1] A coulomb of electricity is the quantity of electricity which will deposit 0.001118 g of silver from a silver solution in an electrolytic cell. (See Sec. 181.)

came to know that electricity is made up of small unit charges called *electrons*. After the existence of the electron was definitely established and its charge measured, the number of electrons in a coulomb was determined. *The accepted value now is* 6.3×10^{18} *electrons per coulomb.*

147. Current Intensity. *The number of coulombs which flow through a given cross-sectional area of a conductor in 1 second is the current intensity and is measured in amperes,* in honor of Ampere, another French scientist, who made many important discoveries regarding electricity and magnetism. The symbol I is used to indicate current intensity.

$$\underset{\text{(in coulombs)}}{\text{Quantity of electricity}} = \underset{\text{(in amperes)}}{\text{current intensity}} \times \underset{\text{(in seconds)}}{\text{time}}$$

$$Q = IT$$

The number of amperes flowing through a conductor may be measured by an ammeter which is simply a galvanometer calibrated to read in amperes and which is placed in the circuit "in series" with the conductor so that whatever current flows through the conductor will also flow through the ammeter. (See Fig. 25.1.)

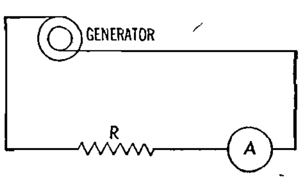

Fig. 25.1. The generator, the resistance, and the ammeter are in series.

148. Electrical Resistance. *Electrical resistance is the opposition offered by conductors to the flow of a current.* If a current is a stream of electrons, it must be that in some conductors the electrons move along more freely than in others since the resistances of conductors vary decidedly. This difference is due in part to the number of free electrons, or in other words, the resistance varies with the kind of material. (See Sec. 126.) Most metals are good conductors and silver, copper, and aluminum are especially good. Other materials such as glass, sulphur, and mica are poor conductors or insulators.

The resistance of a conductor also depends on its temperature. In general, the resistance increases when the temperature increases, but there are various exceptions to this general rule and the change in resistance is not directly proportional to the change in temperature. However, the resistance does vary directly with the length and inversely with the cross-sectional area of the conductor. *The unit for resistance is the ohm,*[1] named for Ohm, a German physicist, who made a detailed study of the factors which determine the resistance of a conductor.

The resistance of a conductor for any given temperature may be found by

$$R = \frac{KL}{A}$$

where R = resistance in ohms
K = a constant depending on the kind of material and its temperature
L = length of conductor
A = cross-sectional area of the conductor

In commercial practice it has become customary to combine K and A into one constant, the numerical values for which are tabulated in handbooks according to the kind of material, the cross-sectional area of the conductor, and its temperature. This constant can then be multiplied by the length to find the total resistance of the conductor.

149. Potential Energy Difference or Voltage. In the last chapter it was shown that, when a conductor is moved at right angles to a magnetic field, there is a resulting force which urges the free electrons to move along the conductor. When these electrons are moved along the conductor they are capable of doing work, i.e., they possess potential energy. The amount of work they can do is directly proportional to the energy that is furnished to the generator. It can also be shown experimentally that the work required to operate the generator varies directly with the strength of the magnetic field L, the number of wires N which cut the magnetic field, and inversely with the time T required to move the wires through the field. Therefore the work which the moving electrons can do as they are moved along the conductor is proportional to NL/T.

The unit for potential energy difference is the volt named in honor of Volta, an Italian, who was one of the first scientists to discover anything about potential energy difference. *The unit has been so*

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[1] The international ohm is defined as the resistance offered by a column of mercury 106.3 cm long, 1 sq mm in cross-section, at the temperature of melting ice. This quantity of mercury weighs 14.4521 g.

chosen that the potential energy difference between any two points is the amount of work which can be done by a unit charge when it is moved by the generator from one of those points to the other. It takes 100,000,000 or 10^8 cuttings per second to equal one volt, therefore the potential energy difference V furnished by a generator may be found by

$$V = \frac{NL}{10^8 T}$$

In practice it has become customary to drop the word "energy" and to speak of the potential energy difference as *potential difference.* In everyday life it is usually referred to simply as the *voltage.*

The potential difference or the voltage across a conductor may be measured with a voltmeter which is simply a galvanometer calibrated to read in volts. It is connected in the circuit "in parallel" with the conductor, or across the conductor, i.e., one terminal of the voltmeter is connected where the current enters the conductor and the other is connected where the current leaves the conductor. (See Fig. 25.2.)

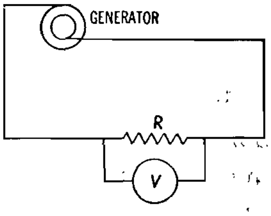

Fig. 25.2. The voltmeter is in parallel with the resistance.

150. Ohm's Law. The mathematical relationship between the current intensity, the potential difference, and the resistance is expressed by Ohm's law.

$$I = \frac{V}{R}$$

where I = current intensity in amperes
V = potential difference in volts
R = resistance in ohms

Thus it is evident that *the current which flows through a conductor is directly proportional to the potential difference applied across the conductor and inversely proportional to the resistance of the conductor.*

Any electrical device, such as a lamp, a toaster, or a fan, may be connected directly to the wires leading from the generator, and the device will operate satisfactorily. However, it will not be possible to learn anything about the potential difference across the device, the current passing through it, or the resistance offered by it, unless electric meters are included in the circuit.

Figure 25.3 shows a circuit containing a *conductor and an ammeter wired in series with the terminals of a generator, and a voltmeter connected in parallel with the conductor.* The ammeter is made with a very low resistance so that it will not appreciably increase the total resistance of the circuit and thus decrease the current. The voltmeter is made with a very high resistance so that only a small current passes through it, but since it is connected to the terminals of the conductor, the voltage across it is the same as the voltage across the conductor. After the current intensity in amperes and the potential difference in volts have been determined, the resistance in ohms may be calculated by use of Ohm's law. In general, it is much simpler to read the ammeter and the voltmeter, and calculate the resistance by use of the formula $R = V/I$ than it is to measure the length and cross-sectional area of the conductor and calculate the resistance by use of the formula $R = KL/A$.

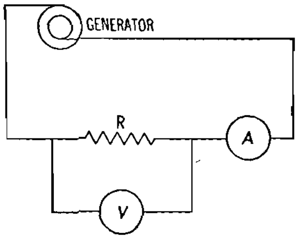

Fig. 25.3. An electric circuit containing a generator, a resistance, and an ammeter in series, with a voltmeter in parallel with the resistance.

151. Electrical Work and Power. The potential difference between any two points has been defined as the amount of work which can be done by a unit charge when it is moved by the generator from one of those points to the other. *Therefore, the total amount of work done in a conductor is equivalent to the product of the potential difference across the conductor and the number of unit charges Q which pass through the conductor.*

$$\text{Work} = \text{potential difference} \times \text{number of unit charges}$$
$$W = VQ$$

Since we have no meter for measuring Q directly but we do know that $Q = IT$ we may substitute IT for Q in the above equation and get

$$W = VIT$$

And since power is rate of doing work

$$P = \frac{W}{T} = \frac{VIT}{T} = VI$$

The unit for the product of V and I has been named the *watt* for James Watt, an English physicist. A larger unit, the *kilowatt*, is obtained from $VI/1000$. *Therefore the units for power are the watt and the kilowatt. The units for work are*

watt-second	*kilowatt-second*
watt-minute	*kilowatt-minute*
watt-hour	*kilowatt-hour*

The unit for the amount of work depends upon whether the product of V and I is left in watts or changed to kilowatts, and upon the time unit chosen. It will be found that the two units for work which are used the most are the watt-second and the kilowatt-hour. The work is usually measured in watt-seconds when we wish to find the corresponding number of calories. The reason for this will be explained in the next chapter. It is usually measured in kilowatt-hours (kwhr) when we wish to calculate the cost of using an electrical device.

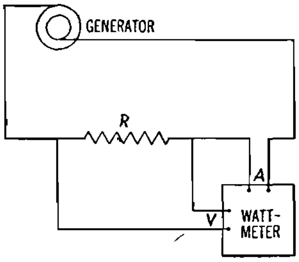

Fig. 25.4. A circuit containing a generator, a resistance, and a wattmeter.

Figure 25.4 shows a circuit in which a wattmeter is used instead of an ammeter and a voltmeter. Since a wattmeter is a combination ammeter-voltmeter, it has both ammeter and voltmeter terminals. The ammeter terminals of the wattmeter are wired in series with the resistance and the generator, and the voltmeter terminals are wired in parallel with the resistance. The reading of the wattmeter is equivalent to the product of IV.

152. Cost of Using Electrical Energy. The electrical energy which is used by any consumer is measured in kilowatt-hours since that unit is large enough to be practical as a commercial unit, and the energy is sold at a given rate per kilowatt-hour.

$$\text{Cost} = \text{kwhr} \times \text{rate per kwhr} = \frac{IVT_H}{1000} \times \text{rate per kwhr}$$

One factor which affects the rate per kilowatt-hour is the method, and therefore the cost, of operating the generator. If the generator is run by a steam, a gas, or a Diesel engine, the cost of operation is dependent on the cost of the fuel used. The fuel may be coal, gasoline, or crude oil. In many sections of the country where water power is available, hydroelectric power plants have been built. They may be operated by a natural waterfall, or the contour of the land may be such that a dam can be built across the stream and the generator operated by a man-made waterfall. In general, the power plants operated by natural waterfalls are able to furnish energy at a lower cost per kilowatt-hour. If a dam has to be built, the cost of building and maintaining the dam offsets the cost of fuel for the engine-driven generators.

Another factor which affects the cost per kilowatt-hour is the distance from the power plant to the place where the energy is to be used. The cost of building and maintaining the line, the energy loss due to heating effects, and the energy loss due to corona effects (ionization of the air which results in a glow along transmission lines) are all factors which increase as the length of the line increases. The uniformity of the load from hour to hour and from day to day also enters into the cost. The power company can operate more economically and furnish energy at a lower rate per kilowatt-hour if the load is fairly uniform. Power plants must be prepared for the peak loads, and if a large percentage of the equipment is not in use a greater part of the time, the overhead expense is increased. The company can also sell energy at a lower rate per kilowatt-hour as the amount required increases. Other factors which enter into the cost per kilowatt-hour are the cost of the transformers, meters, meter reading, bookkeeping, and collecting bills.

The rates in the United States vary from $0.01 to $0.15 per kilowatt-hour. The average is about $0.05 per kilowatt-hour. Usually there is a sliding scale; that is, the rate per kilowatt-hour is less for larger quantities, or for all above a given minimum. The cost to the consumer for a month is found by multiplying the number of kilowatt-hours recorded for that month on the kilowatt-hour meter by the rate per kilowatt-hour. If there is a sliding scale, the number of kilowatt-hours for each rate must be considered.

STUDY QUESTIONS

1. What is a coulomb of electricity?
2. What is a current of 1 ampere?

3. How does a material which is a good conductor of electricity differ from one which is a poor conductor?
4. Define electrical resistance.
5. Name four factors that influence the resistance of a conductor.
6. How does the term "electrical potential energy" correspond to mechanical potential energy?
7. What determines the number of volts furnished by a generator?
8. If the resistance of a conductor is increased but the voltage applied across it is kept constant, is the current intensity increased or decreased?
9. What are the units for electrical power?
10. What are the units for electrical energy?
11. What two instruments are combined in a wattmeter?
12. What factors determine the cost of using an electrical device?

PROBLEMS

1. If 40 coulombs of electricity pass a given point in a conductor in 5 seconds, what is the current intensity in amperes? *Ans.* 8 amp
2. If 4 amperes flow for 5 minutes, how many coulombs of electricity have passed any given point in the circuit?
3. If the resistance of No. 6 copper wire[1] is 0.0004 ohm per foot, how many feet are required for a resistance of 1 ohm? *Ans.* 2500 ft
4. If the resistance of No. 14 copper wire is 0.0026 ohm per foot, what is the resistance of a piece 50 feet long?
5. If 20,000 wires cut 300,000 lines of force in 0.5 second, what is the resulting voltage? *Ans.* 120 v
6. If 10,000 wires cut 100,000 lines of force in 2 seconds, what is the resulting voltage?
7. If the potential difference across a toaster is 120 volts and its resistance is 15 ohms, how large is the current through it? *Ans.* 8 amp
8. If the potential difference across a heating pad is 115 volts and the current through it is 0.5 ampere, what is the resistance of the heating coil?
9. What voltage is required to send 0.6 ampere through a 200-ohm lamp? How many watts does the lamp use? *Ans.* 120 v; 72 w
10. What voltage is needed to send a current of 1.25 amperes through a 96-ohm lamp? How many watts does the lamp use?
11. What is the resistance of a lamp which is operating on 115 volts and is using 60 watts? *Ans.* 220 ohms
12. What is the resistance of a lamp which is operating on 110 volts and is using 100 watts?

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[1] It is customary to list wires by number. Large wires have small numbers. A given number always indicates a given diameter or cross-sectional area. No. 6 wire has a diameter of 0.16 in. and a cross-sectional area of 0.02 in.^{2} and is used for heavy duty wiring such as a line for an electric stove. No. 14 wire has a diameter of 0.06 in. and a cross-sectional area of 0.003 in.^{2} and is used for lighting circuits in a house.

13. What does it cost to use a 100-watt lamp for 3 hours at \$0.04 per kilowatt-hour? *Ans.* \$0.012

14. What does it cost to use a 1000-watt iron for 30 minutes at \$0.04 per kilowatt-hour?

15. How many kilowatt-hours of energy are used by a 1200-watt toaster in 10 minutes? *Ans.* 0.2 kwhr

16. How many kilowatt-hours of energy are used by a 60-watt heating pad in 5 hours?

17. How many watt-seconds of energy are used by a 15-watt lamp in 1 hour? *Ans.* 54,000 wsec

18. How many watt-minutes of energy are used by a 25-watt lamp in 10 minutes?

26

RESISTANCES IN SERIES AND IN PARALLEL

There are two general methods of connecting electrical resistances or conductors — (1) *in series* and (2) *in parallel*, and the terms are descriptive of the ways in which the resistances are connected. In *series* the resistances are connected one after the other as shown in Figure 26.1 and all of the current passes through one resistance, then the next, and so on through all of the resistances in the circuit. This type of wiring seems very simple, but for some purposes it would not do at all, for if several electrical devices are connected in series and one of them is turned off or burns out, the circuit is broken and no current will flow. Everyone is familiar with the small Christmas-tree lights which are wired in series and remembers the difficulty experienced in trying to find which bulb has burned out — thus disconnecting all of the others. In *parallel* the circuit is branched, and current may flow between two points by several independent paths, as shown in Figure 26.2. Houses are wired in parallel. The advantages of this method are evident immediately. Any device in the house may be turned off without breaking the circuit for any other device. Also the same voltage is supplied to each outlet in the circuit.

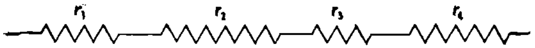

Fig. 26.1. Resistances connected in series.

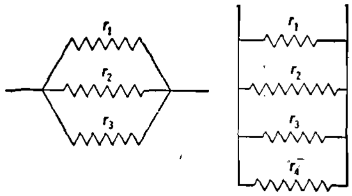

Fig. 26.2. Resistances connected in parallel.

153. Resistances in Series. It has been found experimentally that *the total resistance of several resistances joined in series is equal to the sum of the individual resistances.*

$$R = r_1 + r_2 + r_3 + \cdots$$

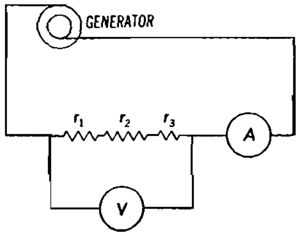

Fig. 26.3. A circuit containing a generator, resistances in series, an ammeter, and a voltmeter.

The current intensity is the same through each of the resistances because, for a given voltage, the size of current which can flow through the circuit is determined by the total resistance of the circuit. If the resistance of the circuit is increased by adding another resistance, then the current will be decreased, but it will still be of equal intensity in each part of the circuit. The voltage across each resistance is proportional to the resistance of that part of the circuit and the total voltage is equal to the sum of the voltages across the individual resistances.

$$V_1 = Ir_1 \qquad V_2 = Ir_2 \qquad V_3 = Ir_3$$

and
$$V = V_1 + V_2 + V_3 + \cdots$$

For example, if resistances of 4, 6, and 12 ohms are joined in series the total resistance is

$$R = r_1 + r_2 + r_3 = 4 + 6 + 12 = 22 \text{ ohms}$$

If the voltage across the total resistance is 110 volts the current is

$$I = \frac{V}{R} = \frac{110}{22} = 5 \text{ amp}$$

The voltages across the individual resistances are

$$\begin{aligned} V_1 &= Ir_1 = 5 \times 4 = 20 \text{ v} \\ V_2 &= Ir_2 = 5 \times 6 = 30 \text{ v} \\ V_3 &= Ir_3 = 5 \times 12 = 60 \text{ v} \end{aligned}$$

The total voltage is equal to the sum of the individual voltages

$$V = V_1 + V_2 + V_3 = 20 + 30 + 60 = 110 \text{ v}$$

If another resistance of 5.5 ohms is added to the circuit the total resistance is then

$$R = r_1 + r_2 + r_3 + r_4 = 4 + 6 + 12 + 5.5 = 27.5 \text{ ohms}$$

and

$$I = \frac{V}{R} = \frac{110}{27.5} = 4 \text{ amp}$$

$$\begin{aligned} V_1 &= Ir_1 = 4 \times 4 &&= 16 \text{ v} \\ V_2 &= Ir_2 = 4 \times 6 &&= 24 \text{ v} \\ V_3 &= Ir_3 = 4 \times 12 &&= 48 \text{ v} \\ V_4 &= Ir_4 = 4 \times 5.5 &&= 22 \text{ v} \end{aligned}$$

and $V = V_1 + V_2 + V_3 + V_4 = 16 + 24 + 48 + 22 = 110 \text{ v}$

If the various resistances are equal, the equation

$$R = r_1 + r_2 + r_3 + \cdots$$

reduces to $R = nr$ where n is the number of conductors included in the series circuit and r is the resistance of one of the conductors.

Series wiring is very useful in experimental work. If a certain voltage is desired, for example 50 volts, and the only available voltage is 110 volts, other resistances may be wired in series to use the extra 60 volts. Or, if a smaller current is desirable, extra resistances in series will increase the resistance of the circuit and decrease the current through the circuit. Usually a rheostat, which is a variable resistance, is used because it is easily adjusted so that the voltage across it or the current through it can be made any desired amount. Some rheostats are made of long lengths of wire wound on a framework, and the connection is made at one end through a metal bar which has a sliding contact key so that all or only a part of the resistance may be included in the circuit. (See Fig. 26.4.) Others are made of plates of carbon which are placed in a nonconducting holder with a screw at one end to adjust the pressure on the carbon

Fig. 26.4. A wire rheostat. (Courtesy Central Scientific Company)

plates, which varies the contact between the plates, and therefore the resistance of the rheostat. The maximum current a rheostat can carry and its maximum resistance are usually stated on the rheostat. Rheostats are made in a great variety of sizes.

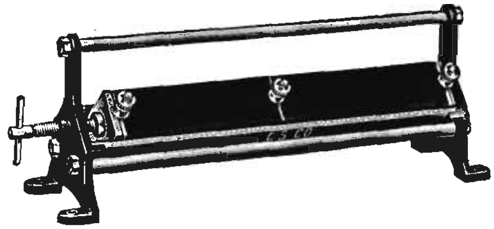

Fig. 26.5. A carbon rheostat. (Courtesy Central Scientific Company)

The speed control on a motor, for example on a sewing machine, is a wire rheostat. As the pressure on the rheostat is increased, the sliding connection moves along the wire so that less and less of the resistance is included in the circuit, and the speed of the motor is increased. When the pressure is reduced a spring moves the sliding contact back and the speed of the motor is decreased.

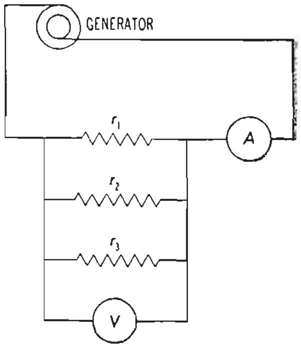

Fig. 26.6. A circuit containing a generator, resistances in parallel, an ammeter, and a voltmeter.

154. Resistances in Parallel. If several resistances are connected in parallel as in Figure 26.6 it is found by experiment that *the total current is equal to the sum of the individual currents.*

$$I = i_1 + i_2 + i_3 + \cdots$$

The voltage across each of the resistances is the same because each resistance furnishes an independent path for the current, and the same potential-energy difference exists across each path. But if the resistances differ, the currents through them will differ. As we would expect from Ohm's law the largest current will flow through the path which offers the least resistance. Thus,

$$I = \frac{V}{R}$$

and

$$i_1 = \frac{V}{r_1}, \quad i_2 = \frac{V}{r_2}, \quad \text{and} \quad i_3 = \frac{V}{r_3}$$

If these values are substituted in $I = i_1 + i_2 + i_3 + \cdots$ we have

$$\frac{V}{R} = \frac{V}{r_1} + \frac{V}{r_2} + \frac{V}{r_3} + \cdots$$

or

$$\frac{1}{R} = \frac{1}{r_1} + \frac{1}{r_2} + \frac{1}{r_3} + \cdots$$

It will be found that the total resistance is less than the smallest resistance in the group, and that as the number of resistances increases, the total resistance decreases. Increasing the number of resistances in a parallel circuit decreases the effective resistance because it increases the total cross-sectional area. As the effective resistance decreases, the total current increases. For example, if a toaster (20 ohms), a pressing iron (15 ohms), and a radiant heater (12 ohms) are connected in parallel on a 120-volt line the current through the toaster will be 6 amperes, through the pressing iron 8 amperes, and through the radiant heater 10 amperes. The total current will be

$$I = i_1 + i_2 + i_3 = 6 + 8 + 10 = 24 \text{ amp}$$

and

$$R = \frac{V}{I} = \frac{120}{24} = 5 \text{ ohms}$$

Also

$$\frac{1}{R} = \frac{1}{r_1} + \frac{1}{r_2} + \frac{1}{r_3}$$

$$\frac{1}{R} = \frac{1}{20} + \frac{1}{15} + \frac{1}{12}$$

and

$$R = 5 \text{ ohms}$$

If another resistance of 30 ohms is added to the circuit the current through it will be 4 amperes and the total current will be

$$I = i_1 + i_2 + i_3 + i_4 = 6 + 8 + 10 + 4 = 28 \text{ amp}$$

and

$$R = \frac{V}{I} = \frac{120}{28} = 4.3 \text{ ohms}$$

or

$$\frac{1}{R} = \frac{1}{r_1} + \frac{1}{r_2} + \frac{1}{r_3} + \frac{1}{r_4}$$

$$\frac{1}{R} = \frac{1}{20} + \frac{1}{15} + \frac{1}{12} + \frac{1}{30}$$

$$R = 4.3 \text{ ohms}$$

If the various resistances are equal, the equation for the total resistance becomes $R = r/n$ where n is the number of resistances included in the parallel circuit, and r is the resistance of any one of the group. Parallel wiring as applied to house wiring is discussed in more detail in Chap. 32.

155. Electric Meters. It will be recalled that a ***galvanometer*** contains a coil of wire mounted in a magnetic field. (See footnote on page 260.) When current flows in the coil, the coil turns — the direction of the motion depending on the direction of the current in the coil and on the direction of the magnetic field. *Why does the coil turn?* When current flows in a wire, there is a magnetic field around the wire. Since this coil is placed in a magnetic field furnished by a magnet, there are two fields, and as a result there is a force acting on the wire which causes it to move.[1] Current enters and leaves the meter at A and B.

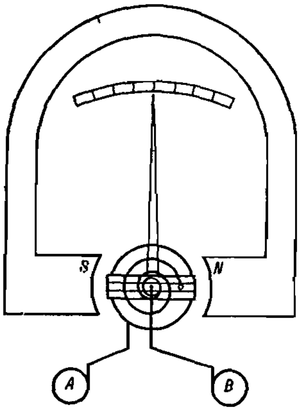

Fig. 26.7. A galvanometer contains a coil of wire mounted between the poles of a horseshoe magnet.

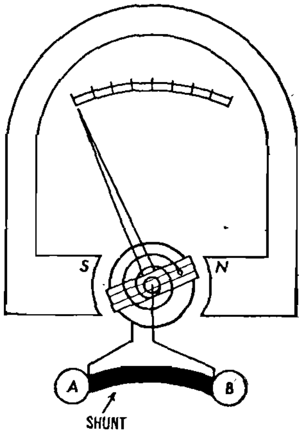

Fig. 26.8. An ammeter is a low-resistance galvanometer. Current enters and leaves the meter at A and B.

An ***ammeter*** is a low-resistance galvanometer. The low resistance is obtained by using a high-resistance moving coil in parallel with an extremely low-resistance conductor which is called a *shunt*. Since the effective resistance is decreased when resistances are connected in parallel, the resistance of the ammeter is slightly

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[1] This explanation is reviewed in Chap. 29, Sec. 173, in explaining why a motor armature rotates.

less than the resistance of the shunt. For a double-range meter two shunts with different resistances are used.

The ***voltmeter*** is a high-resistance galvanometer. The high resistance is obtained by using a high-resistance moving coil in series with an extremely high-resistance stationary coil. Consequently the current through the voltmeter is small. The amount the coil turns depends upon the current through it, but since the current is proportional to the voltage the calibration is in terms of the applied voltage. The voltmeter binding posts *A* and *B* are connected across the load.

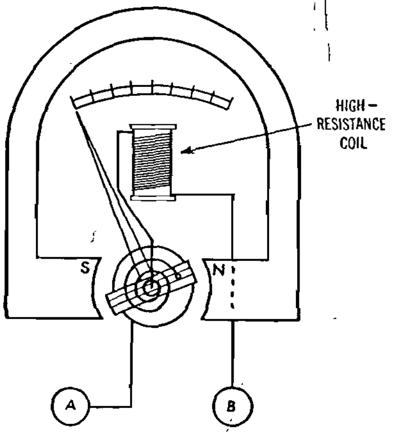


Fig. 26.9. A voltmeter is a high-resistance galvanometer.

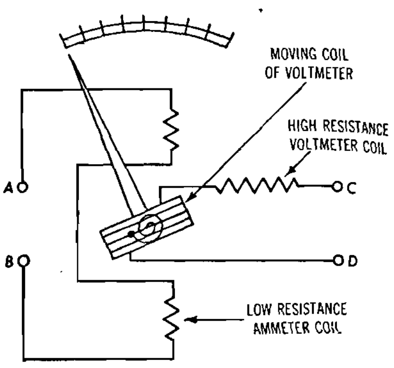


Fig. 26.10. A wattmeter is a combination of an ammeter and a voltmeter.

The ***wattmeter*** consists of two coils. One is a low-resistance stationary coil (binding posts *A* and *B*), which is connected in series with the load and serves as an ammeter. This coil is so arranged that it furnishes a magnetic field in which the second coil is placed. The second coil is connected (binding posts *C* and *D*) in parallel with the load, and serves as a voltmeter. The amount the moving part of this coil turns depends on both the current through it and the strength of the magnetic field in which it is placed.

STUDY QUESTIONS

1. Name some practical uses for series wiring.
2. What happens if one bulb in a string of series-connected Christmas-tree lights burns out, or if one is removed from the circuit?
3. Of what use are rheostats? Are any used in the home?

4. As the number of resistances in a series circuit is increased, does the current increase or decrease?
5. Why is an ammeter wired in series with an electrical device? Since it has an extremely low resistance, how does it affect the current through the device? Why is this desirable?
6. Will the individual devices in a parallel circuit operate independently? Why?
7. As the number of resistances in a parallel circuit is increased, does the total current increase or decrease?
8. A voltmeter has an extremely high resistance. Does it use a large or a small current? Why is this desirable?
9. Why is a voltmeter wired in parallel with an electrical device?
10. What are the advantages of parallel wiring — for example, for house wiring?

PROBLEMS

1. Resistances of 10, 20, and 30 ohms are joined in series and connected to a 120-volt line. What is the total resistance? What is the current? What is the voltage across each load? *Ans.* 60 ohms; 2 amp; 20 v; 40 v; 60 v
2. When 8 small lamps are wired in series and connected to a 120-volt line, the current is 0.3 ampere. What is the total resistance? What is the resistance of each lamp? What is the voltage across each lamp?
3. The current in a series circuit is 2 amperes and the resistances are 20, 40, and 50 ohms. What is the total resistance? What is the total voltage? *Ans.* 110 ohms; 220 v
4. Resistances of 5, 10, 15, and 25 ohms are joined in series and 220 volts applied. What is the total resistance? What is the current? What is the voltage across each load?
5. What is the total resistance if 20 lamps of 250 ohms each are joined in series? *Ans.* 5000 ohms
6. What is the total resistance if 5 lamps of 300 ohms each are joined in series?
7. What is the resistance of a voltmeter if the resistance of the fixed coil is 19,900 ohms and the resistance of the moving coil is 100 ohms? If the voltage across the voltmeter is 120 volts, what is the current through it? *Ans.* 20,000 ohms; 0.006 amp
8. A given voltmeter consists of a fixed coil of 14,800 ohms and a moving coil of 200 ohms connected in series. What is the total resistance of the voltmeter? If the voltage across it is 120 volts, what is the current through it?
9. Resistances of 20, 30, and 60 ohms are joined in parallel. What is the total resistance? If the voltage across the resistances is 60 volts, what is the current through each? What is the total current? *Ans.* 10 ohms; 3 amp; 2 amp; 1 amp; 6 amp

10. Resistances of 30, 60, and 80 ohms are joined in parallel. What is the total resistance? If the voltage across the resistances is 48 volts, what is the current through each? What is the total current?

11. If 3 lamps are joined in parallel and the currents through them are 0.4 ampere, 0.5 ampere, and 0.6 ampere respectively, what is the total current required? If the potential difference is 120 volts, what is the total resistance? What is the resistance of each lamp? Find the total resistance, using the values of the individual resistances.
Ans. 1.5 amp; 80 ohms; 300, 240, and 200 ohms

12. A toaster which uses 10 amperes, an iron which uses 8 amperes, and a heater which uses 12 amperes are joined in parallel. What is the total current required? If the potential difference is 120 volts, what is the total resistance? What is the resistance of each device? Find the total resistance, using the values of the individual resistances.

13. If an advertising sign contains 50 lamps of 200 ohms each, wired in parallel, what is the resistance of the combination? *Ans.* 4 ohms

14. What is the effective resistance in your house if you have 5 lamps on and the resistance of each is 90 ohms?

15. If the resistance of the moving coil in an ammeter is 99.97 ohms and the resistance of the shunt is 0.03 ohm, what is the total resistance of the ammeter? If the ammeter is connected in series to a 12-ohm toaster, what is the combined resistance of the two devices? *Ans.* 0.0299 ohm; 12.02999 ohms

16. A given ammeter consists of a moving coil which has a resistance of 199.95 ohms, and a shunt which has a resistance of 0.05 ohm. What is the resistance of the ammeter? If the current through the ammeter is 8 amperes, what is the voltage drop across the ammeter?

17. *a.* If a toaster which has a resistance of 12 ohms is connected to a 120-volt line, what is the current through it? If an ammeter with a resistance of 0.03 ohm is connected in series with the toaster, what is the reading of the ammeter? *Ans.* 10 amp; 9.975 amp

b. If a voltmeter which has a resistance of 12,000 ohms is connected across the toaster, how much current passes through the voltmeter? What does the ammeter read after the voltmeter is added to the circuit? *Ans.* 0.01 amp; 9.985 amp

18. *a.* If a lamp which has a resistance of 50 ohms is connected to a 120-volt line, what is the current through it? If an ammeter with a resistance of 0.05 ohm is connected in series with the lamp, what is the reading of the ammeter?

b. If a voltmeter which has a resistance of 24,000 ohms is connected across the lamp, how much current passes through the voltmeter? What does the ammeter read after voltmeter is added to the circuit?

27

ELECTRIC HEATING DEVICES

Every electrical heating appliance is fundamentally a conductor of electricity mounted in a suitable framework. The conductor is so chosen that the desired amount of electrical energy can be transformed into heat energy at the place where heat is needed. Electrical heating devices are sometimes said to be 100 per cent efficient, since all of the electrical energy is converted into heat energy, but usually not all of this heat is available for the original purpose. For example, in a coffee percolator an average of 80 per cent of the heat is absorbed by the coffee and 20 per cent is absorbed by the metal or has escaped into the air. An electric iron may transfer from 65 to 85 per cent of the heat through the sole plate to the damp clothes, but the remainder is lost through the top and sides to the air of the room. Electric room heaters might really be considered as 100 per cent efficient since even though some of the heat is required to warm the metal framework, the heat is eventually transferred to the contents of the room. But some heaters are constructed so that a larger percentage of the heat is immediately transferred to the contents of the room and therefore the same amount of energy will warm the room in a shorter time.

If a small amount of heat is needed for a short time, electricity furnishes the quickest, cleanest, and most convenient way of obtaining the energy. In many devices, localizing the heat reduces the total quantity needed to a minimum. Electrical heating is also the safest method — fire hazards are at a minimum and there are no fumes or smoke from combustion. If larger amounts of heat are needed, for example enough to heat a house, the total cost is usually higher than most consumers can afford.

156. Materials Used for Heating Elements. In some of the first electrical devices made for household use the heating elements were made of metals which oxidized at relatively low temperatures and were either short-lived or could not be heated to as high temperatures as were desired. Since metals were such good conductors of electricity, the conductors had to be either very long or else very small in cross-sectional area in order that the current in amperes, and consequently the resulting amount of heat, would not be too great. If heat was developed too rapidly the resulting temperature was too high, the food was burned instead of cooked, and the clothes were scorched before they could be properly ironed. Such long, fine wires were also easily broken and hard to install.

The difficulties encountered in trying to use pure metals for heating elements led to the development of high-resistance alloys which withstand relatively high temperatures without oxidizing and, since they offer more resistance, shorter pieces of larger cross-sectional area furnish the necessary resistance. The element is not only easier to make and install, but it is sturdier and has a longer life. The alloys may be made of various proportions of nickel, chromium, and iron.

The following table shows the relative resistances of a number of materials of the same length and cross-sectional area. Copper has been used as the basis of comparison since it is used more than any other material for conductors in the general transmission of electricity. Aluminum is also used extensively. Silver is the only material which is a better conductor than copper but its cost prohibits its commercial use.

Copper	1.0
Silver	0.9
Aluminum	1.7
Tungsten	3.3
Iron	5.7
Platinum	6.8
Nickel	7.7
Steel	8.8
Nichrome	80
Calorite	70
Chromel	70
Pure water	26,000,000
Water + 5% H_2SO_4	48,000
Glass	90,000,000,000,000,000

157. Relation between Electrical Energy and Heat Energy. Since electrical energy can be converted into heat energy, there must be some relation between electrical units and heat units, i.e., a definite numerical relationship between watt-seconds and calories. This relationship can be determined experimentally. If a current is sent through a small enclosed electrical heating coil which is immersed in water in a calorimeter, the heat given out by the coil will be absorbed by the water and the metal. (See Fig. 27.1.) This amount of heat may be calculated by

$$H = (mst)_{\text{water}} + (mst)_{\text{metal}}$$

Since this heat came from a known amount of electrical energy which can be calculated by

$$\text{Energy} = IVT \text{ or } I^2RT$$

the relationship between the two is

$$H = KIVT \text{ or } KI^2RT$$

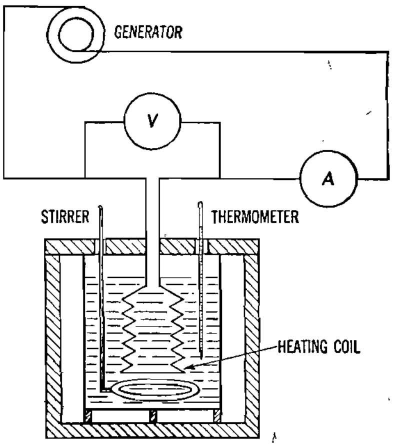


Fig. 27.1. Apparatus for finding the relationship between electrical-energy units and heat-energy units.

where K is a constant showing the relationship between heat energy measured in calories and electrical energy measured in watt-seconds. *It has been found by experiment that 4.186 watt-seconds are equivalent to 1 calorie or that 1 watt-second furnishes 0.24 of a calorie.* Thus we see that the number of watt-seconds of energy must either be divided by 4.186 or multiplied by 0.24 to obtain the equivalent number of calories.

158. Electric Irons. An electric iron is one of the first pieces of electrical equipment purchased in most homes. Electric irons are made in many types and sizes in order that the purchaser may get the shape and weight best adapted to her needs. Most irons are constructed so that the heating element is removable and when burned out may be replaced at a small fraction of the original cost of the iron. The element may be made of flat wire wound on mica plates which have been cut the same shape as the base of the iron. This makes a foundation on which to wind the element, and insulates the turns from each other. This unit is then placed between two layers of mica to insulate the element from the metal parts of the iron. In another type of heating element, the wire is embedded in a composition plate made in the shape of the iron. These elements are very durable, but if the iron is dropped, the plate may crack, and if the wire is broken, the whole plate must be replaced. A third type of heating element is made of a spirally wound wire enclosed in a metal tube but separated from it by some insulating material. The element is bent into the desired shape and the metal for the face of the iron is cast around it. These elements are also very durable.

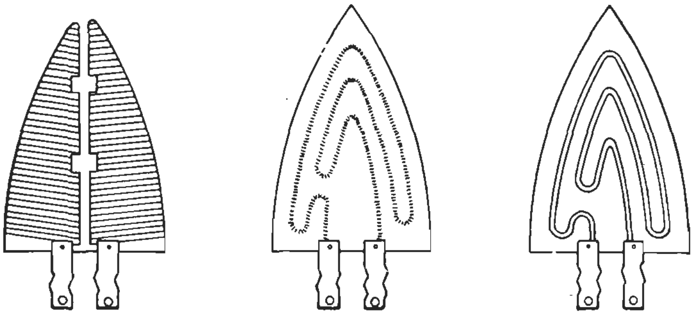


Fig. 27.2. Heating elements for irons.

When in use the iron usually does not need current flowing through it all of the time to keep it at the desired temperature. This will depend upon the weight and kind of material being ironed, and upon the dampness of the material. The cost of operation depends not only upon the rate at which the device uses energy but also upon the time the energy is actually passing through the element. An automatic iron has a thermostat which opens the circuit when the iron reaches the temperature desired. The thermostat may be marked "high-medium-low" or "nylon-silk-cotton-linen." If it is a steam iron, there is a setting indicated for a desirable temperature for producing steam. As the operator turns the thermostat, the pressure exerted on the thermostat is changed and thus the temperature at which the circuit opens is regulated. As soon as the iron cools a little, the circuit automatically closes. Thus a steady temperature can be maintained, and by choosing the proper setting the temperature can be adjusted for the kind of material, and for either slow or quick work.

A 2- to 3-pound iron is probably the most satisfactory for the average household. It should be automatic and will use 8–10 amperes during the time the current is flowing. For average ironing conditions the current is probably not on more than half of the time. If the iron uses 8 amperes at 110 volts and is used for 1 hour with the current flowing 60 per cent of the time, the amount of energy may be calculated by

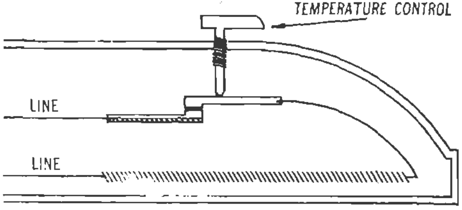


Fig. 27.3. A thermostat for an electric iron.

$$\frac{IVT}{1000} = \frac{8 \text{ amp} \times 110 \text{ volts} \times 1 \text{ hr} \times .6}{1000} = 0.53 \text{ kwhr}$$

At \$0.04 per kilowatt-hour the cost per hour is

$$\text{kwhr} \times \text{rate per kwhr} = 0.53 \text{ kwhr} \times \$0.04 = \$0.02$$

Steam irons may be used for either dry or steam ironing. There are two main types of steam irons - the kettle type and the flash-boiler type. In the kettle type all of the water in the iron is

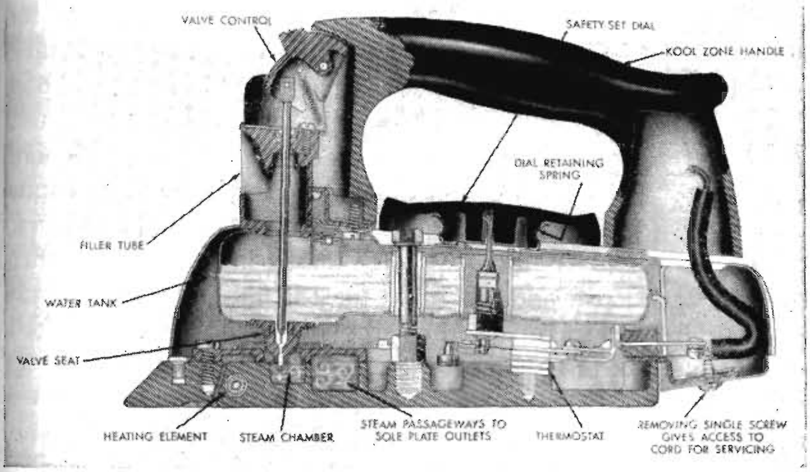


Fig. 27.4. A cross section of a steam iron of the flash-boiler type. (Courtesy The Hoover Company)

heated until it boils and furnishes steam. Usually this type must be emptied before it can be used as a dry iron. The flash-boiler type converts the water to steam as it falls, a drop at a time, from a reservoir onto a hot inner plate. By flipping a control valve it can be converted from a steam to a dry iron readily. There are various arrangements for steam vents and slots on the sole plate of the iron. In practice some are considerably more satisfactory than others, so it is advisable to try several irons before purchasing one.

159. Small Electric Cooking Devices. There is an almost endless variety of electrical cooking devices which are a decided help in the kitchen and dining room. The cost of cooking the food with electricity may be slightly more than with coal or gas, but the added convenience and pleasure more than offset the difference in cost.

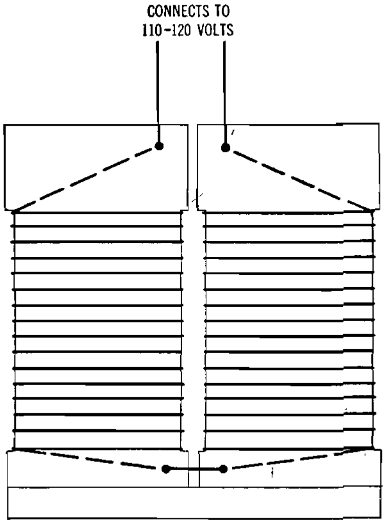


Fig. 27.5. A heating element for a toaster.

Toasters. The heating element of an electric toaster may be made of flat wire wound on mica or it may be made of spirally wound coils of round wire looped over hooks which are fastened into plates of insulating material. One-slice toasters use from 400 to 650 watts. Two-slice toasters use from 800 to 1200 watts. There are various types of thermostats and regulators used on toasters; the toaster may be set for either light or dark toast, and when the toast is finished a thermostat or a timing device opens the circuit and the bread is lifted part way out of the toaster.

Coffee Makers. Electric coffee makers are of two general types — the brewer type (see page 69) and the percolator type. The trend is toward self-contained electric heating units with automatic temperature controls. When the coffee is finished a thermostat turns off the main heating element, but current continues to flow in a small element which keeps the coffee hot. Coffee makers use from 400 to 1200 watts, depending on the type. The high wattage units usually require less time, so the total cost is approximately the same for all types. About 15 cups of coffee may be made for $0.01 at $0.04 or $0.05 per kilowatt-hour.

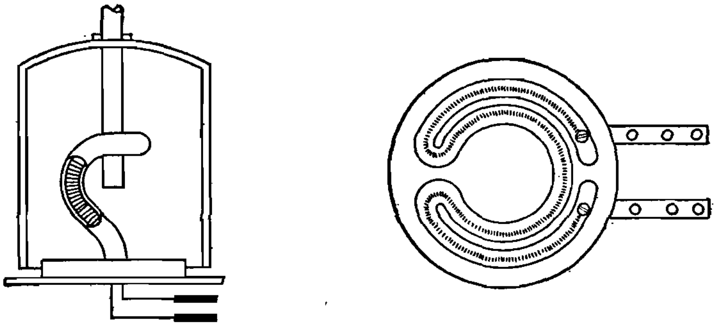


Fig. 27.6. Heating elements for percolators.

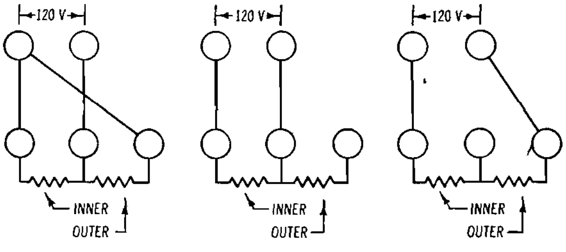
Waffle Irons and Sandwich Toasters. Small waffle irons use about 600 watts and larger ones up to 1200 watts. There are two heating elements — one in the base and one in the lid. Often the grids are removable and the device becomes a sandwich toaster or a grill for bacon or ham and eggs. These waffle irons are usually equipped with an adjustable thermostat so the crispness of the waffle can be controlled, and a signal light to indicate when the iron is hot enough for the batter or when the waffle is done.

Deep-Fat Fryers. Deep-fat fryers are convenient devices for a family that uses this method of cooking enough to make the investment worth while. Since hot fat is potentially a decided fire hazard, a close-fitting lid should be at hand when the fryer is in use so that if the fat catches fire the lid may be put in place quickly to shut off the oxygen supply and smother the flames. The cord should also be disconnected from its socket immediately — therefore, consider the location of this socket with respect to the fryer before starting to heat the fat. Fryers use from 1200 to 1500 watts.

160. Electric Ranges. Electric ranges for household use vary from a small portable type with one hot plate and a small oven or grill to a full-size range with three, four, or even six hot plates and two ovens. Some have deep-well cookers, warming ovens, automatic timing devices for presetting the cooking cycle, surface and oven lights, and glass panels in the oven door.

There are various means of obtaining different heats on the hot plates, and the number of heats may vary from one to eight; or the range may be equipped with a multi-speed control which allows the operator to dial any degree of heat. The most common are the five-heat, the seven-heat, and the multi-speed. In order to understand how a hot plate is constructed to obtain these various heats, it seems best to start with the simplest type and gradually introduce the changes in construction. This approach is also of course the historical approach, since the first hot plates had only one heating element and one heat — obviously not a satisfactory arrangement.

Next, two elements were used and two heats resulted. But soon it was realized that three or four heats could be obtained with only two elements, and later the number was increased to a possible eight heats — still using only two heating elements. In the following discussion voltages of 240 and 120 are used for ease in figuring mathematical relationships, but voltages of 230 and 115 or 220 volts and 110 are also combinations in common use.



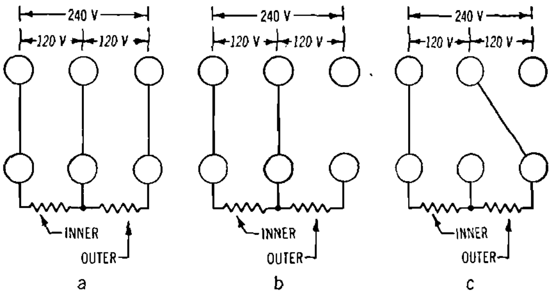
a b c

Fig. 27.7. Electrical connections in switch to provide three heats in a hot plate on 120 volts: *a*, High; *b*, Medium; *c*, Low. (Adapted from *Electrical Appliance Servicing* by W. H. Crouse.)

If the hot plate furnishes three heats, it has two elements and is usually connected to one 120-volt line only. For high heat, the two elements are connected in parallel, for medium heat only one element is used, and for low heat the two elements are connected in series. (See Figure 27.7.) For example, if the resistance of each element is 12 ohms, the resistance, voltage, current, and watts for each heat are shown in the following table.

HEAT	R	V	I	W
High	6	120	20	2400
Medium	12	120	10	1200
Low	24	120	5	600

If the range has more than one hot plate, it is connected to a three-wire, 240-volt line which may be considered as a combination of two 120-volt lines. This is done because the number of amperes required is too high for safety if it is all taken from one 120-volt line. High heat may be obtained as explained above, or it may be obtained by using the two 12-ohm resistances in series but connected to the 240-volt line as shown in Figure 27.8. The resulting current is 10 amperes and the number of watts is equal to 10 amperes × 240 volts = 2400 watts — thus the resulting high heat is exactly the same as shown in the above table.



a b c

Fig. 27.8. Electrical connections in switch to provide three heats in a hot plate using 240-volt and 120-volt circuits: *a*, High; *b*, Medium; *c*, Low. (From *Electrical Appliance Servicing* by W. H. Crouse, 1950, McGraw-Hill Book Company, Inc.)

For four heats the two elements are not alike and each can be used alone to obtain two medium heats. This combination was never extensively used. The three-heat range was accepted for many years, but

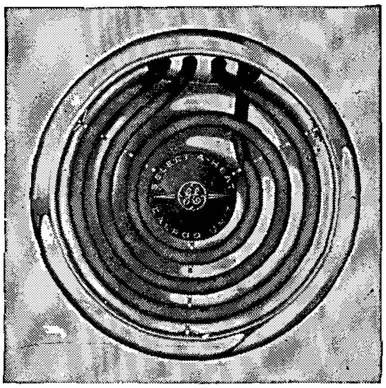


Fig. 27.9. Electric range hot plate with two heating elements. (Courtesy General Electric Company)

housewives began to ask for ranges with smaller differences between the heats and especially for lower heats which would keep food hot but not cooking. The five-heat range was the first answer to this demand.

The five-heat range uses two elements which are alike, and they are used in parallel and in series, but first on 240 volts and then on 120 volts. The following table shows the possible combinations.

HEAT	R	V	I	W
1	24	240	10	2400
2	48	240	5	1200
3	96	240	2.5	600
3	24	120	5	600
4	48	120	2.5	300
5	96	120	1.25	150

It will be noticed that the third heat can be obtained in two ways; however, the two elements in series with 96 ohms, 240 volts, and 2.5 amperes is generally used. These connections are shown diagrammatically in Figure 27.10 a,b,d,e,g.

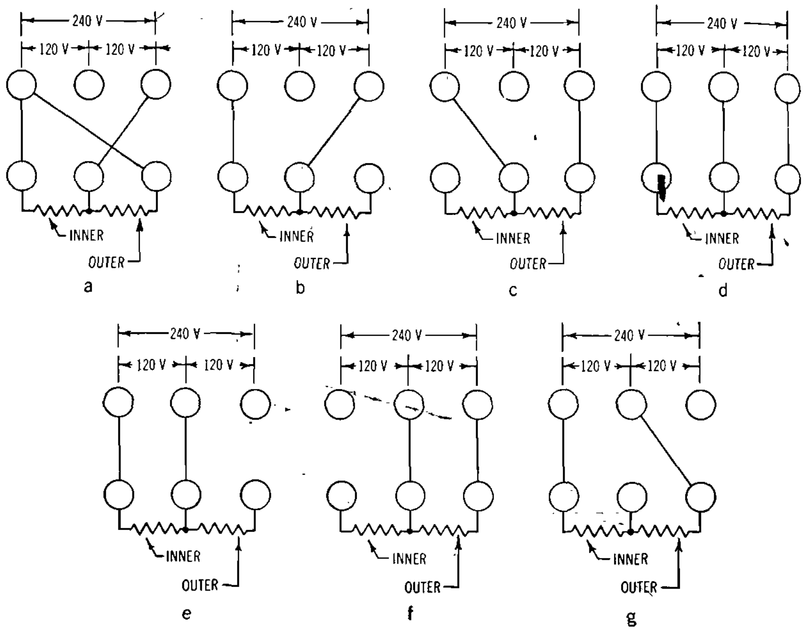


Fig. 27.10. Electrical connections in switch to provide for seven heats. For five heats connections *a*, *b*, *d*, *e*, and *g* are used. (From *Electrical Appliance Servicing* by W. H. Crouse, 1950, McGraw-Hill Book Company, Inc.)

The seven-heat range uses two elements which are not alike, and they are used in parallel and in series on 240 volts and then on 120 volts. (See Figure 27.10.) The following table shows that eight heats are possible, but the two middle heats are so near alike that only one is used — the series connection on 240 volts. The resistances of the two elements may have a different ratio from 40:60 in actual practice, but these values have been chosen here because of the resulting simplicity of the mathematical relationships.

HEAT	R	V	I	W
1	24	240	10	2400
2	40	240	6	1440
3	60	240	4	960
4	100	240	2.4	576
4	24	120	5	600
5	40	120	3	360
6	60	120	2	240
7	100	120	1.2	144

Thus we see that five-heat and seven-heat ranges use 220–240 volts for the higher heats and 110–120 volts for the lower heats.

The multi-speed type of temperature control uses a hot plate with only one element, and it is connected to a 220–240 volt line. The circuit is not on continuously except when the temperature control is set for high. For all other positions of the temperature control, the circuit is opened and closed by a cam[1] operated by a motor which makes one revolution per minute. (See Fig. 27.12, which is a schematic diagram of the system with one hot plate only shown.) When the temperature control knob *J* is turned, the cam *G* is turned, closing contacts *A* and *B*. Closing *B* closes one of the leads to the hot

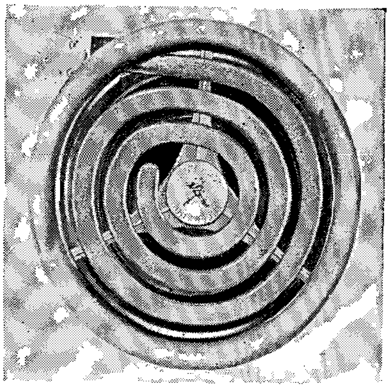


Fig. 27.11. Range hot plate with one heating element. Various heats are obtained by using the multi-speed temperature control. (Courtesy Norris-Thermador Corporation)

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[1] A cam is an egg-shaped disk with the point about which it rotates placed off center. As it turns, its effective radius in any given direction varies.

plate. Closing *A* completes the circuit to the motor, which begins to turn and causes cam *Q* to rotate at the rate of one complete revolution per minute so that the contact points at *C* are opened and closed once a minute. The amount of time *C* is closed depends on the position of *G*, and the time determines the temperature, since current goes to the hot plate only during the time *C* is closed. Any setting other than high will not

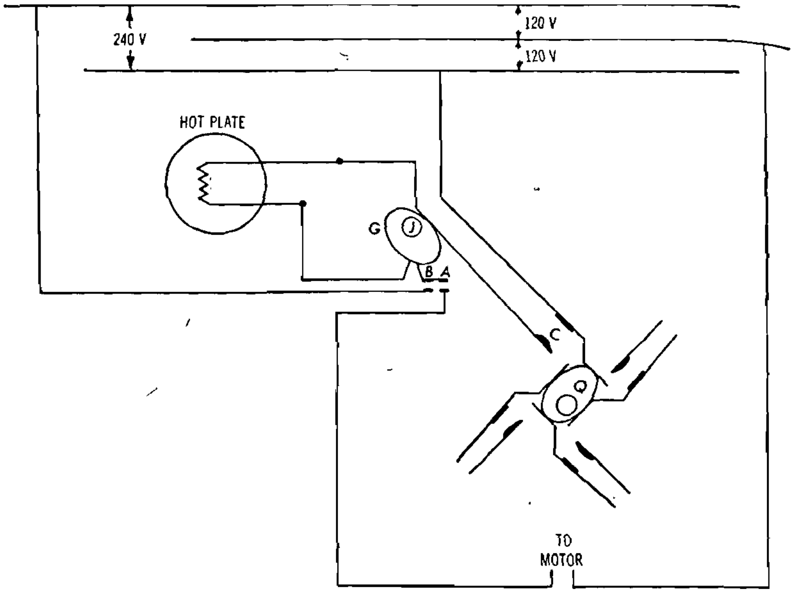

Fig. 27.12. Schematic diagram of multi-speed type of temperature control for hot plate with one heating element. (Courtesy Admiral Corporation)

close the contacts completely, and the motor-driven cam *Q* will open and close *C*. The per cent of time the current flows may be adjusted anywhere between 3 and 100 per cent.

There is a decided trend toward using a hot plate unit built into the working surface with the oven and broiler located in some other part of the kitchen. This plan has several advantages. Storage space for equipment used for surface cooking can be located closer to the place where it will be used, and any heat escaping from the oven is not coming up around the housewife as she works at the surface area. The oven can be located near the mixing and baking center of the kitchen; and, what is a decided advantage, it is placed high enough that it is easy to look into, and is more convenient for putting food into the oven and removing it.

Ovens are usually provided with two heating elements, one in the bottom for baking and one in the top for broiling. The oven is thermostatically controlled and often has a timer which will turn the current on and off at predetermined times. Electric ovens differ from gas ovens in that air is not required for combustion. Therefore they are tightly closed except for a steam vent. They are heavily insulated with Fiberglas or rock wool, which reduces the cost of operation and prevents escape of heat into the kitchen. One should note the finish of the oven and the ease of removing shelves and baffle plates for cleaning.

161. Electric Roasters and Broilers. Roasters and broilers are portable cooking devices which are used for some of the same cooking operations that might be done with a range. They are often used where a range is impractical because of original cost, space required, or amount of cooking to be done. They are often chosen for vacation homes or for small apartments.

Roasters are double-walled with rock-wool or Fiberglas insulation packed between the walls. The heating elements are (1) at the bottom and (2) around the sides of the inner wall. They are thermostatically controlled and some are equipped with automatic timers. They use from 800 to 1600 watts, and care should be taken not to overload the line when they are in use.

Broilers have the heating element in the lid so that the heat is thrown down onto the food. The smoke and spattering grease and the high temperature of the outside of the broiler are sometimes undesirable features. They use from 800 to 1500 watts on high heat; thus the same precaution as to overloading the line applies to broilers as well as to roasters.

162. Electric Water Heaters. Water for the bathroom, laundry, and kitchen may be heated with electricity if the rate per kilowatt-hour is rather low; otherwise, it may prove to be too expensive. But if gas is not available, many people are willing to pay the greater cost because of the satisfaction and convenience of having a constant supply of hot water. Better insulation of the tanks and the decided increase of electric service in rural areas have resulted in a greater use of electric water heaters. The heater consists of an insulated metal storage tank, one or more heating elements, and thermostatic and manual controls. (See page 92 for a diagram.)

The capacity of the tank should be based on the needs of the family. It has been estimated that in the average family each person will use about 15 gallons of hot water per day. One kilowatt-hour will heat about 4 gallons of water 100 degrees Fahrenheit. If the average amount of hot water the family uses per day, the average inlet temperature, the average high temperature desired, and the rate per kilowatt-hour are known, the cost of operation of the tank may be calculated by

$$\frac{\text{Number of gallons}}{4} \times \frac{\text{temp change}}{100} \times \text{rate per kwhr}$$

163. Electric Heating Pads and Blankets. Heating pads are by far the most convenient method for warming beds or for applying heat to the body. They contain coils of high-resistance wire and consequently use a very small current. They are generally made so they can furnish three heats, each of which is thermostatically controlled. Small heating pads use about 50 to 60 watts on high heat.

Electric blankets and electric sheets are useful where extreme cold weather, or preference for lighter bed covers or for unheated bedrooms and warmer bed covers, enters into the decision for providing comfortable sleeping conditions. They are provided with automatic temperature controls and those for use on double beds have two entirely separate heating elements, each with its own control, so that each half can be regulated independently. They use from 100 to 200 watts.

164. Electric Space Heaters. Small electric heaters are used a great deal as auxiliary heating units. On cool mornings or evenings a bedroom, bathroom, nursery, or dining room can soon be made comfortable with a portable heater. These heaters may use from 500 to 1500 watts, and the cost of operation varies from about $0.03 to $0.08 per hour at $0.05 per kilowatt-hour.

In a new type of electric heater the heating element is placed between two glass panels, or is fused on to one side of a glass panel and covered with a heavy coating of shellac. This type of heater does not have a high surface temperature, since the heat radiates from the entire glass panel instead of from the much smaller area of the wires. Also, since glass is a poor conductor, if a child happens to put his hand on the glass he will have time to move it before he is burned.

These glass panels are also made into serving trays for keeping the food hot for family meals or for buffet suppers. The tray is preheated and the hot food is placed on it. The trays are made in various sizes in circular and rectangular shapes.

165. House Heating with Electricity. Heating a whole house with electricity is the safest, cleanest, easiest, and most flexible system possible. But the one factor against electric house heating offsets all of these advantages in most localities — the cost of operation is prohibitive. Even at $0.01 per kilowatt-hour the cost would average about $0.07 per hour on a cold day for one average-sized room. The cost of electricity would have to be reduced to less than $0.003 per kilowatt-hour to compete with coal or gas, and in most localities this rate is impossible.

The amount of heat furnished by 1 kilowatt-hour may be calculated by

$$\begin{aligned} H &= 0.24\,IVT \\ &= 0.24 \times 1000 \text{ watts} \times 3600 \text{ sec} \\ &= 864{,}000 \text{ cal} \\ \text{or} \qquad &= \frac{864{,}000 \text{ cal}}{252 \dfrac{\text{cal}}{\text{Btu}}} \\ &= 3430 \text{ Btu} \end{aligned}$$

Thus the cost per British thermal unit even at $0.01 per kilowatt-hour is $0.01 ÷ 3430 = $0.000,003. (Compare with costs per British thermal unit for fuels in Probs. 1 and 2, page 165.) Of course, the fuels cannot be used as efficiently as the electricity.

166. Choice and Care of Electric Heating Equipment. In choosing a piece of heating equipment, the purchaser must know (1) that it is made for the available voltage and (2) whether it will operate on either alternating or direct current, or on alternating current only. While an attractive appearance is to be desired, it should not be the chief factor in determining the choice of a piece of equipment. Neither should initial cost be the only factor considered. Very often a low purchase price will be more than offset by increased cost of operation, short life of the element, or fire resulting from poor insulation. No electrical equipment should be purchased which does not carry the approval of the National Board of Fire Underwriters. (See Sec. 189.)

The usefulness of a piece of equipment to the purchaser should be carefully considered. Even though it be well built, fully guaranteed, attractive in appearance, and reasonable in price, the purchaser will realize little on her investment if she has no use for the article. An egg cooker might be a good investment for one person but a poor investment for a person who seldom cooks eggs. A waffle iron might be a useful article in a given home, but an electric heater might be still more useful. If a certain amount of money is available for electrical equipment, the devices to be purchased should be considered in relation to the useful return measured in convenience, pleasure, and comfort.

STUDY QUESTIONS

1. Why are alloys instead of pure metals used for electric heating elements?
2. How many feet of copper wire are needed to replace one foot of Calorite in order to furnish the same resistance? Assume the same cross-sectional area.
3. Why is glass a suitable material to use for insulators on telephone poles?
4. Which is the larger amount of energy — a calorie or a watt-second?
5. How does the reading of an ammeter, which is connected in series with an iron, change as the thermostat is moved from nylon to linen? How then is the temperature increased?
6. Describe the two general types of steam irons.
7. Observe the arrangement of the steam vents on several makes of irons. Which do you prefer, and why?
8. What automatic controls are found on toasters?
9. What are the two general types of electric coffee makers?
10. Do you prefer a combination waffle iron and grill, or do you prefer separate devices? Why?
11. What precautions should be observed when using a deep-fat fryer?
12. What voltage is needed for an electric range? Why? Is it supplied by means of two wires or three wires? Why?
13. Explain how three heats may be obtained by using only two heating elements. How may four heats be obtained? What voltage is used?

14. Explain how a five-heat hot plate operates.
15. Explain how a seven-heat hot plate operates.
16. Explain how the multi-speed temperature control operates.
17. What are the advantages of a deep-well cooker?
18. How are oven elements arranged?
19. What automatic controls are used on electric ranges?
20. What is your opinion of electric roasters and broilers?
21. Is it practical to heat water for the home with electricity?
22. What are the advantages and disadvantages of electric blankets?
23. How can we justify the use of small space heaters but not justify electric heating for the whole house?

PROBLEMS

1. How many calories are given out in 1 hour by a radiant heater which uses 10 amperes at 120 volts? *Ans.* 1,036,800 cal
2. How many calories are given out in 1 hour by a heating pad which uses 0.6 ampere at 120 volts?
3. If a percolator uses 5 amperes and has a resistance of 24 ohms, how much heat is developed in 10 minutes? *Ans.* 86,400 cal
4. The resistance of an automatic iron is 15 ohms, and it is connected to a 120-volt line. How much heat is developed in 20 minutes?
5. An electric toaster uses 10 amperes at 120 volts and requires 1.5 minutes to toast 2 slices of bread. What is the cost per slice if the rate is $0.04 per kilowatt-hour? *Ans.* $0.0006
6. What does it cost to cook a waffle if the iron uses 6 amperes at 120 volts and requires 3 minutes per waffle? The rate is $0.05 per kilowatt-hour.
7. How many British thermal units of heat are given out in an hour by an electric heater which uses 1000 watts? At $0.04 per kilowatt-hour, what is the cost per hour of operating the heater? What is the cost per British thermal unit? *Ans.* 3430 Btu; $0.04; $0.000,012
8. How many amperes must a heater use at 120 volts in order to furnish 1000 British thermal units per hour? What is the cost of this energy at $0.05 per kilowatt-hour?

28

ELECTRIC LIGHTS

In the latter part of the nineteenth century many attempts were made to design electric lamps for interior lighting. Edison made his first incandescent lamps in 1879. He used carbon filaments, and he found that the bulbs must be evacuated otherwise the carbon was oxidized at once. Edison searched all over the world for materials from which to make his filaments. He wanted a material which could be heated to a high temperature without vaporizing because a larger percentage of the energy input was then converted into visible light. Another requirement was that the material last a reasonable length of time. Edison made many improvements in carbon filaments, which were used exclusively for 25 years and are still used for some purposes. But in 1906 it was found that tantalum and tungsten filaments gave a whiter light and were more efficient than carbon.

167. Tungsten Incandescent Lamps. Tungsten soon promised to be the best material available for lamp filaments, but the filaments were very fragile and brittle. If the filaments were heated to higher temperatures to improve the efficiency, the bulbs soon became black due to a deposit of vaporized tungsten, and this rapid vaporization caused the filament to "burn out." W. D. Coolidge of the General Electric Company worked for many years trying to improve the methods of preparing the tungsten so that it would be less brittle. He succeeded in making filaments which were far superior to any which had been made previous to that time. Later it was found that if the lamps were evacuated and then filled with an inert gas, such as nitrogen or argon, the blackening due to vaporization of the tungsten could be greatly reduced. This in turn caused a decrease in the efficiency of the lamps on account of the heat transmitted by the gas. The decrease in efficiency was counterbalanced by winding the filament into a tiny coil which concentrated it, resulting in a higher temperature and a whiter light.

The modern gas-filled tungsten lamps are about four or five times as efficient as the carbon lamps which they replaced. Research is still being carried on in an effort to produce better filaments with longer lives which will give whiter light, but in the best tungsten lamps which are now made only about 10 per cent of the energy which is put into a lamp is given out as visible light — the remainder is given out as heat.

It is important to select lamps which have been designed for use on the voltage which is available. If a 110-volt lamp is used on a 120-volt circuit it will burn more brightly, but its life will be decidedly decreased. If a 120-volt lamp is used on a 110-volt line the lamp will last a long time but it will give much less light. Lamps have been designed to give the most light, with a reasonable length of life, when operated on the indicated voltage. The life of a tungsten lamp is about 1000 hours.

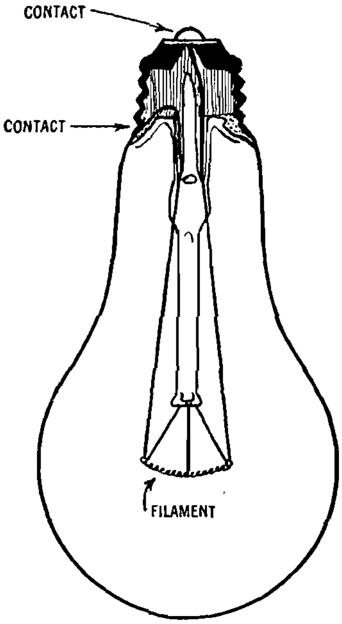

Fig. 28.1. A tungsten filament lamp.

168. Mercury-Vapor Lamps. About 1900 a mercury-vapor lamp was developed. It consisted of a tube containing some mercury, with electric leads to each end of the tube. When it was placed in a horizontal position so that the mercury reached from one end of the tube to the other the current traveled through the mercury, heated it, and some was vaporized. When the tube was tilted to a vertical position, the current continued to flow in the mercury vapor. The newer types of mercury-vapor lamps light without being tilted; a heater coil vaporizes enough mercury to start the arc when the lamp is turned on. The light from these lamps contains yellow, green, and blue visible light and also a great deal of ultraviolet, but practically no red light. As a result colored objects do not appear in their natural colors. Faces of people take on a deathlike appearance because the natural red in the skin does not show. Lipstick, rouge, and nail polish appear black or gray. Even though mercury-vapor lamps have many uses, they are not suitable for interior illumination in places where it is important for colors to appear as they normally do.

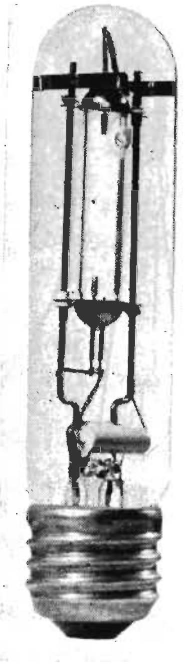

Fig. 28.2. Mercury-vapor lamp. (Courtesy General Electric Company)

169. Sodium-Vapor Lamps. Sodium-vapor lamps are similar to mercury-vapor lamps but the current is carried by sodium vapor and the light given out is a greenish-yellow. They are very efficient since the human eye is most sensitive to that color of light, but again they are not suitable for interior illumination because of the color of the light. However, they are used for street and highway lighting.

170. Fluorescence and Phosphorescence. Ultraviolet light will cause some materials to glow; when these materials absorb the ultraviolet they emit light of a longer wave length. It is believed that when the ultraviolet falls on these materials electrons are displaced from their normal positions in the atoms, and when they return to their original orbits the visible light is given out. If the material glows only while it is under the ultraviolet, it is fluorescent, but if it continues to glow after the ultraviolet is removed, it is phosphorescent. Fluorescence and phosphorescence are sometimes referred to as *cold light* and ultraviolet is called *black light.*

171. Neon Lights. Neon lights, which were invented by a Frenchman, were first installed in the United States in 1924. It was found that, if a high voltage was put across a tube containing a rare gas at a low pressure, the gas would glow. The color of the light depends on the gas used — neon gives a red light, mercury a blue light, and helium a white light. Other colors are obtained by using colored glass tubes. A considerable amount of ultraviolet light is also produced, but it is absorbed by the glass in ordinary neon lights and is therefore wasted. If the inside of the glass is coated with a fluorescent material the ultraviolet light will cause these materials to give out visible light. This makes the lights more efficient and makes it possible to obtain almost any color.

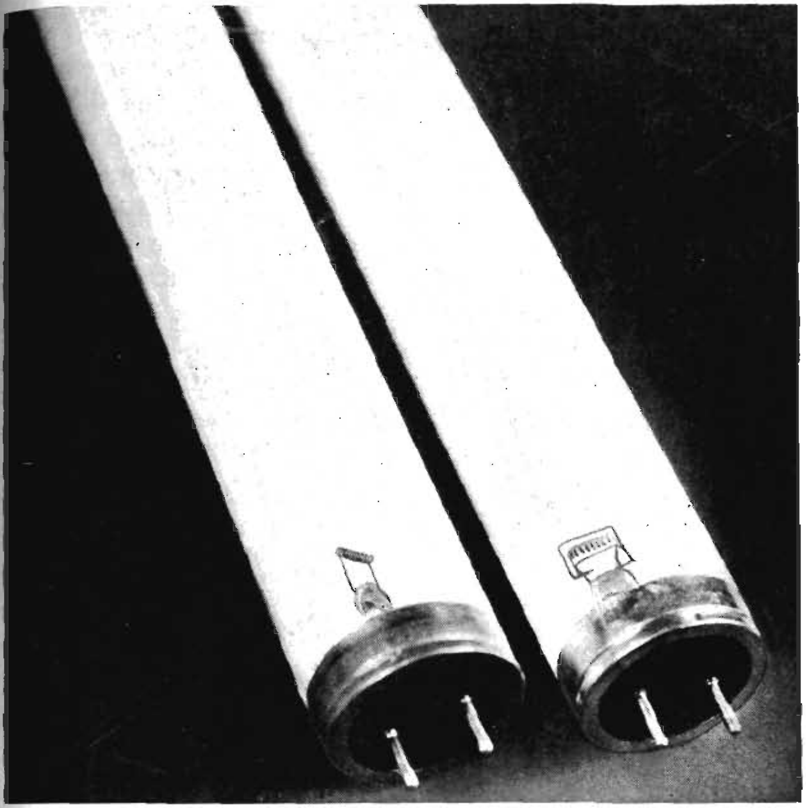

Fig. 28.3. Fluorescent lamps. Note the heating coils at the ends of the tubes. (Courtesy General Electric Company)

172. Fluorescent Lights. A fluorescent lamp is a mercury-vapor lamp with the inside of the tube coated with a fluorescent material which will glow because of the ultraviolet emitted by the mercury arc. The voltage required to operate the tubes depends upon the length and the diameter of the tube. However, many of the fluorescent lamps intended for home use are equipped with a suitable ballast so they may be connected to the usual house lighting circuit. When the lamp is first turned on, current flows through the heating filaments F in either end of the tube, the thermostat T, and the starting ballast B. The tube contains a small amount of mercury, which is vaporized by the heating filaments, and also a small amount of argon gas, which aids in starting the lamp. By the time the mercury is vaporized, the thermostat opens the circuit through the heating coils; and then the discharge takes place through the mercury vapor between the filaments, which now serve as electrodes.

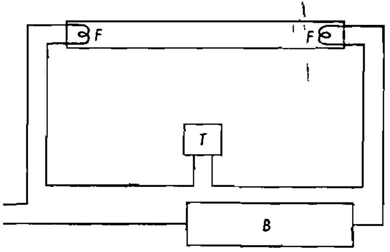

Fig. 28.4. Wiring circuit for a fluorescent lamp.

The light which is given out is a combination of that given out by the mercury arc and that given out by the fluorescent material. The latter is the source of the greater part of the light, and the color is determined by the material used to coat the tube. The following is a partial list of the materials used and the resulting color.

Calcium tungstate	Blue
Magnesium tungstate	Blue-white
Zinc silicate	Green
Cadmium silicate	Yellow-pink
Cadmium borate	Pink
Cadmium borate (with a red filter on the tube)	Red

Mixtures of the above materials, in the proper proportions, are used to make "daylight" fluorescent lamps. By varying the proportions the "daylight" may be a blue-white or a yellow-white. These lamps produce light that is more like daylight than that from any other artificial light which has been made.

The life of a fluorescent lamp is about 2500 hours as opposed to about 1000 hours for a gas-filled tungsten lamp. They are also much more efficient than tungsten lamps. (See table on page 411.) Incandescent lamps waste more energy in the form of heat than do fluorescent lamps; fluorescent lamps also convert part of the ultraviolet into visible light. Burned out tubes or broken tubes should be disposed of in such a way that no one will handle broken pieces. While much has been done to eliminate the danger resulting from getting any of the fluorescent material in an open wound, it still is better not to risk the possibility of cuts that will not heal.

STUDY QUESTIONS

1. What were some of the difficulties encountered by Edison when he first made incandescent lamps?
2. What were some of the problems encountered when tungsten was first used for lamp filaments?
3. What are the advantages of gas-filled tungsten lamps?
4. What is the result if a lamp is operated on a higher voltage than that for which it was made?
5. How does the color of the light produced by a mercury-vapor lamp differ from that produced by a tungsten lamp?
6. What is the characteristic color of sodium light?
7. When were neon lights first used in the United States?
8. What is a "fluorescent material"?
9. How does fluorescence differ from phosphorescence?
10. Describe a fluorescent lamp.
11. How is the "daylight" coating made?
12. How does the efficiency of a fluorescent lamp compare with that of a tungsten lamp?
13. How does the life of a fluorescent lamp compare with that of a tungsten lamp?
14. What is the purpose of the argon gas in a fluorescent lamp?

PROBLEMS

1. What does it cost to run a 60-watt tungsten lamp for 4 hours at \$0.05 per kilowatt-hour? *Ans.* \$0.012
2. What does it cost to run a 150-watt tungsten lamp for its life, assuming it lasts for 1000 hours? The rate is \$0.04 per kilowatt-hour.
3. What does it cost to run a 15-watt fluorescent lamp for 4 hours at \$0.05 per kilowatt-hour? *Ans.* \$0.003
4. What does it cost to run a 15-watt fluorescent lamp for its life, assuming it lasts for 2500 hours? The rate is \$0.04 per kilowatt-hour.

direct current. When the coil is in the position shown, current enters through B_2, flows around the coil, and leaves by B_1. The resultant forces acting on the wires push the right side of the coil down, and the left side up, or in other words the coil rotates in a clockwise direction. When the coil reaches the position at right angles to that shown in Figure 29.2 there are no forces acting on the wires to cause rotation; unless the inertia of the rotating parts is enough to carry the coil past this neutral position the coil will cease to rotate. But, when the armature is carried past this neutral position, the commutator sections have also been turned so that current now enters through the opposite segment and consequently the motor continues to rotate.

However, an armature usually has several coils on it, with additional commutator segments to match the coils. Thus when one coil is in the neutral position the coil at right angles to it is in the position in which the maximum forces are acting on it to produce rotation. Therefore the question of the neutral position becomes unimportant.

If the connections from the source of the direct current to either the commutator or the electromagnets are reversed, the direction of rotation of the motor is reversed; but if the connections both to the commutator and to the electromagnets are reversed, the motor continues to rotate in the direction it was going before these changes were made.

The magnetic field may be furnished by permanent magnets, but it is usually furnished by electromagnets. The electromagnets may be wired in series with the armature, in which case the motor is said to be *series wound*, or they may be in parallel with the armature, and the motor is then said to be *parallel* or *shunt wound*.

175. Alternating-Current Motors. An alternating-current motor may be made in exactly the same way as the direct-current motor described above, with the provision that the field coils must be electromagnets wired in series with the armature. Whenever the current in the armature reverses, the current in the field coils reverses also, and, when both fields are reversed, the resulting forces on the armature wires are in the same directions as before the current reversed. Usually there are many coils on the armature of the alternating-current motor just as there are on the direct-current motor.

Small motors, such as those which have been described, which will run on either alternating or direct current, are known as *universal motors.* They are found on equipment such as kitchen mixers, sewing machines, some vacuum cleaners, and small fans which require very small motors. It has been found that another type of motor, called the *induction motor,* is more satisfactory for devices which require larger motors — for example, refrigerators, washing machines, and large fans. The details of construction are different from those of a universal motor, but the rotation of the armature is still due to the interaction of two magnetic fields. A third type of motor, known as a *synchronous motor,* is found in electric clocks. A full discussion of induction and synchronous motors is beyond the scope of this book.

176. Power Factor. An alternating current is not a current of constant intensity, but one which periodically rises from zero to a maximum, and then decreases to zero again; it is also one which flows first in one direction and then the other. On account of these factors, and of other factors which will not be discussed in this text, it usually happens that the product of the current in amperes and the potential difference in volts gives a larger number than the true number of watts used by a motor. The ratio between the watts actually used and the number indicated by the ammeter and voltmeter readings is known as the *power factor.*

$$\text{Power factor} = \frac{\text{watts}}{\text{amperes} \times \text{volts}}$$

or

$$\text{watts} = \text{amperes} \times \text{volts} \times \text{power factor.}$$

Therefore, unless the power factor is known, a wattmeter should always be used to determine the number of watts used by a motor.

177. Back Voltage. When a motor is rotating, all of the necessary conditions for generating a voltage exist, for there is (1) a closed conductor, (2) a magnetic field, and (3) relative motion between the conductor and the magnetic field. A voltage is generated by the armature, which, because of opposing action and reaction, is always in the opposite direction to the voltage which is applied to the motor, and hence the voltage is called *back voltage.* The difference between the applied voltage and the back voltage is the voltage which determines the current in the armature, and the wires of the armature are designed for this current. When the motor is first started, it turns slowly and does not generate much back voltage, and the ammeter shows that a large current is flowing through the motor; if the motor did not speed up rapidly, this high current would burn out the armature. Except in small motors, an additional resistance is included in the circuit until the back voltage builds up — then the extra resistance is automatically disconnected. If the motor is operating a light load, it turns rapidly and generates a large back voltage, and the ammeter shows that a small current is being used. But if the motor is operating a heavy load it turns slower and generates a smaller back voltage, and the ammeter shows that a larger current is being used. If the back voltage becomes too small the resulting large current through the motor will cause it to overheat and, if the motor is considerably overloaded, it may burn out if it is not protected by a fuse or a circuit breaker.

178. Horsepower of Motors. The motor must be of a suitable size for the device which it is to operate. Motors may be rated by their watt input or their horsepower output. The cost of operation varies with the watt input, but the rate at which a motor does work is usually given in terms of horsepower based on the watt output. One horsepower equals 746 watts. The efficiency of a motor is the ratio of the watt output to the watt input.

HOUSEHOLD DEVICE	HP OUTPUT	COST PER HOUR AT $0.05 PER KWHR
Vacuum cleaner	1/4 to 1/2	$0.01 to 0.02
Electric fan	1/32 to 1/8	0.001 to 0.004
Sewing machine	1/32 to 1/16	0.001 to 0.002
Kitchen mixer	1/32 to 1/16	0.001 to 0.002
Refrigerator	1/4 to 1/2	0.01 to 0.02
Washing machine	1/4 to 1/2	0.01 to 0.02

179. Choice and Care of Motor-Driven Equipment. Too often a motor-driven device is chosen on the basis of its attractive appearance, its gadget attachments, or its low initial cost, rather than on the basis of its construction, safety, and efficiency. Only those motor-driven appliances which have been tested and approved by the National Board of Fire Underwriters (see Sec. 189) should be purchased. The purchaser must be sure the motor is made to operate on the kind of electric circuit which is available in the house. This includes checking on the voltage available, whether the current is alternating or direct, and, if alternating, the number of cycles. Usually current is brought into the house as single phase on two wires, and most household motors are made to operate on that type of current. Larger motors, such as are used on equipment in hotels, hospitals, cafeterias, and other institutions, may require what is known as *three-phase current* (a discussion of which is beyond the scope of this text). If a motor of this type is to be installed, the power company should be consulted as to voltage, number of cycles, and phase of current. Before using any electrical device for the first time, or in a new location, one should check the information on the device with data concerning the local power supply to avoid damaging the equipment.

Some people have trouble with motors because they do not give them proper care. As machines, motors are quite rugged, but when they do need repairs or oiling they should be cared for at once. Precautions should be taken to keep water and dust out of the motor. Occasionally the brushes have to be cleaned and adjusted, or even replaced — sparking at the brushes indicates that adjustment or repair is needed. Metallic abrasives such as steel wool and emery paper should not be used around motors. The bearings of some motors have to be oiled frequently, others only occasionally. Some have the bearings enclosed in oil so that the owner never has to oil the motor, but the oil may have to be changed at stated times. When the device is purchased, directions for oiling are found in the instruction books or are furnished by the salesman, and these directions should be followed carefully. Unsatisfactory operation may result from too much oil as well as from too little.

STUDY QUESTIONS

1. What causes the armature of a motor to rotate?
2. What determines the direction in which the armature rotates?
3. What kind of magnets must be used in an alternating-current motor? Why?
4. What factors enter into the rate at which a motor uses energy?
5. What factors determine the amount of electrical energy used by a motor?

6. Why should a wattmeter be used in the circuit with a motor, instead of an ammeter and a voltmeter?
7. What are some of the factors that enter into the power factor?
8. Does a low power-factor result in low efficiency?
9. What is meant by "back voltage"?
10. How are the power ratings for motors expressed?
11. What information must be given when one orders a motor?
12. What precautions should be observed by a person who is using a motor?

PROBLEMS

1. How many watts does a fan motor require if it uses 0.6 ampere at 120 volts? Assume that the power factor equals 1. *Ans.* 72 w
2. How many watts does a washing-machine motor require if it uses 5 amperes at 120 volts? Assume that the power factor equals 1.
3. How many watts does the motor of a vacuum cleaner use if the current is 5 amperes on a 120-volt line and the power factor is 0.7? *Ans.* 420 w
4. How many watts does a kitchen mixer use if the current is 0.8 ampere on a 110-volt line and the power factor is 0.9?
5. If a motor uses 533 watts and it is 70 per cent efficient, what is its horsepower? *Ans.* 0.5 hp
6. How many watts are required to operate a 1/4-hp motor which is 80 per cent efficient?
7. How many kilowatt-hours of energy are used in 1 hour by an electric clock which uses 3 watts? How many kilowatt-hours are used in 24 hours? What is the cost of this energy at $0.04 per kilowatt-hour? *Ans.* 0.003 kwhr; 0.072 kwhr; $0.003
8. How many kilowatt-hours of energy are used in 5 minutes by a kitchen mixer which uses 70 watts? What is the cost of the energy at $0.04 per kilowatt-hour?
9. What does it cost to run a sewing machine for 5 hours? It uses 40 watts and the electrical energy costs $0.05 per kilowatt-hour. *Ans.* $0.01
10. What does it cost to run a refrigerator for a month? The motor uses 250 watts and runs one-third of the time. The rate is $0.04 per kilowatt-hour.
11. If a vacuum cleaner uses 550 watts, what does it cost per month for energy if it is operated an average of 20 minutes each day? The rate is $0.04 per kilowatt-hour. *Ans.* $0.22
12. What does it cost to run a fan for 2 hours at $0.05 per kilowatt-hour if the fan uses 80 watts?

30

CHEMICAL EFFECTS OF A CURRENT

In the home electricity is not used to produce chemical changes but many articles which have been made by electrochemical processes are used in our everyday lives. Gold- and silver-plated jewelry and tableware, chromium- and nickel-plated fixtures for kitchen and bathroom use, and chromium-plated trimmings and bumpers on cars are examples of electroplated articles which are used extensively. These articles are made of a less expensive metal and then electroplated with a thin layer of a more expensive metal which makes the cost less than if the article were made entirely of the more expensive metal. The coating gives the article a finish which either wears better, rusts less easily, cleans more easily, or is more pleasing in appearance.

180. Metallic versus Nonmetallic Conductors. When a current is sent through a metallic conductor the conductor is heated and has a magnetic field around it, but the current produces no permanent change in the material of the conductor. When a current is sent through a nonmetallic conductor, such as a solution of a salt, a base, or an acid, it is also heated and has a magnetic field around it, but in addition chemical changes are produced in the conductor.

181. Theory of Electrical Conduction by a Solution. When a material such as silver nitrate ($AgNO_3$) or copper sulphate ($CuSO_4$) is dissolved in water it is partially dissociated; that is, the molecules break up into parts called *ions*. This breaking up of the molecules is called *ionization* and the process goes on continually, some molecules breaking up into ions and other ions recombining into molecules. In the silver nitrate solution Ag and NO_3 ions are formed and in the copper sulphate solution Cu and SO_4 ions are formed. The Ag and Cu ions are positively charged and the NO_3' and SO_4 ions are negatively charged. Metallic ions are always positively charged, and the acid radicals are always negatively charged.

If a direct current is sent through the solution, it is found that some of the ions migrate to the *electrodes* by means of which the current enters and leaves the solution which is called the *electrolyte*. For example, if a tray is to be copper plated the current is sent into the solution through the *positive electrode or anode* which is a piece of pure copper. The tray is used for the *negative electrode or cathode*. The *electrolyte* is a solution of copper sulphate. The positively charged Cu ions are attracted to the negative cathode (the tray) where they lose their charges and deposit. The negatively charged SO_4 ions are attracted to the positive anode where they unite with molecules of copper to form more $CuSO_4$, which goes into solution and then ionizes, and the process is repeated. The result is that the cathode becomes heavier, the anode lighter, and the solution remains at the same concentration.

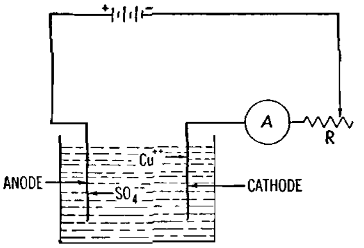

Fig. 30.1. *Copper plating a tray.*

If a spoon is to be silver plated a bar of silver is used for the anode, the spoon is the cathode, and a solution of a silver salt is used for the electrolyte. If a ring is to be gold plated a bar of gold is used for the anode, the ring is the cathode, and the electrolyte is a solution of some gold salt. In any case the anode must be made of the material which is to be plated on the cathode and the electrolyte must be a solution of a compound containing that material. The cathode is in general another material; that is, gold is plated on brass, silver on nickel, or chromium on iron.

It has been found by experiment that the mass of material deposited depends on the kind of material which is being deposited and on the quantity of electricity which is sent through the plating cell. *The electrochemical equivalent K of a material is the mass in grams which is deposited by 1 coulomb of electricity.* Therefore the total mass deposited is

$$M = KQ$$

but since $Q = IT$

then $M = KIT$

where M = mass in grams
K = electrochemical equivalent
Q = quantity of electricity in coulombs
I = current intensity in amperes
T = time in seconds

For example, if the amount of copper deposited by 2 amperes in 25 seconds is found to be 0.01645 gram, then

$$M = KIT$$

$$0.01645 = K \times 2 \times 25$$

and $K = 0.000329$ g per coulomb

TABLE OF ELECTROCHEMICAL EQUIVALENTS

Gold (Au^{+++})	0.000681 gram per coulomb
Silver (Ag^{+})	0.001118
Copper (Cu^{++})	0.000329
Nickel (Ni^{++})	0.000304
Chromium (Cr^{+++})	0.000179
Platinum (Pt^{++})	0.001010

182. Electroplating Technique. The article which is to be electroplated is very carefully prepared. It must be made in the exact shape desired for the finished article and it must be almost as large as the size desired for the finished article since plating in general adds a very thin layer of material. It must be smooth and perfectly clean in order to have the plating adhere well. The article is polished, dipped in an alkaline solution which will remove all traces of grease, rinsed in water, dipped in acid to remove any oxide which may have formed and to give it a bright surface, rinsed again in water, and at once suspended in the electrolyte.

The current intensity must be carefully regulated. In general a deposit put on slowly with a low current will wear better than plating put on more rapidly with a high current. An ammeter and a rheostat are included in the circuit so that the current may be measured and regulated. After the object has been plated long enough to deposit a coating of the desired thickness it is removed, dried, and polished. Sometimes the plating wears better if it is put on in several layers with each layer polished before the next layer is added. If the plating consists of three such layers it is said to be *triple-plated* and if four layers are used it is *quadruple-plated*.

183. Electrolysis of Water. In 1800 it was discovered that a current could be sent through water which contained a little sulphuric acid, and that the water was decomposed into hydrogen and oxygen. The apparatus which is now used for this demonstration is shown in Figure 30.2. The electrodes are made of platinum and are connected to a battery or to a direct-current generator which furnishes 6 to 10 volts. The gas which collects above the cathode is hydrogen and that above the anode is oxygen. Since the gases collect in the ratio of two volumes of hydrogen to one volume of oxygen this experiment proves that water is H_2O.

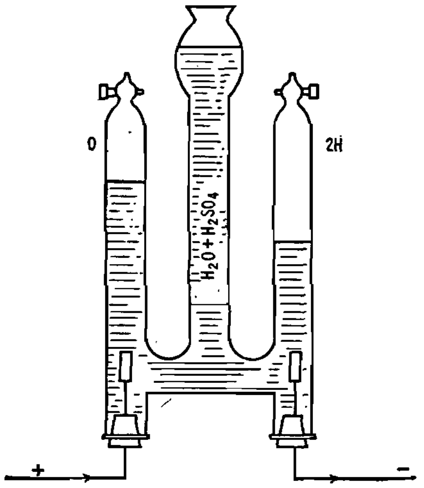

Fig. 30.2. Electrolysis of water.

The chemical changes which occur are accounted for as follows: the sulphuric acid ionizes and each molecule forms two H^+ ions and one SO_4^{--} ion. The H ions go to the cathode where they lose their charges and become free hydrogen gas. The SO_4 ion goes to the anode, but instead of losing its negative charge it unites with an H_2 of a water molecule to form a new molecule of sulphuric acid, H_2SO_4. The O ion of the water molecule loses its charge and becomes free oxygen.

184. Electrolytic Silver Cleaning. Silverware may be cleaned easily by electrolytic methods. The silverware is placed in an aluminum pan, making sure that each piece is in contact with the aluminum. Equal parts of baking soda ($NaHCO_3$) and salt ($NaCl$) are sprinkled over the silverware allowing one teaspoon of each for each quart of water, enough of which must be added to cover entirely each piece of silverware. The water is heated to the boiling point and then poured into the aluminum pan. After a few minutes the silverware is removed and the tarnish, which was silver sulphide, has been decomposed and the silver ions deposited on the silverware as pure silver. However the silver is probably not deposited so smoothly or so securely as it was originally; therefore it must not be assumed that the silverware has not been harmed by allowing it to become tarnished, even though the silver is not removed from the silverware in the cleaning process.

The pan, containing the silverware and the cleaning solution, should not be placed on the stove, and the solution boiled with the silverware in it. Such a high temperature is not necessary for the cleaning process, and it may soften the cement with which the blades of the knives are fastened in the handles. Bone or plastic handles should not be placed in the solution and if the silverware has an oxidized finish it should not be cleaned by this method if the oxidized finish is to be preserved.

185. Industrial Applications of Electrolysis. The commercial applications of electrolysis cover an extensive range. In addition to electroplating, which has already been discussed, several other applications will be mentioned briefly. Most books are printed from electrotype plates. The page is set up in type and a wax impression is made. Since the wax itself is a nonconductor, it is coated with graphite and then copper plated. This thin plate of copper is then separated from the wax and backed with type metal to make it strong enough for use in printing.

Some metals can be obtained in a nearly pure state by electrolytically separating them from their impurities. The crude metal is used as the anode and the pure metal is deposited on the cathode which in the beginning is a thin sheet of the same metal that is to be deposited. Electrolysis plays an important part in the refining of copper, silver, nickel, and many other metals. Even though aluminum cannot be electrolytically deposited from solutions of its compounds, special chemical methods have been worked out, so that the production of aluminum has become one of the most important electrochemical industries in this country. As a result the price per pound has been reduced decidedly and aluminum is now commonly used for all kinds of cooking utensils.

STUDY QUESTIONS

1. How do metallic and nonmetallic conductors differ?
2. Are there any ions present in a solution before a current is sent through it?
3. Explain the process by which water may be separated into hydrogen and oxygen.
4. How is silverware cleaned electrolytically?
5. How is electrolysis used in the refining of metals?

PROBLEMS

1. What quantity of electricity will deposit 2 grams of silver? *Ans.* 1789 coulombs
2. What quantity of electricity will deposit 2 grams of gold?
3. A current of 0.5 ampere flowing for 20 minutes deposits how much platinum? *Ans.* 0.606 g
4. How long does it take to deposit 1 gram of chromium if a current of 1.5 amperes is used?
5. What is the electrochemical equivalent of copper, if a current of 1.5 amperes deposits 0.5922 gram in 20 minutes? *See table.*
6. What material is being deposited if a current of 1.5 amperes deposits 0.55 gram in 20 minutes?

31

TRANSFORMERS

Alternating current is stepped up to high voltage for cross-country transmission to reduce the energy loss along the line, and it is then stepped down to low voltage before it is delivered to the consumer because low voltages are much safer to use. The device which is used for changing the voltage is a *transformer.* Large *step-up transformers* at the power station may increase the voltage to thousands of volts for transmission. At the other end of the line the voltage is reduced gradually by means of several *step-down transformers.*

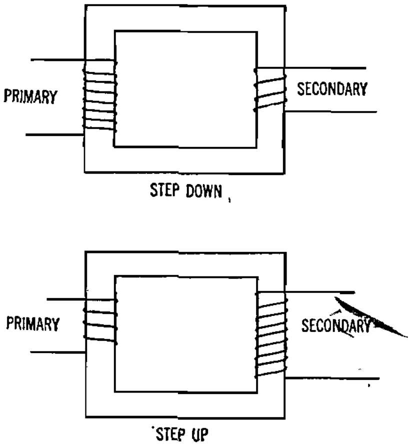

Fig. 31.1. Transformers.

There are two main questions about transformers to be answered. (1) How does a transformer change the voltage? (2) Why is the line loss less at high voltage?

186. Change of Voltage by a Transformer. A transformer consists of two coils of wire which are close to each other but which are not electrically connected. These coils may or may not be wound on an iron core. (See Fig. 31.1.) Alternating current is sent through one coil called the *primary,* and as a result, an alternating current is generated in the other coil which is called the *secondary.* Every time the current in the first coil reverses, the magnetic field associated with it also reverses. Since the secondary coil is close to the primary, it is in the magnetic field of the first coil, the direction of which is constantly reversing. If the secondary coil is on open circuit, no current will be generated in it, but if the circuit is closed, all of the necessary conditions for generating a current exist — (1) a closed conductor, (2) a magnetic field, and (3) relative motion between the coil and the magnetic field due to the constant change in direction of the field rather than to the motion of the coil. Hence an alternating current is generated in the secondary coil. It seems evident that a transformer will not work on a direct current because, since there is no change in the direction of the field, there is no relative motion between the field and the closed conductor, and therefore no current is generated in the secondary coil.

The coils usually are wound on an iron ring and the lines of force tend to stay in the iron; theoretically all of the lines of force cut across the wires of the secondary coil. Since the field reverses at the same rate as the alternations of the primary current, we realize when we look at the formula for finding the voltage furnished by a generator

$$V = \frac{LN}{10^8 T}$$

that L, the number of lines of force, and T, the time, do not make the secondary voltage different from the primary voltage, and therefore the change in voltage must be due to the difference in N, the number of turns of wire in the two coils. Experiment proves that this is true, and that the ratio of the voltages in the two circuits is equal to the ratio of the number of turns of wire in the two coils.

$$\frac{V_P}{V_S} = \frac{N_P}{N_S}$$

For example, if in a step-up transformer there are 5 turns of wire on the primary and 50 on the secondary a 110-volt current will be changed into a 1100-volt current. If in a step-down transformer there are 60 turns on the primary and 3 on the secondary, a 120-volt current will be changed to a 6-volt current. A transformer with this 20:1 ratio between its coils might be used to step down the usual house voltage to a voltage suitable for a doorbell or door chimes.

187. Efficiency of Transformers. If a transformer reduces the voltage, it increases the current or, vice versa, if it increases the voltage, it decreases the current, and theoretically the watts supplied to the transformer and the watts delivered by it are equal. But while large oil-cooled transformers may be as much as 95 to 98 per cent efficient no transformer can be 100 per cent efficient, and small transformers such as those used for doorbells and electric toys are often quite inefficient.

The efficiency of a transformer is found by:

$$\text{Efficiency} = \frac{\text{watts out}}{\text{watts in}} = \frac{I_sV_s}{I_pV_p}$$

But even with some loss of energy at each transformer it is still more economical to step the voltage up at the generator, send it across country at a high voltage, and then step it down to a safe voltage for the consumer.

188. Relationship of Voltage to Line Loss. Transmission lines are made of copper or aluminum which, with the exception of silver, are the two best conductors of electricity. The wires are made as large as possible to reduce the resistance of the line, but there are a number of factors which limit the size which can be used. The larger the wire the greater is the weight, and copper and aluminum are not inexpensive materials; also heavier wires require more and larger poles to support them; so again the expense is increased. In sections of the country

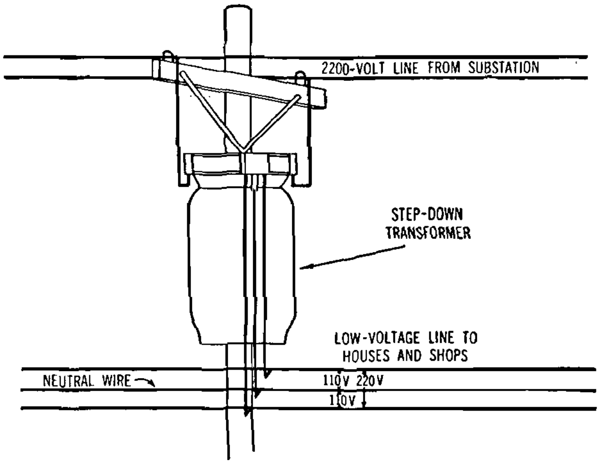

Fig. 31.2. Showing the connections to a step-down transformer on a power line.

where ice may form on the wires a larger weight of ice will collect on the larger wires — in fact it has been found that copper wires are better than aluminum wires for some localities simply because, since copper is a better conductor than aluminum, a smaller wire can be used.

Assuming that the line has been installed with as small a resistance as is practical, let us compare the line losses at two different voltages. (See Fig. 31.3.) Power is to be supplied to the village at the rate of 22,000 watts. If it is delivered at 1100 volts, the current intensity must be 20 amperes. If the resistance of the transmission line is 10 ohms, then the voltage drop along the line will be 20 × 10 = 200 volts or the voltage at the power house must be 1100 + 200 = 1300 volts. But if the same power — 22,000 watts — is delivered at 11,000 volts, the current will be only 2 amperes and the voltage drop along the line will be 2 × 10 = 20 volts or the voltage at the power house must be 11,000 + 20 = 11,020 volts. It is evident that the voltage drop is far less at the higher voltage.

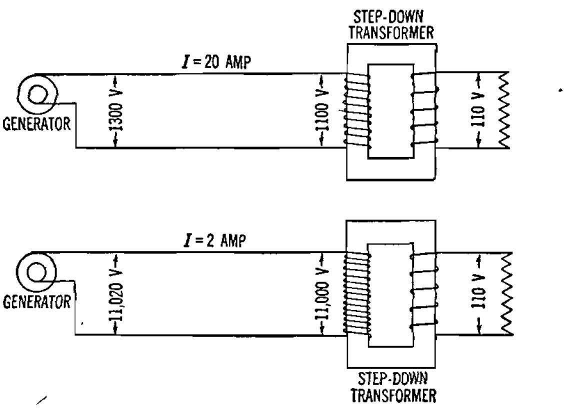

Fig. 31.3. Comparison of line losses at two different voltages.

The energy lost as heat along the line in either case can be calculated by

$$H = 0.24I^2RT$$

but since R is the same in both cases and the losses would be computed for equal periods of time T it is evident that the heat losses would vary with I^2, i.e.,

$$\frac{H_1}{H_2} = \frac{I_1^2}{I_2^2}$$

or

$$\frac{H_1}{H_2} = \frac{20^2}{2^2} = \frac{400}{4} = \frac{100}{1}$$

If the higher voltage is used, the energy loss along the line is decidedly less. In fact if the energy were delivered at 110 volts, the voltage drop and the energy loss would be prohibitive. Even at the high voltages which are used on transmission lines the energy loss often is as much as 10 per cent.

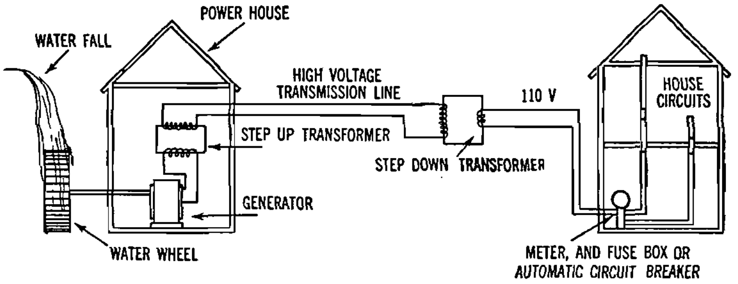

Fig. 31.4. Transmission of electrical energy from the power house to the home.

STUDY QUESTIONS

1. How does a transformer change the voltage?
2. Why will a transformer not work on direct current?
3. What are the factors that limit the amount to which the resistance of the transmission line may be reduced?
4. How do transformers rank in efficiency when compared with other energy-transforming devices?
5. Why is the line loss less at high voltage?

PROBLEMS

1. If the voltage sent into a transformer is 2200 volts and that given out is 110 volts, how many turns of wire must be on the primary if there are 4 turns on the secondary? Is this a step-up or a step-down transformer? *Ans.* 80 turns; step-down
2. If a voltage of 550 is to be stepped up to 66,000 and there are 100 turns of wire on the primary, how many turns must there be on the secondary?
3. There are 10 turns of wire on the primary and 200 on the secondary of a transformer. What is the secondary voltage if the primary voltage is 120? *Ans.* 2400 v

4. A transformer has 4400 volts on the primary which has 500 turns of wire. What voltage is on the secondary which has 1500 turns of wire?
5. A transformer has 10 amperes at 240 volts sent into it. The secondary circuit furnishes 19 amperes at 120 volts. What is the efficiency of the transformer? *Ans.* 95 per cent
6. A transformer has 5 amperes at 600 volts sent in. The secondary voltage is 120, and the transformer is 90 per cent efficient. What is the secondary current?
7. In one case energy is delivered at 120 volts and 60 amperes. In another case energy is delivered at the same rate but at 2400 volts and 3 amperes. Compare the heat losses. *Ans.* 400:1
8. In one case energy is delivered at 110 volts and 20 amperes. In another case energy is delivered at the same rate but at 4400 volts and 0.5 ampere. Compare the heat losses.
9. In Problem 7 what loss of voltage occurred along the line in each case if the resistance of the line was 2 ohms? In each case what voltage would be necessary at the power house? *Ans.* 120 v; 6 v; 240 v; 2406 v
10. In Problem 8 what loss of voltage occurred along the line in each case if the resistance of the line was 3 ohms? In each case what voltage would be necessary at the power house.

32

HOUSE WIRING

An electrical system is becoming more and more an accepted part of any house, but the average householder probably knows less about the installation and intelligent use of the electrical system than about any other part of the house. The housewife usually knows from where the water supply is obtained, how it is distributed about the house, and how the waste water is removed. She usually understands something about the heating system, and probably knows how to operate it. But the electrical system is more of a mystery to her. Perhaps it is easier to visualize water flowing in a pipe, and to understand how heat energy is transferred from one place to another by air, water, or steam, than it is to understand how energy, generated many miles away and transferred by wires, may furnish light or heat, turn a motor, or operate a radio.

Because the average person does not understand the electrical system of the house, she sometimes overloads the circuits, uses unapproved equipment, has unskilled persons make additions to the circuits, often with materials which do not meet the standards of the wiring code, and then is inclined to be skeptical when occasionally she hears of a fire caused by defective wiring.

189. The Underwriters' Laboratories and the Wiring Code. The hundreds of electrical devices and parts in use today are not made in all the different ways the manufacturers may think they might be made, and wiring is not done in just any way the workman may wish to do it. Instead, both the manufacture and the installation must measure up to definite minimum standards which experience has proved are safe and practical.

The equipment sold by reputable dealers carries the stamp of approval of the Underwriters' Laboratories, Inc. The Underwriters are a group of laboratories supported jointly by manufacturers, insurance companies, and other interested groups. Manufacturers submit samples of their devices and parts to the Underwriters, and, if the samples meet the minimum standards, the device is listed as "Approved by Underwriters." The manufacturer may then put the label showing this approval on the corresponding devices or on the carton, or he may use some symbol registered with the Underwriters by which the inspector can identify the manufacturer as he examines equipment in the field. After a device or part has been approved, the Underwriters regularly test samples obtained both from the manufacturer and from retailers to be sure the minimum standards are still being met. On electric cords "bracelet" labels are used.[1] If the cord is attached to a device, and the whole assembly is approved, a "doughnut" label is used on the cord. This approval only means the device is safe if used under the conditions of the approval. Cord approved for one purpose may not be approved for some other purpose. The fact that two devices carry the approval labels does not mean they are of equal quality. One may just meet the minimum requirements while the other may far surpass the requirements.

Even though approved electrical parts and devices are used, if the installation is carelessly or improperly made, shock and fire hazards may exist. For correct installation, the wires and parts not only must be approved, but also must be installed according to the National Electrical Code. This code is simply a collection of rules outlining the wiring methods that over a period of years have been found to be safe and sensible. Often the code suggests several different ways in which an installation may be made, but one of these methods must be followed. The national code is often supplemented by local codes or ordinances which are never contrary to the national code but which may further specify how wiring must be done in that particular

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[1] Lamp cord has a yellow label; 1000-cycle cord has a blue label and is used on toasters, percolators, and devices where the cord is not subject to much bending; 3000-cycle cord has a red label and is used on irons and other devices where the cord is subjected to more bending; 10,000-cycle cord has a gilt label and is designed for long life and hard wear. The term "—cycle cord" indicates the number of bends the cord must withstand in a testing machine.

locality. While the code sets up certain minimum standards, it does not teach one how to wire a house. The wiring may meet the requirements of the code, but still not be a convenient or an efficient arrangement for a given situation. Satisfactory service may require larger wires, more circuits, and better equipment than the minimum standards.

While the Underwriters have no legal jurisdiction, states, counties, and cities usually make laws stating that only approved devices, parts, and wiring which meet the minimum specifications of the code may be used. There is, therefore, no choice but to follow their rules. Moreover, power companies usually will not connect to a house which is not properly wired, and insurance companies may refuse to issue policies on such houses. In some localities it is necessary to secure a permit from the proper authorities before a wiring installation may be made. The wiring must be done by a licensed electrician, or else approved by a wiring inspector.

It is always more economical and satisfactory in the long run to purchase good equipment and parts. The installation should be carefully planned and adequate circuits and outlets installed, because adding circuits and outlets later usually costs about twice as much as if they had been made in the original installation. A satisfactory installation provides for safety, convenience, and comfort.

190. Transfer of Energy from the Power Plant to the Home. The current which is generated at the power plant is stepped up to a high voltage for transmission so that the loss of energy along the line will be as small as possible. Then this high voltage is reduced in several steps, the first of which occurs at the outskirts of the town, and the last at the transformer from which the wires are brought to the house. Two wires with a difference of potential of 110 volts [1] between them are brought from the transformer to the house. If an electric range is to be used in the house, three wires are brought from the transformer, with 110 volts between each outside wire and the center wire, and 220 volts between the two outside wires. These wires are connected to the service switch which, when closed, connects

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[1] This voltage may vary from 110 to 125 volts, depending on the locality, but in this book the number 110 will be used throughout.

the wires to the kilowatt-hour meter. The wires which leave the meter connect to the various branch circuits in the house.

191. The Kilowatt-Hour Meter. As its name indicates, the kilowatt-hour meter measures the amount of electrical energy used in the house. It is essentially an electric motor; the rate at which the armature rotates is proportional to the rate at which energy is being used in the house, and the total number of revolutions depends upon the rate at which it turns and the length of time during which it turns. There are several types of kilowatt-hour meters, but only one very simple type will be explained here. Some of the other types have been found to be more satisfactory in commercial installations, but an explanation of their structure and operation is more involved, and the one which is described here illustrates the basic principles. (See Fig. 32.1.)

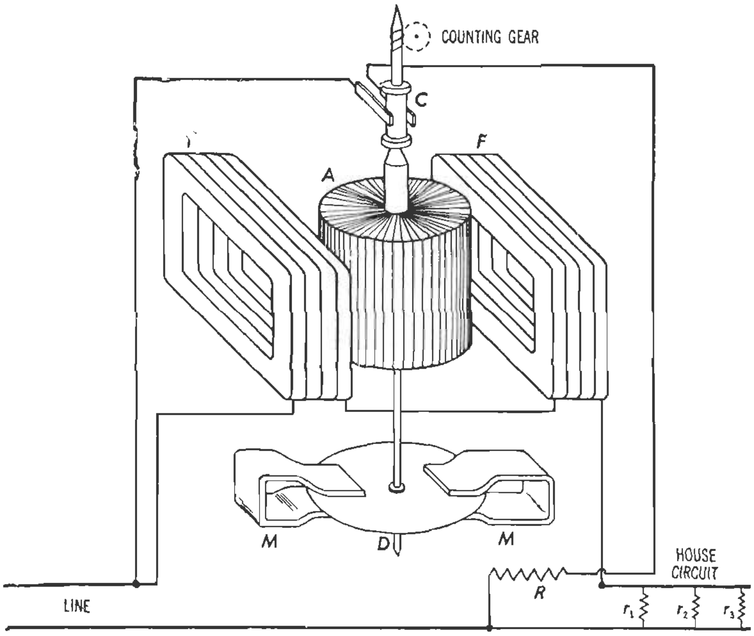


Fig. 32.1. A kilowatt-hour meter.

Like a motor this instrument contains two sets of coils. The armature coils *A* are wired across the power line and consequently are in parallel with whatever electrical devices are in use in the house. The current through them is proportional to the voltage. The magnetic field coils F are in series with the line and the house circuits, and their field strength is proportional to the total current being used in the house circuit. Therefore the force causing the motor to rotate is proportional to the product of I and V or is proportional to the rate at which energy is being used. Whenever this rate is changed by turning electrical devices on or off, the rate at which the motor rotates changes accordingly. Since the motor rotates only when energy is being used, the total number of revolutions is proportional to the product of IVT. (If all of the devices in the house are turned off, no current flows through the field coils F, and therefore the motor ceases to turn.)

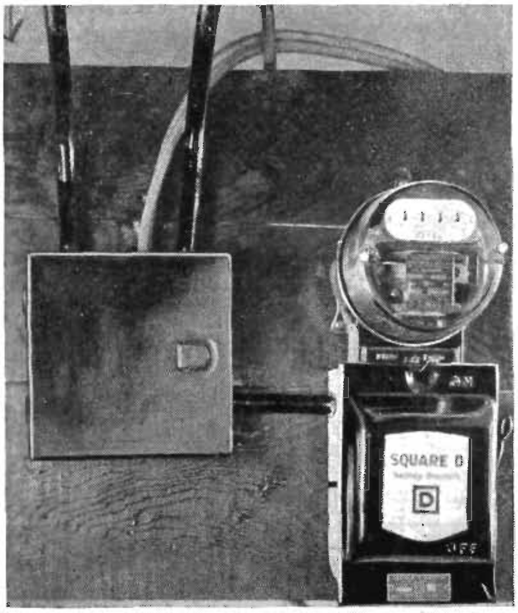


Fig. 32.2. Showing a kilowatt-hour meter and fuse box installed. (Courtesy Square D Co.)

When the armature turns, it operates the recording mechanism which may be either (1) a set of cogwheels which move pointers over numbered dials (the reading of these dials was explained in Sec. 42) or (2) a registering device like the mileage indicator on a car, which gives the reading directly.

The aluminum or copper disk D rotating between the poles of the permanent magnets M acts as a magnetic brake. If the armature turns too rapidly or too slowly its speed can be adjusted by moving the magnets either nearer to or farther from the center of the disk.

192. Fuses and Circuit Breakers. Either fuses or circuit breakers are placed in the main circuit leading into the meter, and in each branch circuit that leaves the meter. They are *safety devices* which will open the circuit if the current becomes higher than it should be. A fuse is essentially a small strip of an alloy which has a low melting point and will melt if the current exceeds the number of amperes the fuse was made to carry. Fuses are made in two general types — plug fuses and cartridge fuses. Plug fuses of the type shown in Figure 32.3 are made in various current sizes up to 30 amperes. Plug fuses are enclosed in a housing which can be screwed into a socket base made just like a lamp socket. Cartridge fuses of the type shown in Figure 32.3 are made in various current sizes up to 60 amperes. Those up to 30 amperes are 2 inches long and those rated between 31 and 60 amperes are 3 inches long. For currents above 60 amperes the fuses are 5 7/8 inches long and have knife-blade terminals. These are *larger than those needed in house wiring. Cartridge fuses* are enclosed in cases which are inserted between spring clips which hold them firmly in place. The service switch should always be open when fuses are either inserted or removed.

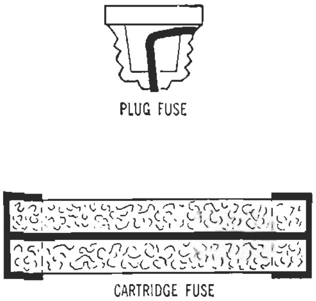


Fig. 32.3. Fuses.

Circuit breakers which are used in house circuits are bimetallic strips of metal which curve when overheated and break the circuit. The device is so made that the circuit is not connected again when the bimetallic strip cools, but must be closed by some person, and if the overload has not been removed, the circuit will soon be opened again. The time required for the bimetallic strip to curve enough to open the circuit varies with the size of the current, but it will always open the circuit before the wires in the wall are hot enough to cause a fire. In some houses the circuit breakers are distributed throughout the house, i.e., the one for the laundry circuit is in the laundry, and the one for the second-floor lights is on the second floor. If an overload causes the circuit to open, it will thus be more convenient to close it after the overload has been removed. It is less expensive to install the circuit breakers if they are all grouped in one panel, but it is more convenient to have them distributed through the house. Circuit breakers can be purchased to carry maximum currents of 15 amperes or higher. Since the bimetallic strip is enclosed, and cannot be removed and a strip of the wrong size substituted, they are considered safer than fuses. While all fuses and circuit breakers will carry a small overload for a short time, they should not be overloaded — that is crowding the safety margin.

Fig. 32.4. Circuit-breaker panel. (Courtesy Square D Co.)

193. Distribution of Current to the House Circuits. Usually the service switch, the fuses or circuit breakers, and the meter are assembled in one place, but the meter should be placed where it is easily accessible to the meter reader, so for that reason, it may sometimes be placed outside the house. If fuses are used they are usually in the same cabinet as the service switch. If circuit breakers are used they may be grouped and placed in the same cabinet with the service switch, or they may be distributed around the house.

The current which flows through the field coils of the kilowatt-hour meter is then distributed to the various house circuits. According to the Wiring Code, house lighting circuits must be installed with wire which can carry 15 amperes safely (not less than No. 14 copper wire) and house power circuits must be installed with wire which can carry 20 amperes safely (not less than No. 12 copper wire). The size of the wire will depend on the material of which the wire is made and the type of insulation used.

Fig. 32.5. Circuit breaker installed in a kitchen. (Courtesy Square D Co.)

If three wires have been brought to the house, part of the house circuits are connected on one of the 110-volt circuits and part on the other one. An attempt is made to divide the house load equally between the two circuits because it has been found that this is the most satisfactory method, both for the power company and for the consumer.

194. Number of Circuits in a House. When houses were first wired for electricity, all of the outlets were placed on one circuit, and, if a fuse was melted, all of the lights in the house went out. As the use of electrical heating appliances increased, it was soon evident that it was much more practical to have several circuits and thus distribute the load. Now it is considered good practice to have two circuits in each room. If an overload occurs on one circuit and it is temporarily open, there will still be a circuit in that room which will carry current. For example, a lighting circuit might be installed for all of the ceiling fixtures for several rooms which are located along one side of the house. The floor and wall outlets in these same rooms might be on another circuit, and probably this second circuit will be made of heavier wire which can safely carry 20 amperes. Separate power circuits should be provided for the laundry, the kitchen, and for any other room where a number of electrical devices which carry large currents are to be used.

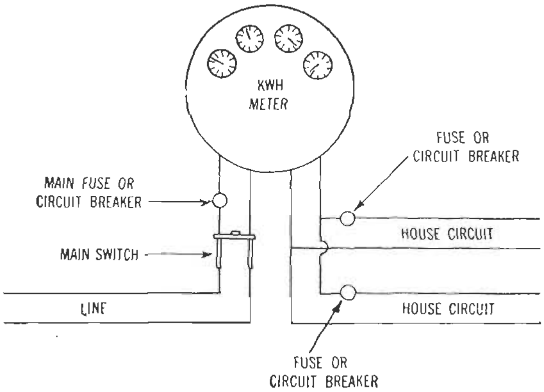
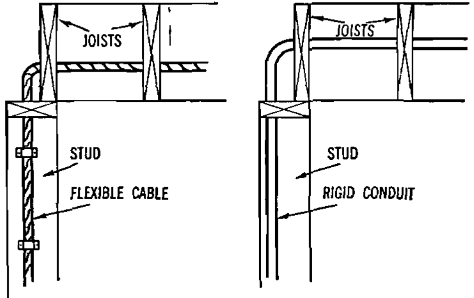


Fig. 32.6. Showing the method of bringing the current from the power line to the house circuits.

195. Methods of Installing the Wiring. After the general plan for wiring the house has been decided upon, the wiring must be done in accordance with the specifications of the code, which states definitely the kind and size of wire which must be used, the type of insulation, and the method of fastening the wires to different kinds of building materials. Sometimes non-metallic sheathed cable is used. The wires are covered with rubber, then wrapped with paper braid, and enclosed in an over-all outer braid made of cotton which is treated with moisture-resisting and fire-retardant compounds. This cable may not be used out-of-doors. In other cases the outer covering is a metal sheath made of two strips of steel wound spirally; this armored cable is flexible enough to bend rather easily. In a third type the insulated wire is enclosed in an iron pipe; this pipe or conduit is harder to bend than the armored cable, and is also more expensive to install. The architect and the contractor will recommend the type of wiring that should be used for the various circuits.



FLEXIBLE CABLE RIGID CONDUIT

Fig. 32.7. Methods of installing house wiring.

196. Outlets and Switches. An electrical outlet consists of any opening where electrical energy is used. Strictly speaking this does not include switches, but they are generally counted when estimating the cost of the wiring installation. The cost of installing any outlet depends in part on the total number of wires brought to that particular outlet. There will always be at least two wires — one by which the current enters and one by which it leaves the outlet — and, if the outlet is for a switch, there may be more than one path by which the current may leave the outlet. Figure 32.8 shows two openings, each of which has two wires brought to it — a lamp outlet and a switch to control it.

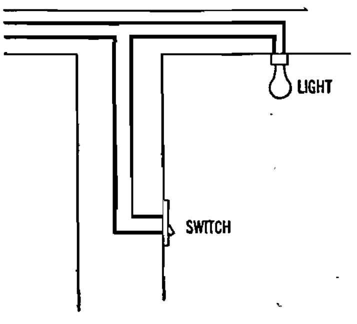


Fig. 32.8. A ceiling light controlled by a wall switch.

It is often a decided convenience to have a lamp or an appliance outlet controlled by two switches. For example, a dining-room light may be turned on or off at either entrance to the dining room; a lamp which lights a stairway may be controlled at either the head or the foot of the stairs; and a garage light may be turned on or off either in the garage or in the house. Figure 32.9 shows diagrammatically the switches and wires which are required for such an installation. As shown, current flows from switch S_1 to switch S_2 through wire *ab* and the lights are on, but if either switch is turned, the lights will go out because one switch is then connected to wire *ab* and the other to wire *cd*. The lights may be turned on again by turning either switch because then both switches will be connected either to wire *ab* or to wire *cd*. The added convenience of such an installation more than pays for the extra initial cost.

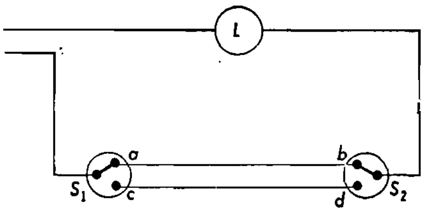


Fig. 32.9. A light controlled by two switches.

197. Lighting Fixtures. The lighting fixtures are not considered a part of the house wiring, but as furnishings. They may be simple and inexpensive or more elaborate and costly, but in any case they should be in harmony with the general character of the room and form a part of the decorative scheme. Lighting fixtures will be more fully discussed in the chapter on Home Illumination.

198. Effect of Electricity on the Human Body. A voltage of 110 volts in general is not fatal, but it may be. The result depends upon the individual, his state of health at the time, the dampness of his skin, and whether he is standing on a wet or a dry surface.

A normal, healthy person, with dry hands, standing on a dry floor, will probably have no serious results from getting his hand across a 110-volt circuit; he will feel a sudden contraction in his muscles, however, and may feel the effect for some little time afterward. On the other hand, if that person is standing on a wet floor, or if his hand is damp, he will find that the result is much more serious. One should never touch electrical appliances while standing in water or on damp surfaces, or when the hands are damp. Another rule to remember is not to touch two electrical devices at the same time, or an electrical device and a water faucet or radiator. One runs the risk of making his body part of the electrical circuit between the two devices, or between the line and the ground if he is touching the water or heating pipes. Another caution is always to disconnect the cord or appliance from the circuit before making any repair or adjustment. The person who tries to remove the base of a broken light bulb from a socket, with pliers, before turning off the current is inviting a good shock. The person who, when he has trouble with a lamp, runs his finger around inside of the socket probably will not discover anything except that it is a good way to get a shock.

After a storm, when telephone and telegraph lines are down, it is a good rule never to touch any wire, not even a wire fence, because it may be in contact with a high-voltage line. First aid for electric shocks is artificial respiration, the same as for drowning or for asphyxiation. The greatest difficulty is that there is very little "half way" in electrical shocks. Either the shock is not severe enough to make one unconscious, or it is fatal.

STUDY QUESTIONS

1. What led to the development of the National Electrical Code?
2. Explain the work of the Underwriters' Laboratories.
3. What does a kilowatt-hour meter measure — rate of using energy or amount of energy?
4. Explain the purpose of fuses and circuit breakers.
5. Why is it poor economy to use larger fuses than the wiring code specifies?
6. Why are automatic circuit breakers to be preferred to fuses? Are there any disadvantages in their use?
7. Why should a house have several circuits?
8. Suggest several plans for grouping the rooms of a house for electric circuits.
9. Are houses wired in series or in parallel? Why?
10. Explain various methods of installing the wiring.
11. What is the very simplest method of installing a light? What are the disadvantages of this type of installation?

12. Explain the wiring for a light which is controlled by two switches.
13. List several precautions to be observed by a person who is using or repairing electrical equipment.
14. List the electrical equipment you have in your home or the equipment you think desirable. After each item, list the average number of watts required and the average time it is in operation per month. Find the total number of kilowatt-hours of energy used and figure the cost of this energy according to the following schedule:

The first 60 kilowatt-hours = \$0.05 each.
The next 40 kilowatt-hours = 0.03 each.
All over 100 kilowatt-hours = 0.02 each.

PROBLEMS

1. If a toaster uses 1100 watts, an iron 800 watts, and a coffee maker 1000 watts, what current is being used if the potential difference is 120 volts? Is this current too large for the usual house power circuit? *Ans.* 24.2 amp
2. Two waffle irons are connected on a 110-volt house lighting circuit. If the irons use 660 watts and 1100 watts, what current is being used? Is the line overloaded?
3. How many 100-watt lamps may be operated on a regular house lighting circuit without overloading it? The circuit is connected to a 110-volt line. *Ans.* 16 lamps
4. How many 1000-watt irons may be operated on a regular house power circuit without overloading? The circuit is connected to a 120-volt line.

LIGHT

33

INTRODUCTION TO LIGHT

What is light? Is it a material? Is it energy? How does it travel? How fast does it travel? These, and many other questions about light, have been debated ever since ancient times. One of the early theories was that light was a fluid emanating from an object and, when this fluid entered the eye, it produced the sensation of sight. Another theory was that the fluid came from the eye and, when it met an object, the object became visible. Then, perhaps to integrate the two theories, some thought there might be two fluids — one from the object and one from the eye — and when the two fluids met vision resulted. As a result of these theories painters showed light streaming either from objects or from the eyes, and poets wrote of "the angry eye flashing fire."

Another theory was that light consisted of tiny particles or corpuscles which were given out by an object and which caused the sensation of sight when they entered the eye. This corpuscular theory was widely accepted until the latter part of the seventeenth century when Huygens, a Dutch physicist, formulated a *longitudinal wave theory* to explain various light phenomena such as reflection (Chapter 34), refraction (Sec. 207), and diffraction and interference (Sec. 217) which he could not explain satisfactorily on the basis of the corpuscular theory. Later during the nineteenth century it was shown that all of these phenomena, and also polarization (Sec. 201), could be more satisfactorily explained on the basis of transverse waves which were later identified as electromagnetic waves. But during the latter part of the nineteenth century certain phenomena, such as the photoelectric

Fig. 33.1. A transverse wave.

effect (Sec. 140) could not be explained entirely by the wave theory, because it seemed that light energy must be emitted or absorbed in finite quantities, called *quanta* or *photons*, the energy of which was proportional to the frequency of the light wave. Thus we now have a modified form of the wave theory, called the *quantum theory*, which includes the wave theory but modifies it in order to explain certain phenomena. The dual nature of light in acting both as waves and as particles has been debated at length by physicists during the last fifty years, but for the beginner the wave theory satisfactorily explains the transmission of light energy.

199. Velocity of Light. The velocity at which light travels has been measured by various methods. One of the most accurate determinations was made by Michelson who set up his apparatus at the observatory on Mount Wilson in California. A rotating mirror, with several faces, was placed on Mount Wilson, and a reflecting mirror was placed on Mount San Antonio, which was a little over 22 miles away. A beam of light from the arc on Mount Wilson was reflected from the mirror surface *a* to the mirror on Mount San Antonio from which it was reflected back to the mirror surface *c* on Mount Wilson. Then the mirror on Mount Wilson was rotated at a rate such that, as the light traveled the round trip (approximately 44 miles), the mirror surface *b* had traveled to the position formerly occupied by *c*.

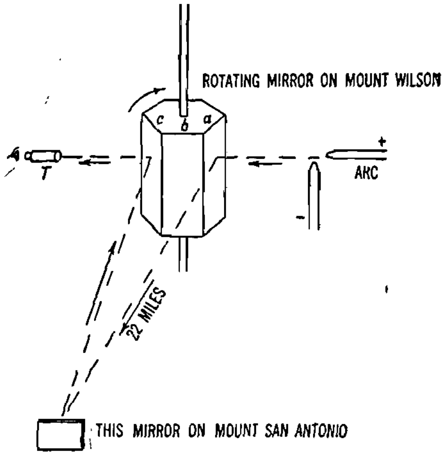


Fig. 33.2. Apparatus for measuring the velocity of light.

From the distance the light traveled and the rate of rotation of the mirror, Michelson calculated the velocity of light from

$$V = \frac{D}{T}$$

This velocity is approximately 186,000 miles per second or 3×10^{10} centimeters per second (3×10^8 meters per second). Traveling at this rate, light would travel more than seven times around the world at the equator in one second. It takes light a little over 8 minutes to travel from the sun to the earth. Sound travels about 0.2 of a mile per second, and a bullet about 0.5 of a mile per second. Compared with the velocity of light, the velocity of sound is extremely small.

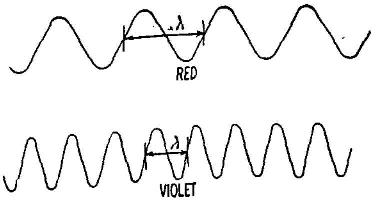


Fig. 33.3. Showing the variation in wave length and frequency for red and for violet light.

Even though all light waves travel at the same rate in a vacuum, or in air, they are not all of the same wave length. The wave length is the distance from a given point in one wave to the corresponding point in the next wave. It is evident that, if the waves all travel at the same rate but differ in wave length, the number of waves per second or the frequency will vary also. The relationship between the velocity (V), the wave length (λ), and the frequency (ν) is

$$V = \lambda\nu \qquad \text{(See Sec. 91.)}$$

200. Rectilinear Propagation of Light. The path of a light wave in any given homogeneous medium is a straight line. Sev-

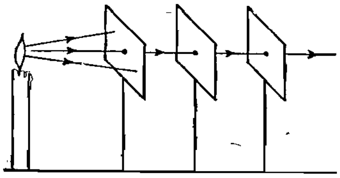


Fig. 33.4. Light travels in straight lines.

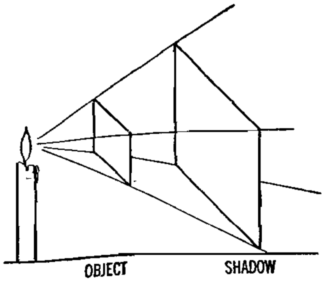


Fig. 33.5. The shadow of an object is similar to the object in shape.

eral simple experiments may be performed to prove this fact. If several cards which have small holes in them are held between the eye and a source of light it will be found that the light source is visible only when the holes are in a straight line. (See Fig. 33.4.) The fact that the shadow of an object is similar in shape to the object itself also shows that light travels in straight lines. (See Fig. 33.5.)

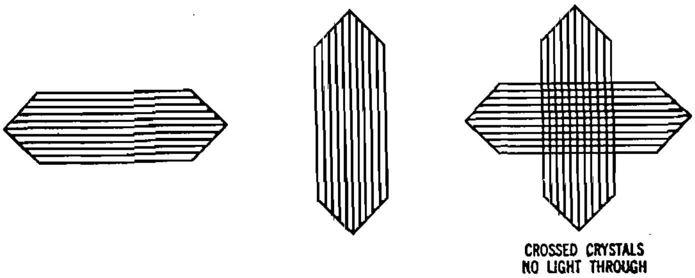


Fig. 33.6. Schematic diagram of tourmaline crystals.

201. Polarized Light. It has been found experimentally that crystals of tourmaline, a semi-transparent mineral, transmit a part of the light which falls on them and absorb a part. These crystals act as if they have parallel openings in them as shown in Figure 33.6. If one of these crystals is held in a beam of light, it is found that the light which is transmitted is vibrating in one plane only. If a second crystal is placed in the path with its axis

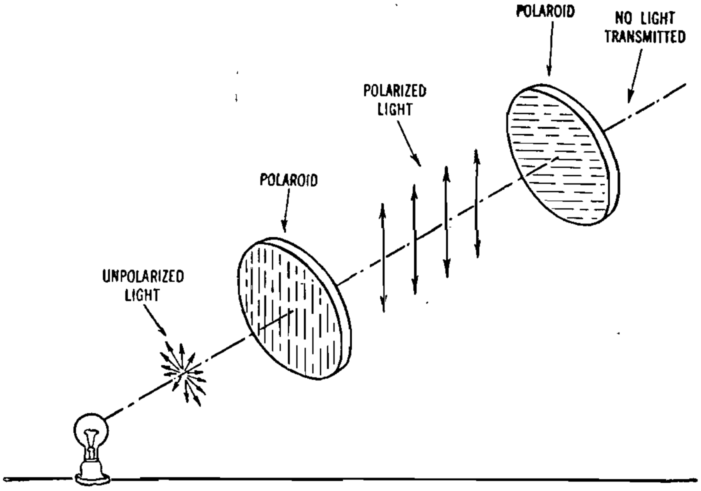


Fig. 33.7. Polarization of light.

parallel to that of the first crystal light is still transmitted, but if one of the crystals is rotated 90 degrees so that its axis is at right angles to the other crystal, then no light is transmitted. For comparison, imagine that a rope is passed through one of the openings in a picket fence and fastened to a tree on the other side. If the free end of the rope is moved so as to cause a transverse wave to travel along the rope, the wave will pass through only if it is a vertical wave. If a second fence is placed back of the first fence, the waves will still go through because the openings in both of the fences are vertical. But if a section of the picket fence is mounted with its openings at right angles to the first fence, then the waves which pass through the first fence do not pass through the second set of openings which are horizontal.

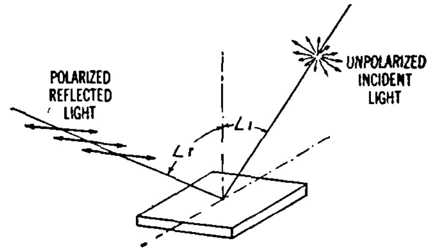


Fig. 33.8. Polarization by reflection.

Polaroid is a new material which is used for polarizing light. It is manufactured by sprinkling quinine crystals on a plastic sheet and then aligning the needlelike crystals by stretching the film. Polarizing sheets much larger than the crystals found in nature can be manufactured and, since this discovery, many practical uses have been found for polarized light. For some of these purposes the expense of the polaroids still prohibits their use, but no doubt that difficulty will soon be overcome. Polaroid sun glasses are familiar to many people. It has been found that when light falls on a concrete highway, on snow, or on water, it is partially polarized; part of the vertical component of the light is absorbed but most of the horizontal component is reflected and causes a glare. If a person wears polaroid glasses with the openings in the polaroids in a vertical position the horizontal light vibrations are absorbed and thus the glare is reduced. Polaroid reading lamps are made with a sheet of polaroid mounted below the light bulb in such a way that the light, which would cause a glaring reflection from a book or work table, is absorbed before it leaves the lamp. If all automobiles were equipped with polaroids on the headlights and on the windshields (all mounted at a predetermined angle), then the polarized light coming from the headlights of one car would be absorbed by the polaroid on the windshield of the other car and as a result neither of the drivers would be blinded by light from the other car. Each driver would have plenty of light from his own headlights to illuminate the road and show the approaching car.

202. The Electromagnetic Spectrum. Visible light is composed of a very narrow range of wave lengths in what is known as the *electromagnetic spectrum.* Included in the electromagnetic spectrum are many other groups of waves which are listed in the following table in the order of decreasing wave length, or of increasing frequency. It will be noticed that the limits overlap and are defined according to the method of observation.

THE ELECTROMAGNETIC SPECTRUM

	WAVE LENGTH
Power lines (30–60 cycles)	10^7 to 5×10^6 meters
Induction heating	10^7 to 20
Radio	3×10^4 to 0.0003
Infrared or heat	0.03 to 0.00008 centimeter
Visible	8000 to 3500 Angstroms
Red	8000 to 6200
Orange	6200 to 5900
Yellow	5900 to 5500
Green	5500 to 4900
Blue	4900 to 4300
Violet	4300 to 3500
Ultraviolet	3500 to 30
X rays	300 to 0.03
Gamma rays	3 to 0.003
Cosmic rays	0.003 to 3×10^{-7}

The information in the above table is shown diagrammatically in Figure 33.9.

The longest waves (those with the lowest frequency) which are indicated in Figure 33.9 are those associated with 60-cycle alternating current used for commercial power and light. Since the velocity of these waves is 3×10^8 meters, the wave length is

$$V = \lambda \nu$$

$$3 \times 10^8 \frac{\text{m}}{\text{sec}} = \lambda \times 60 \frac{\text{vib}}{\text{sec}}$$

$$\lambda = 5 \times 10^6 \text{ m}$$

Shorter waves of considerably higher frequencies are used for therapeutic heat treatments. Wave lengths from about 5000 to 50 meters or frequencies from about 60,000 to 6,000,000 cycles per second are used for this purpose.

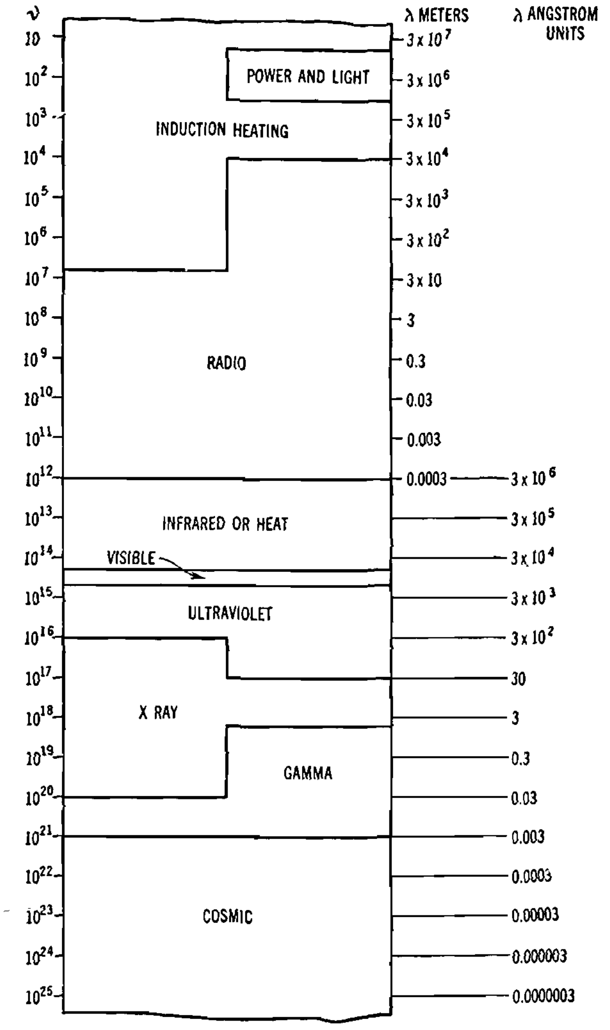


Fig. 33.9. The electromagnetic spectrum.

The frequencies from 550 to 1600 kilocycles per second (550,000 to 1,600,000 cycles per second) are included in the commercial radio broadcasting range. Since the velocity of the radio wave is 3×10^8 meters per second, the wave lengths corresponding to these frequencies are

$$
\begin{aligned}
V &= \lambda \nu \\
3 \times 10^8 &= \lambda \times 550{,}000 \\
\lambda &= 545.5 \text{ m}
\end{aligned}
$$

and

$$
\begin{aligned}
3 \times 10^8 &= \lambda \times 1{,}600{,}000 \\
\lambda &= 187.5 \text{ m}
\end{aligned}
$$

These electromagnetic waves are the carrier waves referred to in the discussion of radio in Sec. 260. They are sent out from the antenna at the radio broadcasting station when the electrons in the antenna are made to oscillate at these high frequencies. The device which causes this oscillation of the electrons is called an *oscillator*. Still higher frequencies (shorter wave lengths) are used in "short-wave radio."

Waves from about 0.03 to 0.00008 centimeter are known as *infrared* or *heat waves*. The wave lengths emitted depend upon the temperature of the radiating body. The temperature sense of the body responds to wave lengths which are longer than those to which the eye is sensitive. For example, if one sits near a radiator he can feel the heat from the radiator, but he cannot see that the radiator is hot. If the hand is held near an electric radiant heater, the radiant energy may be felt before it can be seen, because the eye does not respond until the heater is red hot or glowing. Thus we realize that a higher temperature is necessary for the radiation to be in the visible spectrum.

As the temperature of a glowing body is increased, the color changes from a dull red to cherry red, to orange, to white. This is because, as the temperature increases, a larger percentage of the energy output is in the shorter wave lengths. If the temperature is high enough, the distribution of wave lengths is comparable to that of sunlight, or the emission is "white light." The visible range extends approximately from 0.00008 centimeter in the red to 0.000035 centimeter in the violet. Often these limits are given in terms of Angstrom units (0.00000001 centimeter = 1 Angstrom unit). The visible spectrum then ranges from 8000 to 3500 Angstrom units.

The waves which are too short to cause the sensation of sight are of great importance because of their effects upon the human body. The use of ultraviolet (3500 to 30 Angstrom units) for the prevention and cure of diseases has developed chiefly within the last fifty years. The development of artificial sources of radiation has made possible the use of these short waves, for, although they are radiated by the sun, they are either completely or partly absorbed as they travel through the earth's atmosphere. No wave lengths from the sun shorter than 2800 Angstrom units are transmitted to the surface of the earth, and none shorter than 3100 Angstrom units are transmitted by ordinary window glass. Therefore sunlight which has passed through window glass has had most of the ultraviolet screened out. It is the wave lengths shorter than 3000 Angstrom units which are especially valuable for their bactericidal action. Sunlight is most effective when the sun is high in the sky, since most of the short waves are absorbed when the sun is near the horizon and the radiation has to travel a greater distance through the atmosphere. Ultraviolet also aids in the assimilation of calcium and helps in the prevention of rickets. Ultraviolet causes sunburn, and hastens the fading of some dyes.

Artificial sources of ultraviolet are ultraviolet lamps, popularly known as *sun lamps*, mercury-arc lamps, carbon arcs, and iron arcs. Sun lamps have been developed which give out considerable ultraviolet, from 3300 to 2500 Angstrom units. In one type (see Fig. 33.10) the current passes through a tungsten filament, and heats the mercury which is in the bulb. The resulting mercury vapor then acts as a conductor between the electrodes and a mercury-arc light results. A special glass is used which transmits shorter wave lengths than ordinary glass. The eyes should be protected when one is using one of these lamps, as the shorter wave lengths given out are known to be harmful to the eyes.

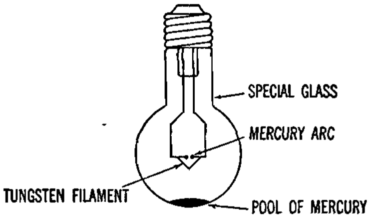


Fig. 33.10. A sun lamp.

Waves from about 300 to 0.03 Angstrom units are known as *X rays*. They are used in treating many skin infections, ulcers, and cancers; they are also used in fluoroscopic work and for making X-ray photographs or radiographs. Although X rays are invisible, they cause some crystals to fluoresce or glow; if these crystals are coated on a special type of lead glass, what is known as a *fluorescent screen* results — it glows when exposed to X rays. If some object is interposed between the source of the X rays and the screen, the X rays are partly or wholly absorbed, and a shadow of the object shows on the screen. If the hand is placed between the source of the X rays and the screen, the bones absorb more of the X rays than does the flesh, and so cast a darker shadow. In Figure 33.12 the shadow of the needle shows its location in the flesh. A doctor may use a fluoroscope to locate a foreign object in the body or to help him set a broken bone. In some cases it is better to substitute a photographic film for the fluorescent screen and then study the resulting radiograph. Growths in the lungs are often located in this way. Radiographs of the lungs are widely used in surveys to detect cases of tuberculosis.

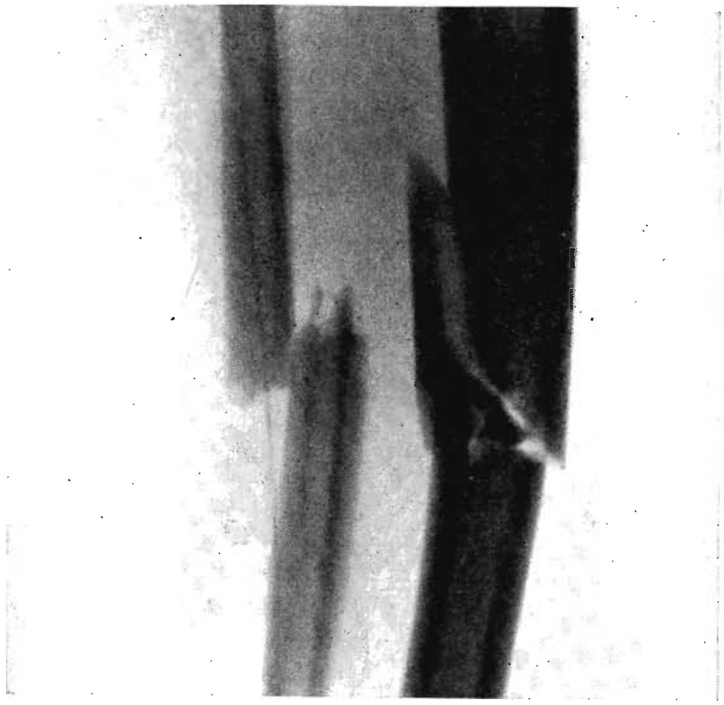


Fig. 33.11. Radiograph of a broken limb. (Courtesy Department of Student Health, K. S. C.)

Figure 33.13 is a diagram of an X-ray tube. A low-voltage direct current is sent through the filament *F* which then emits electrons. A high-voltage (100,000 to 150,000 volts) direct current is connected across the tube so that the target *T* is the positive terminal. The electrons, emitted from *F*, are then shot across to the target *T* where their impact on the target causes the emission of X rays.

Radium emits waves from about 3 to about 0.003 Angstrom units called *gamma rays* which are also used in the treatment of skin infections and cancers. These extremely short, high-frequency waves are emitted by radium in the process of nuclear disintegration.

Fig. 33.12. Radiograph showing a needle embedded in the flesh. (Courtesy Department of Physics, K. S. C.)

Cosmic rays come to the earth from outside of our solar system. They are detected by an apparatus which responds to their ionizing ability. At present there is disagreement as to the nature of cosmic rays. At first it was thought they were electromagnetic waves, but now there is evidence that at least a considerable part of cosmic rays are electrically charged particles. Associated with these charged particles there may also be some radiation of extremely high frequency. There is no known practical use for cosmic rays, but it is well to remember that there was no known use for radio waves when they were first discovered. It is hoped that a study of cosmic rays will lead to a

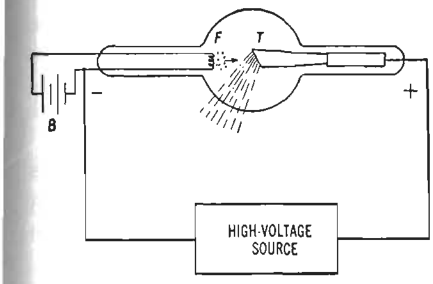


Fig. 33.13. Cross section of an X-ray tube.

better understanding of the nature of matter and of the structure of the universe.

STUDY QUESTIONS

1. What is the present theory concerning the nature of light?
2. How may the velocity of light be measured?
3. Give two numerical values for the velocity of light.
4. As the wave length increases, does the frequency of an electromagnetic wave increase or decrease?
5. What is polarized light?
6. What is polaroid? Explain several uses for it.
7. Do you know of any effects of electromagnetic waves from power lines?
8. What are some applications of induction heating?
9. Are radio waves longer or shorter than visible light waves?
10. For what is infrared used?
11. Is the visible spectrum a relatively large or small part of the complete electromagnetic spectrum?
12. How is a sun lamp constructed? What rays does it furnish?
13. Which has the longer wave length — infrared or ultraviolet?
14. Does a pin in a child's stomach show as a light or a dark image in an X-ray photograph? Why?
15. What is the source of gamma rays? For what are they used?
16. Where do cosmic rays originate?

PROBLEMS

1. The distance from the sun to the earth is 93,000,000 miles. How long does it take light from the sun to reach the earth? *Ans.* 8.3 min
2. The circumference of the earth is 25,000 miles. How long does it take a radio wave to travel half-way around the earth?
3. What is the frequency of vibration for orange light? (Use 0.00006 centimeter as the wave length for orange.) *Ans.* 5×10^{14} vps
4. The average wave length for violet light is 0.00004 centimeter. How many crests occur between a violet source and a point 1 foot away?
5. The assigned frequency of a broadcasting station is 600 kilocycles per second. What is the wave length in meters? *Ans.* 500 m
6. What is the frequency of a broadcasting station if the wave length is 300 meters? Express the answer in kilocycles per second.
7. What is the velocity of a radio wave if its frequency is 800 kilocycles and its wave length is 375 meters? *Ans.* 3×10^8 m per sec
8. What is the frequency of a broadcasting station if the wave length is 250 meters?

34

REFLECTION OF LIGHT

The reflection of light is one of the most common phenomena of everyday life. Most of the things we see are visible because of reflected light, since few of the things we see are self-luminous. Historical records show that the ancients knew some of the laws of reflection of light even though they could not explain why the laws were true, and certainly they did not know what light is or how it is transmitted.

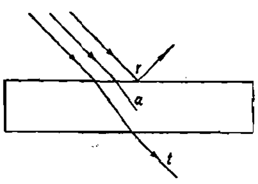


Fig. 34.1. Light may be reflected, absorbed, or transmitted.

When a beam of light which has been traveling in one medium comes to a second medium, some of the light is reflected, some is absorbed, and some may be transmitted. (See Fig. 34.1.) The relative amounts depend upon the wave lengths of the incident light, the angle at which the light meets the second medium, and the nature of the second medium. In this chapter we are concerned only with the light which is reflected.

203. Laws of Reflection. It has been found by experiment that *if a normal is erected at the point where a light ray meets the surface of a new material, the angle between the incident ray and the normal (angle of incidence, i) is equal to the angle between the reflected ray and the normal (angle of reflection, r).*

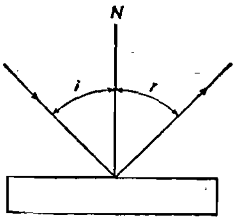


Fig. 34.2. The angle of incidence equals the angle of reflection.

$$\angle i = \angle r$$

If parallel light rays meet a smooth surface, they are reflected as parallel light rays. This is known as *regular reflection*, and often results in a glare. But if parallel light rays meet a rough surface they are diffused, and are not reflected as parallel light rays. While it is true that the angle of incidence equals the angle of reflection for each ray, the angles of incidence vary and therefore the angles of reflection vary. Even a sheet of smooth unglazed paper presents a rough surface to light rays and causes a diffuse reflection, thus avoiding a glaring reflection.

No medium has ever been found which will reflect light of only one wave length unless the incident light contains only one wave length. Consequently we practically never have pure colors in reflected light. It is also found experimentally that if the light meets the new medium at a small angle of incidence more of it is absorbed than if the angle of incidence is large. If the second medium has a polished surface, a large percentage of the light is reflected, but if it has a dark, dull surface more of the light is absorbed.

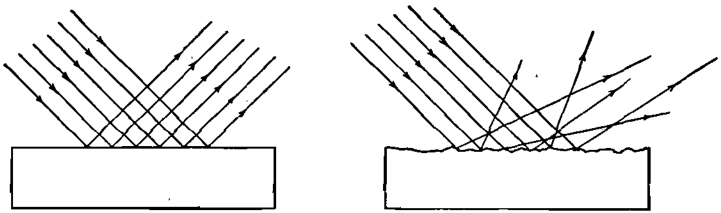


Fig. 34.3. Regular and diffused reflection.

204. Image Formation in a Plane Mirror. Regular reflection is desired when images are to be formed, otherwise the image is distorted. A mirror is made as smooth as possible in order that the image be as much like the object as possible. Probably all have had the experience of looking into a poor mirror and of being either amused or annoyed by the distorted image.

Figure 34.4 shows how an image is formed by a plane mirror. The rays from the object are reflected from the mirror to the eye with the angle of incidence equal to the angle of reflection, but the eye sees the image of the object in the position from which the rays seem to come. The continuous lines show the actual paths of the light rays while the dotted lines show the apparent paths of the rays behind the mirror. Since the rays are reflected at the mirror they do not travel the paths shown by the dotted lines and do not come from *A′* and *B′*. Therefore the image *A'B'* is not a *real image* (one formed where light rays actually do meet) but is a *virtual image* or one which is apparently there. A little thought will soon convince one that there is no image behind the mirror, yet the virtual image that is apparently there is a very useful image. The image is of the same size as the object and as far back of the mirror as the object is in front of the mirror.

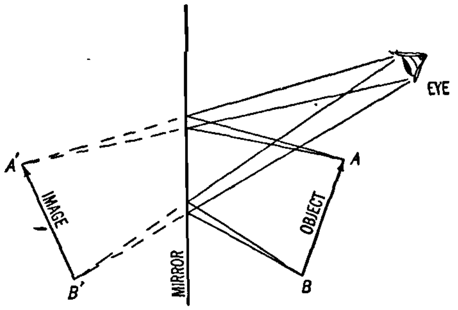


Fig. 34.4. Showing the relationship of object, mirror, image, and eye.

A person may see a full-length image of himself in a mirror which is shorter than he is. The person must stand in such a position that a ray from his foot meets the mirror and is reflected by the mirror to his eye. Also a ray from the top of his head must be reflected by the mirror to his eye. (See Fig. 34.5.)

Good mirrors for household use are made of plate glass backed by a thin coating of silver. A little light is reflected from the front surface of the glass, but most of it is reflected from the metal coating. Mirrors are often used on walls to give an effect of spaciousness, for if large mirrors are placed opposite each other, they reflect images back and forth and make a small room seem much larger than it is.

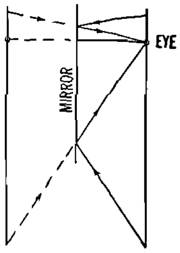


Fig. 34.5. A full-length image may be seen in a short mirror.

205. Curved Mirrors. A curved mirror may be a portion of a *cylinder* (a cylindrical mirror), a portion of a *sphere* (a spherical mirror), or it may be a *parabolic* mirror. (A parabola is a curve which is very simply described by saying it is not a part of a circle, but is shaped somewhat like the end of an egg.) If the mirror is part of the inner surface of one of these curved surfaces it is a *concave* mirror, but if it is a part of the outer surface it is a *convex* mirror.

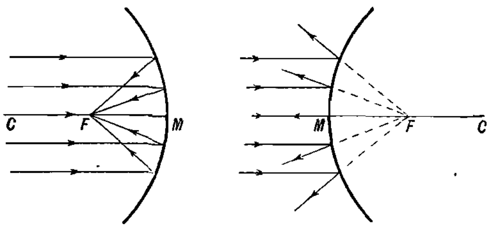
Concave spherical mirrors are used on compound microscopes for reflecting the light from a window or a lamp upon the object to be examined. An ophthalmoscope is a concave spherical mirror with a small hole in the center; with this instrument a physician can reflect light into a patient's eye or throat, and can at the same time look at the brightly illuminated area through the hole in the mirror.

Convex spherical mirrors are used on cars as rear-vision mirrors; they give small but clear images of anything approaching from the rear. The small mirrors in purses and compacts are sometimes convex — a small one even an inch in diameter will give an image of the whole face. Convex spherical mirrors are sometimes used for ornamental mirrors on the walls in a home. Large spheres with mirror surfaces are occasionally used in gardens as ornaments for reflecting images of flower beds or of the sky.

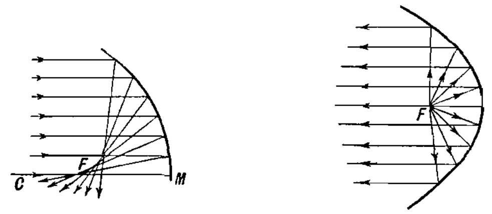
Irregularly shaped mirrors are often found in amusement parks. Various combinations of concave and convex surfaces will produce distorted images which afford considerable entertainment for the observers.

In the case of a spherical mirror, the center of the sphere, of which the curved mirror is a portion, is the *center of curvature C.* The line connecting the middle of the mirror M with the center of curvature is called the *principal axis.* When light rays parallel to the principal axis meet a concave mirror the rays are reflected and pass through, or very close to, a single point which is called the *principal focus F.* The distance from the principal focus to the mirror is the *focal length* and it is equal to one-half the radius of curvature. When light rays parallel to the principal axis meet a convex mirror, the rays are reflected and appear to come from a point F back of the mirror. This is the principal focus, but it is a virtual focus since the rays do not pass through it; it is midway between the mirror M and the center of curvature C.

The failure of parallel rays to converge exactly at a point when reflected by a spherical concave mirror is called *spherical aberration.* In small mirrors this is relatively unimportant, but in large mirrors it is more pronounced. Sometimes it is desirable to reflect all the rays from a light source in one direction; for example, the light from a searchlight or from automobile headlights should all be sent out as parallel rays. If the light source is placed at the principal focus of a concave spherical mirror this result may be accomplished roughly, with the light rays traveling in the opposite directions to those shown in Figure 34.6 but better results will be obtained if a parabolic mirror is used.



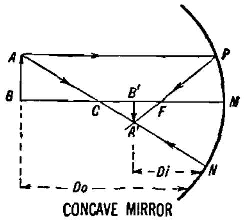
CONCAVE MIRROR CONVEX MIRROR



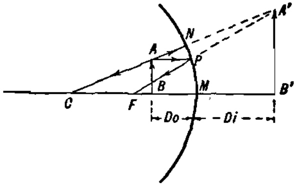
SPHERICAL ABERRATION IN A CONCAVE MIRROR PARABOLIC MIRROR USED AS A REFLECTOR

Fig. 34.6. Curved mirrors.

206. Image Formation in Curved Mirrors. Figure 34.7 shows the method of construction used to locate the images formed by spherical mirrors. If the object *AB* is placed beyond the center of curvature of a concave mirror, the image will be between the center of curvature and the principal focus. To locate it, draw the ray *AN* through *C*; this ray will meet the mirror as a normal ray and be reflected back along *NC*. Draw another ray *AP* parallel to the principal axis, and it will be reflected through the focus *F*. The point *A'* where these two reflected rays intersect is the image of *A*. Other points may be located in a like manner. The image is inverted and in front of the mirror. Since the light really passes through *A'*, the image is a real image. If the object is now placed at *A'B'*, its image will form at *AB*. The rays will travel the same paths as those shown in the diagram, but in the opposite directions. Two points so situated that light from either point is the focus of rays proceeding from the other point are known as *conjugate foci.*



CONCAVE MIRROR
OBJECT BEYOND CENTER OF CURVATURE



CONCAVE MIRROR
OBJECT INSIDE PRINCIPAL FOCUS

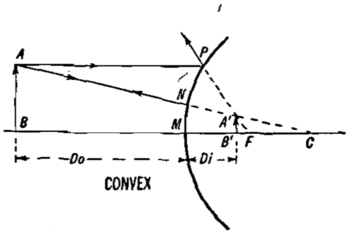


IMAGE IN CONVEX MIRROR

Fig. 34.7. Construction of images formed by curved mirrors.

If the object is placed inside the principal focus of a concave mirror, the image is behind the mirror, erect, enlarged, and since the light rays do not pass through *A'* the image *A'B'* is a virtual image. The image may be located as above by drawing one ray from *A* through the center of curvature, and one parallel to the principal axis. These will diverge after reflection and must be extended back of the mirror to find the point of intersection *A'*.

If the mirror is convex, the image is located by the same method outlined above. The ray *AN* will be reflected as if it came from the center of curvature *C*, and *AP* will be reflected as if it came from *F*. The point *A'* where these rays appear to intersect is the image of *A*. The image is behind the mirror, is smaller than the object, and is always a virtual image.

The size of the image may be computed by using the following ratio, where D_o is the distance from the mirror to the object and D_i is the distance from the mirror to the image.

$$\frac{\text{Size of object}}{\text{Size of image}} = \frac{D_o}{D_i}$$

The formula for finding either D_o, D_i, or F in case the other two distances are known is

$$\frac{1}{D_o} + \frac{1}{D_i} = \frac{1}{F}$$

The object distance, D_o, is always real and positive. The image distance, D_i, is positive for real images and negative for virtual images. The focal length, F, is positive for concave mirrors and negative for convex mirrors.

STUDY QUESTIONS

1. How are nonluminous bodies made visible?
2. What is the general path of a light wave?
3. Name two things that may happen to a beam of light when it meets a reflecting surface.
4. What is the law of reflection?
5. How does the reflection from a smooth surface differ from the reflection from a rough surface?
6. What is a real image?
7. What is a virtual image?
8. What is spherical aberration?
9. How does a cylindrical mirror differ from a spherical mirror?
10. How does a parabolic mirror differ from a spherical mirror?
11. Suggest several uses for spherical mirrors.
12. Suggest several uses for parabolic mirrors.
13. Suggest several uses for cylindrical mirrors.
14. What kind of mirror is used to focus heat or light waves at a point?

PROBLEMS

1. An object is placed 15 centimeters in front of a concave mirror which has a focal length of 10 centimeters. Where does the image form? Is it real or virtual? How many times is it magnified?
   Ans. 30 cm in front of the lens; real; 2
2. An object is placed 5 centimeters in front of a concave mirror which has a focal length of 10 centimeters. Where does the image form? Is it real or virtual? How many times is it magnified?
3. A convex mirror has a focal length of 5 inches. How far from the face must it be held if one is to see an image of the face 3 inches back of the mirror? Is the image enlarged or reduced? Real or virtual?
   Ans. 7.5 in.; reduced; virtual
4. If a person looks into a spherical hub cap which has a radius of curvature of 6 inches, where will he see the image of his face if he is standing 3 feet from the hub cap? Is the image enlarged or reduced? Real or virtual?

35

PRISMS, LENSES, AND GRATINGS

Prisms, and the bright, pure colors which result when white light is passed through a prism, are known to all. The reason for these colors, while relatively simple to explain, is not so commonly known, but the fact that light rays bend as they pass from one medium to another accounts for this phenomenon.

The use of *lenses* dates back to the time of Galileo. He ground lenses, the best of which would magnify objects thirty times. Using these he was able to discover several celestial bodies which were not visible to the naked eye. Children delight in playing with lenses, which they generally refer to as *magnifying glasses*, but not all lenses are magnifying lenses — a lens may form an image smaller than the object which is being observed. Probably the most familiar use of lenses is in eye glasses, and we all carry two lenses about with us — the lenses in our eyes.

Gratings are somewhat unfamiliar to most people, but they are very useful laboratory devices. A grating consists of an extremely large number of very closely spaced parallel slits through which the light passes. The various wave lengths in the beam of light are separated and a spectrum results from the constructive interference which occurs. The colors in soap bubbles and in oil films are also due to constructive interference of light waves.

207. Refraction of Light Waves. When light rays pass out of one medium and into another, they are bent. This bending is known as *refraction*. If the ray passes from a less dense to a more dense medium, it is bent toward the normal, but if the ray passes from a more dense to a less dense medium it is bent away from the normal. For example, a ray of light passing from air into glass is bent toward the normal, but when the ray passes from the glass into the air again, it is bent away from the normal. If the two surfaces of the glass are parallel, the light ray emerges in a path parallel to the incident ray, but displaced to one side. If light rays meet a piece of glass which is not of uniform thickness, the rays will not all be bent the same amount, and they will not emerge as parallel rays. Objects are often distorted when viewed through a poor grade of glass because the glass is "wavy" or not of uniform thickness. A very good grade of glass is necessary for windshields on cars, otherwise the distortion or apparent displacement of objects might lead to serious accidents.

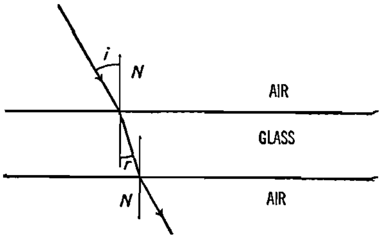


Fig. 35.1. Refraction of light.

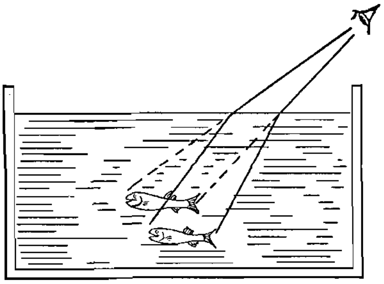


Fig. 35.2. The apparent displacement of an object due to refraction.

Refraction accounts for the fact that, if a spoon is standing in a glass of water, the handle appears to be bent at the surface of the water. An object under water appears to be nearer the surface than it really is on account of refraction. Light from the sun is refracted as it comes down through the increasingly denser layers of air. (See Fig. 35.3.) A ray which enters the earth's atmosphere at B is bent so that, to the observer at E, it seems to come from the direction A. Consequently the sun really is below

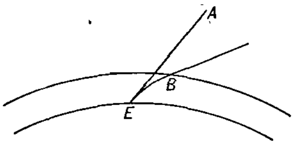


Fig. 35.3. Light is refracted as it passes through the earth's atmosphere.

the horizon before its last rays disappear, and in the morning the first rays appear before the sun is really above the horizon.

208. Prisms. *A prism is a piece of transparent material (glass or quartz) with straight, nonparallel sides.* Its cross section may be in the form of an isosceles triangle, that is, it may have only two equal angles, but usually all three of the angles are equal. When light meets the prism obliquely, the light is refracted and bent toward the normal as it enters the glass. As it emerges at one of the other faces, it is refracted again and bent away from the normal. Thus it follows the path shown in Figure 35.4.

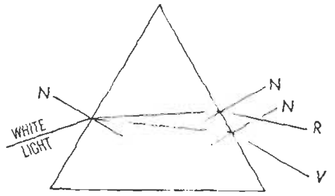


Fig. 35.4. A prism refracts a beam of light.

If the light which meets the prism is made up of rays of more than one wave length — for example, white light which contains all wave lengths from 0.00008 centimeter to 0.000035 centimeter — the various waves are not all bent the same amount; consequently the length of the path through the glass is not the same for all wave lengths. Also, as they emerge, they are bent different amounts — the red is bent the least and the violet the most. The result is that the component wave lengths are separated, and the emerging light forms a band of color, from red to violet, which is called a *spectrum.* Usually the prism is mounted on a *spectroscope* (to see the spectrum), so that the light coming

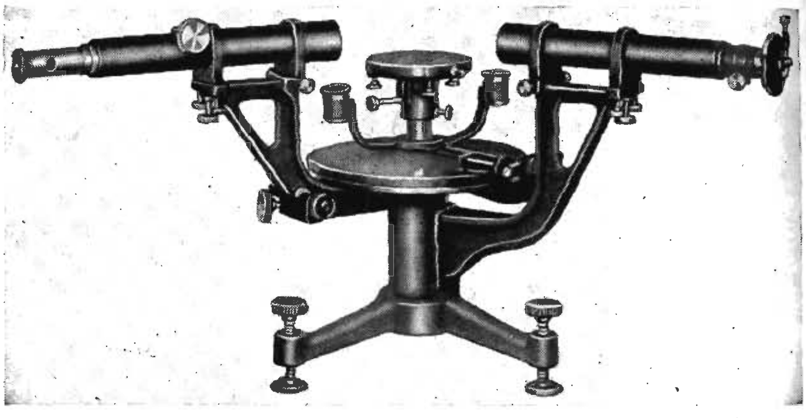


Fig. 35.5. A spectrometer. (Courtesy Central Scientific Company)

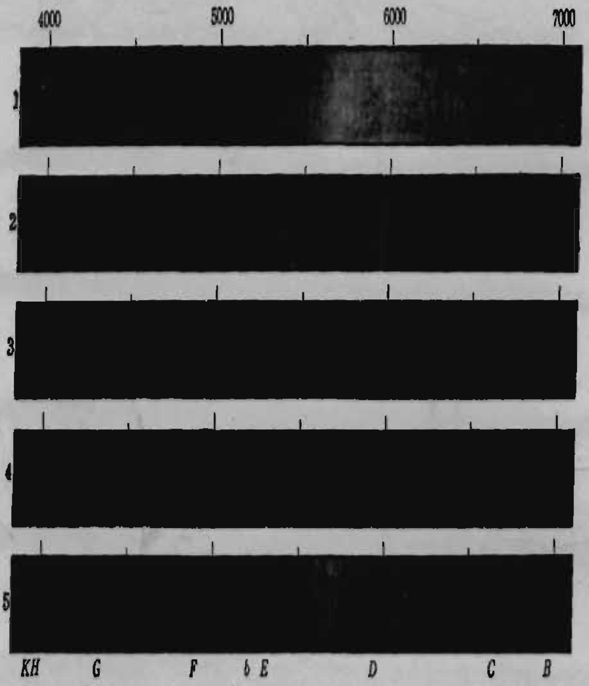
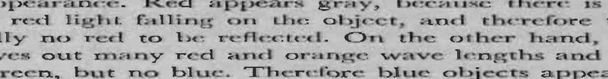


Fig. 35.6. Different types of spectra: (1) continuous spectrum from an incandescent solid; (2) bright-line spectrum of sodium; (3) bright-line spectrum of mercury; (4) bright-line spectrum of calcium; (5) absorption spectrum of the sun, showing some of the strongest Fraunhofer lines. Note the coincidence of the bright lines for sodium in (2) and the dark lines D in (5). (From Williams, S. R., *Foundations of College Physics*, courtesy Ginn and Company)

to the prism can be controlled, and so that the light leaving the prism may be observed more conveniently. If the spectroscope is calibrated so that data may be recorded, it is a *spectrometer*.

209. Continuous and Line Spectra. Some light sources, such as a tungsten-filament lamp or the sun give out wave lengths throughout the entire visible spectrum. When such light waves are spread out by means of a prism, one color gradually merges into the next, and there is a continuous luminous band shading from red to violet. Other light sources give out only certain wave lengths which are characteristic of that source. For example, a mercury arc has one faint line in the red-orange, two in the yellow, two in the green, and several in the blue and violet. Objects illuminated by this light have a peculiar blue-green appearance. Red appears gray, because there is practically no red light falling on the object, and therefore there is practically no red to be reflected. On the other hand, a neon lamp gives out many red and orange wave lengths and considerable green, but no blue. Therefore blue objects appear gray, but red objects look red. A light source which gives out all wave lengths is said to have a *continuous spectrum* while one that gives out only certain wave lengths is said to have a *line spectrum*. The dark lines, called Fraunhofer lines, in the sun's spectrum are present because certain wave lengths emitted by the sun are absorbed by the gases surrounding the sun.

210. Lenses. *A lens is a piece of transparent material (usually glass) with curved faces.* If it is thicker in the center than at the edges, it is known as a *converging* or *positive* lens; but if it is thicker at the edges than at the center, it is a *diverging* or *negative* lens. A line drawn normal to the diameter of the lens and through its center point is known as the *principal axis* of the lens. The center point of a thin lens is its *optical center*.



Converging or positive Diverging or negative

Fig. 35.7. Lenses.

If light rays parallel to the principal axis meet a converging lens, they are bent toward the normal as they enter the lens, and away from the normal as they leave the lens, i.e., they follow the laws of refraction. (See Fig. 35.8.) It is evident that these parallel rays all pass through the point *F*, the location of which depends upon the curvature of the lens and the nature of the material of which it is made. This point at which the light rays meet is known as the *principal focus* of the lens. It is always located on the principal axis. The distance from the optical center of the lens to the principal focus is the *focal length* of the lens. If light rays parallel to the principal axis meet a diverging lens, they also obey the laws of refraction and the result is that they diverge as they leave the lens; therefore they appear to have come from a point nearer the lens than the real source. The point *F* from which they seem to come is the principal focus of the lens, but it is a virtual focus, since the light does not actually go through this point at all. In the case of either a converging or a diverging lens the only rays which are not permanently bent are the ones which pass through the optical center of the lens. This is true for rays which are not parallel to the principal axis as well as for those which are parallel.

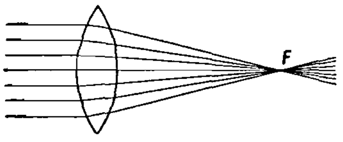


Fig. 35.8. Rays parallel to the principal axis of a converging lens are refracted, and pass through the focus.

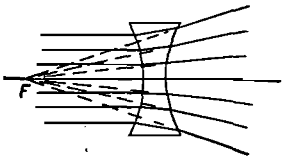


Fig. 35.9. Rays parallel to the principal axis of a diverging lens are refracted, and appear to come from the virtual focus.

211. Images Formed by Lenses. The position and size of the images formed by a convex lens may be obtained by the following method. (See Fig. 35.10.) Draw two rays from the point *A*, one of which is parallel to the principal axis, and one of which

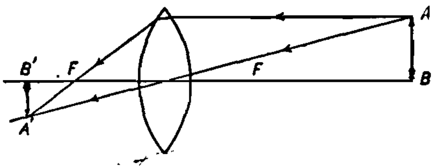


Fig. 35.10. Showing how an image is formed by a convex lens.

passes through the optical center. The ray parallel to the principal axis is refracted by the lens and passes through the principal focus. The one through the optical center is not bent. Where these two rays intersect, an image *A'* of the point *A* from which the rays came, is formed. Other points on the object *AB* may be located, and thus the image *A'B'* is formed.

The size and the location of the image formed by a converging lens depend on the location of the object with respect to the lens and the principal focus. Five cases are shown in Figure 35.11. (1) If the object is more than two focal lengths from the lens, the image is real, smaller than the object, inverted, and is located between the focus and a point two focal lengths from the lens. (2) If the object is just two focal lengths from the lens the image is real, the same size as the object, inverted, and is located just two focal lengths from the lens. (3) If the object is less than two focal lengths from the lens but still outside of the focus the image is real, larger than the object, inverted, and is located more than two focal lengths from the lens. (4) If the object is at the focal point the two rays which emerge from the lens are parallel, therefore meet at infinity, and the image is infinitely far away — in other words, no image is formed. (5) If the object is within the focal length the two rays which emerge from the lens diverge, and seem to come from a point *A'* on the same side of the lens as the object. The image is virtual, larger than the object, erect, and is located back of the lens. This last case illustrates how a lens may be used as a simple magnifying lens.

All of these constructions have been made in exactly the same way and by using only two rays, but several locations of the object with respect to the lens and the focus have been shown, to help the student visualize how the position of the image changes as the position of the object changes. As the object approaches the lens, the image recedes until it is finally at infinity; then it appears again as a virtual image on the other side of the lens.

The position and size of the image formed by a concave lens may be found by the same method outlined above. (See Fig. 35.12.) The rays from *A* diverge as they leave the lens, and appear to have come from a point *A'* behind the lens. The

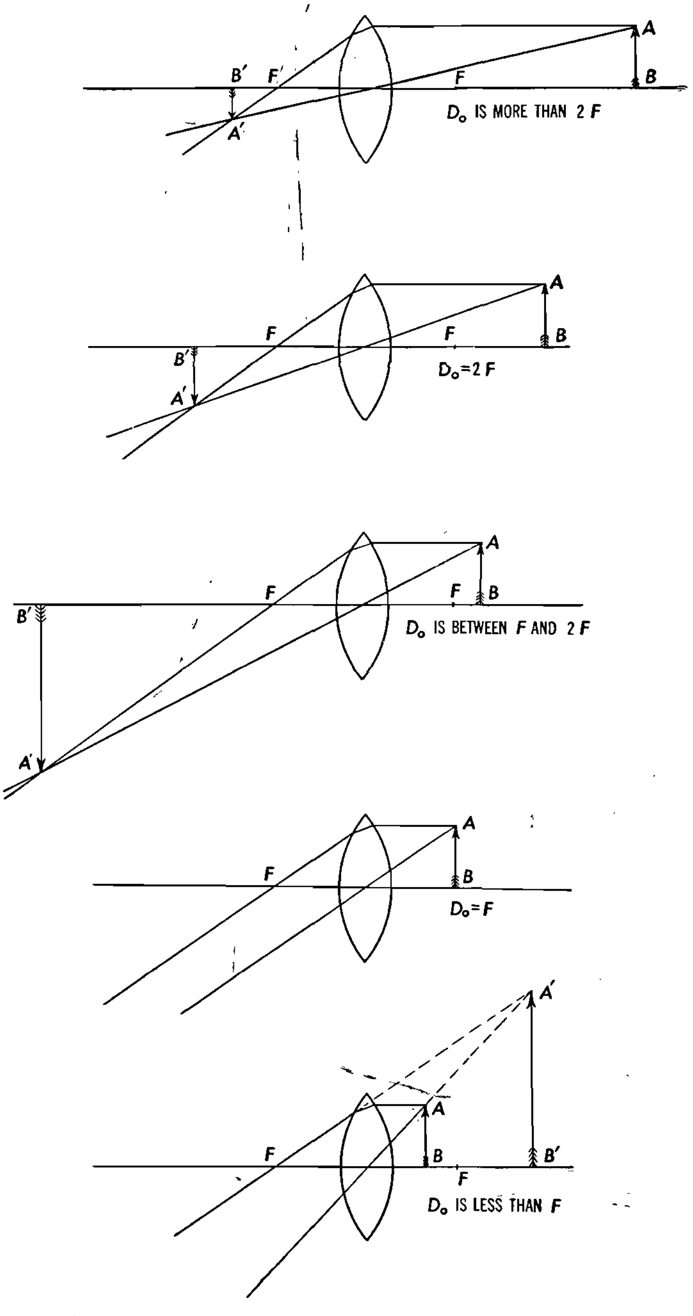


Fig. 35.11. Showing how the position of the image changes as the object approaches a convex lens.

image $A'B'$ is virtual, erect, smaller than the object, and is always located between the lens and the focus. As the object is moved from the lens to infinity, the image moves from the lens to the principal focus.

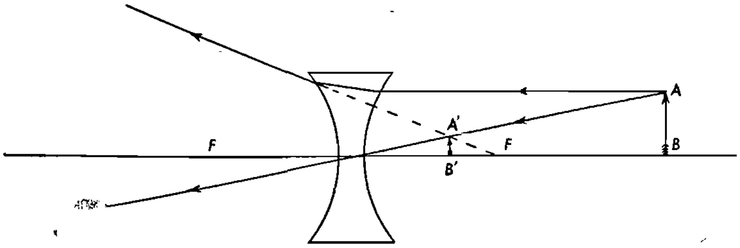


Fig. 35.12. Showing how a virtual image is formed by a concave lens.

For any lens it may be shown experimentally that the following relationship holds true:

$$\frac{1}{D_o} + \frac{1}{D_i} = \frac{1}{F}$$

where D_o = distance of object from lens
D_i = distance of image from lens
F = focal length

The distance of the object is real and always positive. D_i is positive for real images and negative for virtual images. F is positive for convex lenses and negative for concave lenses.

The size of the image may be found from

$$\frac{\text{Size of object}}{\text{Size of image}} = \frac{D_o}{D_i}$$

212. The Eye. The eye consists essentially of a convex lens located in front of a sensitive surface, the retina, on which the light rays are focused. The eye as a whole is surrounded with a tissue known as the sclerotic tissue, which is commonly known as the white of the eye. A transparent opening in this tissue at the front is the cornea. Back of the cornea is a clear liquid called the aqueous humor, which acts as a refracting medium. Next is the colored part of the eye or the iris; an opening in it, the pupil, allows the light rays to pass through to the lens. The iris changes in size and thus regulates the size of the pupil. In dim light the pupil increases in size to allow more light to enter, and in bright light it partly closes in order to protect the eye. The large cavity of the eye is filled with the jellylike vitreous humor which also refracts the light. The lining of this cavity is the sensitive retina, which contains the endings of the optic nerve. Surrounding it is a black membrane called the choroid coat, which prevents any light from entering the eye except that which enters through the pupil.

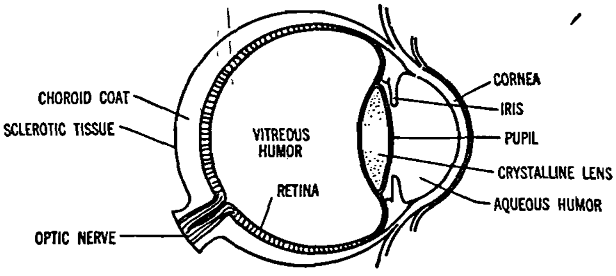


Fig. 35.13. The eye.

The light which enters the eye is focused on the retina by the eye lens, not by changing the distance between the lens and the retina, but by changing the focal length of the lens which is accomplished by the eye muscles. This adjustment of the focal length of the eye lens is called the *accommodation* of the eye. Since the object is always beyond the focal length of the lens of the eye, the image is always real and inverted. When the light rays come to a focus on the retina, certain nerve centers are stimulated and the stimulus is sent to the brain by the optic nerve. It is not known what changes result in the brain from this stimulus, but we do know it results in the sensation of sight. Moreover, while the image on the retina is always inverted, the sensation corresponds to the erect position of the object.

213. Nearsightedness and Farsightedness. If the eyeball is too long, the rays of light come to a focus in front of the retina and the person is said to be *nearsighted*, since he tends to hold the object very near the eye in order to bring the focus on the retina. Such an eye needs a diverging lens placed in front of it to make the rays diverge before they enter the eye so they will come to a focus on the retina. (See Fig. 35.14.) If the eyeball is too short, the rays focus back of the retina and the person is said to be *farsighted*, since he tends to hold the object at which he is looking far away from the eye, in an attempt to bring the focus on the retina. Such an eye needs a converging lens placed in front of it to make the rays converge somewhat before they enter the eye so that they will come to a focus on the retina.

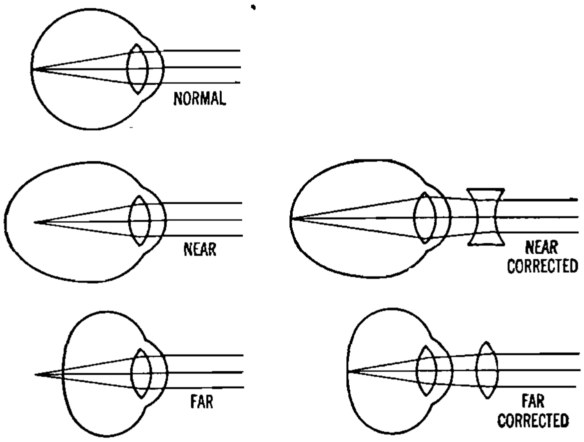


Fig. 35.14. Showing a normal eye, a nearsighted eye, and a farsighted eye, with the proper correction for each of the abnormal cases.

214. Astigmatism. Sometimes the curvature of the cornea or of the lens is not uniform, and the light rays do not all come to a clear focus on the retina. Therefore, along certain radial lines the image is blurred. This results in what is known as *astigmatism.* Such a condition may be corrected by wearing a lens which has been ground to compensate for the lack of uniformity in the eye, so that all of the rays are brought to a sharp focus on the retina.

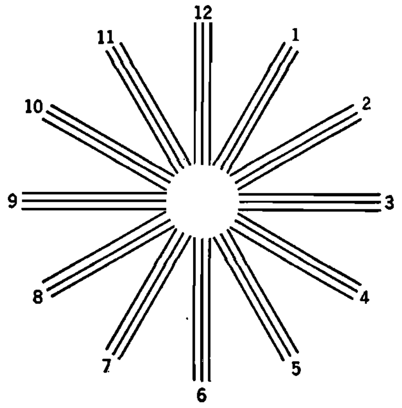


Fig. 35.15. An astigmatism chart.

215. Spectacle Lenses. The term *diopter* is used by oculists to indicate the strength of a lens. The strength of a lens in diopters is the reciprocal of the focal length in meters.

$$\text{Strength in diopters} = \frac{1}{F_{\text{meters}}} \quad \text{or} \quad \frac{100}{F_{\text{centimeters}}}$$

The strength of a convex lens is given in (+) diopters and of a concave lens in (−) diopters. The strength of eye glasses usually falls within the limits of ± 1/4 and ± 4 diopters.

216. Optical Instruments. *a. Camera.* A camera consists of a lightproof box with a converging lens L at the front, and a light-sensitive film S at the back on which the lens focuses an image of the object when the shutter is opened for a short time. The light causes certain changes in the coating of the film. When the film is "developed," a permanent image of the object appears.

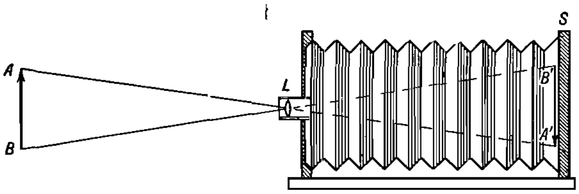


Fig. 35.16. A camera.

b. Simple magnifying glass. A simple magnifying glass, a reading glass, or a simple microscope is a convex lens. The object must be within the focal length, and the eye sees an erect, virtual, and enlarged image. (See Fig. 35.17.)

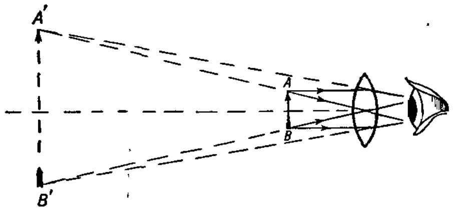


Fig. 35.17. A simple magnifying glass.

c. Compound microscope. A compound microscope has two converging lenses. The object is placed outside the focal length of the objective lens and a real image $A'B'$ is formed. This image is within the focal length of the eyepiece; therefore, the eyepiece forms an inverted, virtual, enlarged image $A''B''$.

d. Opera or field glasses. Opera or field glasses have one converging and one diverging lens in each tube. The objective lens makes the rays converge toward a point S, but before they reach this point, they meet a diverging lens. To the eye on the other side of the diverging lens, the rays seem to have come from $A'B'$. The image is erect and virtual.

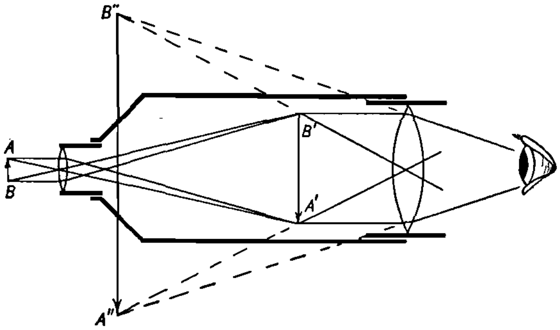


Fig. 35.18. A compound microscope.

e. Telescope. A telescope has two convex lenses. The objective lens forms an image $A'B'$ near its focus, which is near to the

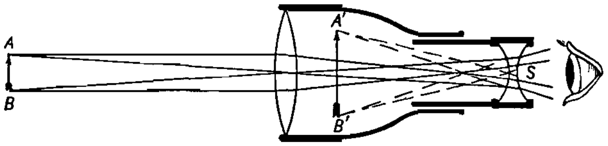


Fig. 35.19. Opera or field glasses.

eyepiece. Therefore, the eyepiece magnifies the image, and the eye sees an enlarged image $A''B''$ of the real image. This second image is therefore an inverted, virtual, enlarged image.

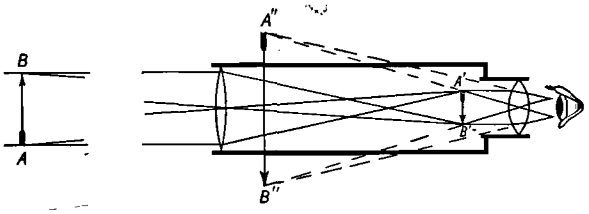


Fig. 35.20. A telescope.

217. Gratings. In Sec. 200 it was stated that light travels in straight lines in a homogeneous medium. But experiment shows that if light passes through a very narrow opening then it spreads out in all directions or it is *diffracted.* If a light source is held back of a narrow slit in a cardboard, the light which passes through the slit spreads out as from a new source. There is a bright image *I* of the slit *S* on a screen *AB*, but there is also light on each side of this image. (See Fig. 35.21.)

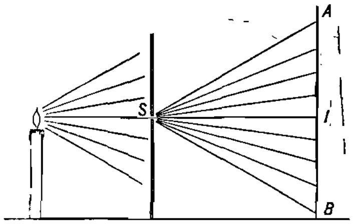


Fig. 35.21. Light rays spread out as they pass through a narrow opening.

If, instead of a white light at *L*, a source which gives out red wave lengths only is used, and two slits are made in the cardboard, the resulting situation is that shown in Figure 35.22. There are certain points on the screen *AB* where red waves meet in phase, i.e., with crest meeting crest and trough meeting trough. This results in what is known as *constructive interference* and results in red lines on the screen. At other points, the waves meet out of phase, i.e., a crest meets a trough; the result is *destructive interference*, and there is no light on the screen. If now a source of another color is substituted for the red source, the images on the screen are like the source in color but are located in slightly different positions than were the red images. If each color of the spectrum is used, the results are alike, except for the locations of the images.

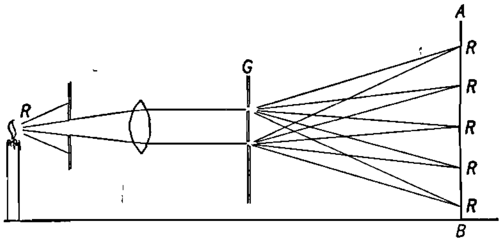


Fig. 35.22. The colored bands are due to interference.

If now a white light is substituted for the colored light at *L*, the result shown in Figure 35.23 is obtained. There are places where red, orange, yellow, green, blue, and violet wave lengths meet. The resulting spectra are found on each side of the central image. The violet rays are bent the least, and the red are bent the most, which is a situation opposite to that resulting from sending light through a prism. The spectra are numbered, beginning on each side of the central image. In order to see more than one spectrum on each side of the central image, it is necessary to have very fine slits and many of them. In practice, a transmission grating is used which is a piece of cellulose with many lines (often as many as 15,000 lines to the inch) on it. The cellulose grating is made by flowing cellulose over a metal grating which has been very carefully made. When the cellulose has hardened, it is peeled off and mounted on glass. The thicker parts of the cellulose transmit diffusely but the thinner parts act like slits. Thus part of the light is transmitted by the spaces between the opaque lines. The resulting pattern is observed to consist of several spectra on each side. Pieces of fine copper screen make good demonstration gratings. If the screen is held between the eye and a long slender electric-light bulb, the spectra show very well, but they are spread out so little that it is difficult to make measurements. The same effect is observed if the eyes are "squinted" so that the eyelashes act as gratings.

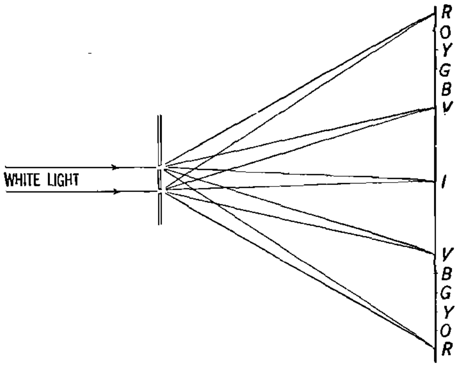


Fig. 35.23. Spectra obtained by the use of a grating.

218. Color Due to Thin Films. When light falls on a thin film, such as a soap bubble or a film of oil on a pavement or on water, part of the light is reflected at the outer surface and some enters the film, is refracted, and then reflected from the inner surface of the film. It is refracted again as it leaves the film. Since this part of the light has traveled farther than the part that was reflected at the outer surface, it is found that in certain places it has traveled

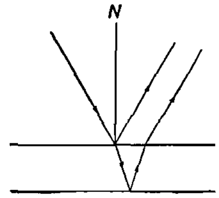


Fig. 35.24. Interference due to thin films.

just enough farther that it emerges in phase with the reflected rays. In certain places red waves are in phase, in others orange, and so on through the spectrum. This accounts for the rainbow colors seen on soap bubbles and oil films. The colors in a fire opal and the colored sheen on the feathers of some birds and the bodies of some insects are all due to interference.

STUDY QUESTIONS

1. How does refraction differ from reflection?
2. Why is white light separated into colors when it passes through a prism?
3. How does a line spectrum differ from a continuous spectrum?
4. Does a daylight fluorescent lamp have a continuous spectrum, a line spectrum, or both?
5. What kind of lens would you use if you wanted to ignite a piece of paper by focusing the sun's rays on it? If you knew the focal length of the lens, how would you make use of that information?
6. Does a nearsighted eye need a converging or a diverging lens? Why?
7. If a lens for an astigmatic eye is placed in front of a perfect eye, what is the observed effect?
8. Just how do eyeglasses help to rest the eyes?
9. Which gives the greater magnification, a simple microscope or a compound microscope?
10. What happens to a light ray when it passes through a narrow opening? What term does a physicist use to describe this result?
11. Define interference. Distinguish between constructive and destructive interference.
12. Why do colored bands result from passing light through a grating?
13. How does the spectrum formed by a grating differ from one formed by a prism?
14. Explain how the eyelashes may act as gratings.
15. Why do soap bubbles show the "colors of the rainbow"?

PROBLEMS

1. If an object is placed 4 feet from a convex lens and a real image is formed 5 feet from the lens, what is the focal length of the lens?
   Ans. 2.2 ft
2. If a convex lens which has a focal length of 16 centimeters is placed 40 centimeters from an object, what is the distance from the lens to the image? If the object is 4 centimeters high, how high is the image? Is the image real or virtual?
3. If an object is placed 2 inches from a positive lens which has a focal length of 6 inches, where is the image formed? How does the size

of the image compare with the size of the object? Is it real or virtual?
Ans. 3 in. back of the lens; image = 1.5 × object size; virtual

4. How far from a positive lens with a focal length of 12 inches do you place an object so that the image will be four times as large as the object? (Two answers)
5. How far from a divergent lens with a focal length of 15 centimeters must an object be placed if the image is to be 5 centimeters from the lens? Is the image real or virtual? Erect or inverted? Enlarged or reduced? *Ans.* 7.5 cm; virtual; erect; reduced
6. What is the focal length of a divergent lens which forms an image one-fourth the size of an object which is 12 inches from the lens? Is the image real or virtual? Erect or inverted?
7. If the focal length of a lens is 25 centimeters, what is its strength in diopters? *Ans.* 4 diopters
8. If a lens has a strength of 2 diopters, what is its focal length?

36

COLOR

Since the earliest times of which we have any record man has shown that he responds to color. In the cave dwellers' homes are found decorations made of colored clays. Colored robes have been worn as marks of distinction down through the ages. Some of the most treasured masterpieces in the field of art are paintings which owe at least a part of their appeal to the beautiful colors of the pigments used by the artists. Man has always responded to the colors of the rainbow, the sunrise, and the sunset.

Probably quite by accident it was found that certain plants and insects could be used in making natural dyes. A royal purple was made from a shellfish found on the coast of Syria, a blue-violet from the indigo plant in Asia, a deep red from the roots of the madder plant in Egypt, and a bright red from the cochineal insect in Mexico. Some dyes were also made from various kinds of ores. Often the special method of extracting the color was a carefully guarded secret, handed down from father to son, and the methods of making some dyes have been lost when the artisan died without imparting his secret to anyone. Until 1865, natural dyes only had been used, but in that year an English chemist, Perkin, quite by accident, made the first organic dye. He was trying to make synthetic quinine and, while he never did succeed in making quinine, he did obtain a vivid violet material which proved to be a good dye, and is today known as *Perkin's violet.* Since then an extensive development has taken place in color chemistry, and now almost any color of dye may be produced in the laboratory.

What is color? The word is used in several senses, and color may be studied from various points of view. To the average person "color" means the various sensations which are registered in the mind through the sense of sight; to the artist it means a paint or a pigment; to the textile worker it means the dye used to produce colored fabrics. A physiologist is interested in knowing how the eye reacts to different color stimuli. The psychologist is concerned with the mental response to the various colors. The chemist studies the chemical properties of the materials which produce color. *The physicist knows that the different color sensations are due to the various wave lengths or frequencies to which the eye is sensitive. He studies the waves and the physical properties of the media from which the waves are reflected, through which they are transmitted, or by which they are absorbed.*

In the sunlight there is a wealth of color, but in the absence of light there is no color. Evidently light and color are intimately connected, and since there is no color apparent in the artist's colors, in the chemist's dyes, or in all the naturally colored objects in nature unless light is falling on them, the physicist's point of view seems to be a good starting place in the study of color.

219. Source of Color. It has already been explained that the eye is sensitive to a narrow band of electromagnetic waves which are known as the *visible spectrum.* If these wave lengths are present in the right proportions, we see white light. If they are spread out by means of a prism or a grating, we see the various colors, although it is impossible to draw sharp dividing lines between them since one color merges gradually into the next. But light sources do not necessarily give out white light. The distribution of wave lengths depends upon the nature of the luminous body and its temperature. For example, if a piece of iron is heated it first appears a dull red, then brighter red, then orange, and, if heated hot enough, appears white. As the temperature increases, the light emitted includes more of the shorter wave lengths. It is impossible to get a source of light which gives out one wave length only. By spreading out the spectrum with a prism or a grating and then using a narrow band from this spectrum one may obtain a source which has only a relatively few wave lengths in it. Most of our colored lights give out wave lengths through the whole spectrum but are richer in certain wave lengths which give the light its characteristic color.

If the light is coming from a so-called red source, that is, one in which the red predominates, the energy distribution might be that of Figure 36.1, but if from a so-called violet source the energy distribution might be that of Figure 36.2.

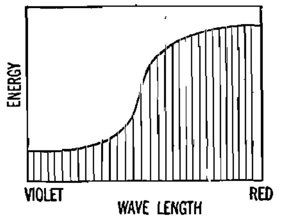


Fig. 36.1. Energy distribution of light from a red lamp.

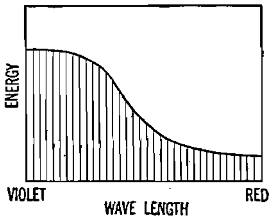


Fig. 36.2. Energy distribution of light from a violet lamp.

220. Physical Properties of Materials. We must realize that if various lights look different to us when the rays come directly from the source to the eyes, then certainly objects will change in appearance when illuminated by one and then by another of these light sources. This explains why two pieces of cloth which seem to match under artificial light in a store may not match when viewed in sunlight, or why two pieces may match in the daytime and not at night. The "daylight lamp" is an attempt to furnish an artificial light which matches daylight as nearly as possible, but none has been devised so far which accomplishes this perfectly. However, the daylight fluorescent lamp is a reasonably satisfactory substitute for daylight. But, even though the wave-length distribution nearly matches, the source is often placed so close to the material which is being illuminated that the light is too direct and glaring, and does not give the same sensation in the eye. If materials are being purchased for use under artificial light, it would seem advisable to purchase them under artificial light; for example, an evening dress might be a lovely rich color by daylight, but dull and uninteresting by artificial light; or the reverse may be true — it may appear much lovelier by lamplight than by daylight. If campus or street clothes are to be selected, look at them in daylight before purchasing.

A part of the light which falls on a surface is always absorbed; i.e., there are no perfect reflectors, though some are far better than others. Polished metal surfaces and mirrors may reflect practically all of the light which falls on them, but some dull, dark objects may absorb practically all of the incident light. In the case of colored materials, certain wave lengths are absorbed to a much greater extent than are others. This selective absorption is determined to a large extent by the nature of the material, and by the color of the dye. But no matter what the material, or what dye has been used on it, it can only reflect or absorb, as the case may be, those wave lengths which are found in the light which falls on it. A material which appears to be a beautiful, rich red in daylight may appear to be a dull gray if illuminated by a light in which blue predominates, but the color of a blue material may seem to be intensified by having blue light only fall on it. In other cases a blue material may look less blue when illuminated by blue light instead of white light. If so, it is because part of the color sensation received when the material is illuminated by white light is due to the reflection of small amounts of other colors by the so-called blue material. If a material looks white when illuminated with white light, it is because it reflects some of all the visible wave lengths; if black, because it absorbs all or nearly all of each wave length; if red, because it reflects most of the red and absorbs most of the other wave lengths; if blue, because it reflects most of the blue and absorbs most of the other wave lengths.

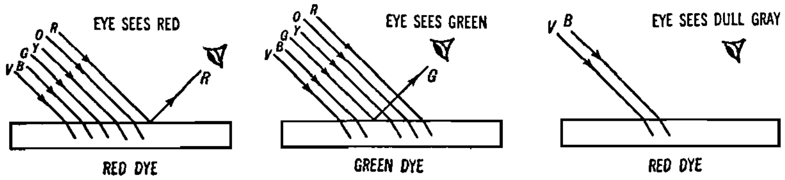


Fig. 36.3. Color due to reflected light.

Part of the light which is not reflected may not be absorbed either, but may pass through the material and emerge on the other side as transmitted light. Clear glass transmits a large per cent of the light which falls on it (possibly 95 per cent — the amount varies with the thickness), and the transmitted light contains the same proportions of the various wave lengths as the incident light — that is, the transmitted light is white light. Glass which appears red by transmitted light is transmitting the red waves chiefly and absorbing a large part of the other colors.

Thus we find that, when we see objects by reflected light, the color an object appears to have is determined by the light which falls on it, and which is then reflected. If we see an object by transmitted light, its color is determined by the light which falls on it and which is then transmitted.

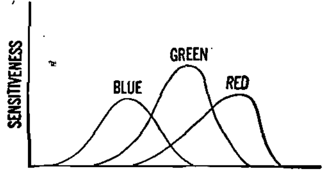


Fig. 36.4. Showing the variation in the sensitiveness of the eye with a change in the wave length, according to the Helmholtz theory of color vision.

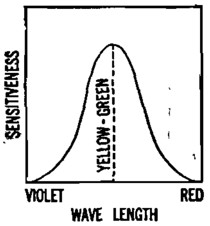


Fig. 36.5. Total sensitivity of the eye.

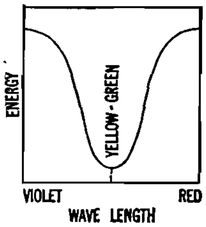


Fig. 36.6. Energy required for visibility.

221. Response of the Eye to Color. How does the eye respond to the various wave lengths which reach it? Do two people looking at the same object receive the same color sensation? The process by which the energy of a light wave is converted into the sensation of sight is not definitely known, but it is thought to be electrical in nature. A possible answer to the first question is found in the *Helmholtz theory* of color. According to this theory the retina of the eye contains *three sets of nerve endings*, one of which is chiefly sensitive to red, one to green, and one to blue wave lengths. The curves of Figure 36.4 show the supposed sensitivity of the three sets of nerve endings in the eye to the various wave lengths. It will be noticed that these curves overlap; i.e., each set of nerves is slightly sensitive to other colors. The three curves may be combined into one curve to show the response of the eye to the colors of the spectrum. (See Fig. 36.5.) This curve shows that the eye is most sensitive to the *yellow-green* wave lengths. One way of testing this response to color is to use a light source for which the energy output may be measured. The energy for each color is made just great enough for the light to be visible. Then if energy is plotted against wave

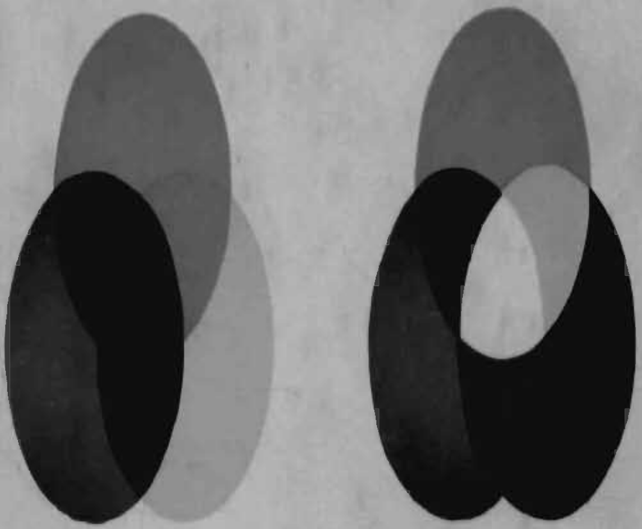


Fig. 36.7. Colors produced by subtraction and by addition.

length, it is found that the least energy is required in the yellow-green. (See Fig. 36.6.)

If one set of these nerves is not sensitive, the person is said to be *color-blind*. Red color-blindness is the most common, though green and blue color-blindness occur also. Color-blindness is not due to lack of color education, but to a physical defect in the eye which cannot be overcome. It is estimated that one person in fifty is to some degree color-blind. The defect is much more common in men than in women. Often a person does not realize that he does not see colors as others do. If a person is color-blind to red he cannot distinguish between red and green lights. If he is color-blind to green, a green light appears to be a faint purple. Some lines of work are not open to people who are color-blind.

Thus we arrive at the conclusion that *the color we see when we look at a light source depends first upon the wave lengths emitted by the source and second upon the sensitivity of the eye to the wave lengths that come to it; the color we see when we look at nonluminous objects depends first upon the wave lengths emitted from the light source, second upon the nature of the object from which the light is reflected or through which it is transmitted, and third upon the sensitivity of the eye to the wave lengths which come to it.*

222. The Subtractive Method of Producing Colors. If a color is produced by absorbing certain wave lengths so that only a part of the incident light is reflected or transmitted, the color has been produced by the *subtractive method*. If pigments are mixed, the light which comes to the eye is made up of the wave lengths not absorbed by any of the pigments in the mixture. For example, if blue and yellow pigments are mixed, the light which comes to the eye is made up of the wave lengths not absorbed by either of the pigments in the mixture, and the resulting color is green. The reason is that the blue pigment absorbs most of the red end of the spectrum and reflects blue and green while the yellow pigment absorbs most of the blue and red ends of the spectrum and reflects yellow and green. The waves reflected by both pigments are in the green. However, if the reflected light from this green pigment is examined, it will be found that, while it is chiefly green, there are small amounts of the other wave lengths. By varying the amounts of the blue and yellow pigments, various greens may be produced.

In the same way mixtures of red and yellow pigments produce oranges, and mixtures of red and blue produce purples. Subtractive colors result also when light is passed through pieces of colored glass. If blue glass is held between the eye and a source of white light, the light coming through is apparently all blue, but if, in addition to the blue glass, a piece of yellow glass is also interposed, the light which reaches the eye is green. If the yellow and blue glasses are reversed, the result is the same.

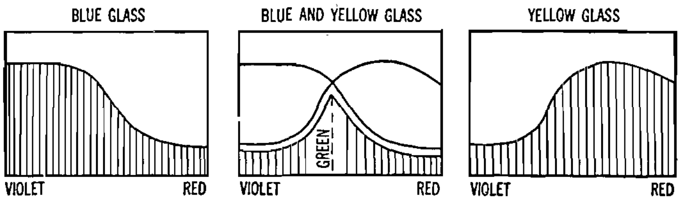


Fig. 36.8. Transmission of light through two pieces of colored glass.

The yellow glass transmits yellow and green. The blue glass transmits blue and green. The green is transmitted by both. The light which was absorbed was subtracted from the incident light.

The subtractive primaries are red, yellow, and blue. If pigments of these three colors are mixed in the proper proportions, they tend to produce black since all wave lengths are absorbed. Actually the resulting mixture is usually a gray because some light is reflected from the surface of the pigment or from the surface on which the pigment has been placed. Red, yellow, or blue pigment cannot be produced by mixing other pigments, but the correct proportions of either two or three of these three colors will produce any other color.

223. The Additive Method of Producing Colors. If several circles of light are projected on a screen with an apparatus which makes it possible to shift the circles, it will be noticed that the screen is brighter where two circles overlap and still brighter where three overlap. The intensity of the light in one of these overlapping areas is the sum of the separate intensities. If colored filters are introduced into the light beams which light these circles, colored areas will appear on the screen. If two of these circles are shifted until they overlap, the area which is receiving light from two sources will be brighter than the areas which are receiving less light. Moreover, the color sensation will be that produced by the sum of the two separate colors. If proper intensities of yellow and blue are used, the resulting sensation is that of white light because the yellow stimulates the red and green nerve endings and the blue of course stimulates the blue nerve endings.

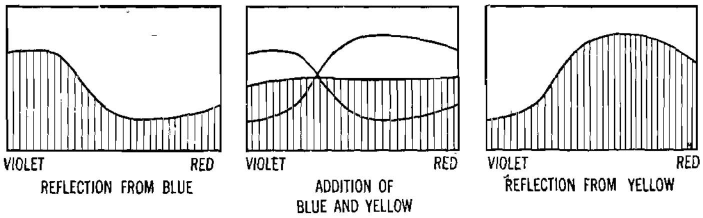
The eye differs from the ear in that it cannot separate the sensations which come to it. If the trained ear listens to an orchestra, it can pick out the notes of the violin, the flute, or the horn. But the eye responds to the mass sensation — it cannot separate white light into its components. For example, the same sensation of white light is produced in the eye by the following combinations of lights:

Proper proportions of
blue and yellow
purple and green
blue-green and red
blue, green, and red

Any two colored lights which produce the effect of white light are said to be *complementary*. Any color combination may be produced by using proper proportions of red, green, and blue light. Moreover none of these three colors can be produced by combining any other colors. *Therefore, red, green, and blue are the three additive primary colors.* The following colors may be produced by adding primary colors of light.

Red and blue = purple
Red and green = yellow
Blue and green = blue-green

When light is reflected from colored objects, the eye responds to the sum of all the reflected waves. For example, if yellow and blue paint are applied to a surface in tiny dots and the



REFLECTION FROM BLUE

ADDITION OF BLUE AND YELLOW GIVES WHITE

REFLECTION FROM YELLOW

Fig. 36.9. The eye sees the sum of the reflectance curves.

surface is held some distance from the eye, the area appears gray-white. Since the light is reflected from equal areas of blue and yellow, the result in the eye is the sum of the two stimuli. If segments of a disk are painted with yellow and blue paint, and then the disk is rotated rapidly, the eye sees a gray-white color. Theoretically the sensation in the two experiments should be white, but the gray is due to the impurity of the reflecting surfaces.

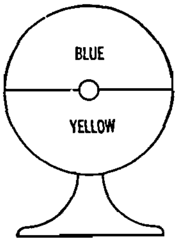


Fig. 36.10. A color wheel.

Some artists make use of the additive method of producing colors. The pigments are applied in tiny dots of several colors, and the eye sees the sum of the reflected colors. Textile manufacturers produce some of their color effects by weaving threads of various colors — gray cloth made of black and white threads is a common example. The "life" or "warmth" of some tans and grays is due to fine threads of red in the material. A "cool" gray results if blue threads are woven into the material.

224. Color Vocabulary. There is an almost endless list of names used in designating colors. The ones in the following list give some indication of the sources from which color names have been taken: peach, rose, lemon yellow, tomato red, sky blue, royal blue, oxford gray, midnight blue, rust, garnet, ruby, sapphire. In the world of fashion one season a color has one name, and another season it is named something else.

The only pure colors are spectrum colors. It is impossible to have a colored light containing only one wave length, but it is possible to use a very narrow band of wave lengths which cause practically the same color sensation. These bands are said to differ in hue. *Hue is that characteristic of a color which is determined by the wave length.* There are an endless number of hues possible, though in general they are grouped into red, orange, yellow, green, blue, and violet. Red-orange, yellow-orange, yellow-green, and blue-violet are simply a few of the intermediate hues between the customary main divisions.

If samples of gray paper, varying from nearly white to nearly black, are arranged in order, they provide a scale for value. *The value of a color is a measure of its ability to reflect or to transmit light.* White reflects practically all light; black absorbs practically all. A sample of gray paper which is nearly white reflects more light than a piece which is nearly black; therefore it is said to be of *higher* value. Samples of any hue may also be arranged in order of their value — a light red is of higher value than a dark red. The following comparison also illustrates the terms.

VALUE (FROM HIGH TO LOW)

Very light gray	Very light orange
Light gray	Light orange
Medium gray	Medium orange
Dark gray	Dark orange
Very dark gray	Very dark orange

It must be remembered that for colors of the same value, the eye is most sensitive to yellow-green; that is, if equal amounts of energy are reflected or transmitted by different colors, the yellow-green appears to be the brightest.

If samples of colored papers which are all of the same hue and of the same value are arranged in order beginning with the brightest and ending with the dullest, they form a scale for intensity. *The intensity of a color is determined by its purity.* A color may vary from full intensity to a low intensity which is practically a neutral gray. If several hues of the same value are reduced in intensity, they all approach the same neutral gray. The following table illustrates the terms.

INTENSITY

Full purity	Pure orange
1/4 neutralized	Slightly grayed orange
1/2 neutralized	Moderately grayed orange
3/4 neutralized	Decidedly grayed orange
Neutral gray	Neutral gray

Hue, value, and intensity are the three dimensions of a color in somewhat the same way that length, width, and height are the dimensions of an object.

225. Color Systems. Since all colors can be arranged in an orderly system according to their wave lengths, their values, and their intensities, that would seem to be the scientific way to designate colors. According to this plan, the hue of a color would be designated by its wave length, its value by the per cent of light reflected as compared to a similar white surface, and its intensity by the percentage of purity of the color. Since visible light varies from red of about 8000 Angstrom units (1 Angstrom unit = 0.00000001 centimeter) to violet of about 3500 Angstrom units, there is a possibility of about 4500 hues (8000 − 3500 = 4500), each differing by 1 Angstrom unit. Each of these hues might have 100 steps in its value scale, each differing by 1 per cent, and 100 steps in its intensity scale, each differing by 1 per cent. For example, a light, intense red might be designated as:

Hue = 7300 Angstrom units
Value = 90 per cent
Intensity = 94 per cent

If that same red were reduced in value it might be designated as:

Hue = 7300 Angstrom units
Value = 40 per cent
Intensity = 94 per cent

If the original light red were grayed considerably, it might be designated as:

Hue = 7300 Angstrom units
Value = 90 per cent
Intensity = 30 per cent

A dark, dull blue might be designated as:

Hue = 4400 Angstrom units
Value = 20 per cent
Intensity = 40 per cent

While such a system is very complete, it has not been adopted for use by the general public because it is a more exacting system than is required for most color work. But for the person who is doing research in the physics of color it is a satisfactory system, because each of the dimensions of color can be definitely measured. Two of the simpler color systems which are in general use are the *Prang* and the *Munsell* systems.

226. The Prang Color System. The color chart for the Prang system is shown in Figure 36.11. The three primary colors are red, yellow, and blue. The three binary colors which are formed by combining the primaries in pairs are orange, green, and violet. The primary and binary colors together are known as the *six standard colors.* Intermediate colors are formed by combining a primary and a neighboring binary; for example, yellow and green form the intermediate yellow-green. The next step is

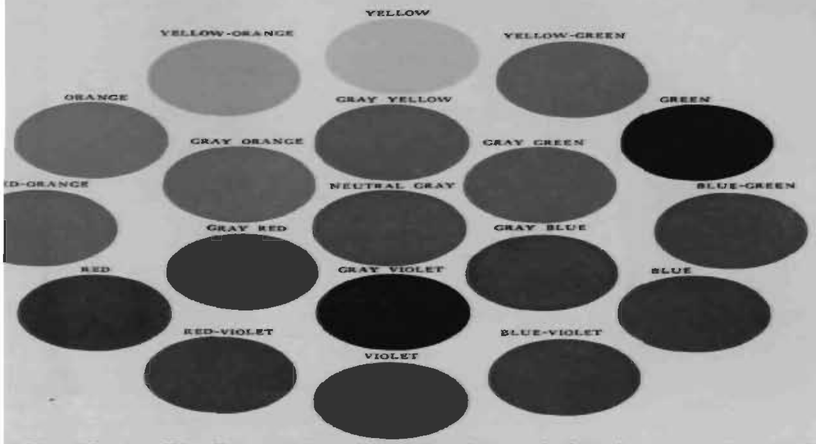


Fig. 36.11. The Prang color chart, showing variations in hue, value, and ntensity. The various hues are indicated around the circumference of the ircle. The value decreases from the top to the bottom of the chart. The ntensity decreases from the circumference to the neutral gray center.

a yellow-yellow-green. The system soon becomes complicated if carried too far. The Prang system provides for seven steps in the value scale between white and black. No colored pigment or dye can be so light as white or so dark as black. Following is the value scale of the Prang system. (Also see Fig. 36.12.)

W = White
HL = High light
L = Light
LL = Low light
M = Middle
HD = High dark
D = Dark
LD = Low dark
B = Black

The values of the normal colors in the Prang color chart are arranged as follows:

HL = Yellow
L = Yellow-orange and yellow-green
LL = Orange and green
M = Red-orange and blue-green
HD = Red and blue
D = Red-violet and blue-violet
LD = Violet

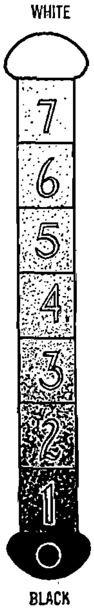


Fig. 36.12. Value scale for the Prang color system.

The pure or full-intensity colors are placed on the circumference of the Prang color chart, and the partly neutralized or less intense colors are placed nearer to the center, which is neutral gray. Again we see that, as the intensity of any color is decreased, it approaches the same neutral gray. The intensity of a color may be decreased by adding some of the color which is directly across from it in the color circle. Such pigment colors, when combined in the correct proportions, form a neutral gray. They are known as *complementary* colors. It will be noticed that the complement of any primary color is the binary formed by the other two primaries, and that the complement of any binary is the primary which is not included in the binary. There are many steps possible, of course, between full intensity and neutral gray for any hue, but in Figure 36.11 only three steps in intensity are shown. They are:

Full intensity
1/2 neutral or 1/2 intensity
Neutral gray

227. The Munsell Color System. The color chart for the Munsell system is shown in Figure 36.13. The three dimensions of color in this system are hue, value, and chroma. The hues appear around the circumference of the sphere. The vertical axis of the sphere is the value scale with white at the top and black at the bottom. Chroma (or intensity) variations are shown on paths running out horizontally from the neutral gray axis.

Munsell divided the colors of the spectrum into five principal hues and five intermediate hues as follows:

PRINCIPAL	INTERMEDIATES
Red	Yellow-red
Yellow	Green-yellow
Green	Blue-green
Blue	Purple-blue
Purple	Red-purple

His reason for this division was that the colors of the twelve-color chart did not combine to form a neutral gray but formed a gray with a warm cast, while if he used the ten hues, at equal chroma and value steps, he obtained a perfectly neutral gray. The colors between the principal and intermediate hues are indicated by numbers. The mid-point of each of the principal and intermediate colors is numbered 5. The middle green is 5G; the middle blue-green is 5BG. The colors between 5G and 5BG are designated as 6G, 7G, 8G, 9G, 10G (the hue half-way between 5G and 5BG), 1 BG, 2BG, 3BG, and 4BG. With five principal hues and five intermediate hues, or ten hues, named around the circumference, and ten numbers between each pair of names, there is a total of one hundred divisions, which may be indicated in the hue circle.

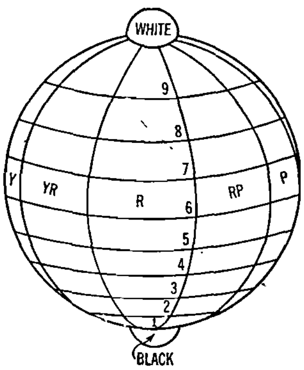


Fig. 36.14. The color sphere.

Values in the Munsell system are also indicated by numbers. There are nine steps between black and white. Black is N 0/ and white is N 10/. Any hue then might have values from one to nine inclusive.

Chroma or intensity in the Munsell system is indicated by a number also. Munsell found that, if he used the ten colors at full or spectral intensity, he did not obtain a neutral gray. If he worked with complementary colors, he could not always produce a neutral gray with equal parts of the two colors at full intensity. He found the greatest variation in the blue-green and red complements. There he had to use two parts of blue-green to one part of red to obtain a neutral gray. He divided the colors at value 5/ into various numbers of chroma steps as follows:

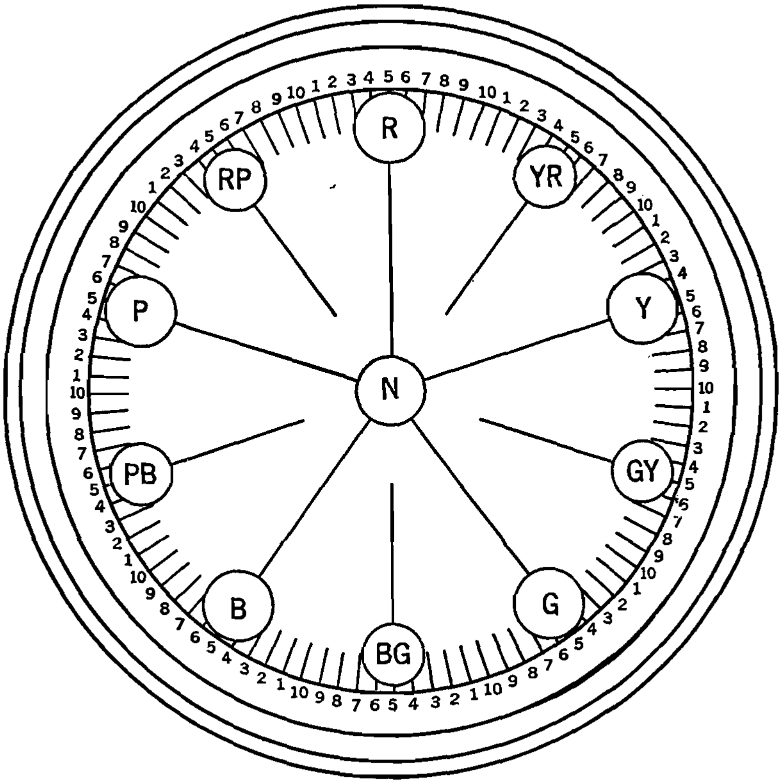


Fig. 36.15. The 100-hue color circle for the Munsell color system.

Red	10	Yellow-red	7
Yellow	7	Green-yellow	6
Green	7	Blue-green	5
Blue	6	Purple-blue	8
Purple	6	Red-purple	6

If he combined the ten colors using chroma 5 in each case, he could produce a neutral gray. He was limited to chroma 5 be-

cause that was full intensity for blue-green. If he combined correspondingly numbered chroma steps of any two complementary colors, he could produce a neutral gray. The chroma number is written after a line which divides it from the value number. Chroma /1 is an almost neutral gray; /2 is a little less neutral.

The complete Munsell notation is written

Number-Hue $^{\text{Value}}/_{\text{Chroma}}$.

A tomato-red may be 6 R 5/8; a lemon color may be 3 GY 7/5; a dark blue may be 7 B 3/4.

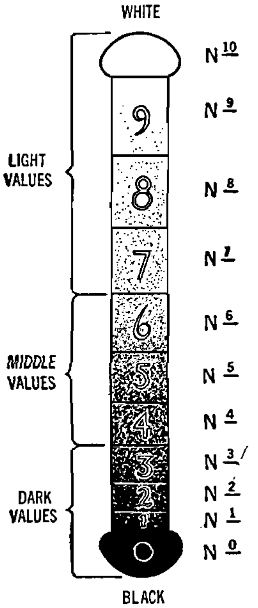


Fig. 36.16. The value scale for the Munsell color system.

228. The Prang and Munsell Systems Compared. The Munsell system furnishes the more complete method of describing a color accurately because it provides more steps for indicating the hue, it has nine rather than seven value steps for any hue, and a method of indicating the chroma which not only tells how the color in question compares with full intensity for that color, but also gives a relative rating for comparison with other colors. It is also three dimensional instead of two dimensional. The Prang system is the chief one used in elementary art work, but the Munsell system is used more extensively in scientific work. Even after a color has been described in either the Prang or the Munsell notation, it will be found that it varies in appearance if the materials on which it is used are different. Felt and velvet dyed in the same bath apparently vary in color because of the difference in the texture of the material. The same wall paint appears entirely different on a rough plaster than it does on a smooth plaster. So the problem of matching colors is still a problem, especially when it is remembered that colors which seem to one person to match, may not appear to do so when viewed by some other person, because of the difference in the response of various eyes to colors.

Instruments known as *colorimeters* have been developed for color analysis and color matching. A colorimeter used in connection with a color photometer (a spectrophotometer) should be employed in every textile mill in order to standardize dye stuffs and pigments used in dyeing cloth. These instruments should be employed in paint factories, in order that the paint and enamel color charts may be standardized.

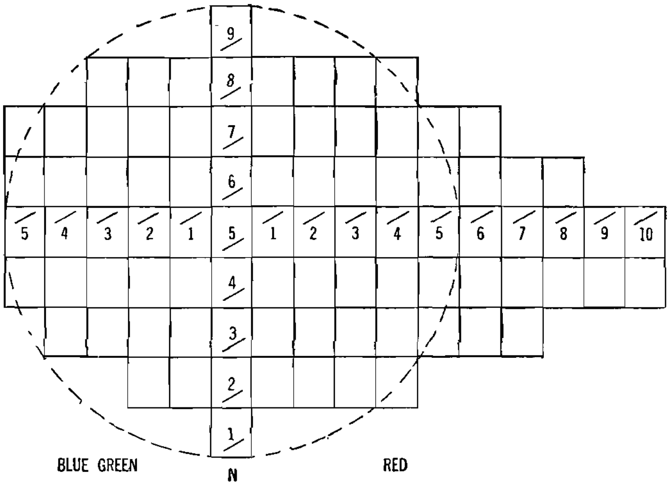


Fig. 36.17. Chroma steps for the Munsell color system.

STUDY QUESTIONS

1. What is white light?
2. Why does the color of the light which falls on an object make a difference in its appearance?
3. Why may two objects which are illuminated by the same light appear entirely different in color?
4. Is it possible that the same object may appear a different color to each of the people looking at it? Why?
5. What color causes the greatest response in the eye in proportion to the energy received by the eye?
6. What is the theory as to how the nerves in the eye respond to color?
7. What is color-blindness?
8. What difficulty does a person who is red color-blind have in picking strawberries?
9. What color tests are most carefully checked for locomotive engineers?
10. Which method of mixing colors does a child use when he plays with his box of water colors?
11. Explain how either the subtractive or the additive method might be used in stage lighting.

12. What determines the hue of a color?
13. What determines the value of a color?
14. Which has the higher value — light yellow or dark yellow?
15. What determines the intensity or chroma of a color?
16. Which has the stronger chroma — burnt orange or brown?
17. Why did Munsell use five main colors instead of six? Which of the Prang colors did he omit?
18. Write the Prang notation for peach color. Write the Munsell notation for peach color. Do the same for lettuce green.

37

HOME ILLUMINATION

The sun is the chief light source of the solar system. It is continually emitting radiant energy, and some part of the earth is receiving energy from the sun at all times. The fixed stars are also light sources, but they are so far away from the earth that the amount of light received from them is negligible. The moon is not a light source — it reflects light from the sun to the earth.

It will be recalled that luminous bodies are those which emit light; nonluminous bodies are those which do not emit light and are visible only because light from some luminous source falls upon them, and part of that light is reflected to the eye. For example, if a person enters a dark room, he may stumble over a chair because it is nonluminous, but if there is light in the room, the chair reflects part of the light which falls on it, and thus it is made visible. Some black bodies which do not reflect light become visible only when placed in front of a lighter background which reflects light and thus outlines the nonluminous, nonreflecting body. The letters on this page are visible because of the light reflected from the white paper. Black silhouettes are placed on a white background and are visible chiefly because of the light reflected by the background.

229. Artificial Light Sources. Since, for at least a part of the 24 hours of the day, we are dependent on some form of artificial light, it is important that we know something of the development of artificial lighting. The first artificial-light sources used in the home were fires. Of course, heat was the primary purpose of the fire and light was of secondary importance. Later, pine knots were collected to use in the fire at night, and pine torches were used for portable lights. Vegetable and animal oils were also burned in open vessels, and the addition of wicks made of dry wood or grass was an improvement, since they made more rapid oxidation possible.

During the Middle Ages candles were devised, and they marked a definite step in the development of a convenient artificial-light source. A pound of tallow made enough candles to last 60 hours if burned one at a time; that is, they furnished 60 candle-hours of light. But the labor involved in making them was considerable. The discovery of petroleum in Pennsylvania, about a hundred years ago, provided materials for artificial illumination which made it possible to develop larger lighting units, and to produce light at a lower cost than it could be produced by candles. Artificial illumination progressed through various stages, including small kerosene lamps, kerosene mantle lamps, open-flame gas lights, gas-mantle lights, and gasoline lights.

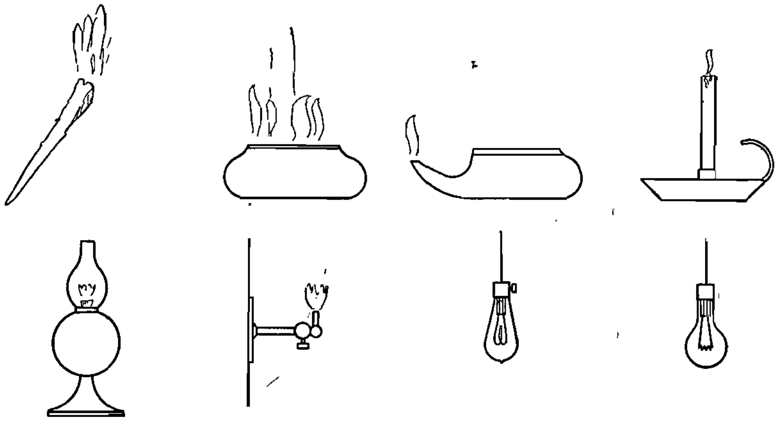


Fig. 37.1. Early light sources.

The incandescent-carbon electric light developed in 1879 by Thomas Edison provided a light source which far surpassed anything else known at that time, but these first carbon filaments were very inefficient — a large part of the electrical energy was converted into heat instead of light. Also, the cost of electrical energy was high, and the cost of the lamp itself was high. For example, the carbon lamp used about five times as much energy as the present gas-filled tungsten lamp; the energy cost perhaps three or four times as much per kilowatt-hour as the average rate now; and the lamp itself cost about fifteen times as much as a tungsten lamp costs today. Therefore, the total cost per candle-hour was possibly twenty-five or thirty times as great as at the present time. But the light was so much brighter, so much safer, and so much more convenient, than anything else known at that time that, for a number of years, the demand exceeded the supply.

It is interesting to note that in all the artificial-light sources discussed up to this point, the source of the light has been glowing carbon. Resinous woods, fats, oils, kerosene, gasoline, and artificial gases are all rich in hydrocarbons. When heated to high temperatures, the carbon becomes incandescent and gives out light. The presence of unoxidized carbon in flames shows up as soot.

In 1906 it was found that tungsten filaments were far superior to carbon, and during the last few years the use of fluorescent lamps has increased rapidly. Both of these light sources have been discussed in Chap. 28 on Electric Lights and that chapter should be reviewed at this time.

230. Measurement of Illumination. Since the candle was used for such a long time for illumination, it is natural that, when other light sources were developed, their "light-giving ability" was rated in terms of the familiar candle. The standard candle was very definitely defined as to size, material, and conditions for burning. Other standards have been developed from time to time. The standards now used are tungsten lamps issued by the Bureau of Standards; they are, however, rated in terms of candle power. *The candle power is defined as an illuminating ability equal to that of the standard candle.*

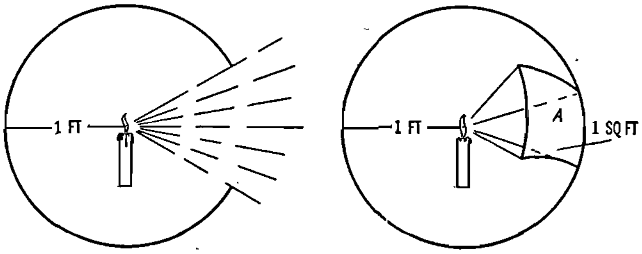


Fig. 37.2. A lumen is the amount of light energy which falls on an area of one square foot, every point of which is one foot from a one candle power source.

If a standard candle is placed at the center of a sphere (the inner surface of which must absorb 100 per cent of the incident light), all of the light given out by the candle falls on the inside surface of that sphere. If an opening is now cut in the sphere, part of the light escapes through this opening. If the radius of the sphere is 1 foot and the area of the opening is 1 square foot, the amount of light energy which escapes through the opening is known as 1 *lumen.* Since the area of the sphere is $4\pi r^2$, the area of this sphere will be $4\pi 1^2 = 12.57$ square feet. Therefore, the total quantity of light given out by a standard candle is 12.57 lumens.

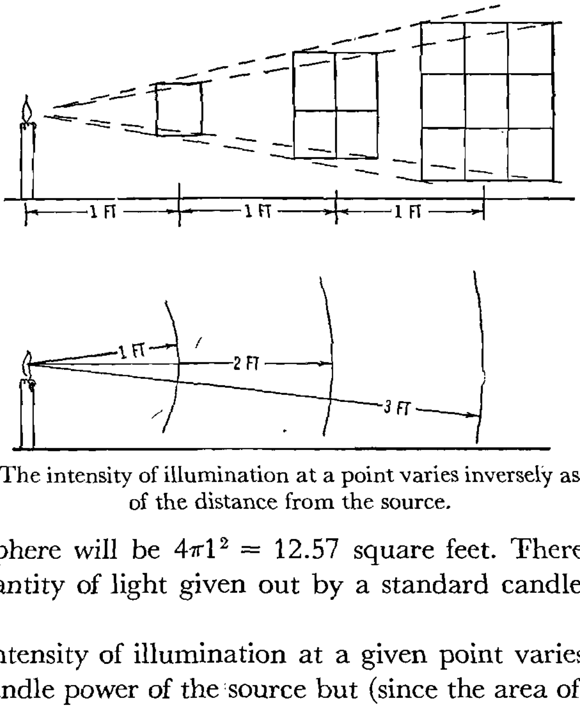


Fig. 37.3. The intensity of illumination at a point varies inversely as the square of the distance from the source.

The intensity of illumination at a given point varies directly as the candle power of the source but (since the area of a sphere increases as the square of the radius) inversely as the square of the distance of that point from the light source. The intensity of illumination may be found by

$$I = \frac{cp}{d^2}$$

where I = intensity of illumination (in foot-candles)
cp = candle power of the source
d = distance between the light source and the point where the illumination is to be measured (in feet)

231. The Foot-candle Meter. The eye is no more reliable for judging the intensity of a light source or the intensity of the resulting illumination than the temperature sense is for judging temperature. If a person comes into a moderately lighted room from a dark room, it may seem to be well illuminated, but to another person coming from a brightly lighted room, the second room seems dark. The same result is noticed when one enters a theater from the brightly lighted lobby — it is hard to distinguish objects; but, after one has been in the theater a short time, individuals and objects are easily distinguished. This change is due chiefly to the fact that the pupil of the eye increases in size in order to let more light enter the eye. Since the eye is unreliable in its judgment, the intensity of the light source and of the resulting illumination should be determined by some means which does not involve the response of the eye. A device for measuring the intensity of illumination is the foot-candle meter. The type which is described here contains a *photronic cell* of the type which operates without a battery. (See Sec. 140.) The cell is connected to the terminals of a sensitive galvanometer and, since the size of the current depends upon the intensity of the light falling on the cell, the scale may be calibrated to read directly in foot-candles. This instrument is small, easily portable, and accurate enough for measurements in homes, offices, schoolrooms, or factories.

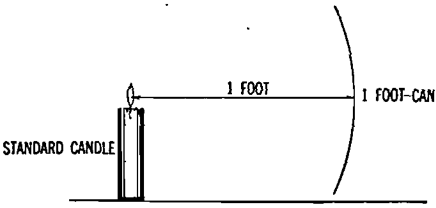


Fig. 37.4. A foot-candle is the intensity of illumination at a point which is one foot from a one candle power source.

In the first section of the table entitled "Illumination Values for the Home," the illumination values given are for typical home tasks and for persons with normal vision. Due consideration has been given to such matters as cost and practical attainability. Under some conditions more light may be necessary or desirable, and is often attainable. These illumination values may be obtained by using combinations of ceiling and wall lights, portable lamps, and lamps designed for a specific function. The values listed have been determined with a foot-candle meter placed on the work surface with the light-sensitive cell on the same plane as the work.

In the second section of the table illumination values are given for general lighting. These are intended to minimize undue brightness ratios between the areas illuminated for special tasks and the surrounding areas. In those places where close visual application is not involved, the values listed aim to assure enough light for safe passage, for eye comfort, and for a pleasing atmosphere. These values represent an average of a number of readings taken throughout the room on a plane 30 inches above the floor, with the light-sensitive cell held in a horizontal position.

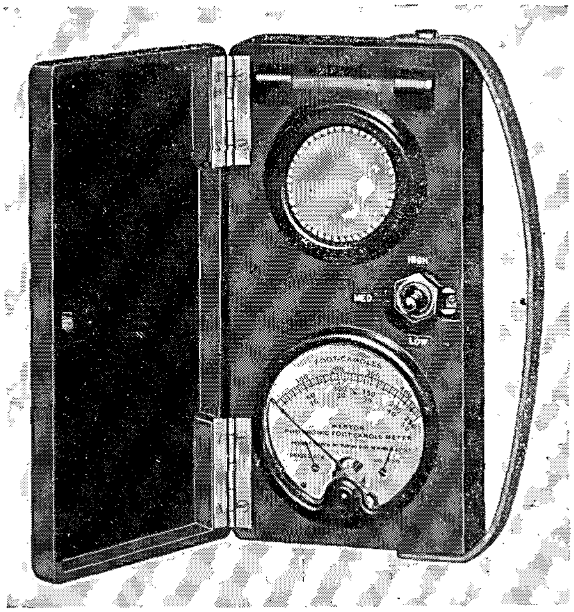


Fig. 37.5. A foot-candle meter. (Courtesy Weston Electrical Instrument Corp.)

Even the amounts listed in the table are far less than the number of foot-candles used for the same purposes in daylight. But the source of light in the daytime — the sun — is far away, and the light which falls on the surface has been reflected from many surfaces and is diffused and softened. For most types of work a person tries to avoid direct sunlight, because it results in a glare. The intensity of illumination due to sunlight varies greatly according to the season, the time of day, and the clearness or cloudiness of the sky. In direct sunlight on a clear summer day, the intensity may be 10,000 foot-candles. On the same day under a large tree, it may be 1000 foot-candles, while at a north window where all of the light is reflected light, it may be only 500 foot-candles.

ILLUMINATION VALUES FOR RESIDENCES[1]

SPECIFIC VISUAL TASKS	FOOT-CANDLES RECOMMENDED
Reading	
Prolonged periods (smaller type)	40
Casual periods (larger type)	20
Sewing	
On dark goods, fine needlework	150 or more
Average sewing (prolonged)	40–80
Average sewing (periodic)	20–40
Writing	20
Children's study table	40
Game tables	
Card table	10
Ping-pong, table tennis	20
Kitchen	
Work counter, range, and sink	40
Dressing table mirror	20
Bathroom mirror	40
Laundry	
Ironing board or tubs	40
Workbench	40
GENERAL LIGHTING	
Entrance hall, stairways, and stair landings	5
Living room, library, sunroom	5
Dining room	5
Kitchen	10
Bedroom	5
Bathroom	5

If, in order to reach the recommended number of foot-candles, the source of light is placed too near the surface to be illuminated, the resulting light is harsh and glaring. Of course, as the source is placed farther away, its size has to be increased, and

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[1] From "Illuminating Engineering Society Recommended Practice for Residence Lighting," 1953 (condensed).

this results in a greater cost for energy, but the quality of the light is improved.

232. The Photometer. *A photometer is a device used for determining the candle power of an unknown light source.* In one type of photometer two light sources are used, and if the candle power of one of these sources is known, the candle power of the other may be calculated. The photometer is a long, light-tight box containing a calibrated scale on which the two lamps may be shifted back and forth. A lamp is placed at each end of the scale. Near the center is a screen, and two mirrors are set in such a manner as to reflect a view of each side of the screen through an eyepiece to the observer. In an improved type of photometer the "observing" is done by a *photronic cell.* The lamps are shifted back and forth until the two sides of the screen appear to be equally illuminated. Let I_s be the intensity of illumination due to the standard lamp and I_x the intensity of illumination due to the unknown lamp. When in adjustment

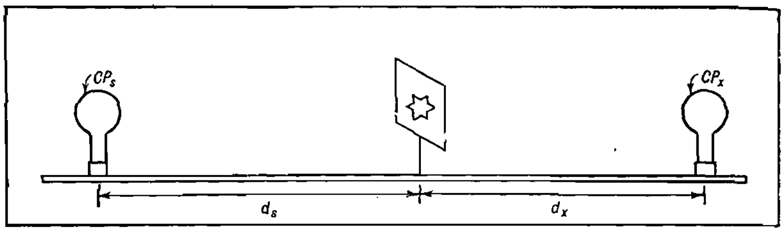

Fig. 37.6. A photometer.

$$I_s = I_x \tag{1}$$

but

$$I_s = \frac{cp_s}{d_s^2} \tag{2}$$

and

$$I_x = \frac{cp_x}{d_x^2} \tag{3}$$

Equating (2) and (3)

$$\frac{cp_s}{d_s^2} = \frac{cp_x}{d_x^2}$$

Therefore

$$\frac{cp_s}{cp_x} = \frac{d_s^2}{d_x^2}$$

It should be noted that while the intensity of illumination at a given point varies *inversely* as the square of the distance of that point from the source, the relative candle powers of the two lamps vary *directly* as the squares of the respective distances.

The candle power of a lamp may be calculated also from the reading of the foot-candle meter and the distance from the lamp to the meter, provided all of the light which reaches the meter comes directly from the lamps, i.e., no reflected light should reach the meter. Then

$$cp = Id^2$$

233. Efficiency of Lamps. The efficiency of an electric lamp is usually expressed in terms of *lumens per watt* but it may be expressed in terms of *candle power per watt.*

$$\text{Efficiency} = \frac{\text{output}}{\text{input}}$$

$$= \frac{\text{lumens}}{\text{watts}}$$

or

$$= \frac{\text{candle power}}{\text{watts}}$$

APPROXIMATE EFFICIENCIES OF VARIOUS LIGHT SOURCES[1]

NAME OF LIGHT SOURCE	WATTS	LUMENS*	LUMENS PER WATT†
Tungsten, white, frosted	60	840	14
	100	1600	16
	150	2550	17
	200	3600	18
Tungsten, 3-light	300‡	5100	17
Tungsten, daylight, frosted	60	540	9
	100	1000	10
	150	1650	11
	200	2400	12
Tungsten, lumiline, frosted	30	240	8
	60	540	9
Fluorescent, daylight	15	495	33
	30	1200	40
Fluorescent, green	15	900	60
	30	2250	75
Fluorescent, red	15	45	3
	30	120	4

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* To obtain candle power divide lumens by 12.57.

† To obtain candle power per watt divide by 12.57.

‡ Both filaments of a 100–200–300-watt lamp.

[1] Courtesy General Electric Company.

234. Standards for Good Illumination. The standards for good illumination may be stated very simply. There must be (1) a steady light, (2) of the proper intensity, (3) with no glare, and (4) of pleasing color. One of the first requirements of an artificial-light source is that it furnish light of uniform intensity. The flicker of candles causes a severe eyestrain on account of the constant adjustment of the eye to the varying intensity. The average person cannot judge whether the intensity of the illumination is correct merely from his ability to discern objects, because the eye adjusts itself to almost any intensity of illumination. When one stops to think that the eye can see in a dimly lighted room and also in the bright sunlight where the illumination may be 10,000 times as intense, he realizes that the eye can adjust itself to a wide variety of situations. Of course in these extreme cases a person is conscious of too little or too much light, but where the illumination is not extremely low or high, the eye does the adjusting with no warning that the light is not ideal. That does not mean, however, that the eye makes the adjustment with no effort. In some cases where the light is steady and of the right intensity, it is a poor color or of poor quality because of the nature of the source or because of the distribution. Over a period of time, poor lighting tires the eyes, and the resulting eyestrain may affect other parts of the body, causing headaches, nervousness, and indigestion.

The chief factors causing glare are: (1) too much light, (2) a source which is too bright, (3) light which is too direct, (4) polished reflecting surfaces, and (5) excessive contrasts in brightness.

Glaring light produces eye discomfort and fatigue, and may result in serious injury to the eye. When glaring light enters the eye, the pupil contracts, and instead of being at normal tension, it is under the strain of constant contraction. If the glare is due to too much light, the intensity may be decreased by reducing the size of the light source, but glare is more likely to be due to some other cause. The brightness of a light source or of an area which is reflecting light is usually expressed in foot-lamberts. *A foot-lambert is the brightness which results when a surface either radiates or reflects 1 lumen per square foot.*[1] In other words the brightness is the number of lumens per square foot.

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[1] This brightness is equivalent to an intensity of illumination of 1 foot-candle.

Excessive brightness may be reduced by enlarging the luminous area. For example, the surface area of the filament in an electric-light bulb is extremely small, and its brightness is extremely intense. If the bulb is frosted, the luminous area is increased, and the brightness is reduced. Then if the bulb is placed in a white glass globe, the luminous area is still further increased, and the brightness is again reduced.

BRIGHTNESS OF COMMON OBJECTS, SURFACES, AND LIGHT SOURCES [1]

	FOOT-LAMBERTS
Outdoors in Daytime	
North sky (10 degrees above horizon)	1000
South sky (near sun — hazy)	35,000
White cloth in sunlight	4000
Grass in sunlight	900
Light Sources	
Full moon, clear sky	1500
Sun as observed at earth's surface	450,000,000
Candle flame	4300
40-watt inside-frosted lamp	15,000
60-watt inside-frosted lamp	57,500
100-watt inside-frosted lamp	90,000
40-watt lumiline — white frosted	1200
15-watt 18 in. 1.0 in. dia. fluorescent white	1940
15-watt 18 in. 1.5 in. dia. fluorescent white	1360
20-watt 24 in. 1.5 in. dia. fluorescent white	1630
20-watt 24 in. 1.5 in. dia. fluorescent daylight	1450
40-watt 48 in. 1.5 in. dia. fluorescent white	1760
40-watt 48 in. 1.5 in. dia. fluorescent daylight	1490
Bowls of I.E.S. portables	1490
Shades of I.E.S. portables	275
Common Indoor Objects under Artificial Lighting	
Well-printed book with 50 foot-candles	38
Well-printed book with 20 foot-candles	15
Wall — 35% D.R.F.* — with 10 foot-candles	3.5
Wall — 55% D.R.F. — with 10 foot-candles	5.5
Wall — 55% D.R.F. — with 2 foot-candles	1.1
Rugs — 5% D.R.F. — with 5 foot-candles	0.25
Rugs — 5% D.R.F. — with 10 foot-candles	0.5
Rugs — 5% D.R.F. — with 20 foot-candles	1
Rugs — 20% D.R.F. — with 5 foot-candles	1
Rugs — 20% D.R.F. — with 10 foot-candles	2
Rugs — 20% D.R.F. — with 20 foot-candles	4

* D.R.F. = diffuse reflection factor.

If the light source is too near the surface to be illuminated, or if the reflecting surfaces are highly polished, the light reflected

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[1] Courtesy General Electric Company.

to the observer is glaring. If parallel light rays meet a smooth surface, they are reflected as parallel light rays, but if the surface is irregular, the reflected light is diffused; therefore a slightly rough surface is generally preferable. If the light source is moved farther away, less direct light falls on the surface, and more light is reflected from other surfaces to this surface and then to the eye. This results in a softer, more diffused light. Glare may often be eliminated by changing the texture of the reflecting surface. Painting a wall with a glossy paint often causes a serious glare, but painting that same wall with a dull, flat paint of the same color softens the light. A book printed on glazed, shiny paper is much more likely to reflect a glare into the reader's eyes than one printed on a rough, dull-surfaced paper. Sometimes a picture which reflects a glare must be moved to another location in the room in order to eliminate the unpleasant reflection.

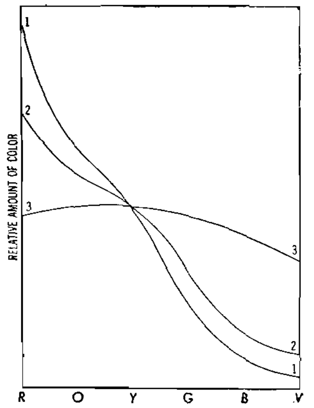

Fig. 37.7. Color distribution of various light sources.

1. Tungsten — 600 lumens — 40 to 50 watts.
2. Tungsten — 3000 lumens — 150 to 200 watts.
3. Average clear day or a daylight fluorescent.

Often a surface which reflects an unpleasant light into the eyes will seem to be properly illuminated if the light intensity of the surrounding area is increased. For example, if a study lamp is placed close to a printed page and the rest of the room is dark, the page may reflect a glare which seems to disappear as soon as other lights in the room are turned on. The page is now more highly illuminated than before, but it does not appear to be so, because there is less contrast with the surroundings. Some of the light coming to the eye is diffused light from other sources.

The standard for the color of an artificial-light source is the color of the light from the sun; i.e., for general illumination the most satisfactory artificial sources are those which make colors appear practically the same in artificial light as they do in daylight. Most artificial sources furnish more light in the red end of the spectrum and less in the blue end than is found in sunlight. The color distribution from a daylight fluorescent lamp is the nearest to that of the sun of any of our artificial-light sources. The following table gives approximate values for the relative color distribution of various light sources. These data are shown graphically in Figure 37.7.

SOURCE	RED	ORANGE	YELLOW	GREEN	BLUE	VIOLET
Tungsten, 600 lumens (40–50 watts)	200	120	100	43	17	12
Tungsten, 3000 lumens (150–200 watts)	150	110	100	60	30	20
Average clear day or a daylight fluorescent	94	100	100	96	85	70

235. Types of Interior Illumination. Interior illumination may vary all the way from *direct to indirect*. Each type has advantages and disadvantages, which will be pointed out.

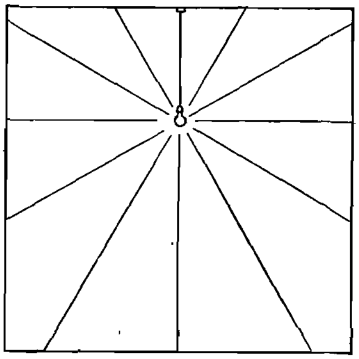

Fig. 37.8. Direct lighting.

In *direct lighting*, the light comes directly from the source to the place where it is to be used. The very simplest system of direct electric lighting is an unshaded, clear-glass lamp. This is the least expensive method of getting enough light since none of the light is lost in reflection; but it is also the poorest method of lighting since it causes serious eyestrain, sharp shadows, and glare, and does not produce a pleasing effect.

The use of frosted lamps is the first improvement. These lamps diffuse the light and protect the eye from the direct rays coming from the filament. Properly chosen shades or reflectors further protect the eyes and direct the light to the desired areas. The light then either comes directly from the source or is reflected by the shade. If the lights are placed high enough and at the proper places, this type of lighting is fairly satisfactory, but the farther the lamps are from the area to be illuminated, the larger they must be to furnish enough light.

In *indirect lighting* the source of the light is never visible; therefore all of the light must be reflected before it reaches the objects to be illuminated. The lights may be placed behind a cove molding which runs around the room not far below the ceiling, and which extends upward far enough to screen the light bulbs from the eye at any point in the room. Good reflectors are placed behind the bulbs at such an angle as to throw the light upward and outward to the ceiling, from which it is reflected to the objects in the room. Where cove lighting is not used, indirect lighting is accomplished by the use of an opaque reflector suspended beneath the lamp so that the light is reflected to the ceiling and then to the objects in the room. (See Fig. 37.9.) One objection to this method is that there is usually an area in the center of the room directly under the bowl which is under-illuminated. Floor and table lamps of the indirect type have been used considerably in the last few years. The color and texture of the ceiling are very important in indirect illumination. If the ceiling is not a good reflector, too much of the light may be absorbed instead of reflected. White, smooth surfaces make the best reflectors, but slightly rough, ivory-tinted ceilings are generally used, because they give a more pleasing effect. The approximate percentage of light reflected by several surfaces is given below:

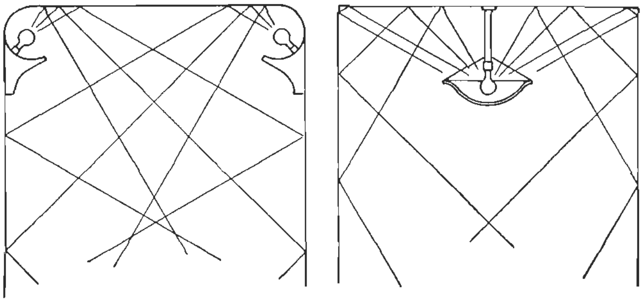

Fig. 37.9. Indirect lighting.

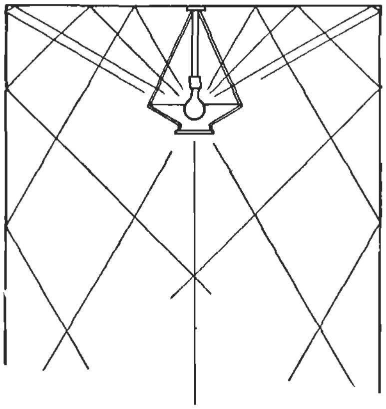

Fig. 37.10. A combination of direct and indirect lighting.

	PER CENT
Rough white paper	84
White letter paper	75
Newspaper	60
Light yellow paper	64
Light orange paper	50
Pale azure paper	39
Sky-blue paper	36
Light pink wallpaper	35
Light blue wallpaper	30
Black cloth	2
Black velvet	1

Rooms lighted indirectly sometimes appear overilluminated in the upper part of the room and underilluminated in the

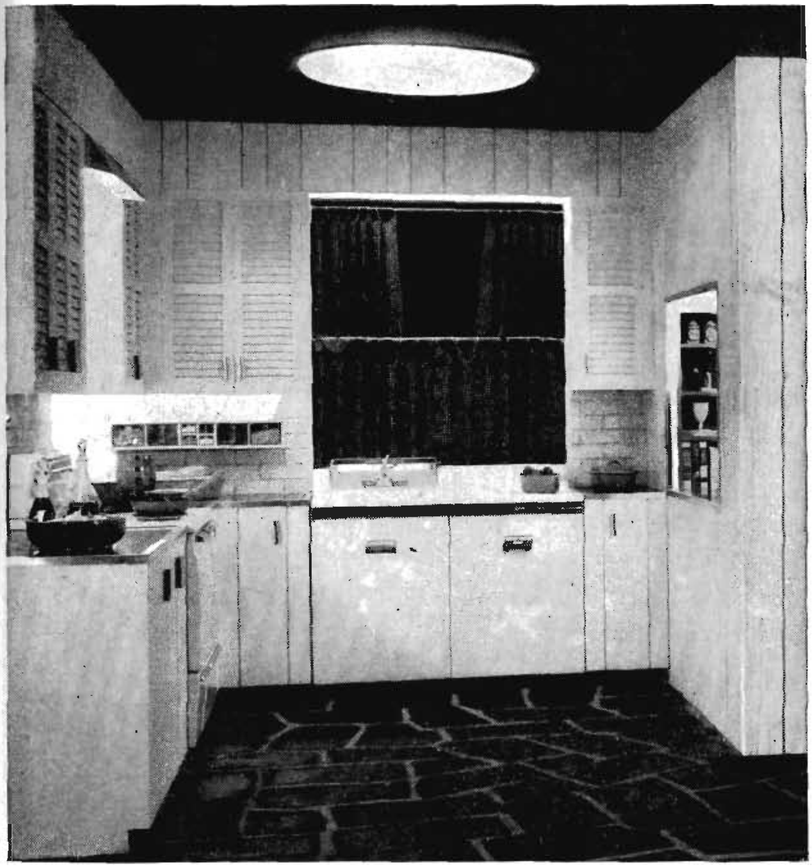

Fig. 37.11. This kitchen has a ceiling fixture, 36 inches in diameter, to give over-all lighting throughout the room. (Courtesy General Electric Company)

Fig. 37.12. This living-dining room has 15 light sources each planned for various family activities. Note the two lighted valances — one the full length of the room and another across the room divider — which help to create an air of spaciousness. (Courtesy General Electric Company)

Fig. 37.13. This bed-sitting room has a fluorescent lighted cornice over the corner windows, conveniently placed reading lamps and lights at each side of the mirror.

lower part of the room. It takes skillful design to get the desired results. The indirect system requires several times as much light as would be required if direct lighting were used; therefore the upkeep costs more as well as the installation. The principal recommendations for this type of lighting are the absence of glare, good distribution of light, and lack of sharp contrasts and shadows.

Fig. 37.14. This bathroom has a completely lighted ceiling. Fluorescent tubes are concealed by a translucent ceiling. The mirror is surrounded with fluorescent tubes concealed by frosted glass panels. (Courtesy General Electric Company)

By using a translucent bowl in place of an opaque one, as in Figure 37.9, the light distribution becomes that shown in Figure 37.10. Part of the light is reflected to the ceiling and part comes directly through the bowl. This system has some of the advantages of both systems, and is only slightly more expensive than direct lighting. It eliminates the sharp contrast between the nonluminous reflector and the brightly lighted ceiling. The ratio between transmitted and reflected light varies greatly. The bowl may be so thin that it transmits a great deal of light, or it may be so dense and dark that it barely glows. For general illumination a combination of direct and indirect lighting is generally used and is much to be preferred to direct lighting of the same intensity.

STUDY QUESTIONS

1. What is the chief light source for the solar system?
2. What element has been most common in artificial-light sources?
3. Why are tungsten lights better than carbon lights?
4. Why does the intensity of illumination decrease so rapidly as the distance from the light source increases?
5. Why is the eye a poor judge of illumination?
6. How many foot-candles are recommended for reading a newspaper?
7. What is the purpose of a photometer?
8. How is the efficiency of a lamp expressed?
9. What are the standards for good illumination?
10. What causes a glare?
11. What is the standard for color distribution of an artificial-light source?
12. How does the color distribution of a daylight fluorescent lamp compare with that of the sun?

PROBLEMS

1. What is the intensity of illumination at a point 4 feet from a 120-candle-power lamp? *Ans.* 7.5 ft-c
2. What is the candle power of a lamp which furnishes 10 foot-candles at a point 3 feet from the lamp?
3. A 70-candle-power lamp is placed 30 centimeters from the photometer screen. What is the candle power of a lamp which produces the same illumination on the screen when it is placed 60 centimeters from the screen? *Ans.* 280 cp
4. Where do you place a 20-candle-power lamp to balance a 30-candle-power lamp which is 3 feet from the photometer screen?
5. What is the efficiency of a 150-watt tungsten lamp if it furnishes 2550 lumens? *Ans.* 17 l per w
6. If a daylight fluorescent lamp furnishes 495 lumens and its efficiency is 33 lumens per watt, how many watts does the lamp use?
7. What is the efficiency of a 30-watt daylight fluorescent lamp if it furnishes 100 candle power? *Ans.* 3.3 cp per w
8. What is the efficiency of a 100-watt tungsten lamp if it furnishes 133 candle power?

SOUND

38

THE PRODUCTION AND TRANSMISSION OF SOUND

The average person, if asked to define sound, says that it is something one hears, just as heat is something one feels, or light is something one sees. This is true as far as the sensation is concerned, but there is a cause for each sensation, and it is the cause of the sensation that is of most interest to the physicist.

Sometimes people debate the question, "Is there a sound if a tree falls in the forest and there is no one there to hear it?" Both *yes* and *no* are correct answers to the question. It depends on what is meant by the word "sound." If you are thinking of the cause of sound — the vibrations in the air produced by the falling tree — the answer is *yes*, but if you are thinking of the sensation of sound the answer is *no* because there is no ear there to receive the energy and no auditory nerve or brain center to respond to the energy. Let us again suppose that two people are there to see the tree fall — but one of the two is deaf. The cause of the sound is there and the energy is carried to each person. One experiences the sensation of sound, but the other one does not because his hearing mechanism has lost the ability to respond to sound energy.

236. The Cause and Transmission of Sound Waves. If one touches a bell, a piano string, a tuning fork, or the throat when it is emitting sound, one always finds that the sounding body is vibrating. These vibrations set up pulsations in the surrounding medium, and energy is carried to some receiving device such as the ear.

A simple experiment will help to demonstrate the nature of the cause of the sound. If a tuning fork is struck with a soft mallet, the prongs begin to vibrate. Sometimes the vibration is great enough to be visible; usually it can be felt if the finger is held against the fork; and usually the sound can be heard. As the prongs move back and forth, they produce compressions and rarefactions in the surrounding medium. These disturbances travel out from the source and are known as *sound waves.*

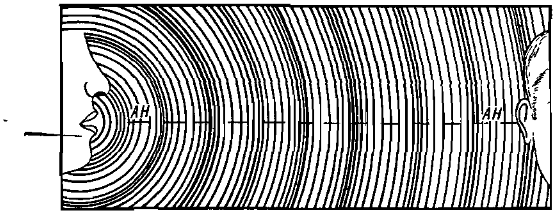

Fig. 38.1. Sound energy is transferred by a series of condensations and rarefactions.

The cause of sound is a series of vibrations in a material medium which have the required frequency and intensity to affect the auditory nerve.

Sound waves are *longitudinal* waves in contrast to electromagnetic waves which are *transverse.* The succeeding compressions and rarefactions in the conducting medium cause the particles of the medium to move back and forth in the direction in which the sound wave is traveling. It will be recalled that the motion in a transverse wave is at right angles to the direction in which the wave is traveling.

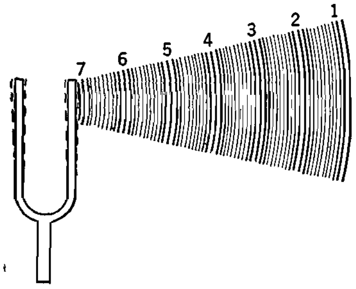

Fig. 38.2. Sound waves from a tuning fork.

Sound waves may be transferred by solids, liquids, and gases, but not by a vacuum. There must be a material to transfer the energy. A simple experiment will show that sound cannot be transmitted through a vacuum. If an electric bell is suspended in a bell jar, the sound of the bell can be heard as long as there is air in the jar, but if the air is pumped out, the sound of the bell gradually diminishes until it cannot be heard, though the tapper can still be seen vibrating. If the air is readmitted, the sound gradually increases until it reaches its first intensity. If the bell is fastened rigidly to the glass, the effect is not so pronounced because the vibrations of the gong are transferred to the glass, and by the glass to the air. This experiment shows that sound waves do not travel through a vacuum, but only through material mediums.

Sound energy is not always considered as a separate form of energy but as a special form of mechanical energy. Since sound is a succession of compressions and rarefactions in a medium, it is a form of energy which is capable of doing work such as setting the eardrum into vibration to cause the sensation of hearing, or moving the diaphragm of the transmitter in a telephone, or the diaphragm of the microphone in a public-address system or in a radio broadcasting system. These latter devices will be explained in the chapter on Electrical Sound Devices.

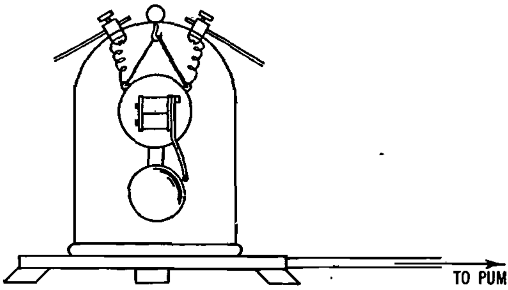

Fig. 38.3. The sound of the bell cannot be heard when the air is exhausted from the jar.

237. The Human Ear. The human ear is the means by which the energy of mechanical movement of material particles is transferred to the auditory nerve and then to the brain where the sensation of sound results. It is the receiving station for sound energy just as the eye is the receiving station for light energy.

The ear is divided into three chambers as shown in Figure 38.4. The *outer ear* consists of the visible ear and the canal leading to the middle ear. The division between the outer and middle ear is a vibrating diaphragm — the eardrum. The *middle ear* contains three small bones known as the hammer, the anvil, and the stirrup. These bones transfer the vibration of the eardrum to the oval window, which is a membrane-covered opening to the inner ear. The round window is a membrane-covered opening from the middle ear to the Eustachian tube. The *inner ear* consists of the vestibule, the cochlea, and the semicircular canals. The vestibule is the space between the oval window and the cochlea. The cochlea is a spiral canal, shaped like a snail shell, and filled with a liquid; it is divided into two spiral portions by the basilar membrane, which is about 0.01 inch wide, and about 1.2 inches long when uncoiled. The endings of the auditory nerves (about 3000 in number) are closely associated with the basilar membrane. The semicircular canals have no part in hearing; they are filled with a liquid and serve as organs of balance.

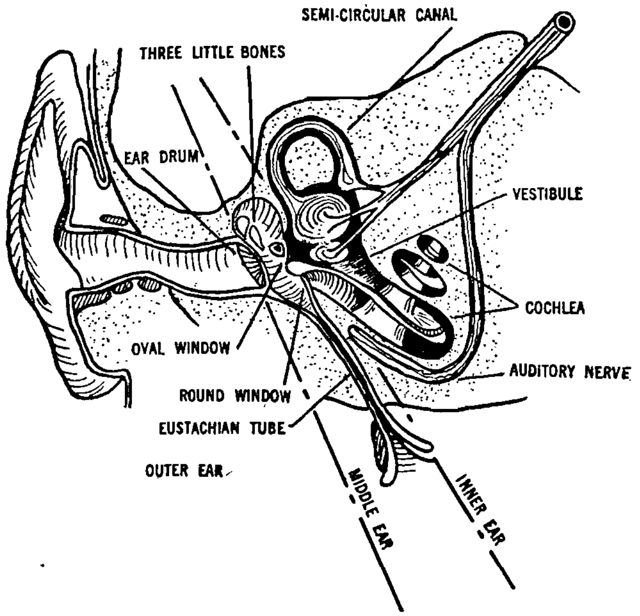

Fig. 38.4. The human ear.

When sound waves reach the eardrum, the vibrations are transmitted through the three bones to the membrane covering the oval window, then through the liquid in the inner ear to the basilar membrane, and finally to the auditory nerves by means of which the stimulus is transmitted to the brain. The sensation of sound results. Most ears are sensitive to frequencies between 16 and 20,000 vibrations per second. If any of the parts of the ear cease to function normally, the person becomes more or less deaf. Since the outer ear serves to catch the sound waves and direct them to the eardrum, elderly people who have difficulty in hearing often cup the hand back of the ear to increase the amount of sound energy sent to the eardrum. Often the chief difficulty is with the eardrum; it may harden and not respond to the sound waves which reach it, or it may have been destroyed by accident or illness. In that case the sound waves are transmitted to the inner ear with less force and the person is partially deaf. In other cases the nerves respond to some frequencies and not to others. In either case the hearing can sometimes be improved by wearing some type of electrical hearing aid. (See Sec. 256.)

238. The Velocity of Sound. Time is required for sound to travel from one place to another; the puff of smoke from a gun is seen before the sound is heard; steam is seen escaping from a whistle before the whistle is heard; the flash of lightning is seen before the thunder is heard. Sound travels through a material medium with a velocity which is characteristic of that medium, but the velocity in any medium varies as the temperature changes.

The velocity of sound in air is 1087 feet per second or 331 meters per second at 0°C. The velocity increases about 2 feet per second or about 0.6 meter per second for each degree Centigrade rise in temperature. At 20°C the velocity is almost 1127 feet per second or 343 meters per second. The velocity of sound in air is often given as about 1100 feet per second. In iron, sound travels about 16,000 feet per second. A hammer blow on a steel rail some distance away can be heard by placing the ear on the steel rail of the track before it can be heard through the air, because sound travels faster in steel than in air.

APPROXIMATE VELOCITY OF SOUND

Air	1,100 ft per sec
Water	4,600
Sea water	5,600
Iron	16,000
Copper	12,900
Aluminum	16,600
Glass	16,250
Wood	12,000

239. Length and Frequency of Sound Waves. If a tuning fork or an electric bell makes 100 vibrations per second and the sound travels 1100 feet per second, each wave is 11 feet long. If the sounding body makes 200 vibrations per second, each wave is 5.5 feet long. The relationship between the velocity, wave length, and frequency is:

$$V = \lambda\nu$$

where V = velocity of sound
λ = wave length
ν = frequency of vibration

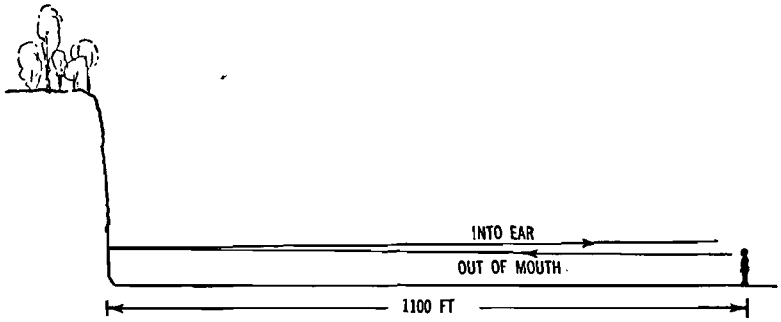

Fig. 38.5. A person standing 1100 feet from a high cliff will hear the echo of his voice about 2 seconds after he has spoken.

240. Reflection of Sound Waves. Nearly everyone has had the experience of hearing his own voice reflected or echoed back to him. Sometimes several echoes of the same sound are heard one after the other. If a person stands about 1100 feet from a cliff and speaks a word in a fairly loud voice, the sound will travel to the cliff and return, reaching him about two seconds after he has spoken. The depth of a well can be estimated by calling a word at the top of the well and noting the time it takes for the sound to reach the bottom and to be reflected back to the ear. Whispering galleries are constructed so that they reflect sounds from one particular point to another. In auditoriums and churches, sounding boards are sometimes placed back of the speaker to reflect to the audience the sound which would otherwise travel upward and backward. These must be properly designed, or the re-

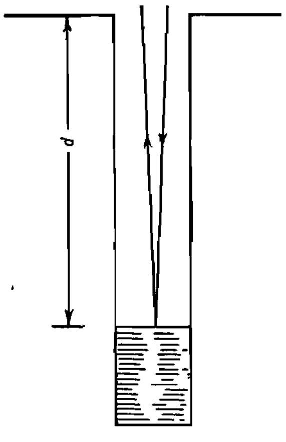

Fig. 38.6. The depth of a well may be estimated by noting the time required for sound to travel to the bottom of the well and back to the top.

flected sound will interfere with the direct sound and result in a confusion of the sounds. Broadcasting studios often have the walls entirely covered with heavy draperies to reduce the reflection of sound and the consequent possibility of confusion of sounds. As with light, it is found that *the angle of incidence of a sound wave is equal to the angle of reflection.*

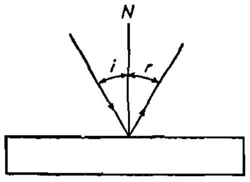

Fig. 38.7. The angle of incidence equals the angle of reflection.

241. Refraction and Diffraction of Sound Waves. Sound waves are *refracted* as they pass from one material to another. If a sound wave enters a medium in which its velocity is less, it is bent toward the normal, and if it enters a medium in which its velocity is greater, it is bent away from the normal. It is a common experience to hear a sound from around the corner of a building, showing that *diffraction* of sound waves also occurs.

242. Sound Insulation. The importance of sound insulation in homes, apartment buildings, office buildings, hotels, and school buildings is being realized today more than ever before. For many years the amount of unpleasant noise has been increasing because of more crowded living conditions, greater concentration of industries, and increased use of machinery. Streetcars, automobile horns, typewriters, and large motors cause noises and vibrations which tend to decrease the efficiency with which people work. Some work has been done in trying to eliminate the sources of unpleasant sounds; for example, the use of so-called noiseless typewriters, regulations concerning the use of automobile horns, and the replacement of streetcars by rubber-tired busses.

There will always be some unpleasant noises in buildings which cannot be eliminated, but they may be absorbed near the source and not allowed to travel from one room to another. There are two types of noises to be considered: those which originate in the room or enter the room through open windows and doors, and those which originate in machinery, in or near the building, and are transmitted by the framework of the building. Sounds of moderate intensity are usually absorbed when they reach the walls of the room. Many noises can be prevented from entering a room by closing the doors and windows. Other noises may be deadened by using carpets and hangings. But the noises which travel in the framework of the building are not so easy to absorb. Various changes in construction have been used. Walls can be built in several thin layers separated by blankets of absorbing materials. Air ducts and elevator shafts can be lined with soundproofing materials. Layers of soundproofing material can be placed between the ceiling and the next floor above. Any material which is inelastic and of low density tends to be a good sound insulator. Ground cork, hairfelt, Fiberglas, and composition materials are used.

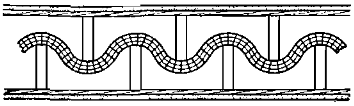

Fig. 38.8. Sound insulation may be provided by a blanket of sound-absorbing material.

The *absorption coefficient* of any substance is the percentage of the sound energy falling upon it that is absorbed. All of the sound which reaches an open window is absorbed; i.e., none is reflected; therefore its absorption coefficient is 100 per cent. The following are the absorption coefficients for several materials:

	PER CENT
Metal objects	1
Cement floors	2
Brick wall	3
Plaster, ordinary	3
Window glass	3
Linoleum	3
Smooth wood	4
Heavy drapes	12
Heavy carpets	20
Plaster, acoustic	20
Sound insulation materials	30–70
Open window	100

One of the problems that must be considered when soundproofing materials are used on the interior surfaces of a room is that of redecorating. Since the sound-absorbing ability of the material depends to a large extent on its porous surface — thus exposing many small cavities which absorb the sound energy — a paint which will cover the soiled surface will also seal the small cavities. Research on paints has been carried on in an attempt to make a paint which will cover satisfactorily without causing too much decrease in the sound absorption.

One solution is to make small holes in the soundproofing material — possibly 1/8 inch in diameter and spaced at about 1/2 inch intervals. These holes do not fill up when a reasonably thin paint is applied and they absorb a large range of frequencies.

243. Sound in Auditoriums. An architect who is to design an auditorium must consider (1) the shape and size of the room, (2) the probable sounds which may be made in the room, (3) the sounds which may enter the room from the outside, (4) the variation in the number of people who may be in the room at different times, (5) the material of which the walls are to be made, and (6) the period of reverberation which is the time required for the sound intensity to be reduced to inaudibility after the source of the sound has ceased.

When sound waves strike a large area such as a wall, the sound is reflected, and if the reflecting surface is curved, the sound energy may be concentrated at one place. Usually it is better practice to use flat surfaces to avoid too much concentration of the energy; otherwise the sound may be too loud in one part of the auditorium and too weak in another part. Figure 38.9 shows an auditorium which has good sound distribution and Figure 38.10 shows one with very poor distribution. The loudness of the sound in an auditorium depends upon the intensity of the source (the speaker, singer, or orchestra), the distance from the source, and the reflecting ability of the walls and fixtures. When the sound strikes the wall, it is reflected from one wall to another many times before it is completely absorbed. This constant reflecting of the sound increases the loudness of the sound, and in that way is a help, but it may also result in an echo or in too long a reverberation, which is undesirable. Therefore the period of reverberation must be calculated when the plans for the building are drawn, and if it is such that it will cause interference, the period may be shortened by changing

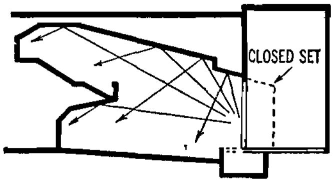

Fig. 38.9. A cross section of a well-designed auditorium.

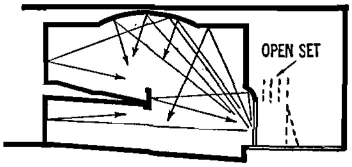

Fig. 38.10. A cross section of a poorly-designed auditorium.

the design of the room, or by using some kind of acoustical plaster which reflects less sound than ordinary plaster. Carpets, drapes, upholstered seats, and the audience also tend to lower the reverberation period of the auditorium.

A slightly longer period of reverberation is desirable for a music hall than for a lecture hall. The musician prefers the longer period of reverberation so that one sound will blend into the next. A hall which is ideal for a lecture may be too "dead" for a music hall. If the hall is to be used for both purposes, the reverberation period should be a compromise between the ideal periods for each.

244. Loudness of Sounds. The loudness of a sound is a sensation which is decided by the nerve stimulus which reaches the brain. But this stimulus will depend on the intensity of the sound energy reaching the auditory nerve and the sensitivity of the auditory nerve.

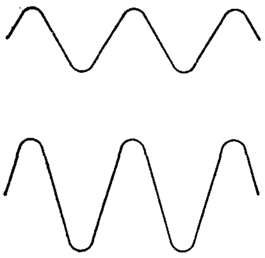

Fig. 38.11. Variation in amplitude.

This raises the question of what determines the intensity of sound energy. The first factor is the rate at which energy is supplied to the vibrator which in turn influences the rate at which energy is given out by the vibrator. If a tuning fork is struck gently, it vibrates with the same frequency as it does if it is struck harder, but the amplitude of the vibration in the surrounding medium is greater in the second case. Consequently the particles of the medium through which the energy is transmitted have a greater displacement in the same length of time or the intensity of the sound energy is greater in the second case.

The next factor is the character of the transmitting medium — materials differ widely in their ability to transfer sound energy. In general the more elastic a material is the better it transmits, for light-weight, porous, inelastic materials do not readily transmit sound energy. The distance through which the wave is transmitted helps to determine the intensity of the sound energy delivered. In general the intensity varies inversely as the square of the distance because the sound wave spreads out as a spherical shell. The frequency of the vibration is also a determining factor, since it is found by experiment that the ear responds to some frequencies better than to others. The maximum sensitivity of the average ear is at about 2000 vibrations per second (vps). The range of audibility of the average ear is from 16 to 20,000 vibrations per second. Finally the sensitivity of the individual to the intensity of the sound energy which reaches the auditory nerve is a factor in determining loudness.

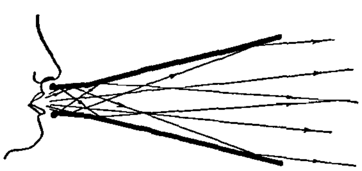
Fig. 38.12. A megaphone.

Since sound waves tend to spread out in all directions, often much of the energy is wasted because it does not travel to the place where it is needed. Consequently, devices are sometimes used to prevent the sound energy from spreading out and to direct it to a definite place. A megaphone is a simple device which is used at football games to direct the energy of the cheerleader's voice to the people in the various sections of the stadium. Speaking tubes in offices and apartment houses serve the same purpose. A doctor uses a stethoscope to direct the sounds from the body cavity to his ears. The earpieces also prevent other sounds from entering his ears and thus it is easier to hear the sounds which are traveling up the tubes of the stethoscope.

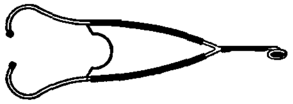
Fig. 38.13. A stethoscope.

It is of course impossible to measure the loudness of a sensation because the sensitivity of the ear and the mental state of the person at the time enter into such a measurement. But the intensity of the energy reaching the ear can be measured. The apparatus known as a *loudness-level meter* or sometimes as a *noise meter* or an *applause meter* is essentially a microphone that receives the sound energy and converts it into electrical energy which operates a sensitive galvanometer. The instrument is calibrated to read in decibels.

A decibel (0.1 bel) is approximately the smallest difference in intensity which the average ear can detect. Between the threshold of hearing (the lowest intensity to which the ear responds) to the greatest intensity which the ear interprets as sound and not pain, the average person can distinguish about 130 steps in intensity; in other words, the hearing range covers about 130 decibels. The following table gives some relative ratings for the intensities of sounds.

	DECIBELS
Threshold of pain	130
Boiler factory	100
Train in subway	95
Loud music in house	80
Noisy café	70
Noisy office	60
Ordinary conversation	55
Average office	50
Quiet office	40
Average residence	30
Average whisper	20
Country highway	15
Rustle of leaves	10
Threshold of hearing	0

Figure 38.14 shows the sensitivity of the ear to sounds of varying intensity and frequency. From this chart it is evident that of two sounds of the same intensity one may be audible and the other inaudible because of the difference in frequency. Data for such a chart are obtained by having a person listen to sounds of various frequencies and in each case noting the intensity of sound energy required at the lower limit for audibility and at the upper limit for pain. The area included in the auditory range tends to decrease as a person grows older.

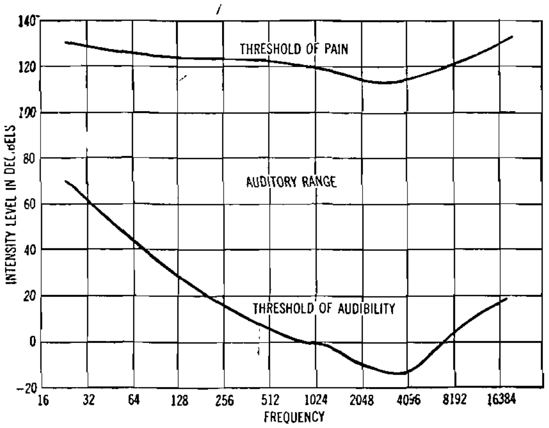

Fig. 38.14. Showing the sensitivity of the ear to sounds of varying intensity and frequency.

Another interesting feature of the loudness-level meter is that it can be adjusted to respond to the total energy, a purely physical measurement, or it can be adjusted to respond as the average human ear would respond; i.e., it is then adjusted to respond to frequencies between 16 and 20,000 vibrations per second with the greatest sensitivity at about 2000.

STUDY QUESTIONS

1. What causes a sound wave?
2. How is sound energy transferred?
3. After a flash of lightning, the thunder may not be heard for several seconds. Why? After the thunder starts it may last for several seconds. Why?
4. Why does a sore throat sometimes affect the hearing ability?
5. What causes echoes in buildings? How may they be prevented?
6. The floor in an office was formerly covered with a heavy carpet. Now it is covered wtih linoleum. Is this change a help in decreasing the noise in the room?
7. Why are flat walls better than curved walls in an auditorium?
8. Why should a music hall have a longer period of reverberation than a classroom?
9. Explain what is meant by a difference in loudness of 1 decibel.
10. What are the factors that limit the auditory range?

PROBLEMS

1. How long does it take for sound to travel 10 miles if the temperature of the air is 20°C? *Ans.* 47 sec
2. If a steam whistle is heard 5 seconds after the escaping steam is first observed, how far away is the whistle? The temperature of the air is 25°C.
3. If it takes sound 10 seconds to travel a given distance in air, how long will it take to travel the same distance in sea water? *Ans.* 1.96 sec
4. How much is the time required for sound to travel 10 miles in air reduced when the temperature rises from 10°C to 30°C?
5. What is the frequency of a sound if its wave length is 3 feet on a day when the temperature is 15°C? *Ans.* 372 vps
6. What is the length of the sound wave which has a frequency of 400 vibrations per second? The temperature is 15°C.
7. What is the velocity of sound if a fork which has a frequency of 256 vibrations per second has a wave length of 4.4 feet. What is the temperature of the air? *Ans.* 1126.4 ft; 19.7°C
8. What is the velocity of sound if a fork with a frequency of 512 vibrations per second has a wave length of 0.65 meters? What is the temperature of the air?

39

MUSICAL SOUNDS AND MUSICAL INSTRUMENTS

Sounds may be divided into two classes — *noises and musical sounds.* Noises are usually thought of as disagreeable sounds; they may be loud, sudden, startling, and are a mixture of irregular vibrations. A musical sound is agreeable, and the vibrations occur at regular intervals. If a door slams, a dish crashes on the floor, a wagon rolls along a pavement, or thunder rumbles in the sky, the result is a noise. But if a key on a piano is struck, the vibrations are sustained and regular, and the result is a musical note.

245. Characteristics of a Musical Sound. Sound sensations differ from each other in three characteristics: *pitch, loudness,* and *quality.* The differences are determined by the physical properties of the sound wave, the distance between the sounding body and the ear, the intervening medium, and the ability of the ear to respond to the energy which reaches it.

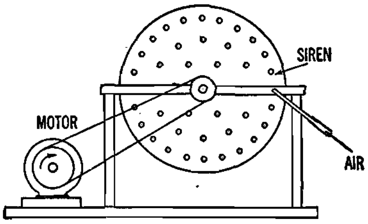

Fig. 39.1. A siren.

246. Pitch. *The pitch of a sound is the auditory sensation which is determined by the frequency of the vibration.* The relationship between pitch and frequency may be demonstrated with the aid of a siren. A siren consists of a disk mounted in such a way that it may be rotated at any desired speed. The disk has holes uniformly spaced in concentric rings. If a column of compressed air is directed against the disk while it is in rotation, a puff of air passes through each hole. If the number of puffs per second is increased by turning the disk more rapidly, the frequency of the sound is increased, and the pitch becomes higher. The distances between the holes in the different rings vary, and since the linear velocity varies as the radius, almost any frequency may be obtained by choosing one or another ring, or by varying the rate of rotation. If the number of puffs per second is twice as great in one case as in another, the frequency of the sound and the resulting sensation of pitch is twice as great for the first case. The greater the frequency, the higher the pitch.

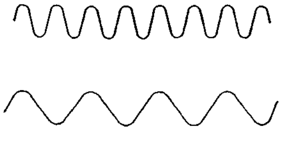

Fig. 39.2. Variation in frequency.

247. The Doppler Effect. The pitch seems to vary if the distance between the person and the source of the sound is changing. All have noticed the change in pitch of a locomotive whistle or automobile horn as it passes by. If an electric buzzer is swung around in a circle so that it alternately approaches and recedes from the ear, a rise and a fall in pitch are noticed for each revolution. Since the pitch of any sound is determined by the number of vibrations reaching the ear per second, it is evident that, as a locomotive or a car approaches, the ear receives an increasing number of sound waves per second, but if the source is receding from the ear, fewer waves reach the ear per second. *When the distance between the source of sound and the ear is decreasing, the pitch is raised, and when the distance is increasing, the pitch is lowered.* This is known as the *Doppler effect.*

248. Loudness. The loudness of a sound sensation has been discussed in the preceding chapter. It is determined by the amplitude of the sound wave, the distance from the source to the ear, and the intervening medium — all of which enter into the intensity of the sound energy which reaches the ear, the frequency of the vibration, and the sensitivity of the ear.

249. Quality. Sound waves which have the same frequency and intensity may differ in the complexity of their vibrations and thus produce very different sensations in the ear. A sounding body seldom produces a vibration of one frequency only. In addition to the fundamental or vibration of lowest frequency there may be one or more overtones. The frequency which is twice the fundamental is known as the *first overtone.* The frequency which is three times the fundamental is the second overtone. The number of overtones present and the resulting complexity of the sound depend on the nature of the vibrating body and on the way in which the body is set into vibration.

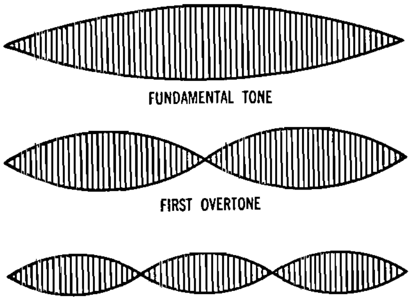

Fig. 39.3. Fundamental and overtones.

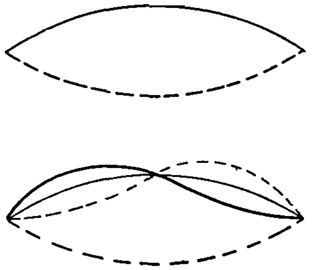

Fig. 39.4. Strings may vibrate as a whole and in parts at the same time.

The number of overtones produced by a violin string varies with the position at which it is bowed; if a violin and a piano both sound middle C there is no difficulty in distinguishing one from the other because of the differences in the overtones. The sound emitted by a horn for any given note depends upon the way the musician blows it. One voice differs from another singing the same note at the same loudness, because of the differences in the vocal cords and resonance cavities of the two singers, and the kind of training they may have received. The ear receives these complex sounds and detects differences which are not due to either pitch or loudness. *The differences in sound sensations which are due to the number and distribution of overtones are differences in quality.*

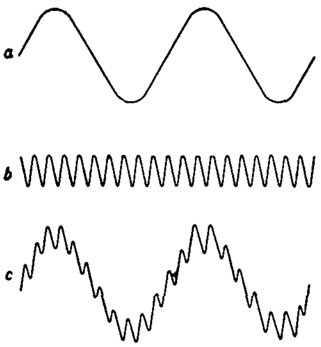

Fig. 39.5. Combination of two sound vibrations.

a = the fundamental
b = an overtone of higher frequency
$c = a + b$.

250. Resonators. A vibrating body may cause another body near it to vibrate if the second body has the same natural period of vibration. This is because energy from the first body is transferred to the second body by means of the sound waves. Such bodies are said to be in *resonance* or in *sympathetic vibra-*

tion. Suppose two tuning forks of the same frequency are mounted on wooden boxes which are open at one end, and of such dimensions that the air columns within the boxes have the same period

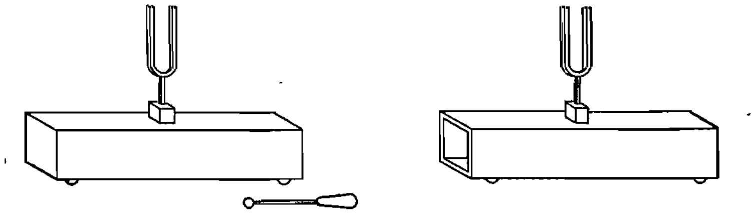

Fig. 39.6. Resonance or sympathetic vibration.

of vibration as the forks. If one of the two forks is set in vibration, the other soon begins to vibrate. If the first fork is stopped, the other one continues to vibrate for a time. Part of the energy of one column of air has been transferred to the other and from there to the second fork. Without the boxes the energy from the first fork which reaches the second fork is not sufficient to start the second fork vibrating. If unlike forks are used, the second fork does not pick up energy from the first. If a note is sung into a piano while the loud pedal is down, the string of corresponding frequency is set in vibration. Sometimes other objects in the room are set in vibration when certain notes are sounded on an instrument. A vase may be set in vibration or a panel of wood in a door may respond sympathetically because it has the same natural frequency of vibration.

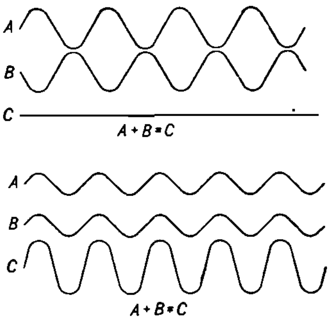

Fig. 39.7. Two sound waves of the same frequency may either cancel or reinforce each other.

251. Beats. Two sound waves may unite in such a way as either to reinforce or to destroy each other. If two mounted tuning forks of the same pitch are placed side by side and struck with a soft mallet, they give a steady sound. But if the pitch of one fork is changed

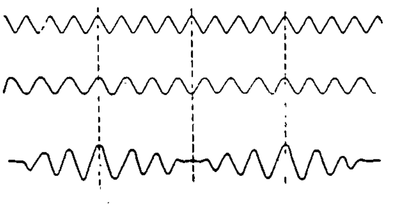

Fig. 39.8. Showing the cause of beats.

slightly by putting a rider on it, a throbbing or variable sound results. The rider has lowered the pitch of the second fork; therefore the two sets of vibrations are sometimes in step and sometimes out of step. The throbbing sounds are called *beats. Beats are caused by the interference of sound waves of slightly different frequencies.*

252. Musical Scales. The harmony or discord resulting from the combination of two or more tones depends upon the ratio of the frequencies. If the frequencies form simple ratios such as 1:2, 1:3, 2:3, 3:4, 4:5, and 5:6 the result is harmonious. For example, the frequency of middle C is 256 vibrations per second; the frequency of E (above middle C) is 320 vibrations per second. These frequencies are in the ratio of 256:320 or 4:5 and therefore are a harmonious combination. But the frequency of D (above middle C) is 288 vibrations per second and the ratio of 256:288 or 8:9 is not a simple ratio, and the combination is not pleasing. When the frequencies of two notes are in the ratio of 1:2, they are said to be one *octave* apart. Middle C has a frequency of 256 vibrations per second. The C one octave above has a frequency of 512 vibrations per second and the C one octave below has a frequency of 128 vibrations per second. The piano has a range of eight octaves, while the average human voice has a range of less than two octaves.

It has been found that the ear recognizes as most harmonious those combinations of notes whose frequencies are proportional to any of the numbers 1, 2, 3, 4, 5, and 6. Any combination or rapid succession of frequencies which do not have simple frequency ratios produces a discord. If the frequencies are in the ratio of 4:5:6, the notes form what is called a *major triad*, and if they are played simultaneously, they form a *major chord*. If the frequencies are in the ratio of 10:12:15, they form a *minor triad* or a *minor chord*, which is a little less harmonious than the 4:5:6 combination. If the ratios 4:5:6 and 10:12:15 are compared, it will be noted that 4:6 is the same as 10:15 but the difference is in the middle note — 4:5 is not the same as 10:12. Any note may be chosen for the first note of the triad and the ratios built up as explained above.

A major scale is one in which the 1st, 3rd, and 5th notes form a major triad; also the 4th, 6th, and 8th, and the 5th, 7th, and 9th notes form major triads. A minor scale is one in which the 1st, 3rd, and 5th notes form a minor triad.

Several different frequencies are used as the starting point for determining the frequencies of the other notes. The physicist starts with middle C equal to 256 vibrations per second. This results in E equal to 320, G equal to 384, A equal to 427, and C above middle C equal to 512 vibrations per second. Musicians use a scale based on A above middle C equal to 440 vibrations per second. This results in middle C equal to 264, E equal to 330, and C above middle C equal to 528 vibrations per second.

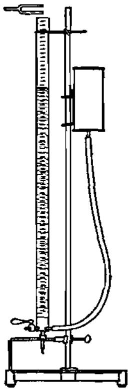

Fig. 39.9. The tuning fork is the generator and the air column is the amplifier.

253. Musical Instruments. Of all the sounds that reach the human ear a certain proportion come from some kind of musical instrument, and of all the pleasing sounds that come to the ear those from musical instruments form a large per cent. Musical instruments in general have two parts: the *generator* of the vibrations, and the *amplifier* which aids in transferring the energy of the vibrator to the air. Since the amplifier can give out only those frequencies which it receives from the generator, it does not add frequencies to the sound; but it does increase the audibility of the sound by increasing the rate at which energy is given out. However, as this rate increases, the duration of the vibration decreases. Consequently the amplifier is a very important part of the musical instrument.

If a vibrating tuning fork is held above a tube containing water, the height of which may be varied, the length of the air column may be adjusted until the sound from the tuning fork is amplified. Here the tuning fork is the generator, and the air column is the amplifier. If an unmounted tuning fork is set firmly against a table top, the sound is amplified, because the table top is forced into vibration by the motion of the fork handle. When a piano key is struck, the string corresponding to it is set in vibration, but a large part of the sound which comes to the ear is the result of the amplification by the sounding board.

Musical instruments may be divided into four main groups according to the physical characteristics of the vibrating source. These groups are (*1*) *vibrating strings*, (*2*) *vibrating rods*, (*3*) *vibrating columns of air*, and (*4*) *vibrating membranes or plates.*

Vibrating Strings. A string that is tightly stretched between two supports may be set in vibration (1) by bowing it as on a violin, (2) by striking it with a hammer as on a piano, or (3) by plucking it as on a harp, banjo, or mandolin. If a string is stretched between two supports and a sliding bridge is placed under it, the length and tension of the vibrating part may be regulated. Careful experiments with this apparatus, which is called a *sonometer*, prove certain rules. (1) The vibration frequency varies inversely as the length of the vibrating string. Thus the pitch is increased as the length of the string is decreased. (2) The vibration frequency varies directly as the square root of the tension. Thus if a string gives 100 vibrations per second when under a tension of 9 pounds, it gives 200 vibrations per second when under a tension of 36 pounds. (3) The vibration frequency varies inversely as the square root of the mass per unit length of the string. The strings which give the bass notes in a piano are wound spirally with wire to get the necessary mass. The number of vibrations per second may be found by

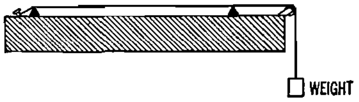

Fig. 39.10. A sonometer is used to illustrate the laws of vibrating strings.

$$n = \frac{1}{2l}\sqrt{\frac{t}{m}}$$

where l = length of the vibrating segment
t = tension in the string
m = mass per unit length

The piano and harp have many strings, and each string gives but one note. The size and length of the strings are determined when the instrument is made, and the tension is adjusted when the instrument is tuned. The violin, mandolin, guitar, and banjo have few strings, and each string is made to give a large number of notes by pressing on it at various places and thus changing the length of the vibrating segment. Thus, with only a few strings of varying sizes, a wide variation of frequencies is possible.

If a string is struck, bowed, or plucked near one end, it gives out more overtones than if it is bowed in the middle; thus the quality of the tone is improved. In a piano the strings are struck one-seventh of the length of the wire from the end. On a violin, bass viol, or mandolin the bowing or plucking is always done near one end of the string.

The sounding board is an important part of any stringed instrument, because the sound given out by the strings alone lacks volume; i.e., the energy is given out too slowly. In an upright piano the sounding board is in a vertical position; in a grand piano it lies horizontally. Since an upright piano is usually placed against a wall and is more or less closed in, there is less opportunity for the free movement of the waves than there is in a grand piano, especially if the cover of the grand piano is raised. In a violin or guitar the bridge rests on a thin sheet of wood, which is a sounding board. The front sounding board is connected to the back sounding board by means of a sounding post. The two form what is called the *sounding box*. When a string vibrates, the sounding box is set in vibration, and the quality of the resulting tone is determined by the number of overtones present, their relationship to the fundamental tone of the string, and their relative amplification. The shape and the quality of the material of the sounding box help to determine the quality of the sound.

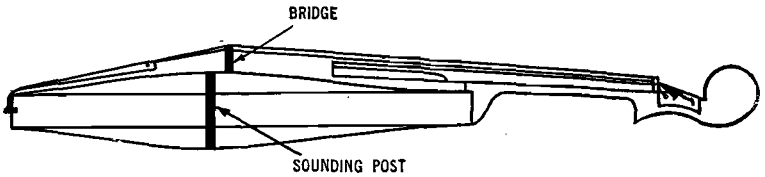

Fig. 39.11. A violin.

The intensity of the sound varies with the force applied to the string in setting it in vibration. On a piano the key may be struck gently or sharply. The pedals also vary the distance of the hammers from the wires and therefore regulate the force with which the hammers strike. In the case of stringed instruments which are bowed or plucked, the amplitude is determined by the force applied by the bow or the fingers.

Vibrating Rods. A tuning fork is the simplest example of a vibrating-rod instrument. The rod is bent into a U shape, and a handle is fastened at its mid-point. When a fork is set in vibration, the prongs move back and forth. As the prongs move apart, the mid-point of the fork rises; as the prongs move together, the mid-point of the fork falls. When held in the hand, the fork makes very little sound even though it is struck sharply, but if the handle is placed firmly against a table top, the vibrations set up in the table top amplify the sound. If the fork is mounted on a box of the proper dimensions, its sound is amplified.

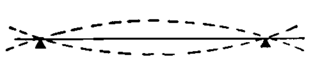

Fig. 39.12. Vibration of a rod.

A xylophone consists of bars of wood or metal of various lengths, resting upon two supports at points which are one-sixth of the length of the rod from the ends. When the bars are struck at their mid-points, they vibrate as shown in Figure 39.12. In a marimba each bar is mounted over a resonator to reinforce the sound.

The reed of a musical instrument is a thin bar clamped at one end and free at the other end. It vibrates in the same way as one prong of a tuning fork. The frequency of vibration may be increased by shortening the reed or by reducing its cross section at its free end. The frequency may be decreased by loading the free end or by reducing the cross section near the clamped end. In reed instruments, such as oboes, clarinets, harmonicas, reed organ pipes, and accordions, the reeds are set in motion by a jet of air.

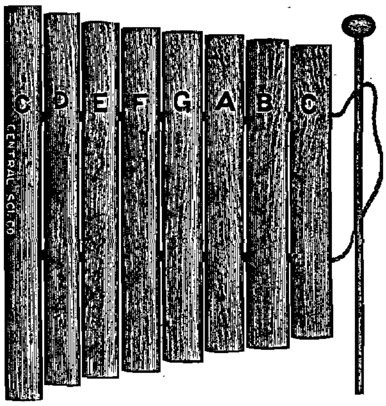

Fig. 39.13. A xylophone. (Courtesy Central Scientific Co.)

Vibrating Columns of Air. Some of the musical instruments which make use of vibrating columns of air are the pipe organ, flute, clarinet, cornet, and trombone. In these instruments the vibration takes place along the length of the vibrating medium instead of transversely as in a string.

The use of an air column as a resonator or amplifier has been explained. An organ pipe is such a resonating column of air which is set in vibration when a jet of air strikes the vibrator at the bottom of the pipe. There are two methods of producing the vibrations. The jet of air may strike an edge of the opening as in a whistle, or it may strike a thin strip of metal which acts as a reed. The pipe may be either closed or open. In a closed pipe there is always a place of minimum motion of the air at the closed end, and a place of maximum motion at the open end. In an open pipe there is a place of maximum motion at each end. See Figure 39.14 for diagrams of closed and open pipes. The pitch of any given pipe is determined by its length. Long pipes emit low notes; short pipes emit high notes. This rule holds for both open and closed pipes.

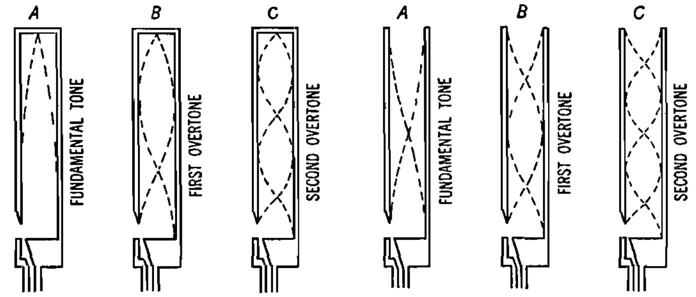

Fig. 39.14. Diagrams of closed and open organ pipes.

By blowing harder on a pipe one may make it give out overtones, and thus improve the quality of the sound. It may be shown that an open pipe is capable of producing twice as many overtones as a closed pipe, and therefore it can give a richer sound. The material and shape of the pipe also help to determine the overtones; certain tone qualities are characteristic of certain types of pipes. A wood pipe sounds different from a copper pipe of the same dimensions. A round pipe sounds different from a rectangular pipe.

In a flute or clarinet the length of the pipe is varied by openings along the length of the pipe which are controlled by the fingers. This is equivalent to cutting off the tube at that particular opening. In a cornet the length of the air column is varied by means of pistons or valves. In a trombone the length of the air column is varied by sliding a portion of the tube in and out. In the wind instruments mentioned in this paragraph the vibration of the air column is caused by the vibration of the lips of the performer.

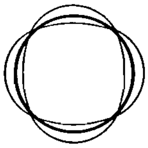

Fig. 39.15. Vibration of a bell.

Since the velocity of sound varies with changes in the temperature, the pitch of a pipe changes with changes in temperature; an increase in temperature results in an increase in pitch. An organ should be tuned when the temperature is the same as it will be when the organ is played. A musician who plays a pipe instrument must be sure that his instrument has reached room temperature before the concert starts. The intensity of the sound depends upon the force with which the air is sent into the instrument, and the quality depends upon the material of the instrument, the shape of the horn, the diameter of the tube, and the shape of the mouthpiece, as well as the ability of the musician.

Vibrating Plates and Membranes. Gongs and cymbals are vibrating plates. The pitch of the sound emitted depends on the area and thickness of the plate. A bell vibrates in quarters; thus the edge of the bell takes elliptical shapes which are alternately at right angles to each other. (See Fig. 39.15.) Vibrating membranes are found on tambourines and drums; a tambourine has only one membrane, but a drum has two with an enclosed volume of air between. The top membrane is set in vibration and the energy is transferred to the lower membrane by the intervening air. The kettle drum is the only drum which has a variable tone. It must be tuned to the key in which the orchestra is playing. The tuning is done by means of setscrews around the "head" of the instrument.

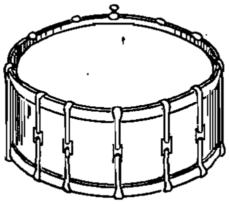

Fig. 39.16. A drum has two vibrating membranes.

254. The Human Voice. The most extraordinary musical instrument of all is the human voice. The voice mechanism (larynx) is located at the top of the trachea and is commonly referred to as the *Adam's apple.* Sounds are produced by two thin membranes, one on each side of the throat, called *vocal* *cords*, and by the vibration of the tongue and lips. In breathing the vocal cords are not under tension, but in speaking the muscles bring the cords nearly together, and the air which is forced through the narrow opening (the glottis) causes the cords to vibrate. By changing the muscular tension one may change the pitch of his voice, though any one person has a normal speaking pitch which he unconsciously uses. A person is said to have a high-pitched voice or a low-pitched voice if his pitch varies much from the average. The loudness of the voice depends upon the force with which the air is forced through the opening between the membranes. The quality of the voice is determined by the membranes themselves, the shape of the mouth cavity, the position of the lips, the nasal cavities, and the method of breathing. A person may learn to improve the quality of the voice by learning to control the muscles of the throat and by breathing properly, but the shape of the voice box and membranes is probably the most important factor in a good voice, and no amount of training will result in a rich voice if the physical structure of the throat and nose is not right.

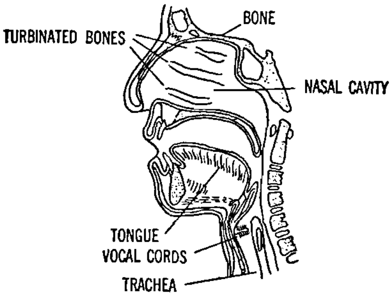

Fig. 39.17. The voice box and vocal cords.

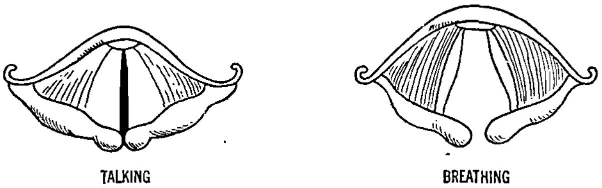

Fig. 39.18. Top view of vocal cords.

People tend to speak in higher pitched tones when excited because of the general nervous tension of the body. A person who has a high-pitched, unpleasant speaking voice may lower the pitch by learning to relax the throat muscles. The pitch of a man's voice is usually between 100 and 140 vibrations per second, and of a woman's voice between 200 and 270 vibrations per second. The range of the human voice is less than that of any other musical instrument. The average person can sing notes over a range of one and one-half to two octaves. Two and one-half octaves is a large range.

The power of the voice is small. In lifting an average-size book 6 inches one expends as much energy as he transforms into sound energy in speaking to an audience of average size for 1 hour.

STUDY QUESTIONS

1. How does a noise differ from a musical sound?
2. Does the frequency of a sound influence the speed at which the sound travels? Do the high-frequency notes of a distant orchestra reach you before the low-frequency notes of the same chord?
3. Is there a difference between "the intensity of a sound" and "the loudness of a sound sensation"? Why?
4. The lowest C string of a piano has a frequency of 64 vibrations per second. The C, three octaves above middle C, has a frequency of 2048. *If the two sounds reach the ear with the same intensity,* which will produce the louder sensation in the ear?
5. What are some of the factors that influence the quality of a sound?
6. Which one of the three factors — pitch, loudness, and quality — enables one to distinguish one orchestral instrument from another, or one person's voice from another?
7. What is resonance?
8. What is the result if two sound waves of slightly different frequencies are combined?
9. How may you determine mathematically whether two vibrations will produce a pleasing effect if combined?
10. If middle E has a frequency of 320 vibrations per second, what is the note that has a frequency of 1280?
11. What are the two main parts of any musical instrument? What is the function of each part?
12. As a violinist tightens a string on his instrument is he increasing or decreasing the pitch?
13. How does the vibration frequency of a string vary with the length?
14. How are piano wires tuned?
15. Why is a grand piano preferable to an upright piano for a large room?
16. Why does the loudness of the sound from a tuning fork increase when the fork is set on a table top?
17. Why do the various bars of a xylophone vibrate with different frequencies?
18. How does the sound from an open organ pipe differ from that from a closed pipe?

19. How may overtones be produced in a pipe?
20. Why is it important that a musical instrument reach room temperature before it is tuned?
21. Is there any part of a gong which remains stationary while it is sounding?
22. Explain how a person may temporarily change the pitch of his voice.
23. Can a person make any permanent change in the pitch of his voice?

PROBLEMS

1. If the frequency of C is 128 vibrations per second, calculate the frequencies of E and G in the major chord CEG. *Ans.* 160 vps; 192 vps
2. If the frequency of F is 1365 vibrations per second, calculate the frequencies of A and C in the major chord FAC.
3. If the frequency of F is 341.3 vibrations per second, calculate the frequencies for A♭ and C in the minor chord FA♭C. *Ans.* 409.6 vps; 512 vps
4. If the frequency of G is 384 vibrations per second, calculate the frequencies for C and E♭ in the minor chord CE♭G.
5. A given string which is 60 centimeters long is vibrating at 384 vibrations per second. What is its frequency if the length is decreased to 20 centimeters? *Ans.* 1152 vps
6. A given string which is 40 centimeters long is vibrating at 440 vibrations per second. If the frequency is to be raised to 880 vibrations per second, what length will be necessary?
7. If the frequency of a string is 320 vibrations per second when the tension is 16 pounds, what is the frequency when the tension is increased to 36 pounds? *Ans.* 480 vps
8. If the frequency of a string is 300 vibrations per second when the tension is 9 pounds, what tension will be required to raise the frequency to 500 vibrations per second?

40

ELECTRICAL SOUND DEVICES

In the preceding chapter a number of sound instruments were discussed which were grouped together as musical instruments since they are used in producing musical tones. This chapter explains numerous electrical devices which have been developed to aid in (*1*) *increasing the loudness of sounds*, (*2*) *transmitting sounds*, and (*3*) *reproducing sounds at places far distant from the sound source.* The telephone is used to transform sound energy into a pulsating electrical current which can be sent across the country and then used in a receiver to produce vibrations which correspond to the vibrations of the original sound. In other words the receiver substitutes for the original speaker. The public-address system makes it possible for a person to speak in his usual tone of voice and yet be heard distinctly in all parts of a large auditorium; or if the person is speaking or singing out-of-doors, the sound of his voice may reach people who are several blocks away. Miniature public-address systems called *hearing aids* may be used by people whose sensitivity to sound energy has been impaired. Others of these electrical sound devices are used to transform sound energy into electromagnetic wave energy, which travels out through space, where it may be absorbed by a suitable receiver and transformed again into sound energy, i.e., the radio broadcasting system. The development of the vacuum tube has made possible the public-address system, the radio, and countless other marvels of the twentieth century.

255. The Telephone. A simple telephone system consists of two microphones and two receivers with electrical energy furnished by a suitable battery.

The Microphone. The microphone used in a telephone consists of a diaphragm and a small box containing granular carbon through which an electric current flows. (See Fig. 40.1.) When sound waves meet the diaphragm, it vibrates and causes a variable pressure on the granular carbon; thus it changes the resistance of the circuit of which the microphone is a part, and as a result a variable current flows in the circuit. The voice energy does not generate an electric current — that is furnished by the battery — but it does cause variations in the current which are characteristic of the voice.

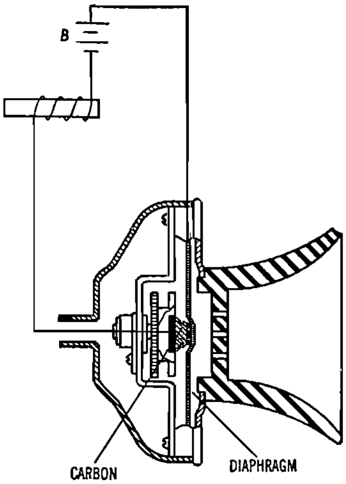

Fig. 40.1. A telephone transmitter or microphone.

The Receiver. The ordinary telephone receiver (see Fig. 40.2) contains a U-shaped permanent magnet *M* which is wound with many turns of fine wire at each pole. A diaphragm *D* of thin steel is mounted so that its center does not quite touch the poles of the magnet, but it is attracted by the magnet and thus is under a constant slight strain inward. When the variable current from the microphone flows in the wire around the poles of the magnet, the strength of the magnetic field varies. Thus the force acting on the diaphragm of the receiver varies, and causes it to vibrate. The permanent magnet is used because the diaphragm responds more accurately to the slight changes in the magnetic field if it is already in a strong magnetic field and

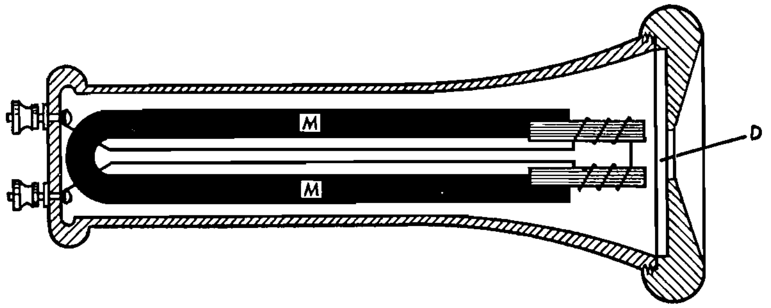

Fig. 40.2. A telephone receiver.

under tension. This mechanism is enclosed in a hard rubber case with a small hole, in the earpiece which allows the vibrations caused by the diaphragm to be transmitted to the eardrum by means of the intervening air. The modern telephone has the transmitter and receiver in one unit, but the basic principles of operation are the same as explained above. The magnet in the receiver is C-shaped.

A Two-Party Telephone System. The sending and receiving apparatus for two parties only is shown in Figure 40.3. Party X speaks into the transmitter *T*, and the vibration of the diaphragm causes a variable direct current to flow through the coil *P* which has but few turns of wire. As a result, an alternating current of higher voltage is induced in the coil *S* which has many turns of wire. This alternating current travels along the line to receiver *R'* which party *Y* is holding to his ear, and alternately strengthens and weakens the poles of the permanent magnet in the receiver. This results in a variable magnetic field through the diaphragm which causes it to vibrate.

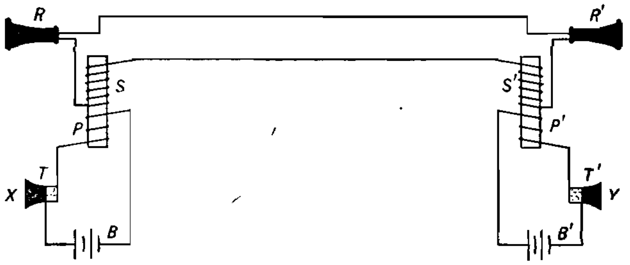

Fig. 40.3. A two-party telephone system.

The ringing device for calling central or another party is not shown, but when the receiver is in its cradle the circuit shown in Figure 40.3 is open, and the line is connected to the ringing device. In large cities battery systems are not practical because of the difficulty of keeping so many batteries in working order. Instead, a large central generator is used which furnishes current to all of the phones of the system.

The above description of a telephone system is simplified to give the fundamental idea of transmission of sound by means of electricity. The modern telephone system, with its dialing apparatus and electronic controls, is far beyond the scope of this book.

256. Vacuum Tubes. In 1883, Edison, in trying to improve his electric lights, made a discovery which at the time seemed to have no particular significance but which since has proved to be the basic principle of vacuum tubes used in public-address systems, radio, television, movies, telephones, and many other devices.

Edison put a metal plate as well as the filament into his light bulb and then evacuated the bulb. The filament was heated by means of a battery *A* as shown in Figure 40.4. Another battery *B* and a galvanometer *C* were connected in series between the plate *P* and the filament *F*. This tube did not have the grid *G* shown in Figure 40.4. When he heated the filament and had the plate *P* connected to the positive side of the battery, a current was indicated by the galvanometer. But if the plate *P* was connected to the negative terminal of the battery, no current was indicated by the galvanometer. Since the addition of the plate did not improve the light, Edison made note of his discovery and went ahead with other methods for improving his electric lamps.

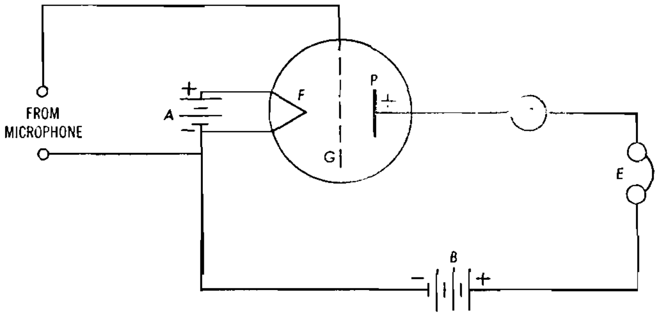

Fig. 40.4. A three-element vacuum tube or triode.

Now we know that when the filament is heated electrons are emitted which form a cloud around the filament and develop a space charge which eventually stops the emission of more electrons. But if the plate *P* is introduced and made positive, the electrons are attracted to it and a current results. If *P* is made negative, it repels the electrons and there is no current. The number of electrons which leave the filament in a second depends on the kind of material of which it is made and its temperature.

The number may be increased by raising the temperature. The speed with which the electrons travel to the plate may be increased by increasing the voltage between F and P. This basic idea of the vacuum tube is now known as the *Edison effect* in honor of the scientist who first discovered it. Later a third electrode was added to the tube in order to control the number of electrons passing from the filament to the plate. This third electrode is the grid G in Figure 40.4. The effect of the grid is like a shutter which, opening and closing, controls the flow of electrons from the filament to the plate. If the grid is positive it increases the flow of electrons, and if it is negative it repels the electrons and decreases the flow to the plate. As the current varies, a change in sound results in the earphones E. In the next section we shall see how a current generated by the voice may be connected to the grid to control the flow of electrons, and consequently to control the current to a loud-speaker.

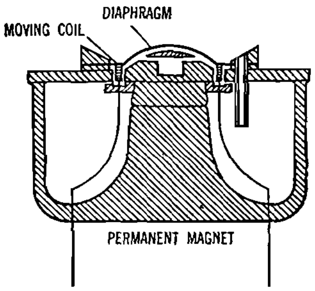

Fig. 40.5a. A moving coil microphone of the type used in a public-address system or in a radio broadcasting station.

257. The Public-Address System. When one speaks into the microphone of a public-address system, the energy of the voice generates an electric current which is amplified and then sent to the loud-speaker, which reproduces the sound.

The Microphone. The microphone which is used in a public-address system or in a radio broadcasting station must be one which will aid in careful reproduction of tone quality. One type which may be used contains a permanent magnet, a sensitive diaphragm, and a small coil of wire, as shown in Figure 40.5a. As the diaphragm vibrates, it causes the small coil of wire which is fastened to it to move back and forth in the strong magnetic

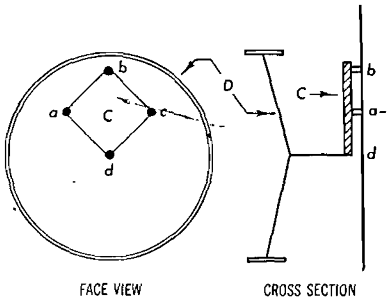

Fig. 40.5b. A crystal microphone of the type used in a public-address system or in a radio broadcasting station.

field of the permanent magnet. Consequently a current is generated in the coil. In this microphone the energy of the voice is used to move the coil and thus generate the current, which varies as the voice does — or in other words, carries the characteristics of the voice. Another type of microphone consists of a diaphragm D and a crystal C mounted as shown in Figure 40.5b. The crystal chosen is one which develops a potential difference between certain surfaces when it is deformed by bending. Points a, b, and c are permanently fixed, but d is fastened to the diaphragm. Thus, when the diaphragm vibrates, the crystal is subjected to a variable force which bends it, and the potential difference which results is applied to the amplification system. As in the first type the output current carries the characteristics of the voice.

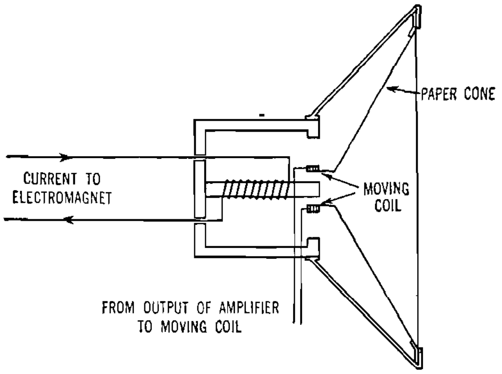

Fig. 40.6. The loud-speaker.

The Amplification System. The variable current from the microphone is connected to the grid of the vacuum tube, where it imposes its characteristics on the current from the filament to the plate. The filament is heated the desired amount by changing the volume control. Consequently, the current in the plate circuit is like the voice current but stronger; this current goes to the loud-speaker.

The Loud-Speaker. The loud-speaker contains either a permanent magnet or an electromagnet which acts on the small moving coil as shown in Figure 40.6. When current from the amplifier flows through the moving coil, the coil is attracted to the magnet, the amount of the movement depending on the strength of the current through its windings. This movable coil is fastened to the apex of a paper cone; the coil and cone form a light-weight vibrator, which responds to a large range of frequencies. When the paper cone vibrates, it causes the air in front of it to vibrate, and thus the energy is transferred to the people in the audience. To be successful, such a system must be able to reproduce sounds over a wide range of frequencies without distortion.

258. Hearing Aids. A person whose sensitivity to sound energy has been impaired by accident, illness, or increasing age often cups his hand back of his ear in order to increase the amount of sound energy entering his ear. The early-day ear trumpet served the same purpose and in addition helped to keep unwanted sounds from reaching the ear, much as a doctor's stethoscope does.

One of the earliest electrical hearing aids, first made about 1930, was essentially a miniature telephone system consisting of a carbon microphone, a receiver, a battery, and a small rheostat to control the amplification. These instruments could furnish sufficient amplification, but the tone quality was not satisfactory.

A later type of hearing aid, introduced about 1936, is essentially a miniature public-address system, with small vacuum tubes furnishing the means for amplification. These instruments usually reproduce speech more uniformly over a wider frequency range and are more free from objectionable inherent noises than the carbon microphone aids.

A more recent type of hearing aid (1953) uses a transistor for amplification. While a discussion of transistors is beyond the scope of this text, it is interesting to note that the current required for operation is decidedly less for this type of hearing aid. Therefore smaller batteries may be used and the bulk of the instrument is consequently reduced. Also the cost of operation is decreased.

Any of these hearing aids may be used as air-conduction or as bone-conduction instruments, depending on the need of the user. Air-conduction is more generally used, since it requires less power than bone-conduction; but if sound energy cannot be transferred through the middle ear to the inner ear, it may be transferred through the bone back of the ear. If the auditory nerve has ceased to function, a hearing aid cannot help the person to hear.

259. Radio Broadcasting and Receiving. In the public-address system the energy is transmitted from one part of the apparatus to another by wires, and all of the apparatus can be collected in one place and the circuits observed. In radio the broadcasting station may be a long way from the receiving set (your radio), yet no wires connect the two. How then is the energy transferred?

The Broadcasting Station. In the studio the sound energy is received by a microphone similar to the one used in the public-address system. The resulting variable current goes to the control room, where it is amplified and combined with the current which is used to operate the oscillator — the device which sends out the electromagnetic waves. (See Sec. 202.) In Figure 40.7 the high-frequency (500 to 1600 kilocycles per second for commercial broadcasting) carrier wave is shown, then the voice wave, and finally the modulated carrier wave which results from the combination of the carrier wave and the voice wave. When the station is on the air, the carrier wave is sent out continuously from the antenna. When sound energy generates current in the microphone circuit, a modulated carrier wave is sent out. The type of modulation shown in Figure 40.7 is known as *amplitude modulation* (AM) and is the type of modulation which is used extensively at the present time in commercial broadcasting. Another type of modulation is known as *frequency modulation* (FM). Here the voice current changes the frequency rather than the amplitude of the carrier wave.

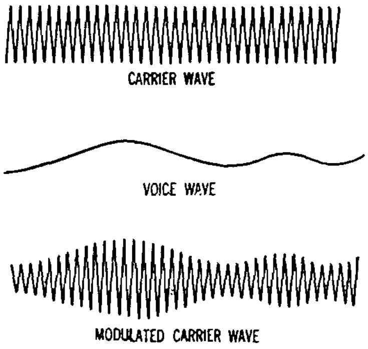

Fig. 40.7. Illustrating modulation.

The Receiving Set. The energy which is transferred from the broadcasting station by electromagnetic waves to your radio is "picked up" by the aerial. When the radio circuit is tuned to the frequency of the desired station, a high-frequency alternating current is generated in the aerial by the radio waves. Since this is a very feeble current, it is amplified by energy furnished either

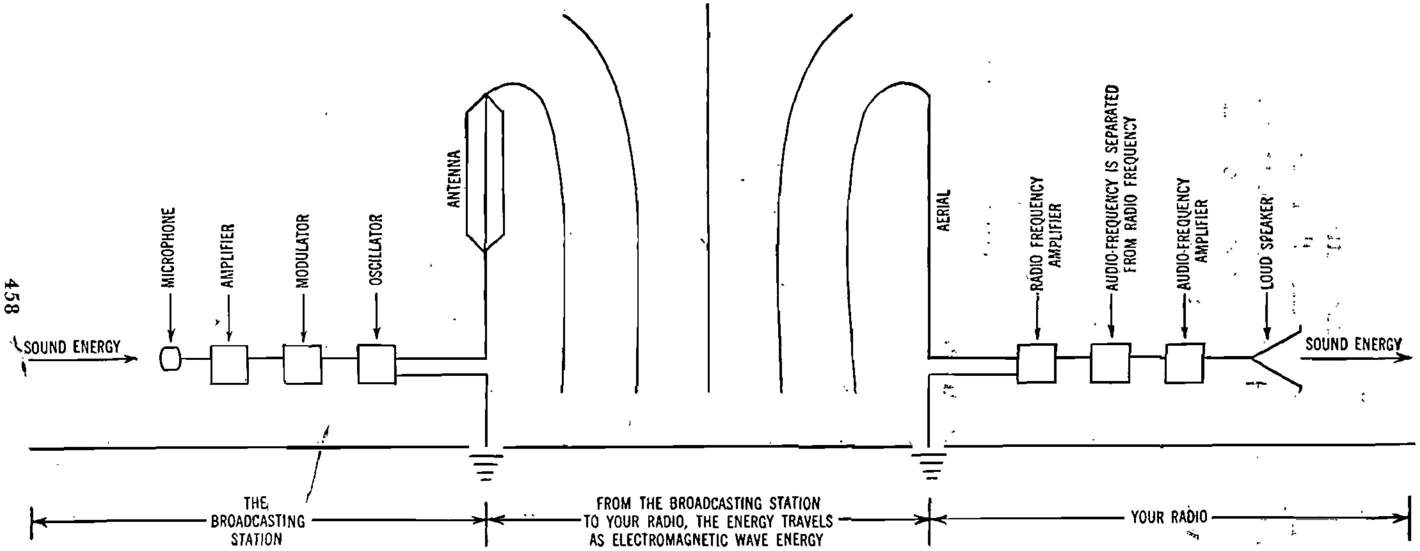

Fig. 40.8. A diagrammatic illustration of a radio broadcasting and receiving system.

from a battery or from the usual house lighting circuit. Then by means of other tubes in the radio the variations in the modulated wave are amplified, or in other words the voice current is amplified; and it is this current which flows through the small coil at the apex of the cone of the loud-speaker and causes the cone to vibrate — with the same frequencies as the sound which occurred in the broadcasting station perhaps hundreds of miles away. If instead of a loud-speaker a telephone receiver is used, the system becomes a radio telephone.

STUDY QUESTIONS

1. How does a telephone transmitter or microphone change sound energy into electrical energy?
2. How does a telephone receiver change electrical energy into sound energy?
3. How are the small changes in the current in the transmitter circuit increased for cross-country transmission?
4. How is the electrical energy for a city telephone system furnished?
5. Explain how a 3-element vacuum tube operates.
6. Explain how the microphones used in public-address systems change sound energy into electrical energy.
7. In a public-address system what is the source of the energy which is used to amplify the voice current?
8. Explain how a loud-speaker changes electrical pulsations into sound vibrations in the air.
9. In which of the following cases is the speaker's voice probably more pleasing to the audience?
   a. Medium-sized auditorium. Speaker raises his voice so it can be heard in all parts of the room.
   b. Same room, same speaker. Speaker talks in his usual tone of voice, and depends upon a good public-address system to amplify his voice.
10. Why do some deaf people have the receiver of a hearing device clamped to the head back of the ear instead of placing it in the ear?
11. What is the "carrier wave" in radio telephony or radio broadcasting? Why is it necessary?
12. How does the "voice wave" change the "carrier wave"?
13. When a person buys a radio, what part of the whole radio system is he purchasing?
14. How does amplitude modulation differ from frequency modulation?

APPENDIX

RELATIONS BETWEEN ENGLISH AND METRIC UNITS

1 yd = 0.91 m
1 mi = 1.609 km
1 km = 0.62 mi
1 sq in. = 6.45 sq cm
1 sq yd = 0.84 sq m
1 cu in. = 16.387 cu cm
1 cu ft = 0.028 cu m
1 cu cm = 0.061 cu in.
1 qt = 0.946 l
1 oz = 28.35 g
1 tsp = 5 cu cm

STANDARD CAN SIZES

	NET WEIGHT
No. 1	10 1/2 oz to 1 lb
No. 2	1 lb 2 oz to 1 lb 4 oz
No. 2 1/2	1 lb 12 oz to 1 lb 14 oz
No. 10	6 lb 4 oz to 6 lb 14 oz

NET WEIGHT PER BUSHEL OF VARIOUS FOODS *

	POUNDS
Apples	48
Beets	56
Cherries (with stems)	56
Grapes (with stems)	48
Peaches	48
Pears	50
Peas (green, in pods)	30
Plums	52
Popcorn (shelled)	56
Potatoes	60
Sweet potatoes	50
Tomatoes	56
Turnips	55
Walnuts (black)	50

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* In Kansas.

LIQUID MEASURES

1 gal = 231 cu in.
1 qt = 57.75 cu in.
1 qt = 2 pt
1 pt = 2 cups
1 cup = 16 tb
1 tb = 3 tsp

DRY MEASURES

1 bu = 4 pk
1 pk = 8 qt
1 qt = 67.2 cu in.

USEFUL FORMULAS

Circumference of a circle = $2\pi r$
Area of a circle = πr^2
Area of a sphere = $4\pi r^2$
Volume of a sphere = $4/3\,\pi r^3$
Lateral area of a cylinder = $2\pi rh$
Volume of a cylinder = $\pi r^2 h$

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