IRON AND HEAT

Beams, Pillars, and Iron Smelting

EXHIBITING IN SIMPLE FORM THE PRINCIPLES CONCERNED IN THE CONSTRUCTION OF IRON BEAMS, PILLARS, AND BRIDGE GIRDERS, AND THE ACTION OF HEAT IN THE SMELTING FURNACE

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With numerous Illustrations

Capio Lumen

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PREFACE.

This little work is intended to present in simple form the fundamental principles concerned in the construction of Iron Beams, Pillars, and Bridge Girders; and as it is designed to benefit those who are more intimately acquainted with practical operations as workmen than with the principles on which practice is based, common arithmetic only is used in the treatment of the questions; and the endeavour is, rather to explain circumstantially the rules of common use than to develop new theories.

The sections on Iron Smelting may be regarded as rudimentary, though the action of the heat, in its various operations inside the furnace, is followed up so closely, from its generation opposite the blast-nozzles, to its final escape in the molten matter and the chimney gases, that the essential conditions of the smelting process may be clearly apprehended.

The design, however, is not so much to explain the art of Iron Smelting, as simply to exhibit the action of heat upon the different materials concerned; the compass of the work being too limited to admit of more.

J. A.

Gateshead, *September*, 1870.

IRON AND HEAT.

SECTION I.

1. There is no definite beginning to the science of mechanics at all resembling in simplicity the alphabet of language; but, as we intend to limit our inquiry to simple questions relating to iron beams and pillars, the lever gives us an easy entrance to the subject, and we shall find that, right on to the end, the cases will resolve themselves into mere questions of leverage, all more or less simple; so that, to make our course clear for the end in view, we will begin by a few rudimentary illustrations of the principle of the lever.

2. Here is a Salter's balance: when we place a 14-lb. weight in the scale, the pointer simply indicates 14 lbs. We now place a thin-edged block in the scale for a fulcrum, which we letter *a*, Fig. 1, and upon this fulcrum rests a straight rod, 2 feet long, so that it rocks balanced. The 14-lb. weight suspended from one end of the rod at *b*, 1 foot from *a*, will require a force of 14 lbs. at *c*, likewise 1 foot from *a*, to balance it; but the pointer at *d* will show that the fulcrum *a* has to bear twice 14 lbs., or 28 lbs.

3. Again, using two weighing balances, Fig. 2, with a fulcrum in each, and a 28-lb. weight hung from the middle where the fulcrum is in Fig. 1, the pointers *d* and *e* indicate only 14 lbs. weight on each scale.

4. When we shift the weight to *f*, so as to make the distance *f b* equal 6 inches, and the distance *f c* equal 18 inches, the proportions of the weight borne by the scales will be 21 lbs. for *b* and 7 lbs. for *c*, because the distance *b c* is four times as great as the distance *b f*: therefore 28 lbs. divided by 4 gives 7 lbs. for *c*; and *c f* being three-fourths of the distance *c b*, we have three-fourths of 28 lbs.,

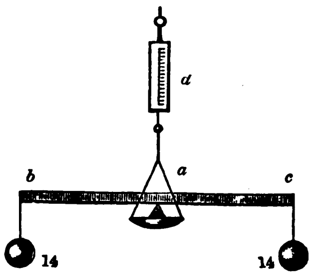

Fig. 1.

or 21 lbs. for *b*; or we may put it thus, making it a question of simple proportion, as practised in common arithmetic, when three known quantities being given, it is required from them to find the fourth quantity :—

$$b\,c : 28 :: b\,f : 7$$
$$b\,c : 28 :: c\,f : 21$$

that is,

inches.	lbs.	inches.	lbs.
24 :	28 ::	6 :	7
24 :	28 ::	18 :	21
			28 lbs.

5. If the lever in Fig. 1 be shifted along, as in Fig. 3, so that the distance *a b* equals 6 inches, and the distance *a c* equals 18 inches, we find that at *c* one-third of the 14 lbs. weight, or 4·66 lbs., will balance 14 lbs. at *b*, because *a c* is three times as long as *a b*; and that the pointer *d* indicates a pressure on *a* of 18·66 lbs. only, because

the power at *c* is only 4·66 lbs. to be added to the 14 lbs. at *b* to get the total dead weight on *a*. The power *c* acts at three times the distance of *b* from *a*, with the same balancing effect at *a* as *b* has with its shorter distance but heavier weight; but the pointer *d* can indicate only the simple weights acting vertically, without regard to the leverage that they employ in balancing each other.

6. If from *c*, in Fig. 3, we shift the power to *e*, which is the same distance from *a* that *b* is, we find that *e* requires 14 lbs. to balance *b*, and that *d* indicates 28 lbs., as in Fig. 1. At *f* the power requires to be 7 lbs. to balance *b*, because *f* is at twice the distance of *b* from *a*.

7. When we use 4·66 lbs. power at *c* to balance 14 lbs. at *b*, the lever *a c* has to bear at the point *e* a strain in its fibres equal to 14 lbs., and at *f* a strain equal to 7 lbs.

8. The pointer stands at 30 lbs.; but the 2 lbs. differ-

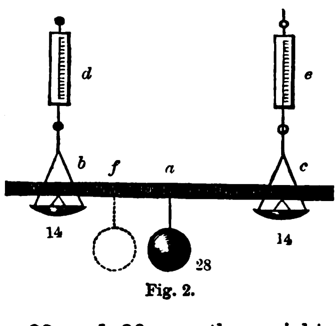

Fig. 2.

ence between 28 and 30 are the weight of the lever and fulcrum, which we leave out of account, so as to keep the forces of weight and power simple; but we may observe here that in a case of leverage like that of Fig. 3, the weight of the lever itself must be taken into account, as you will see plainly that the arm *a c* must be heavier than the arm *a b*, so that in actual practice the weight 4·66 lbs. at *c* will include the difference between the respective weights of the two arms; but we will speak of this more particularly further on.

9. In Figs. 1 and 3 the levers as drawn are what is termed of the *first* order, the fulcrum *a* being between the weight *b* and the power *c*.

10. In Fig. 2, if we make *b* the fixed fulcrum and *c* the power, with the weight between, we have a lever of the *second* order.

11. And, again, using Fig. 1, if we make *c* the fixed fulcrum, and use the weighing balance *d a* for the power, we have a lever of the *third* order.

12. Laying the scales of the spring balances aside, and using the spring cases in the manner shown in Fig. 4, one at each end of the 2-foot lever, which we place on the fulcrum *a*, so that the distance *b a* is equal to *a c*, and then wedging up the fulcrum *a* until the pointers *d* and *e* indicate a strain of 5 lbs. at the ends of the lever *b* and *c*, then, as these two strains of 5 lbs. each draw the lever downwards with a united force equal to 10 lbs., it is clear,

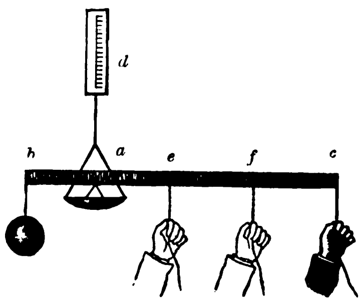

Fig. 3.

and has been proved in the case of Fig. 1, that the fulcrum *a* has that 10 lbs. to bear.

13. In explaining Figs. 2 and 3 we showed that as the length of leverage increased, so did the necessary force decrease. We will here, in few words, show that, as might

be expected, the necessary force increases as the length of leverage diminishes.

14. Let us divide *b c*, in Fig. 4, into eight equal distances, and let us keep the spring *d* where it is in Fig. 4, with 5 lbs. strain upon it as before, but shift the spring *e* to *h*.

Then, as *h* is only three divisions from *a*, while *b* is four, we find that a power of 6·66 lbs. is required at *h* to balance 5 lbs. at *b*, because 5 lbs. multiplied by four parts, *b* to *a*, equals 20, and this divided by three parts, *a* to *h*, equals 6·66 lbs.

15. Again, multiplying 5 lbs. by four parts, *b* to *a*, and

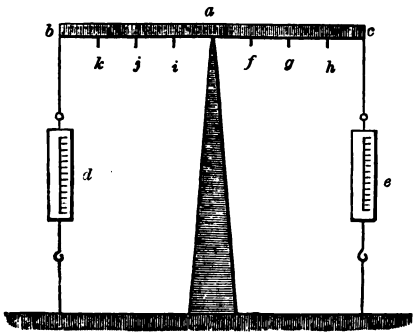

Fig. 4.

dividing by two parts, *a* to *g*, we find that 10 lbs. are required at *g* to balance 5 lbs. at *b*; and, dividing the 20 for *a b* by the one part *a f*, that 20 lbs. is required at *f* to balance 5 lbs. at *b*.

16. Let us place a 2-lb. weight, as in Fig. 5, on the outer end of the arm *a c*. You see that the pointer *e* now shows only 4 lbs. strain, while the pointer *d* has risen to 6 lbs.; that is, the arm *a c* being now 2 lbs. heavier at *c* than the arm *a b* at *b*, the spring *e* has 2 lbs. less work to do in balancing the force of the spring *d*, and as the two forces at *b* and *c* have to be balanced simply, and the lever *b c* is stiff

enough not to bend, *d*, in rising to the 6-lb. mark, allows *e* to fall to the 4-lb. mark.

17. But when we keep the lever *b c* level, as in Fig. 6,

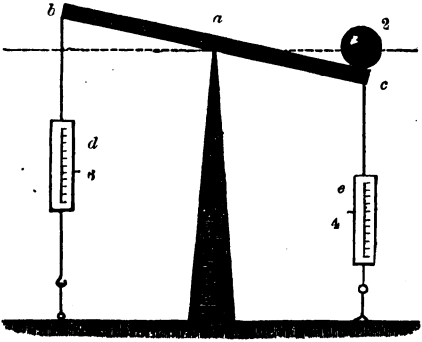

Fig. 5.

we have to pull the spring *d* down till the pointer shows 7 lbs. force, which will balance the 2 lbs. weight at *c*, in addition to the 5 lbs. force on the spring *e*.

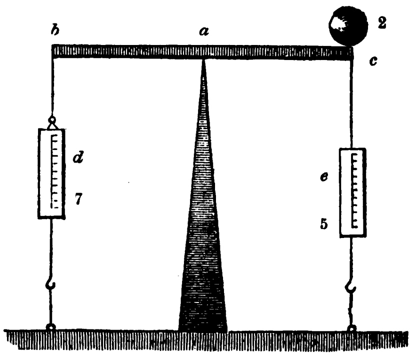

Fig. 6

18. In Fig. 5 the fulcrum *a* has to bear a load of 12 lbs. only; but in Fig. 6 it has to bear 14 lbs.

19. Instead of the springs, let us use simple weights,

as in Fig. 7, and hang 5 lbs. from each end of the lever *b c*. We now see that an addition of 2 lbs. at *c* requires a corresponding addition of 2 lbs. at *b* to preserve the balance, which causes *a* to bear a load of 14 lbs., the same as in Fig. 6.

20. In practice, the weight of the beam has to be taken into consideration in estimating the load upon the fulcrum

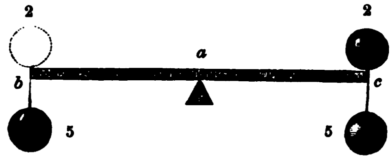

Fig. 7.

or point of support: and when the arms are unequal, the difference has to be taken into account in estimating the balancing weights.

21. In Fig. 8 the beam *b c*, of uniform breadth and thickness, and 2 feet long, is balanced on a point *a* in the middle of its length.

The weight for total length *b c* is 10 lbs., which gives

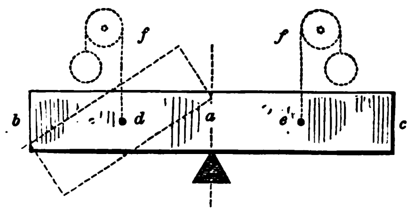

Fig. 8.

5 lbs. to each of the two arms *a b* and *a c*. Now, as the beam at *a* presses on the fulcrum with its whole weight simply, while the parts *a b* and *a c* each possess one-half of this weight, with leverage increasing outwards from nothing at *a* to half the whole length at *c* and *b*, there must be a point somewhere along the arms, at which, if

support were given equal to the simple weight of each arm, to both arms, the fulcrum *a* would be relieved of all weight, in such a manner that were the beam cut in two at *a*, the two halves, *a b* and *a c*, balanced by the hanging weights over the pulleys *f f*, would preserve their horizontal position until force was applied to move them, or, moving on these points as on a centre, would rest balanced in any position they were moved to.

These points lie in the centre of gravity of the arms, all weight around and outside of which is so balanced that it acts as if it were all condensed into the point; and that the points lie in the middle of the arms at *e* and *d*, when the beam is of uniform breadth and thickness, is easily proved by placing one of the halves on a knife-edge, as in Fig. 9.

22. Let us again take the whole-length beam, as in

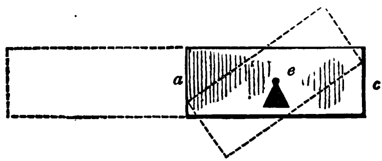

Fig. 9.

Fig. 8, and balance the weight of the arm *a c* by fixing a fine wire rocking-spindle in the centre of gravity *e*, so that all motion must be from *e* as a centre. We require now to find the effect of this relief on the fulcrum at *a*. We have found that in effect the whole weight of the arm *a c* is condensed into the point *e*, which is now supported, so that none of its weight can rest on the fulcrum at *a*; there is therefore only the arm *a b* to consider, and as its whole weight has been found to be in effect condensed into the point *d*, and is in amount 5 lbs., we have 5 lbs. pressing on the fulcrum *a*, with a leverage equal to the distance *e d*, and as *e* is acting as a centre, *a* being midway between *e* and *d* has to bear a load equal to 10 lbs., the lever with its centre or fulcrum at *e*, the load at *d*, and the sustaining power at *a*, having become of the *third* order.

23. Supposing the arm *a b*, Fig. 10, of the lever *b c* were firmly fixed in a wall, and it were required to find the strain at *a* given by the 5-lb. force at *b*, we should still have to treat the question as a case of leverage; but as the arm has to bend, instead of merely rocking freely on the fulcrum edge, we shall find the conditions more difficult to explain.

24. Let *a b*, in Fig. 10, be the solid beam sticking out of the wall: a force applied at *b* will bend it till the end gets to say *e f*.

Now it is the case, as you may readily see after a little

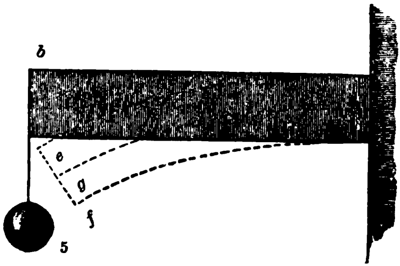

Fig. 10.

reflection, that the fibres are not all suffering the same sort of strain; but that those above the middle line *c g* are being stretched, while those below that line are being crushed; and you can as easily see that, the top and bottom sides being in such opposition, so to speak, there must be a line of fibres somewhere between the two that are neither crushed nor stretched. This line is called the *neutral axis*.

25. Wood in general bears stretching better than crushing, and so does wrought iron; but with cast iron the case is reversed, so that the position of the neutral axis, when the strains are heavy enough to develop the neu-

trality of the middle fibres, varies with the difference of the material employed. But it is near enough for our present purpose to say that it is about midway between the top and bottom sides. Its precise position in a beam under strain has been much debated; but we believe it is correct to say that it lies in the line of the centre of gravity of the sectional area when the strain is small, and that it is only in cases of extreme stress, or of ultimate fracture, that it is found shifted to a position coresponding to the relative crushing and stretching strengths of the materials, that is, to the centre of the forces. It is well to know its position, because, in cases where struts and tie-beams, liable to severe strains, come together for joining at one place, it is advisable, where it can be done, to set them so that their neutral lines all run to meet at one point. The bolts or rivets used will be stressed according as they are placed on the line or axis, or outside of it.

26. As the lever we have been using for our illustrations is very small, we will fix a cross-head to it, so as to magnify the action of the fibres on the wall-line. The length of the arm *c b*, Fig. 11, is 12 inches, and of the cross-head, which represents the depth of the beam where it enters the wall, 4 inches, *a c* and *c d* being each 2 inches.

The rod *c b* may be regarded as in the neutral line. We next hinge the lever by a pin through the cross-head at *c*, to allow freedom of motion to the ends, *a d* and *b*, when affected by the weights applied.

The 5-lbs. weight is suspended at *b*, and by cords from *a* and *d*, passing over the small pulleys, *e* and *f*, we hang weights until we balance the 5-lbs. weight at *b*, so as to bring the arm, *c b*, to a level.

We find that the weights hanging from *e* and *f* require to be each of 15 lbs. to do this, because, from the centre pin, *c*, to each of the two points, *a* and *d*, is 2 inches, and by the simple law of leverage the arm, *c b*, being six times the length of *c a* or of *c d*, we get 5 lbs. at *b*, multiplied by six times, which equals 30 lbs., to be halved between the two short arms, *c a* and *c d*, or 15 lbs. to each.

27. Let us shift the hinge to *d*, and using the cord and weight over the pulley *f* only, we find that 15 lbs. will still balance 5 lbs. at *b*, because *a d* is 4 inches, *c b* is three times as long, or 12 inches, and 5 lbs. multiplied by three gives 15 lbs. as the balancing weight at *a*.

28. On placing the hinge again at *c*, and letting the end *d* go free, using only the weight over *f*, we find that

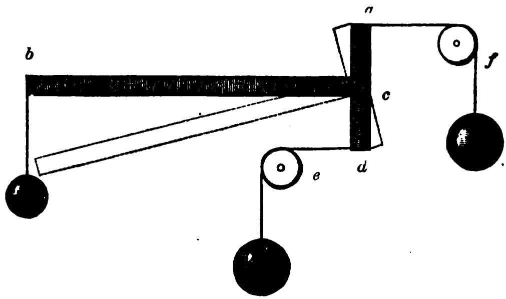

Fig. 11.

30 lbs. is required to balance the 5 lbs. at *b*, because *d* is not in action to take its half as before.

29. But, supposing the arm *c b* were a solid one, as in Fig. 10, and of 4 inches uniform depth to the outer end *b*, 12 inches long, and firmly fixed in the wall at *a d*, and it were wanted to know the stress in the body of the arm at *a d*, the simple rule we have here given for leverage only would not give us it, as that rule assumes that the beam is perfectly rigid in itself, and free to rock on its resting point.

30. For easy illustration, we assumed that the neutral line lay midway between the top and bottom sides, but

we will now endeavour to determine its position when the strain is just at the breaking point.

31. There are tables to give us the strength of different materials to resist crushing and stretching. We will suppose the beam to be of ash wood, the tenacity of which, according to one of these tables, is 17,200 lbs. per square inch of sectional area; that is, it will take that weight to break, by tearing, a rod 1 inch in thickness and in breadth, when the rod is held plumb with the weight on the lower end. From the same table we find that the strength to resist crushing is equal to a pressing load of 9,000 lbs. per square inch of area.

32. In the case of a beam at rest, all the fibres, top and bottom, are alike free from strain. When we apply a light load to the end of the beam in Fig. 10, just enough to cause observable deflection, the length of the curve of the upper line, *a e*, where the fibres are in a state of very moderate tension, will not differ appreciably from the length of the lower curve, *d f*, where the fibres are being very lightly compressed.

33. Now, as the stiffness of a beam consists of the resistance which it can offer to a force tending to make it assume the curved form, and as that resistance is made up of two powers, one of which acts in tension on the upper or rounded side, and the other in compression on the lower or hollow side, it follows that, in strains progressing from a state of rest onward to the breaking point, the powers of the beam will, in the first stages, be strained so far within the limit of their strength, that the neutral line, barely developed, may be held to lie about midway; but, in the later stages, the weakest of these powers begins to yield under stress, while the stronger power has yet strength and to spare: and it would appear from evidences in broken beams of iron as well as of wood, that the latter power yields up from the half of the beam it acts in, for the relief

of the weaker power, as much of the sectional area as more or less nearly corresponds with that difference in strength.

34. This, however, must not be regarded as fixed and easily demonstrated, because very much depends upon the nature of the material, as the parts of the weaker power that are the most distant from the neutral line, and that therefore are subjected to more severe strain than the inner and nearer parts, may not be able to stretch sufficiently to let the stress cross the middle line, and take up for its help all the area that the stronger power can dispense with.

35. We will seek to make this clear by the lines in Fig. 12, which we make to agree with the proportions

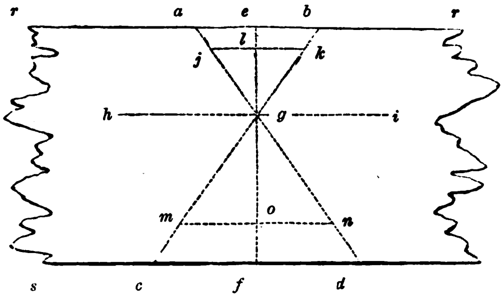

Fig. 12.

for the stretching and the crushing powers in ash. We will suppose these lines drawn upon one of the vertical sides of the beam, so that the top and bottom lines, *r r* and *s s*, would be curved when the beam bent under a load. Regarding the indications of strain in the difference between the respective lengths of the top and bottom curves, we will speak by-and-by.

36. The stretching and crushing strains above and below the neutral line must be equal, though one of the two resisting powers may be overcome before the

other. To maintain this equality, however, the distance *c d*, in Fig. 12, representing the proportionate crushing strain when near the breaking point, must be made as much longer or shorter than *a b* as the power of the material to bear crushing is greater or less than its power to bear stretching.

37. By dividing the 17,200 by the 9,000 lbs. for ash, we get a proportion, or ratio as it is called, of 1·91 to 1. So that if we make the distance *c d*, in Fig. 12, equal to 1·91 inches, *a b* will require to be 1 inch. You see we reverse the position of the ratios, and place the greater quantity on the under side or line of crushing, because ash, being better able to resist a stretching than a crushing force, requires that the sectional area of the crushing side should be as much greater than the area of the stretching side, as the power to resist stretching is greater than that to resist crushing. By so doing we have the greater area with weaker strength balancing the smaller area with greater strength.

We now draw a line diagonally from *b* to *c*, and another from *a* to *d*; the point *g*, where these two lines cross each other, is in the neutral line *h i*, relating to the breaking strain; and the power to resist stretching, represented proportionately by the triangular space *g a b*, is equal to the power to resist crushing represented by the triangular space *g c d*.

38. The fibres in the neutral line *g* have no strain at all upon them, while those farthest off at the top and bottom sides, *a b* and *c d*, have greatest strain; we must, therefore, strike an average between this no strain and greatest strain, which we do by finding the centre of gravity of each triangular space, and as the centre of gravity of a figure of this form is one-third of the depth *e g* or *f g*, measuring from *e* or *f*, we fix these points at *l* and *o*, and draw lines *j k* and *m n* passing through them, and parallel to the bases, *a b* and *c d*, of the triangles.

39. Now, as the length of the lines *a b* and *c d* represent proportionately the respective powers to resist stretching and crushing, we find that these lines, *j k* and *m n*, represent proportionately the average strains in their respective areas; so that when the lines *a b* and *c d* have values which are respectively represented by 17,200 lbs. for the first, and by 9,000 lbs. for the last, the lesser lines *j k* and *m n* give in their shorter lengths the reduced average values by which the respective areas, *g c d* and *g a b*, may be multiplied, when an estimate is required of the forces exerted on the top and bottom sides of the neutral line.

40. The strength of beams is directly as the breadth, and inversely as the length, but as the square of the depth; that is, if the breadth be, say doubled, the strength is simply doubled; and if the length be doubled, the strength is only one-half of what it was when the length was single. As regards the squaring of the depth some explanation is necessary.

41. The depth *f e* of the beam in Fig. 12 is made up of a certain number of fibres, which bear their respective shares of the stress in the proportion of their leverage distance from the neutral line, where the leverage is nothing. The fibres at *a b* are outermost on the curve that will be formed by the bending of the beam, and will therefore be more stretched than those fibres that lie nearer the neutral line; but their greater leverage distance from *g* to *e* enables them to bear their greater strain, with no more absolute fatigue, up to the breaking point, than is felt by the fibres, say on the line *j k*, with their proportionately lighter strain, but shorter leverage *g l*.

But, as the fibres subjected to the tearing force must stretch, in the same manner as india-rubber stretches, a certain extent before rupture takes place, it is plainly to be seen that the fibres which form the outside of the curve, as at *a b*, will reach that stretching limit first, and consequently will break first. The fibres lying nearer the neutral line will not break until the fracture outside of them has opened sufficiently to let them stretch to the same extent as the outer fibres.

42. In estimating the total resistance offered by the fibres contained in the depth *g e*, Fig. 12, we must first observe that the term fibre means any small fraction of the depth, so that we may assume any number of them to make up the depth; but the greater the number we assume, the greater will be the number of our figures, should we have to square all their respective distances, to find the proportionate strain on each.

43. Let us suppose the fibres between *j k* and *a b* to be cut away; the beam so reduced in depth would be reduced in strength to the extent of the depth cut away, multiplied by the leverage belonging to it; showing that the fibres being all of equal natural strength, the greater stress that comes upon them as they recede from the neutral line is counterbalanced by the greater leverage in the increasing distance from that line.

In thus reducing the depth, however, the neutral line would shift to a point lower down, so as to maintain the balance between the two powers of the beam that respectively resist the crushing and the stretching forces; but this does not affect the question of loss of strength caused by the cutting away of so many fibres, because when estimating by the simple leverage distances, we get always the same sum total of these fractional distances for a given depth, no matter at what point of that depth we place the neutral line.

44. The squaring of the depth of a beam, therefore, means no more than the multiplying of so many fibres composing the depth by the leverage, which is the same as that depth; and as in estimating the strength of a beam the crushing and the stretching forces act equally in resisting the strain, though with different sectional

area, the full depth, *e f*, is taken, and multiplied by the two leverage distances, *g e* and *g f*, that is, by *e f*, to get the full fibre depth by the full leverage.

45. We will try to explain by figures the reason for using the full leverage *e f*, instead of the leverage between the centres of gravity *l* and *o*.

The distance between *g* and *e* is as 3 to 2 for the distance between *g* and *l*, so that the fibres at *l* have only two-thirds of the strain upon them that those at *e* have; but *g e*, with the neutral line at *g* placed as shown for ash, measures 1·38 inches in the 4-inch depth of beam, when the two powers of resistance in the beam are respectively represented by the 1·91 inches and 1 inch distances on the upper and lower lines, as at *c d* and *a b*.

46. By dividing the 12 inches length of the beam by this 1·38 inches, we get $\frac{12}{1\cdot38} = 8\cdot69$ times the distance *g e* is contained in the length of the beam, that is, the length of the beam represented by the line *b c*, in Fig. 13,

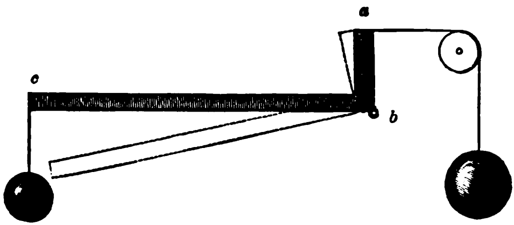

Fig. 13.

is as 8·69 to 1 for *a b*, which represents the distance *g e* of Fig. 12; in this we must suppose the angle at *b*, in Fig. 13, to be hinged, to allow the leverage to act.

Now as the effect of the stress upon the fibres is, for our present purpose, sufficiently represented by their proportionate distances from the neutral line, when we seek merely a relative estimate of the forces at work within the beam, we employ simply the 3 to 2 proportions already got for *g e* and *g l*, of Fig. 12. This being understood, we multiply 8·69 by 3, and get 26·08 as the relative stress in the outer fibres of the upper line *a b*.

47. And, as regards the inner fibres, *g l* being one-third shorter than *g e*, and therefore measuring only ·92 inch, it follows that the 12 inches length of beam is $\frac{12 \cdot 00}{0 \cdot 92} = 13 \cdot 04$ times as long; therefore, referring again to Fig. 13, the beam *b c* is as 13·04 to 1 for the fibre distance *b a*, the latter representing the distance *g l* of Fig. 12.

Multiplying 13·04 by the 2 which stands for the proportionate strain or distance at *l*, gives likewise 26·08 as the relative stress in the inner fibres of the line *j k*; and as this proves that the capacity for resistance in the fibres that form the depth of the beam is equal from top to bottom, it is sufficient for the estimation of the fibrous strength to use the simple distances $g e + g f = e f$ for the multiplier, when squaring *e f*, the depth.

48. It follows as a consequence of this rule, that the comparative stress on any fibre may be ascertained by squaring its distance from the neutral line, that is, by multiplying that distance by itself.

49. When the upper side, *a b*, of the triangle, *a g b*, in Fig. 12, represents proportionately the strength, say for tension found in the tables, we can find the proportionate assistance rendered by the inner fibres, when the outer fibres are stressed to the extent of that strength, by measuring the horizontal lengths, as *j k*, lying within the triangular area.

50. Thus, for ash, the line *a b* represents 17,200 lbs. per square inch of sectional area as the power of resistance to a stretching force.

Now, if we take the fibre, *j k*, which passes through *l*, the centre of gravity of the stretching force, we find that its proportionate length by measurement from *j* to *k* is as 2 is to 3 for the length of the outside fibre, *a b*; so that, multiplying 17,200 lbs. by 2 and dividing by 3, we get 11,466 lbs. per square inch as the proportionate stress at the line *j k*—so long as the outer fibres remain unbroken. When we multiply this reduced force by the leverage already found for *g l*, thus—

$$11466 \times 13{\cdot}04 = 149516,$$

which is nearly the same as we get when we multiply the tabular force by the leverage already found for *g e*, thus

$$17200 \times 8{\cdot}69 = 149468.$$

When the outer fibres give way the inner fibres in succession break only when the stress brought upon them increases to the standard 17,200 lbs. per square inch, but being at a disadvantage regarding leverage, the load overcomes them with increasing ease as the fracture extends inward.

51. We can illustrate this disadvantage of the inner fibres, regarding leverage, by changing the distances in the cross-head lever of Fig. 11.

It will be sufficient if we take one side only, *c a*, to correspond with *g e* or *g l* of Fig. 12. Let the neutral line (represented by the thin arm, *c b*, Fig. 11) be placed on the cross-head in the position found for ash, that is, in the 4-inch depth, at 1·38 inches from the top side, *a*, and 2·62 from the bottom side, *d*. Having done this, we hang the 5 lbs. weight as before at *b*, and again use counterbalancing weights hanging by a cord over the pulley, *f*. We now employ the 8·69 and 13·04 leverages previously found, and, multiplying 8·69 by 5 lbs., get 43·45 lbs. for outside fibres required at the pulley, *f*, to counterbalance 5 lbs. at *b*.

52. We now shift the cord, *a f*, one-third nearer to *c*, so as to make *a* correspond with *l* of Fig. 12, and therefore ·92 inch from *c*. We here have a leverage of 13·04 times to

multiply by 5 lbs., which gives us 65·20 lbs. at *f* required to balance 5 lbs. at *b*; consequently the fibres at the last position, ·92 inch from *c*, are enduring one-half more stress than was required of the fibres at 1·38 inches from *c*, or as 3 to 2.

53. But this excess of stress is due to simple loss of leverage; whereas the strength of a beam varies as the square of the depth, thus, $g\,e = 3^2 = 9$; and $g\,l = 2^2 = 4$, which shows a reduction in strength of fully one-half, when the depth is reduced one-third.

54. The strength of our beam of 12 inches length by 4 inches depth is say equal to 1 power, when the breadth is only 1 inch. By increasing the breadth to two inches we increase the strength to equal 2 powers; and if the breadth be made 4 inches the strength is raised to equal 4 powers. Let the beam of 12 inches length be equal in strength to say 1 power; we reduce the strength to ½ power when we increase the length to 24 inches; but when we make the length 6 inches only we raise the strength to 2 powers.

55. When we understand this simple proportion of increase or reduction as regards the breadth and length, we can easily see that when the strength as regards the depth is not in like simple proportion, but as the square of the depth, that is, as the depth multiplied by itself, a square inch of sectional area added to the depth must give more assistance to the strength of the beam than a square inch added to the breadth; thus, if the strength of our beam of 4 inches depth by 2 inches breadth (equal to eight sectional square inches) be equal to 2 powers, and we get only 2 powers more, or 4 powers altogether, by doubling the breadth, that is, by making the sectional area $4 \times 4 = 16$ square inches, we get a strength equal to 16 powers when we keep the breadth two inches as at first, but make the depth 8 inches, $8 \times 2 = 16$ sectional square inches, the same as the other.

56. We will square both the depths to show how the difference arises.

4 inches depth × 4 inches leverage = 16,
8 ,, ,, × 8 ,, ,, = 64,

$\frac{64}{16} = 4$ times, so that the strength of the 16 sectional square inches, with the 4 inches depth, being assumed to be nominally equal to 4 powers, the same area with the 8 inches depth is 4 powers × 4 times = 16 powers.

57. When we consider the matter a little more closely, we can see likewise that if the strength of 8 inches depth at the wall end be necessary to bear a given load placed at the outer end of the 12 inches length, that is, to bear the 12 inches leverage of the load, less depth than 8 inches would be sufficient at, say, the middle of the length, where the load can exert no more than 6 inches leverage.

58. We will try to explain this by means of Fig. 14.

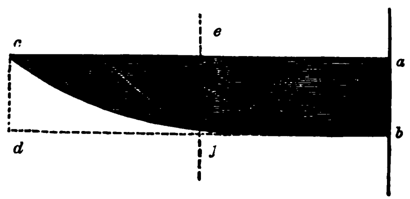

Fig. 14.

a b c d is the side of the rectangular beam 12 inches long by 8 inches deep. The load is supposed to be suspended from the point *c*.

The square of the depth, *a b*, is 8 × 8 = 64, with 12 inches leverage for load, and we want to know what depth of beam is needed at any point in the length, *a c*, to be of equal strength with this full depth at the wall end, proportionate to the stress suffered at these points.

59. The rule is one of simple proportion, so that, having got 64 as the square of the full depth at the wall, we use that number as the middle term, and, taking any point, say *e*, 6 inches distant from the load end *c*, multiply the 64 by it, and divide by the full leverage 12 inches, thereby getting 32 as the square of the depth, *ef*. Now, we find that the square root of 32, or the number that multiplied by itself will give 32 (as 8 times 8 gave 64), is 5·65 inches, the depth required at *e* to be relatively as strong as the 8 inches depth at the wall.

We will put the figures into the regular form thus,—

$$\overset{\text{inches.}}{12} : \overset{ab}{64} :: \overset{\text{inches.}}{6} : \overset{ef}{32}.$$

$\sqrt{32} = 5{\cdot}65$ inches depth at *e*, and similarly for any other point, measuring always from the load end. Were we to find the depths for as many points as would enable us to draw the line *bfc* in its true form, we should find that one-third of the beam may be thus cut away from the under side as useless for strength, and that the line *bfc* would form a common parabolic curve, the properties of which do not concern our present inquiry.

60. The rule we have given applies to square-cornered or rectangular beams, such as we have been using, and to flanged beams, which we will describe later on, and requires that the breadth be kept uniform.

61. As we may not have occasion again to speak regarding this reduction of the sectional area, we may here remark further that, supposing our beam were 11 feet in length, and supported at both ends, with a clear span of 10 feet between the supports, and that we wished to keep the depth the same from end to end, we can begin from the middle of the span, and reduce the breadth gradually as we proceed toward the ends, without decreasing the strength, by a rule not very different from that which we have used in reducing the depth of the beam projecting from a wall, when the load is dis-

tributed, but a different method has to be used when the load is in the middle.

62. In either case, however, we require to find the sectional area required at the points of support to resist what is termed the shearing stress, produced by the combined weight of the beam and load. The leverage of the load does not here operate, the simple dead weight alone being in action.

63. In tables of the strength of materials, we find that good cast iron possesses a resistance to shearing equal to 32,500 lbs. per square inch. If, therefore, the beam and load weigh together 65,000 lbs., which would give to each point of support one-half of that, or 32,500 lbs., equal to the resistance per square inch opposed to shearing, one square inch of sectional area at each point of support would be shorn through under this pressure: we therefore provide for safety by making the area 4 square inches at least, so that the material shall not be tested beyond one-fourth of its shearing strength.

64. These 4 square inches being the sectional area required at the points of support to bear the load named, we find the sectional area required for the middle by rules which we will explain in due course, and then, when the load is in the centre, and we wish to make the strength uniform by decreasing the breadth towards the ends of the beam, we draw straight lines from the breadth found for the middle to the breadth of the 4 inches area at each of the points of support, and thus get for the figure of the whole beam as regards the breadth, a double taper, as shown by the dotted straight lines, *a k b*, *a c b*, Fig. 15.

65. When the load is in the centre, and we make the strength uniform by decreasing the depth towards the ends of the beam, we find the area at the ends to resist shearing, and the area at the middle for transverse strength as before; then, measuring from the ends at

the points of support, as we did from the point *c*, Fig. 14, find the depth for any point between the centre and the points of support, in the same manner as for that figure. We thereby get not a straight-lined taper as for the breadth, but a parabolic curve, because, whereas the strength of a beam, as we have already seen, is simply as the breadth, it is as the square of the depth; hence the curve. The curved line which is thus found we draw from the top of the middle depth to the top of the depth of the end area, as in Fig. 16.

66. When the load is distributed, we get curves instead of straight lines for the outlines of the figures, in breadth as well as in depth; because the load being equally distributed along the length, each point in that length is bearing directly its proportionate share of the dead weight, in addition to the transmitted strain from the parts lying nearer the middle, so that its sectional area requires to be proportionately greater than when, as in the case of a central load, the strain is mainly a transmitted one from the centre.

67. Theoretically, when finding the curves of uniform strength for a distributed load, the distance between the points of support is taken as the length of the beam, which causes the curves to meet just where they touch the points of support; but as the beam has to be supported at the ends, and an area provided to resist the shearing stress, we will employ the full length of the beam.

68. Let *a b*, in Fig. 15, be 11 feet, and let *d* be the middle point in the beam, with the half-breadth *d c* equal to the load that has to be borne. We find that the half-breadth at any other point, say *e f*, is to the half-breadth *d c* as $e\,a \times e\,b$ is to $d\,a \times d\,b$, and similarly for any other point.

Thus, *d a* and *d b* are alike 5·5 feet, and we will assume that *e a* is 3·5 feet and *e b* 7·5 feet, and that *g a* is 10·0, and *g b* 1·0 foot.

Then $d\,a \times d\,b = 30{\cdot}25$ proportional power
$e\,a \times e\,b = 26{\cdot}25$ „ „
$g\,a \times g\,b = 10{\cdot}00$ „ „
$i\,a \times i\,b = 2{\cdot}68$ „ „

or, using the figures only,—

$5{\cdot}5 \times 5{\cdot}5 = 30{\cdot}25$ „ „
$3{\cdot}5 \times 7{\cdot}5 = 26{\cdot}25$ „ „
$1{\cdot}0 \times 10{\cdot}0 = 10{\cdot}00$ „ „
$0{\cdot}25 \times 10{\cdot}75 = 2{\cdot}68$ „ „

So that, if the half-breadth *d c* equal 6 inches, the half-breadths at the other points will be reduced as follows, again using the simple rule of proportion. The propor-

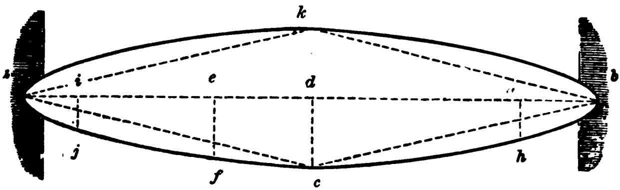

Fig. 15.

tional power of *e f* is 26·25; we multiply this by the 6 inches half-breadth, and divide by the 30·25 proportional power of *d c*, and get 5·2 inches as the reduced half-breadth *e f*, and, treating the 10·0 and the 2·68 powers in the same manner, get 1·98 inches and 0·53 inch as their respective half-breadths.

69. For readier apprehension we put the figures into form thus,—

$d\,c = \ldots\ldots\ldots 30{\cdot}25 = 6{\cdot}0$ inches
$e\,f = 30{\cdot}25 : 6 :: 26{\cdot}25 : 5{\cdot}2$ „
$g\,h = 30{\cdot}25 : 6 :: 10{\cdot}00 : 1{\cdot}98$ „
$i\,j = 30{\cdot}25 : 6 :: 2{\cdot}68 : 0{\cdot}53$ „

70. In finding how much can be taken from the top side of a rectangular beam of uniform breadth without

reducing the strength, the load being uniformly distributed, we treat the depths as we treated them in Figs. 14 and 16, measuring our lengths from the ends of the beam at the points of support.

71. When the load is uniformly distributed along a rectangular beam of uniform breadth projecting from a wall, as in Fig. 14, one-half of the depth can be cut away along the dotted straight line, *c b*, of that figure, because the centre of gravity of the load is now in the middle of the length, in place of the outer end *c*. In the latter case, that is, with the load at *c*, we have at the wall the load leverage equal to the whole length of the beam, whereas, with the load equally distributed, we have the

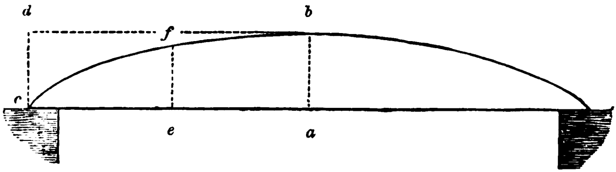

Fig. 16.

leverage equal to one-half the length, so that as we have seen it to be necessary in graduating the depth for the load at *c* to employ the square of the depth, when the whole length leverage is concerned we use the depth simply, when the leverage for the same load is reduced by reason of the equal distribution to one-half the length; hence, in the case of the depth at any point *e*, we have—

$$c\,e : e\,f^2 :: c\,a : a\,b^2$$

when the load is at *c*, but when it is uniformly distributed we have—

$$c\,e : e\,f :: c\,a : a\,b.$$

72. When these rules are used the depth must be kept uniform when the breadth is graduated, or the breadth when the reduction is being made in the depth.

SECTION II.

73. We will now direct our inquiry to beams of a different material and less simple form, and shall depend greatly upon the separate researches of Fairbairn and Hodgkinson for our data.

74. Fig. 17 represents a cast-iron beam of the most approved and the strongest form, usually termed Hodgkinson's.

The upper and lower flanges are proportional to the respective powers of cast iron to resist stretching and crushing forces in a manner similar to the triangular spacing of the powers of resistance in Fig. 12.

75. We find here that the neutral line more closely coincides with the middle of the depth than in the case of rectangular beams, as there is only the limited area of the comparatively thin mid-web to produce a difference.

76. Hodgkinson found, by experiment, that in the strongest section for cast iron, the bottom flange, C D, contained about six times the area of the top flange, F G.

Cast iron of a good quality exposed to a crushing force is able to bear a pressure of 105,678 lbs. per square inch sectional area; but when suffering tension, it gives way under a force of 17,628 lbs. per square inch.

$\frac{105678}{17628} =$ six times nearly that cast iron is better able to resist crushing than stretching.

77. The mid-web between the top and bottom flanges requires to be stiff enough to transmit the strain, and in so doing is respectively stretched and crushed in the parts lying above and below the neutral axis; but these being only inner parts, allow the main stress to be borne by the flanges.

78. When we leave the limited assistance of the mid-web out of consideration, the resisting sections being

mainly at top and bottom, it follows that each section acts with a leverage equal to the distance between the centres of resistance of the flanges respectively in the lines *m* and *n*, consequently, making that depth, *m n*, in Fig. 17, equal to 11 inches, the area of the top flange, F *f* G *g*, equal 2 square inches, and C *c* D *d* equal 12 square inches, we get a balance in figures thus:—Multiply the depth, *m n*, by the area, C *c* D *d*, for the stretching power, and we get $11 \times 12 = 132$. Now multiply the same depth by the area, F *f* G *g*, for the crushing power, and by six times for the ratio of greater power of cast iron to resist crushing than to resist stretching, and we get $11 \times 2 \times 6 = 132$, so that the two powers are balanced in the beam

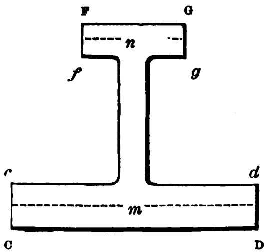

Fig. 17

79. This mode of estimating the balance assumes that the respective areas of the flanges are in the ratio of one to six, and for the sake of simplicity we have left out of account the help afforded by the mid-web, but shall have to include it in our estimate of the full strength of the section.

80. In using the areas of the flanges, we took no note of the breadth or thickness; but we can easily see that if we merely make the areas proportionate, without respect to thickness or breadth, and, keeping the full depth of beam 12 inches, as in Fig. 17, give a clumpy form to the bottom flange, as shown in Fig. 18, we have the parts on the inner line *c d* so far from the point of greatest stress C D as to give little assistance to the parts at C D.

81. If, on the other hand, the flange be made very broad and thin, the parts at the extreme ends, C and D, being unsupported, and therefore at a disadvantage, compared with those parts which lie nearest to the junction

with the mid-web, and having to transmit their assistance through an arm of comparatively great length and little thickness, the strength of the whole flange is less than when the parts lie more gathered in about the junction with the mid-web.

82. Tate's Rule, which we will give presently, takes the thickness of the flanges into consideration; but as it assumes conditions which may be wanting, and employs a constant which is either too much or too little, according as the iron is above or below the average strength, we will, before proceeding with the rules of ordinary practice, endeavour first to explain a method of estimating the

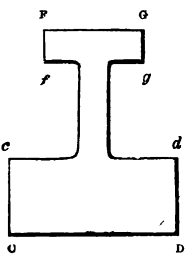

Fig. 18.

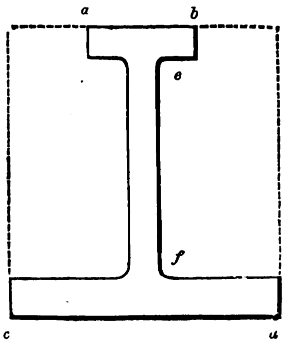

Fig. 19

strength of any double-flanged section, when the respective powers of the material to resist tension and compression are known.

83. This method we offer less for direct practical use, being a little tedious, than for illustration of the manner in which the resisting forces act within the beam, according to the situation of the resisting parts.

84. In employing it to find the breaking strength, we must consider the material on the outer lines, *a b* and *c d*, in Fig. 19, as subjected respectively to full breaking stress in tension and compression, and the inner parts as bearing

less and less strain, until at the neutral line all stress has ceased in the manner described in relation to the triangular spaces in Fig. 12.

85. We will not in this present case use triangular spaces; but our treatment of the distances from the neutral line, in Fig. 20, will give the proportionate resistances equal to what we should get by using triangular spaces.

86. We will treat the whole section very nearly the same as if it formed part of a simple rectangular section of the shape shown by the dotted lines, A B E F, in Fig. 20, and we wanted merely to know what proportion of the whole strain belongs to the middle part, which represents the flanges and mid-web of the lighter section.

87. The proportionate spaces occupied by the top and bottom flanges, *a b* and *c d*, Fig. 19, may be regarded as taking the place of the proportionate triangular spaces of Fig. 12; but we cannot fix the position of the neutral line so directly as in that latter case.

88. We will take for our example one of Hodgkinson's experimental beams, which broke with a load of 12 tons 16 cwts. at the centre.

The dimensions of the section, Fig. 20, are as follow:—

Beam supported at both end.
Distance between supports = 9 feet.
Depth at centre = 10·25 inches.
Bottom flange, 6·14 × 0·77 = 4·727 square inches.
Top flange, 2·10 × 0·27 = 0·567 ,, ,,
Thickness of mid-web at *c* = 0·26 inch.
Ditto *g* = 0·35 ,,

89. The taper of the mid-web throws the respective centres of gravity closer to the lower end of each of the two divisions than when the thickness is uniform; but for the present we will merely give the positions.

The taper in this particular beam is so slight, and the web is so thin, that it might practically be treated as of uniform breadth; but as beams are sometimes formed with the web of considerable taper and thickness, we will later on explain a method for finding the centre in a tapered figure.

90. To find the neutral line in Fig. 20, let *b* and *h* be middle lines in their respective flanges, and *e* midway between *a* and *i*. Also let *d* and *f* be the centres of gravity in the respective upper and lower divisions of the mid-web.

Multiply the length, *e c*, by the average thickness to get the area of the upper division, and add this to the area of

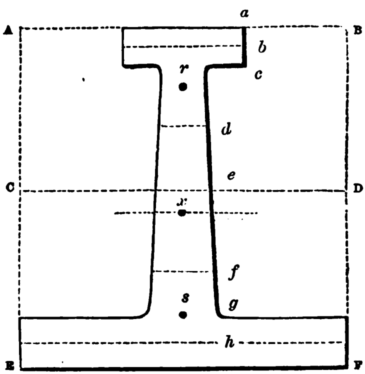

Fig. 20.

the top flange. Subtract this united area from the rectangular area, A B C D, and we get the difference between the sectional area of the upper half of the flanged figure, and half the area of a rectangular section, in breadth equal to the lower flange, and in depth equal to the beam, the centre of gravity of the whole of which rectangular section would be in the middle line *e*.

91. Treat the lower division similarly, and subtract the difference got for it from the difference got for the upper

division, and divide the result by twice the whole sectional area of the flanges and mid-web: we thereby get the distance of the neutral line proper to the flanged section below the middle line *e* at *x*.

92. We shall find it convenient to indicate the respective areas by letters, thus, call the

Area of the	lower flange	m
,, ,,	lower mid-web	n
,, ,,	upper mid-web	o
,, ,,	upper flange	p

$$\left.\begin{array}{l} m = 4{\cdot}727 \text{ square inches area} \\ n = 1{\cdot}424 \quad ,, \quad ,, \quad ,, \end{array}\right\} 6{\cdot}151$$

$$\left.\begin{array}{l} o = 1{\cdot}370 \quad ,, \quad ,, \quad ,, \\ p = 0{\cdot}567 \quad ,, \quad ,, \quad ,, \end{array}\right\} 1{\cdot}937$$

$$8{\cdot}088$$

$$\text{ABCD} = 31{\cdot}467 \quad ,, \quad ,, \quad ,,$$

$$\text{CDEF} = 31{\cdot}467 \quad ,, \quad ,, \quad ,,$$

$$\text{ABCD} - op = 31{\cdot}467 - 1{\cdot}937 = 29{\cdot}53 \text{ difference}$$

$$\text{CDEF} - mn = 31{\cdot}467 - 6{\cdot}151 = 25{\cdot}316 \quad ,,$$

$$4{\cdot}214 \quad ,,$$

$$8{\cdot}08 \times 2 = 16{\cdot}16$$

$$\frac{4{\cdot}214}{16{\cdot}16} = {\cdot}26 \text{ inch from } e \text{ to neutral line } x$$

Distance e to i = 5·125 inches
·26

4·865 inches x to i.

93. The whole depth of the beam at the middle being 10·25 inches, we have the intermediate distances as follow:—

a to b = 0·135 inch.
a ,, d = 2·885 ,,
a ,, x = 5·385 ,,

i to h = 0·385 inches.
i ,, f = 2·755 ,,
i ,, x = 4·865 ,,
x ,, r = 3·285 ,,
x ,, s = 3·96 ,,

The distances *a d* and *i f* are found for the altered areas of the mid-web divisions produced by the finding of the neutral line *x*, and the points *r* and *s* are the respective centres of gravity for the areas under tension and compression, the method of finding which we have yet to explain.

94. The iron of which the beam we have taken for an example was made had a power to resist compression equal to 110,908 lbs. per square inch, and a power to resist tension equal to 17,136 lbs. per square inch.

95. We have now to find the centre of gravity for the lower areas, *m n*, under tension, and, employing the ordinary rule for finding the centre of gravity for any two or more detached bodies, will use the line *i* as the base line for our first distances.

We multiply the area *m* by the distance *i h*, and the area *n* by the distance *i f*, and adding the two products together, divide by the two areas simply united, and thus get the distance from the base line *i* of the centre of gravity *s* for the whole area under tension, and this deducted from the length *i* to *x* gives the distance *x s*.

$$m \times i\,h = 4{\cdot}727 \times {\cdot}385 = 1{\cdot}819$$
$$n \times i\,f = 1{\cdot}330 \times 2{\cdot}755 = 3{\cdot}664$$
$$\overline{6{\cdot}057} \qquad\qquad \overline{5{\cdot}483}$$

$$\frac{5{\cdot}483}{6{\cdot}057} = {\cdot}905 = i\,s$$

$$i\,x - i\,s = 4{\cdot}865 - {\cdot}905 = 3{\cdot}96 \text{ inches} = x\,s$$

96. When the centre of gravity is required for the area under compression, the top line *a* is made the base line,

and the areas p and o treated in the same manner as we have treated m and n; but to get the breaking strength, we require merely to find the stress in the section under tension. Were we to attempt to estimate by the compressive strength of the material in the upper parts, quite a different method would have to be adopted, owing in part to the relative proportions of the upper flange and its division of the mid-web varying at a different rate to the relative proportions of the lower flange and its division of the mid-web when the depth a to i is increased or diminished.

97. The tensile strength of the iron is 17,136 lbs. per square inch of sectional area; but in a case of breaking by bending, we can look for that full stress only on the outside line i, which breaks first: hence we multiply 17,136 by the distance $x\,s$, and divide by the distance $x\,i$, to get the mean or average stress per square inch for the whole area under tension.

We then multiply that average stress per square inch by the area of $m\,n$, and get the total stress for that area, when the parts on the outside line i are on the point of breaking.

$$\frac{17136 \times x\,s}{x\,i} = \frac{17136 \times 3{\cdot}96}{4{\cdot}865} = 13948 \text{ lbs. per square}$$

inch average stress.

$13948 \times 6{\cdot}057 = 84483$ lbs. total tensile stress.

98. But as the main stress is borne by the thickness of the flange between g and i, we use the leverage distance x to h, the middle line of the flange, to multiply this total stress, and divide by one-eighth of the span, all in inches, and thereby get the breaking load in pounds; thus—

$$\frac{84483 \times 4{\cdot}48}{\frac{108}{8}} = \frac{378483}{13{\cdot}5} = 28035 \text{ lbs.} = 12{\cdot}515 \text{ tons.}$$

The actual breaking weight was 12·8 tons, or ·285 ton more than we have got by this method of estimating, erring on the safe side.

99. We will presently employ two other methods of estimating the strength, viz., Hodgkinson's for ordinary practice, and Tate's. Meantime, we will simply note results obtained from them for comparison.

The former gives only 11·66 tons, being 1·14 tons less than the actual breaking load; while the latter gives 12·63 tons, being ·17 ton under. As the dimensions of the beam increase, however, these two methods, and the one we have been using, give much closer results.

100. Thus, again using the section and letters of Fig. 20, and assuming that the iron is of the same quality as in the experimental beams, from the breaking strengths of which the constants were derived, that is, of 17,136 lbs. per square inch tensile strength, we shall take one of Fairbairn's beams, and find the breaking strength by each of the three modes.

Span	= 26 feet
Depth of beam at centre	= 27·5 inches
Top flange = 3 × 1	= 3·0 square inches
Mid-web x to c = 13·048 × 1	= 13·1 ,,
,, x to g = 10·452 × 1·25 Thickness at x = 1 inch ,, ,, g = 1½ ,,	= 13·065 ,,
Bottom flange 16 × 3	= 48·00 ,,
Distance e to the neutral line x	= 0·298 inch.

Hodgkinson's simple method gives 110 tons
Tate's . . . . 112 ,,
The third method . . . . . . 111·95 ,,

breaking load on the centre of the beam.

101. It must be observed that these rules are applicable only to beams somewhat similar in form to that which Hodgkinson proved to be the strongest, and on

account of the varying quality of iron, can be relied on to give only approximate results.

102. When beams of ┳-form are employed, or beams with double flanges, in which the parts situated close to the upper and lower extremities of the depth, about the lines *a* and *i*, Fig. 20, are not respectively at *a* and *i* in near proportion to the tensile and compressive resistances of the material, the strength of the beam will be as the strength of the extremity of that upper or lower division in which the proportionate resistance is less than is required to balance the greater resistance offered by the other, because the strength of the weaker section is sooner expended than that of the stronger. Thus, were the top and bottom flanges of a cast-iron beam of equal breadth and thickness, the parts under compression within the line *a* would be enduring only one-sixth of their breaking stress when the parts under tension within the line *i* were on the point of breaking.

103. The whole area of the section, however, being active in resistance in degree corresponding to the distance of the parts from the neutral line, the help afforded by the interior section ought to be taken into consideration when determining the respective areas of the upper and lower flanges when a close estimate is required; more especially when circumstances require the mid-web to be thick.

104. Sometimes, in the case of comparatively short spans, when the greatest stress may happen by concussion, as from falling weights upon a floor, the mid-web in ┳-shaped and in double flanged beams is thick, and formed with considerable taper in changing the thickness to suit the flanges. We will, therefore, here explain one mode of finding the centre of gravity, and in order to give room for the necessary lines and letters, will exaggerate the thickness as in Fig. 21.

105. Let the depth between the lines *a b* and *c d* equal

4·355 inches, the thickness *a b* equal ·305 inch, and the thickness *c d* equal ·35 inch, these being the dimensions of the mid-web section in tension, Fig. 20, the strength of which we have just now been estimating.

Draw the diagonal line *a d*, so as to form two triangular areas, *a d c* and *d a b*.

The points *f*, *e*, and *g* are in the middle of the respective lines *a c*, *a d*, and *b d*.

Draw the four lines *e c*, *f d*, *a g*, and *b e*; the points of crossing *h* and *i* are the centres of gravity of the respective triangular spaces, and will be found to lie at two-

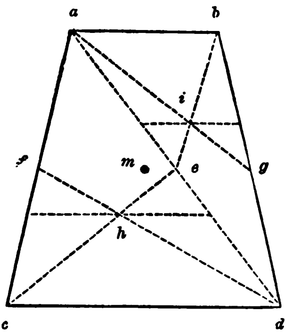

Fig. 21.

thirds of the whole depth *d* to *a b*, or *a* to *c d*, measuring from *d* and *a*.

Now, as we may assume the whole weight to be condensed into these points, we make the areas act for the weights, and multiply the area *a d c* by the distance of *h* from the base line *c d*, then multiply the area *d a b* by the distance of *i* from the base line *c d*.

Add the two products together, and divide the total by the whole area *a b d c*, the result is the distance of the centre of gravity *m* of the whole figure, from the base line *c d*.

106. But, now that we understand how the centres

of gravity *h* and *i* are got, and that the three divisional distances *a b* to *i*, *i* to *h*, and *h* to *c d* are equal distances, we may at once, in the case of any regular taper figure such as we have drawn, begin by assuming that the centre of gravity for the thinner end lies at two-thirds of the whole depth, and the centre for the thicker end, at one-third of the whole depth, measuring from the base or thicker end. And, as the area of a triangular figure is got by multiplying the whole depth *a b* to *c d*, by *c d* and dividing by 2; and also, the whole depth *c d* to *a b* by *a b*, and dividing by 2, we will proceed to use these measures for finding the centre of gravity required, and will find for the lower section of mid-web in Fig. 20, *e* to *g*.

107. The depth *e* to *g* is 4·355 inches; one-third of this is 1·452, and two-thirds 2·9 inches:

$$\frac{4{\cdot}355 \times {\cdot}85}{2} = 0{\cdot}762 \text{ square inches for } a\ d\ c$$

$$\frac{4{\cdot}355 \times {\cdot}805}{2} = 0{\cdot}664 \quad ,, \quad ,, \quad ,,\ d\ a\ b$$

$$1{\cdot}426 \quad ,, \quad ,, \quad ,,\ a\ b\ c\ d$$

$$0{\cdot}762 \times 1{\cdot}45 = 1{\cdot}1119 \text{ power at } h$$

$$0{\cdot}664 \times 2{\cdot}9 = 1{\cdot}9256 \quad ,, \quad ,,\ i$$

$$3{\cdot}0375$$

$\frac{3{\cdot}0375}{1{\cdot}426} = 2{\cdot}13$ inches to centre of gravity *m* for the whole section, measuring from the base line *c d*, and consequently, 4·355 — 2·13 = 2·225 inches from the line *e*.

108. Treating the upper section, *e* to *c*, in Fig. 20, similarly, and measuring as before from the base or thicker end, we get 2·361 inches as the distance of the centre of gravity for the whole of that section, and 1·371 square inches as the area.

109. In the triangular spaces of Fig. 12, the centre of gravity, that is, the centre of the figure, is found at one-third of the whole vertical depth, when measured from the base line. This centre being also the centre of

resistance, is true for rectangular beams, when the parts lying outside of the triangular spaces are helping; but it would be otherwise were these outside parts cut away so as to leave the triangular spaces alone under the stress, as the flanges and mid-web are in the case of a double-flanged beam, because, the inner half of the space which included the wedge point touching on the neutral line, would then contain much less resistance than the outer half which had the base line for one of its sides, as we should find by multiplying the two half areas separately by their respective leverage distances from the neutral line.

110. We will now apply the rules of common practice to the section of Fig. 20.

Hodgkinson employs a "constant" which remains the same, hence its name, for all double-flanged beams approximating to the strongest form, that is, with the top and bottom flanges in near balance of strength. It is derived from the mean of many experiments, and "is formed on the supposition that the strength of the flanges is so great, that the resistance of the middle part between them," which we have termed the mid-web, "is small in comparison, and may be neglected."

In using it, the depth of the beam, and the span, that is, the clear distance between the supports, must be in inches; but when these are expressed in feet, the constant must be divided by 12; thus, being 26 for inches it is only 2·166 for feet.

Hodgkinson's rule reads thus:—

$$\frac{26 \times \text{area of bottom flange in sq. in.} \times \text{depth in inches.}}{\text{Length between supports in inches,}} =$$

= the breaking load in tons at the centre of the span.

Applied to Fig. 20, we have

$\frac{26 \times 4{\cdot}727 \times 10{\cdot}25}{108} = 11{\cdot}66$ tons at centre, which is less than the actual load that broke the experimental beam, but allowance must be made for the special quality of the iron of which the beam was made.

111. Tate's rule takes the thickness of the flanges into consideration, and is based "on the hypothesis that the areas of the top and bottom flanges are to each other in the inverse ratio of the force of compression to that of extension in the particular beam." Let

a = the area of the bottom flange
b = the depth ,, ,, ,,
c = the depth of the top flange
d = the whole depth of the beam
l = the clear distance between supports
w = the breaking weight in tons at middle of beam:

Then

$$w = \frac{16\,a\,(2\,d - b - c)^2}{l\,(2\,d + b - c)} = \text{tons at middle.}$$

112. The 16 here used is another constant quantity, less than the constant used by Hodgkinson on account of the altered conditions of the rule. It requires that the dimensions be in inches. Again using the section of Fig. 20, we have the terms as follows:—

$$w = \frac{16 \times 4{\cdot}727\,(2 \times 10{\cdot}25 - {\cdot}77 - {\cdot}27)^2}{108\,(2 \times 10{\cdot}25 + {\cdot}77 - {\cdot}27)} = 12{\cdot}63 \text{ tons}$$

breaking load at centre of beam.

113. As this formula is a little more complex than the other, it may be well to explain the treatment of the quantities.

$16 \times 4{\cdot}727 = 75{\cdot}63$ to be used for multiplying the square of the quantity within the brackets, $2 \times 10.25 = 20{\cdot}50$, from which before squaring must be deducted the two minus quantities ·77 and ·27 = 1·04; 20·50 — 1·04 = 19·46, which must be squared thus, $19{\cdot}46 \times 19{\cdot}46 = 378{\cdot}69$. This must now be multiplied by the 75·63, and we get 28,640, to be divided by the quantity below the line, which is the length of the span in inches multiplied by twice the whole depth of the beam, to which, however, must first be added the thickness of the lower flange minus the thickness of the upper flange.

$$2 \times 10{\cdot}25 = 20{\cdot}50$$
$$\cdot77 - \cdot27 = 0{\cdot}50$$
$$21{\cdot}00 \times 108 = 2268$$
$$\frac{28640}{2268} = 12{\cdot}63 \text{ tons.}$$

114. Keeping the areas of the flanges the same, but spreading the bottom flange out to a greater breadth by thinning from ·77 to ·60 inch thickness, and, using Tate's rule as before, we get for breaking load at the centre, 12·97 tons, which, owing to our having increased the leverage distance from the upper to the centre of gravity of the lower flange, shows a gain in strength equal to ·33 ton, or about one-third of a ton. By further thinning and thereby making the leverage distance still greater, we get a further gain in strength theoretically, but, practically, the extremities of the flanges may be now so far removed from the support of the mid-web, that they give way under a lighter load than would be required to break the beam were the material less spread out.

115. The ratio of breadth to thickness of the bottom flange in the case of Hodgkinson's experimental sections of strongest form, was about 10 to 1; but the strains up to the breaking point were applied with care and regularity not to be expected in ordinary practice, the less regular circumstances of which require the flanges to be more compact. A ratio of 5 for breadth to 1 for thickness is not unusual.

A ratio of from 3 to 4 for breadth to 1 for thickness is often used for the top flange, but a good deal depends upon the nature of the strain expected and the length of span.

116. We may now pass on from these questions relating to sectional strength to others relating to the span,

and the manner of applying the load, and will find it sufficiently near our purpose to take any simple quantities to represent the span and the breaking load at centre, say 10 and 30.

SECTION III.

117. Let Fig. 22 represent a beam, it may be of wood or of iron, with a load of 30 tons, representing the breaking strength, resting on the middle, A, of a 10-foot span, B C.

We will leave the weight of the beam out of consideration, as we are treating simply of forces, and are not estimating the strength of any given size of beam, having

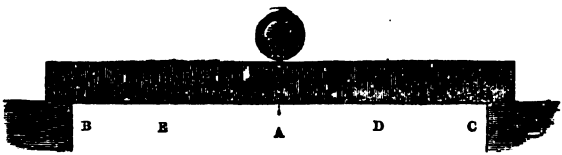

Fig. 22.

already assumed that the strength is equal to a load of 30 tons, which load must of course practically include the weight of the beam itself, distributed along its own length.

With 30 tons load at A, each of the supports, B and C, is bearing one-half, or 15 tons, but each is bearing it at the end as it were of a lever 5 feet long.

118. Now, supposing we were to cut the beam at A, so as to make two half-beams, B A and C A (Fig. 23), each with its load of 15 tons, we find the stress at B and C, in general terms, by multiplying the load 15 tons by the distance 5 feet, which gives us 75; and we call this quantity the "moment" of the load borne by the end at A.

In scientific works there are many such terms used that may be somewhat embarrassing to one unaccustomed to them, when they occur not singly but in groups, but they really very much simplify description, by making single words represent compound quantities.

119. Were we to distribute the 15 tons equally along the half-beam, A C, we should find the "moment" of the load one-half what it was when all borne at A, because, as we

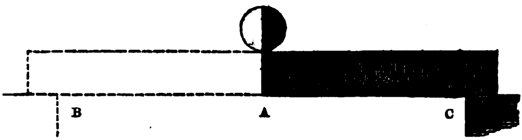

Fig. 23.

found when considering Fig. 8, the centre of gravity of the load when equally distributed being found in the middle of the arm, as at D in Fig. 24, we multiply the load 15 tons by the distance C D, equal 2·5 feet, and get 37·5 as the "moment" of the load distributed.

120. The moment of the whole 30 tons at the centre, A, of the whole span, B C, Fig. 22, is found by multiplying

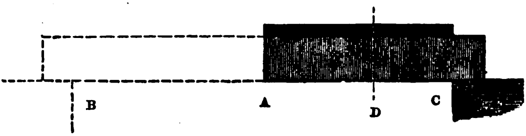

Fig. 24.

the 30 tons by B E or C D = 2·5 feet, or one-fourth the span, which gives us 75.

It is, for the whole load and the whole length supported at both ends, simply the same as for Fig. 23 with half the load and half the length supported at one end only, with this difference merely, that in the latter figure when the end is fixed, the beam breaks at C, whereas in Fig. 22 it breaks at A, when the ends are free. We get a like result for the moment of the whole load when we multiply the whole length, B C, by one-fourth the load—thus, 10 × 7·5 = 75.

121. The moment of the whole load equally distributed is found by multiplying the 30 tons by C F = 1·25 feet, or one-eighth of the span, which gives 37·5 for Fig. 25. This, with its double support, is simply the same as for the singly supported half-length of Fig. 24, the break occurring at A instead of at C.

122. We must bear in mind that the moment of the load is simply the load multiplied by its distance from

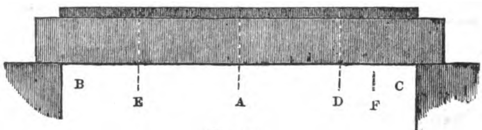

Fig. 25.

nearest support. We see how it changes, according as the load is either equally distributed or all bearing on the centre; the simple dead-weight of the load, meanwhile, whether distributed or central, remaining constant in its simple downward pressure of 30 tons, divided between the supports, B and C.

123. The beam has been assumed to break at centre, A, with a load of 30 tons, the span, B C, being 10 feet, and the ends simply resting on supports.

The curve formed by the beam will be greatest at A, Fig. 26, where the centre load is pressing, and will flatten

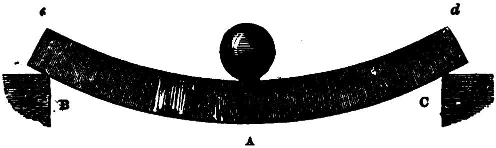

Fig. 26.

as it approaches the supports, B and C; so that, supposing the ends to overlie the supports sufficiently for observation, it would be seen that the portions between C *d* and

B *e* were nearly straight; and, as the curve is sharpest where the load is greatest, it is plain that the greatest stress in the beam will be felt at A.

124. Let us firmly tie down the ends, *e* and *d*, upon the supports, B and C, use the same load, and we shall find the beam bending at A, in Fig. 27, less than it did with the ends loose, because so much of the load is required

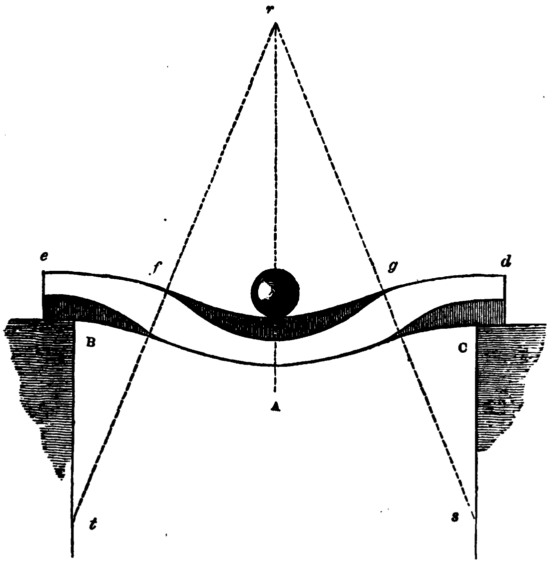

Fig. 27.

to produce the bends at *f* and *g*, that the middle, though bearing directly the whole load, is relieved from a corresponding amount of the bending stress; the action of the contrary bends, A, *f*, and *g*, being to distribute the strain more uniformly along the whole length, so that if the stress at A, Fig. 26, be equal to 1, the stress at A, Fig. 27, will be equal to ½ only, the other half being taken up by the counterbends, *f* and *g*; consequently the beam, as in

Fig. 27, is twice as strong as it is in Fig. 26, or may be made with its sectional area one-half less than that required for Fig. 26; but we here leave out of account the weight of the beam itself, which acts as a distributed load, and assume that the load is easy.

125. If we now let the beam project from the face of a wall, B C (Fig. 28), and let the same weight bear upon the free end, A, at 10 feet from the wall, so that the projection will be equal to the span in the former cases, we

Fig. 28.

find that the stress at B C will equal 4, so that the projecting beam would require to have a sectional area four times as great as Fig. 26, and eight times as great as Fig. 27, to be of equal strength.

126. The moment of the load in Fig. 28 is got by multiplying the whole span by the whole load, thus— $10 \times 30 = 300$. This treatment is the same as when finding the moment for Fig. 23; and, as we in Fig. 28 have twice the load and twice the distance, the moment is $2 \times 2 = 4$ times as much as found for Fig. 23, thus— $75 \times 4 = 300$.

127. At the points, *f* and *g*, where the counterbends meet, the crushing and the stretching forces, as it were, exchange places in the manner shown in Fig. 27, where the dark spaces represent the crushing force, and the light spaces the stretching, so that the line of exchange represented by *r t* and *r s* passes through particles which are in a neutral condition as respects stretching and crushing, but which are exposed to a shearing force

caused by the force exerted by the counterbends to straighten themselves in opposite directions.

On this account, in the case of wrought-iron beams, formed of thin plates and angle iron, buckling of the vertical plates or mid-web is apt to take place at the points, *f*, *g*, and A, when the beam is tied down at the ends, and at A only when the ends are free.

The top flange shortens by compression, while the bottom flange lengthens by tension; the mid-web or vertical plates connecting these flanges, being less subjected to these forces, is compelled to buckle to accommodate itself to these alterations in the flanges, or top and bottom horizontal plates.

The mid-web yields to the shearing force by buckling more readily when the ratio of its depth to thickness is great; but we will speak of this more fully shortly.

128. The ends of the beam in Fig. 27 are assumed to be so firmly tied down at the supports, B and C, as to be immovable, so that the increased length of the beam, measured on the curve it makes when loaded, must be derived from the stretching of its fibres or parts. Were the beam actually hinged in the middle of its depth to the fixed supports at B and C, and the load placed in the middle, as before, the greater length required to allow the beam to make the curve would be derived from stretching, as we can show by Fig. 29, in which the curve is drawn from the centre, D; but let us first observe that in this case the lines, *d e* and *f g*, which form the squared ends, are supposed to turn freely on the hinges, so as always to point to D, the centre of the curve.

129. A load on the middle of the beam would not make the curve a circular arc, but would, as before remarked concerning Fig. 26, make the bend sharpest at A, but it will serve our present purpose perfectly well to suppose it to be such as might be made from a centre, D.

We will exaggerate the proportions for better observation, making the straight distance across, between the hinges, equal to 10 feet, the depth of the beam 2 feet, and the radius of the curve from D to the hinge line, *b a c*, equal 7 feet.

Now we can, by using a pair of compasses, measure the lengths of the curved lines, and ascertain the amount of stretching or of crushing to which the fibres or parts are subjected, by the extent which the curved lines are

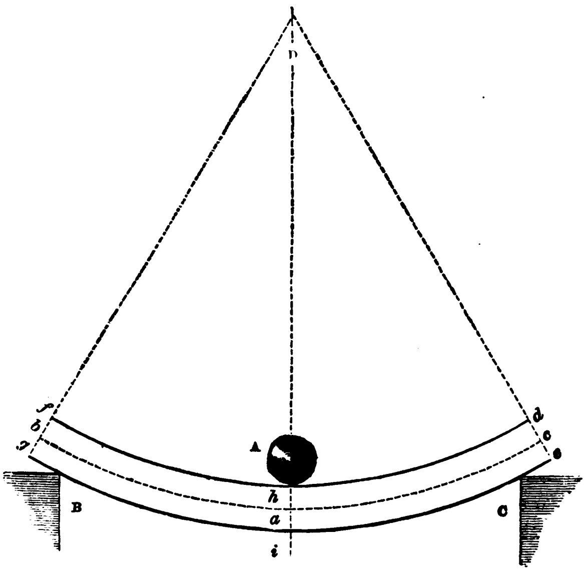

Fig. 29.

longer or shorter than the original length of the beam before the load was put on.

130. We thus find that, when 1 represents the original length, the line *g i e* measures 1·27, and the middle or hinged line, *b a c*, 1·12, while the upper line, *f h d*, measures only 0·956; consequently the latter has been crushed to a shorter length, and the two former have

been stretched to a greater length, than the original distance across, and for the neutral line, or in this case where the forces are not balanced, simply the line of neutral fibre which separates these unequal stretching and crushing forces, we have to seek about midway between the middle line, *b a c*, and the upper line, *f h d*.

181. Had we placed the hinges a little higher up than the middle of the beam, we should have got this neutral line in the line *f h d*, and if higher up still, should have had the whole beam under a stretching force.

182. The distance of the counterbends, *f* and *g*, from B and C, in Fig. 27, depends upon the load, but as this distance, representing the leverage, decreases as the load increases, nearly, the ratio that the resistance to bending bears to the load remains constant, nearly.

The depth of the beam is assumed to be so proportioned to the span that the bending force of the load will be resisted by a balance between the tensile and compressive powers of the material.

Were the depth very small and the span great, the beam would act under a load less like a beam than like a string, and, of course, would have no counterbends at *f* and *g*.

183. When the section along the length B C is uniform, it is clear that what we may term the "moment" of bending, that is, the load by the distance from the counterbends, must be proportionate for all parts of the beam, whether in the middle or near the ends, and thus, that the points B, C, A are resisting equally. Were they resisting unequally, that is, did the bend A require more force than either of the other two bends B and C, that would show that the beam is stiffer in the middle than at the quarters B and C, which it can be only by being made relatively stronger.

184. Beams formed as in Figs. 15 and 16 are stiffer in the middle than at the quarters, when tested by the

shorter leverage distances of Fig. 27, and therefore are of uniform strength only when simply supported at the ends. Were the ends firmly fixed as in Fig. 27, the counter-bends would be found as much nearer to B and C than shown for a simple beam of uniform section, as the stiffness at the middle exceeds the stiffness at the quarters, that is, the greater stiffness of the centre would take more leverage to reduce the greater stiffness to a balance with the lesser stiffness between *f* and B, or *g* and C.

Our present remarks, therefore, have reference mainly to simple beams or girders of uniform section; and, as before remarked, we exclude the effect of the beam's own weight uniformly distributed.

135. The resistance to bending being thus assumed to be uniform, the leverage distances, B *f* and *f* A, will be proportionate to the stress, due to the bending moments at A and B, of the load at A, plus the distributed weight of the arms, B *f* and *f* A.

136. In estimating the stress in the centre of the bends *f* and *g* we must regard the part of the beam which lies between them as an independent beam, which with its load is, as it were, suspended from the points *f* and *g*.

137. We must bear in mind that our forces here relate merely to the load multiplied by its distance from support, and that, before we can estimate the full effect upon the body of the beam, we must deal also with the depth and breadth if the form be rectangular, or with the lower flange area and the depth, if flanged. And, further, that the deflexion due to a load distributed is five-eighths of what is due to the same load at the centre, instead of only one-half; showing that the bending of the fibres, or parts composing the depth, modifies to the extent of one-eighth the simple moment of the load, which when distributed, acts as in Fig. 25.

This five-eighths of the deflexion for the load distributed is the same as would be got by placing five-eighths of the full load at the centre.

138. We have hitherto been using 30 tons for the load, but as that is the breaking stress, and the counterbends at one-fourth of the span correspond with the stress from a safe working load, with the elasticity uninjured, we will in this case use a perfectly quiet load of 10 tons only, which gives us a load of 5 tons to be supported at each of the points *f* and *g*. 5 tons × B*f* equal 2·5 feet, or one-fourth of the span, give 12½ tons stress at B; the load acting as in Fig. 22, but the effect modified by the counterbends *f* and *g*.

139. Now this 12½ tons stress, the moment of half the load × one-fourth of the span, is exerted in supporting one-half of the middle part *f g* of the beam and centre load, and must be subtracted from the moment, as in Fig. 22, of the whole load × quarter-span B E, so that as the latter moment is 10 tons × B E equal 2·5 feet = 25, we get by the subtraction the reduced quantity 12½ as the acting moment in the arm C *g* or B *f*, of a load of 10 tons on a span of 10 feet, with the ends firmly tied down.

140. The moment can be got simply by multiplying the half-load, 5 tons, by the quarter-span, A *f* or A *g*, equal 2·5 feet = 12½, corresponding with 37·5, Fig. 25.

141. The same load, but with the ends free, as in Fig. 22 or 26, would give a moment of 25 tons; one half of 10 tons at A, multiplied by B A, equal 5 feet, being equal to 25 tons.

142. When the load is distributed uniformly along the span of a beam of uniform section, the counterbends occur nearer to the ends, B and C, because the parts B*f* and C *g* are then, in addition to the stress transmitted from the middle part, *f g*, bearing directly a portion of the entire load.

In that case, when the load is not sufficient to injure the elasticity of the material, the middle length, *f g*, is about as 0·6 to 1·0 for the whole span; so that in a span of 10 feet fg would measure about 6 feet, but as the load is increased so will this middle distance lengthen, the points f and g approaching nearer to the ends B and C.

143. The deflexion at the point of breaking of the beam of section Fig. 20 was ·68 inch. We will now explain a method by which this may be estimated, and for this purpose must employ the modulus of elasticity, which is a power invented by Dr. Young. When expressed in feet it gives the height to which a body would have to be piled in order that any small addition to its top, of its own substance, might compress the rest to an extent equal to the bulk of that added quantity.

144. A column of ordinary cast iron, the cross sectional area of which is 1 square inch, and the height 700 feet, weighs 1 ton. This weight pressing on a continuation of the column below it will shorten the supporting column $\frac{1}{8214}$th part of the 700 feet, or $\frac{700}{8214} = \cdot085$ foot.

Now, as we have 12·8 tons load upon our beam, we multiply ·085 foot got for 1 ton, by the whole load 12·8 tons, and get 1·0905 feet as the extent to which a column 1 inch square, and 12·8 times the 700 feet height, would be shortened by compression, or the extent to which the 700 feet height would be shortened, supposing its sectional area to remain 1 square inch, but its weight, say by a top load, increased to 12·8 times.

145. To obtain the full modulus of elasticity, so that any addition to the height of the column will compress to an extent equal to its own bulk, we must multiply 700 feet by 8,214 times, which gives 5,750,000 feet height of column, and as the weight of 700 feet is 1 ton, the weight of the whole column is 8,214 tons, or 18,400,000 lbs. We find in tables furnished by Fairbairn and Hodgkinson, from estimates based on experiments on the transverse strength of cast-iron bars, that the moduli ranged from

22,907,700 to 11,539,333 lbs., showing that the modulus of elasticity or stiffness is practically dependent on the quality of the iron.

146. We will not use the full modulus, but will employ the proportion of it which we have found for 12·8 tons, and which gives 1·09 feet as the extent of compression for a column 1 inch square.

We divide this by the number of sectional square inches in the area of Fig. 20, and get 0·135 foot, which we now multiply by the whole depth of the beam, and divide by the distance between the centres, *r* and *s*, of the tensile and compressive resistance, and thus get 0·19 foot as the extent of alteration in the length of a beam that is bending under the stress, as in Fig. 30, in which the length measured along the neutral line *a b* remains

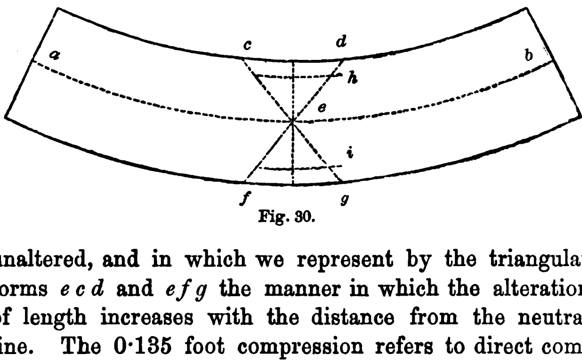

Fig. 30.

unaltered, and in which we represent by the triangular forms *e c d* and *e f g* the manner in which the alteration of length increases with the distance from the neutral line. The 0·135 foot compression refers to direct compression without bending, whereas the 0·19 foot is the measure of the greater extension of the outer parts, owing to the force in a case of bending radiating, so to speak, from the point *e* in the triangular form.

147. We now divide the number of times this last fractional quantity 0·19 is contained in the whole number 1·00 by the constant 8, and get the deflexion approximately in inches.

$$\frac{700}{8214} = \cdot 085 \text{ ft.} \times 12\cdot 8 \text{ tons} = 1\cdot 09 \text{ feet.}$$

$$\frac{1\cdot 09}{8\cdot 088 \text{ sq. in.}} = 0\cdot 135 \text{ foot.}$$

$$\frac{0\cdot 135 \times 10\cdot 25}{7\cdot 255} = \frac{1\cdot 383}{7\cdot 255} = 0\cdot 19 \text{ foot.}$$

$$\frac{1}{0\cdot 19} = \frac{5\cdot 3}{8} = 0\cdot 66 \text{ inch deflexion.}$$

$0\cdot 68 - 0\cdot 66 = 0\cdot 02$ inch deflexion less than got by experiment.

148. The rules which we have employed in estimating the strength and deflexion of double-flanged beams are applicable also to sections of the T-form.

SECTION IV.

149. The strength of malleable iron flanged beams, Figs. 31, 32, and 33, may be found by the same rules as used in the case of cast iron beams, but with a different constant.

The constant for cast iron, shaped as in Fig. 20, is 26 for Hodgkinson's rule, though usually in practice a lower figure, 25, is adopted for safety.

For wrought iron, formed as in Fig. 32, it is 60, unless means are used to prevent the mid-web from bending at *a* and *b*, when 75 may be used.

The mid-web of the solid rolled-iron section, Fig. 31, being stiff enough to prevent this bending, 75 may be used for it, and also for the form shown in Fig. 33.

150. The ratio of tension and compression for wrought iron being nearly as 2 to 1, the sectional area of A B, the top flanges in Fig. 31, should be nearly twice the area of C D, the bottom flanges.

In Fig. 32 a lower ratio than this is sufficient, because the rivet holes in the lower flanges, C D, under tension, lessen the difference, so that about 9 for A B to 6 for C D gives equal strength. The joints in the top plates

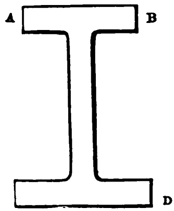

Fig. 31.

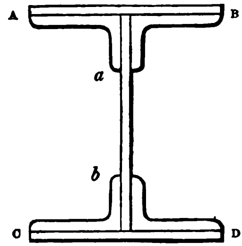

Fig. 32.

butt together, so that the riveting does not appreciably weaken.

151. The flanges in Fig. 33 are better supported than

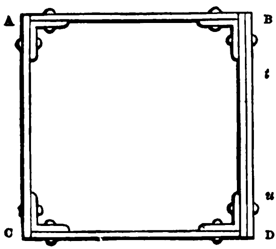

Fig. 33.

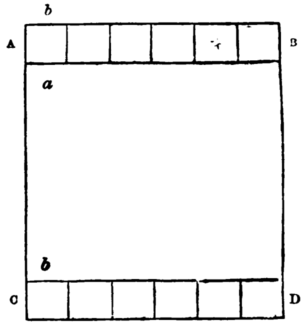

Fig. 34.

in Fig. 32, and therein lies the advantage of this shape over that of the latter figure.

Fig. 34, for large sizes, has the top and bottom formed of a series of rectangular tubes, or cells, as they are termed, such as Fig. 33, riveted together, so that the cross sectional area of the iron which forms the respective top and bottom series of tubes A B and C D is so favourably distributed for stiffness, that is, for keeping all the parts square to their work under strain, as to allow of the sectional area of the iron composing the top flanges A B to be as 12 to 11 for the bottom flanges C D, and of the constant being increased to 80.

This form of beam is known as Fairbairn's.

152. The rule in general use for estimating the strength of these sections, figures 31 to 34, is thus expressed:—

$$\frac{\text{Area of C D} \times \text{depth at middle of span} \times \text{constant}}{\text{Length between supports}} =$$

= Breaking weight at centre in tons.

The depth and length must be either both in feet or both in inches. If the depth be in inches and the length in feet, the constant must be divided by 12, which will reduce it to 5·0 in place of 60, for Fig. 32.

153. The sectional area of the iron composing either the upper or the lower series of cells A B and C D, Fig. 34, affords greater strength than the same area got from a single plate stretching across from A to B, or from C to D, mainly because of the better preservation of form. The single plate would offer equal resistance could it be kept from buckling.

The cellular form is used only for bridges of considerable span, where the cells can be made big enough for easy riveting, and also for periodical scraping and repainting inside.

When the plain plate form is adopted, the sectional area of the top, as we before remarked, has to be nearly twice the area of the bottom plates, and the plates which connect the top and bottom require to be thicker and better supported than when the cellular form at top and bottom is used, because the top being under compression, the plain top plates, when the load say is on the middle, are too thin of themselves, and therefore buckle too easily, to do much in the way of transmitting the pressure backward towards the piers. The same sectional area of material, in honey-combed form as in the cellular system, acts to greater advantage in this respect, because of the greater thickness or depth *a b*, Fig. 34.

154. The top plates or cells when resisting pressure have to act in the manner of posts, and we can very simply illustrate the difference between the plain plate and the cellular systems, by taking say a 4-feet length of thin brass tube, 2 inches diameter by $\frac{1}{25}$ inch thick, the sectional area of which is one-quarter inch, and, pressing it endwise with all our might against the wall, compare its stiffness with a slip of hoop brass, also of one-quarter inch sectional area, made up of 2 inches breadth, by $\frac{1}{8}$ inch thickness.

You will find that the tube resists, but that the thin slip when held flat bends with its own weight when we raise its point to the wall.

But, supposing we were to fix one end of each firmly to the wall, and, by means of weights hanging over pulleys to subject them to a stretching strain, fairly applied, we should find them break on nearly equal terms.

Were the same sectional area put into the shape of the open flanges in Fig. 32, and the depth kept at 2 inches, we should have greater stiffness than in the circular form, as the bulk of the material would then be in the top and bottom flanges, at the greatest distance from the neutral line, whereas in the circular form, in a case of bending, much of the material is near the neutral line.

155. In the case of the cells of Fig. 34, or of the plates of Figs. 32 and 33, there is a right proportion of thickness of plate to diameter or depth, for getting the greatest effect from any given sectional area, and the rules for estimating the strength of long and short columns apply here.

156. Mr. Fairbairn found by experiment, on cells set

upon end, and tested as short pillars, the ratio of diameter to height of pillar not allowing the pillar to bend under the load which caused the side plates to buckle, as in Fig. 35, that "the ultimate resistance for wrought iron of a single square cell to crushing by the buckling or the bending of its sides, when the thickness of the plates is not less than *one-thirtieth* of the diameter of the cell, is 27,000 lbs. per square inch sectional area of iron; but when a number of cells exist side by side," as in A B and C D, Fig. 34, "their stiffness is increased, and their ulti-

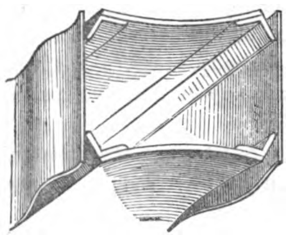

Fig. 35.

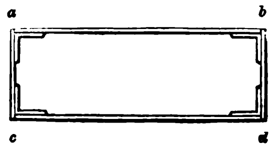

Fig. 36.

mate resistance to a thrust may be taken at 33,000 to 36,000 lbs. per square inch section area of iron."

157. He found also "that the strength of the square and rectangular tubes decreases as the size of the cells is increased;" that the rectangular form, Fig. 36, is the weakest when the side *a b* is wider than the side *a c;* the addition of a mid-web *e*, Fig. 37, nearly doubling the strength.

158. He found at same time that for pillars standing erect to their work the circular form is the best, for this reason, that in the circular form the material is symmetrically arranged round the centre of gravity, which is in the centre of the pillar, whereas, in the square form, the material in the corners being most distant, suffer more stress than the material in the middle of the sides, so that the corners would be the first to chip off.

159. Taking the ultimate breaking load for cast iron at 80,000 lbs. per square inch, Professor Gordon has shown that when the diameter or thickness of a pillar is $\frac{1}{26 \cdot 4}$ of the length, cast iron and wrought iron are found to be of equal strength, their ultimate strength, or their breaking load being at that ratio 29,280 lbs. per square inch of sectional area, but the decrease in strength as the length of pillar increases, the diameter remaining the same, is much quicker in cast iron than in wrought iron; thus, when the diameter or thickness is $\frac{1}{10}$ of the length, the breaking load per square inch for cast iron is 64,000 lbs., and for wrought iron 34,840 lbs; but when the ratio is $\frac{1}{40}$, cast iron breaks with 16,000 lbs., and wrought iron with 23,480 lbs., showing that for long thin pillars wrought iron is best adapted, but that for short thick pillars cast iron offers the greatest resistance per square inch; and this directly applies to the case of girders, in which, if the whole depth of the beam requires in respect to thickness to exceed the ratio of $\frac{1}{26 \cdot 4}$, the mid-web or side plates, which act in the manner of long thin pillars, connecting the top and bottom, are stronger per square inch of section when of wrought iron.

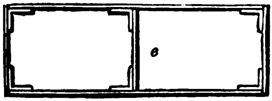

Fig. 37.

160. Beams have been made with the top flanges of cast iron and the bottom flanges of wrought, but the two do not work well when thus used together.

Cast iron being hard and rigid, squeezes together in a much less degree than wrought-iron stretches, so that, after suffering stress beyond the limit of elasticity, it is found either that the wrought iron has got a set while the cast iron is yet uninjured, and free to recover its original straightness but for this set in the wrought iron, or else that the cast iron is crushed before the wrought iron has done all the stretching it is capable of.

161. Rankine states that in computing the strength of pillars, the diameter or thickness is to be measured from *r* to *s* in Figs. 38 to 46, and the lines *r s* are in the direction in which the pillars, or struts, or girder plate stiffeners, are most flexible.

Fig. 46 is corrugated iron set vertically on edge.

162. Figs. 38 and 43 show angle and **T**-iron stiffeners

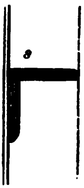

Fig. 38.

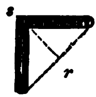

Fig. 39.

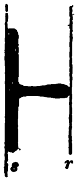

Fig. 40.

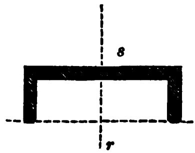

Fig. 41.

applied to girder plates, say for the sides A C and B D of Fig. 34; so that in computing the stiffness of the plates so supported, and using the rules for long pillars, the distance, *r s*, may be taken for the diameter or breadth, and the height between the top and bottom cells, less what is covered by the corner angle-iron—or from *t* to *u*

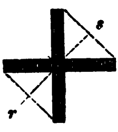

Fig. 42.

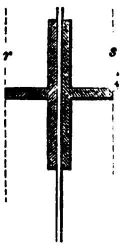

Fig. 43.

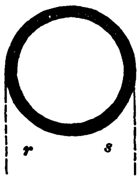

Fig. 44.

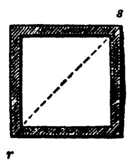

Fig. 45.

in Fig. 33—may be taken for the length; and the number of angle or **T**-iron stiffeners in the sides A C and B D made many or few according to their sectional strength.

163. If we keep the length of pillar and the sectional

area the same, but make the pillar solid, instead of hollow as in Figs. 44 and 45, we shall get *r s* so much less than for the hollow form, that, supposing the diameter is 6 inches for the hollow form and 3 inches for the solid—that is, 2 to 1—the change to the solid form, with reduction of diameter, will be equal to increasing the length for the hollow form 2½ times—that is, from 10 to 25 feet

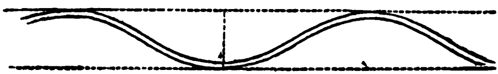

Fig. 46.

—and this increase of length will make the pillar about 4·75 times weaker than when only 10 feet long, because, according to Hodgkinson, in cast-iron pillars of the same thickness the strength is inversely proportional to the 1·7th power of the length, nearly.

The 1·7th power of 25 feet is 238, and of 10 feet is 50·119, equal to a ratio of 4·75 to 1; but this ratio must be reduced according to a rule, which we shall soon speak of, and which takes into account decrease of strength from the early yielding of the material to crushing force. In general terms, the strength of hollow columns is found to be nearly equal to the difference between that of two solid columns, the diameters of which are equal to the external and internal diameters of the hollow one.

164. The rule for the strength of cast-iron pillars is thus stated by Hodgkinson:—

Let P = breaking load; A = 44·16 tons per square inch for "constant," in the case of solid pillars with flat ends; A^1 = 44·3 tons per square inch, the constant for hollow pillars with flat ends; d = diameter of solid pillar in inches; D = external diameter of hollow pillar in inches; d_1 = internal diameter in inches; and L = length in feet.

(1) $P = A \dfrac{d^{3\cdot6}}{L^{1\cdot7}}$ for solid pillars.

(2) $P = A^1 \dfrac{D^{3\cdot6} - d_1^{3\cdot6}}{L^{1\cdot7}}$ for hollow pillars, when the length in either case is not less than 30 times the diameter.

The sectional area of the solid pillar 3 inches diameter is 7 square inches; and as the sectional area of the hollow pillar which is 6 inches external diameter requires to be the same, we find that the internal diameter must be about 5·22 inches.

165. The expression $d^{3\cdot6}$ means that the diameter in inches has to be raised to the 3·6th power, and $L^{1\cdot7}$ that the length in feet has to be raised to the 1·7th power.

Raising to a fractional power involves more than mere decimal multiplication; thus, $d^{3\cdot6}$ is found by cubing the diameter, then multiplying this cubic quantity by its 5th root—that is, by the number which, when multiplied into itself 5 times, in the same manner as the diameter was cubed, will equal the cube of the diameter.

166. We may thus express the formula for the 3·6 and the 1·7 powers, but they can be much readier found by simple logarithms when tables are at hand.

(3) $d^3 \times \sqrt[5]{d^3}$; or, using figures only,

$$3^3 \times \sqrt[5]{3^3} = 27 \times \sqrt[5]{27} = 27 \times 1{\cdot}93 = 52{\cdot}196$$

equals the power of the 3 inches solid diameter.

Let the length of the pillar be 10 feet, we then have—

(4) $L^{1.7} = L \times \sqrt[10]{L^7} = 10 \times \sqrt[10]{10000000} = 10 \times 5{\cdot}012 = 50{\cdot}119$ equals the power of the 10 feet length.

167. The rule for the raising of powers is termed "involution."

We require to raise the diameter 3 inches to the

3·6 power. In the first column of the tables of simple logarithms we find the logarithm of the number 3 is 0·4771213. Multiplying this by 3·6, as in a simple case of decimals, we get 1·717636 as the logarithm of the power. Looking in the second column we find opposite the logarithm 1·71600—which is a little less than what we want—the number 52, which is the power of $3^{3·6}$ nearly. The exact number wanted is 52·196, which can be got by more exact treatment, but 52 is near enough for ordinary use.

The 1·7 power is got similarly.

The logarithm of 10 is 1·00, of 100 is 2·00, of 1,000 is 3·00, and of 10,000 is 4; and so on for higher powers, rising by 10 times the preceding number for each whole unit of the logarithm.

When the logarithm exceeds 2·00 we look for the fractional quantity in the columns beyond the number 100, and the number which is opposite that fractional quantity is the power sought for. When the logarithm is 3 and a fraction we look for the fractional quantity beyond 1,000, and so on. The logarithms we here refer to are those got by the multiplication of the first logarithm for the diameter by the 3·6 power.

Hodgkinson, in his work on cast-iron beams and pillars, gives tables of the powers for ready reference.

168. The powers for the solid pillar 10 feet long by 3 inches diameter we have found to be—

(5) $\frac{52·196}{50·119} = 1·041$ to be now multiplied by A^1, the constant already given for solid pillars with flat ends.

$44·16 \times 1·041 = 45·97$ tons ultimate or breaking load.

169. Let us now find what the hollow pillar breaks at. We will at once take from the tables the respective fractional powers for 10 feet length, so that the question stands thus—

$$(6)\qquad 44{\cdot}3 \times \frac{632{\cdot}91 - 380}{50{\cdot}119} = 223{\cdot}537 \text{ tons.}$$

170. Let us now double the length of the hollow pillar by making it 20 feet, all else remaining the same, and taking the new fractional power for 20 feet.

$$(7)\qquad 44{\cdot}3 \times \frac{632{\cdot}91 - 380}{162{\cdot}84} = 67{\cdot}69 \text{ tons.}$$

171. When the length is increased to 25 feet, with diameter and sectional area as before, we have—

$$(8)\qquad 44{\cdot}3 \times \frac{632{\cdot}91 - 380}{238} = 46{\cdot}9 \text{ tons.}$$

172. The ratio of length to diameter in case (5) is $\frac{L}{d} = \frac{120}{3} = 40$ for length to 1 for diameter, and the breaking load is equal to 14,716 lbs. per square inch, there being 7 square inches in the section of this and the other pillars.

The ratio of (6) is $\frac{L}{d} = \frac{120}{6} \quad \frac{20}{1}$. We shall have to reduce this breaking load by a further calculation, which we will explain presently. The breaking load, however, as we have here got it, is equal to 71,532 lbs. per square inch.

The ratio of (7) is $\frac{L}{d} = \frac{240}{6} = \frac{40}{1}$, and the breaking load = 21,660 lbs. per square inch.

The ratio of (8) is $\frac{L}{d} = \frac{300}{6} = \frac{50}{1}$, and the breaking load = 15,000 lbs. per square inch.

(5) and (7) are not similar pillars, else, being in the same ratio, the breaking load would be equal; but on this point we have yet to speak.

173. The formulæ we have been now using are for pillars whose length is not less than 30 times the diameter, so that they break by bending.

The cast iron used by Mr. Hodgkinson in his experiments bore a crushing force per square inch of 49 tons, which is considerably more than ordinary cast iron will bear; but, as the strengths per square inch used in the equations (1) to (8) are for the same quality, we must use this high figure in the questions still before us.

174. This 49 tons, then, is the ultimate crushing force per square inch when the pillar is so short that it cannot bend under the load.

The sectional area of our hollow pillar is 7 square inches, so that 7 × 49 = 343 tons are required to crush the area when there is no bending.

Were the length such that the pillar broke under one-fourth of this weight, or 85·75 tons, this would show that only one-fourth of the cross sectional strength of the pillar —that is, one-fourth of the strength to resist pure crushing—was at work, the bending taking away the power to bear the remaining three-fourths; or we may put it thus— that the pillar breaks by bending, and that the one-fourth load is expended in bending to the breaking point.

But, as at one-fourth of the ultimate breaking load the limit of elasticity is reached, and the iron begins sensibly to crush, and as one-fourth of the ultimate breaking load is found to produce this effect, when the ratio of length to diameter is about 30 to 1, the modifying rule for columns of a ratio lower than that begins its use here.

175. If three-fourths of the ultimate crushing load be required to break the pillar—that is, ¾ × 343 = 257·25 tons—then three-fourths of the whole sectional area ¾ × 7 = 5·25 square inches is resisting crushing, and 1·75 square inches is resisting the bending force; that is, the pillar which requires this proportion of the ultimate breaking load to break it is so stiff, that its tendency to bend is only as 1, while its capacity to receive the load as a crushing force is 3. But long before this three-fourth crushing pressure is reached the elasticity

of the iron will be impaired, preparatory to destructive crushing.

176. Hodgkinson found that in cast-iron pillars, whose length was less than thirty times the diameter, one-fourth of the ultimate crushing load is sufficient to commence such change in the cohesion of the particles by crushing, that the fulcrum, so to speak, of the bending force yields to the pressure, and the pillar bears comparatively less than when the ratio of the length to the diameter is so great that the breaking load required is less than this one-fourth of the ultimate crushing load.

177. Let Figs. 47 and 48 represent pillars bending.

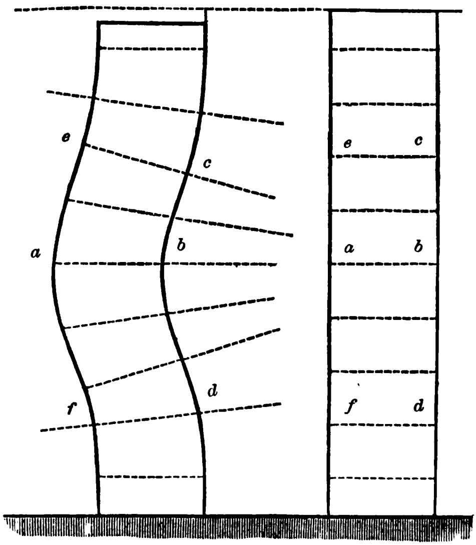

Fig. 47.

The bending force is on the side *a*, and the crushing on the side *b*.

In Fig. 48, the ratio of length to diameter is great, consequently, as the converging lines *a b*, *e c*, and *f d* show, the difference between the parallel space lines *e c* and *f d* in the pillar when straight, and the same when bent—that is, measuring on the lines *c d* and *e f*—is so little, because of the smallness of the diameter, that the pillar breaks by bending; whereas, in Fig. 47, the difference is greater on account of the largeness of the diameter, and the pillar breaks under both a bending and a crushing force.

178. To meet this comparative decrease of strength for

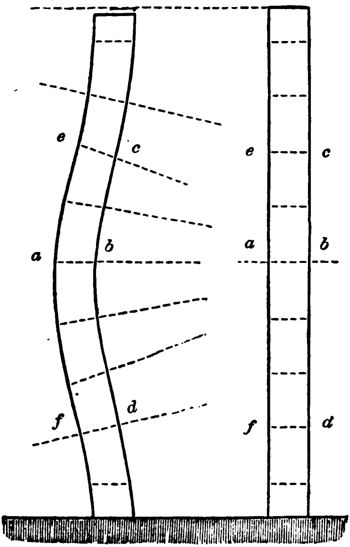

Fig. 48

short pillars, Hodgkinson gives a rule, which is only supplementary to the rules already given for long pillars, and is used to complete the calculations for the former.

P = the actual breaking load for short pillar.

b = the breaking load found by the rule for long columns.

c = the ultimate crushing load for the area of cross section when there is no bending. We have already stated it at 49 tons per square inch.

(9) $$P = \frac{b \times c}{b + \frac{3c}{4}}$$

179. Equation (6) finds the strength by the rule for long pillars; but as the ratio of length to diameter is only 20 to 1, we must take the breaking load got by it, and place it for *b* in equation (9), and the ultimate breaking load for the seven square inches area being 343 tons, we will place that for *c*, so that the new question stands thus—

(10) $$P = \frac{223{\cdot}537 \times 343}{223{\cdot}537 + \frac{3 \times 343}{4}} = 159{\cdot}7$$ tons, the true breaking load, in place of 223·537 found by (6).

180. We will now make the length 14 feet, the diameter being 6 inches as before: this will give a ratio of 28 to 1, length to diameter.

(11) $$44{\cdot}3 \times \frac{632{\cdot}91 - 380}{88{\cdot}801} = 125{\cdot}81$$ tons, according to the rule for long columns; but

$$P = \frac{125{\cdot}81 \times 343}{125{\cdot}81 + \frac{3 \times 343}{4}} = 113$$ tons true breaking load.

181. We will now make the length 15 feet, with the ratio 30 to 1, length to diameter.

(12) $$44{\cdot}3 \times \frac{632{\cdot}91 - 380}{99{\cdot}851} = 112{\cdot}21$$ tons; but

$$P = \frac{112{\cdot}21 \times 343}{112{\cdot}21 + \frac{3 \times 343}{4}} = 104{\cdot}18$$ tons true breaking load.

182. We will now make the length 17 feet, with a ratio of 34 to 1, length to diameter.

$$(13) \qquad 44{\cdot}3 \times \frac{632{\cdot}91 - 380}{123{\cdot}53} = 90{\cdot}72 \text{ tons.}$$

$$P = \frac{90{\cdot}72 \times 343}{90{\cdot}72 + \frac{3 \times 343}{4}} = 89{\cdot}4 \text{ tons true breaking load;}$$

showing that the reducing rule holds good to a ratio of rather more than 34 to 1 theoretically, though its use is limited to ratios under 30 to 1.

183. Going back to equations (5) and (6), we find that the 6-inch hollow pillar (6), as reduced in (10), is 3·47 times stronger than the 3-inch solid pillar (5); and that increasing the length of hollow pillar from 10 feet, as in (10), to 25 feet, as in (8), has made the longer pillar (8) 3·4 times weaker than (10), and consequently of nearly the same strength as the thin solid pillar (5).

184. The ratio of the pillars (5) and (7), length to diameter, is alike 40 to 1; but they are not similar pillars, as the one is solid and the other is hollow.

Let us assume that the 6-inch diameter (7) is solid, and compare it with the 3-inch solid (5). We find that the former when solid breaks at 171·6 tons: dividing this by 45·97 tons for the 3-inch diameter gives us 3·73 times the 6-inch diameter is stronger than the 3-inch; so that, though the 6-inch pillar of 20 feet length contains 8 times the weight of iron, it bears only 3·73 times the load.

185. Hodgkinson says, regarding this, that "in similar pillars the strength is nearly as the square of the diameter, or of any other linear dimensions, and as the area of the section is as the square of the diameter, the strength is nearly as the square of the transverse section;" or, to put it in form, the strength is as $\frac{d\ 3{\cdot}6}{L\ 1{\cdot}7}$.

The square of the lesser diameter is $3 \times 3 = 9$, and of the greater $6 \times 6 = 36$, $\frac{36}{9} = 4$ times, so that 3·73 times is less than would be got by the square of the diameter; but as the rules are based on the mean or average results of experiments with a series of pillars having a wide range of ratio, they are positive only as respects the mean ratio of this range.

186. Allowing for the difference in the respective breaking loads for different cast iron, taken by Gordon and Hodgkinson, namely—80,000 lbs. per square inch by the first-named, and 109,800 lbs. per square inch by the last—these results, worked out by Hodgkinson's rules, agree with Gordon's tabular quantities, some of which we gave in connection with the relative strength of cast-iron and wrought-iron columns.

187. Hodgkinson's reducing equation (9) for short pillars is arranged so that there is left out from its divisor $\left(b + \frac{3c}{4} = b + c - \frac{1}{4} \text{ of } c\right)$ one-fourth of the ultimate breaking load already spoken of as reaching the limit of elasticity at the line drawn between long and short columns, so that the remaining three-fourths of the ultimate crushing strength left yet unexpended in the pillar, whose length is not more than 30 to 1 of diameter, is alone used in finding the comparatively reduced strength of the short pillar; and as the reduced result gives the true breaking load of the pillar, the working load should not be more than one-fourth of that for a quiet burden. But if there be vibration to aggravate the stress from the dead load, the load should be much less than one-fourth of the breaking weight.

188. The rules we have hitherto been dealing with relate to pillars with their ends square and firmly set, or secured solidly by riveting, as in the case of T-iron supports to girder plates.

When the ends are rounded, as in the case of Fig. 49, the pillar breaks with about one-third of the load that breaks the square-ended pillar, showing that the rounding of the ends has taken away two-thirds of the strength; and the same loss is suffered when the pillar acts as a strut, or as a connecting-rod, hinged at both ends, as in Fig. 50, because, in either case, the stress acts mainly through the centre line.

Were the eyes, *a* and *b*, of the hinged strut heated and shrunk firmly on to the hinge pins, the full strength as for riveted or square ends will be got only when the ratio

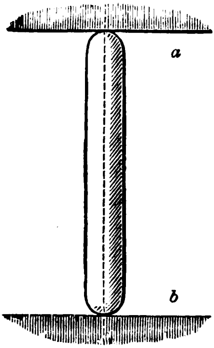

Fig. 49.

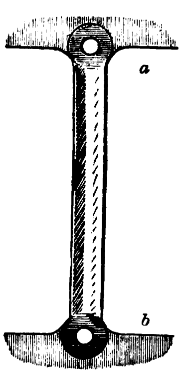

Fig. 50.

of length to diameter is so great, that the breaking load is insufficient to crush, and the pillar breaks by bending.

189. The pillar, as in Fig. 49, or as in Fig. 50, when the pins work easily in the eyes, is as free to bend as a beam placed horizontally on end supports, with the ends free as in Fig. 26; whereas the pillars with ends square and firmly set, or, as in Fig. 50, with the eyes shrunk on to pins, can bend only in the manner shown in Fig. 27, which accounts for some of the difference in comparative strength in the case of long pillars, when tested against

short ones; but in this question of square ends against rounded ends, the difference is mainly owing to the reduced area of the ends in contact with the load and sole plate, or with the rounded surface of the pins, allowing crushing to take place sooner.

190. When one end is square and one rounded, as in the case of a piston-rod, the rod breaks with about two-thirds of the strength of square-ended pillars; that is, its strength is midway between the square-ended and the round-ended pillars.

191. Hodgkinson's rule for pillars with rounded ends is—

$$P = 13 \times \frac{D^{3 \cdot 6} - d^{3 \cdot 6}}{L^{1 \cdot 7}}$$

The constant here is only 13 tons, which is 3·4 times less than the constant for square-ended pillars.

192. A long pillar that is uniformly equal in diameter, with its ends firmly fixed, is equally strong with a pillar of the same diameter, and half the length, with the ends rounded.

193. Hodgkinson found that enlarging the diameter in the middle part, as is usual in the case of connecting-rods, increased the strength not more than $\frac{1}{7}$th or $\frac{1}{8}$th; but that this does not hold good in the case of hollow pillars, either with the middle enlarged or with the lower end greater in diameter than the upper end, when the sectional area is uniform; that is, when the enlargement of diameter is at the expense of the thickness of the shell.

194. We learn from him further that when a square-ended pillar is so badly set that the stress comes upon the corners, as in Fig. 51, the strength available will be the same as for Fig. 49, with rounded ends.

195. And also, that pillars of uniform section riveted at one end and hinged at the other, or flat at one end and rounded at the other, break at $\frac{1}{3}$ of the length (nearly) from the hinged or the rounded end; therefore he recom-

mends that part of the length to be proportionately stronger than the rest. Pillars of this description will bend in the same manner as beams that have one end firmly fixed and the other merely supported.

196. Cast-iron under crushing force:

When the lateral dimensions, or diameter of the section, are great compared with the height, the middle of the height becomes flattened and increased in diameter so as

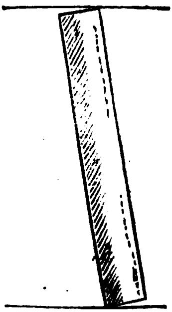

Fig. 51.

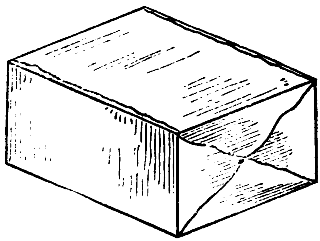

Fig. 52.

to burst there; but when the diameter is equal to, or less than, the height, fracture takes place by wedge-shaped pieces breaking off, as in Fig. 52.

The angle of wedge fracture in cast iron is such that the height of the wedge is somewhat less than $\frac{3}{2}$ of the diameter. This is the angle of least resistance for this material.

197. Wrought iron under crushing stress flattens and enlarges in diameter without splintering.

198. A beam or long column that is bending under a burden that is less than the breaking load, resumes nearly its original form on the load being removed; the extent to which it falls short of that form is termed the permanent "set," and was found by Hodgkinson to equal the 1·88th power of the contraction in length by compres sion, and a little higher than that for the extension in

length by stretching. This is equal to the square of the length of contraction or extension nearly; that is, to the square of the difference between the original straight length of the beam and the length measured on the curve of deflection.

199. A beam or long column that has received a permanent set from a given load, may have that load applied again and again, without increasing either the load deflection or the permanent set, so long as it is re-applied in precisely the same manner as at first, showing that all loads less than that which caused the set are acting within a limit of elasticity.

200. In some experiments made by Hodgkinson with cast-iron beams of T sectional form, with very wide flanges, but short middle rib, tested with the broad flanges alternately up and down, the strength for this particular section was found to be three times greater when the flanges were in tension, than when in compression with the narrow end of the middle rib in tension; but that the deflection for a given weight was the same in both, so that when the flanges were in tension with their three times greater load, the deflection was proportionately three times as great; and the ⅓ load that broke the beam when the narrow point of the middle rib was in tension, gave an equal deflection to that got from the same load when the flanges were in tension.

SECTION V.

201. Elasticity is believed to be no more than the range or play of attractive and repulsive forces in matter.

When good wrought iron is subjected to a strain of 10 tons per sectional square inch, it is stretched so as to increase its length 1-1000th part. Its natural elasticity is considered to be near its limit at that point, and the addition of a little more will produce decided permanent set.

If the same bar be heated to from 150° to 200° above its ordinary temperature, it will, by heat-expansion, similarly elongate by 1-1000th of its length without sensible injury.

202. Walls that are bulging out are sometimes brought to the plumb again by means of rods heated in the middle, screw-nuts being used at the ends which project through the walls, to take up the elongation produced by the heat, so that when the heating lamps are removed, and the rods allowed to contract by cooling, the ends can follow the contraction only by bringing the walls in with them; a double set of rods being used for this purpose, each set heated alternately.

203. As heat increases, attractive force appears to loosen its hold upon the atoms of the iron, while repulsion seems to operate with increased effect; so that when the temperature rises sufficiently to soften the iron, as in forging heat, the atoms stand free of one another, to an extent measurable by the expansion, and thus have room to rearrange themselves under any stress that may now be applied externally; as, for instance, from the screwing of the nuts upon the ends of the rods; but, as the tensile strength depends upon the energy of the attractive force between the atoms, a very small power applied to the tightening of the nuts when in this state would be sufficient to break the rods, though, on account of the freedom of motion among the atoms, the rods would stretch before breaking much more than when strained in the cold state. Were the screwing stopped short of an actual break in the hot state, and the natural contraction by cooling allowed to begin, the atoms would continue rearranging themselves under the gradually increasing tension, until the tension becomes equal to the breaking strength of the

rod for the temperature it breaks at. If the tires of carriage-wheels be put on too hot, they will bind so tightly before contraction has ceased, as to leave too little working strength between the tension they finally cool at and the breaking tension.

204. Were the rods allowed to cool from a red heat free from any external strain such as was produced by this tightening of the nuts, they would contract with their elasticity uninjured, that is, with the attractive and repulsive forces in perfect balance among the atoms, and therefore in natural condition for perfect strength; and any local or part-strains that before heating may have been produced in the rods—as for instance, when straightening accidental bends while cold—will all have been removed. This has been ascertained by direct experiment; thus, bars bent and re-straightened in a cold state, broke under a less load, when not heated red, and allowed to cool gradually before testing, than when they had been so heated and cooled.

205. A bar of tough wrought iron bent as in Fig. 53

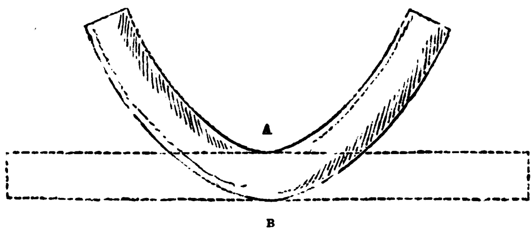

Fig. 53.

has in the bent state the particles on the inner line A in a state of compression, and those on the outer line B in a state of tension. If straightened cold, this condition will be reversed, the particles A will be forced into a state of tension, and those of B into a state of compression, with a tendency to rupture among the particles at A, as may be observed when breaking small rod iron by bending force. In the bent state the particles are at rest in a permanent set.

The particles under compression are squeezed together so as to make the thickness of the upper half at A swell out, while those under tension are so drawn as to make the thickness less at B than originally.

The particles have to roll or slide upon each other with no other hold, so far as is known, than their mutual attraction.

On straightening the bar the particles which form the bulged part at A, having had their fibrous continuity broken by the crushing, possess less strength under tension now than the particles B had at the first bending; so that if rupture does not take place at A in the act of re-straightening, it will be liable to take place at B on re-bending the bar, as B will now be in tension after two previous disturbances of the particles that compose it.

206. In further illustration of the readiness with which the atoms of iron rearrange their relative positions in a bar under stress, we may instance wire-drawing, in which, by small reductions at a time, a rod is reduced in diameter by repeated drawing through perforations in hard steel plates.

207. We may readily assume that an equal number of atoms is contained in a pound of thin wire as there is in a pound of the original rod: so that, if 2 feet length of the rod and 6 feet of the wire weigh alike 1 lb., the sectional area of the wire will equal only $\frac{1}{3}$ of the area of the rod, so that the atoms or particles must have rearranged themselves in the reduction.

If we look at the sand running through the neck of a minute-glass, the tube of which is of small diameter, a very general but not an incorrect idea may be formed of the manner in which the atoms are drawn into their new positions. Were the sand which lies next the glass differently coloured from the central quantity, the grains passing through would be seen mixed.

208. The pressure to which wire is subjected in passing in a cold state through the draw-plate makes it harder and finer in the grain, but, contrary to what might be expected, its weight for bulk is decreased. It expands more, however, under heat than iron of coarser and looser grain, probably because the particles having been reduced to smaller size the spaces between them are more numerous, and it is in these spaces that the source of elasticity lies.

209. It is well known that the act of rolling or wire-drawing iron disposes the particles in parallel lines, evidence of which is had in the appearance of the skin of rolled bar-iron or of wire that has been for a time subjected to the action of sea-water.

Kirkcaldy's experiments have shown that if a bar be broken by a sudden blow, the fracture has a crystalline appearance; whereas if it be broken by force slowly applied, the fibrous texture is made apparent.

Hodgkinson, on the other hand, dealing with the material in different form and greater bulk, found that in beams broken by a blow the position of the neutral line was sometimes, but not invariably, made apparent by the respectively crystalline and fibrous appearance of the upper and lower sides of the fracture. He found the position of the neutral line more clearly indicated by those appearances in the slow fracture of columns that were too long to break otherwise than by bending. In Kirkcaldy's experiments, however, the character of the fracture is stated to be dependent somewhat on the shape of the specimen and its degree of hardness.

210. In breaking small sections such as Kirkcaldy used, the action of a sharp blow passed so quickly through the section, that the particles were jerked asunder so as to present a granular appearance, no time being allowed for

the stress to feel along the fibres to their weakest parts; whereas in larger sections the vibrations from the blow would take longer time to pass through, and give more time for the fibrous arrangement of the particles to yield at the weak points.

211. It has been asserted that continued vibration, when severe enough to encroach upon the ultimate limit of elasticity, will sooner or later change the texture of iron from the fibrous to the crystalline character, but this is still an unsettled question.

212. A series of experiments made under the direction of the Commission on Railway Structures, show that cast-iron bars, vibrating under repeated blows from a suspended weight, resisted the effects of 4,000 blows, each blow bending the bar through one-third of the deflection the bar would break at. When the blows were made heavier, so as to bend the bar through one-half of the breaking deflection, one bar only, out of seven, was able to stand 4,000 blows in succession, some breaking with less than 130 blows, owing to slight flaws.

When the blows were made so heavy as to bend through two-thirds of the breaking deflection, 178 blows were sufficient to cause fracture, showing that the incessant sliding of the particles backward and forward on each other to allow of the bending, quickly destroyed cohesion in the case of the heavier blows, so that when fracture took place the bars broke under considerably less strain than they would have borne with a quiet load.

213. Wrought-iron bars, on the other hand, appeared to be very little affected in strength by 10,000 blows from a revolving cam, each blow being in effect equal to half the load which, when quietly applied, produced a considerable permanent set among the particles.

214. Iron is increased in strength by being rolled cold, or wire-drawn, and also by being stretched under moderate strain when heated to a dull red.

Professor Johnson, of the United States, heated to 500° Fah. a bar of iron having a strength of 60 tons, and then by stretching 6½ per cent. of its length, raised the strength permanently to 72 tons.

The results of experiment lead to the belief also that when an ordinary bar has been broken cold by direct tensile strain not long continued, the parts have been made stronger by the stretching than the whole length in its original or normal state. Against this belief, however, there is an opinion that as a bar will always break at its weakest point, at each successive test, the break occurs at the point which is now the weakest, but which is stronger than the point that last broke.

215. This much is certain, that the part-bar does not break with less load than before broke the whole bar, that is, that the ultimate tenacity or breaking strength is never found less in the part than was found in the whole. It has been saved from injury during the destructive part of the stress due to the breaking load by the part at the fracture, more or less abruptly, giving way as the point of weakness. Also, it is certain that no weight less than the load which produced the permanent elongation or "set" in tension can make the set greater.

216. A bar that is being tested for tensile strength elongates by the yielding of its whole length; but short bars stretch proportionately more than long bars.

217. The rule for the elongation per foot or inch of the bar's length we find to be, where—

L = length of bar,
l = elongation in feet or inches,
$\left.\begin{matrix}2{\cdot}5\\0{\cdot}18\end{matrix}\right\}$ are constants.

$$l = {\cdot}18 + \frac{2{\cdot}5}{L}$$

In a series of experiments made by Lloyd with wrought-iron bars, using a tensile strain of 32 tons per square inch, 120 inches length stretched 26 inches, = ·216 inch stretch per inch length, while 10 inches length stretched 4·2 inches, = ·42 inch stretch per inch length.

218. When the bar has been once broken, and one of the parts is being retested, and has got the load that made the first break hung quietly to it, a small addition to this load is requisite to make a new break, but a blow, more or less heavy according to the character of the iron, and the nearness of the permanent set from the last breaking load to the breaking point now, will have the same effect as an addition to the load, the vibration putting the already stretched particles in motion for rupture.

219. A bar that breaks by tension thins out at the point of fracture. The reduced area of the thinned part cannot contain the same number of fibres as the less reduced parts that have been only stretched within the limit of elasticity. The bar breaks in the thinned part, but the ultimate strength to resist tension is gauged by the area of the simply stretched part, and not by the contracted area at the point of fracture, as the latter serves mainly to indicate the comparative toughness.

In explanation of this, it would appear from actual test that the moment the particles begin, as they generally do more or less suddenly, to slide on one another at the increased rate observable in the diminishing of the diameter at the place of fracture, the elasticity of the bar has been overcome, that is, the hanging load, plus the natural repulsive force among the particles, have together carried the cohesive force to the limit of its holding power, on passing which the particles, like balls let loose in close succession from a state of rest on an inclined plane, start off downwards with a quickly increasing velocity, governed by the laws relating to falling bodies, until, as illustrated in Fig. 54, those that are first let loose having the lead in this increasing speed, soon so outrun those coming on behind that the cohesive force loses its hold entirely, and the bar breaks.

But this is merely illustrative, and can operate only when the iron is soft and fibrous, and when the force is not of the nature of a blow.

Cast-iron snaps suddenly, with little observable contraction at the place of fracture.

220. The limit of elasticity in coarse, hard, crystalline iron lies nearer the limit of ultimate strength than in iron

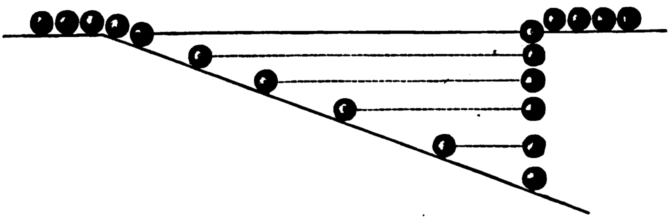

Fig. 54.

of fine soft fibre; and it would appear that in different specimens of iron, possessing about the same ultimate breaking strength, the limit of elasticity is found so variable that no rule for it can be formed.

In soft fibrous iron a fraction of the load that would break is sufficient to give a decided permanent set; whereas in hard, unyielding cast iron it may take, more or less, nearly the whole load. This has to be considered when questions of deflection in beams arise.

221. We do not know the strength of cohesion remaining in the reduced part at the fracture, that is, in the length *a b*, Fig. 55, as that length is too short for direct test to be made.

Some experiments for transverse strength, however, made by Fairbairn, lead to the belief that the particles there have get a permanent set, just bordering on rupture. In a place quite free of vibration, he loaded long cast-iron bars with nineteen-twentieths of the breaking load. Some of them bore this for five years, the deflection steadily but minutely increasing during the whole time, but greatest during the first fifteen months; and as the deflection of one of the bars came to a rest at

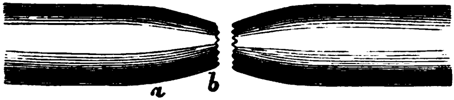

Fig. 55.

the end of the second year, while the small and gradually lessening rate of increase per year for the others appeared to be equal, even though some were loaded with only thirteen-twentieths of the breaking weight, there seemed reason to believe that the deflection would remain stationary on reaching a point as far short of the breaking point as the actual load was short of the load required to break.

On removing the loads so as to let the bars recover themselves from the deflection, he found on re-applying weights that some of the bars broke with only one-twentieth of the original breaking load. Showing that the effect of nineteen-twentieths of the breaking load when borne for a great length of time was to give the particles a permanent set that retained only one-twentieth of the original strength. The lighter load produced fracture because of the disturbance among the particles, caused by the changing of the loads.

We do not know the precise effect heat would have had in rearranging the particles of cast iron so as to restore the lost strength, but as the wrought-iron beams severely bent in the course of other of Fairbairn's experiments were frequently restored to their normal or original condition as regards cohesion, by partial annealing previous to further test, and always when so treated exhibited renewed strength, there might be similar restoration in the case of cast iron, but possibly the heat might require to be greater than a bright red, to give expansion enough for rearrangement of the particles.

222. In some of Hodgkinson's experiments on the transverse strength of cast iron of different sorts, we find that hard white iron deflects as 1 to 1·5 average for hard whitish grey, the latter being less hard than the former; and that hard white deflects as 1 to 2·224 for soft grey, showing that the deflection is not uniform with the breaking load, but that it decreases as the hardness increases.

The moduli of elasticity given by Hodgkinson for the different sorts of iron vary with the hardness, so that in finding the deflection by calculation, when we use the modulus properly belonging to the quality of the iron under treatment, we have no need to consider the difference in bending strength between white and grey qualities.

The modulus we have used in the rule for deflection is high. Lower qualities of iron will simply require the lower modulus to be substituted for that high one when the extent of compression per ton load is required.

SECTION VI.

223. Cast iron, wrought iron, and steel, have only two essential ingredients, viz., pure iron and carbon.

Wrought iron may contain 0·25 per cent. of carbon without becoming steely; but when it contains 0·6 per cent., it strikes fire with a flint after tempering; but this depends greatly upon the purity of the metal, so that the purer, and therefore the softer, the metal, the greater must be the proportion of carbon.

Steel suitable for cutting instruments contains from 1·0 to 1·5 per cent. of carbon.

Steel containing 1·75 per cent. of carbon cannot be welded.

When iron is combined with 2 per cent. of carbon, it cannot be forged under the hammer.

Iron that has more than 1·9 per cent. of carbon is no longer steel, but cast iron.

224. Carbon exists in cast iron in two conditions, viz., chemically combined with the iron—that is, crystallising with it as if possessed of a kindred nature—or it may be merely mixed up with it in such manner that the carbon appears in the intervals between the crystals of the iron.

225. Cast iron is of three general sorts, viz., white, grey, and mottled, with varieties between, some of which are bluish, on account of other ingredients than pure iron and carbon.

The strength of cast iron does not depend so much on the whole quantity of carbon contained as on that with which it is chemically combined.

226. Remelting of the iron in the cupola reduces the quantity of mechanically mixed carbon, and increases the proportion of combined carbon.

Fairbairn, in experiments with hot blast pig-iron, found that bars from the first melting, of 1 inch square and 4·5 feet between the supports, broke under a transverse strain of 490 lbs., with deflection equal to 1·44 inches, and that the strength increased progressively with the remelting, until it reached its maximum at the twelfth, when it required 692 lbs. to break it, the deflection having increased to 1·666 inches. From this point it decreased till at the eighteenth it broke with 312 lbs.; but the deflection was now only 0·476 inch. The density, however, continued increasing to the last, and the strength to resist compression increased with it, but in an irregular manner after passing the twelfth remelting.

227. The results showed that tenacity increases uniformly with the density up to a given point, after which increased density is accompanied by diminished tenacity; but as in some cases great tenacity is found accompanied by comparatively low density, the results of these experiments are given only as applying to the description of iron used.

228. By keeping cast iron fusing at high heat for from two to three hours, fewer remeltings are required to bring it to this condition of maximum strength. In the condition of maximum strength, the iron has become denser and heavier, and consequently more rigid than before, so that it will stretch less under tensile strains and deflect less under transverse strains from a given load.

The softest kinds of iron will endure a greater number of remeltings with advantage than the harder kinds.

229. The grey and mottled sorts only are used for ordinary castings, being easily fused, and less brittle than the white sort, which is used in the making of wrought iron and steel; but there are several qualities of the white sort.

In some cases the whiteness is produced by suddenly cooling molten metal, which, if let cool slowly, would be grey: when this is done, the white has the carbon in the combined state, that is, it has it hidden within the iron crystals.

White iron of this description is easily fused. The white iron used in the making of wrought iron is specially made with a minimum per-centage of carbon contained in it.

230. The respective amounts of combined and of free carbon in cast iron are found by dissolving the metal by means of an acid, the free carbon being always left unaffected, while the combined carbon has gone with the dissolved metal, the exact amount of the latter being ascertained by another process.

231. In dissolving white cast iron which has nearly all its carbon chemically combined, the carbon, released from combination with the metal at the same time as the hydrogen is evolved by the decomposition of the acid, seizes upon the hydrogen to form a hydro-carbon, that is, to combine and form an oil which is afterwards found floating on the surface of the solution.

232. The free carbon, called graphite, which is to be seen in a fracture of grey iron, crystallised independently in the intervals between the crystals of iron, has its chemical liking or affinity satisfied in its independent crystalline state, and remains unaffected by the hydrogen.

SECTION VII.

233. We have now to consider the treatment of the iron ore in the smelting furnace for the production of the different sorts of iron, but must first explain the character of the different materials employed.

234. The only ores of iron employed are the oxides and the carbonates, so called because of oxygen and carbon being the principal elements in combination with the iron.

When they contain less than 25 per cent. of iron, they cannot be smelted profitably by themselves; but sometimes poorer clayey ores are used to mix with the harder ores to ease the melting and the separation of the earths from the iron.

235. Calcareous ironstone contains lime in combination, so that less fluxing material has to be thrown into the furnace. Fluxes in iron smelting are substances which differ according to the nature of the ore, but which consist principally of lime, clay, and sand, and are thrown in with the fuel and the ore to seize upon and combine

chemically with the earthy parts of the ore on their reaching heat sufficient to melt them, and thus liberate the iron.

236. Argillaceous ironstone contains clayey elements in combination, which fuse more readily when silex or pure sand is added in the furnace, or when ore containing silica is mixed with it. When the ore contains only quartz or silica, both clay and lime must be added; but as the argillaceous or clayey kinds are much more common than the siliceous kinds, a mixture is generally made, so that only lime is needed. When there is too little lime and much clay and silex combined with the iron, the clay and silex keep hold of a portion of the iron, which is consequently lost in the slag.

237. A mixture of ores, so as to give an easily fusing proportion of these three earthy matters—viz., lime, clay, and silica—is better than adding special fluxes to single ores which are deficient.

The most fusible flux, used with charcoal fuel, is obtained by adding to native clay, which varies but little in its composition, two-thirds of its weight of carbonate of lime. This forms what is termed a double silicate, in which the silica, of the one part, possesses twice as much oxygen as do the united alumina and lime of the other part in their state of combination.

Long exposure to furnace heat would waste this oxygen, and as it reduced in quantity, so would the compound become less and less fusible.

The temperature at which a double silicate fuses is almost always lower than the medium temperature of fusion of the various simple silicates which compose it; sometimes it is even below that of the most fusible of these simple silicates when alone. A similar difference in the fusing temperature is observable in metallic alloys, such as a mixture of lead, tin, and bismuth, with a similar hardening when long exposed to heat.

238. When coke is used in the furnace, there is often a considerable quantity of sulphur which cannot be altogether prevented from combining with the iron, and which requires a change in the composition of the flux. The proportion of silica must be reduced, so as, by its reduction, to leave the lime more free to enter into combination with the sulphur, and so becoming sulphide of calcium amongst the slag. Calcium is the metallic element in lime which, when combined with a single measure of oxygen, is known as quicklime.

239. Silex, known also as silica, or silicic acid, is one of the commonest substances in nature. It is formed by a combination of the simple element silicium with oxygen.

By itself it constitutes rock crystal, quartz, sand, &c., and when in combination with other matters it forms granites, slate, common glass, &c. All rocks which are not calcareous or of a limy nature are siliceous.

240. The meaning of the term acid used in connection with silex and certain gases, must not be taken in reference to taste, but simply as denoting the presence of a certain large proportion of oxygen, which, though a colourless gas in one of its states, without either taste or smell, got this name, signifying, "I produce sourness," at a time when it was thought all acids contained it, and consequently that all things containing it must be more or less of an acid nature.

As a convenient term in chemistry it applies alike to rock crystal, to certain liquids, and to one of the gases generated by combustion.

241. Oxygen has been termed the great combining substance of nature. Of all substances it is the most widely distributed. It forms eight-ninths by weight of water, the other one-ninth being hydrogen.

Almost one-half of our solid rocks are made of it, and one-fifth of our atmosphere, the remaining four-fifths of the latter being nitrogen.

It is everywhere present, and is ready at all times to unite with any one of that class of bodies called combustible, when exposed to it at the necessary temperature.

242. Aluminium is another very common substance. Its oxide, formed by its combination with oxygen, is called alumina, and in this oxide state it is often found crystallised in nature, and is found nearly pure in the precious stones, the ruby and the sapphire, the colour being derived from a combination with the oxides of some other metals.

243. Alumina is infusible in ordinary furnace heat. When combined with silica and a certain proportion of water it forms the clays, so that clay is called a silicate of alumina.

Almost always, however, a small quantity of silicate of potassa is combined with it. This latter substance enters also into the composition of the majority of the crystalline rocks, and also into that of glass.

244. Calcareous rocks or limestones are composed of carbonate of lime, one of the most extensively diffused substances on the surface of the globe.

Iceland spar, so highly prized by opticians for its double refracting properties, and also marbles, chalks, &c., are composed of it, under different chemical conditions.

245. Carbonate of lime is composed of an earthy, metallic element called calcium, combined with oxygen and carbonic acid, carbonic acid being a special compound composed of oxygen and carbon.

Before fusing, it decomposes by parting with its carbonic acid elements, and being left in the intense heat of the furnace, in the form of the oxide of calcium, or simple quicklime, is in a highly favourable state as a flux, for recombination with the other matters it is in contact with.

246. Lime by itself does not fuse at the highest temperature we have ever been able to produce in furnaces.

The same may be said of silex and of alumina.

The strongest heat known produced by the oxy-hydrogen blow-pipe fuses them with difficulty when taken singly.

Alumina is, after the diamond, the hardest substance in nature.

247. In the case of siliceous and dense hematite ores, of a refractory nature, deoxidation, that is the extraction of the oxygen which is chemically combined with the iron in the ore state, is apt to take place mainly on the crust of the ore block, thus leaving the main work to be done when the ore reaches the melting heat, when there is no time afforded for carbonizing, as the iron must then either run or burn, hence an inferior white iron, containing a minimum dose of carbon is produced. This evil is in addition to the loss already spoken of, caused by the imperfectly fused slag retaining a portion of the iron.

248. The argillaceous and carbonaceous ores are of totally different structures. The operation of roasting in a kiln expels the carbonic acid of the latter ore, and leaves the roasted ore of a porous structure open to the carbonic-oxide gas of the smelting furnace, the united surfaces of all the pores giving the gas so much greater breadth to work on, that the deoxidation and subsequent carbonization of the iron are complete, for the production of grey iron.

249. Iron smelted from carbonaceous ores contains more carbon than iron smelted from argillaceous ores. On this account, the former are better suited for foundry iron, and the latter for conversion into malleable iron and steel.

250. Carbonaceous ores being of a very fusible character require less blast, and as the weaker pressure of a reduced blast suffers the gases to linger longer on their way up through amongst the descending ore, the iron is allowed time to absorb the large per-centage of carbon required for grey iron.

251. If the metal be wanted for conversion into malle-

able iron, the blast must be quickened, so as by quick combustion of the fuel to bring down the ore at a faster rate, and make the velocity of the rising gases too great for the deoxidizing and carbonizing operations to be completed. This will save waste in the refinery and puddling furnaces, there being less carbon to expel from the iron.

A further increase of the blast will produce white iron, because the absorption of carbon by iron is rather a slow process, and cannot be hastened by forcing the combustion of the fuel, but must be allowed time for the regular combination to take place. Forcing the heat simply hastens the melting.

252. When grey or foundry iron is to be made, an extra proportion of fuel is used; but as grey iron is produced by a weaker blast than is used in the case of forge white iron, it is considered that this extra proportion of fuel acts mainly in allowing the iron longer time to absorb the requisite amount of carbon, seeing that the rate of combustion is regulated by the blast alone. An accidental increase of the blast would raise the temperature at the melting place by increasing the rate of combustion, and as this would enlarge the fire and carry the heat farther up, the iron that had not yet absorbed sufficient carbon to make it grey would be melted down, and the colour of the metal produced would be whitish.

The blast may be accidentally increased when the hot blast is being used by allowing the fire which heats the blast pipes to get low: the air inside of the pipes is less expanded, being colder, consequently, so long as the blowing engine moves at the same rate, a greater weight of air passes through the tuyer pipe than when hotter.

253. The strength and manner of applying the blast depends greatly upon the nature of the fuel; thus, pure charcoal burns with a clear, bright, porous surface, which enables the air to come into intimate and clean contact with the carbon, for the quick formation of carbonic acid

in the first place, and of carbonic oxide a little higher up.

254. If the fuel be mixed with earthy matters, and therefore impure, a crust is apt to form, which prevents the air from getting to the carbon, so that the temperature is kept low. Only a portion of the air is then decomposed by combustion near the tuyeres, and the rest in its upward velocity becomes decomposed, or converted into carbonic acid, at a slow rate, so high up in the belly of the furnace, that the carbonic oxide which is subsequently formed, has too little of the material above it to operate upon with full effect in the manner we will presently explain, so that the iron comes down to the melting zone imperfectly deoxidized.

255. The number of tuyeres to each furnace varies at different works. The usual number is three; but sometimes as many as twelve are employed. The greater the number, the smaller the bore, when the pressure per square inch of the opening is the same.

The nature of the fuel and the width of the hearth have to be considered in determining these points.

The greater weight in each of the three larger jets is likely to carry the air farther across the hearth than the lighter and smaller jets can force it; but the more numerous jets diffuse it better round about.

The pressure of the blast varies from 2 lbs. to 3½ lbs. per square inch, according to the dimensions of the furnace and the kind of coal used.

256. We learn from Truran concerning the working of certain cold-blast furnaces at Dowlais, using argillaceous ores, that the materials for grey iron were in the furnace forty hours before being made liquid. That the rate at which the materials sank in their progress to the melting point was at the top 28 inches per hour; at the lower part of the belly, where carbonization was taking place with full effect, the rate was reduced to 7 inches per hour,

but that it increased to 35 inches per hour in the last stage at the hearth.

An increase or reduction of the blast, with proportion of ore and coal as before, would make this rate of descent correspondingly quicker or slower.

For white iron nearly the same time was used, the proportion of ore to fuel being greater than for grey iron.

When more easily fused ores were used thirty-three hours before melting were sufficient.

257. The air passing through the tuyeres up through the mass of ore and fuel required, in the case of Dowlais grey iron, seven seconds, and for white iron, four seconds, showing that white iron requires a quicker blast; that is, a greater volume of air than does grey iron.

258. Each ton of grey iron melted required 13 tons of air by the blast, which rose through the material in the belly of the furnace at the rate of 415 feet per minute, and escaped by the chimney in the form of gas at the rate of 1,660 feet per minute. For this quantity of air $5\frac{3}{4}$ tons of solid matter, consisting of coal, ore, and limestone flux were used.

259. The gaseous and liquid products respectively issuing from the furnace top and from the hearth, are nearly in the same *ratio* for white and grey irons. For the production of grey foundry iron, the weekly consumption of solid materials thrown into the furnace was 747 tons, and of air thrown in by blast, 1,690 tons. $\frac{1690}{747} = 2{\cdot}26$ tons of air to 1 of solid materials; but as out of the solid material there were got only 130 tons of grey iron, $\frac{1690}{130} = 13$ tons of air to 1 of iron.

For the production of white iron of good quality for the forge, the weekly consumption of solid material was about 884 tons, and of air 2,312 tons, $\frac{2312}{884} = 2{\cdot}61$ tons of air to 1 of solid material; but as out of the solid material there were got 170 tons of white iron, $\frac{2312}{170} =$ 13·6 tons of air to 1 of iron.

260. By urging the blast so as to throw in a greater quantity of air more iron can be got in a given time; but, if the fuel be not correspondingly increased, the time allowed is shorter for the deoxidation and carbonization, and so the iron will turn out of white quality. If the amount of fuel, however, be increased in like measure with the air, so as to occupy longer time in consuming, grey iron can still be got at the increased rate of production. This, however, refers more particularly to the furnaces in question, as quality and quantity of iron produced vary somewhat in the ratio of the internal capacity of the furnace, and the volume of air blown in. Thus if the furnace be narrow, the rising gases from a given volume of blast must pass upward through amongst the ore with greater velocity than when the furnace is wide. The narrow furnace would with this given blast be favourable for white metal, where the wide furnace would favour the making of grey.

261. Truran, in drawing a comparison between two different furnaces, shows that the furnace which consumed least fuel to the ton of metal produced, having a slower blast than the other, occupied nearly twice the time in forcing the gases up through the ore, thus keeping them in longer contact with the ore in the upper parts, and retaining the deoxidized iron longer in carbonizing contact with the red-hot carbon above the melting zone. The consumption of carbon, to produce 1 ton of crude iron, and the different proportion to produce 1 ton of iron and slag combined, was nearly the same in both furnaces, but the quicker blast, smelting harder ore, even with three hours longer time, produced only an inferior white, while the slow blast produced a fair ordinary grey.

262. One consequence of increasing the blast for white iron is that the iron on reaching the sphere of melting heat is less fusible than the grey kind at that point, and requires all the intensity of heat produced by the quicker blast in front of the tuyeres to melt it; nay, owing to the great affinity of pure iron for oxygen and the impossibility of melting pure iron even with the fiercest heat, there is much danger of its burning, in which case the heat generated by the burning iron may become intense enough to carry the melting heat to a higher level in the belly of the furnace, and bring down the iron quickly in such crude state as to be very poor iron indeed. The affinity between oxygen and carbon being greater than between oxygen and iron, as is shown in the deoxidizing process, iron while being easier fused so as to get quickly away down out of danger, when it contains carbon, is at the same time relieved by the action of the carbon during the exposure to the oxygen; the relief, however, comes chiefly from the quicker escape.

263. Sometimes the iron has to be burned purposely, to melt down half-fused blocks that have got stuck to the sides when the furnace has been working cold. This is done by increasing the proportion of ore to fuel in feeding the furnace, so that the blocks remain till these altered proportions reach the hearth to take effect there in the increased blast. This fierce heat is reduced back to its proper degree by returning to the ordinary proportions of ore and fuel, with reduced blast.

264. When hot blast is employed, it is usual to raise it to between 600° and 700° Fah., though it is often as high as 1,000°; and in the Cleveland district, where heating batteries of brick instead of iron are used, a temperature of blast as high as 1,500° has been attained, and in certain instances even higher.

The heat thrown in with the air is measured by the fuel consumed in heating the battery of blast pipes, but as that heat is small in amount compared to the heat that would be given out by the fuel saved, it still remains to be explained clearly how the furnace fuel is so saved.

265. A reduction of the proportion of fuel to ore in cold-blast furnaces increases the quantity of iron produced in a given time, but then it is always made white by this reduction, and produced in a harder and more crude state, whereas, by the hot blast, both grey iron and white are produced with the proportionate saving in fuel.

266. The heat thrown in with the blast enables a less total quantity of fuel to give the heat required, and this less quantity of fuel being fed with oxygen from a less weight of expanded air, the time occupied by the combustion of the reduced fuel—this being ruled by the supply of oxygen—is nearly the same as when the heavier cold blast with the correspondingly larger proportion of fuel is used, so that time being given by the latter for the full carbonization required for grey iron, it is given also by the former.

267. Before proceeding further, however, we must make note of a few of the simple leading principles of chemical action, iron smelting being purely a chemical process, with heat operating as the agent in all the changes effected. We will glean from Reid and Wilson.

SECTION VIII.

268. Before chemical action can take place, the particles between which it is exerted must be brought by mixture into the nearest possible contact.

All bodies do not act chemically on each other.

Compounds can combine with elements and also with each other. Often this new combination, though complex, retains all the ingredients, but in some cases some of the elements are thrown adrift to combine with others in like circumstances. The larger the quantity of any ingredient, combined with another, the more easily is a portion of it separated.

The less the quantity of any substance united to another, the more readily does an additional quantity enter into combination.

The larger the quantity of any chemical agent brought into play, if not excessive, the more speedily will its action be effected; but there is danger in this of producing, by an excess, very different combinations to those wanted.

In judging of the excess, the surface exposed—so to speak—of the substances to be acted upon have to be considered.

Temperature, among other circumstances, has much to do with chemical action; thus quicklime, at ordinary temperatures, attracts carbonic acid strongly, but when heated they do not combine, which is the reason of carbonic acid being allowed to escape from carbonate of lime when in the furnace.

Two ingredients in combination may be separated by a third substance attracting one; this is termed a case of simple elective affinity.

When two compounds decompose each other, two new compounds being formed by an exchange of elements, it is said to be a case of complex affinity.

269. In the case of carbonic acid combining with an additional measure of carbon, we have the change that takes place thus expressed:—

Carbonic acid	carbon 1 measure oxygen 2 measures	carbon 1 measure oxygen 1 measure
Carbon 1 measure		oxygen 1 measure carbon 1 measure

The combining measure of carbon by election attracts one of the two measures of oxygen from the volume of carbonic acid, and separates in the manner shown to form two volumes of carbonic oxide, concerning which we will speak fully later on.

From the latter gas the carbon required for the deoxidation of the iron in the ore state is derived.

270. The term oxide denotes a less quantity of oxygen than an acid possesses.

271. Two elements in combination will resist the attraction of a third element approaching them, when the attraction of the first and second for each other is greater than the attraction of the third.

Or the reverse of this may take place. The combination between the first and second may enable them to unite themselves to the third, where the third would have had no attraction for them separately. As tested by the degree of fusibility, this applies to the combination of silex, lime, and alumina in the furnace.

272. The silicate of lime melts only at a very high temperature, and the silicate of alumina only at a much higher; and as melting must precede or be simultaneous with combination, it follows that without this extreme temperature no combination can take place. Whereas, when lime is mixed in the furnace with silex and alumina, its affinity for the silicate of alumina is so strong as to force the union of the two latter substances at a considerably lower temperature than they separately require; but this, as before remarked regarding fluxes, requires certain definite proportions of the respective substances.

273. Bodies coming into contact with each other at the instant they may be separating from a combination which is suffering decomposition, are peculiarly prone to combine with each other, and are then said to be in a "nascent" state; that is, the forcible disruption taking place in the process of decomposition throws the attractive forces into a condition of electrical excitement, which

enables new combinations to be effected quicker than when, earlier in the process, these forces were still partly satisfied in the combination breaking up.

274. There are only a very few substances that can be combined in any proportion like spirits and water. Many combine in any proportion till a certain quantity of one ingredient has been absorbed, beyond which no more can be taken.

This appears to be the case with iron and carbon. Iron will combine with any quantity of carbon up to about 6 per cent. of carbon, and cannot be made to take more.

275. Lime, silex, and alumina combine in various proportions, but a limit is soon reached with silex or alumina in excess, beyond which no fusion can take place at ordinary furnace temperature, and of course all further combination is prevented.

276. Atmospheric air is a mechanical mixture composed of 4 parts of nitrogen to 1 of oxygen. When the oxygen is taken up by the carbon in the furnace, the nitrogen goes free, and passes out at the top mingled with the other gases in a simply heated state.

277. Nitrogen acts a neutral part in the fire, neither burning nor supporting combustion, unless there be hydrogen from ordinary coal for it to combine with, when it burns to a slight extent if there be free oxygen present.

278. It serves mainly to dilute the other gases, so that oxygen, upon which combustion is so dependent, and which forms only one-fifth of the whole volume of air, can be consumed only in a manner similar to the particles of gunpowder in Gale's safety-mixture of ground glass and powder, the particles of powder in which being kept separate by the intervening particles of glass are prevented from burning otherwise than separately, so that the combustion is slow, and without violence.

279. The same amount of heat is got from 1 lb. of oxygen that has to be abstracted from the air, as is got

from 1 lb. of oxygen free and simple; the only difference being in the greater time required to bring the atmospheric oxygen into contact with the fuel, owing to the great volume of neutral element it is intermixed with.

Were the oxygen available in a pure state—that is, free from admixture—the heat produced by it would be too concentrated for iron-smelting purposes, whereas, when mixed with four-times its own volume of a perfectly neutral element, such as nitrogen, its power is diffused, and its action so delayed that time is given for all the different processes, of first heating the ore to the temperature necessary for the carbonic oxide to abstract the oxygen from the iron in its oxide state, and then for the iron so liberated to take up the required amount of carbon from the fuel to make it fusible.

280. When the metal is wanted with a minimum percentage of carbon contained in it, the blast is quickened, so as to bring more oxygen into combustion with the fuel. This intensifies the heat, pours upward a greater body of higher-heated gases, to warm by contact the descending materials, and bring them sooner to the melting temperature.

281. In the case of the hot blast, the proportion of oxygen to nitrogen is of course the same, but as the heat carried in by the blast is often near the temperature at which coal fires, the action is quicker than when, as in the case of the cold blast, the fire already existing has first to give a portion of its heat to raise the entering air to the temperature necessary for combustion, and on this account the combustion under a hot blast is more active and complete in the neighbourhood of the tuyeres than when the cold blast is employed; the final melting is delayed till the material nears the tuyeres, where the melting heat is as it were concentrated for sharper action, and as the heat carried in by the blast enables the smelting to be done with less fuel inside, the smaller quantity of

fuel is sooner burnt away in the zone of fusion, and, consequently, the successive layers of ore come down more rapidly, and yet the deoxidation of the ore and the succeeding process of the carbonization of the iron have had sufficient time for the production of grey iron; because the completeness of the decomposition of the air in the neighbourhood of the tuyeres allows carbonic oxide to be formed low down, so as to have the longer range and greater time in rising from that low level to the topmost layers, and thus effecting the deoxidation of the iron at so high a level as to leave sufficient depth of red-hot carbon between there and the fusion-zone for the slow process of carbonization of the iron to be completed even at the increased rate of production.

We shall have occasion to speak further on this point when estimating the fuel consumed in heating the blast.

282. The region of the carbonic acid formation is in what is termed the zone of fusion, which reaches no higher than the point where the carbonic oxide, with its lower temperature, begins to form.

283. The formation of the carbonic oxide so low down saves the fuel from active combustion until it nears the tuyeres. The carbonic oxide warms the bodies that it cannot combine with as it rises, but at a rate so quickly decreasing that by the time it reaches the topmost layer of materials its own temperature may have sunk to between 500° and 600° Fah., which is too low to do much more than carry off the moisture from the materials.

284. Should the materials be wet when charged into the furnace, the moisture will aborb so much heat into the latent state from the rising gases that on escaping their temperature may be considerably lower than 500°, because the specific heat of water being 1·0, while that of gas, say air, is only about 0·267, it follows that a given weight of water requires, to raise it to any given temperature, nearly four times the quantity of heat that would

raise the same weight of gas to that temperature, hence for every lb. of water that is raised 1° nearly 4 lbs. of gas must lose 1°, and as water can pass away only in the form of vapour or steam, and as steam at 212° contains about 1,146° of heat above freezing temperature, of which 966° are latent, and therefore not sensible to the thermometer, the gas possessed of lower specific heat must lose $\frac{1146}{0{\cdot}267} = 4292°$ of its heat, when equal weights, viz., 1lb. of each, are taken, before the water can be removed.

We shall have occasion to speak more fully regarding the specific heat, or capacity for heat, of different substances when we are estimating the consumption of carbon in the furnace.

285. The materials as they sink at slow rate, meet heat rising also at slow rate by conduction from body to body, which helps to raise the temperature in the upper half of the furnace high enough for the chemical processes to take effect; but carbon being a slow conductor, the process of conduction must depend mainly upon the metallic ore, and the heating process must depend mainly upon the gases rising from the fire.

286. The flame that is seen issuing from the mouth of many blast furnaces is from the firing of the carbonic oxide amongst the fuel on the top on its reaching the atmosphere. In the case of small-sized furnaces, the gases on reaching the topmost layer of materials will escape at a much higher temperature than that which we just now mentioned.

287. Carbonic acid is the first sensible gaseous product of the combustion of carbon, and has its formation attended with a great development of heat.

On its rising through amongst red-hot carbon, its oxygen recombines with carbon in the different measure already stated, and becomes carbonic oxide, but in changing to this state the sensible temperature becomes suddenly lowered. We know that the heat is not lost but simply rendered latent, or hidden, as it all reappears on the gas being fired.

We know also that gas hides heat, that is, abstracts it from the sensible temperature when expanding, as in the case of carbonic oxide, to a greater volume against the ordinary pressure of the surrounding atmosphere. The disappearance of heat, therefore, in the change from the acid to the oxide state is explainable, but only as regards results, as we are yet only feeling our way to a knowledge of what heat really is, and how it acts to cause the effects that alone are observable.

288. In the conversion of carbonic oxide into carbonic acid by abstraction of oxygen from the ironstone, the latent heat does not reappear in the sensible form which attends its combustion with free oxygen in heating stoves and under boilers, because in the latter case it is an instantaneous combination between two bodies already in the gaseous state, whereas in the former case the gaseous carbonic oxide has to discharge its latent heat into the oxide of iron, to raise the temperature for the liberation of the oxygen from its fixed combination with the iron, and this requires not only the heat that is latent in the gas, but also takes from the sensible temperature, so that the condensation of volume that attends the acid form is not sufficient to compensate for the loss; and further, should the forcing of the furnace bring down the iron to the hotter part of the fire before deoxidation by the gas has been completed, a still greater absorption of heat would take place there when both the carbon and the oxygen concerned in the deoxidating process have to be liberated from their respective fixed states in the coke and the ironstone.

289. Carbonic acid is believed to take up carbon for conversion into carbonic oxide till the heat has fallen below 1,000°, but carbonic oxide continues to draw the

oxygen from the ironstone till the temperature falls below 500°, though much depends upon the nature of the fuel and the ore: thus anthracite, which is specially rich in carbon, is of so refractory a nature that it has been known to pass twice through an iron-smelting furnace without material reduction of its bulk; while the denser sorts of ores, not carbonaceous, require so high a temperature to soften them, that carbonic oxide parts with both its latent and its sensible heat with but limited effect upon them, so that deoxidation in their case is mainly effected by direct contact with the red-hot fuel low down in the furnace.

290. At 1,400° Fah. it has been found that carbon readily penetrates pure iron so as to carbonize it. Its entrance into the body of the iron is effected by means of chemical attraction; and as it must first be reduced to an impalpable state, the same as that in which it exists in gas, carbonic oxide may be regarded as the carbonizing agent, even when the iron is in contact with red-hot carbon.

291. Bars of pure iron are convertible into steel when embedded in powdered charcoal, and exposed to a temperature such as we have just now mentioned.

292. When iron is burnt in the furnace with oxygen from the blast, it is a loss so far as the smelter is concerned, but, chemically, were all the gases rising from the flame collected they would be found to contain every atom lost from the iron, whole and perfect in itself, but all now arranged in groups differently constituted from the original combinations, owing to the new conditions of combination produced by the introduction of new elements.

293. Compound matter can be decomposed, that is, can have the cohesion existing at ordinary temperatures between its different elements altogether overcome by heat or by solution, and as regards that change only can the term destruction be applied, reconstitution in another form being immediately effected, under the changed conditions

of affinity due to the higher temperature in the presence of new elements, the elements entering into new partnership by either simple or complex affinity, according to the number and the character of the ingredients.

294. Our ordinary conception of fire is simply that heat is got at the expense of fuel, but when it is chemically shown that nothing is annihilated, but that a receiver at the chimney top would, when the soot and ashes were added, restore the entire weight of the fuel and the air used, and neither more nor less than that, it is hard to understand the source of the heat and light, and though much has been said and written on the subject, it has never been satisfactorily explained.

295. Density decreases the capacity for heat, that is, as density increases, the capacity for heat or the specific heat decreases, and *vice versa.*

The atomic weight multiplied by the specific heat found for the body is a constant quantity for simple elements, that is, the product is the same for all.

296. Substances are called combustible when they combine so energetically with oxygen as to become luminous.

Every substance has a temperature of its own for taking fire. Up to this temperature the mutual attraction of the atoms in combination is greater than the attraction of oxygen; so that oxygen, being what is termed a supporter of combustion, combines at the temperature required by the combustible.

297. From experiments made by Wedgewood, there is reason to believe that all bodies susceptible of the requisite temperature become red-hot at exactly the same point. Wood and most liquids are dissipated before their temperature can be sufficiently raised to be luminous.

298. Gases do not become luminous even at much higher temperature than suffices for solids; but solids, when introduced into vessels containing gases highly heated, may become luminous, showing that the gas,

though not luminous itself, is capable of heating a solid body to the shining temperature, but at great expense to its own sensible temperature, owing to the difference between the specific heat of gas, and that of a solid.

299. Charcoal takes fire at 700° Fah., hydrogen at 800°, carbonic oxide at 1,000°.

Oxygen and hydrogen begin to burn in combination at 800°, but the temperature of the flame is not less than 5,000°, the effect of the combustion itself being instantly to raise the temperature beyond the degree necessary for the commencement of the process.

SECTION IX.

300. We will now proceed to speak of the action of the heat within the furnace, but will first give the combining quantities of the two gases which are the principal agents in the operations, and also of the ores and fluxes; that is, the proportions by weight in which the elements combine chemically, as distinguished from mere mechanical mixture; particular explanations will follow in due course.

301. Carbonic acid:—

$$CO_2 = 12 + (16 \times 2) = 44 \text{ combined atomic weight.}$$

$$\frac{32}{12} = 2{\cdot}66 \text{ oxygen to 1 of carbon}$$

$$\frac{32}{44} = 0{\cdot}73 \text{ per cent. oxygen}$$

$$\begin{array}{l} 0{\cdot}27 \text{ ,, ,, carbon.} \\ \hline 1{\cdot}00 \end{array}$$

302. Carbon oxide:—

$$CO = 12 + 16 = 28 \text{ combined atomic weight.}$$

$$\frac{16}{12} = 1{\cdot}33 \text{ oxygen to 1 of carbon}$$

$$\frac{16}{28} = 0{\cdot}571 \text{ per cent. oxygen}$$

$$\begin{array}{l} 0{\cdot}429 \;\text{,,} \quad \text{,,} \quad \text{carbon} \\ \hline 1{\cdot}000 \end{array}$$

303. Peroxide of iron—red oxide—hematite :—

$$Fe_2 O_3 = (56 \times 2) + (16 \times 3) = 112 + 48 = 160.$$

$$\frac{48}{160} = 0{\cdot}30 \text{ per cent. oxygen}$$

$$\begin{array}{l} 0{\cdot}70 \;\text{,,} \quad \text{,,} \quad \text{iron} \\ \hline 1{\cdot}00 \end{array}$$

$$\frac{48}{112} = 0{\cdot}429 \text{ oxygen to 1 of iron.}$$

304. The prefix "per" signifies in combination highest or most intense; thus the peroxide of iron contains the maximum proportion of oxygen to iron.

The prefix "proto" is used to indicate that, in the case of a protoxide, there is only a single measure of oxygen in the combining proportions; and in the case of a protocarbonate, that there is only a single measure of carbon in the combining proportion.

305. Black oxide of iron—magnetic iron ore :—

$$Fe_3 O_4 = (56 \times 3) + (16 \times 4) = 168 + 64 = 232.$$

$$\frac{64}{232} = 0{\cdot}276 \text{ per cent. oxygen}$$

$$\begin{array}{l} 0{\cdot}724 \;\text{,,} \quad \text{,,} \quad \text{iron} \\ \hline 1{\cdot}000 \end{array}$$

$$\frac{64}{168} = 0{\cdot}38 \text{ oxygen to 1 of iron.}$$

306. Protoxide of iron :—

$$Fe\,O = 56 + 16 = 72.$$

$$\frac{16}{72} = 0{\cdot}222 \text{ per cent. oxygen}$$

$$\begin{array}{l} 0{\cdot}778 \;\text{,,} \quad \text{,,} \quad \text{iron} \\ \hline 1{\cdot}000 \end{array}$$

$$\frac{16}{56} = 0{\cdot}286 \text{ oxygen to 1 of iron.}$$

807. Protoxide of iron is seldom found in a pure state, the single measure of oxygen not satisfying the affinities of the iron, so that it readily unites itself with the peroxide of iron; but it is generally found associated with carbonic acid, becoming fixed thereby so as to form what are termed proto-carbonates in clay or argillaceous ironstones.

808. Proto-carbonate of iron:—

$Fe\,O + C\,O_2$ or $Fe\,C\,O_3$, we may take the first form.

$Fe\,O = (56 + 16)\;72 + C\,O_2 = (12 + 32)\;44 = 72 + 44 = 116.$

$\frac{44}{72} = 0{\cdot}611$ carbonic acid to 1 of protoxide of iron.

$\frac{56}{116} = 0{\cdot}483$ iron to 1 of proto-carbonate of iron.

809. Silicic acid, or silica:—

$$Si\,O_2, = 28 + 32 = 60.$$

$\frac{32}{60} = 0{\cdot}533$ per cent. oxygen

$0{\cdot}467$,, ,, silicium

$1{\cdot}000$

$\frac{32}{28} = 1{\cdot}143$ oxygen to 1 of silicium.

810. Alumina:—

$$Al_2\,O_3 = 54 + 48 = 102.$$

$\frac{48}{102} = 0{\cdot}470$ per cent. oxygen

$0{\cdot}530$,, ,, aluminium

$1{\cdot}000$

$\frac{48}{54} = 0{\cdot}888$ oxygen to 1 of aluminium.

811. Carbonate of lime:—

$Ca\,CO_3$, or $CaO\,CO_2$, we may take the latter form, as it separates the oxide of calcium, or quicklime, from the carbonic acid.

$$CaO = 40 + 16 = 56 + CO_2 = 56 + (12 + 32) = 100.$$

$$\frac{44}{100} = 0{\cdot}44 \text{ per cent. carbonic acid}$$

$$\begin{array}{l} 0{\cdot}56 \text{ ,, ,, quicklime} \\ \hline 1{\cdot}00 \end{array}$$

$$\frac{44}{56} = 0{\cdot}786 \text{ carbonic acid to 1 of quicklime.}$$

312. Quicklime:—

$$Ca\,O = 40 + 16 = 56.$$

$$\frac{16}{56} = 0{\cdot}285 \text{ per cent. oxygen}$$

$$\begin{array}{l} 0{\cdot}715 \text{ ,, ,, calcium} \\ \hline 1{\cdot}000 \end{array}$$

$$\frac{16}{56} - 0{\cdot}40 \text{ oxygen to 1 of calcium.}$$

SECTION X.

313. On the slow passage downwards of the materials charged into the furnace, they gradually become heated, in which condition the cohesion of the particles becomes loosened, so that on the approach of another hot body similarly affected by the heat, and whose elements have strong natural liking or affinity for one or more of the elements of the other, the attracted elements are free to separate from their original connections, and enter into new combinations; thus, the excess of carbon in the carbonic oxide rising from the fire below takes hold of and combines with the oxygen of the heated ore, and escapes with it at the furnace mouth, and leaves the iron free for entering into combination with carbon, which it now begins gradually to absorb. The iron, however, is still intimately mixed with earthy matters belonging to the ore, and does not get free until they together, after a very

slow passage, reach the melting heat, where the iron escapes by trickling down through amongst the white-hot fuel into the metal-well in the hearth, where it lies protected from the oxygen of the blast by the earthy matters which have now taken the form of slag, and lie floating on the top.

314. As iron is found in the peroxide form in many ores, we will adopt that form as the simplest in estimating the quantities of the other bodies required to operate in the reduction of the ore.

315. We find that 2 measures by weight of iron in the peroxide form have to be liberated from 3 measures of oxygen, and as the latter have to be absorbed by carbonic oxide, every measure of which can receive only 1 additional measure of oxygen, it follows that 3 measures of carbonic oxide are required for every 2 of iron; so that in estimating the weight of carbonic oxide requisite to deoxidize the peroxide of iron, we use the formula—

$$Fe_2O_3 + 3CO = \underset{\text{Peroxide.}}{(112 + 48)} + \underset{\text{Car. oxide.}}{(3 \times 28)} = 160 + 84.$$

And as these figures represent proportionately the respective weights of the combining quantities, it follows that we shall get the ratio of carbonic oxide required to free the iron when we divide the weight of the 3 measures of carbonic oxide by the weight of the pure iron;

thus, $\frac{84}{112} = 0{\cdot}75$ carbonic oxide required to deoxidize or to free 1·00 of iron from its combined oxygen.

And as we have already found that carbonic oxide is composed of carbon 0·43 per cent., and oxygen 0·57 per cent., we find that 1·00 of pure iron has required for its deoxidation 0·322 of carbon combined with 0·427 of oxygen. But we get this proportion of carbon to iron at once by dividing the weight of carbon by the weight of pure iron in the combining proportions; thus—

$$\frac{3\,C}{2\,Fe} = \frac{3 \times 12}{2 \times 56} = \frac{36}{112} = 0{\cdot}3214 \text{ carbon to 1 of iron;}$$

so that 0·32 × 20 cwts. = 6·4 cwts. of carbon per ton of iron, and 0·427 × 20 cwts. = 8·54 cwts. of oxygen to form carbonic oxide with that carbon; and, further, when this oxide becomes an acid by the absorption of the second measure of oxygen from the ironstone, we have 6·4 cwts. carbon + 17·0 cwts. oxygen.

316. Following deoxidation comes the carbonizing of the iron and the melting.

Should there be 4 per cent. of carbon contained in the finished pig-iron, 0·0416 cwt. will be required for every 1 cwt. of iron = 0·832 cwt. per ton of iron.

317. The melting heat of iron varies according to the amount of carbon contained, but for ordinary cast iron 2,786° is given as the melting temperature, and about 4,000° inclusive of the latent heat.

318. Now the specific heat—that is, the capacity for heat—of iron being about 0·12, while that of carbon is 0·20, water, the standard, being 1·00, it follows that the heat that would raise water 1° in temperature would raise carbon 5° and iron 8·33°; or, looking at the question in another way, if iron requires 2,786° of sensible heat to melt it, carbon with 1,671° and water at 334·32° sensible heat contain respectively the same total quantity of heat, as would be at once shown were a pound of each, at the respective temperatures named, thrown into and cooled in a vessel of water—the temperature of the water would rise to an equal height in the three cases. The iron, with its more fervent heat, has least heat hidden, whereas the water, with its comparatively low sensible heat, has its store mostly in the hidden or latent state.

319. Water composed of 2 of hydrogen to 16 of oxygen by weight, is introduced here simply because it is used

as a standard in measuring heat—the heat required to raise 1 lb. of fluid water 1° in sensible temperature being termed *a unit of heat.*

320. The combustion of 1 lb. of carbon into the form of carbonic acid gives out heat sufficient to raise the temperature of 1 lb. of water 14,000°, assuming that water could remain in the state of water at that temperature. It comes to the same thing to say 14,000 lbs. of water raised 1°, or to say that the combustion of 1 lb. of carbon gives out or evolves 14,000 units of heat.

321. In passing carbonic acid with this heat over red-hot carbon, it has, as we before remarked, to discharge a portion into the fixed carbon to bring it into the gaseous state previous to combination with it for the formation of carbonic oxide; and, as the total heat developed in the formation of carbonic oxide is only about 4,000 units, it follows that 10,000 of the 14,000 units have been expended in the process, 6,000 of which have entered into the latent state in making the carbon gaseous, and the remaining 4,000 are required to maintain the standard heat in the oxide gas, which has expanded to twice the volume that the 14,000 units occupied in the acid form; and, as we have already mentioned regarding gases, in this expansion to a double volume lies in great measure the reason for the absorption of heat into the latent state; while, conversely, contraction of the volume discharges it into sensible form.

322. If done quickly, as in the rapid combinations from which fire issues, the whole of the effect is developed as it were at a blow, hence the intensity of the heat.

We will presently explain, circumstantially, how the 14,000 units of acid heat are disposed of in the change from the acid to the oxide state.

323. When we compute by bulk or volume, the two volumes of oxygen in $C\,O_2$ absorb the single volume of

carbon into themselves to form carbonic acid without enlarging their own dimensions, though the volume of carbon—that is, the atomic combining volume of chemistry—fills the same space as a volume of oxygen, or of any other of the bodies that are chemically measured by volume.

The two volumes now forming carbonic acid have increased their density or weight without adding to their bulk, but in the conversion from the acid to the oxide state the second volume of carbon, in seizing upon one of the two volumes of oxygen, is not absorbed by that volume of oxygen, but combines with it to form a double volume, and in doing so liberates the first volume of carbon from its absorbed state to form, likewise, one of two volumes with the second volume of oxygen. Thus, each of the two double volumes of carbonic oxide, with an atomic weight equal to 28, occupies the same space as the two volumes of carbonic acid with an atomic weight of 44.

824. Carbonic oxide is thus the more rarefied, and has the higher specific heat 0·288, while carbonic acid, with its greater density, has only 0·22—that is, carbonic acid is sooner filled with heat, and sooner allows heat it may be receiving or developing to appear as it were on the surface in sensible form, in much the same manner as a vessel 0·22 cubic foot capacity would be sooner filled, and so let the water run over, than another vessel of 0·288 cubic foot capacity.

Water, as the standard, would in such a case be represented by a third vessel of 1·00 cubic foot capacity, while iron would be represented by a fourth vessel, the capacity of which would be 0·12 cubic foot.

But here we must observe, that this illustration of capacity must not be taken literally, when the relative capacities of such different matters as gases, and solids, and liquids are in question; because, 1 lb. of gas occupies an immensely greater space than 1 lb. of either iron or water; the illustration, therefore, has reference merely to equal weights, irrespective of bulk.

SECTION XI.

825. We will now proceed to explain, circumstantially, the action and shifting of the heat when the gases change their form, and will first treat the pound of carbon by its combining volume in each of the two gases.

Thus, 1 volume of carbon = 1 lb. combines with the requisite 2 volumes of oxygen = 2·66 lbs. to form carbonic acid, which is generated with 14,000 units of heat in the melting zone; and, as we before remarked, these 3 volumes contract into the space of 2 volumes, while the addition of a fourth volume—viz., 1 of carbon—causes expansion to 2 double-volumes, occupying the space of 4 volumes, which is equivalent to a double expansion, and hence the absorption of heat into the latent state.

We have then, firstly, for the carbonic acid,

volumes.		volumes.		units.		lb. carbon.		units heat.
3	occupying	2	with	14000	÷	1	=	14000;

and, secondly, for the carbonic oxide,

volumes.		volumes.		units.		lb. carbon.		units heat.
4	occupying	4	with	14000	÷	2	=	7000.

Thus we get 7,000 units of heat for every pound of carbon in carbonic oxide, or for every 1·33 lbs. of oxygen, whether in the acid or the oxide state; and as the units developed or found active in carbonic oxide have been found by actual test in melting ice to be only 4,000 for every pound of carbon, it follows, as heat can no more be annihilated than can matter, that the expansion has hidden 3,000 units; so that 4,000 units × 2 lbs. carbon = 8,000 units, which being subtracted frcm 14,000 = 6,000 units latent heat, available for heating the fixed oxygen of the ironstone when the condensed carbonic acid form is resumed, on the extraction of that oxygen.

326. So long as the volumes of the carbon and the oxygen of the carbonic oxide, which has to part with this latent heat, remain simply united—that is, as regards the space necessary for each of these elements, which may be considered as so intermixed as to share equally the two spaces—the latent heat will remain inside, being necessary for the permanent expansion of the gas in its oxide state, and heat will pass from the gas in just the same simple manner as it would pass from heated air; but as in the chemical change that takes place the carbon is absorbed by the two volumes of oxygen, simultaneously with the liberation of the second of these two volumes from the ironstone, the latent heat is liberated as the carbon enters; so that the three volumes, now occupying the space of two, contain the heat, 7,000 units, that was before held by the double volume of the oxide, and would possess the same temperature, notwithstanding the introduction of the third volume, were it not for a considerable absorption of heat by the fixed oxygen when being made gaseous, in excess of what the oxide, in the act of conversion to the condensed acid form, is able to throw out into sensible form.

This excess we will presently consider.

327. We thus get a development of active heat when the volume is contracted, as in changing from the oxide to the acid state, when we take up oxygen from the ore, and an absorption of heat into the latent state when the volume is expanded, as in changing from the acid to the oxide when we take up carbon from the fuel; but we shall show this more clearly when we estimate the actual quantities required in the furnace operations, for which purpose we will use the combining weights and specific heats of the different materials.

328. When we introduce specific heat into the question, we must not expect other than approximate results, as the specific heats of gases have proved difficult to determine, and there are considerable differences between the respective amounts of the different authorities.

We will use Delaroche and Berard's figures, and will test by them the correctness of the results we have already arrived at, and will assume that the 14,000 units from carbonic acid, and 4,000 from carbonic oxide, per pound of carbon are correct.

329. The specific heat of carbon is 0·20, oxygen 0·236, carbonic acid 0·221, carbonic oxide 0·288, when equal weights are taken.

The combining weights for carbonic acid are—

1lb. carbon + 1·33 + 1·33lbs oxygen = 1 + 2·66 = 3·66lbs. acid per pound of carbon inclusive;

and for carbonic oxide—

1 lb. carbon + 1·33 lbs. oxygen = 2·66 lbs. per pound of carbon.

		specific heat.			
Carbon	1 lb.	× 0·20	=	0·20	carbonic acid.
Oxygen	2·66 lbs.	× 0·236	=	0·62	
				0·82	

$\frac{\cdot 20}{\cdot 82} = \cdot 244 \times 14000$ units $= 3416$ units as the proportion belonging to 1 lb. of carbon in carbonic acid.

$\frac{\cdot 62}{\cdot 82} = \cdot 756 \times 14000$ units $= 10584$ units as the proportion belonging to 2·66 lbs. of oxygen in carbonic acid, equal to 3,979 units per pound of oxygen.

330. Now, as in carbonic acid the carbon which is contained within the oxygen is already in a gaseous state, it only withdraws its own proportion of heat units from the 14,000 when it comes out to assume independent form in the oxide state; and this proportion, as we have just found, leaves only 10,584 units for the 2·66 lbs. of oxygen

and the second lb. of carbon which has to be raised to a gaseous state from its fixed condition in the fuel.

When this additional carbon is made gaseous it will possess the same number of units as the first lb., viz., 3,416, which, when subtracted from the 10,584, leaves only 7,168 units for the two combining weights of oxygen, or 3,584 to each.

$10584 - 3416 = 7168 \div 2 = 3584 + 3416 = 7000.$

331. We thus get the same total result for carbonic oxide when reckoning by weight as we got by volume, but we must modify the proportions of heat found for the separate elements by treating them when combined in the gases as possessed of the specific heat belonging to the gas, thus,—

	specific heat.	
Carbon 1 lb.	× 0·221	= 0·221
Oxygen 2·66	× 0·221	= 0·587
		0·808

$\frac{\cdot 221}{\cdot 808} = \cdot 2735 \times 14000 = 3829$ units for carbon, being very nearly the 4,000 units got per lb. of carbon from carbonic oxide in combustion.

$\frac{\cdot 587}{\cdot 808} = \cdot 726 \times 14000 = 10164$ units for oxygen.

$10164 + 3829 = 13993$ units for 1 lb. carbon in carbonic acid.

332. It is usual to speak of carbon as being the combustible and oxygen as being the supporter simply, but it is believed that actually both are combustibles, and we find that the proportion of heat for a lb. weight of oxygen, and of carbon and oxygen combined in carbonic acid, when the specific heat of the acid, and not of the elements separately, is employed, is, as might be expected, practically the same; thus,—

$\frac{10164}{2\cdot 66} = 3821$ units per lb. of oxygen.

$\frac{14000}{3\cdot 66} = 3825$ units per lb. of carbonic acid.

333. The total heat in carbonic oxide possessed of 1 lb. of carbon having been found to be 7,000 units, we now proceed to use that heat in the extraction of the combining measure of oxygen, viz., 1·33 lbs. from the ironstone.

334. Carbonic oxide to acid by taking up oxygen,

$$\left.\begin{array}{l} \text{Carbon } 1\text{ lb.} \times \cdot 20 = \cdot 20 \\ \text{Oxygen } 1\cdot 33 \times \cdot 236 = \underline{\cdot 31} \\ \qquad\qquad\qquad\qquad\quad \cdot 51 \end{array}\right\} \text{carbonic oxide}$$

Oxygen 1·33 × ·236 = ·31 in the ironstone,

$\frac{\cdot 20}{\cdot 51} = \cdot 39 \times 7000 = 2744$ units as the proportion for 1 lb. of carbon in carbonic oxide.

$\frac{\cdot 31}{\cdot 51} = \cdot 608 \times 7000 = 4256$ units as the proportion for 1·33 lbs. of oxygen in carbonic oxide, equal to 3,200 units per lb. of oxygen.

335. To raise the fixed oxygen of the ironstone to the gaseous state, with the carbonic oxide temperature, will take the same number of units of heat as the operating weight of oxygen belonging to the carbonic oxide possesses, that is, 4,256 units, but, 4256 + 4256 = 8512 units, and as the oxide possessed no more than 7,000 units, it follows that 8512 — 7000 = 1512 units are required more than the carbonic oxide can give, and which can be got only from a proportionate addition to the 6·4 cwts. of carbon which we have already found to be the combining weight in the carbonic oxide, required for chemical combination with the fixed oxygen per ton of iron in the ore state; so that this additional quantity of carbon is simply to supply the loss of heat.

336. The 1,512 units loss per lb. of carbon is shown in a more direct manner thus,—

4256 units for the fixed oxygen
2744 ,, received from the carbon
1512 units loss, because by the concentration of heat in

the reduction of the bulk from 3 to 2 volumes the heat of the carbon acts within the 2 volumes of oxygen, so that the volume of oxygen liberated from the ironstone requires only the difference between what the carbon introduces when absorbed, and the heat possessed by the first or operating volume of oxygen, to maintain the 7,000 unit standard found for the operating double volume of carbonic oxide: but more on this point presently.

337. We have here used the specific heat for carbon and oxygen separately, and must modify the respective proportions of heat as before, treating the bodies as possessed of the specific heat ·288 belonging to the carbonic oxide which they form together.

Carbon	1 lb.	× ·288	=	·288
Oxygen	1·33	× ·288	=	·383
				·671

$\frac{\cdot 288}{\cdot 671} = \cdot 429 \times 7000 = 3003$ units per lb. of carbon, or per lb. of carbonic oxide.

$\frac{\cdot 383}{\cdot 671} = \cdot 5708 \times 7000 = 3995$ units per 1·33 lbs. of oxygen, which is nearly equal to the 4,000 units for carbonic oxide in combustion, and possessed of 1 lb. of carbon.

$\frac{3995}{1 \cdot 33} = 3000$ units per lb. of oxygen.

$3995 + 3003 = 6998$ units, which is practically equal to the 7,000 units found when estimating by the volume.

338. We get the units per lb. of gas directly when we divide the total heat in the gas by the number of lbs. weight thus, $\frac{7000}{2 \cdot 33} = 3004$ units per lb.

The slight differences are occasioned by the decimals in the weight of oxygen being cut short.

339. To make sure that the loss of heat taking place in the removal of the oxygen from the iron be actually as we have found it when using the lb. weights and specific heats of the simple elements, we will seek it by another mode.

340. The specific heat ·236 of free oxygen is higher than the ·22 of the carbonic acid, of which it forms a part, but, on the other hand, the ·20 of the carbon is so much below ·22 that 1 lb. of it requires in addition to its own fully one-half of the capacity that the 2·66 lbs. of oxygen have to spare.

The oxygen absorbs the carbon, and thereby becomes denser with a correspondingly reduced capacity for heat, so that when by itself having had capacity for the quantity ·236, it can now contain only ·22 as carbonic acid.

The carbon, however, while increasing the density of the oxygen, has its own density increased by the combination, but in less degree than the other, so that it also can contain less heat now than when free, consequently the whole that is to spare from the ·236 original capacity of the oxygen is required in establishing the ·22 mean capacity.

341. Specific heat, however, seems to depend upon some internal conditions (which are more difficult to determine in the gaseous than in the solid state) as well as upon the degree of density; thus, if we take equal volumes of carbonic acid and carbonic oxide (each containing 1 lb. of carbon), and an equal volume of oxygen, the atomic combined, or combining weights of which are respectively, in the order named, 44, 28, and 32, we have the specific heats in the same order ·221, ·288, and ·236.

These atomic weights being merely proportionate quantities, may be taken to represent ounces or lbs. or cwts., or we may say that the weight of carbonic acid is to the weight of carbonic oxide as 44 is to 28.

342. We will use the combining lb. weights per lb. of

carbon, and multiply them by their respective specific heats, thus,—

Carbonic acid.....	3·66	× ·22	=	·805
Carbonic oxide...	2·33	× ·288	=	·671
Oxygen...........	2·66	× ·236	=	·627

343. These weights of gas all fill the same space, so that if we represent the lowest of the results by 1 for oxygen, we get the relative proportions for equal bulks thus,—

Carbonic acid $\frac{\cdot 805}{\cdot 627} = 1{\cdot}28$ ratio

Carbonic oxide $\frac{\cdot 671}{\cdot 627} = 1{\cdot}07$,,

Oxygen $\cdot 627 = 1{\cdot}00$,,

344. When we multiply the weights of the elements by the specific heat belonging to them separately, we have as follows,—

Carbonic acid { oxygen 2·66 × ·236 = ·627
carbon 1·00 × ·20 = ·200
·827

Carbonic oxide { oxygen 1·33 × ·236 = ·313
carbon 1·00 × ·20 = ·200
·513

Oxygen 2·66 = ·236 = ·627

And, when we represent the oxygen by 1 as before, we have the relative proportions thus,—

Carbonic acid $\frac{\cdot 827}{\cdot 627} = 1{\cdot}33$ ratio

Carbonic oxide $\frac{\cdot 513}{\cdot 627} = 0{\cdot}82$,,

Oxygen $\cdot 627 = 1{\cdot}00$,,

345. No perfectly conclusive explanation of this variableness has yet been given; at least none that can be

expressed in simple terms. We have assumed, merely for convenience in description, that the 1 lb. of carbon is simply absorbed by the 2·66 lbs. of oxygen to form acid; we thereby escape complexity; but, it is believed that the differences we have shown are dependent partly on the number of points of contact of carbon with carbon, of oxygen with oxygen, and of carbon with oxygen.

Chemical force, which is different in carbon to what it is in oxygen, has its action modified according to the combinations, and the distance separating the atoms that are free for mutual attraction.

There is another matter that has much to do with chemical force, and that is yet unexplained, viz., the development, in place of the absorption of heat, in the expansion of carbon from the solid to the gaseous state; but those questions of chemical force do not lie directly in our simple course; and, as the specific heats have been found by actual experiment most carefully conducted, we accept and use them with the same assurance of approximate exactness as when employing the 14,000 and 4,000 units of heat in combustion.

846. We will now ascertain how far the 1,512 units, which we have already found lost or deficient in the raising of the peroxide oxygen to the gaseous state, is covered by the gain in temperature produced by condensation: and, in estimating, will treat the carbon and the oxygen of the carbonic oxide separately, but will employ for both the specific heat of the oxide state; then treat the oxygen of the ironstone with its own specific heat, and will use as a divisor the specific heat product belonging to their ultimate state as carbonic acid, when the ironstone oxygen has been received into combination; and will thereby get the number of units or degrees of heat that appear in the carbonic acid.

847. Owing to the difference in specific heat, less heat is required in the acid state to raise to a given tempera-

ture than is necessary in the oxide state, so that 7,000° apparent heat in case (1), will raise the same weight in case (2) to 8,515°.

$$\begin{array}{llll} \text{(1) Carbon 1 lb.} & \times \cdot 288 & = \cdot 288 & \rbrace \text{ carbonic oxide} \\ \quad \text{Oxygen } 1{\cdot}33 & \times \cdot 288 & = \cdot 383 & \\ \quad \text{Oxygen } 1{\cdot}33 & \times \cdot 236 & = \cdot 313 & \text{— in ironstone} \\ & & \overline{\cdot 984} & \end{array}$$

$$\begin{array}{llll} \text{(2) Carbon 1 lb.} & \times \cdot 221 & = \cdot 221 & \\ \quad \text{Oxygen } 2{\cdot}66 & \times \cdot 221 & = \cdot 588 & \rbrace \text{ carbonic acid} \\ & & \overline{\cdot 809} & \end{array}$$

$$\frac{\cdot 984}{\cdot 809} = 1{\cdot}2163 \times 7000 = \begin{array}{l} 8515 \text{ units} \\ 7000 \\ \hline 1515 \text{ units apparent gain.} \end{array}$$

348. We will find the units in each of the bodies separately, using as our divisor the ·809 found for the carbonic acid state.

$$\text{Carbon } \frac{\cdot 288}{\cdot 809} = \cdot 356 \times 7000 = 2492 \text{ units}$$

$$\text{Oxygen } \frac{\cdot 383}{\cdot 809} = \cdot 4735 \times 7000 = 3314 \text{ ,,}$$

$$\text{Oxygen } \frac{\cdot 313}{\cdot 809} = \cdot 387 \times 7000 = \underline{2709} \text{ ,,}$$

$$8515 \text{ ,,}$$

These 8,515 units are, however, for 3 volumes, contracted into the space of 2 volumes. The contraction by absorption of the carbon leaves the units belonging to the carbon free to be deducted from the total that would be required to maintain the 3-volume temperature.

349. The deduction reduces the requirements for equal temperatures in the 2-volume space to 8515—2492 = 6,023 units, which for the 2 volumes with their greater density corresponds to 8,515 units for the 3 volumes before condensation; but, though the strict requirements of the 3 volumes when occupying the space of 2 are only 6,023 units to preserve the same temperature as 3 volumes occupying the space of 3, with 8,515 units, it happens

that, as the carbon when absorbed carries its proportion of the heat in with it, it adds it to the heat of the oxygen in the reduced volume so as simply to make the heat of that volume more intense because of the concentration.

350. We have thus a gain from two sources, firstly, from the reduced capacity of carbonic acid for heat; and secondly, in the intensity through concentration; but, in using ·809 as the divisor, we have included the first in the 8,515 units, and in simply concentrating we only narrow the bulk through which the heat has to act; the total amount of heat, 8,515 units, remaining the same as was found for the greater bulk, that is, for the three independent volumes.

351. In dealing with the oxygen and the carbon of the compound gases, having employed the specific heat belonging to the compounds which they formed, we get the same number of units per pound for each of the ingredients in combination; hence if the introduction from the fuel of 1 lb. of carbon into the carbonic acid of the first formation causes a loss of 6,000 units in latent heat, owing to the expansion, we might reasonably expect that the absorption of 1 lb. of oxygen, with contraction which reduced the bulk to its original 14,000 units dimensions, would cause this 6,000 units latent heat to reappear; thus, had the second measure of oxygen been got from the atmosphere for combustion, the heat generated would have been 14,000 units per pound of carbon, instead of only 8,515 units, when work in heating and making the entering body gaseous has to be done. We therefore subtract 8,515 from 14,000, and get 5,485 units lost in raising the oxygen of the ironstone to the gaseous state previous to its combination with the carbonic oxide, and dividing this latter amount by the pounds-weight of the additional measure of oxygen that is thus operated upon, we get the number of units loss for each pound of this additional oxygen.

$14000 - 8515 = 5485$

$\frac{5485}{1 \cdot 33} = 4124$ units loss per pound of oxygen made gaseous.

352. The weight of oxygen combined with the iron in the peroxide state is 8·5 cwts. for every 20 cwts. of iron.

$8 \cdot 5 \times 112 = 952$ lbs.

$952 \times 4124 = 3926048$ units loss per ton of iron,

that is, with reference to the 14,000 units per pound of carbon that would be developed were the oxygen supplied from the atmosphere, instead of from a fixed state in the ore.

353. We now divide this last-found quantity by 14,000, and get the weight of carbon in pounds requisite to maintain the heat in the deoxidizing gas.

$$\frac{3926048}{14000} \quad 280 \text{ lbs.} = 2 \cdot 5 \text{ cwt.}$$

$6 \cdot 43 + 2 \cdot 5 = 8 \cdot 93$ cwts., or, as our quantities are only theoretically approximate, say 9 cwts. of carbon.

354. We will next endeavour to find the quantity of carbon required to melt 20 cwts. of iron, and believe the simpler mode will be to find the weight of carbonic acid that in the process of combustion will supply the units of heat required by the iron: the proportion of carbon in that acid will be the carbon wanted.

355. This assumes that the carbon so found could continue giving its heat out at the 14,000 unit-degree to the last atom. Practically this could not happen were the precise weight of gas alone, as it can never sink below the temperature of the body it may be operating upon, and iron melts at about 2,783° Fah.; but it is correct enough so to assume, when we estimate afterwards by the heat of the gases escaping at the top, the weight of carbon that has been consumed along with the strict melting quantities to maintain the temperature.

356. The specific heat of iron is ·12 approximately. It varies with the temperature in common with other substances. At 212° it has been found to be ·11 and at 662°, ·126.

The total number of Fah. degrees of heat possessed by it at the melting temperature has been estimated at 4,000° latent and sensible. 4000° × ·12 = 480 units of heat per pound of iron, 20 cwt. × 112 × 480 = 1075200 units required for the melting of 20 cwts. of iron.

357. We may here observe, however, that the melting temperature 2,783° Fah., as found by Pouillet, though generally accepted, is not considered perfectly certain; while the 4,000° latent and sensible must be taken as simply approximate, heats so high as these being difficult to gauge.

358. Previously our estimates related mainly to quantities in chemical combination; but now we have to deal with the simple communication of heat from the operating body of carbon in combustion to the surrounding bodies, and amongst them we must give to the nitrogen of the air its due proportion.

359. In the case of carbon in combustion, with the double measure of oxygen CO_2, forming carbonic acid, the capacity for heat of the acid requires to be satisfied by abstraction from the 14,000 units; but, as our estimates of the consumption of carbon in combustion, will assume that the gas concerned in the several distinct processes, parts with all its heat to outside bodies, so as to require extra carbon to restore sufficient heat to maintain its own temperature on a balance with that of the receiving bodies, we regard the gas as emptying itself of the first heat, so that the whole 14,000 units are available for work.

360. As the respective temperatures of the giving and the receiving bodies vary, so also do the respective quantities of heat contained internally, as these quantities are

simply proportional to the total heat; thus, as the specific heat of water is the standard, and is reckoned 1·00, while that of iron is only ·12, it takes $\frac{1\cdot00}{\cdot12} = 8\cdot33$ lbs. of iron to contain internally the same heat as 1 lb. of water, as we have before observed, or, conversely, $\frac{\cdot12}{1\cdot00} = \cdot12$, that is, $\frac{1}{8\cdot33}$ part of the heat that shows 1° temperature in water by the thermometer will show 1° temperature in 1 lb. of iron, and similarly with all other substances proportionately to their specific heat; so that 1 lb. of carbon in combustion with 2 combining measures of oxygen, in giving out 14,000 units with the carbonic acid thus formed, would raise 1 lb. of free carbonic acid brought into contact with it, $\frac{14000}{\cdot221} = 63348°$, with reference to water heat, or would raise 63,348 lbs. 1°, assuming that the carbon could discharge all its heat into the other.

361. This is owing to the 14,000 being standard water units, or degrees as indicated by the thermometer, and to the capacity for heat of the carbonic acid, which is to receive the heat, being only $\frac{1}{4\cdot52}$nd, or a little more than one-fifth of the capacity of water; so that $\frac{1}{4\cdot52}$ of the heat required for water satisfies the smaller capacity of carbonic acid, and as all bodies indicate the same temperature by thermometer, when their heat capacity is just filled, it follows that 63,348 lbs. of free carbonic acid would indicate 1° by the Fahreinheit thermometer, with the same total heat that would raise 14,000 lbs. of water 1°.

SECTION XII.

362. Atmospheric air is composed of ·23 oxygen + ·77 nitrogen, so that by the simple rule of proportion, as

·23 : ·77 : : 2·66 lbs. oxygen : 8·90 lbs. nitrogen approximately.

363. One pound of carbon in active combustion has its 14,000 unit standard reduced by the nitrogen of the air required to supply the oxygen in the proportions we will now show.

	1	lb. carbon	× ·20	=	·20	Carbonic acid
Air	2·66	,, oxygen	× ·236	=	·62	Carbonic acid
Air	8·90	,, nitrogen	× ·275	=	2·44	
	12·56				3·26	

364. The total weight 8·90 lbs. of the nitrogen indirectly concerned in the production of 14,000 units of heat is here represented by the reduced weight 2·44, which means that the capacity for heat of the 8·90 lbs. of nitrogen is just equal to the capacity of 2·44 lbs. of water; so that when we divide the 14,000 water units by 2·44, we get the number of degrees that a weight of nitrogen, equivalent in capacity for heat to 2·44 lbs. of water, would be raised by the complete combustion of 1 lb. of carbon, or, what amounts to the same thing, we get the number of equivalent weights raised 1°, or water unit; thus—

$$\frac{14000}{2 \cdot 44} = 5737 \text{ equivalent weights of nitrogen raised } 1^\circ.$$

365. Nitrogen is not chemically combined with the oxygen when forming atmospheric air, but simply mixed with it; and when the oxygen seizes on the carbon, the nitrogen is let go free to escape at the furnace mouth as a simple mixture; still, with the other gases, it can act, as we before observed, merely as a diffuser or diluter of the heat generated by the chemical combination of the carbon and oxygen, and as such, can receive heat only under the same conditions as the iron and slag; and the proportionate weight of nitrogen to the weight of carbon being known, we use the reduced unit measure 5,737 got for it to find the equivalent but yet unknown weight of iron that would be melted by the same heat.

366. Iron, with its lower capacity for heat, will reach the same active temperature with a less total quantity of heat than is required by nitrogen when equal weights are taken; and the respective capacities being ·12 and ·275, we find that 5,737 units in the equivalent weight of nitrogen, with reference to water, will raise nearly 2·5 times the weight of iron to the same temperature: $\frac{\cdot 275}{\cdot 12} = 2\cdot 3$; but ·12 for iron is simply a mean struck between ·110 at 212° Fah., and ·126 at 662° Fah.; and as we are considering the relation between the heat of a metal and that of a gas, we ought to take the specific heat for the metal for the lower temperature, to be in closer correspondence with that used in finding the specific heat of the gas, and we find that when we make the specific heat ·112, we get a ratio of 2·44; and as $\frac{2\cdot 44 \text{ for nit.}}{2\cdot 44 \text{ for iron}} = 1\cdot 0$, we have $2\cdot 44 \times 5737 \times 1 = 14000°$.

367. We have already found the total number of units of heat, 1,075,200, required for the melting of 20 cwts. of iron, dividing this by the nitrogen measure, we get—

$$\frac{1075200}{5737} = 187 \text{ lbs.} = 1\cdot 66 \text{ cwts. of carbon required.}$$

368. And as we have assumed that the heat has been communicated through the medium of the nitrogen, we may consider the nitrogen as first receiving, then parting with its heat to the iron, and passing off void of heat; but practically the loss to itself is compensated to a sufficient extent by a share of heat being received from the extra carbon that is acting in the furnace merely to maintain the general temperature.

369. The silica of the ironstone we have found to be 21·5 cwts., and the limestone 9 cwts., together 30·5 cwts.

We have now to consider the quantity of carbon necessary for the fusion of this into the form of slag.

We will assume that it fuses at the same temperature as the iron, viz., 4,000°, latent and sensible, the precise heat being yet not clearly ascertained ; but in acting upon this assumption, the results we get are likely to be lower than the actual requirements.

370. Should the lime and silica, &c., not be in the right proportions for easy fusion, or not be sufficiently mixed together for chemical action to take place, the heat cannot find an entrance into the interior of the lumps, so as to be absorbed there, and as the carbonic acid of the first, or 14,000 unit heat, is rising amongst red-hot carbon, it becomes converted into carbonic oxide, and then ceases to be directly serviceable for the melting process.

371. There would be the same total quantity of heat in the carbonic oxide state that had been generated in the carbonic acid state, but the expansion of volume and the consequent absorption of heat into the hidden state have produced a thinning effect similar to that of dilution or diffusion, in which neither time nor copiousness of the flow of the gas can raise the bodies that are being operated on to more than a simple specific heat share of the heat thus weakened.

Were the oxide heat greater than the required melting heat, the melting would go on, but at a rate decreased in proportion to the reduction in the heat from its higher power.

372. The specific heat of silica is ·179, alumina ·20, and of quicklime ·205. We will adopt the latter, and will use the nitrogen equivalent as before; thus—

$$\frac{\cdot 275}{\cdot 205} = 1\cdot 34, \text{ so that } \frac{2\cdot 44 \text{ for nit.}}{1\cdot 34 \text{ for slag}} = 1\cdot 82,$$

and $1\cdot 34 \times 5737 \times 1\cdot 82 = 14000°$.

$30\cdot 5$ cwts. $\times\ 112 = 3416$ lbs.

$3416 \times 4000° \times \cdot 205 = 2801120$ units.

$\frac{2801120}{5737} = 490$ lbs. $= 4\cdot 88$ cwts. of carbon required for the fusion of 30·5 cwts. of slag material.

373. Before proceeding further, we will sum up the quantities of carbon found necessary for the several processes we have named.

Per ton of iron.	Carbon.
Combining with the peroxide oxygen	6·43 cwts.
Required to maintain temperature in the deoxidizing process	2·50 ,,
Melting the iron	1·66 ,,
,, the slag	4·38 ,,
	14·97 ,,
Carbonizing iron, 4 per cent.	0·83 ,,
	15·80 ,,
Oxygen removed from the iron	8·50 ,,
Carbonic acid from the limestone ...	3·96 ,,
	12·46 ,,

374. Now these quantities of carbon are approximately correct theoretically only, and as they contain no allowance for the varying conditions of the furnace, they have no concern at all with either its formation or its size.

375. Coke is not pure carbon, an ash is left to become incorporated with the slag. The ironstone, though calcined, possesses impurities, and the ore and fuel when charged into the furnace are often wet. There is loss of heat by radiation from the sides of the furnace, and loss by conduction into the ground—this latter loss, however, is a slow one; but to meet them all requires an additional allowance of fuel, the precise weight of which we will not seek to determine directly when the circumstances on which the losses are dependent are so various. But when we have ascertained the heat escaping in the gases at the top, and added the carbon required to produce it to the quantities already found, we can arrive at some idea of the extent of the losses by taking the difference between

the ascertained total consumption in practice, and these theoretical quantities for the particular parts named of the whole process of smelting.

SECTION XIII.

376. There are chemical reactions among the silicates inside the furnace, which have not yet been precisely determined, but which affect the proportions of the several gases escaping at the top. Thus, oxygen is found in variable quantities, in excess of what is introduced by the air of the blast, and exclusive of the known quantities extracted from the ironstone, and possessed by the carbonic acid of the limestone.

377. To avoid complexity, we will treat the oxygen of the blast, and the 14·97 cwts. of carbon, as uniting to form carbonic oxide, because, though in the first instance the entering oxygen must combine with what we will here term a half-measure of carbon to form carbonic acid, it cannot well escape from taking up the second half a little higher up, and so becoming carbonic oxide; and as red heat is carried up to a considerable height inside the furnace, the oxide that has become acid by combining with the peroxide oxygen in the lower levels, may be reconverted into oxide, and might in part again react in like manner till the temperature falls below red heat, about 1,000°. The velocity of the gases in their passage upward, however, does not allow time for many such changes; and as carbonic oxide absorbs oxygen from iron till the temperature gets as low as 600°, the probability is that the greater proportion of the carbonic acid formed by the absorption of the ironstone oxygen, escapes as carbonic acid at the top.

378. It must be understood that these possible reactions from carbonic acid to oxide increase the con-

sumption of carbon to an uncertain, but perhaps not very great, extent beyond the quantity we have already found for the deoxidizing process, and also that the oxygen found in excess of the quantities derived from the air, and the peroxide of iron, and the limestone carbonic acid, will take up carbon, as no free or uncombined oxygen is ever found in the escaping gases of a furnace that is working well.

379. This extra oxygen is thought to be in part derived from the decomposition of silica down in the melting heat, the silicium combining with the metal in small quantity, sometimes to the extent of 3 to 4 per cent. of the weight of iron, and letting the oxygen go free; and as silica contains ·533 per cent. oxygen to ·467 per cent. silicium, the oxygen, by weight, slightly exceeds the weight of silicium taken up by the iron. Taking the amount at 3 per cent. for the oxygen, this would amount to about 67 lbs. = ·6 cwt. per ton of iron.

$$\frac{2240 \text{ lbs.}}{100} = 22{\cdot}40 \times 3 = 67 \text{ lbs.} = {\cdot}6 \text{ cwt.}$$

380. To form carbonic oxide, this would require $\frac{{\cdot}6}{1{\cdot}33} = {\cdot}45$ cwt. carbon.

381. As silicium, however, is taken up in variable quantities, generally less than 3 per cent., we will not add this ·45 cwt. carbon to the 14·97 cwts., but leave it to be considered in the difference between the theoretical and the practical consumption of the fuel.

382. We will now estimate the weight of oxygen required for the 14·97 cwts. of carbon to form carbonic oxide, and the proportion of nitrogen that accompanies that oxygen when entering as common air—nitrogen being in the proportion of ·77 to ·23 of oxygen.

$$14{\cdot}97 \times 1{\cdot}33 = 19{\cdot}91 \text{ cwts. oxygen,}$$

$$\frac{19{\cdot}91 \times {\cdot}77}{{\cdot}23} = \frac{66{\cdot}65 \;\;,, \;\; \text{nitrogen,}}{86{\cdot}56 \;\;,, \;\; \text{common air.}}$$

383. This weight, added to the weights of carbon, of oxygen from the ironstone, and of carbonic acid from the limestone, gives—

Carbon	14·97
Air.......................................	86·56
Peroxide oxygen	8·50
Carbonic acid from the limestone	3·96
	113·99, say 114 cwts.

of gas escaping at the furnace mouth, which weight we now multiply by the temperature and the specific heat to get the total number of units of heat, and will use the divisor as before to find the weight of carbon. But we have first to ascertain how much of the escaping gas is in the oxide state, and how much in the acid state, before we can determine the specific heat.

384. The nitrogen being in a free state, and only mingled with the other gases, retains its natural specific heat ·275; though, in using a fixed measure of specific heat for all temperatures, we can procure merely approximate results, seeing that the specific heat of bodies varies with the temperature to an appreciable extent, as we have instanced in the case of iron.

385. There being ·44 per cent. carbonic acid in limestone, and ·27 per cent. carbon in carbonic acid, we get the respective weights included in the 9 cwts. of limestone, thus—

9 cwts. × ·44 = 3·96 cwts. carbonic acid,
3·96 × ·27 = 1·07 ,, carbon in the acid.

The carbonic acid must be included in the escaping gases when estimating the heat lost, but we must exclude the carbon it contains from the quantity in combustion, because limestone carbonic acid being already formed, can only receive heat like nitrogen. The 14,000 units heat in the formation of carbonic acid is attended with contraction of volume, which does not take place in the simple escape from combination with the lime.

386. The 8·5 cwts. of peroxide oxygen per 20 cwt. of iron requires for its extraction an operating weight of carbonic oxide, composed of 8·5 cwts. oxygen and 6·43 cwts. carbon, making with the former, when the extraction is complete, 23·43 cwts. acid.

$8{\cdot}5 + 8{\cdot}5 + 6{\cdot}43 =$	23·43	cwt.
Add from limestone	3·96	,,
	27·39	,,

387. We assumed that the whole of the oxygen concerned in the combustion passed into the oxide state, consequently that the oxide allowance of carbon was required. To the 14·97 cwts. carbon required for the deoxidizing process and the melting, we will add the oxide measure of oxygen and the 8·5 cwts. of ironstone oxygen and the 3·96 cwts. of limestone carbonic acid, and from the total weight of carbon and oxygen thus got will subtract the 27·39 cwts. of carbonic acid to get the weight of carbonic oxide.

388. Gases escaping at the top :—

Carbon	14·97	cwts.	} Carbonic oxide.
Oxygen	19·91	,,	}
Oxygen	8·50	,,	Peroxide.
Carbonic acid .	3·96	,,	Limestone.
	47·34	,,	
Carbonic acid	27·39	,,	
Carbonic oxide	19·95	,,	

The proportionate weights, simply stated, of the gases composing the whole weight escaping, inclusive of nitrogen, are—

Nitrogen	66·65	cwts.	=	·585 of whole weight.
Carbonic acid ...	27·39	,,	=	·240 ,, ,, ,,
Carbonic oxide	19·95	,,	=	·175 ,, ,, ,,
	113·99	,,		1·000 whole weight

$$\frac{66{\cdot}65}{114} = {\cdot}585 \text{ of the whole weight.}$$

889. The relative proportions according to volume are as follows. We will take a double volume of each of the three gases thus, treating them by their atomic weight for similar volumes.

Carbonic acid	12 + 16 + 16	= 44 = 2	volumes.
Carbonic oxide	12 + 16	= 28 = 2	,,
Nitrogen	14 × 2 vols.	= 28 = 2	,,

$$\text{Nitrogen} \ldots\ldots \frac{66{\cdot}65}{28} = 2{\cdot}38$$

$$\text{Carbonic oxide} \ \frac{19{\cdot}95}{28} = 0{\cdot}71$$

$$\text{Carbonic acid} \,.\, \frac{27{\cdot}39}{44} = 0{\cdot}422$$

890. To simplify the estimate, let us assume the relative proportion ·422 found for carbonic acid to be equal to 1, and ascertain the amounts for the other two relatively to this numerical unit.

$$\text{Carbonic acid} \qquad = 1{\cdot}00$$

$$\text{Carbonic oxide} \ \frac{\cdot 71}{\cdot 422} = 1{\cdot}68$$

$$\text{Nitrogen} \ldots\ldots \frac{2{\cdot}38}{\cdot 422} = 5{\cdot}64$$

891. We learn, however, from the experiments made by Bunsen and Playfair, Ebelman and others, that the gases escape from the top in other relative proportions than those we have here named; but their results are so discordant, owing to many different circumstances, that no certain law can be deduced from them to guide us to ordinary or average proportions.

The reactions already spoken of from the oxide to the acid, and back to the oxide state, are calculated greatly to alter the proportions of the respective gases.

892. The furnaces concerned in the experiments were, of course, supplied with fuel to meet all the extra losses which we have yet to ascertain by the difference between

the theoretical and the practical quantities; and as the proportion of that extra fuel was arrived at by discovering the wants of actual practice, and is not a precisely constant quantity, nor one that is as yet clearly amenable to arithmetic, but is ruled to some extent by the manner in which the furnace is found to be doing its work, we might, as our purpose is simply to show a method for finding quantities, adopt for our incomplete quantities of oxide and acid gases the same relative proportion that we find in some of Ebelman's results with full working quantities, that is, about 1 of carbonic acid to 2·5 of carbonic oxide by volume; but as carbonic acid can change to carbonic oxide only by taking up fresh carbon from the live coke, which would necessitate a corresponding increase in the weight of carbon, we will simply use the proportions we have got, and see about the 1 to 2·5 proportion afterwards; here observing that the excess of carbonic oxide in Ebelman's proportions is due to the extra carbon which is supplied mainly for the maintenance of heat, and which, acting simply in the capacity of fuel, may be expected to come up mainly in the oxide state.

393. We will now multiply the weights of the gases by their respective specific heats, add the results together, and, dividing by the total weight, get the specific heat proper to them when mixed so as to form one volume.

Nitrogen	66·65	cwts.	× ·275 =	18·328
Carbonic acid .	27·39	,,	× ·221 =	6·053
Carbonic oxide	19·95	,,	× ·228 =	4·548
	113·99	,,		28·929

$$\frac{28{\cdot}929}{114} = {\cdot}254 \text{ mean specific heat.}$$

394. We can now find the weight of carbon concerned in the heat lost with the escaping gases, the temperature of which we will assume to be only 600°, by multiplying the total weight of the gas by the mean specific heat and

by 600°, and dividing by the nitrogen equivalent as before.

$$\frac{\overset{\text{cwts}}{114} \times 112 \times \cdot254 \times 600^\circ}{5737} = 339 \text{ lbs.} = 3\cdot03 \text{ cwts. carbon};$$

or, more directly,

$$\frac{28\cdot929 \times 112 \times 600^\circ}{5737} = 339 \text{ lbs.} = 3\cdot03 \text{ cwts.}$$

395. For the conversion of 3 cwts. of carbon into the oxide state, 3·03 × 1·33 = 4·02 cwts. of oxygen are requisite; but it will keep our statements in clearer form if we do not introduce this extra oxygen, till we estimate for the whole of the extra carbon. We, therefore, simply add the carbon to the quantities previously found, and include the ·83 cwt. taken up by the iron.

396. That the heat escaping with the gases at the top can come only from extra fuel will seem clear, when we consider that all the quantities of carbon already found for the several processes were simply sufficient for those processes, the heat absorbed by the materials being no more than balanced by the heat afforded by the given quantities of carbon, so that this heat, which rises past to escape, is simply in excess of the quantity required for absorption.

397. 14·97 + 3·03 + 0·83 = 18·83 cwts. theoretical quantity of carbon, required for the smelting of 20 cwts. of iron, from ore of the particular constitution we have named, and with the given proportion of limestone.

SECTION XIV.

398. We learn, however, that in the Cleveland district, where such ores are used, the quantity required in practice, with certain large furnaces employing hot blast at

1,000°, and with the temperature of the escaping gases about 600°, is about 26 cwts. of coke per ton of iron, a comparatively low consumption due to the better working of large than of small furnaces, the greater internal capacity containing more material in a greater depth above the fire to absorb heat from the gases before escaping.

399. We do not know the proportion of ash in the coke used, but as 5 per cent. is not an extraordinary proportion, while it sometimes ranges as high as 20 per cent., we will assume the former to get at the true weight of carbon contained, as the weights we have found are not for coke, but for the pure carbon derivable from it, and convertible into gas, which the ash of fuel is not, or it would not remain as ash.

$$\frac{26 \text{ cwts.} \times 5 \text{ per cent.}}{100} = 1{\cdot}3 \text{ cwts. ash.}$$

$$26 - 1{\cdot}3 = 24{\cdot}7 \text{ cwts. pure carbon.}$$

$24{\cdot}7 - 18{\cdot}83 = 5{\cdot}87$ cwts. difference between the quantities we have got theoretically and those required in practice.

400. Now the heat from this excess of carbon is expended in the several ways we before mentioned, viz., in radiation and conduction, in completing the calcination of the ore, fusing the ash, evaporating the water, and in covering the failure of effect in the case of unequal mixture of the materials in the furnace, that is, of refractoriness of the earthy matters in the melting heat. In the latter case, where the full effect is missed, we would find, could we follow it, the heat thus unexpended increasing the temperature of the escaping gases.

401. $5{\cdot}87 + 3{\cdot}03$ cwts. estimated as escaping with the gases $= 8{\cdot}9$ cwts. extra carbon.

402. We will now find the weight of oxygen required to

convert this extra carbon to the oxide state, and also the weight of nitrogen in the air containing this oxygen.

$$8{\cdot}9 \times 1{\cdot}33 = 11{\cdot}837 \text{ cwts. oxygen}$$

$$\frac{11{\cdot}837 \times {\cdot}77}{{\cdot}23} = 39{\cdot}63 \quad ,, \quad \text{nitrogen}$$

$$51{\cdot}467 \quad ,, \quad \text{air}$$

$$11{\cdot}837 + 8{\cdot}9 = 20{\cdot}737 \quad ,, \quad \text{carbonic oxide.}$$

403. We now by multiplying these quantities of nitrogen and oxide by their respective specific heats, get the equivalents referred to water heating, but must multiply by 112 to bring the result to equivalent pound units.

$$39{\cdot}63 \times {\cdot}275 = 10{\cdot}898$$

$$20{\cdot}737 \times {\cdot}288 = 5{\cdot}972$$

$$16{\cdot}870 \times 112 = 1889$$

404. The gas we will suppose escapes at the same temperature as before, viz., 600°; we multiply by this, then use the nitrogen equivalent as before for the divisor, to get the waste by the escaping heat.

$$\frac{1889 \times 600^\circ}{5737} = 197 \text{ lbs.} = 1{\cdot}759 \text{ cwts.}$$

8·9 cwts. — 1·759 cwts. = 7·141 cwts. carbon, the heat of which is expended inside the furnace before the escaping gases reach the top.

405. We cannot deal, however, with this quantity directly, but must first find the heat that is generated when the oxygen belonging to it first enters into combustion to form carbonic acid at the 14,000 unit rate per pound of carbon, and, as the quantity of oxygen is the same for 2 lbs. of carbon in the oxide form at 4,000 units as it is for 1 lb. of carbon in the acid form at 14,000 units, and we are now proposing to deal with it in the latter form, we must halve the 8·9 cwts. of carbon, there being oxygen only for the half to form carbonic acid; the second half being absorbed at a higher level in the furnace.

406. Reducing this first half to pounds, we multiply by 14,000 and get the units of water heat in action in the melting zone, overcoming difficulties there that the theoretical quantities we have previously found have nothing to spare for.

$$\frac{8{\cdot}9}{2} = 4{\cdot}451 \times 112 = 498{\cdot}51 \text{ lbs. of carbon,}$$

498·51 × 14,000 units = 6979140 units total heat developed.

407. We may here check the exactness of the 5,737 divisor previously found, by reducing the 10·898 cwt. equivalent just now found for the extra nitrogen to pound measure, and using it thus,—

$$10{\cdot}898 \times 112 = 1220{\cdot}57$$

$$\frac{6979140}{1220{\cdot}57} = 5718$$ equivalents, being 19 less than the quantity first found by the smaller weight, a difference that is owing to the ratio that we have taken for the nitrogen in air being only closely approximate.

408. Having found for one-half of the carbon, we must ascertain what happens when the second half is taken up.

Being an extra allowance for general heating purposes only, we have no special work for it to do by which its effect might be measured, and therefore we measure the effect upon the gases concerned in the development of the heat, and, as the carbonic acid gas that gives out the 6,979,140 units requires to have its own capacity for heat satisfied, we multiply its weight by ·221, add the product to the product got for the second half of the carbon which has to be extracted from the coke, multiplied by ·20, and, bringing the whole to pound measure, add again to the 1220·57 found for the nitrogen, to get thereby a divisor for the total heat developed in the acid state.

Oxygen......	11·837 cwts.		
Carbon	4·451 ,,		
Carbonic acid	16·288 × ·221	=	3·599
Carbon	4·451 × ·20	=	0·892
			4·491

$$4{\cdot}491 \times 112 = 402{\cdot}99$$
$$1220{\cdot}57$$
$$1723{\cdot}56$$

$$\frac{6979140}{1723{\cdot}56} = 4049 \text{ divisor.}$$

409. The specific heat of the gases being lower than that of water as the standard for unit measure, and the 14,000 units by which the 498·51 lbs. of carbon were multiplied being water heat units or degrees indicated by the Fahrenheit thermometer, the 1723·56 is the weight of gas equivalent to the 498·51 lbs. of carbon thus treated, so that, making it a case of simple proportion,

498·51 : 1723·56 : : 4049 : 14000.

410. Further, we have already found that there is a loss of 6,000 units of active heat per pound of carbon when the acid becomes an oxide, and as the gas we are now dealing with is assumed to escape in the expanded oxide state, this hidden heat must be deducted from the total units of the first acid form, the remainder divided by our new divisor 4049 will give the weight of carbon, the heat of which, though the gas escapes in the oxide form, is partly expended upon the materials in the furnace before that form is taken.

$$498{\cdot}51 \times 6000 = 2991060 \text{ units latent.}$$
$$6979140 - 2991060 = 3988080 \text{ units active.}$$

$$\frac{3988080}{4049} = 985 \text{ lbs.} = 8{\cdot}80 \text{ cwts., which is } {\cdot}10 \text{ cwt.}$$

less than the weight sought for, a near approximation.

411. We will now sum up the quantities of carbon and of gases we have estimated for the smelting of 20 cwts. of iron from Cleveland ore.

Chemical combination with oxygen of ironstone	6·43	cwts.
Replacing heat lost	2·50	,,
Melting iron	1·66	,,
,, earthy matters	4·38	,,
Heat escaping with the gases	3·03	,,
,, ,, ,, ,,	1·759	,, }
Extra fuel to cover waste, &c.	4·111	,, }
	23·870	,,
Carbonizing 4 per cent.	0·83	,,
	24·700	,,

412. Gases escaping:—

Nitrogen	66·65	cwts.	Theoretical quantities.
Carbonic acid	27·39	,,	
Carbonic oxide	19·95	,,	
Nitrogen	39.63	,,	For additional carbon.
Carbonic oxide	20·737	,,	
	174·357	,,	

Carbonic oxide	40·687	cwts.
,, acid	27·390	,,
Nitrogen	106·28	,,
	174·357	,,

413. Oxygen 19·91 cwts. from first air

Oxygen	19·91	cwts.	from	first air
,,	8·50	,,	,,	ironstone
,,	11·837	,,	,,	additional air
	40·247			
,,	2·880	,,	,,	car. acid of limestone
	43·127			

414. Carbonic oxide $\frac{40·687}{27·390} = 1·485$ of oxide to 1 of acid by weight, or, computing as before, $\frac{44}{28} = 1·571 \times 1·485 = 2·33$ to 1 by volume.

415. 1 carbon + 1·33 oxygen = 2·33 to be used as a

divisor in ascertaining the weight of carbon in the oxide, 1 carbon + 2·66 oxygen = 3·66 divisor for the acid.

		Carbon.		Oxygen.		
$\frac{40 \cdot 687}{2 \cdot 33}$	=	17·462	+	23·225		
$\frac{27 \cdot 39}{3 \cdot 66}$	=	7·483	+	19·907		
		24·945	+	43·132	= 68·077	
		1·08	+	2·88	from limestone	
		23·865	+	40·252		

416. But according to some of Ebelman's experiments, 2·5 of oxide to 1 of acid by volume may be nearer the average proportion when escaping at the top, though, as the relative proportions are greatly dependent upon the size of the furnace, the condition it is in, and the quality of metal that is being produced, we will employ this ratio merely for the purpose of ascertaining how our weights of carbon and of oxygen stand in relation to it.

417. We will employ the atomic weights as before for equal volumes—viz., 44 for acid and 28 for oxide.

$$\frac{28 \times 2 \cdot 5 \text{ times}}{44} = \frac{70}{44} = 1 \cdot 591\,;$$

1·591 + 1 = 2·591 to be used as a divisor of the whole weight of gas, to find the weight of the proportionate volume of carbonic acid in the $\frac{1}{1 \cdot 591}$ ratio.

$\frac{68 \cdot 077}{2 \cdot 591}$ = 26·284 cwts. of carbonic acid.
41·793 " " oxide.
68·077

418. $\frac{26 \cdot 284}{3 \cdot 66}$ = 7·181 cwts. carbon,

$\frac{41 \cdot 793}{2 \cdot 33} = \frac{17 \cdot 937}{25 \cdot 118}$ " "

1·08 from limestone,
24·038
23·87
0·168 cwts. in excess of the weight of

carbon we have found by estimate, consequently the ratio is too high for that weight.

419. We will now estimate the total effective heat developed in the combustion of the 23·87 cwts. of carbon, and the 31·737 cwts. of oxygen supplied by the blast in the oxide proportion.

420. The nitrogen of the blast being already in the form of gas equally with oxygen, requires to be included in the specific heat equivalent, which we will use as a divisor; but the carbon and the oxygen of the limestone carbonic acid, and also the peroxide oxygen, will have to be excluded from this estimate, because they are bodies merely operated on in a fixed or solid state at the beginning, and therefore are in the same position in this respect as the iron and silica and quicklime.

Oxygen, 1st	19·91	cwts.		
,, 2nd	11·837	,,		
	31·747	,,	$\times$ 112 $\times$ ·236 =	838·8
Carbon	23·870	,,	$\times$ 112 $\times$ ·20 =	534·68
Nitrogen ...	106·280	,,	$\times$ 112 $\times$ ·275 =	3273·42
	161·897	,,		4646·90

$\frac{23 \cdot 87}{2} = 11 \cdot 935$ cwts. carbon to form carbonic acid with the 31·737 cwts. of oxygen.

421. 11·935 $\times$ 112 $\times$ 14000 units = 18728080 units total, which we now divide by the specific heat equivalent 4646·9 found for the weight of gas.

$\frac{18728080}{4646 \cdot 9} = 4030$, which we now use as the divisor for the available heat left after the deduction of the 6,000 units lost in the latent state per pound of carbon taken up in the change from the acid to the oxide form.

422. 11·935 cwts. carbon $\times$ 112 $\times$ 6000 = 8026320 units lost in the latent state.

18728080
8026320
10701760 ÷ 4030 = 2655 lbs. = 23·71 cwts. carbon, being 0·16 cwt. less than the actual weight; the difference being due to the ratios of oxygen and nitrogen, which for simplicity are merely closely approximate, as we before observed.

SECTION XV.

423. We will now proceed to estimate the heat procurable from the carbonic oxide of the escaping gases, when fired with as much fresh air admitted as will supply oxygen to transform the oxide into acid gas.

The nitrogen from the furnace combustion, and what will be let free from the additional air in the firing of the gas, and also the carbonic acid formed in the furnace, will act now simply as diluters or thinners of the heat.

The carbon of the carbonic oxide has no power to attract the required second measure of oxygen from the carbonic acid, because that would simply shift the oxide form from itself to the carbon it was robbing.

The case would be different were it possible for volumes to combine with fractional parts of volumes.

The atomic weights which we have been using, and are now about again to use, represent the relative weights of the combining volumes, which are equal in the space they occupy for all bodies, the difference in material, constitution, or in density being indicated by the difference in weight for the fixed volume.

424. In estimating the relative weight of two volumes of air, we will show a fraction, but that has nothing to do, strictly speaking, with combining proportion, as we seek merely to know the weight of air which will fill the space

of 2 volumes; and as the proportions in which nitrogen and oxygen in air are mixed are 4 volumes of the former to 1 of the latter = 5 volumes, we get the total atomic weight for the 5 volumes, and take two-fifths of the weight, hence the fraction.

425. The gases escaping from the furnace are as follow:—

Nitrogen		106·28	cwts. per ton of iron
Carbonic acid		27·39	,,
Carbonic oxide	{	17·462	,, carbon
		23·225	,, oxygen
		174·357	,,

426. Recombination with fresh oxygen, and consequent contraction of volume, being necessary for complete combustion at the maximum heat, the carbon of the carbonic acid, being satisfied with its two measures of oxygen, remains passive, so that the 17·462 cwts. of carbon in the oxide are alone concerned in the active combustion of the gases, and for this weight of carbon an additional quantity, 23·225 cwts., of oxygen is required from fresh air, and this will be accompanied by 77·752 cwts. of nitrogen.

427. $\frac{23{\cdot}225 \times {\cdot}77}{{\cdot}23} = 77{\cdot}752 + 23{\cdot}225 = 100{\cdot}977$ cwts.

of fresh air. We will now multiply the weights of the several gases, including the fresh air, by the respective specific heats.

Nitrogen	106·28	× 112	× ·275 =	3273·42
Carbonic acid .	27·39	× 112	× ·22 =	674·89
,, oxide	40·687	× 112	× ·288 =	1312·39
Fresh air	100·977	× 112	× ·267 =	3019·61
	275·334			8280·30

275·334 × 112 = 30837·4 lbs. of gas.

428. $\frac{8280{\cdot}3}{30837{\cdot}4} = {\cdot}2685$ average specific heat for the whole body of escaping gas.

429. We have already found that 1 lb. of carbon in active combustion, so as to form carbonic acid, can raise one 2·44 lbs. equivalent of the nitrogen which accompanies the double measure of oxygen, 5,737 units or water-heat degrees, or 5,737 equivalents one degree.

In this we considered the combined carbon and oxygen which were undergoing combustion as the operating body, which contained the whole of the 14,000 units, and the proportion of nitrogen that went in with the oxygen as the body to be operated upon. This was simply for the purpose of getting a standard by which to estimate the heating effect upon the solid materials in the furnace.

430. Now, however, in estimating the heat procurable from the firing of the carbon in the escaping gases, we have to treat the whole volume of these gases, and also of the fresh air admitted, as absorbing heat from the total heat generated.

431. In the former case we treated the heat as if in a loose free state, and capable of being all discharged into the bodies it was operating upon; but we now seek to know the general temperature.

432. 17·462 cwts. carbon × 112 = 1955·74 lbs. in 40·687 cwts. of carbonic oxide.

1955·74 × 14000 units = 27380360 units total heat from the firing of the gases.

433. $\frac{27380360}{8280 \cdot 3} = 3307°$ Fahr. temperature of the flame; so that, supposing it were practicable to abstract the whole of the heat, each of the 8280·3 unit equivalents, referred to water, of gas of great volume would raise the temperature of 1 lb. of water of small volume 3,307°; and as the total amount of heat in steam at 212°, according to the experiments of Regnault, is 1146°, reckoned from freezing-point 32°, this heat would evaporate 2·885 lbs. of water.

434. This, however, is only the theoretical effect, and

assumes that the whole of the heat is available, which it is not, as there is always a loss in the heat necessary to create a draught in the chimney.

A temperature of 600° Fah. is not unusual at the junction of ordinary furnace flues with the chimney; and as this is the temperature we have assumed for the gases escaping from the smelting furnace, we have let the one balance the other.

435. We will now suppose that the heat has to be given to the air of the smelting furnace blast, passing through pipes set in the furnace where the firing of the escaping gases takes place.

436. We have already estimated the weight of nitrogen in the blast to be 106·28 cwts., and of oxygen, 31·737 cwts., together equal to 138·017 cwts. of air.

$$106{\cdot}28 + 31{\cdot}737 = 138{\cdot}017 \text{ cwts. air,}$$

$$138{\cdot}017 \times 112 = 15457{\cdot}9 \text{ lbs.}$$

$15457{\cdot}9 \times {\cdot}267 = 4127{\cdot}25$ equivalents which represent the air reduced to the same measure as water regarding capacity for heat.

437. We now add this to the 8280·3 got for the gases, and treat the whole as if the enclosing blast pipes were removed, so as to allow the blast air to circulate freely through amongst the gases.

$4127{\cdot}25 + 8280{\cdot}3 = 12407{\cdot}55$ total equivalent measure.

438. $\frac{27380360}{12407{\cdot}55} = 2206°$ Fah. of heat as the temperature of the flame of the fired gases when diluted by the volume of blast air.

439. We know, however, that the blast air is not heated to this degree, and that about one-half of this temperature is the most that can be looked for in ordinary heating stoves. Were the fired gases drawn through very thin and very long tubes, surrounded by the blast air as the tubes of a locomotive boiler are by water, uniformity of

heat in the blast air and the fired gases might be got nearly.

440. We have given only the combining weight of oxygen accompanying nitrogen for the firing of the carbonic oxide. In practice this would be insufficient, as the flame would be choked by its own products, intermixing with the combustible bodies, and so would burn slower with a lower heat. In ordinary boiler furnaces it is usual to allow about twice the weight of air required by combustion, so that the carbon in combustion may have readier command of free oxygen than if there were only the combining allowance present, seeking its way to it through amongst the spent rising gases. A larger allowance of air, therefore, lowers the general temperature because of the greater weight of gaseous matter to absorb the given number of heat units, the absolute amount of heat being ruled by the weight of carbon in the oxide. This lowering of the temperature, in addition to the loss of heat in the gases escaping at a much higher temperature than 600°, would reduce the proportion of heat available for the blast air to about the temperature which is reached in practice, about 1000°.

441. Change of temperature alters the capacity for heat; but we have taken little notice of this alteration, because in the most of our estimates, we have treated the heat as for total absorption by the receiving bodies.

The question is one that relates to expansion and pressure, that is, to expansion of volume with the pressure kept uniform throughout, and to increase of pressure with the volume maintained the same size as at first.

442. Expansion with uniform pressure happens in the case of these furnace gases, and is accompanied with a greater absorption of heat than when the volume is kept constant with increasing pressure; but this branches out into a subject somewhat foreign to that which we have had in hand, as it belongs to the "dynamics of heat."

We will, therefore, in this direction, content ourselves for the present with these slight observations.

443. When equal volumes in place of equal weights are taken, the ultimate result is nearly the same as for the latter. We will here estimate by volume to show this, and use the quantities of gases escaping from the smelting furnace, and the air required for firing the oxide; and as carbonic oxide and acid gases are reckoned in the simplest combining proportions, as of 2 volumes, we will find the respective weights of 2 volumes of the several gases concerned, viz., air, nitrogen, carbonic oxide, and carbonic acid, and then, according to the weights per 2 volumes of these, will use the respective total weights, to get the relative total volumes.

444. We must here refer back to our remarks upon the weight of combining volumes, Paragraph 389, made before we entered into consideration of the heat procurable from the firing of the gases.

445. The atomic weight per 2 volumes we fixed to be as follows:—

Air	$\frac{2}{5}$ of 5 volumes	=	2 volumes	= 28·8
Nitrogen	14 + 14	=	,, ,,	= 28·0
Carbonic oxide	16 + 12	=	,, ,,	= 28·0
Carbonic acid	16 + 16+12	=	,, ,,	= 44·0

446. Actual weights per ton of iron:—

Fresh air	=	100·977 cwts.	
Nitrogen	=	106·28 ,,	from furnace.
Carbonic oxide	=	40·687 ,,	from furnace.
Carbonic acid	=	27·39 ,,	from furnace.

447. Using the atomic weights, we will now find the relative proportions by volume simply:—

Air......... $\frac{100·977}{28·8} = 3·506$

Nitrogen .... $\frac{106·28}{28} = 3·795$

Carbonic oxide $\frac{40·687}{28} = 1·453$

Carbonic acid $\frac{27·39}{44} = ·622$

448. We will now assume the 3·506 of air to be equal to 1, and will find the relative proportions by volume of the other gases:—

$\frac{3·795}{3·506} = 1·082$ relative volume of nitrogen

$\frac{1·453}{3·506} = 0·414$ „ „ carbonic oxide

$\frac{0·622}{3·506} = 0·177$ „ „ carbonic acid

1·000 „ „ air

449. The relative proportions being to air as 1·00, we now multiply the weight of air by the relative volumes of the other gases, use the totals added together, as the divisor of the 27,380,360 units of heat belonging to the 17·462 cwts. of carbon in the oxide, and multiplying the result by the average specific heat of the whole gases united, get the same temperature nearly as already got when estimating by the specific heat relating to weight irrespective of volume.

450. This course of figuring is not intended for direct practical use, but only for the purpose of proof so far as one system based on another can be used to prove the approximate correctness of the one it is based on.

100·977 × 112 =	11309·42	lbs. of air	= 1
11309·42 × 1·082 =	12236·79	„ nitrogen	= 1·082
11309·42 × 0·414 =	4682·09	„ car. oxide	= 0·414
11309·42 × 0·177 =	2001·76	„ car. acid	= 0·177
	30330·06		

451. $\frac{27380360}{30330·06} = 902·7°$, but in this we have been treating the gases as possessed of the same capacity for

heat as water; we have, therefore, to divide this result by the ·2685 average specific heat already found for the whole volume.

452. $\frac{902 \cdot 7^\circ}{\cdot 2685} = 3362^\circ$ temperature of the flame of the fired gases, when no more than the combining proportion of oxygen is admitted, and when the stifling effect of the spent gases mixing with the yet unfired oxygen is left out of consideration.

This is 55° in excess of the temperature got when estimating by the weight alone.

453. Heating of the blast air:—

Nitrogen	106·28	cwts.
Oxygen...	31·737	,,
Air	138·017	,,

$$\frac{138 \cdot 017 \times 112 \times \cdot 267 \times 1000^\circ}{14000} = \frac{4127250}{14000} = \overset{\text{lbs.}}{294} = \overset{\text{cwts.}}{2 \cdot 625}$$

of carbon required to heat the 138·017 cwts. of air to the temperature of 1,000° Fah.

454. This weight of carbon must be reckoned as included in the total of 24·7 cwts. per ton of iron, but as it is merely the quantity required theoretically for heating the weight of air to the temperature named, and is exclusive of the waste of heat by the chimney of the air-heating furnace, an additional quantity dependent upon the description of furnace employed will be required in practice.

455. The fuel consumed by the boiler furnace of the blowing-engine ought also to be taken into account in ascertaining the full weight of fuel or carbon per ton of iron smelted. The 24·7 cwts. carbon concern merely the heat inside the main or smelting furnace, either as directly generated there, or carried in by the heat imparted to the air of the blast.

456. The 138·017 cwts. of air admitted cold would absorb the same amount of heat inside the furnace in

rising to 1,000° as it takes up in the separate heating furnace; but the advantage claimed for the hot blast lies in the heated air being readier for its appointed work on entering, so that combustion with the carbon takes place directly in front of the tuyeres; whereas the cold blast at the necessary velocity has become diffused before combustion is completely effected, so that in the case of the hot blast we have the heat concentrated in a comparatively thin horizontal layer of the descending material, whereas in the other case we have the same total quantity diffused through a layer considerably thicker, consequently the pound weight of material occupying a given space in the thin layer is being subjected to a sharper and more decisive heat than it is in the thicker layer. And, as the difference between the concentrated heat of the thin layer and the diffused heat of the thicker layer is analogous to the difference between a sharp-edged blade and another with a dull edge, a given amount of cutting can be done by the former, with less expenditure of force than can be done by the latter; and we might carry the parallel a little further, and say that the dull blade will not cut at all if very blunt, just as the diffused heat will not melt at all when dulled to even so little as 1° below the melting temperature, though the one may bruise and the other may soften the respective bodies they are acting on.

457. The intensity of the concentrated heat in the case of the hot blast, enables it to penetrate and fuse the materials with less fuel in combustion than is required in the case of the cold blast, just as the keenness of the sharp blade renders less force necessary in cutting.

458. The precise reason, however, of the hot blast developing heat from combustion so rapidly on its entrance is yet in doubt; the effect is out of proportion to the apparent cause.

459. The efficacy of the hot blast is less observable when fuel that is easy of combustion is used, than when

hard coke or inferior raw coal is employed, because the density of hard coke, or anthracite, prevents the blast from penetrating beyond the crust, so that combustion is more superficial than when the coke is soft and porous. A cold blast abstracts heat from the fire, in rising to the temperature it finds inside the furnace, in greater portion by the nitrogen, which forms nearly four-fifths of the whole, and merely receives and diffuses heat; consequently, when blowing upon blocks that have only the crust ignited, the part it strikes on is apt to be blown cold; whereas, when blowing upon soft porous coke, which readily heats through to the centre, there is a depth of fire to play upon, which is fed by the entrance of the blast into the pores; so that the air jet, where it first strikes this fuel, is operating upon a surface as much greater than the surface of the former as the area of the crust of the block, plus the area of the walls of the pores in the crust, is greater than the area of the impervious crust alone.

The cooling action of the blast, therefore, is rendered less apparent in the greater area than in the smaller; and this is in a measure independent of the particular temperature which the differently constituted bodies respectively require before ignition can take place, and consequently, the temperature necessary to maintain combustion (paragraph 296).

SECTION XVI.

460. Fowler's "Regenerative" stoves for heating the blast air have the "waste" gas from the smelting furnace introduced, along with the necessary quantity of fresh air, at the bottom of a central shaft of fire-brick, which rises to within a few feet of a brick dome-shaped roof, of con-

siderably greater diameter than the central shaft, and supported by thick outer walls, likewise of brick. The space all around between these outer walls and the central shaft is filled with bricks, so arranged that the fired gas, on rising up through the central shaft and completing its combustion in the wide space left vacant under the roof, may be able to circulate freely downwards through amongst them on its way to the chimney, and leave its heat behind in the bricks, for the blast air to take up, when sufficient heat having been thus stored, the waste gases are diverted into a second similar stove, and the blast air, cold, but under pressure, is admitted through a valve in the outer wall to flow upward through the heated brick battery to the roof chamber, thence downward through the central shaft, at the bottom of which are valves for regulating the inflow of the gases for firing, and the outflow there of the blast into the capacious but short main leading to the furnace.

The temperature of the central chimney is sufficiently high for the immediate ignition of the gas when admitted with the requisite fresh air through the bottom valve.

461. The bricks that are topmost in the battery are ever hottest, because they are nearest to the combustion chamber under the roof.

By the time that the heating current of fired gas has reached the bottom course, on a level with the ground flue leading to the chimney, the bricks, by absorption of the heat, may have lowered the temperature to an average of 400°; but the extent of this reduction is dependent altogether upon the dimensions, and more particularly upon the height of the battery.

At the works of Messrs. Cochrane, near Middlesborough, where these stoves have been brought to a high state of efficiency, the gases are cooled down from a temperature of about 2,300° in the combustion chamber, to 300°, or less, at the bottom of the battery, where the chimney flue commences.

The height of the battery in this case is 26 feet; the bricks composing it are of 1 inch thickness, and the distance they are apart is 3 inches.

In ordinary cast iron heating-stoves, the temperature of the escaping gas has been found to be between 1,200° and 1,300° for a temperature of blast inside the pipes of 1,000°.

Two or more stoves are required, for alternate service; one to be heating the blast, while the other or others are having the temperature restored by the firing of the waste gas from the furnace.

462. We will here approximately ascertain the weight of brick required to impart the necessary heat to the blast air.

			per lb.
Air	sp. gr. =	·0012 =	13·36 cubic feet.
Fire-brick ...	,,	= 2·200 =	12·6 cubic inches.
Water	,,	= 1·00.	

Fire-brick = 137 lbs. per cubic foot, so that 137 lbs. × 13·36 cubic feet for air = 1830 times air is greater in volume than fire-brick, when equal weights are taken.

463. The specific heat of air is ·267, and of fire-brick ·1917; so that ·1917 ÷ ·267 = ·718, for brick, to 1 for air, is the ratio of their respective capacities for heat; consequently, ·718 × 100° = 71° 8, is the temperature any given weight of air would be raised by the quantity of heat that shows 100° in an equal weight of fire-brick.

464. About 8,000 cubic feet of air per minute are passed through the heating stoves we have just spoken of, so that 8000 ÷ 13·36 = 599 lbs. of air per minute; and, 8000 ÷ 1830 = 4·37 cubic feet of brick, weighs likewise 599 lbs.; but we must here raise this measure for brick to put it on an equality in heat capacity with air, thus:—

sp. ht. sp. ht. cub. ft. cub. ft.
·1917 : ·267 : : 4·37 : 608, and, 6·08 × 137 lbs. = 832 lbs. of brick, to contain the same quantity of heat as 599 lbs. of air.

465. With these equivalent proportions, when 599 lbs. of air are raised in the stove from zero to the temperature of 1,400°, it follows that 832 lbs. of brick will be in effect cooled from 1,400° sensible temperature to zero, in imparting this heat to the air; consequently, as the average reduction in temperature in the battery is small—say about 100° in 1 hour—the equivalent weight of brick for an hour's work must be not less than 14 times that of the air passed per hour; thus—

lbs. min. hour lbs.
599 × 60 = 35940 × 14 = 503160

$$\frac{503160 \text{ lbs. air}}{832 \text{ lbs. brick}} = 604 \times 6{\cdot}08 = 3672$$ cubic feet of solid brick.

(cub. ft.)

466. In the larger stoves the solid contents of the batteries are stated to be only 3,040 cubic feet, but the heat stored in the enclosing walls, and roof, and central shaft, must likewise be taken into account, though the surface in contact with the air is very much less in their case, in proportion to the solid bulk, than in the case of the bricks in the honey-combed formation of the battery.

Further, we here assumed that the temperature of the bricks was no greater than 1,400°; whereas it is believed to be not less than 2,300° at top. The temperature at bottom is about 300° in the larger stoves, which, assuming that the temperature at the middle is the mean, gives an average temperature, roughly, of $\frac{2300° + 300°}{2} = 1300°$; but the heat radiating from the solid brick roof, and issuing from the walls, must so maintain the temperature as to establish a much higher average than this.

467. The difference in the capacity for heat between brick and air is provided for in the 832 lbs. of the former to 599 lbs. of the latter; but we may assume the weights to be equal, and the difference to be brought to a balance by a higher temperature in the brick; thus—

·1917 : ·267 : : 1400° : ·1950° required by the brick to impart 1,400° to the air; consequently, the higher the average temperature ranges in the battery, above 1,400°, the nearer may we reduce the 832 lbs. for brick to equality with the 599 lbs. for air.

468. In experiments with the larger stoves the blast has been heated to 1,880°, but their regular working temperature is between 1,400° and 1,500°.

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