Chapter XXXIX.—THE MECHANICAL POWERS. LEVERS, PULLEYS, GEAR WHEELS, ETC.

POWER is distinguishable from force or pressure in that the term power means force or pressure in motion, and since this motion cannot occur without the expenditure of the force or pressure, power may, with propriety, be termed the expenditure of force or pressure.

If we suppose a piston to stand in a vertical cylinder sustaining a weight upon its surface and compressing the air within the cylinder, so long as there is no motion no work is done, as the term "work" is understood in a mechanical sense, and the weight merely produces a pressure. If, however, the weight be removed, the compressed air will force the piston upward, performing a certain quantity of work which may best be measured by the amount of power exercised or expended.

The mechanical value of a given amount of power cannot be either increased, diminished or destroyed by means of any mechanical device or appliance whatsoever through which it may be transmitted.

It may be concentrated, as it were, by decreasing the amount of its motion. It may be distended, as it were, by increasing the distance through which it moves, or it may be expended in giving or producing motion, but in either case the amount of duty or work done is the exact equivalent of the amount of power applied.

A gain or increase in speed is not, therefore, a loss of power, but merely a variation in the mode of using or utilizing such power.

For instance, 1 lb. moving through a distance of 12 inches in a given time represents an amount of power which may be employed either as 1 lb. moving a foot, 2 lbs. moving six inches, or $\frac{1}{2}$ lb. moving through 24 inches, in the same space of time, the amount of the power or duty remaining the same in each case, the method of utilization merely having differed.

It is an inexorable law of nature that power is concentrated in proportion as the amount of its motion is diminished, or distended in precise proportion as such motion is increased.

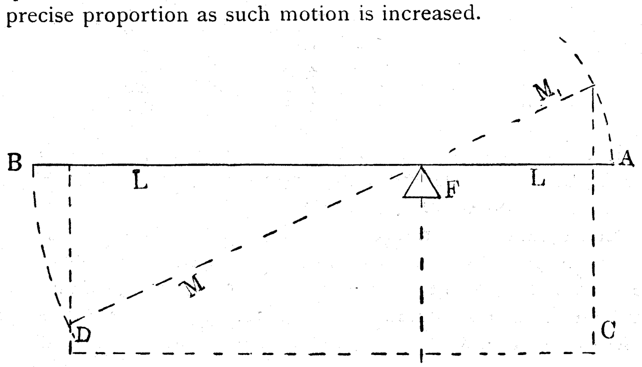

Fig. 3351.

Suppose, for example, that in Fig. 3351 L is a lever having its fulcrum at F, which is 4 inches from end A, and 8 inches from end B, and (leaving the weight of the lever out of the question) if we place an 8 lb. weight on A it will just balance 4 lbs. at B.

If the lever is moved, the amount of motion will be twice as much at end B as it is at end A.

If we apply the power at A, the lever has become a means of converting 8 lbs. moving a certain distance into 4 lbs. moving twice that distance, and nothing has been either gained or lost.

If we apply the power at B, the lever has merely been used as a means of converting 4 lbs. moving a certain distance into 8 lbs. moving one half that distance, and nothing has been gained or lost.

Suppose that end A was moved an inch, and the power at that end will be 8 inch pounds or 8 lbs. moving an inch, whereas at the end B the power is 4 lbs. moving 2 inches; we have, therefore, reduced the weight in the same proportion that we have increased the distance moved through.

Suppose now that the lever is moved to the position denoted by

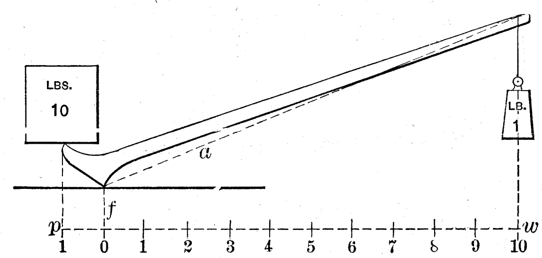

Fig. 3352.

the dotted line M M, and the leverages will be altered; that at end A becoming that denoted by the distance from F to the vertical C, and that for end B being denoted by the distance from F to the vertical D.

This occurs because we are dealing with gravity, which always acts in a vertical line.

A crow bar is an excellent example of the application of the lever. In Fig. 3352, for example, we have a 1 lb. weight on the long end of the lever, and as we are dealing with a weight, the effective length of the long end of the lever is from the fulcrum *f* to *w*, which is divided into 10 equal divisions. The short end of the lever is from *f* to *p*, which is equal to one division, hence the 1 lb. is balanced by the 10 lbs.

A simple method of distending power is by means of pulleys or gear wheels. Suppose, for example, that in Fig. 3353, we have a weight of 12 lbs. suspended from a shaft or drum, whose radius *a*

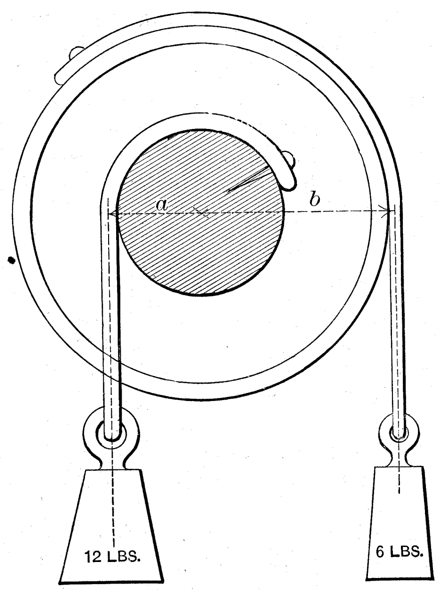

Fig. 3353.

is 10 inches, and that on the same shaft there is a pulley, whose radius b is 20 inches, and the two weights will balance each other.

In this case the falling of either weight would not effect the leverage, because the distance of both weights would remain the same from the centre of the shaft. The leverage of the 12 lbs. is denoted by the line a, and that of the 6 lbs. by b.

So far as the transmission of power is concerned, therefore, pulleys are in effect revolving levers, which may be employed to concentrate or to distend power, but do not vary its amount.

Suppose we have two shafts, on the first of which are two pulleys, B and C, Fig. 3354, while upon the second there are two pul-

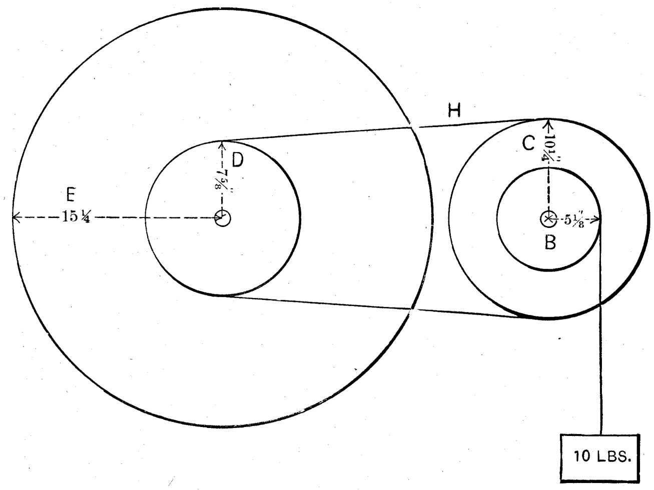

Fig. 3354.

leys D and E. A belt H, connecting C to D. Let the pulleys have the following dimensions:

If we take the first pair of wheels B and C, we have that the velocity will vary in the same ratio or degree as their diameters vary, notwithstanding that their revolutions are equal.

	Radius.	Diameter.	Circumference.
B =	$5\frac{1}{8}$ inches.	$10\frac{1}{4}$ inches.	32.2 inches.
C =	$10\frac{1}{4}$ "	$20\frac{1}{2}$ "	64 4 "
D =	$7\frac{5}{8}$ "	$15\frac{1}{4}$ "	47.9 "
E =	$15\frac{1}{4}$ "	$30\frac{1}{2}$ "	95.8 "

The velocity is the space moved through in a unit of time, and as it is the circumference of the pulley that is considered, the velocity of the circumference is that taken; thus, if we make a mark on the circumferences of the two pulleys, B and C, Fig. 3354, the velocity of that on C will be twice that upon B, or in the same proportion as the diameters.

Let there be suspended from the circumference of B 10 lbs. weight, and let us see the degree to which this power will be distended by this arrangement of pulleys, supposing the weight to rotate B, and making no allowance for the friction of the shaft.

Suppose the weight to have fallen 32.2 inches, and we have 10 lbs. moving through 32.2 inches, this power it will have transmitted to pulley B.

To find what this becomes at the perimeter of C, we must reduce the number of lbs. in the same proportion that the perimeter of C moves faster than does that of B; hence we divide the circumference of one into the other, and with the sum so obtained divide the amount of the weight; thus, 64.4 (circumference of C) ÷ 32.2 (circumference of B), = 2; and 10 lbs. ÷ 2 = 5 lbs., which, as the circumference of C is twice that of B, will move twice as fast as the 10 lbs. at B, hence for C we have 5 lbs. moving through 64.4 inches.

Now C communicates this to D by means of the belt H, hence we have at D the same 5 lbs. moving through 64.4 inches.

Now E moves twice as fast as D, because its circumference is twice as great, and both are fast upon the same shaft, hence the 5 lbs. at D becomes $2\frac{1}{2}$ lbs. at E, but moves through a distance equal to twice 64.4, which is 128.8 inches. To recapitulate, then, we have as follows:

The weight	gives	10 lbs.	moving	through	32.2 inches.
Pulley B	"	10 "	"	"	32.2 "
" C	"	5 "	"	"	64.4 "
" D	"	5 "	"	"	64.4 "
" E	"	$2\frac{1}{2}$ "	"	"	128.8 "

That the amount of power is equal in each case, may be shown as follows:

For C, 5 lbs. moving through 64.4 inches is an equal amount of power to 10 lbs. moving through 32.2 inches, because if we suppose the first pair of pulleys to be revolving levers, whose fulcrum is the centre of the shaft, it will be plain that one end of the lever being twice as long as the other, its motion will be twice as great, and the 5 at $10\frac{1}{4}$ inches just balances 10, at $5\frac{1}{8}$ inches from the fulcrum, as in the common lever.

In the case of D we have the same figures both for weight and motion as we have at C, because D simply receives the weight or force and the motion of C. In the case of E, we have the motion of the weight multiplied four times; for the distance E moves is 128.8 inches, which, divided by 4, gives 32.2 inches, which is the amount of motion of the weight, hence the 10 lbs. of the weight is decreased four times, thus 10 lbs. ÷ 4 = $2\frac{1}{2}$ lbs., hence the $2\frac{1}{2}$ lbs. moving through 128.8 inches is the same amount of power as 10 lbs. moving 32.2 inches, and we may concentrate or convert the one into the other, by dividing 128.8 by 4, and multiplying the $2\frac{1}{2}$ lbs. by 4, giving 10 lbs. moving 32.2 inches.

If, therefore, we make no allowance for friction, nothing has been lost and nothing gained.

Thus far, we have taken no account of the time in which the work was done, more than as one wheel is caused to move by the other, and all of them by the motion of the weight, they must all have begun and also have to move at the same time. Suppose, then, that the time occupied by the weight in falling the 32.2 inches was one minute, and the amount of power obtained may be found by multiplying the lbs. of the weight by the distance it moved through in the minute, thus 10 lbs. moving 32.2 inches in a minute gives 32.2 inch lbs. per minute, being the amount of power developed by the 10 lb. weight in falling the 32.2 inches.

We may now convert the power at each pulley perimeter or circumference into inch pounds by multiplying the respective lbs. by the distance moved through in inches, as per the following table:

	Distance moved. Lbs.		Inches.		Inch lbs. of power.
Weight at B	10	×	32.2	=	322
" " C	5	×	64 4	=	322
" " D	5	×	64.4	=	322
" " E	$2\frac{1}{2}$	×	128.8	=	322

If we require to find the power in foot lbs. per minute, we divide by 12 (because there are 12 inches in a foot), thus 322 inch lbs. ÷ 12 = 26.83 foot lbs. per minute.

Now suppose that B was moved by a belt, with a pull of 10 lbs. at its perimeter, and made 100 revolutions in a minute instead of one, then the pull at the perimeters of C, D, and E would remain the same, but the motion would be 100 times as great, and the work done would therefore be increased one hundred fold. It will be apparent, then, that the time is as important an element as the weight.

The velocity and power of gear wheels are calculated at the pitch circle.

Now suppose the gear A in Fig. 3355 has 30, gear B 60, gear C 10 and gear E 80 teeth, and that 5 lbs. be applied at the pitch circle of A; to find what this 5 lbs. would become at the pitch circle of E, we multiply it by the number of teeth in B and divide it by the number of teeth in C, thus:

	Lbs.
At pitch of circle A	5
Number of teeth in B	60
Number of teeth in C 10)	300
	30

Answer, 30 lbs. at the pitch circle of E.

Now suppose that on the shaft of A there is a pulley 20 inches in diameter, and that on this pulley there is a belt exerting a pull of 5 lbs., while on the shaft of E there is a pulley 16 inches in diameter, and to find how much this latter pulley would pull its belt, we proceed as follows:

	2)20	= Diameter of pulley on A.
	10	= Radius of pulley on A.
	5	= Pull on pulley A.
Number of teeth in A	= 30)50	= Pull at centre of shaft of A.
	1.666	
	60	= Number of teeth on B.
Number of teeth on C	= 10)99.960	= Pull at axis of shaft of B.
	9.996	
	80	= Number of teeth on E.
Radius of pulley on shaft of E	8)799.680	Pull at axis of shaft E.
	99.96	Pull at perimeter of last pulley.

We have in this case treated each pulley as a lever whose length equalled the radius of the pulley, while in the case of the wheel we have multiplied by the number of teeth when the power was transmitted from the circumference to the shaft, and divided by the number of teeth (the number of teeth representing the circumference) when the power was transmitted from the shaft to the teeth.

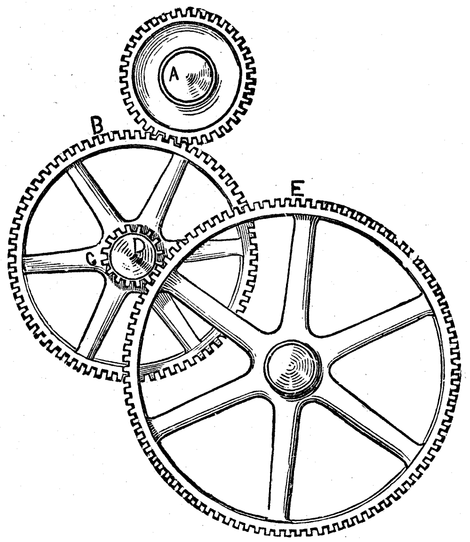

Fig. 3355.

We thus find that power is composed of three things, first, the amount of impelling force; second, the distance that force moves through; and third, the time it takes to move that distance.

If we take a number of pulleys, say four, and arrange them one after another so that they drive by the friction of their circumferences, then the amount of power transmitted by each will be equal and the velocities will be equal, whereas, if we arrange them as in Fig. 3354, the power will be equal for each, but the velocities or space moved through in a given time will vary.

What is known as the unit of power is the foot lb., being the amount of power exerted in raising or lifting one lb. one foot, and from what has already been said, it will be perceived that this is the same amount of power as 12 lbs. moving a distance of one inch.

Watt determined that the power of a horse was equal to that necessary to raise 33,000 lbs. one foot high in a minute, and this is accepted, in English speaking countries, as being a horse power.

An engine or machine has as much horse power as it has capacity to lift 33,000 lbs. a foot high in a minute.

CALCULATING THE HORSE POWER OF AN ENGINE.

The horse-power of an engine may be calculated as follows:

Rule.—Multiply the area of the piston by the average steam pressure upon the piston throughout the stroke, and by the length of the stroke in inches, which gives the number of inch pounds received by the piston from the steam during one stroke.

As there are two piston strokes to one revolution of the engine, we multiply by two, and thus get the number of inch pounds received by the piston in one revolution.

By multiplying this by the number of revolutions the engine makes in a minute, we get the number of inch pounds of power received by the piston in a minute.

By dividing this by 12, we get the number of foot pounds the piston receives per minute, and dividing this by 33,000 lbs. we get the horse-power of the engine.

It has already been stated that Watt determined that a horse was capable of exerting a power equal to the raising of 33,000 lbs. one foot high in a minute, hence, having foot pounds of the engine per minute, dividing them by 33,000 gives the horse power.

This gives the amount of power received by the piston, but it is evident that the engine cannot exert so much power, because part of it is expended in overcoming the friction of the moving parts of the engine.

The amount of the piston power expended in overcoming the friction depends upon the fit of the parts, upon the lubrication and the amount of the load.

Thus, the friction of the cross head guides, of the cross head pin, of the crank pin and of the crank shaft bearings will increase with the amount of resistance offered to the piston motion.

The average pressure on the piston is a difficult thing to find, however, for several reasons.

First, because the pressure in the cylinder may, during the live steam period, vary from that in the steam chest because of the ports being too small or from the passages being choked from a defective casting.

Second, because the steam is wire drawn during the time that the slide valve is closing the port to effect the cut off.

Third, because the live steam in the port and passage at the time the cut off occurs gives out some power during the period of expansion.

Fourth, because there is some condensation of the steam in the cylinder after the point of cut off, and there is no means of finding by calculation how much loss there may be from this cause.

During the live steam period there is also loss from condensation in the cylinder, but this is made up for by steam from the steam chest.

Fifth, the loss from condensation after the cut off has occurred will vary with the speed of the engine, and is greater in proportion as the piston speed is less, because there is more time for the condensation to occur in.

Sixth, there is some pressure on the piston between the time that the exhaust begins and the piston ends its stroke.

Seventh, because the compression absorbs some of the piston power.

Assuming the average pressure on the piston to be known, however, we may calculate the horse power as follows:

Example.—What is the horse power of an engine whose piston is 20 inches in diameter, and stroke 30, the revolutions per minute being 120, and the average pressure on the piston 60 lbs. per square inch?

Diameter of piston	20
Diameter of piston	20
Diameter of piston squared	400

	.7854	
	400	
Area of piston	= 314 1600	(☞ these two ciphers neglected.)
	60	average steam pressure.
lbs. pressure on piston	18849.60	(☞ this cipher neglected.)
	30	length of stroke in inches.
	565488.0	inch lbs. per stroke.
	2	two piston strokes per revolution.
	12)1130976	inch lbs. per revolution.
	94248	foot lbs per revolution.
	120	revolutions per minute.
	1884960	
	94248	
	11309760	foot lbs. per minute.

```
33000)11309760(342.72 = horse power of engine.
      99000
      140976
      132000
       89760
       66000
       237600
       231000
         66000
         66000
```

In working out the calculation, the ciphers that are decimals and are on the right hand are neglected or taken no account of, because they represent no value and may therefore be discarded.

Thus the area of the piston is 314.1600 inches, the two right hand ciphers having no value. Again the lbs. pressure on the piston is 18849.60 lbs., and the right hand cipher, having no value, is discarded. The inch lbs. per stroke is 565488.0, and the decimal cipher, representing nothing, is discarded when multiplying by the 2.

We have in this case taken no account of the fact that the piston rod prevents the steam from acting against a part of the piston area during one stroke; hence for correct results we must subtract from the area of the piston one half the area of the piston rod.

The horse power thus obtained is that which the engine receives from the steam, and is more than the engine is capable of exerting to drive machinery, because a part of this power is consumed in overcoming the friction of the working parts of the engine.

TESTING THE HORSE POWER OF AN ENGINE.

The useful horse power of a stationary engine may be readily and accurately obtained by means of a pair of scales, and a brake, as shown in Fig. 3356, which is constructed and used as follows:

On the crank shaft of the engine is a pulley enveloped by a friction brake, which consists of an iron band, to which wooden blocks are fastened.

The ends of the iron band do not meet, but are secured together by a bolt as shown.

By screwing up the bolt the wood blocks are brought to press against the circumference of the wheel.

represents the length of the lever, shall stand parallel with the surface of the platform of the scale.

To test the horse-power, we proceed as follows:

Suppose the pressure of the end of the lever on the scale is found by the weight on the scale beam to be 540 lbs., the diameter on which the brake blocks act being 3 feet, the length of the leverage being 5 feet 3 inches, as marked, and the engine making 150 revolutions per minute, and the calculation is as follows:

```
                                540   lbs. on scale.
                                5.25  leverage in feet.
                                27 00
                               108 0
                              2700
radius of pulley in feet 1.5)2835.00(1890 lbs. at pulley perimeter.
                              15
                              133
                              120
                               135
                               135
                               ...0
```

Then

```
3.1416
     3     diameter of pulley in feet.
9.4248     circumference of pulley in feet.
   150     revolutions per minute.
4712400
 94248
1413.7200  velocity of pulley perimeter.
     1890  pounds at pulley perimeter.
12723480
1130976
141372
2671930.80 foot lbs. per minute.
```

Then

```
33000)2671930.80(80.9
      264000
       319308
       297000
       223080
```

Answer, $80\frac{9}{10}$ horse power.

In this calculation we have nothing to do with the size of the

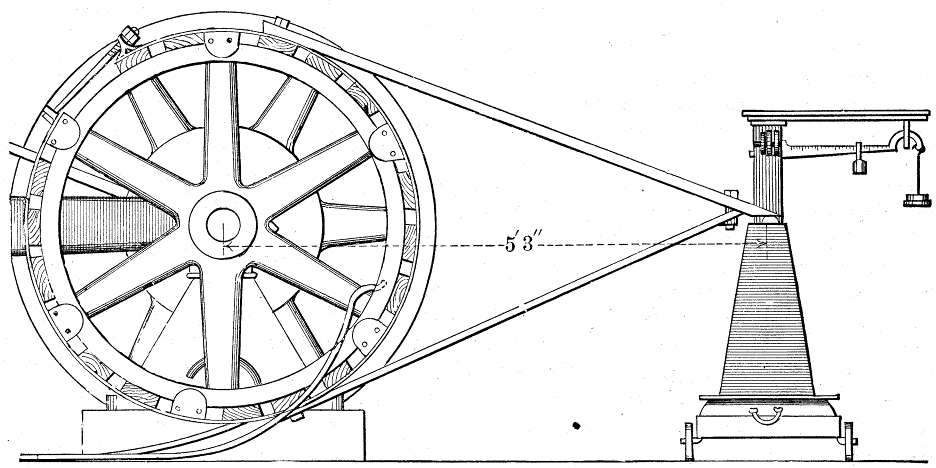

Fig. 3356.

This forms a friction brake that would revolve with the wheel, were it not for two arms that are secured to the brake, and rest at the other end upon a block placed upon a pair of scales.

The principle of action of this device is that the amount of friction between the brake and the wheel is weighed upon the scales, and this amount, multiplied by the velocity of the wheel at its circumference and divided by 33,000, is the horse-power of the engine.

It is necessary, in arranging this brake, to have its end rest upon the scale at the same height from the floor as the centre of the crank shaft, so that the line marked 5′ 3″ (5 feet 3 inches), which

cylinder or the steam pressure, because the scale beam tells us how many lbs. the brake exerts on the scale, and we treat the brake and brake pulley as levers. Thus by multiplying the lbs. on the scale by the leverage of the brake arm we get the number of lbs. exerted at the centre of the crank shaft, and by dividing this by the radius of the brake pulley we get the number of lbs. on the circumference, or, what is the same thing, the perimeter of the brake pulley.

By multiplying the circumference of the pulley in feet by the revolutions per minute, we get the speed at which the pounds travel, and by multiplying this speed by the number of lbs. we get the foot lbs. per minute, which, divided by 33,000, gives us the effective horse power of the engine.

This effective horse power is correct, because in loading the engine by the brake the crank pin, the cross head guides, etc., are all placed under the same friction as they would be if it was a circular saw, or some other piece of machinery or machine that the engine was driving.

SAFETY VALVE CALCULATIONS.

Among the most frequent questions asked in an engineer's examination are those relating to the safety valves of boilers.

These questions may be easily answered from a study of the following:

The safety valve is a device for relieving the boiler of steam after it has reached a certain pressure.

This it accomplishes by letting the steam escape after it has reached the required pressure.

At what pressure the safety valve will blow off depends upon the position of the weight on the safety valve lever.

The calculations referring to this part of the subject are, finding how much weight will be required to be placed at a given point on the lever, in order, with a given sized valve, to blow off at a given pressure.

Finding the position on the lever of a given amount of weight, in order to blow off at a certain pressure.

Finding, with a given sized valve and a given weight, how to mark off the lever and where the notches must be cut for given pressures.

In each of these calculations there are three elements: first, the area of the valve and the steam pressure, which constitute the effect of acting to lift the valve; second, the amount of the weight and its position upon the lever, which acts to keep the valve closed; and third, the weight of the lever and of the valve, which act to keep the valve closed.

In Fig. 3357 we have a drawing of a safety valve shown in section, and if there was no weight upon the lever, the pressure of steam the valve would hold in the boiler would be that due to the weight of the valve and of the lever upon the valve.

To find out how much this would be, we would have to put the valve itself and the pin *a* on a pair of scales and weigh them

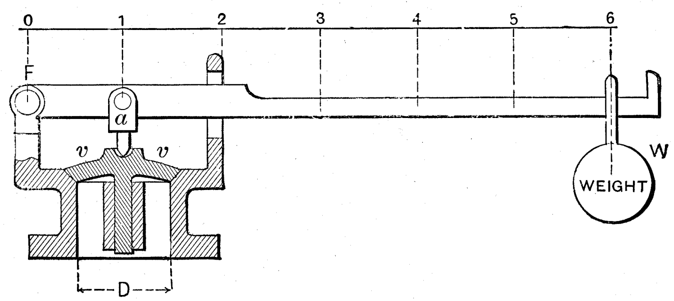

Fig. 3357.

Then put a piece of string through the hole at *a* in the lever, and see how much it weighed when suspended from that point.

Suppose the valve and pin to weigh 2 lbs. and the lever (suspended by the string) 10, and the total will be 12 lbs.

Next we find the area of the valve, and suppose this to be 8 square inches; then we may find how much pressure the valve would keep in the boiler, by dividing the area of the valve into the weight holding the valve down, thus:

	Lbs.
Weight of valve and pin,	2
" " lever,	10
Area of valve, 8)	12
Pressure the valve would hold,	1.5 lbs.

The area of the valve is that part of its face receiving the steam pressure when the valve is seated, so that if the smallest part of the valve diameter is equal to the diameter of the seat bore, the diameter from which the valve area is to be calculated will be that denoted by D in the figure, and cannot in any case be less than this. But if the smallest end of the valve cone is of larger diameter than the smallest end of the seat cone (which should not, but might be the case), then it is the smallest diameter of valve cone that must be taken in calculating the area, because that is the area the steam will press against.

Now suppose we rest a 20 lb. weight on the top of the valve that is on the point denoted by 1, and there will be 32 lbs. holding the valve down, thus, weight of valve 2 lbs., of lever 10, and weight added, 20 lbs, and to find how much pressure this would hold in the boiler, we divide it by the valve area, thus:

Weight on valve.
Valve area = 8) 32
4 = pressure valve will hold.

But suppose we put the weight on the lever, in the position shown in the figure, which is six times as far from the fulcrum F of the lever as the valve is, and its effect on the valve will be six times as great as it would if placed directly upon the valve, so that leaving the weight of the valve and of the lever out of the question (as is commonly done in engineers' examinations), we may find out what pressure the valve will hold, as follows:

Rule.—Divide the length of the lever by the distance from the centre of the valve to the centre of the fulcrum. Multiply by the amount of the weight in lbs., and divide by the area of the valve.

Example.—The area of the valve is 8 inches, the distance from the centre of the fulcrum to the centre of the valve is 4 inches, and the distance from the fulcrum to the point of suspension of the weight 24 inches, the weight is 40 lbs., what pressure will the valve hold?

Length of lever.
From fulcrum to valve, 4)24
6
40 amount of weight.
Area of valve, 8)240
30
Lbs. per square inch the valve will hold = 30.

The philosophy of this is clear enough when we consider that as the weight is six times as far from the fulcrum as the valve is, and each 1 lb. of weight will press with a force of 6 lbs. on the valve, hence the 40 lbs. will press 240 lbs. on the valve, and as the valve has 8 square inches, the 240 becomes 30 lbs. for each inch of area.

Example.—The area of a safety valve is 8 inches, the distance from the fulcrum to the valve is 4 inches, and the weight is 40 lbs., how far must the weight be from the fulcrum to hold in the boiler a pressure of 30 lbs. per square inch?

In lbs.
From fulcrum to valve, 4)40 amount of weight.
10

Area of valve, 8 square inches.
Pressure required, 30
10)240
24
Answer = 24 inches from the fulcrum.

Example.—The diameter of a safety valve is 4 inches, the distance from the centre of the fulcrum to the valve is 3 inches, a 50 lb. weight is 30 inches from the fulcrum, what pressure will the valve hold?

3 diameter of valve.
3
9
.7854
36
45
72
63
7.0686 = area of valve.

3)30
10

50 = weight
10 = leverage of weight.
Area of valve, 7.068)500.coc(70.7=lbs. pressure per sq. in.
49476
52400
49476
2924

HEAT.

The heat unit, or the unit whereby heat is measured, is the quantity of heat that is necessary to raise 1 lb. of water from its freezing temperature (which is 32° Fahrenheit) 1°, and this unit is sometimes termed a *thermal unit.*

The reason that some specific temperature, as 32° Fahrenheit, is taken, is because the quantity of heat required to heat a given quantity of water 1° increases with the temperature of the water; thus, it takes more heat to raise 1 lb. of water from 240° to 245° than it does to raise it from 235 to 240, although the temperature has been raised 5° in each case.

The whole quantity of heat in water or steam is not, however, sensible to the thermometer, or, in other words, is not shown by that instrument. The heat not so shown or indicated is termed *latent* heat.

Water obtains latent heat while passing from a solid to a liquid state, as from ice into water, and while passing from a liquid to a gaseous state, as while passing from water into steam, and the existence of latent heat in steam may be shown as follows:

If we take a body of water at a temperature above freezing, and insert therein a thermometer, the decrease in the temperature as the water becomes frozen will be shown by the thermometer. If, then, its temperature being say at zero, heat be continuously imparted to the ice, the thermometer will mark the rise in temperature until the ice begins to melt, when it will remain stationary at 32° so long as any ice remains unmelted, and it is obvious that all the heat that entered the water from the time the ice began to melt until it was all melted became latent, and neither sensible to the sense of feeling nor to the thermometer. Similarly, if the water, after the ice is all melted, be heated in the open air, the thermometer will mark the rise of temperature until the water boils, after which it will show no further rise of temperature, although the water still receives heat. The heat that enters the water from boiling until it is evaporated away is the latent heat of steam. The latent heat of water is 143° Fahrenheit, and that of steam when exposed to the pressure of the atmosphere, or under an atmospheric pressure of 15 lbs. (nearly), is 960°, which may be shown as follows:

If a given quantity of water, as say 1 lb., has imparted to it a continuously uniform degree of heat sufficient to cause it to boil in one hour, then it will take about $5\frac{1}{3}$ more hours to evaporate it all away, hence we find the latent heat by taking the difference in the amount of heat received by the water, and that shown by the thermometer thus:

		Degrees.
Temperature by thermometer at boiling point...		212
Less the temperature of the water at first.......		32
Heat that entered the water in the first hour.....		180
Hours that the water was subsequently heated..		$5\frac{1}{3}$
		900
One-third of 180............................	=	60
Heat that entered the water during the $5\frac{1}{3}$ hours		960 degrees.

This, however, is not quite correct, as it would take slightly more than $5\frac{1}{3}$ hours to boil the water away, and the heat that entered the water after it commenced to boil would be about 966 degrees.

If the steam that arose from the water while it was boiling were preserved without increasing the pressure under which it boiled, and without losing any of its heat, it will have a temperature the same as that of the water from which it was boiled, which is a temperature of 212°, so that neither the steam nor the water account, by the thermometer, for the 966° of heat that entered the water after it boiled, hence the 966° became latent, constituting the latent heat of the steam when boiled from and at a temperature of 212°.

The total heat of steam is the sensible heat, or that shown by the thermometer, added to the latent heat; hence the heat necessary to evaporate water into steam at a temperature of 212° (which corresponds to a pressure of 14.7 lbs. per square inch) is 212° + 966°, which is 1178°, and these, therefore, are the number of degrees that must be imparted by the coal to the water, in order to form steam at a temperature of 212°.

WATER.

Water is at its greatest density when at a temperature of 39.1° Fahrenheit, that is to say, it occupies its least space and weighs the most per given quantity (as per cubic inch) when at that temperature.

At a lower temperature water expands, its freezing point being 32° Fahrenheit, below which it forms ice. The weight of a cubic foot of water when at its maximum density (39.1) is 62.382 lbs. Water also expands as its temperature is increased above 39.1°; thus, while it is heated from 39.1 to 212°, its volume increases from 1 to 1.04332. The expansion for each degree of heat added to its temperature increases from 0 at 40° Fahrenheit to .0043 at 212°.

The rate of expansion of water at a temperature above 212° is unknown.

STEAM.

At every temperature above freezing point water passes from the liquid into a gaseous state, the gas being termed steam. While water is below its boiling point its evaporation occurs at its surface only; but when its mass is heated to boiling point, and additional heat is imparted to it, evaporation occurs from the water lying against the surface from which it receives the heat, and an ebullition is caused by the vaporized water passing through the mass, the ebullition being what is known as boiling.

The temperature at which water boils depends upon the pressure acting upon its surface, the boiling point being at a lower temperature in proportion as the pressure is reduced; thus water at the top of a mountain, where the pressure of the atmosphere is less than at the sea level, would boil at a lower temperature than 212°, which is the boiling point when the atmospheric pressure is 14.7 lbs., which it is assumed to be at the sea level. Conversely, the boiling point is raised in proportion as the pressure upon its surface is raised, whether that pressure consists of air or of steam. As, however, the pressure is increased, the boiling point is at a higher temperature. So long as the steam is in contact with the water both are at the same temperature, as denoted by the thermometer (although they do not contain the same quantity of heat, as will be shown presently), and the steam is termed *saturated* steam.

The pressure of saturated steam cannot be either increased or diminished without either increasing or diminishing its temperature, hence there is a definite relation of pressure to temperature, which enables the pressure to be known from the temperature, or conversely, the temperature to be known from the pressure. But if the steam be separated from the water and heated, it may be what is termed *superheated,* which is that it may be surcharged with heat or contain more heat than saturated steam at the same pressure. Such additional heat, however, is latent.

The pressure of steam is the lbs. of force it exerts upon a given area, as upon a square inch. In non-condensing engines the effective pressure of the steam is its pressure above that of the atmosphere, because the exhaust side of the piston being exposed to the atmosphere receives the atmospheric pressure, which must be overcome by a corresponding pressure of steam on the steam side of the piston, and this pressure is not, therefore, available for producing work or power in the engine.

In condensing engines, however, the exhaust side of the piston is (as nearly as practicable), relieved of the atmospheric pressure, and assuming a perfect vacuum to be formed, the whole of the steam pressure is exerted to propel the piston, in which case the steam pressure is termed the *absolute* pressure.

In considering the weight or density or the expansion of steam, its *absolute* and not its effective pressure must obviously be taken.

What is termed dry steam is *saturated* steam that does not contain what may be termed entrained water, which is water held in suspension in the steam, which may be caused by the surface of the water through which the steam is allowed to rise being too small in proportion to the volume of steam formed, in which case the rapid passage of the steam through the water causes it to carry up water with it and hold it in suspension, this action being termed *foaming* or *priming*.

Suppose, for example, that a boiler be filled with water up to the bottom of the steam dome, then all the steam formed would require to find exit from the water within the area of the dome, and the violence of the ebullition would cause foaming. Obviously, then, to obtain dry steam there must be provided a sufficient area of water surface for the steam to pass through.

But water so entrained is evaporated into steam, if the steam is wire drawn, that is, allowed to expand and reduce in pressure.

THE EXPANSION OF STEAM.

A cubic inch of water, when evaporated into steam at a pressure of 14.7 lbs. per square inch, occupies as steam a space or volume of 1644 cubic inches, and its weight will be equal to that of the water from which it was evaporated.

If additional heat be imparted (after its evaporation into steam), such additional heat becomes latent and does not cause an increase of sensible temperature or of pressure.

The weight of a given volume of steam, therefore, bears a definite and constant relation to the pressure and sensible temperature of the steam, so that the pressure or the sensible temperature being known, the weight of a given volume, as say a cubic foot, may be known therefrom. Or the weight of a cubic foot of steam being known, its sensible temperature and pressure may be known therefrom.

This would not be the case if steam expanded by heat. Suppose, for example, we have a cubic foot of steam at any absolute pressure, as say 15 pounds per square inch, a cubic foot weighing .0387 of a lb., and its sensible temperature will be 213°. Now it is evident that the weight will remain the same whatever the amount of heat that may be imparted to the steam. Now if the steam were maintained within the cubic foot of space, and was capable of expansion by the absorption of additional heat, its pressure would increase and its weight remaining the same, there would be no definite relation between the weight and the temperature and pressure.

But if the cubic foot of steam were allowed to expand so as to occupy more space, then additional heat is necessary to prevent its condensation.

The relation between the temperature, pressure, and weight of steam is not quite proportional to the volume, because steam is not a perfect gas, and does not, therefore, strictly follow Marriotte's law.

A perfect gas is one that during expansion or compression follows the law laid down by Boyle and Marriotte, this law being that, if maintained at a constant temperature, the volume is inversely proportional to the pressure.

For example, the quantity of gas that, if confined in a cubic inch of space, would give a pressure of 80 lbs. per square inch, would give a pressure twice as great (or 160 lbs. per inch of area), if confined in one-half the space, that is, if compressed into one-half of a cubic inch. Conversely, if the cubic inch was allowed to expand until its pressure was 40 lbs, it would occupy 2 cubic inches of space, assuming, of course, that the temperature remains the same. Since, however, if a gas be compressed, its temperature is increased by reason of the friction of the particles moving one upon the other, the law of Marriotte may be better explained as follows:

Suppose we have three vessels, A, B, and C, filled with a fluid which is a perfect gas, the temperatures being equal. Let the pressure be: A 40, B 80, and C 160 lbs. per square inch, then 2 cubic inches of the fluid in B will weigh the same as 4 cubic inches in A, because that in B is at twice the pressure of that in A, and the 2 cubic inches in B will weigh the same as 1 cubic inch in C, because its pressure is one-half that of C, or, what is the same thing, whatever number of cubic inches of the fluid in C it takes to weigh a pound, it will take twice as many in B, and four times as many in A to weigh one pound.

But steam is not a perfect gas, as is evidenced by the fact that its volume does not increase in a ratio inverse to its pressure. For example, if a cubic inch of water be evaporated into steam at a pressure of 14.7 lbs. per square inch, its volume will be 1644 cubic inches, and its temperature 212° Fahrenheit.

But if the cubic inch of water be evaporated into steam at twice the pressure, which is 29.4 lbs per square inch, its volume will be 838 inches.

The volume then is not inversely as the pressure, although the actual quantity and weight remain the same, as is proven by the fact that if the steam at either pressure were condensed it would pass back into the cubic inch of water from which it was generated.

This may be accounted for in the difference in the boiling point of the water in the two pressures, or in other words, by the difference in the temperatures; thus the boiling point of the water at a pressure of 14.7 lbs. is 212°, while that for the pressure of 29 4 is increased about 38.4 degrees, and the steam is at the higher pressure expanded by these 38.4 degrees of heat, which adds to its pressure, although not affecting its actual quantity or weight.

The amount of this expansion may be estimated as follows:

Taking the 1644 cubic inches, and supposing the steam to be a perfect gas, we divide it by 2 to obtain half the volume, $1644 \div 2 = 822$.

If then we subtract this 822, which is the volume of the steam if it acted as a perfect gas from the 838 it actually occupies, we get 16 ($838 - 822 = 16$), which is the number of cubic inches of expansion due to the increase in the boiling temperature.

THE CONVERSION OF HEAT INTO WORK.

When steam performs work a certain portion of the heat it contains is converted into work, the steam simply being a medium of conveying the heat into the cylinder in which the motion of the piston converts this proportion of heat into work. It has been proven that a given quantity of heat will pass into a given quantity of work, and conversely that a given quantity of work is convertible into a given quantity of heat, and it has also been proven that so much heat is convertible into so much work, independent of the temperature of the heat during its conversion into work, power, or energy, all three of these words being used to imply pressure, force, or weight in motion.

The accepted measurement of the conversion of heat into work is known as *Joule's equivalent; Joule* having determined that the amount of power exerted in raising 772 lbs. one foot is the equivalent of the amount of heat that is required to raise the temperature of 1 lb. of water when at or near its freezing point (that is, at a temperature of 32°) one degree.

This is called the *mechanical equivalent of heat*, being merely the quantity of heat necessary to do a certain amount of work, but having no relation to the time in which that work was done.

The conversion of heat into work and of work into heat may be demonstrated as follows: Suppose a cylinder to be so situated that heat can neither be transferred to it or from it, and that saturated steam be admitted under the piston so as to fill one-half of the cylinder at a pressure of 50 lbs.

Suppose then that we raise the piston from an independent application of power, the steam simply expanding to fill the space given by the piston, but not exerting its force to move the piston.

Now suppose the experiment is repeated, permitting the force of the steam to lift the piston, and the temperature of the steam will be less in the second than it was in the first, proving that in the second experiment a certain portion of the heat in the steam was converted into the work of raising the piston.

If we desire to reconvert the work into heat, we may force the piston back again to its original position, and its temperature will be restored to what it was before we allowed it to raise the piston. It is here, of course, assumed that there is no friction in moving the piston in the cylinder.

The apparent or external work performed by steam in expanding and moving a piston against a given resistance is measurable by multiplying the amount of the resistance against which the piston moved by the distance it moved through, thus:

Suppose a piston weighs 100 lbs. and had resting upon it a weight of 50 lbs., and that it be raised by the expansive action of steam a distance of a foot, then, since the total resistance it moved against would be (supposing it to move frictionless in the cylinder) 150 lbs., and since the amount of motion was 1 foot, the external or apparent amount of work performed by the steam will be 150 foot lbs., or 150 lbs. moved 1 foot.

But in expanding, the steam has performed a certain amount of what is called *internal* work, that is to say, its particles or atoms have done work in expanding, and this work has been done at the expense of some of the heat in the steam, so that the loss of heat due to the motion of the piston is the amount of heat converted into work in moving the piston against the piston resistance, added to that converted into the internal work due to the expansion of the steam.

It is because of this internal work that the steam in expanding does not strictly follow Marriotte's law.

The mechanical theory of heat is, that the atoms of which bodies are composed are at absolute rest when at a temperature of 461.2° below the zero of Fahrenheit, which is supposed to be absolute cold, and at any degree of temperature above this the atoms are in motion; the extent and force of their motion determines what we know as the temperature of the body.

Atoms are capable of transmitting their motion to adjoining atoms of the same or of other bodies, losing, of course, the amount of motion they transmit, and it is in this way that heat is conveyed from one to another part of the same body, or from one body to another, this being known as the heat of *conduction*.

But heat may be conveyed by means of what is known as *radiation*, and also by *convection*.

Thus, the air surrounding a heated body becomes heated, and by reason of its expansion it then becomes lighter and rises, a fresh supply of cooler air taking its place, becoming in turn heated, and again giving place to cooler air; the heat thus conveyed away by the fluid or air is conveyed by what is termed *convection*.

Heat also passes from a body in straight lines or rays, which do not heat the air through which they pass to their own temperature, but do impart that temperature to a solid body, as iron or water; the heat that passes from a body in this manner is termed radiant heat, or the heat of *radiation*.

In the cylinder of a steam engine, therefore, the heat contained in the steam is disposed of as follows:

A certain portion of it is converted into work through the medium of the piston.

Another portion is conveyed away by the walls of the cylinder, this portion including the heat of convection and that of radiation.

Yet another portion is converted into internal work. Referring to the latter, suppose that steam is permitted to expand and its atoms will be in motion, which motion has been derived at the expense of or from the conversion of a certain quantity of heat.

The amount of the heat so converted obviously depends upon the amount of the motion. Suppose, for example, that steam is generated in a closed vessel as in a steam boiler, and that a certain pressure having been attained, the steam is permitted to pass off as fast as it is formed from the boiler, then the amount of atomic motion will remain constant, because the pressure remains constant; but suppose instead of the steam passing off, it be confined within the boiler, then the pressure will increase and there will be a greater resistance to the motion of the atoms, hence their motion will be less, and less of their heat will therefore be converted into atomic motion, and, as a consequence, more of it will exist in the form of sensible heat; hence while the pressure of steam continues to increase, its heat is increased, not only by reason of the heat it receives from the furnace, but also by reason of that abandoned by the steam, because it is prevented by the pressure, from expending it in atomic motion.