STEAM

STEAM ENGINE

EVERS

Charles D. Hunter

Charles D. Hunter
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STEAM

AND THE

STEAM ENGINE:

LAND, MARINE, AND LOCOMOTIVE.

BY

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PREFACE.

The chief aim of the author of this book has been to supply a want that he, in common with a large body of teachers, has experienced for many years. There is on Steam no *cheap* work that a teacher can put into the hands of his pupils, to give them at once a full and comprehensive idea of the whole subject. The author has striven to supply this defect, and to produce a work correct in its facts, safe in its deductions, and containing, where possible, new and original matter, or the old matter presented under new aspects. How far he has succeeded is for others to judge.

An attempt has been made, not only to give the reader an insight into the details and specialities of the different kinds of engines employed to do man's work, but to make him understand the various principles upon which each part of the Steam Engine does that work, the relation these parts bear to each other, and the life or physiology, so to speak, of the whole.

The syllabus of the Government is covered not servilely by following its details, but by omitting what is unnecessary, and adding much that is required for a full knowledge of the subject. Originality of matter in this subject cannot be expected. Freshness of arrangement and simplicity of illustration have been sought. In thus aiming to render the subject intelligible, the author has endeavoured to avoid all appearance of cram, so baneful to the true progress of the student in any branch of science whatever.

The subject is divided into chapters, and the student is recommended to peruse them in their order, taking up the mathematical questions at the end as soon as the first two or three chapters have been read.

To the Teacher I would say, be not content with the expositions and details given; but seek for graphic illustrations within your own reach, and avail yourself of every opportunity that presents itself to make the class acquainted with the Steam Engine at work.

H. E.

PLYMOUTH, *Nov.* 1872.

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STEAM.

CHAPTER I.

Definition—Properties of Steam: Elasticity, Latent Heat—Water is a Solid, a Liquid, and a Gas—Latent Heat of Water—Ebullition—Latent Heat of Steam—Consumption of Heat in Liquefaction and Vaporisation—Boiling Point—Steam and its Properties—Superheated Steam: Density, Volume, Expansion.

1. **Definition.**—Steam is the invisible, elastic fluid generated from water by the application of heat.

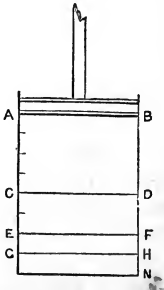
2. **Steam is Invisible.**—When steam is issuing from the spout of a kettle or from a safety valve, if we examine it *close* to the spout or valve, we see nothing. It is only at a distance from these orifices that the steam is rendered visible, by parting with its heat to the air with which it is in contact; when visible it ceases to be steam, and is called vapour. But many object to such a hard and fast line separating vapour from steam, and say, steam is vapour and vapour is steam. Vapour escapes from the surface, but is by no means generated, as a rule, at the surface. **Evaporation** is the escape of vapour. **Vaporisation** is the conversion of liquid into vapour. The moment heat is applied to water vaporisation commences, and evaporation takes place. It has been suggested * that the heat applied to water produces the *single effect* of converting part of the water into steam or vapour, and not heating part of the water and turning another part into vapour, and that the vapour thus formed in the body of the liquid, is diffused through the whole mass, and this vapour alone acts upon the thermometer, causing it

* By Mr. C. W. Williams.

to rise with the increase of its own temperature. This is simply Dalton's law, "that all gases which enter water or other liquids by means of pressure, and are wholly disengaged again by the removal of that pressure, are mechanically mixed and not chemically combined with the liquid. Gases so mixed with water retain their elasticity or repulsive power among their own particles, just the same in water as out of it."

3. Vapour and Steam.—We may for convenience make the following distinction: When water passes away insensibly without the mechanical application of heat, it is termed **Vapour**; but when heat is directly applied to produce this vapour, we consider it **Steam.**

4. Steam is Elastic.—Take a cylinder or box, into which is tightly fitted a piston, and fill it with steam. If we now maintain the cylinder and steam at the same temperature, and apply a sufficient force to compress the steam into half the space, and then suddenly withdraw the force, the steam will again expand and fill the same space as before, driving the piston back again to its original position. The piston is returned to its place by the elastic force of the steam. Or we may illustrate the elasticity of steam much better thus: Suppose our cylinder full of steam, to be steam at a pressure of 15 lbs. on the square inch, and let the piston be at A B, and that from B to N be sixteen inches. If the piston be forced half-way down, or eight inches, to C D, then the steam occupying one-half its former space its pressure will be doubled, or on each square inch the pressure will be 30 lbs. Next force the piston to E F, four inches farther down, so as to reduce again the volume of the steam by one-half, or to compress it into one-quarter of its original volume, then the pressure will be again doubled, and will now be 30×2 or $15 \times 4 = 60$ lbs. on the square inch. If it be forced to G H, two inches still farther down, or the volume again decreased one-half, or occupying one-eighth of the original space, the pressure is now 60×2 or $15 \times 8 = 120$ lbs. on the square inch. We



see by this illustration that the pressure increases as the space decreases. This is called Mariotte's or Boyle's law, and is generally expressed thus: *The temperature remaining the same, the volume of a given quantity of gas is in inverse ratio to the pressure which it sustains.*

5. Latent Heat.—The heat not sensible to the thermometer is termed latent heat or hidden heat.

6. Water is a Solid, a Liquid, a Gas.—If we take a lump of ice, we see water in its solid form, the temperature of which may be below the freezing point. Ice is one-ninth lighter than water. Apply heat to the lump of ice, the temperature is soon raised to 0° C., and in whatever way we continue our application of heat, we cannot increase the temperature, but the whole of the heat we employ sets to work to melt the ice; when all is liquefied, then the *water* will increase in temperature, through 10° C., 20° C., 60° C., etc., till it reaches the boiling point 100° C.; after which, however much heat, and however long we apply it to the water, we cannot make the water hotter than 100° C. The additional heat simply converts the water into steam or gas, and is employed in pushing and keeping the atoms asunder, and is carried off as latent heat.

7. Latent Heat of Water (or Ice).—If a pound of ice at 0° C., be mixed with a pound of water at 79·4° C., the water will gradually dissolve the ice, being just sufficient for that purpose, and the residuum will be two pounds of water at 0° C. The 79·4 units of heat which are apparently lost, have been employed in performing a certain amount of work, *i.e.*, in melting the ice or separating the molecules and giving them another shape, and as all work requires a supply of heat to do it, this 79·4 units has been consumed in performing the work necessary to melt the ice, and is called the **Latent Heat of Water.** If the pound of water were reconverted into ice, it would have to give up the 79·4 units of latent heat; hence we see why it should be called the latent heat of water, and not the latent heat of ice. The three forms of water are, then, (1) a solid, as ice; (2) a liquid, as limpid water; (3) a gas, as steam.

8. The Ebullition of Water.—The boiling point of water is that temperature at which the tension of its vapour exactly balances the pressure of the atmosphere.* The student must bear in mind the law of convection, as explained farther on. As part of that law of convection, he may observe, that if water be placed in a Florence flask, and held over a gas-burner, he will see small globules rise from the bottom and ascend a small distance, until the colder water above destroys their buoyancy; this continues, the globules rising higher and higher, till the heat of the water increases to 100° C., when they reach the top and produce what we call ebullition. It is the heated water becoming specifically lighter, and rising up with considerable force.

9. Latent Heat of Steam.—The latent heat of steam at a pressure of 15 lbs. or about thirty inches of mercury, is 537·2° C. We will describe an experiment which will help to illustrate this point, and fix the fact in the memory. Let us suppose that we have two very small vessels connected at their tops by a tube. Let one contain a pound of water, at the temperature of 0° C., and the other five and a half pounds, at the same temperature. If a spirit lamp be applied beneath the vessel containing the one pound of water, its temperature will gradually rise to 100° C., when ebullition will begin, and if the heat be continued, the water will not increase in temperature, but will pass off as steam along the tube to the second vessel, where the five and a half pounds of cold water will condense the steam and absorb the heat, which first enters and passes from the one pound, as long as the spirit lamp is applied to it. This operation of condensation and absorption will continue until the one pound of water is all converted into steam and re-converted into water. At the moment that the evaporation of the pound of water is completed, the heat transferred by the steam from one vessel to the other will cause the five and a half pounds of water to boil. It will be found that there are now in the second vessel, six and a half pounds of water, at a temperature of 100° C. As the 1 lb. takes 100 units of heat to make it boil, the $5\frac{1}{2}$ lbs. take $5\frac{1}{2} \times 100 = 550$ units; or as there are $6\frac{1}{2}$ lbs. of water in B, the total quantity of heat is $100 \times 6\frac{1}{2} = 650$ units of heat. A thermometer placed in the water would show a temperature of 100° C. This 100° only being sensible to the thermometer,

* Tyndall's *Heat as a Mode of Motion.*

the other 550°, which we know to be there, are hidden or latent. Exact experiments make the $5\frac{1}{2}$ lbs. 5·372. Hence the latent heat deduced from the experiment will be $5{\cdot}372 \times 100 = 537°{\cdot}2$. This 537°·2C., or 966°·6F., is the latent heat of steam. In making the experiment, ounces or smaller quantities of water are employed, and not pounds.

10. A Unit of Heat.—A unit of heat is defined as the amount of heat necessary to raise the temperature of a pound of water one degree. Hence the units of heat in a pound of steam at 100° C., number 637·2.

11. Consumption of Heat in Liquefaction and Vaporisation.—This is but another way of putting the facts connected with the latent heat of water and steam. We have seen that the latent heat of water is 79°·4C, or to liquefy a given quantity of ice requires this amount of heat; to raise the water to its highest temperature consumes 100°C. more; next, to vapourize it consumes 537°·2C.

12. The Boiling Point of Water Depends upon Pressure; or, the temperature at which the ebullition of water begins, depends upon the elasticity of the air or other pressure. At the level of the sea, the barometer standing at 29·905 (or very nearly 30) inches of mercury, water will boil at 100°C.; but the higher we ascend above the sea level, the more the temperature of the boiling point diminishes. For every 1062 feet of height, water will boil at a temperature 1°C. less; because as we ascend the pressure of the atmosphere decreases. In precisely the same manner the pressure of steam upon the surface of the water in a boiler will have a tendency to raise the boiling point; because the tension of the vapour has a greater pressure to overcome before it can free itself from the water. But we are here presented with another law—*the sum of the latent* and sensible heat of steam is constant. The latent heat of steam (as we have just seen), at a pressure of 15 lbs., is 537°·2C., and the sensible heat 100°C., making a total of 637°·2C., or 1146°·6F. Now if water under a pressure of 30 lbs. boil at a temperature of 122°C., the latent heat of such steam is $637°{\cdot}2 - 122° = 515°{\cdot}2$C.

This is Dr. Black's theory of *latent heat*, or, more correctly, it is called Dr. Black's theory of the *latent* and *sensible* heat of *steam*. It is termed his theory because, after a very large series of experiments most carefully conducted, he was the first to propound the theory, which was one greatly in advance of his time, and shows him to have been a man of no ordinary mind.

The experiments of Regnault tend to modify the above theory advanced by Dr. Black. He has arrived at the conclusion that the total amount of heat in a given quantity of steam increases slowly with every increase of temperature. Regnault constructed the following formula, which gives pretty nearly the total amount of heat in steam at all temperatures :—

$$\text{Actual temperature of steam} = 1082^\circ \text{F.} + \cdot 305 \text{T}^\circ.$$

This cannot be modified to give us the formula for degrees centigrade, but must be entirely reconstructed. This matters but little, seeing how easy it is to find the total amount of heat in degrees Fahrenheit, and then to reduce it to centigrade. Remember, then, that the constant number 1082° must be increased ·305 degrees Fahrenheit for each unit of temperature, to give us the total amount of heat in steam under any given pressure.

13. High Pressure Steam Does not Scald.—If steam at high pressure be issuing from an orifice, and the hand be placed in it, it will not be scalded. The reason must be that, as it issues into the air, the pressure is decreased and reduced to 15 lbs. The steam, therefore, immediately takes to itself the deficient latent heat from the air. If the pressure had been 30 lbs., the deficient latent heat would have been 22° C. The steam is, therefore, busily employed in taking these 22° of heat from the atmosphere, and even from the hand placed in it; and so, under the circumstances, will rather cool the hand than scald it.

14. Measure of the Pressure of Steam.—The pressure of steam is measured by atmospheres. Steam of 15 lbs. pressure is steam of one atmosphere, of 30 lbs. pressure of two atmospheres, etc. It is frequently used as high as six or seven atmospheres; but even ten, or 150 lbs. pressure, is employed. Steam below two atmospheres is termed *low pressure steam*, and all pressures above, *high pressure steam*.

15. Density of Steam and Specific Volume.—The density of steam is ascertained by placing in an exhausted glass globe, the capacity of which is known, a certain weight of water. The globe is next placed in a bath of mercury, and heat is applied until the whole of the water in the globe is converted into steam. The temperature at which this takes place, the volume of the glass globe, and the weight of the water employed, are the three elements from which the density is calculated. The specific volume of the steam is found by dividing the capacity of the globe by the weight of water employed in the experiment.* At a pressure of 9 lbs. per square inch, the point of saturation, by Sir Wm. Fairbairn's and Mr. Tate's experiments, was 86°·8C., and specific volume 2620; at 27·4 lbs. the point of saturation was 118°·2C., and specific volume 906; at 45·7 lbs. the point of saturation was 134°·8C., and specific volume 583.

16. Point of Saturation.—At the instant, in the above experiments, when all the water is converted into steam, we have "the point of saturation," or the temperature at which steam at that pressure contains most vapour. Directly it has reached the point of saturation, the steam, for every increase of temperature, rapidly expands in volume; or, if confined, its elasticity is greatly increased. Steam does not accurately obey the laws of gases—the density of saturated steam being always greater than that of gas.

17. The Ratio of the Temperature, Density, and Elasticity of Steam when in Contact with the Water from which it is Generated.—From what was said on latent heat it is evident that the vapour rising from water must contain more heat than the water. When steam is generating in a boiler, and not allowed to escape as fresh quantities rise from the water, the *density* and *elasticity* of the steam must increase; at the same time, to effect this change, heat is being constantly added to the boiler; we may express the result thus:—As the temperature increases, so does the elasticity. This arises not alone from the expansive property of steam, but from the continual additions of more steam generated by the continued increase of temperature, which must add increment after increment to the density and elasticity. The steam is now in a state of saturation, and has in it the greatest possible

* See Fairbairn's *Useful Information for Engineers*, Second Series, Lecture viii.

amount of vapour it can have at that temperature. We see from what precedes that a certain pressure accompanies a fixed temperature, and *vice versa*, so that we cannot increase or decrease the one without a corresponding change in the other.

18. Temperature, Density, and Elasticity when not in Contact with the Water.—If steam be taken from a boiler, and further heated or surcharged, the above relations of temperature, density, and elasticity no longer hold good. In superheating steam, as we increase the temperature we *decrease* the density, for there is now no accession of watery vapour; but the elasticity is *increased* in such a manner that it follows no normal standard, or at least no law has been discovered that will give us the relations of temperature, density, and elasticity when heated and not in contact with the water from which it was generated.

On these last two points, let it be remarked, that as steam is allowed to run from the boiler to the cylinder, it is invariably attended by a loss of heat from radiation; and being deprived of a portion of its heat, it becomes steam of a different description to what it was when in contact with the water from which it was generated, where it was constantly receiving fresh accessions of heat. To maintain the normal relation of temperature, density, and pressure, it must be in contact with the water; while, when we superheat steam, it receives an entirely different character, and we must have no confusion in our minds as regards this difference.

The following table is worthy of attention:—

The temp. being	$-40°$ F. or $-50°$ C.	the pressure in lbs. is	·006	p. sq. in.
,,	$-10°$ F. or $-23°\frac{1}{3}$ C.	,,	·021	,,
,,	$10°$ F. or $-12°\frac{2}{9}$ C.	,,	·045	,,
,,	$40°$ F. or $4°\frac{4}{9}$ C.	,,	·131	,,
,,	$100°$ F. or $37°\frac{7}{9}$ C.	,,	·930	,,
,,	$212°$ F. or $100°$ C.	,,	15·	,,
,,	$300°$ F. or $149°$ C.	,,	72·7	,,
,,	$325°$ F. or $162°\frac{2}{9}$ C.	,,	106·8	,,

Much trouble has been taken by Dalton, Fairbairn, Arago, and Dulong to determine the above relations. The pressures are here given as corrected by Fairbairn.

19. The Volume and Density of Steam in relation to the Volume of Water from which it is produced.

1 cubic foot of steam at a pressure of 15 lbs.		temp. 121°·8 C.	will weigh	$\frac{62.5}{882}$ =	·07086 lbs.
,, ,, ,,	30 above the atmosphere.	,, 135°·4 C.	,,	$\frac{62.5}{608}$ =	·10279 ,,
,, ,, ,,	45	,, 149°·5 C.	,,	$\frac{62.5}{467}$ =	·13383 ,,
,, ,, ,,	60	,, 153°·8 C.	,,	$\frac{62.5}{381}$ =	·16404 ,,
,, ,, ,,	75	,, 161° C.	,,	$\frac{62.5}{323}$ =	·19349 ,,
,, ,, ,,	90	,, 166°·8 C.	,,	$\frac{62.5}{281}$ =	·22241 ,,
,, ,, ,,	105	,, 172°·9 C.	,,	$\frac{62.5}{249}$ =	·25100 ,,
,, ,, ,,	120	,, 178° C.	,,	$\frac{62.5}{224}$ =	·279017 ,,
,, ,, ,,	135	,, 182°·6 C.	,,	$\frac{62.5}{203}$ =	·30788 ,,
,, ,, ,,	150	,, 187° C.	,,	$\frac{62.5}{187}$ =	·33422 ,,

The numbers 882, 608, 467, etc., are the relative volumes of steam at the given temperatures.

The weight of a cubic foot of steam at various temperatures is obtained by dividing $62\frac{1}{2}$ pounds, the weight of a cubic foot of water, by its relative volume, and we are to consider that the weights of water in the last column produce a cubic foot of steam at the given temperatures and pressures. In the third column the numbers are expressed so as to show how the weights are obtained, while the denominator of each fraction is the respective relative volume in each case.

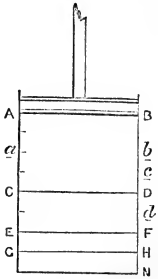
20. Relative Volume.—The relative volume of steam is the quantity of steam generated from a given quantity of water divided by that water. De Pambour's definition is, "The relative volume of steam is the quotient of the absolute volume of the steam by the corresponding volume of water."

21. Expansive Working of Steam.—Steam is admitted to the cylinder at a very high pressure, thus giving the piston a great initial velocity, and before it has completed its stroke the steam is cut off, or no more is allowed to enter, the rest of the stroke being completed by the elastic force of the steam already in the cylinder. The steam expands as the piston moves onwards, and consequently its pressure, in conformity with Marriotte's law, is constantly diminishing, until the piston is at the end of its stroke, it is thus brought gradually to rest, when at that instant fresh steam enters, and the process is repeated on the other side of the piston.

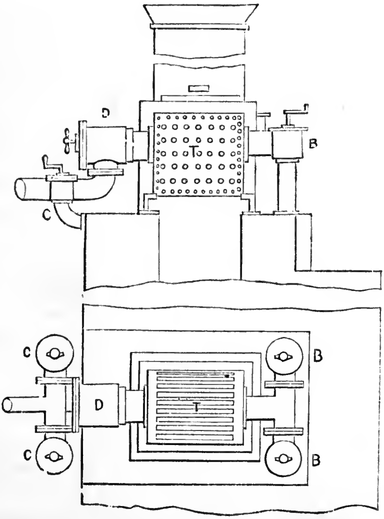
It is not brought gradually to rest through the diminishing pressure of steam alone. This is effected by the *cushioning*, which will be explained in its proper place.

When the steam is allowed to expand in the cylinder, more time is given for evaporation in the boiler, so that steam accumulates, and a saving is effected by using the smallest possible quantity during each stroke of the piston. From a minimum amount of steam a maximum amount of work, by using it expansively, is obtained.

Suppose steam, whose initial pressure is 80 lbs., is admitted to the cylinder A N, 8 feet long, and that the piston performs 2 feet of its stroke to *a b*, when the admission of steam is suddenly intercepted, the elastic force of this one-quarter of a cylinder full of steam will now be called upon to complete the stroke. When the piston gets to C D, the pressure will be one-half, or 40 lbs., as the steam fills double the space; at E F only one-third, for it then fills three times the space, and so on. To find the pressure at *c d*, F H, etc., and in fact at every point of the stroke, the student is referred to the questions at the end, which should be commenced at once.



22. Superheated or Surcharged Steam.—It has become a practice to allow the steam, before it enters the cylinder, to pass from the boiler into a series of tubes, or into a strong iron chamber in which a large quantity of vertical or horizontal tubes are fitted; in these the steam is further heated to increase its elasticity by the heat that is passing away up the funnel



SUPERHEATER.

or stack; thus, from a given quantity of steam a maximum amount of work is obtained with a minimum amount of fuel consumed. The annexed figure is one form of the apparatus, which is generally placed in the uptake or at the bottom of the stack.

The steam from the boiler passes through B into the series of tubes T; in the upper figure they are seen in section, in the lower in plan; around the tubes the heated air and gases play, so that the steam receives additional heat and passes by way of D through C and C to the cylinder.

23. The Advantage of Superheated Steam is, that as we increase the pressure the amount of work done by the engine rapidly increases also; but the quantity of heat contained in high-pressure steam is very little more than that in low pressure. For instance, the units of heat in steam at 230° F., pressure of $21\frac{1}{4}$ pounds, is 1152° F.; at 330° F., or 104 pounds pressure, it is 1183° F., or only 30° F. more.

Since it is heated by the waste products of combustion passing up the funnel or stack, it is more economical than ordinary steam, but it is by no means economical if this heating is carried to excess. To ensure efficiency it wants little more than drying.

In consequence of its great heat, superheated steam does injury to the internal parts of the engine; it burns the packing, and eats away the cylinders, especially having an injurious effect upon those of indifferent workmanship. As steam is superheated so its elasticity is increased, or the elasticity varies with the temperature. In practice many engineers do little more than dry the steam; for this purpose a small chest, or outer casing, is sometimes fitted round the bottom of the funnel, the steam passes through a short pipe from the boiler to this casing, and is then led away to the cylinder to do its work.

24. Law of Expansion of Superheated Steam.—Superheated steam near the point of saturation expands very rapidly and irregularly, but if the superheating be continued the rate of expansion rapidly declines, and soon approaches that of a perfect gas whose co-efficient of expansion is $\frac{1}{273}$ for every degree centigrade of expansion.

It has been found that when the point of maximum saturation was between 79°·4C and 82°·2C, the mean rate of expansion was $\frac{1}{105.5}$ when the superheating was continued from 82°·2 to 93°·3C, the co-efficient of expansion fell from $\frac{1}{105.5}$ to $\frac{1}{354}$.

EXERCISES FROM EXAMINATION PAPERS (CHIEFLY).

1. What is meant by *capacity* for heat and *latent* heat?

What is the latent heat of steam under the ordinary atmospheric pressure (1867)?

What weight of injection water at 80° will suffice to condense a given quantity of steam into water at 120°?

Capacity for heat is explained in next chapter.

The degrees are 80° F. and 120° F. = $26°\frac{2}{3}$ C. and $48°\frac{8}{9}$ C.

Each unit of water is raised $48°\frac{8}{9} - 26°\frac{2}{3} = 22°\frac{2}{9}$ C.

The total heat in the steam is 637°·2 C. This has to be reduced $637°\frac{1}{5} - 48°\frac{8}{9} = 588°\frac{3}{9}$ C. (nearly).

$$\therefore \text{ total units of water required } = \frac{588\frac{3}{9}}{22\frac{2}{9}} = 26\tfrac{1}{2} \text{ nearly.}$$

It may be here observed that no unit is given for the water, but the question is put generally; hence, if we consider the quantity of steam as that generated from a cubic foot, inch, or pound of water, the answer is $26\frac{1}{2}$ cubic feet, inches, or pounds.

2. The steam enters the condenser at a temperature of 212° F.; the water pumped out of the condenser is at a temperature of 110° F. What weight of injection water must be supplied for each pound of steam which enters the condenser?

Before answering this question the student must draw attention to the fact, that the temperature of the condensing water is not given. He must therefore assume a temperature, say 10° C., and answer the question as shown above. *Ans.* 17·81 lbs.

3. Show, by an experiment, how the latent heat of steam may be ascertained.

4. What do you mean by the latent heat of water or ice? Which is the more correct expression?

5. Show, as to a class, that steam is elastic and invisible.

6. Give a definition of steam, and distinguish between vapour and steam.

7. Describe the several methods by which heat is propagated.

Explain the terms capacity for heat and latent heat.

What is the latent heat of steam (1864)?

8. Distinguish between common steam, superheated steam, surcharged steam, and saturated steam (1866).

9. Define capacity for heat, latent heat, and unit of caloric (1865).

10. What is meant by superheated steam?

What advantages are gained by its use (1865)?

11. What is meant by latent heat?

Show under what circumstances heat becomes latent (1866).

12. Show how to determine the weight of injection at a given temperature, which must be mixed with a given weight of steam, that the whole may be reduced to water at another given temperature (1866)?

13. Compare the weights of injection water at 50°F. to be mixed with a given weight of steam, that the temperature of the mixture may be 110°F. (1866)? *Ans.* 17·81 : 1.

14. What is the latent heat of steam?

How is its amount ascertained (1867)?

15. Distinguish between sensible and latent heat?

What is the smallest weight of water at 32° which will be sufficient to condense a pound of steam at the atmospheric pressure (1858)? *Ans.* 5·37 lbs.

16. What is the distinction between sensible and latent heat?

Describe an instrument for measuring the former (1868).

17. Under what circumstances generally (1) does heat become latent, (2) does latent heat become sensible?

What amount of latent heat becomes sensible when ice is thawed into water (1868)?

18. Two ounces of water at 60° are placed in an evaporating dish, which is covered, except a small opening, by a glass plate. The flame of a gas-burner causes the water to boil in $3\frac{1}{3}$ minutes, and the whole is evaporated after 22 minutes more have elapsed. What should you infer as regards the latent heat of steam from this experiment?

What is the correct numerical value given by a more exact process?

The water is heated in $3\frac{1}{3}$ minutes from 60°F. to 212°F., or through 152°F.

It is then evaporated in 22 minutes.

It is evaporated in $\frac{22}{3\frac{1}{3}} = 6{\cdot}6$ times the time it took to boil.

$\therefore$ heat put into the steam is $152° \times 6{\cdot}6 = 1003°{\cdot}2$. F.

$\therefore$ the latent heat of steam is 1003°·2 F.

The correct numerical value given by a more exact process is 967° F.

Had the time given in the experiment been 21 minutes 10 seconds, the answer would come out 936°·7 F., which is as near as it can be wished to get to the actual result.

19. Describe an experiment proving that water is an extremely bad conductor of heat.

In what way, then, can a large mass of water, such as that in a steam boiler, be readily heated (1869)?

20. Explain the meaning of latent heat.

State Black's law as to the latent heat of steam formed under different pressures.

Is this law strictly verified by experiment (1869)?

21. Under what circumstances does heat become latent?

How much water did Watt consider necessary for the condensation of a cubic foot of steam at the atmospheric pressure?

State the considerations which led to the practical conclusion at which he arrived in the case of a condensing steam engine (1869).

Watt supposed temperature of hot well to be 100° F.
" " " injection water 50° F.

Working this out, as in Example 1, gives 22·24.

Therefore, he concluded, 1 cubic inch of water turned into steam will require $22\frac{1}{4}$ cubic inches of water to condense it. Watt allowed 28·9 cubic inches, or about a wine pint, for every cubic inch of water evaporated, because as a practical man he knew that *every* atom of water would not do all required of it. Hence he in practice allowed above one quarter more than his theory allowed.

22. How can it be shown that the temperature at which water boils depends upon external pressure?

What is high pressure steam (1869)?

23. Describe accurately the difference between steam in contact with the water from which it is generated, and when not so in contact.

State the law connecting the pressure, volume, and temperature in the latter case?

What is the formula employed by De Pambour as applicable to the former (1865)? See chapter on De Pambour's theory.

24. State the laws which regulate the pressure of steam: (1) When in contact with water; (2) When not in contact with water (1865).

25. What is meant by temperature?

What are the general effects of adding heat to or subtracting it from a body (1865)?

26. How much steam will be required to fill a cylinder, whose diameter is 60 inches and length 6 feet, forty times per minute, the volume of the steam being 1200 times that of the water from which it was formed (1864)?

Ans. 3·927 feet, or 3·927 cubic feet of water must be evaporated per minute to give the necessary supply of steam.

CHAPTER II.

HEAT.

Definition—Expansion and Contraction—Expansion and Contraction of Water—Co-efficient of Expansion—Molecular Power of Expansion and Contraction—Atomic Forces—Radiation and Absorption—Conduction—Friction—Temperature and Measures of Temperature—Thermometer—Pyrometer—Specific Heat—Calorimeter—Convection—Heat and Work—Mechanical Equivalent of Heat.

When heat is imparted to a body its atoms push each other asunder, and the molecules commence to oscillate more or less rapidly. The more intense the heat, the quicker the particles oscillate; by raising the temperature you increase the oscillations, while cooling is a decrease of vibration, or loss of motion.

25. Bodies Expand by Heat and Contract by Cold.—The law is almost universal that bodies expand by heat and contract by cold.

(*a*). The most familiar illustration we have of this law is in the expansion and contraction of water when under the influence of heat and cold. Take water at a temperature of 4° C.; after the heat has been applied for a short time, it will begin to expand, and will continue to expand as the temperature increases, till it reaches the boiling point 100° C. After this, if we continue to apply heat, no alteration will take place in the temperature of the water. The additional heat that passes into the water is employed in converting the water into steam. A cubic inch of water will supply 1669 cubic inches of steam, or nearly a cubic foot. The result of another experiment was that a gallon of water, evaporated at 100° C., produced nearly 1800 gallons of vapour. When cold is applied to this vapour it contracts to its original volume.

(*b*) In building such bridges as the Albert Bridge, Saltash, the Britannia and Conway tubular bridges, spaces are left for the expansion and contraction of the iron. The difference between the lengths of these bridges measured during the extreme heat of summer and the extreme cold of winter, is considerable.

(*c*) Experience has taught us that, in laying down the rails for a railway, spaces of about three-eighths or a quarter of an inch must be left to allow the rails to expand in length. Were this not done, the molecular force of expansion would be sufficient to draw the spikes or lift the sleepers and rails out of their places.

Mr. Stephenson once stated that, in consequence of laying three or four miles of line, near Peterborough, with close joints, the heat of the sun on a warm day caused such an extension that the rails and sleepers were lifted in one place from the ballast so as to form an arch fifty feet long and three feet high in the air.

(*d*) The simplest plan to separate a crank from a shaft on which it has been shrunk, or, in fact, to disconnect any rust joint, is to apply heat, when the bodies (being of different dimensions) expand unequally and separate.

(*e*) Many other illustrations might be given, as, when warehouses constructed with fire-proof floors, etc., have been destroyed by fire, the walls of the buildings which were considered indestructible have been thrown down by the enormous expansion of the iron girders, tie-beams, etc. Wheelwrights and carriage builders, when they wish to place the tire upon a wheel, expand it by placing it in a fire, then slip it upon the wheel, and suddenly cool it, when the molecular power of contraction holds and binds the whole wheel firmly together.

26. Bodies Contract by Cold.—This may be illustrated by most of the foregoing instances of expansion by heat. A cubic foot of steam becomes a cubic inch of water when contracted by cold. The ends of railway rails are more widely separated in winter than summer. This point will be further illustrated under the heading of Molecular Force; but a good illustration will be found in the method by which collars are shrunk on a shaft. A neat way of putting collars on heavy marine shafts where the journals come, is this: bosses are turned on the shaft, and two ribs, three or four-sixteenths of an inch high, are left on the bosses for the collars, which must be prepared in the lathe, and then heated and slipped over the ribs, then upon contracting with the cold they will firmly grip the shaft.

27. The Exception to the Universal Law of Expansion by Heat and Contraction by Cold.—Suppose we have a body of water at 100° C., and expose it to cold, it will gradually lose its motion or heat, cooling down through 90°, 60°, 30°, etc., and will contract or occupy a smaller space until it descends to 3·8° C., when it will contract no more, for it has reached the point of maximum density. From 3°·8, as the water becomes *colder* it *expands*, till it reaches the freezing point 0° C., so that the ice is specifically lighter than the water, and consequently floats upon the surface. Were it not so, or did the water in the act of freezing become heavier, it would sink to the bottom, and all rivers and ponds would become frozen masses of ice in temperate and sub-arctic latitudes, which could not be melted till a July sun exerted all its influence. Consider the effects of this upon the earth: a boreal climate would extend beyond the Straits of Gibraltar. Every plumber, and almost every housekeeper, to the advantage of the former, and the annoyance of the latter, knows the effects of this expansion upon lead water-pipes. It splits rocks in frozen regions, and makes enormous fissures in the earth. We may state the fact succinctly thus:—Water expands at the moment of freezing, or contracts on melting, nearly 10 per cent. A cubic inch of ice gives ·908 cubic inches of water, or one cubic inch of water gives 1·102 of ice at the same temperature. Bismuth is another exception, it expands on cooling, and exerts an enormous force.

28. Co-efficient of Expansion.—The linear, superficial, or cubical co-efficient of expansion is the amount a body expands in length, surface, or volume on being heated one degree. The superficial is twice the linear, and the cubical *three* times it. All elastic fluids expand about the same, or $\frac{1}{273} = \cdot 00366$ part of their volume, on being heated one degree centigrade, or $\frac{1}{490}$ for 1° F.

The following is a list of a few of the chief co-efficients of expansion :—

	Linear.	Cubical.
Glass,	·00000876	·0000254
Copper,	·0000171	·0000512
Brass,	·0000185	·0000554
Iron (wrought),	·0000118	·0000354
Lead,	·0000284	·0000890
Tin (Cornish),	·0000217	·0000690
Silver,	·0000191	·0000574
Gold,	·0000151	·0000453
Platinum,	·0000088	·0000264
Zinc,	·0000297	·0000890

It should be noticed in all cases how near the cubical co-efficient is three times the linear. The superficial will be found by simply doubling the numbers in the first column.

29. The Enormous Power of Extension and Contraction.—When bodies expand, the molecules of which they are composed are pushed farther asunder by the oscillatory motion communicated to them. The heat may be described as entering the substance, and immediately setting to work, separate the particles. The power or energy they exert to do this is immense. The following are illustrations of the energy of molecular forces. We have already mentioned several under the heads expansion and contraction :—

(*a*) When a dry wooden wedge is driven into the crevice of a rock, and moistened with water, the wedge swells and splits the mass. Thus many accidents have happened to grinders through the wedges swelling between the axle and the stone, and causing the latter to burst. Of course, in this case, centrifugal force assisted the wedges.

(*b*) When a rope is moistened, the diameter becomes larger, and the rope shorter, for the fibres are drawn in by this enlargement. It is said that, in lifting the statue of Nelson into its place in Trafalgar Square, the ropes had stretched through the great weight, and the blocks were close to each other. The whole operation would have failed, although the hero was within a very short distance of his place, had not a sailor cried out, "Wet the ropes." The hint was immediately taken, and the work accomplished.

(*c*) Water is turned into steam by heat; this heat endows the water with (atomic) force sufficient to drive the locomotive, to propel the steamship round the world, to work the mill, the forge, the hammer, the pump, etc.

(*d*) If the wall of a large building be bulging out, and an iron girder placed in a proper position, the power of contraction by cold will subserve the purpose of bringing it into the perpendicular. It has been done on a large scale in France. A girder (or girders) was fitted across the building with strong wall-plates at each end, and screwed up as tightly as possible. All along the girder was applied a number of gas jets, and as it expanded by the heat, the screws were tightened. The girder was then allowed to cool, and the strain of its contraction was sufficient, after repeating the process several times, to draw the walls into the perpendicular.

(*e*) We may almost add, that the Gulf Stream and the trade winds are caused by the atomic force of heat (but see *Convection*).

30. Molecular Force, or Atomic Force.—All molecules are under the influence of two opposite forces. The one, *molecular attraction*, tends to bring them together; the other, *heat*, tends to separate them, its intensity varies with its velocity of vibration. *Molecular attraction* is only exerted at infinitely small distances, and is known under the name of *cohesion*, *affinity*, and *adhesion*.

31. Cohesion.—By the force of cohesion this paper is held together. Heat and cohesion are directly antagonistic. When heat predominates in liquids, they become gases; when cohesion predominates, they become solids, or they may assume the spheroidal form, as exhibited in the dew-drop, a tear, etc. The manufacture of shot gives a striking illustration how the two forces, cohesion and gravitation, act. The lead for the shot is melted at the summit of a high tower; the molten lead, mixed with a little arsenic to give it the exact amount of fluidity, is then poured into a kind of sieve. It passes through the holes by its own weight (gravity), and in falling through the air, assumes—through the force of cohesion acting on it, in the same way as in the rain-drops—the form of a sphere; by the attraction of gravitation, it falls to the ground.

32. Affinity or **Chemical Affinity** is another form of molecular force. If oxygen and hydrogen be chemically united, in the proportion of one to two, they form water. The molecules are united by chemical affinity, but held together by cohesion. By the same force light is produced. The majority of light-giving substances are composed of hydro-carbon. The oxygen of the air first combines with the hydrogen, because it has the greatest affinity for it; the carbon is then set free, and we have an intense light, as the carbon passes from the hydrogen into the oxygen during the great evolution of heat caused by the chemical combination.

33. Adhesion is the molecular force exerted between bodies in direct contact. If two pieces of lead have their pure metallic surfaces laid bare, and be put together with a twist and pressure, they become united by this force. So will steel, or iron, or brass, unite with lead, if their clean and flat metallic surfaces be brought into contact. In punching out leaden bullets from the solid lead, as is done at Woolwich, the steel dies will adhere to the lead and become one solid mass, unless grease be used to prevent too close contact. Two pieces of flint-glass will thus unite when truly flat and clean. Before the introduction of the thrust-block to receive the thrust of the screw-propeller shaft, the whole thrust or force to drive the vessel was received upon a fixed steel plate. Instances have been known in which the end of the screw-shaft and the steel plate have so firmly adhered to each other, that the shaft has broken elsewhere. This simply resulted from the constant and enormous friction having consumed all the oil, etc., between the two; and two pure metallic surfaces were formed, which united under pressure.

The atomic force of heat has been sufficiently illustrated under the headings of expansion and contraction. But we must not omit to notice how this is connected with our subject, steam. By employing these atomic forces we obtain the fire necessary to generate the heat required, which endows the water with potential energy sufficient to do all our work, and this simply by observing how they act, and making them, by using natural laws, work for us.

34. Radiation and Absorption of Heat.—*Good and bad radiators.*—Radiant heat is heat passing out of bodies into the air in straight lines. We have also the radiant heat of the sun, conveyed by the ether to our atmosphere, and passing through it to the earth. Some bodies will allow radiant heat to pass out more freely than others. The tea in an earthenware teapot cools more rapidly than in one of silver. A boiler unpainted, unclothed, or not surrounded as far as possible by sawdust, ashes, etc., will radiate far more heat, or require more fire to keep up steam, than one that is protected and well surrounded by some of the substances mentioned. Glass is a better radiator than pewter. Colour does not effect radiation. If too much water be filled into a boiler at first, the fires will not burn so well as if only a little water were in the boiler; because the fire absorbs too much cold at a time, or too much cold is conducted from the water to the fire to allow it to burn properly. For the same reason too much fuel thrown on a fire tends to put it out.

35. Absorption is the power of taking in heat. Coated surfaces absorb more readily than uncoated. Lampblack readily absorbs heat, and quite as readily allows it to radiate. There is this reciprocity between radiation and absorption,—good radiators are good absorbers, bad radiators are bad absorbers. Take the same instance again. An earthenware teapot is a good absorber and a good radiator. Hence good tea is made in it. For its possessor, by placing in on the hob, puts it where it can readily absorb heat, and so all the flavour and strength is properly extracted from the leaves. Coat bodies with ever so thin a layer of metal it becomes a powerful defence against radiant heat. We thus see that the engine driver, who keeps his cylinder covers constantly bright, powerfully protects them from a loss of heat. Steam pipes should be well clothed to prevent this radiation.

36. Conduction.—If we place a poker or piece of iron in the fire, the molecules of the iron in the fire immediately begin to oscillate, and each molecule strikes its neighbour, passing the motion on; so that the end of the poker out of the fire also becomes warm. The process by which the heat is passed up the poker is called conduction. There are good and bad conductors. The metals are generally good conductors, and the earths, sawdust, ashes, stone, glass, chalk, etc., bad conductors. Silver is one of the best conductors. If we call its power of conduction 100, that of copper is 74, of gold 53, iron 12, lead 9, bismuth 2. A knowledge of this property of heat will teach an engineer on what to bed or surround his boiler, so that the least possible heat may be conducted out of it; also, in what he may case his steam pipes, cylinder, etc., to attain the same end.

37. Friction.—Every school boy knows the effect of sharply rubbing a metal button on the desk, and clapping it on to his neighbour's hand. Any amount of heat may be generated by friction. The breaks of a railway train are constantly set on fire by this cause. The friction caused by axles, journals, etc., on bearings, quickly makes them hot. Oil keeps a bearing cool, because it lessens the friction. No amount of oil will keep a badly turned bearing or an improperly scraped one cool, for the inequalities left by bad workmanship are the best generators of heat.

The action of the lubricant is this: a thin film of the lubricant is partially capable of preventing the surfaces of the two pieces of machinery coming into contact, it thus reduces the resistance due to friction, and assists also in conducting away the heat generated by friction.

The resistance from friction depends not alone on the roughness of the surface, but the force of pressure, the load or work done. On the same surface a double load will produce double the amount of friction, a treble load treble the amount, etc. This statement must be taken within certain limits. Friction does not at all depend upon the magnitude of the surface in contact. Let a block of brass, weighing 100 lbs., be placed on a flat, smooth surface of cast iron, it will require a force of 22 lbs., or $\frac{22}{100} = \frac{11}{50}$ of the whole to draw it along. If another 100 lbs., the same size and shape, be attached to the side of the other, it will require 44 lbs. to draw it along, still $\frac{44}{200} = \frac{11}{50}$ of the whole weight. Now, let the second block be placed upon the first, so that with the same weight we have only one-half the rubbing surface, experiments conclusively show that the friction is still $\frac{11}{50}$, or it requires the 44 lbs. still to drag the two weights over the cast iron, although the surfaces in contact are diminished by one-half. This $\frac{11}{50} = \cdot 22$ is called the co-efficient of friction.

The laws of friction received great attention from Coulomb, General Morin, etc. The following are a few of the co-efficients that may possibly prove of service to the engineer. Unguents were not used in their determination :—

Oak on oak,	·62
Wrought iron on oak,	·49 to ·62
Cast iron on oak,	·65
Wrought iron on cast,	·19
Cast iron on cast,	·16
Cast iron axles on Lignum Vitæ bearings,	·18
Copper on oak,	·62
Iron on elm,	·25
Pear tree on cast iron,	·44
Iron axles on Lignum Vitæ bearings,	·11 (with oil.)
Iron axles on brass bearings,	·07 (,, ,,)

The two laws of friction may be expressed thus:—(*a*) Within certain limits *the friction of any two surfaces increases in proportion to the force applied to press them together.* (*b*) *The friction is entirely independent of the magnitude of the two surfaces in contact.* It must never be forgotten that the friction of motion is wholly independent of the velocity of motion. To reduce friction lubricants are employed, such as grease, tallow, oil, soft soap mixed with oil, black lead, etc., with water and sulphur; the two latter act in a very different manner to the lubricants, and are generally used in extreme cases. The co-efficient of wrought iron on oak is ·49 in the dry state, but apply water it is reduced to ·26, while soap will reduce it to ·21. Oil, tallow, lard, etc., have all about the same effect, whether it be wood on wood, wood on metal, or metal on metal, the co-efficient being ·07 or ·08, or lying somewhere between; but in the case of tallow interposed between metal and metal the co-efficient rises to ·1. Water reduces the temperature of bearings, because it boils at a very low temperature, and thus a large amount of heat is carried away *in steam as latent heat.* Sulphur boiling at a temperature 108° C., acts on the same principle.

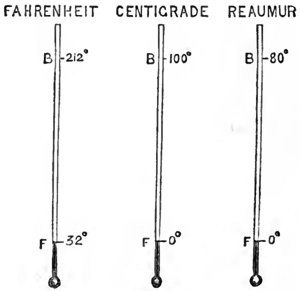
Cold water should never be thrown upon a hot axle or bearing, there being great risk of fracture owing to the sudden contraction of the metal.

38. Temperature and Measures of Temperature.—The temperature of a substance is the amount of sensible heat it contains. This heat is measured by the thermometer, pyrometer, or calorimeter.

39. The Thermometer.—The thermometer is used for measuring the intensity of the heat in air, water, etc. It mainly consists of a tube with a capillary bore, and a bulb at the end containing mercury or quicksilver. By the side of the tube is the scale, graduated into degrees, from which the temperatures are read off. The filling of the bulb and part of the tube with mercury requires the nicest manipulation, so that all air and moisture shall be totally excluded from the tube, after which the end is hermetically sealed. There are three methods of graduating the thermometer:—

(1) FAHRENHEIT'S.
(2) CENTIGRADE.
(3) REAUMUR'S.

40. (1) Fahrenheit's Thermometer.—Gabriel Fahrenheit was born at Dantzic, and settled at Amsterdam as an instrument maker, where, in 1725, he improved the thermometer by substituting mercury for spirits of wine, thus greatly increasing its accuracy. The expansion by heat and contraction by cold of mercury, is the same for all temperatures, at least practically so, for which a thermometer is used. Hence the superiority of mercury over alcohol or water. Fahrenheit named the freezing point 32°, and the boiling point 212°. The reason for this choice may be briefly noticed. Ice in the act of freezing, and also during its conversion into water, retains always the same temperature; boiling water, under the same pressure, also maintains the same temperature as long as it boils, and you cannot make it hotter under the circumstances. Therefore no better starting points for the graduation of the thermometer can be secured, especially as pure water is always procurable.



THERMOMETERS.

In Fahrenheit's time it was supposed that the greatest degree of cold attainable was reached by mixing snow and common salt, or snow and sal-ammoniac. A thermometer plunged into a mixture of this kind was found to fall much below the point indicated by melting ice. The point to which the mercury fell by contraction, when plunged in this mixture, Fahrenheit marked 0°, the interval between this and the freezing point he divided into thirty-two equal divisions, hence the freezing point came to be indicated by 32°. The equal divisions were continued upwards, and the mercury, by expansion, reaching 212° when the thermometer was immersed in boiling water, this 212° was called the *boiling point.* This is briefly the reason for Fahrenheit adopting his method of division, and why he has $212° - 32° = 180°$ between the freezing and boiling points. Fahrenheit's scale is the one used in England. A much lower temperature than 0° F. has been observed. Mercury becomes solid at $-40°$ F. This temperature, which has often been observed by Arctic explorers and others, would perhaps be a better limit to the scale, because it would then register the utmost extremes of heat and cold to which the mercurial thermometer is sensible.

41. (2) **Centigrade Thermometer**—Celsius, a Swede, adopted another mode of division. He marked the freezing and boiling points on his thermometer, calling the former 0°, the latter 100°, and divided the interval between into a scale of one hundred parts. This method of indicating the measure of heat is called the *centigrade,* and is found so convenient that it is fast superseding Fahrenheit. The sooner it displaces the other modes the better, as the decimal and a uniform scale seem very much wanted, and are certainly the most convenient. This scale is mostly used in France.

42. (3) **Reaumur,** or Romer, introduced a much more arbitrary division of the scale, which is commonly used in Germany. He called the freezing point 0°, the boiling point 80°. We now see that in Fahrenheit's scale there are 180° between the freezing and boiling points, in the centigrade 100°, in Reaumur 80°.

Rules to compare the reading of one thermometer with that of another:—

(1) To convert Fahrenheit's degrees to centigrade—
Subtract 32°, then multiply by 5, and divide by 9.

(2) To convert centigrade to Fahrenheit—
Multiply by 9, divide by 5, and add 32°.

(3) To convert centigrade to Reaumur—
Multiply by 4 and divide by 5, or subtract one-fifth.
(4) To convert Reaumur to centigrade—
Multiply by 5 and divide by 4, or add one-quarter.
(5) To convert Fahrenheit to Reaumur, or Reaumur to Fahrenheit—
First bring them into centigrade, then reduce to Fahrenheit or Reaumur, whichever may be required.

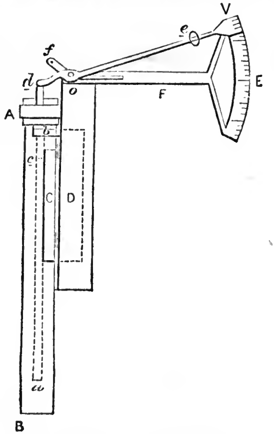
Exercises on the reduction of the number of degrees of one thermometer to an equivalent number of another, will be found at the end.

43. The Pyrometer.—The pyrometer is used for showing the change produced in solid bodies by the application of heat, from this change the temperature is calculated. The pyrometer has been brought forward in many shapes, such as the Sevres, Wedgewood's, Ellicott's, Guyton's, Daniell's, Lavoisier and La Place's, etc. Wedgewood's pyrometer consisted of two pieces of brass, each 24 inches long, fastened on a plate, with two of the ends five-tenths of an inch apart, and the other two three-tenths apart. Small cylinders of carefully cleaned and well baked clay were made so as to exactly fit into the larger end when the clay was just red hot. On exposure to greater and intense heat the clay shrank, and the farther it passed down between the bars the higher the temperature of the fire, furnace, etc. The shrinkage of clay is not *uniform at all temperatures*, so Wedgewood's apparatus has been abandoned for Lavoisier and Laplace's, of which a full description will be found in Mr. Balfour Stewart's *Treatise on Heat*, page 26.

44. Daniell's Pyrometer.—This is a valuable instrument, and consists of two distinct parts—

(1) The Register.
(2) The Scale.

45. The Register.—A B consists of a solid bar eight inches long, cut out of a piece of black-lead earthenware, down its centre is drilled a hole, marked by the dotted lines, reaching nearly to the bottom. A tube of platinum (*a c*) is first placed in the hole, above this and touching it is a tube of porcelain (*cd*), called the *index*. Round the register at A is a strap of platinum which can be tightened by a wedge, not shown in the figure; when the index is forced out by the heat expanding the bar of platinum, the strap prevents it from returning.



DANIELL'S PYROMETER.

46. The Scale consists of a frame formed of two rectangular plates of brass, C and D, C is joined on to D by two hinges; C acts as a guard to keep the register A B in its place. The strap also rests on the projection *b*, which also performs the same office. E is a graduated arc formed on the end of the arm F, which moves on a fixed centre *f*, while *d e* is another arm moving on its centre *o*, and carrying a vernier, V, and terminating in a knife-edge at *d*. When about to be used, the register is placed behind the scale, as seen in the figure, so that the tube of porcelain just touches the arm *de*, the position of the vernier is noted, then the register *alone*, with the index and platinum bar in it, is exposed to the heat to be measured; it is next taken out of the heat and allowed to cool; after which it is applied to the scale, or placed as in the figure, the strap preventing the index from returning to where it was pushed by the expansion of the platinum; it is evident that the vernier will be moved downwards through the arm *e*, being moved on its fulcrum *o*, and indicate the temperature corresponding to the expansion of the platinum. The difference between the first and second readings will be the temperature sought.

47. Mr. Houldsworth's Pyrometer,* as used in his experiments on the combustion of fuel, is a useful and simple apparatus. At the bottom it consists of a bar of copper resting on iron pegs, placed in one of the side flues, and fixed on the end of the boiler. One end of this bar comes

* See Fairbairn's *Useful Information for Engineers.* First Series.

through the brickwork and gives motion to the short arm of a lever, the longer arm of the lever answers the purpose of an index, pointing to a graduated scale of temperatures. As the bar of copper expands and contracts by the varying temperature of the flue, it compels the index to move backwards and forwards. To the larger arm of the lever is also attached a rod parallel to the former, which also moves backwards and forwards with the change of temperature. During the oscillations this latter bar causes a lead pencil to press on a revolving cylinder, round which is fastened a sheet of paper, so that a line is traced indicating the variations of temperature in the flue, as exhibited by the expansion and contraction of the bar of copper.

48. The Use of the Pyrometer is to exhibit the temperature of furnaces, ovens, kilns, etc. Mr Houldsworth established by it the following interesting facts:—

(1) *That the admission of a certain quantity of air behind the bridge acts most advantageously.* The oxygen of the air combines with the carbon and hydrogen of the fuel, and a greater amount of heat is developed for generating steam. The smoke is also consumed; whenever smoke is seen we have a sure sign of waste. Too much air cools the furnace, too little gives an imperfect combustion; but when the proper supply is maintained we have perfect combustion. The carbon of the coal, which is seen so frequently escaping as smoke, is converted into carbonic acid gas, and the hydrogen, combining with a less proportion of oxygen, is converted into vapour.

(2) *A regular and continuous supply of air to the furnace increases its heating powers* $33\frac{1}{2}$ *per cent.*

(3) *The supply of air may enter behind the bridge through the bars, or through the furnace doors, so long as it is properly regulated.*

(4) *The supply of air must vary with the nature of the coal.* With light burning fuel less air will be required than with caking coal, because in the latter case the charge in the furnace becomes a compact mass excluding the air, while the former leaves clear spaces between the bars for its entry.

(5) *For perfect combustion a high temperature is necessary.* This fact was established by Sir Humphrey Davy.

49. Specific Heat, or Capacity for Heat, is the power of storing up heat.

50. The Calorimeter is not used to measure the temperature of a body, but to ascertain the total amount of heat in it, or to find the specific heat.

Two similar metallic vessels are placed one within the other, so as to leave a space between them. This space is filled with pounded ice, while a discharge-pipe proceeds from the bottom of the external vessel to carry off all water that may be produced through the liquefaction of the ice by the external air. A third, and nearly similar vessel, is placed within the second, leaving a space between it and the second vessel, which is also filled with pounded ice; a second discharge-pipe (with a stop-cock) proceeds from the second vessel without communicating with the outside one. Each vessel is provided with its proper cover. It is obvious that the ice in the inner space cannot be affected by the temperature of the external air when the calorimeter is closed. The substance, whose specific heat we wish to ascertain, is placed, after observing its temperature, within the third or inner vessel. It is perfectly clear that any heat the body may contain, will communicate or lose its motion to the ice in the *second* space, or the ice will take up the heat from the substance as latent heat, and become converted into water; this is then allowed to pass through the discharge-pipe leading from the inner vessel, and is collected. This water will at all times be proportional to the heat stored up in the given substance placed within the calorimeter.

Supposing a body at 50° to be placed in the calorimeter, and permitted to sink to 40°, or through 10°, if the quantity of ice melted be ten grains, this would be a grain for every degree. If we divide the weight of melted ice by the number of degrees through which the body has fallen, we obtain the quantity which the body would melt by falling through 1°. This quantity expresses the specific heat of the body. By the calorimeter, it has been ascertained that to raise the temperature of water 1°, requires thirty times as much heat as would be required to raise mercury 1°. Or the same heat that would raise 1 lb. of water 1°, would raise the temperature of 30 lbs. of mercury 1°; and this is what is meant when we say the specific heat of mercury is $\frac{1}{30}$ or $\cdot 0\dot{3}$ that of water. Iron requires $3\frac{2}{3}$ more heat than lead to work in it the same change of temperature; practically, this means that lead will heat $3\frac{2}{3}$ times quicker than iron; at the same time it will cool very much more quickly than iron. It is obvious that to heat 2 lbs. of water 1°, requires twice as much heat as to heat 1 lb. of water 1°. The relative quantity of heat necessary to produce the same change of temperature in different bodies is their specific heat. We said the capacity for heat of water was thirty times that of mercury; hence this latter substance is so well adapted for thermometers; we see at once how sensible it must be to the least accession or subtraction of heat. Again, the capacity for heat of air at constant pressure, is about one quarter that of water, or more accurately ·237; hence 1 lb. of water, whose specific heat is 1, on losing 1° of heat, will increase the temperature of $\frac{1}{\cdot 237} = 4\cdot 2$ lbs. of air 1°. But water is 770 times heavier than air. Hence if we compare volume instead of weight, a cubic foot of water, on losing 1° of temperature, will increase that of $770 \times 4\cdot 2 = 3234$ cubic feet of air 1°.

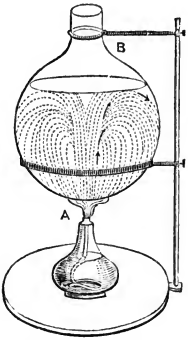
Capacity for heat may be defined as the quantity of heat necessary to raise the *same weight* of different substances through the same *number of degrees* of temperature, but it must not be defined as the amount of heat necessary to raise a pound weight of a given substance one degree in temperature, or else we shall confound it in the case of water with the unit of heat. Capacity for heat is found thus: one, two, three pounds, ounces, etc., any weight may be chosen, of any substance, and heated so many degrees, one, two, three, etc. (generally heated in boiling water), and then put into the calorimeter, when according to the quantity of ice melted we have the capacity for heat. The quantity each substance liquefies is noted, the whole compared with water as a standard, and the capacity for heat determined.

The following are the specific heats or capacity for heat of a few well known substances :—

Iron, .	·1098	White marble,	·2158	Air, . .	·2370
Mercury,	·0330	Sulphur, . .	·1844	Steam, .	·4805
Silver, .	·0557	Platinum, .	·0355	Ice, . .	·5040
Copper, .	·0949	Glass, . .	·1770	Water, .	1·0000

51. Convection.—Convection is the transfer of heat by sensible masses of matter from one place to another. Water can only be heated by convection; it is scarcely possible to heat it by conduction. Our rooms are ventilated by convection, smoke ascends the chimney by the same principle, and all our winds and currents, in both air and water, are caused by this convection. The wind-sails of a ship afford an instance in which this law of nature is made available for ventilation.

If A B be a glass vessel or large Florence flask filled with water, when heat is applied at A, the water near A is immediately heated and expanded, and becoming specifically lighter rises up, and the colder water from above falls down to supply its place; this continual change goes on as long as the heat is applied at A, and is called convection. If a little cochineal be placed in the water, it will sink to the bottom of the flask, and heat being applied as before, the cochineal directly leaves the bottom, ascends up the middle, and then descends by the sides, returning again to the heat. By this simple experiment the action of convected water is made visible to the eye.



CONVECTION OF WATER.

Let C D be a large test-tube filled with water, and held by an holder in the position indicated by the figure; then let heat be applied at D, it will be found almost impossible to heat the water in the test-tube, for the heated or convected water rises perpendicularly up from the heat, confining itself to the top of the tube, and scarcely any heat is *conducted* downwards; for, of course, the convected or light water cannot run down, or mix itself with, or rather communicate its motion to, the heavier water below. Large masses of water can only be heated by convection,

CONDUCTION OF WATER.

and therefore all furnaces should be placed as low down in the boilers as possible, while below the bars there should be but little if any water.

A patent fire-door is used for boilers, which is nothing but the application of the principle of convection : the doors are made with front and back plates, and hollow within. In the front plate are a few openings from one to one and a half inches in diameter; the back plate is thoroughly perforated with smaller holes. The air goes in at the bottom of the front plate and out at the top, carrying off the heat, thus the front of the door is never heated to redness, the current of convected air carrying off the heat. In precisely the same way the funnels of steamers are kept cool, and passed through the wood of the decks. A casing is placed entirely round the funnel, passing into the engine-room, and sometimes spreading out over the boilers. A stream of air then continually runs up between the funnel and the casing; this air takes the heat out of the funnel as it passes upwards, and keeps it from becoming too hot. Holes are often made at the bottom of the casing for the passage of additional air.

52. Conversion of Heat into Work, and Work into Heat.— A fire is lighted in the furnace of a locomotive; when the steam is sufficiently elastic, the train moves out of the station, the consumption of heat drives the train along; when it approaches a station the driver shuts off the steam and puts on the brake, which destroys the momentum of the train, by reconverting it into heat, causing smoke and sparks to issue forth from the brake.

A good illustration to show that heat is consumed in mechanical work will be found in the following :—

Let a large quantity of air be forced into a strong box, then let it cool until it is of the same temperature as the surrounding air, now open a hole in the box, when the air will violently issue forth, but intensely cold. To drive out this air, force is required, or work must be done; to do this work no heat can be obtained from the outside, so it consumes the heat that it possesses within itself, and issues forth very cold.

53 Mechanical Equivalent of Heat.—(*a*) Heat is motion —the motion of the ultimate particles.

(*b*) Whenever work is done, heat is consumed in exact proportion to the work done.

(*c*) The evolution of heat is ever in proportion to the mechanical energy expended.

(*d*) A thermal unit is the quantity of heat necessary to raise a pound of water 1° C. in temperature; this is the exact amount expended in raising 1392 lbs. one foot high, or 1 lb. 1392 feet high.

If the thermal unit of 1° F. be used, then the mechanical equivalent is that this heat would raise 772 lbs. one foot high, or 1 lb. 772 feet high. The mechanical equivalent of heat has been determined by some of the most persevering and exact experiments of modern science.

Let it be supposed that a cubic foot of gas or air is contained in a vessel, with a square foot for its base and fitted with a piston of the same dimensions, and that heat is applied to the gas, which is at liberty to expand and drive up the piston. If the temperature of the gas be raised through 273° C., the gas will double its volume; and as the piston is one square foot in area, this square foot, or 144 square inches, will be opposed in its ascent by the pressure of the atmosphere; and, therefore, we shall have $144 \times 15 = 2160$ lbs. lifted one foot high by the act of the air doubling its volume. This cannot be stated too distinctly, so it is repeated in another shape. When a cubic foot of air is made to double its volume by increasing its temperature 273° C., it performs 2160 units of work.

In the experiment, if we applied the heat, but kept the air from expanding, or compelled the volume to remain constant, by continually adding additional weights to the piston (one ounce for each degree), we should find that when heated 273° we had added 273 ounces, but that less heat was consumed in this latter case than in the former, in the proportion of 1 : 1·421, or,

$$\frac{\textit{Heat at constant volume,}}{\textit{Heat at constant pressure,}} = \frac{1}{1{\cdot}421}$$

We have now to apply these facts to water, and to show how the additional heat required in the one case will give the mechanical equivalent of heat.

A cubic foot of air, since its specific gravity is $\frac{1}{770}$, weighs $\frac{770}{1000}$ ounces $= 1{\cdot}29$ ounces.

The capacity for heat of air is ·24.

Therefore, the 273° C. of heat that were applied to the air will heat $1{\cdot}29 \times {\cdot}24 = {\cdot}31$ ounces of water through the same temperature, or $\frac{{\cdot}31 \times 273}{16} = 5{\cdot}28$ pounds one degree.

Or, ·31 ounces of water heated 273° C. is the same as 5·28 pounds heated 1° C.

But this water is supposed to be heated under constant pressure. Let us, therefore, find what quantity we should have had, if it had been heated by the heat that was consumed when the volume was kept constant. It evidently follows from the proportion given above,

$$1{\cdot}421 : 1 :: 5{\cdot}28 \text{ lbs.} : 3{\cdot}72 \text{ lbs.}$$

Subtracting 3·72 from 5·28 gives 1·55 lbs.* This must be the quantity of water heated by the excess of heat between constant volume and constant pressure; and this excess of heat must have performed the 2160 units of work.

Since the heat necessary to raise 1·55 lbs. of water 1° C., performs 2160 units of work; therefore the heat necessary to raise 1 lb. of water 1° C. is equivalent to $\frac{2160}{1{\cdot}55} = 1393{\cdot}5$ units of work.

Hence the heat necessary to raise 1393·5 pounds one foot high will raise a pound of water one degree centigrade. This 1393, or more precisely 1390,* is called the mechanical equivalent of heat. "Heat and mechanical energy are mutually convertible; and heat requires for its production, and produces by its disappearance, mechanical energy in the ratio of 1390 foot pounds for every thermal unit."†

It will help to a thorough conception of the above if the student will endeavour, by the same course of reasoning, to find the mechanical equivalent of heat in terms Fahrenheit. He must use 490° for 273°, and his conclusion will be that the heat required to raise a pound of water one degree Fahrenheit will perform 771·4 units of work.

Hence 772 is the mechanical equivalent of heat for each degree Fahrenheit.

* Several of these numbers are taken as if the decimal places are worked out farther than shown in the context.

† Ganot's *Physics*, page 411.

EXERCISES CHIEFLY FROM EXAMINATION PAPERS.

1. What do you understand by *conduction* and *convection* as applied to heat (1867)?

2. What is meant by the following terms as applied to heat:—*Conduction*, *convection*, *radiation*, and capacity for heat (1865)?

3. What do you understand by the conduction of heat? Mention one or two good, moderate, and bad conductors of heat (1869).

4. What is meant by capacity for heat? The capacity for heat of mercury is ·033, how much at the temperature of 240° will be sufficient to raise 12 lbs. of water from 50° to 58° (1867)?

Ans. 16 lbs.

5. Show how to convert degrees on a centrigrade into degrees on Fahrenheit's scale.

What temperature F. corresponds to 18°·5C. (1866)?

Ans. 65°·3F.

6. Show how a thermometer is graduated. Compare the graduations on Fahrenheit's, Reaumur's, and the centigrade scale. Reaumur's scale shows a temperature of 15°, what will the centigrade and Fahrenheit's scales respectively show for the same temperatures (1868)? *Ans.* $18\frac{3}{4}$°C., $65\frac{3}{4}$°F.

7. Describe the calorimeter and Daniell's pyrometer. For what purposes are these instruments respectively used (1868)?

8. A centigrade thermometer marks 5°, what will a Fahrenheit thermometer mark (1865)? *Ans.* 41°F.

9. Give a few simple experiments and illustrations to show that bodies expand by heat and contract by cold.

10. Obtain a formula for determining the weight of water which must be mixed with a given weight of steam, in order that the mixture may be reduced to a water of a given temperature (1868).

Let t = the temperature of injection water.

t' = ,, ,, ,, the water coming from the hot well.

∴ Each unit of water is raised $t' - t$ degrees of temperature.

The total heat in steam is 637·2°C., which has to be reduced $637{\cdot}2 - t'$.

$$\therefore \text{ Units of water required} = \frac{637{\cdot}2 - t'}{t' - t}$$

Applying this formula to the next example, we have

$$\frac{637{\cdot}2 - t'}{t' - t} = \frac{637{\cdot}2 - 48\frac{8}{9}}{48\frac{8}{9} - 15\frac{5}{9}} = 17{\cdot}6$$

that is, each unit of steam, be it inch, foot, or pound of water converted into steam, will require 17·6 cubic inches, feet, or pounds, to condense it; and as we have 20 lbs. in the next example, the weight of condensing water is $17{\cdot}6 \times 20 = 352$ lbs.

11. What weight of water, at 60°F., must be mixed with 20 lbs. of steam of one atmosphere in order to produce water at 120°F. (1868)?

Ans. 17·6 lbs. for each pound of steam.

12. What is meant by capacity for heat? Show how to calculate the temperature of a mixture of two substances whose temperatures and capacities for heat are given. 1 lb. of copper (capacity for heat ·095) at the temperature 520° is mixed with 2 lbs. of water (capacity for heat 1) at temperature 60°, what is the common temperature of the mixture (1866)?

Let w be the weight of one body, $t°$ its temperature, and c its capacity for heat.

Let w' be the weight of the second body, $t'°$ its temperature, and c' its capacity for heat.

Now since the capacity for heat of a body may be taken as the amount of heat required to increase the temperature of a given weight one degree

$\therefore$ $w\,c$ represents w raised one degree.
$\therefore$ $w\,c\,t°$,, w ,, t degrees.
also $w'\,c'\,t'°$,, w' ,, t' ,,
or $w\,c\,t$ and $w'\,c'\,t'°$ represent the total heat in w and w'.

Let x be the temperature of the mixture of the bodies $w\,c$ and $w'\,c'$.

$$\therefore\ w\,c\,t + w'\,c'\,t' = x\,(w\,c + w'\,c')$$

$$\therefore\ x = \frac{w\,c\,t + w'\,c'\,t'}{w\,c + w'\,c'} \quad - \quad - \quad - \quad - \quad (1)$$

$$\text{also } c = \frac{w'\,c'\,x - w'\,c'\,t'}{w\,t - w\,x} = \frac{w'}{w}.c'.\frac{x - t'}{t - x} \quad - \quad - \quad (2)$$

$$\text{similarly } c' = \frac{w}{w'}.c.\frac{x - t}{t' - x} \quad - \quad - \quad - \quad (3)$$

Substituting in equation (1) we can solve the question thus:

$$x = \frac{1 \times {\cdot}095 \times (520° - 32°) + 2 \times 1 \times (60° - 32°)}{1 \times {\cdot}095 + 2 \times 1}$$

$$= \frac{{\cdot}095 \times 488 + 2 \times 28}{{\cdot}095 + 2} = \frac{102{\cdot}36}{2{\cdot}095} = 48{\cdot}85$$

$\therefore$ *Ans.* $= 48{\cdot}85 + 32 = 80°{\cdot}85$F.

Or we might have reasoned thus:

Let x = common temperature of the mixture.

Copper is depressed $(520 - x)°$
Water is raised $(x - 60)°$

	Lbs.	Sp. H. of Water.	Sp. H. of Cop.
$\therefore$ $(520 - x)$:	2 $(x - 60)$: :	1 :	·095

$$\therefore\ 2\,x - 120 = 49{\cdot}4 - {\cdot}095\,x$$
$$\therefore\ 2{\cdot}095\,x = 169{\cdot}4$$
$$\therefore\ x = 80°{\cdot}85 \text{ F.}$$

The answer in the centigrade scale would be

$$= \frac{1 \times {\cdot}095 \times 271\tfrac{1}{9} + 2 \times 1 \times 15\tfrac{5}{9}}{1 \times {\cdot}095 + 2 \times 1}$$

$$= \frac{511{\cdot}8}{18{\cdot}855} = 27°{\cdot}14\text{C.}$$

or reduce the 80°·85F. to centigrade will give the same answer.

13. Show how to graduate a thermometer. Why is it necessary to take the height of the barometer into account in determining the boiling temperature (1866)?

14. Give your reasons for concluding that heat and work are convertible, the one into the other. Describe an experiment by means of which the mechanical equivalent of heat may be ascertained, and state its numerical value—(Honours, 1869).

15. What is the great exception to the universal law of expansion by heat and contraction by cold? Can you give any other exception?

16. Explain what is meant by the *co-efficient* of expansion, and show the enormous power of expansion and contraction by a few illustrations.

17. What do you mean by the molecular forces, and what are their names?

18. How do radiation and absorption affect the steam-engine and its working? State clearly what you mean by the reciprocity of radiation and absorption.

19. What are the laws of friction? Give a few simple illustrations.

20. What are the instruments employed to measure temperature? Upon what principle are they all constructed?

21. What facts have been proved by the use of Mr Houldsworth's pyrometer? Give a description of it.

22. Explain the term cushioning, and clearance (1866 and 1868).

CHAPTER III.

THE STEAM ENGINE.

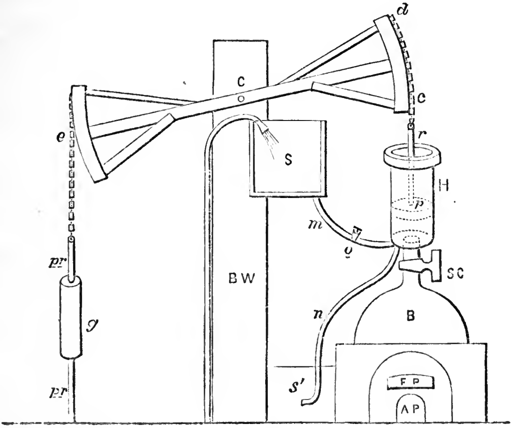
Savary's—Newcomen's—Watt's—Cylinder and Crank—Single and Double Acting Engines — Clearance — Cushioning — Galvanic Action—Beam Engines—Parallel Motion—Guides—Governor—Throttle Valve—Cataract—Eccentrics—Expansion Gear.

54. (1) Savary's Engine.—Savary's was the first steam engine employed to pump water. He took out his patent in 1698. His engine consisted of a cylinder, in which steam was employed to produce a vacuum only, after which he relied upon the pressure of the atmosphere to raise the water. At the top of his cylinder were two openings, each fitted with a pipe and a stop-cock. These were so arranged that the same handle opened one stop-cock and shut the other simultaneously. One pipe communicated with a boiler and admitted steam to the cylinder, the other with a cistern and admitted cold water to the cylinder. From the bottom of the cylinder a pipe led down to the water. It acted thus: Suppose the handle of the stop-cock moved, and steam admitted to the cylinder, the instant it was full the handle was pushed back, and a dash of water from the other cock condensed the steam and formed a vacuum; then the pressure of the air on the water at the bottom of the mine forced the water up into the cylinder, which was prevented from returning by a valve opening upwards; on a second admission of steam, its elastic force acting on the water drove it through a valve in the side of the cylinder opening outwards; this steam was again condensed as before, etc. We thus see the principle upon which it acted. The water was first forced by atmospheric pressure into a vacuum, after which the elasticity of the steam pressing upon its surface was made to raise it still higher through another passage. The inefficiency of this machine is apparent. Its defects were: that steam was used in a cold cylinder; that the steam was always in contact with cold water; and, therefore, the greater part of it was lost; that the engine was limited in its range and purpose; that it must be always far down in the mine from which the water was raised.

55. (2) Newcomen's Engine.—Thomas Newcomen was a Devonshire man, and the first to work out the idea of a piston (at least in England). His engine was used for pumping. In fact, the one idea of the early labourers at the steam engine was to adapt it, or to invent a machine, to pump water out of the Cornish mines.

Newcomen placed his cylinder immediately above his boiler, from which steam passed directly through a stop-cock. As soon as the piston was at the top of its stroke, a cock was opened and cold water admitted into the cylinder to condense the steam; a vacuum being thus obtained, the pressure of the air, 15 lbs. on the square inch, immediately drove down the piston, which was attached by a chain to the end of a sway beam moving on its centre. The piston being thus forced down by atmospheric pressure pulled up the other end of the beam at the same time, and with it the pump-rods, water, etc. When fresh steam was admitted it forced up the piston against the atmosphere, while the weight of the pump-rods, etc., at the other end assisted the steam. The weight of the pump-rods, etc., was generally made equal to half the pressure of the air on the piston. This engine raised 7 or 8 lbs. for each square inch of the piston. Newcomen's was a *single acting* engine, because the steam acted on one side of the piston only.

Newcomen's engine is represented in the figure on the opposite page, AP is the ashpit, FP the fireplace, B the boiler, SC a stop-cock to admit the steam into the cylinder H from the boiler B. The cylinder was bored as truly as possible, open at the top and closed at the bottom, being connected with the boiler by a short pipe containing the steam-cock. A piston *p* was made to move up and down in the cylinder, as air-tight as practicable, by packing its edges with hemp and covering the upper surface with water. The piston rod *r* was attached by a chain *c* to the circular arc *c d*, forming the end of the beam *e d c, which was now for the first time introduced.* The beam, working on its centre C, was framed of strong timbers



NEWCOMEN'S ENGINE.

firmly put together and strengthened by iron bars and straps. The whole beam was supported on a strong brick wall, B W. To the chain *e* attached to the other arc was fastened the rod *p r* of the pump to be worked in the mine. The power of the engine was in the *down stroke.* The pump-rod was made heavy enough to act as a counterpoise by attaching weights *g* to it, so that it was heavier than the piston, piston-rod, friction, etc. When the cock S C was opened and *air* admitted, it would rise freely without violently jerking out the piston *p*. A safety valve was placed on the top of the boiler. The manner in which the engine worked was as follows:—

The boiler B was filled with a proper quantity of water, and the steam "got up" to a pressure a little above that of the atmosphere. The cock S C was opened (supposing the piston at the bottom of the cylinder), and the steam entered the cylinder, when the piston ascended partly through the force of the steam, but chiefly in obedience to the counterpoising weights *g*. Just before the piston reached the top of the cylinder the steam-cock was shut and another cock *o* was opened, which allowed water from the cistern S to flow through the pipe *m* and condense the steam in the cylinder, producing a vacuum, when the pressure of the external air, acting on the top of the piston, caused it to descend with a force proportionate to its area; and as this force amounts to nearly 15 lbs. on the superficial inch, it was fully competent to raise the end of the beam *e*, and with it the pump-rods and water. We thus see that the real work was done by the *atmosphere*, and why it was called an atmospheric engine.

Originally it was much less perfect than here described, for the condensation was in the first instance performed from the outside of the cylinder. The admission of water into the cylinder to condense the steam was discovered accidentally, through some holes wearing in the piston of an engine which permitted the water placed upon it to keep it air-tight to run through and condense the steam, although we must remember Savary had introduced steam into his cylinder and *condensed it in the cylinder*. The great difficulty of opening the cocks at the proper moment was conquered by Humphrey Potter,* who attached some strings and catches to the cocks of an engine he was employed to work at Wolverhampton, in order to release himself from the trouble of attending them; his contrivance gave the first idea of "hand gear." The greatest nicety and attention on the part of the workman was necessary in turning the two cocks at the proper moment; for if steam were permitted to enter the cylinder for too great a length of time, the piston would be carried out of it or blown out of its place; while, on the contrary, if not opened soon enough, it would strike against the bottom with sufficient force to break the cylinder. The steam was liable to become mixed with air, which was disengaged from the injection water. This air, together with the injection water, was discharged by a pipe *n* into the cistern *s'*. The pipe *n* terminated in a valve to preserve the vacuum, which valve, from the peculiar noise it made was called the *snifting valve* or *snifting clack*.

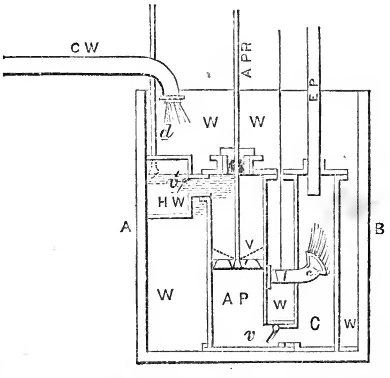
* Millington's *Mechanical Philosophy*.

Mr. Henry Beighton, of Newcastle-upon-Tyne, effected most important improvements in Newcomen's engine, by using what he called a "plug tree" for admitting and shutting off the steam, by introducing a small force pump to feed the boiler, and otherwise giving a better arrangement to the working parts. In fact, the machine was frequently known as Beighton's Fire Engine.

It was an *atmospheric engine*, because it depended upon the pressure of the atmosphere to perform the down stroke—in fact, to do the chief part of the work.

Its great disadvantage was that the cylinder was at one time required to be hot and at another cold; that the fresh steam entered a cold, wet cylinder whose temperature had just been reduced, thereby losing *three-quarters* of its power.

56. (3) Watt's Engines.—Watt, having the model of an atmospheric engine, such as we have just described, to repair, asked himself the question, whether it were not possible to prevent the wasteful expenditure of steam. He saw intuitively the great defect of the engine, and set himself to solve the problem of a separate condenser In this he completely succeeded, and never left the steam engine until it was comparatively a perfect machine. The above figure is a fair representation of the *great* improvements he introduced.



CONDENSER AND AIR PUMP.

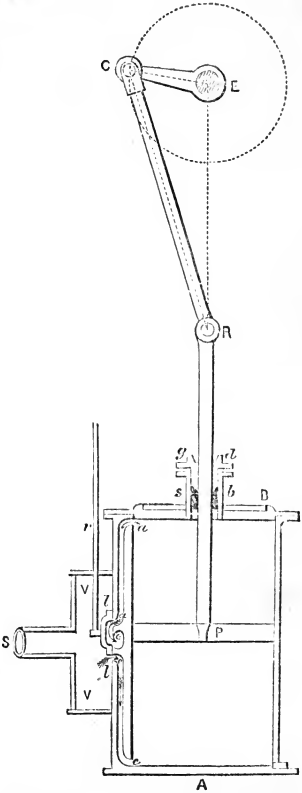
A B is a large casting, within which is placed the condenser C, the air pump AP, and the hot well HW. V is the piston or bucket of the air pump, with its two valves shut down, but shown by dotted lines as they will appear when the piston V is descending. E P is the exhaust pipe, to convey the used steam from the cylinder into the condenser C. C W is a pipe bringing cold water from the pump, *v* the foot valve, *v′* the delivery valve. W W W W is water surrounding the condenser and air pump, to keep the condenser cold.

Let us suppose that the steam having been used comes from the cylinder, through the exhaust pipe E P. The moment it enters the condenser, it is met by a scattered jet of cold water from the rose head *c*, and is condensed. The condensed steam and water fall to the bottom of the condenser, and pass or are drawn through the foot valve *v*. Then the piston or bucket V of the air pump comes down into the water; the pressure of water opens the two butterfly valves, and the water passes through the valves and so gets above the piston. When the piston is drawn up the two valves are closed by the weight of the water above them, which is next forced or delivered into the hot well H W, through the delivery valve *v′*, from whence part of it is pumped into the boiler through *d*, a part of the *feed pump*. As the air pump ascends a vacuum is formed in A P, at least as good a vacuum as exists in the condenser C, so that the condensing water passes by gravity, etc., through the foot valve *v*, or "follows the bucket." As the air pump descends we see *v* must close, so must *v′*; on the contrary, as it ascends both delivery and foot valve will open.

All water contains air more or less. The heat of the steam disengages the air from the condensing water, which would rise through the exhaust pipe, and prevent the proper escape of steam, besides counteracting its pressure if not got rid of. The air pump was, therefore, added by Watt to his invention of the condenser, to prevent air from accumulating and obstructing the engine. Hence its name, *air* pump, its office being not only to pump out the condensing water, but to keep the condenser free from air.

57. Cylinder and Crank.—The Figure on opposite page is a representation of a cylinder with a locomotive or three-ported slide. Cylinders are constructed of cast iron and bored with the nicest precision. They must be perfect cylinders, the same diameter from end to end.

A B is the cylinder, P the piston, and P R the piston rod. C E the crank. and E a section of the main shaft turned by the crank and connecting rod C R. *s b* is the stuffing box, and *g d* the gland. *l l* is the slide, and *r* the slide rod by which the engine moves the slide up and down. S is the end of the steam pipe which brings the steam from the boiler to the cylinder. *a* is the upper port, *c* the lower port. *e* is the exhaust port by which the steam escapes from the cylinder to the condenser after it has done its work.



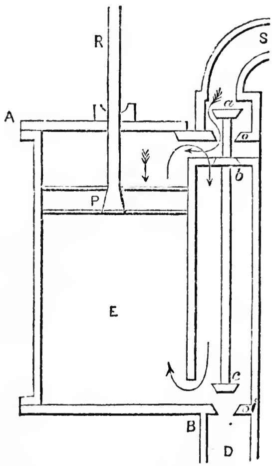
CYLINDER, CONNECTING ROD, AND CRANK

58. How the Engine is Worked.—Suppose the slide is in the position shown in the figure, and that steam fills the valve chamber V V, through the steam pipe S. Now, it cannot pass the back of the slide into the upper port *a*, because the slide is covering it over; neither, for the same reason, can it pass to the exhaust *e*; but it can pass into the lower port *c* in the direction of the arrows and drive up the piston P, while, as the piston goes up the steam that drove it down and filled the cylinder on the upper side above the piston, is escaping freely through *a*, in the direction of the arrows, and passing off to the condenser through *e* the exhaust port.

When the piston has arrived at the upper end of the cylinder, or at the top of its stroke, the slide *l l* has moved down lower, so that the lower port *c* is closed against the admission of steam, and the upper one *a* opened; therefore, steam will enter the upper port and escape at the lower, in a contrary direction to the arrows, the piston returning to the bottom of the cylinder.

59. Watt's Single Acting Engine.—In this engine A B is the cylinder, P the piston, P R the piston rod, S the steam pipe, D leads to the exhaust, *a b c* are three valves on one spindle, *a* is the steam or throttle valve, *b* the equilibrium, and *c* the exhaust or eduction valve.

The following is an explanation of the action of this engine:—Steam comes along the steam pipe S from the boiler, when the valves *a b c*, being in the position shown in the figure, with *a* and *c* open and *b* closed, the steam enters the cylinder A B in the direction marked by the arrows with tails, and drives the piston down, causing the pump valves at the other end to ascend. Steam that may have been under the piston in E can freely pass away to the exhaust D. The moment the piston is at the bottom of its stroke the valves move to their second position, so that *a* and *c* rest on their seats *o*, while *b* is opened. Thus, the steam that drove the piston down can run through valve *b*, in the direction shown by the arrows without tails, get under the piston P, and assist in driving it up. The pump-rods at the other end are balanced by a counterweight to assist this expanding steam. The action is then continuously repeated: *a* and *c* open, steam enters through *a*, drives down P, and the steam under P escapes through *c*, then *a* and *c* are closed, and steam runs round through *b*, to assist the upward motion of the piston.



SINGLE ACTING ENGINE.

60. Double Acting Engines.—When steam drives the piston both up and down the engine is termed double acting.

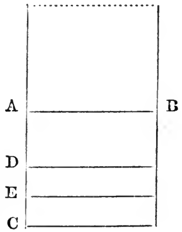
All our modern engines are double acting; but Newcomen's was an atmospheric and single acting engine, the piston being driven up by steam but down by atmospheric pressure. Watt's first engine was single acting; the steam drove the piston down, while the weight of the rods, etc., at the other end of the beam brought it up.

61. Clearance.—When a piston makes its stroke it is not allowed to touch the top and bottom of the cylinder for fear of knocking them off.

The space between the top and bottom of the cylinder and the piston, when the latter is at the end of its stroke, is the *clearance.*

Again, the term *clearance* sometimes includes the capacity of the ports, passages, etc., with which the clearance proper is in communication. Clearance is always accompanied by a certain amount of loss, an average proportion of the steam pressure which varies with the amount of expansion; or, the loss occasioned by clearance is *decreased* by an *increase* in the degree of expansion.

62. Cushioning.—When the steam is shut in before the end of the stroke, the piston acts against it as against a cushion, and so is brought gradually (comparatively speaking) to rest. Suppose the piston is in the position A B when the steam is shut in, and that from A to C is 12 inches. Let us also suppose that the elastic force of the steam remaining behind is 2 lbs., when the piston gets to D, 6 inches down, by Marriotte's law, its elastic force will be 4 lbs.; when at E, 9 inches down, it will be 8 lbs., etc. So we see at once the effects and advantages of cushioning, and that it must bring the piston gradually to rest, by destroying its momentum.



63. The Piston, and how Fitted—Packing, etc.—As the piston is a most important part of the engine, great care and thought have been bestowed upon it. It must be perfectly steam tight, and, at the same time, it is required to move easily within the cylinder. A cylindrical piece of iron is chosen and turned about a quarter of an inch smaller in the diameter than the bore of the cylinder, and around it is cut a deep groove square in section; into this is fitted a metallic ring of brass or steel, but generally cast iron; this ring either fits steam tight against the cylinder by its own elasticity, or is forced against it by springs or compressed air. Formerly "packing" was much used, when some rope yarn was platted the exact size of the square groove, the precise length was cut off, and the ends neatly sewn together—care being taken that no turns were left in the yarn. The whole was well greased before it was fitted in. Metallic piston rings are now most in fashion, the piston being composed of two distinct parts, the piston proper and the junk ring. The junk ring is bolted on to the piston by bolts tapped into the piston and heads recessed into the junk ring. A metal ring is next turned exactly the size of the cylinder, and then cut, when cut we know such a ring will develop its elastictiy, and some force will be required to place the ends in contact again. It thus forms a powerful spring, and is placed between the junk ring and the piston, where a place has been left for it. The piston is now complete, and the spring or metal ring being compressed into its proper position, the whole is placed within the cylinder, forming a very steam tight easy piston.

Pistons are seldom packed now, but the air pump bucket is; because packing is cheaper, and also because in this case it answers better, for a large amount of galvanic action sets in and eats away the piston of the air pump.

64. Galvanic Action and Oxidation of Metals.—Metals are subject to two kinds of deterioration—galvanic action and oxidation. When two different metals come in contact, especially if they are constantly wet, a galvanic action sets in between the two, and one destroys the other. For instance, who has not observed that old iron railings are frequently wasted away towards the bottom, close against the lead that fastens them into the stone? The reason is, that a galvanic current passes from one to the other, and the soft lead wastes away the hard iron. If we take, in the following order, silver, copper, tin, lead, iron, and zinc, we have them in their relative positions as regards galvanic action, and the farther they are from one another in this list the greater the effects of galvanic action. Those coming first in order will destroy any that follow them. Copper, when in contact with tin, lead, iron, zinc, etc., will waste them away, but not silver—the silver will eat away the copper, tin, lead, etc. When copper pipes are fastened by iron bolts or screws, the iron is soon destroyed, especially in damp situations.

Oxidation is a chemical action. When iron rusts we have an instance of oxidation. The oxygen of the air combines with the iron and forms oxide of iron (or rust). When the oxygen of the air combines with copper we have oxide of copper, or verdigris.

Two other facts which are closely allied to oxidation and galvanic action may be stated, namely:—when superheated steam is employed in jacketed cylinders, and much tallow introduced, it is found that the tallow is decomposed, and *carbonises* the piston, so that it becomes more like a piece of plumbago than anything else. Cast iron long immersed in sea water may be cut with a knife.

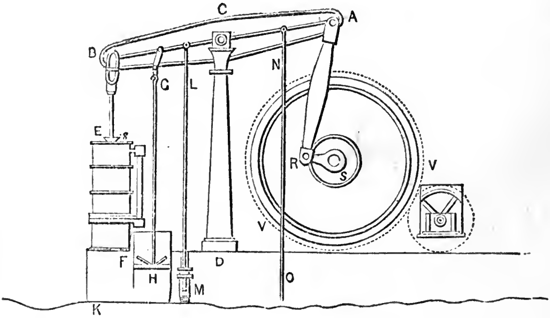
65. Stuffing Boxes and Glands.—These are used in several parts of an engine. A good example may be seen in the fig. in par. 58, p. 53. The piston rod enters the cylinder through the stuffing box *s b;* while the packing, the part marked so dark within the stuffing box, is pressed down in its place by the gland *g d*; bolts pass through the flanges of both, so that when the steam leaks through the cover by the side of the piston rod, we have only to screw the gland down on to the packing and the leak is stopped by the packing being forced against the piston rod. A depression will be seen round the top of the gland close to the piston rod, it is to hold oil or tallow to lubricate the piston rod.

66. (4) Beam Engines.—Newcomen's was a beam engine and so was Watt's, but the latter was far more perfect * than the former. The crank was not patented in time by Watt, he therefore used the sun and planet wheel for a crank. The

* Notwithstanding the variety of forms into which it has been moulded, the steam engine is still the same machine in all its simplicity of principle as when it came from the hand of Watt; it has the same reciprocating action, the same principles of separate condensation, and the same mechanical organization as it had 80 years ago. What can exceed in beauty of contrivance the parallel motion, the governor, and other motions by which this wonderful machine is rendered effective. Innumerable attempts have been made at its

beam was so advantageous and so thoroughly incorporated in the steam engine, that to early engineers it seemed an inseparable part of it as much as the cylinder and piston, therefore when it came to be adapted to marine propulsion, the side lever was the only modification that presented itself. The great advantage of the beam engine is that to the parts requiring it, it gives a longer leverage, and therefore greater power; a long connecting rod is employed, and thus an immense advantage is gained. Again, a fly-wheel was used with it to accumulate power.

A B is the *beam* moving on its main centre C, supported by a frame and pillars, of which C D is a front one; B E is the *piston rod* working in and out of the *stuffing box s*, at the top of the *cylinder* E F; G H is the *air pump rod*; H



BEAM ENGINE.

the *air pump* within the *condenser* H K (only part of which is shown); L M is the *feed pump rod*; M the *feed pump*, into which the plunger is seen descending; N O is *the pump* to force up water for condensation; A R is the *connecting rod*;

improvement, and yet with the exception of working high pressure steam expansively, and by this means economizing fuel, there has been no change in the principle of the steam engine, either in its condensing or non-condensing form. It is still the engine of Watt; his name is stamped as indelibly upon it as Newton's upon the law of gravitation.—Fairbairn's *Useful Information for Engineers*, Second Series, p. 205.

R S the crank; S the main shaft, on which is firmly fixed the *fly wheel* V V. The two dotted circles represent gearing.

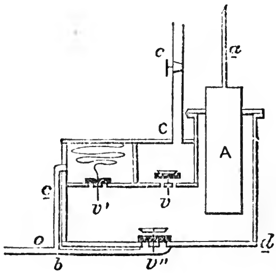
The above are the essential parts of the engine, each of which shall be described in detail as far as necessary. The other parts are the *governor*, to open and shut the *throttle valve* in the *steam pipe*, the *slide* and slide casing, the starting gear, the parallel motion, the eccentric, etc.

67. (1) **The Beam** is a lever of the first kind, and needs no description after an examination of the figure. The power is conveyed into the cylinder which moves the piston, the weight is the force conveyed by the crank, the fulcrum is the main centre.

68. (2) The piston, the cylinder, the air pump, condenser, and stuffing box, have been already described.

69. (3) **The Feed Pump** is an ordinary force pump with a plunger to force the water into the boiler.

A is a solid plunger; *v*, *v*′, and *v*″ are three valves; *b v*″ is the pipe that brings the water to the feed pump; *c o* carries away the waste; C *c* leads to the boiler, while *c* is a cock to shut off the feed from the boiler.



FEED PUMP.

It acts thus: let us suppose the plunger is raised up, then a vacuum is left in the valve box *c d*, therefore water rises through the suction valve *v*″. Let us suppose *c d* is filled, then the descent of the plunger will force the water through the delivery valve *v* and up the feed pipe C *c* to the boiler. But suppose the cock *c* should be closed, then the great pressure of water will force back the strong spring and open the valve *v*′, so that the water can pass down the waste water pipe *c o*. Sometimes instead of this arrangement for the waste water, the pump rod is disconnected when no feed is wanted, and thus the power necessary to work the pump is saved; or the water is turned off before it reaches the feed valve box, and the pump wastes its strength in lifting air.

70. (4) **The Pump** is an ordinary pump for raising water.

71. (5) The Connecting Rod and Crank have been already partially described. They are used for converting a rectilinear into a circular motion. The connecting rod should be as long as possible; it is generally from three and a half to four times the length of the stroke, but when cramped for room or otherwise, a much shorter rod is made sufficient. The longer the connecting rod the greater its advantage. It has more leverage, and therefore does more work. A short connecting rod gives much pressure upon the slides and a great strain on the crank and crank-pin, but with a long connecting rod this pressure and strain are avoided. With a short connecting rod it is difficult to properly adjust the cut off.

72. (6) The Short and Long Connecting Rod.—That is the best engine for its purpose, whatever that purpose may be, that with a given total length possesses the longest connecting rod. Marine engines frequently have the disadvantage of a short connecting rod; it is a main condition with a marine engine that it should occupy but little space, while its momentum cannot be stored up in a fly-wheel. The disadvantages that a marine engine labours under from having a short connecting rod are four:—

(*a*) The friction is increased on the guide pieces.

(*b*) The friction is increased on the crank shaft bearings, for at one time the crank thrusts the shaft downwards and at another pulls it upwards.

(*c*) The friction or strain is greatly increased on the joint pin between the connecting rod and piston.

(*d*) The steam is admitted into cylinders in such a manner, that two violent initial pressures constantly and rapidly succeed each other, consequently an irregularity of motion is produced.

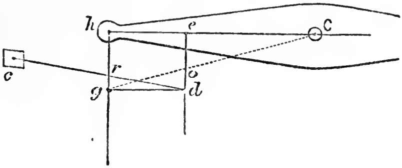
73. (7) Fly Wheel.—The fly wheel is an accumulator of power, and assists the crank over the "dead centres." When the crank and connecting rod are in one straight line, as they must be twice in each revolution, the crank is said to be on its dead centre, because there the force of the piston is dead or ineffective. It is evident that when the crank is at right angles to the connecting rod, that the latter has most power on the former, but when the top or bottom dead centre is reached there is no reason why it should not remain there;

but the action of the fly wheel then shows itself, for having on it a certain accumulated velocity, it cannot stop but goes forward, carrying with it the crank over the dead centre. We thus have through the momentum of the fly wheel no perceptible variation in the velocity of the engine, but the unequal leverage of the connecting rod is corrected, producing a steady and uniform motion. The fly wheel, it must be remembered, is a *regulator* and reservoir and not a creator of motion, and when no fly wheels are used, as in marine engines, we must recollect that smoothness of motion is not an absolute requisite, and that the momentum of the engines themselves carries the cranks over the dead centres; but far more generally a pair of engines work side by side, whose cranks are at different angles, so that one assists the other at the critical moment. The accumulated velocity in the fly wheel, where the motion is required to be excessively equable, should be six times that of the engine when the crank is horizontal. The efficiency of the fly wheel in producing uniformity of velocity is materially modified by the motion of the machinery which the engine is required to drive, and regularity of motion is of much greater importance in some cases than in others, so that in proportioning a fly wheel to a given engine, attention must be paid to many particular circumstances which cannot be given in a general rule.

74. (8) The Parallel Motion. — Although the parallel motion has been almost superseded by simpler pieces of mechanism, such as guides, quite as efficient, yet a description cannot be wholly omitted.

If the end of the piston rod *g* had been connected to the end of the beam, the piston rod would have been bent alternately to right and left as the beam rose and fell, and a continual jarring would be going on, constantly destroying the stuffing box, and rendering the cylinder leaky.

Let us suppose that the simple lines in the adjoining figure represent the parallel motion, C *h* is half the beam, *h g* is the main link, *c d* the radius bar or bridle rod. As *h* moves up and down it describes an arc of a circle, with its convexity to the left. Now *c d*, the radius bar, moves on its fixed centre *c*, consequently the point *d* will describe an arc with convexity to the right; so *h* throws *g h* to the left, and *c d* throws *d e* and with it $g\ h$ to the right. Therefore it is evident that if these links and rod be proportionately adjusted, we shall have an arrangement that will compel the point g, and with it the whole piston rod, to move exactly perpendicularly. To accomplish this there are joints at g and d.



PARALLEL MOTION.

To find the proper length of the bridle rod,

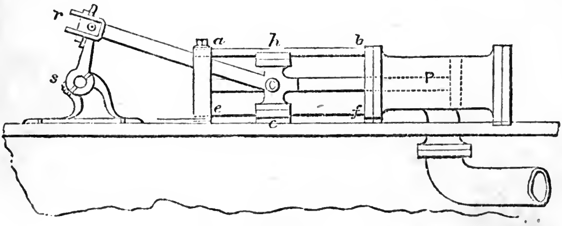
Divide C h in e so that

$$Ce : cd :: do : oe$$

where o is the point to which the air pump rod is attached,

$$gd \text{ or } he : Ce :: do : oe$$
$$\therefore he : Ce :: Ce : cd$$
$$\therefore cd = \frac{Ce^2}{he}$$

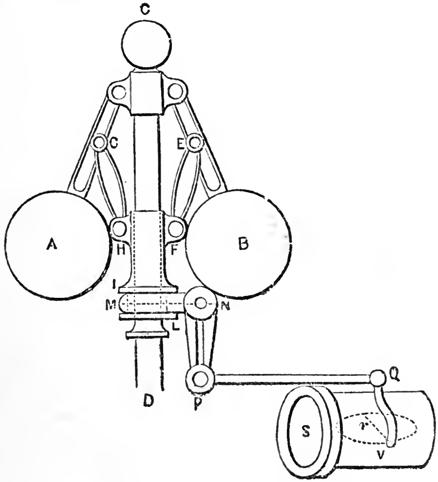
The parallel motion will work most accurately when the radius rod from c to d is about the same length as the beam from C to h, they should therefore be kept as nearly equal as circumstances will permit.



GUIDE.

75. Guides.—The parallelism of the piston rod is preserved very frequently now by the use of guides. The above figure will at once give an idea of what a guide is. P is the cylinder, the dotted lines show the piston and piston rod continued to the cross head $c\ h$; C r is the connecting rod, and $r\ s$ the crank; the main shaft is s; the cross head $c\ h$ slides between the bars a b and e f, which guide the piston rod parallel. Instances of the same are seen in various figures following.

76. The Governor.—The governor consists of two balls, A and B, fixed on the ends of two arms and so arranged that they can freely revolve round the spindle C D. Motion is imparted to the balls either by a pulley which is driven by a cord passing over another pulley on the main shaft by the side of the fly wheel, or else by a pair of bevel wheels placed immediately below D.



GOVERNOR AND THROTTLE VALVE.

When at rest the balls will remain close to the governor spindle, as in the figure, but when in motion the faster it moves the farther the balls will fly asunder by centrifugal force. As they separate, the arms A C and B C will extend outwards, and will bring up with them the short arms G H and E F, which will move up the collars I L, when the arm M N will pull point N to the left; P is a fixed joint and P Q is firmly attached to P N, so that point Q will be lifted up and close the throttle valve V in the steam pipe S, by means of two arms, one of which, Q V, is shown in the fig.

moving the valve on its spindle. Thus, the faster or slower the main shaft moves, the faster or slower will the governor move and close or open the throttle valve and regulate the supply of steam, so that the engine may always be moving at the same velocity. In flying outwards, the balls attain a certain vertical height. How to find this height, and the length of the pendulum, is shown in the miscellaneous examples at the end. The weight of the balls does not affect the action of the governor at all, for if a heavy ball increases the centripetal force, it also increases the centrifugal in the same ratio. It is called the conical pendulum, or pendulum governor, because its motions are regulated by the same laws as those which regulate the ordinary pendulum.

77. (9) **Throttle Valve.**—From the last figure a good idea can be obtained of the throttle valve. It is a circular or elliptical plate moving on a spindle. Its opening, as regulated by the governor, determines the volume of steam that shall pass to the cylinder.

78. **Governors.**—A good governor must be entirely self-adjusting, and require no aid from the engineer. It must also regulate the supply of steam to the valves, so as to keep up a uniform velocity in the deliverer of work. When a water-mill and engine are combined to drive a mill, we have a test that will try the efficiency of a governor more than any other. The first thing in the morning, when the water is perhaps on a level with or running over the weir, let us suppose the water does eight parts of the work and the engine two. As the water is used and lowered behind the dam, more work is gradually thrown on to the engine, so that towards the end of the day, the engine may perhaps be doing the eight parts and the water only two. The governor during all this gradation of change should be so capable of acting, that when the water-wheel loses its force, that of the engine should increase in the same ratio, and keep the mill moving at a uniform velocity. To effect this, the governor, as well as working a common throttle valve, has to put in action an arrangement of bevel wheels, to set the sluice in motion. When the balls fall to a certain point, they throw into gear a system of mechanism, consisting of an ordinary

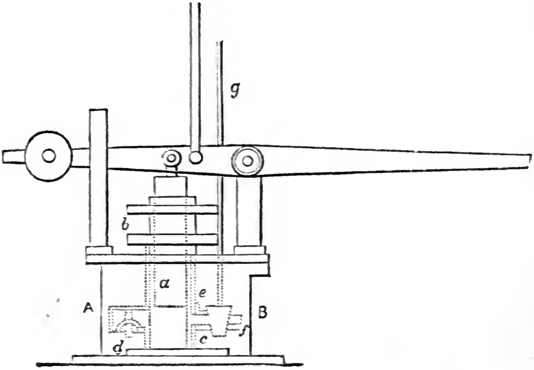
clutch and bevel wheels, which move the ponderous sluice by which the water passes to the wheel.

"This laborious duty of moving the sluice is assigned to the water-wheel itself to perform; and the office of the governor is merely to suggest to the unreasoning wheel which way to move its own sluice, so as to feed itself properly and regularly. This is accomplished by a very familiar combination of two bevel wheels running loose upon a shaft, with a clutch between them, and working into a third—the third being the wheel that communicates with the sluice. Each of the two wheels, when giving motion, necessarily turns the third wheel in opposite directions; and as the governor rises or falls by change of velocity, it reminds the third wheel, by means of the clutch being made to slide or move either to the one bevel wheel or to the other, in order that the proper wheel may have the motion which is suitable for the necessary movement; and during the periods when the required speed of the water wheel is maintained, both of the bevel wheels are at rest, the governor being always sensitive and on the alert to jog the one or the other."*

79. The Cataract.—The cataract supplies the place of the governor in the single acting Cornish pumping engines. It consists of a small pump plunger *a* and barrel *b c* set in a cistern of cold water A B; *d* is a valve opening inwards, so that when the plunger *a* ascends, the water passes through *d* from A B into *b c*; *f* is a cock opened and shut by the plug *e*, moved by the plug-rod *g*, worked by the beam overhead. If the plunger be forced down, the water will pass through *f* in proportion to the opening of *f*. When the beam has moved fully up, it liberates the rod that works the plunger; then as the chamber fills with water through *d*, as the plunger ascends. so when the latter comes down the pressure of water will close *d*, and the weight of the plunger will force the water through *f* as rapidly as the opening will allow. The way it is carried away is not shown in the figure. If the cock be shut, the plunger cannot descend; if only slightly opened, it will descend gradually, etc. As soon as a certain quantity of water has passed through *f*, its

* Anderson's *Cantor Lecture*, 1869.

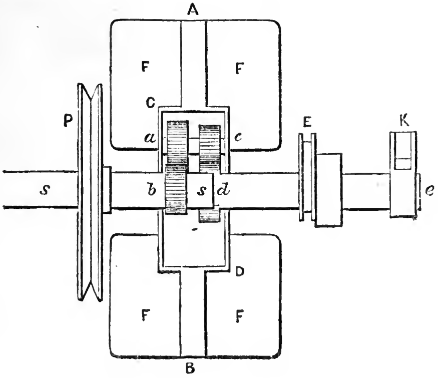
weight opens the injection valve, and condensation takes place, when the engine can complete its stroke; for the engine can only make the stroke as the water is supplied for condensation. It thus regulates the speed of the engine; for if the cock be fully open, condensation takes place at once, and if only partly open, condensation will be delayed till the water is supplied.



CATARACT.

80. Marine Governor.—Owing to the unsteady motion of a ship, arising from pitching, rolling, etc., the ordinary pendulum governors are unfitted to regulate the speed of the engines. Mr. Silver has solved the problem how to adapt a governor to a marine engine. He has employed several arrangements for carrying out his ideas. The one of which a section is shown in the figure on the opposite page, seems the best adapted to the purpose.

A B is a small fly-wheel about 18 inches in diameter, on which are fixed two fliers or vanes, F. The faster the engine goes the greater resistance will these vanes offer to the air. P is a pulley worked by a cord and fixed on the spindle *s s*, while E is an eccentric and K a lever. To E at the top of the pulley, for the position given in the figure, is affixed a spring. The engineer has to tighten up or slacken this spring according to the speed at which it is intended to drive the engines. K is the lever from which



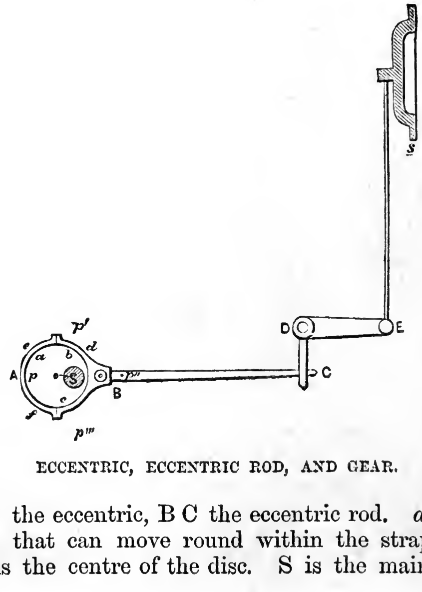
SILVER'S MARINE GOVERNOR.

the motion is conveyed to open or close the throttle valve. Within C D are four pinions to communicate the action necessary to effect the purpose of the contrivance. Sometimes there are six pinions, one below *b* and *d* respectively.

At the uniform speed of the engine, it revolves together in connection with the engine as the motive power; but when accelerated by the running of the engine, as when the screw is out of water, the increased pressure on the governor fans, or blades, causes the motion to act on the eccentric E, and the lever K carried on the tube *d e*. (We must understand *d e* is not a continuation of *s s*.) Then the spring attached to E or the arm to K, according to whichever arrangement is adopted, acts to close the throttle valve. The pinion *b*, keyed on the solid shaft *s s*, gearing in the wheel *a*, which runs on a loose pin *a c*, transmits the motion to *c* and to *d*, a pinion keyed on the tube *d e*, which acts upon the lever, and, as said before, regulates the speed of the engine. It is excessively sensitive, and the least increase or retardation of speed causes it to act upon the valve. When the pulley is running very fast, the inertia of the fliers and the resistance of the air will not allow the fliers to go as fast as the pulley, so the pinion *a* runs as it were back on *b* (or *b* overtakes *a*), and acting on the spring at E and the lever at K, the latter closes the throttle valve. In one arrangement of this governor, the spring itself works the valve.

81. To Close the Throttle Valve.—To maintain the spring at the elasticity at which it is set requires a certain speed, and when the engine falls below this speed the spring slackens itself, and allows the valve to open.

82. Eccentric.—The eccentric consists of a disc of metal encircled by a hoop or strap, to which is attached the eccentric rod; in the disc is a hole to pass it on to the main shaft. The centre of the eccentric does not coincide with the centre of the shaft. When the shaft revolves it carries with it the disc, which, moving with the hoop, gives a reciprocating motion to the eccentric rod.



ECCENTRIC, ECCENTRIC ROD, AND GEAR.

A B is the eccentric, B C the eccentric rod. *a b c* is the solid disc that can move round within the strap or band *d e f*; *o* is the centre of the disc. S is the main shaft, on which the disc is tightly keyed. As the eccentric or disc revolves within the strap, it will be easily seen that the point p moving round will come into the positions p' p'' and p''', and that the point C will be thrown alternately to the right and left. C D E is a bell-crank lever supported on D, a fixed point, and therefore since C moves alternately right and left, E moving along the arc of a circle will receive a vertical reciprocating motion, and alternately pull the slide s up and down. The distance between the two centres o and S (marked by a line in the figure), is called the *throw* of the eccentric. The disc is generally keyed on one-sixteenth of a revolution in advance of being at right angles to the crank. The throw of the eccentric is the eccentricity, or the radius of the circle described by its centre during a revolution of the crank shaft.

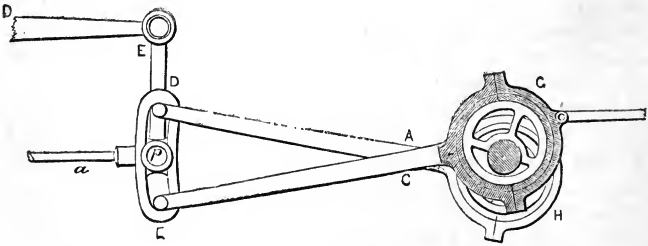
83. To Reverse the Engine with the Single Eccentric.— When an engine is fitted with a single eccentric, the engine is reversed by hand. The engineer notices whether the piston was moving up or down; if *moving up*, he takes the starting bar and admits steam to the *top* of the piston, so that it immediately descends, and the shaft begins to move in an opposite direction. The eccentric is fitted on to the shaft, so that it can be moved halfway round, or rather there are two stops on the eccentric, and one on the shaft. The shaft revolving, as we have just said, moves without the eccentric, so that the stop on the shaft leaves one of those on the eccentric, and when the shaft has moved halfway round, it comes against the second stop on the eccentric, which will be then in its proper position for working the slides, and so the motion of the engine is continued. To throw this eccentric in and out of gear, a recess is cut in the eccentric rod (care being taken that it is in its exact position), to this a pin is fitted to connect it with the slide rod, or gab-lever pin. When the engineer has started the engine by hand (by lifting up the slide with the starting bar), and wishes to attach the motion of the eccentric to it, he watches his opportunity and lets the rod fall on the pin; the pin will in half a stroke fall into the recess. It is kept in its place by a bar or strip of iron placed over the entrance of the recess, held there by a spring.

84. The Double Eccentric, or Stephenson's Link Motion.—This contrivance, used both in the locomotive and marine engine, was invented by Stephenson to enable the engineer to quickly reverse his engine, and so go backwards or forwards at pleasure.

It consists of two eccentrics, H and G, with their rods A D and C E, the one called the forward, the other the backward eccentric. The two are connected by a link, D E, with a slotway in it. In the slotway moves the block *p*, fastened to the end of the valve rod *a*.

The bell crank lever, D E *p*, is to move the link up or down. When the forward eccentric is moved so as to work the valve rod it moves the slide, and the ship or locomotive goes forward; but when the backward eccentric works the slide rod, the engine is reversed. The link motion is thus a simple and expeditious mode of reversing the engine expeditiously, and almost without trouble to the engineman.

When we consider that the forward eccentric rod, A D, sends the engine one way, and the backward rod, C E, sends it the other, we see that the travel of the slide has been reversed,



STEPHENSON'S LINK MOTION.

as it were. Again, if the pin and link be placed in the position shown in the figure, the slide has then but little travel, and we can see that this travel is increased just in the same proportion as the bell crank lever, D E *p*, moves the link D E up or down from the mid position. As the amount of opening for steam depends upon the motion of the slide, by leaving p in different positions in the slot, we open and close the port at and during varying times. This is done by not placing the block at the extremity of the link, but at a distance from it, and resting the lever in its proper place. For this purpose an arc or sector with notches in it is attached to the link motion, to fix the handle in and secure the required opening the engineer may deem best for the speed required. This is not expansion, but rather wire-drawing the steam. In fact, Stephenson's link motion cannot properly be used to give different grades of expansion, it only alters the travel of the slide; for when the pin is in the middle of the link, the motion of neither eccentric is imparted to the slide rod. The pin being at the end of the link, the slide rod will receive full motion, and full steam will be given to the cylinder; but when the block lies nearer to the centre of the link, less and less steam is given to the engine, and consequently it moves the more slowly. This point is more completely illustrated under the heading "*The manner in which the Link Motion distributes the Steam*," in the chapter on the Locomotive Engine.

85. Expansion Gear for Marine Engines.—Various plans are adopted by different makers. Some use cams placed on the shaft in such a position that when the valve is connected with the cam, by an arrangement of rods, levers, etc., steam can be admitted into the cylinder, but when not so, the ports are closed against the admission of steam. The great objection to this arrangement appears to be, that when the roller comes off the cam, it, together with the valve, drops with a sudden jar, which causes a very unpleasant noise in the engine-room, and also a great amount of wear and tear in the machinery itself.

The best plan appears to be to have an eccentric, to which is connected a sliding valve in the steam chest. This eccentric is fixed to the shaft in such a position, that when the valve is in connection with it, it shuts off steam at the required portion of the stroke. The different grades of expansion are regulated by a lever with recesses in it. This is among the connections of the expansion gear. Care is taken when throwing it out of gear that the expansion valve is not closed, or else the engine will stop. In some cases the throttle valve is used as an expansion valve, under which circumstance the full benefit of expansion is not gained, for that requires the total cut-off of steam, which the common throttle valve cannot do on account of its shape, but it wire-draws the steam. The expansion valve and eccentric to work it are perfectly distinct from the slide valve and ordinary eccentric.

EXERCISES CHIEFLY FROM EXAMINATION PAPERS.

1. Give an account of the steam engine before the time of Watt, with a description of his improvements (1866).

2. Explain the terms cushioning, clearance, lap, and lead (1866).

Lap and *lead* are explained in a succeeding chapter.

3. What is a circular inch?

A safety valve 7 inches in diameter is loaded to 6 lbs. on the square inch, what would be the load on each circular inch (1867)?

A circular inch is a circle whose diameter is one inch.

Ans. 4·7124 lbs.

4. The area of a piston is 4876·84 square inches, find the diameter of the air pump, which is half that of the cylinder; find also the capacity of the pump, supposing it similar to the cylinder (1867).

Ans. Dia. of air pump, 39·899 inches. Cap., 1219·21.

5. Describe with a sketch the single acting engine (1867).

6. What is the foot valve? Is it a necessary appendage to a steam engine? If it is not used, what arrangement must be made in consequence (1867)?

There need be no different arrangements made when an engine is worked without a foot valve; for the bucket of the air pump must in any case come right down into the water, as there is a vacuum both in condenser and air pump, so the water cannot in sufficient quantities follow the bucket, but must pass through the bucket valve in the down stroke when it plunges into the water. When no foot valve is fitted it is customary to let the steam enter the condenser as near the top as convenient, for it is found that a little more water remains in the condenser than is generally the case. Where surface condensation is employed you *must have a foot valve*, because the steam and condensing water not mixing there is a greater amount of vapour to deal with, which is likely to expand and contract in the passages, following the bucket, but not passing through it.

7. The area of a piston is 4476 square inches, and the diameter of the piston-rod is one-eighth that of the piston, find it (1868).

Ans. Dia. of piston rod, 9·43 inch.

8. The pressure of steam is 15 lbs. on the square inch, and that of the uncondensed vapour is 2 lbs., compare the effective force in the up and down stroke respectively (1868).

If the pressure of the atmosphere is greater than half the sum of the pressures of steam and uncondensed vapour, then the pressure in the down stroke is greater than the pressure in the up stroke, and *vice versa*—

Pressure of steam $= 15 + 15 = 30$
Pressure of uncondensed vapour $= 2$

$$\therefore \text{Half their sum} = \frac{30+2}{2} = 16 \text{ lbs.}$$

Pressure of atmosphere = 15 lbs.

∴ the pressure is greater in the up stroke than in the down stroke.

9. Describe generally the improvements introduced by Watt into the steam engine (1868).

10. The initial pressure of steam in a cylinder whose stroke is 5 feet 4 inches, is 45 lbs., and expansion commences when 2 feet 3 inches have been performed; find the pressure at the end of the stroke. Find also the horse power if the area of the cylinder is 2218 square inches, and the number of strokes per minute 30 (1868).

Ans. Terminal pressure 18·984 lbs.

For horse power, see questions at the end.

11. How is steam admitted into the cylinder? Describe with a sketch the usual mode in marine engines for working the gear connected with the slide (1868).

12. What means are used to keep the piston rods and air pump rods steam tight (1867)?

13. Give an account of the principal discoveries of Watt, and the advantages derivable from them (1867).

14. Investigate an expression for the length of the radius bar in Watt's parallel motion.

15. A pair of double cylinder engines is substituted for single cylinder engines of 78 inches diameter, if the total area of the piston and length of stroke be the same in both cases, compare the surfaces of the cylinders exposed to the friction of the pistons (1867).

Ans. $1 : \sqrt{2}$.

16. Give a sketch of the feed valve box and pipes, and name the valves. Is it necessary to have an air vessel to the exit pipe when an overflow valve is fitted to the box (1867)?

It is not necessary to have an air vessel fitted under such circumstances; the air vessel, as in the case of the fire engine and other pumps, is to give a *continuous stream* of water, which is not required in the overflow of a feed valve.

17. What are the foot valve and delivery valve? What is meant by blowing through? How is it effected (1868)?

18. Describe the method adopted for keeping the cylinder, air pump, slide valves, etc., air and steam tight. Describe the strap, gib, and cutter, and explain their use (1868).

Blowing through, and strap, gib, and cutter are explained in a succeeding chapter.

19. Show how to find the work done by a crank. What force applied to the extremity of a crank at right angles to it will do the

same work as a mean pressure of 4 tons acting on a piston throughout the up and down stroke (1868)?

Let P be the pressure on the piston, and p be the power applied to the extremity of the crank at right angles to it.

Then the units of work done by P in the up and down stroke $= P \times 2l$, where l is the length of the stroke.

The extremity of the crank moves through a distance $= 2\pi\frac{l}{2}$, for if the length of the stroke be l, the radius of the circle described by the end of the crank, or the length of the crank, is $\frac{l}{2}$.

$\therefore$ units of work performed by p at right angles to the end of the crank $= p \times 2\pi\frac{l}{2}$.

By the condition of the question these two units of work must be equal.

$$\therefore P \times 2l = p \times 2\pi \times \frac{l}{2}.$$

$$\therefore 2P = p\pi.$$

$$\therefore p = \frac{2P}{\pi} \text{ (generally).}$$

In the particular case given above

$$p = \frac{2 \times 4}{\pi} = 2{\cdot}546 \text{ tons.}$$

20. Describe Newcomen's atmospheric pumping engine, and point out its defects (1869).

21. How does the steam act in (1), a single acting condensing engine? (2) a double acting condensing? (3) a high pressure engine (1869)?

22. Describe with a sketch some form of slide valve as connected with the steam cylinder of an engine, and explain its action (1869).

23. Describe the great improvement introduced by Watt into the construction of the steam engine. Distinguish between a single acting and a double acting engine; what valves are necessary for the working of a single acting condensing engine (1869)?

24. Describe some form of steam slide valve adapted for a double acting engine. How are the faces of such a valve prepared so as to make it steam tight (1869)?

For latter part of this question, see Chapter VII., par. 148.

25. Describe the construction of a piston, and explain the method adopted for keeping the piston and piston-rod steam tight. Describe also the strap, gib, and cutter, for tightening the brasses at end of a connecting rod (1869-71).

26. The circumference of a piston-rod being 30·5 inches, find its diameter (1866). *Ans.* 9·708.

27. The total pressure on a pair of equal pistons is 90 tons at the rate of 45 lbs. on each square inch, find their diameter (1866).

Ans. 53·4 inches.

28. Explain the action of the governor and throttle valve in regulating the speed of an engine (1869).

29. Find the load on the air pump bucket of a steam engine when seventeen feet below the level of the water outside the ship, the pressure of the atmosphere being $14\frac{3}{4}$ lbs., and that of the steam

within the condenser $2\frac{3}{4}$ lbs. (a cubic foot of water weighing 64 lbs.) (1865). *Ans.* $19\frac{5}{9}$ lbs. per square inch.

30. Enumerate the things to be done in a double acting condensing steam engine, and describe generally the method of accomplishing them, so as to give a fair idea of the engine itself (Honours, 1869).

31. Explain the principle of Watt's parallel motion in its simplest form. Show how to arrange that two or more points shall describe parallel straight lines (Honours, 1869).

32. Describe some form of slide valve as fitted to the steam cylinder of a double acting engine. Sketch the valve in section, with the openings over which it slides, and give it some amount of lap on the steam side. How is the face of such a valve made truly plane (1871)?

33. What is done by the air pump in a steam engine? What are the foot and delivery valves? and where are they placed (1871)?

34. The cylinder of an engine is 74 inches in diameter and the stroke is $7\frac{1}{2}$ feet, what is the capacity of the cylinder? How many pounds of water must be evaporated in order to fill such a cylinder with steam at an actual pressure of 15 lbs., it being given that steam at 15 lbs. pressure occupies a space equal to 1670 times that of the water from which it is generated (1871)?

Ans. Capacity 224·002 feet.
Cubic feet of water ·1341.

35. Give a description of the steam engine in use before the time of Watt, with an account of his improvements (1863).

36. Mention the distinguishing feature of the atmospheric single acting and double acting engines. What kind of engine is generally fitted to steam vessels? and what kind is best suited for land carriage (1864)?

37. The mean indicated pressure of steam from above the piston was 14·9 lbs., and the vacuum pressure 3·2 lbs., and the corresponding pressures from below were 15·4 and 2·7 lbs.; what were the mean effective pressures per square inch during the up and down strokes respectively (1864)? *Ans.* 11·7 lbs. and 12·7 lbs.

38. The length of the stroke of a steam engine is 5 feet 6 inches, and the boiler pressure 12 lbs. above the atmosphere, the steam is cut off after the piston has traversed 2 feet; find the pressure of the steam in the cylinder when it opens to the exhaust, which is 2 inches before the piston arrives at the end of a stroke (1865).

The steam is cut off 2 inches from the end of the stroke; so, therefore, steam pressure is continued for 5 feet 4 inches $= 5\frac{1}{3}$ feet.

The total pressure of steam is 12 lbs. + 15 lbs. = 27 lbs.

The following relation always exists :—

Initial pressure : terminal pressure : : whole stroke : part of stroke performed.

$\therefore$ 27 : terminal pressure : : $5\frac{1}{3}$: 2.

$$\therefore \text{ terminal pressure} = \frac{27 \times 2}{5\frac{1}{3}} = 10\frac{1}{8} \text{ lbs.}$$

39. Explain the manner in which the steam acts in Watt's single acting pumping engine. Why is this engine so much more economical in steam than the old atmospheric (1870)?

40. The diameter of a safety valve is 10 inches, find the difference in total pressure of the steam to raise the valve if it be 9 lbs. per circular inch above what it would be if it were 9 lbs. per square inch (1864). *Ans.* 193·14 lbs. less when 9 lbs. per circular inch.

See questions at the end.

41. What is the diameter of a valve containing 125 square inches (1865). *Ans.* 12·6 inches.

42. In what way is steam admitted into the cylinder? How is the apparatus worked (1865)?

43. Draw in section the cylinder and the slide valve of a double acting engine, and explain the manner in which the valve regulates the admission and exit of the steam (1870).

44. Why is it economical to cut off the steam before the piston has gone to the end of the cylinder? The length of the stroke of an engine is 8 feet, the pressure of the steam on entering the cylinder is 30 lbs. on the inch; at what point should the steam be cut off, so that the pressure at the end of the stroke may be 5 lbs. per inch (1870)?

Ans. 1 foot 4 inches, or $\frac{1}{6}$.

45. Sketch in section the steam cylinder and valves connected with it, as arranged in Watt's single acting pumping engine. Explain the object and use of each valve, showing at what periods of the stroke they should be respectively open or closed (1870).

46. Explain the principle upon which the parallel motion of a beam engine is constructed (1870).

47. Describe the construction and arrangement of the working parts in a double cylinder engine, and point out the advantages of such engines in carrying out the expansive work of steam (Honours, 1870).

48. State what you understand to be the advantage of working with superheated steam in an expansive condensing engine, explaining what will probably occur in the interior of the cylinder, according as the steam is superheated or otherwise (Honours, 1870).

See former chapter.

49. It was stated by Watt that neither water nor any other substance colder than steam should be allowed to enter or touch the steam cylinder during the working of an engine. Show that this rule was not adopted in the case of the atmospheric engine, and describe the arrangement by which Watt gave effect to it (1871).

50. There are three valves connected directly with the steam cylinder in Watt's single acting condensing engine, name them. During what portions of the up and down stroke of the piston should these valves be respectively open or shut? and for what reason (1870)?

51. State the principle of Watt's single acting engine as applied in pumping. What valves are necessary for the working of the engine? How is the number of strokes to be made per minute regulated? Describe the cataract employed for that purpose (1871).

52. Show that a single slide valve will suffice to work a double acting engine in the place of two steam and exhaust valves. Explain with a sketch the action of any slide valve (1871).

53. Describe the locomotive or three-ported valve, as applied in

engines of short stroke. Why is its use so restricted? Show that lap added to the valve produces expansive working of the steam (1871). See Chapter VII.

54. Describe the eccentric for working the slide valve of a steam engine. How is it thrown in and out of gear? How is it attached to the slide rod in an oscillating engine (1870)?

For latter part of question, see next chapter.

55. Describe fully the double eccentric, and show how the eccentrics are fixed on the shafts. What is meant by back lash?

When one part of an engine runs or falls back on another with a noise it is called back lash, as the single eccentric will sometimes do against the stops, and one toothed wheel against another.

56. Describe the eccentric as applied in giving motion to a slide valve. In what way must you change the position of the eccentric pulley upon the shaft relatively to the crank in order to reverse the motion of an engine (1871)?

57. Describe the double eccentric with a sketch (1869).

58. The single eccentric is fitted with a weight to balance it, what would be the effect on the slide if it were to become detached (1866)?

The slide would fall in the casing in certain positions and would be useless; the fact is, the engine could not be worked.

59. Describe the method of reversing a marine engine when fitted with a single eccentric (1871).

60. How is an engine reversed when fitted with a single eccentric (1870)?

61. Explain how the reverse motion is obtained in engines fitted for paddle wheels and screw vessels respectively (1871).

62. Describe some arrangement of expansion gear suitable for a marine engine. What form of valve would you employ (1870)?

63. Explain the way in which the eccentrics of marine engines are fixed on the shaft. Explain also the method of obtaining the back motion (1864).

CHAPTER IV.

MARINE ENGINES.

Condensing and Non-Condensing—Side Lever—Twin Screw Engines —Hammer Engines—Compound Engines—Continuous Expansion Oscillating Engines—Steeple Engines—Maudslay's Twin Engine —Beam and Geared Engine—Trunk Engine—Horse Power—Duty.

ENGINES are first divided into two classes:—

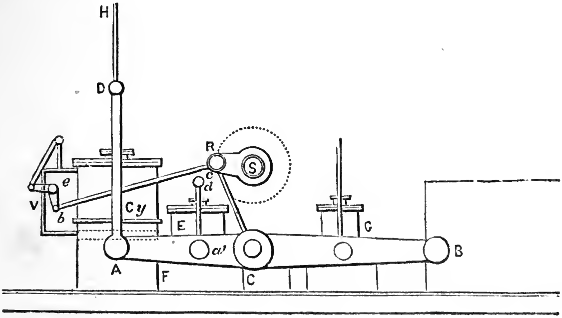
(1) CONDENSING ENGINES, miscalled low-pressure.
(2) NON-CONDENSING ENGINES, miscalled high-pressure.

We should avoid the use of the two terms high and low pressure, as they are scarcely applicable to engines of the present day.

86. Marine Engines are generally divided into two classes —those adapted to drive the paddle wheel, and those best suited for the screw. The chief difference seems to be, that engines to drive the screw are *direct* acting, *i.e.*, their piston-rods are directly attached to a crank on the shaft, while in the case of paddle wheels they are not always *direct acting*, but the motion is conveyed through the intervention of side levers. In the direct acting engine, it is often a prime object with the engineer to obtain a long stroke. To gain this end, many of the various modifications in marine engines have been suggested.

But let it be well understood that no particular engine, perhaps with the exception of the side lever, is entirely confined to either class. Every student should seek opportunities to examine the engines in his neighbourhood as minutely as possible. An hour spent in this way will sometimes add more information to the student's repertory than days at his books alone.

87. The Side Lever Engines.—The first engine employed to drive the paddle wheel was a side lever, in which the ordinary beam pumping engine was modified to obtain the requisite rotatory motion, and the beam placed by the side of the cylinder, condenser, etc., to stow it into as compact a space as possible. In the original side lever the end A of the beam AB was worked up and down on its centre C by the side rods AD, while to the end B was attached the connecting rod working the crank above.



SIDE LEVER ENGINE.

Our figure is a new arrangement of this engine, Cy is the cylinder, in which the piston is shown by dotted lines, the piston-rod is immediately behind AD, and not shown. As the piston moves up or down, the end of the cross head at D lifts up or down the beam AB by means of the side rod AD, and turns it *on its centre* B; as it reciprocates on its centre B, the connecting rod CR turns the crank RS, which carries with it the paddle shaft S.

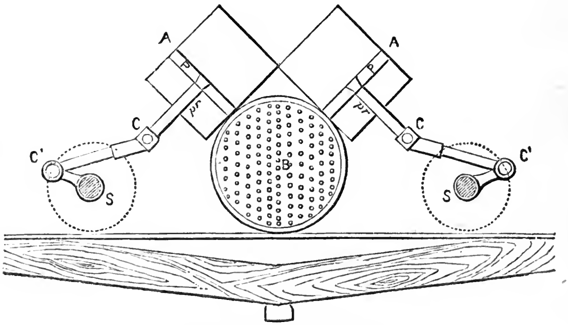
E is the air pump, underneath which is the condenser C′ F. The air pump is worked by its side rods *a d*, in the same way as the larger cylinder Cy is worked; G can be used both as a feed and bilge pump. B is attached to strong framing. The whole works as a lever of the second class.

V the valves are worked by the rod *bc* working the bell crank lever on its centre *e*, which gives an alternate upwards and downwards stroke to the slide valves. The details connected with *b c* are not properly shown, *c* being attached near to the main shaft.

The piston-rod is compelled to move perpendicularly by means of the guide rod D H moving between two guides.

In all side lever engines there are *two* side levers and two side rods both to cylinder and pumps; the side rods are connected to the two ends of the piston cross head, which is made, for this purpose, a little longer than the diameter of the cylinder.

The condenser F C beneath the air pump sometimes extends underneath the cylinder.



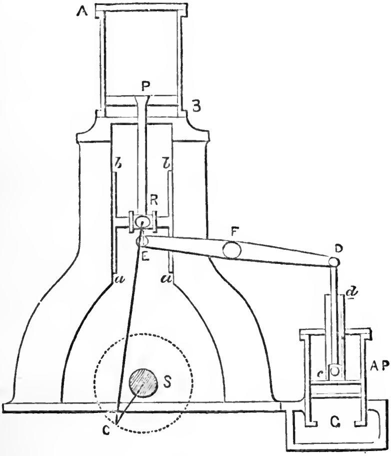
TWIN SCREW ENGINES.

88. Twin Screw Engines.—Many engines placed similarly to the above have been constructed to drive twin screws. The propellers are fixed one on each side the rudder, and a little in front of it. With two screws so situated a ship can very readily be turned round—an advantage frequently of considerable moment. There is great trouble in framing sufficiently strong brackets to carry the screws; all the machinery must be in duplicate, which necessarily occupies more room and requires more attention. H.M.S. "Abyssinia" is fitted with engines placed somewhat in the position shown in the above figure; but frequently engines to drive twin screws are arranged horizontally, the port and starboard engines lying forward and aft of each other.

In engines built for some Spanish gunboats, B is the surface condenser, and is placed in that position to form a frame and support for carrying the engines. Another arrangement is to fix the ordinary condenser in the same position to perform the same function. Hence, such engines will occupy but little space.

A and A are the cylinders with their pistons PP, and piston rods *pr*. C C′ are the connecting rods, C′ S the cranks, while the shafts S are shown by circles in section.

89. Hammer Engines.—These engines, which differ little from an ordinary vertical engine, are so called because



HAMMER ENGINE.

they are supported on a frame resembling that of a steam hammer, with the cylinder in a similar position to that of the steam hammer — viz., overhead. They are direct acting.

A B is the cylinder, P the piston, P R the piston rod, C R the connecting rod, and C S the crank with shaft S. The guides *a b* working in the sides of the frame preserve the parallelism of the piston rod. A P is the air pump, with its piston-rod working in a trunk *c d*. The lever, D E, which works the air pump, moves on the centre F by means of a small rod which comes from the centre of the guide block to the end of the air pump beam, as shown in the figure.

The condenser is G, from whence the water is forced out by the air pump on its down stroke. It is a single acting air pump. This class of engine is very much used in our commercial marine, on account of the small space they occupy.

There is plenty of room round the engine, which is economized, and used for the stowage of coals, stores, etc., and frequently for the engineers' bath and mess rooms (in large steamers), so that they are always at hand and near their work.

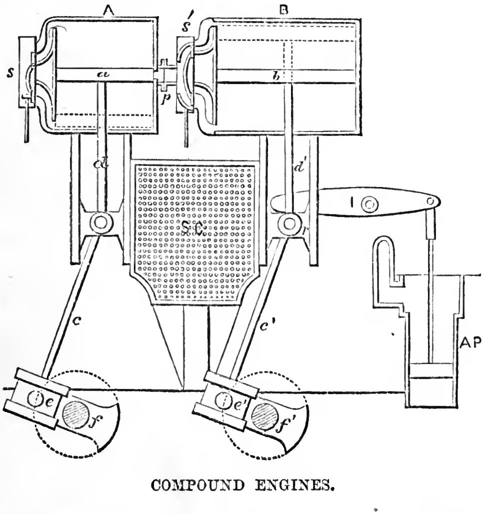
90. Compound Engines, called also **High and Low Pressure Engines.**—A compound engine is an engine with two cylinders, the one frequently double the diameter of the other. Steam is admitted from the boiler into the smaller cylinder, and after it has driven the piston *up* or *down* it is then allowed to pass into the larger cylinder, when, by its expansive property, it drives the larger piston *down* or up. Woolf was the first to introduce this principle; it has been practically applied by Humphrey and others, and further modified into what is called the *continuous expansion* principle by Messrs. Stewart and Nicholson.

In Woolf and Humphrey's engines the larger cylinder is worked entirely by the exhaust steam from the smaller; but in Stewart and Nicholson's the steam partially acts on both pistons at the same time; but we will presently further explain this.

The compound engines proper are arranged in two ways, either the cranks are placed at certain angles, or else when one is at the top of its stroke the other is at the bottom. When one crank is set at an angle with the other, the steam is kept back for an instant after driving the piston of the small cylinder up or down until wanted in a receiver, to be ready to enter the larger cylinder when its piston arrives at the end of its stroke. This is a serious evil involving a loss of power. We will explain the following figure as a compound engine on the two principles indicated.

(*a*) *Woolf's or Humphrey's Compound Engine.*—A is the small cylinder, B the larger one.

The cranks are not at right angles, but when one piston is at the top of its stroke the other is at the bottom, at least generally it is so, but not originally as introduced by Woolf. A whole revolution has to be performed to complete the expansion of any given cylinder full of steam. The steam is allowed to pass from the top of one cylinder to the bottom of the other, being first admitted from the boiler to the smaller cylinder. Usually the two cylinders are not distinct, but directly connected together.



COMPOUND ENGINES.

(*b*) *Compound Engine with Continuous Expansion.*—Let us suppose the piston of the smaller cylinder at the top of its stroke, and that of the larger one at the middle of its upward stroke. The steam from the boiler is then admitted by the slide *s*, above the piston *a*, which, therefore, commences its downward stroke; the admission of steam is not continued beyond the middle of the stroke, and it may be cut off at any earlier or more convenient point by the link motion. The piston *a*, as it passes the middle of the stroke, uncovers port *p*, then the steam, which gave a great initial velocity to *a*, escapes to the top of the larger cylinder B, the piston *b* of which has continued its upward stroke and arrived at the top. The steam has now to drive down both pistons by expansion, *a* from the middle, *b* from the top of its stroke, as seen by *a* and dotted piston in B; when *a* gets to the bottom, piston *b* is in the middle of its stroke going down, as seen by *b* and dotted piston in A; now, by valve *s*, steam is admitted below *a*, and the exhaust in cylinder A, although opened, is covered by a gridiron slide, so exhaust is prevented until *a* has made part of its upward stroke, and *b* nearly finished its down stroke. Then the intermediate slide *s′* closes port *p* in centre of cylinder A, and immediately the upper ends of both cylinders are open to separate exhaust passages. By this method of regulating the supply of steam, the pressure resisting the upward motion of *a* assists the downward motion of *b*. Again, as the larger piston is at that time moving faster than the other, this back pressure, if we may so term it, will have more influence upon *b* than *a*, and so cause a good effect upon the whole.

The amount of work lost by the opposing pressure on piston A, is more than compensated for by the extra pressure obtained on piston B; but the extent to which the exhaust may be kept back, requires much consideration and care. The cranks are, of necessity, from the relative positions of the pistons, at right angles, and no intermediate chamber is employed, unless we consider *s′* as a travelling chamber, but the steam is passed directly from one cylinder to the other. The complete expansion of any given cylinder full of steam, is completed in three-fourths of a revolution, and so is not exposed to radiation and conduction so long as in Woolf's system.

General explanation:—A and B are the two cylinders. We must consider that there are two pairs of engines to drive the two shafts or twin screws. The action of the slides *s* and *s′* has been previously explained; *d* and *d′* are the piston rods; *c* and *c′*

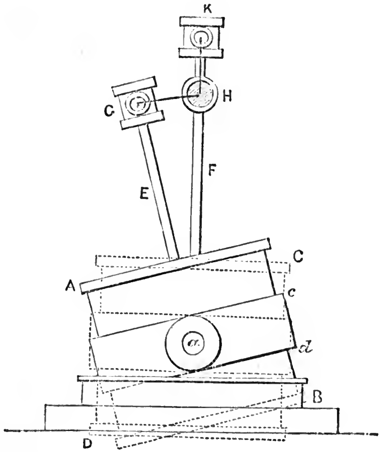
the connecting rods, working *e* and *e'* the cranks; *f* and *f'* are large pieces of cast iron to balance the cranks, and assist them over the dead centres; S C are the surface condensers.

The air pump is shown at A P, the upper part of which is the hot well. This air pump is worked by the lever I, from the crosshead *r* of the piston.

The theory of the action of compound engines is simply this: that a great initial velocity given to a piston does more economical work than a pressure continued throughout the stroke, as has been fully explained in expansive working; and if this initial velocity be given on a small surface it does most work, while, if the steam have less power, it will do most work acting upon a larger surface. For convenience, economy in working, and economy in construction, the principles of making the initial steam act upon a small surface of piston is the correct one, the larger surface being acted upon by the steam when partially expanded.

91. Balancing the Crank.—It has been the practice with a few engine makers to put a heavy piece of metal, sometimes weighing a ton or more, opposite the crank, which they call a balance or counterweight. The intention is, that it shall serve to counteract the weight of the crank when not in a perpendicular or vertical position. Some affirm that they greatly assist in keeping the motion of the machinery firm and smooth; other experienced men do not agree with them, saying that when one engine is at its dead centre, the other is at its greatest power, viz., at half stroke, and, therefore, the motion must be uniform, and that balances are only so much useless metal and dead weight creating additional friction. If the drum of the threshing machine be not balanced it will move unsteadily. In vertical engines, such, for instance, as the table engine, it is found necessary, in order to produce a regular and even motion, to balance the weight of the piston, side rods, etc., by casting the fly-wheel in such a manner that one side shall be heavier than the other, it is then fixed so that the heavy side is rising during the down stroke, and falling during the up stroke, by which means an equal and steady motion is produced, no more power being required to lift the piston than to throw it down. The fly-wheel of such an engine can be moved by hand, which could not be done were the wheel unbalanced; this will, perhaps, illustrate the utility of the plan.

92. Oscillating Engines are a triumph of engineering skill. They have been brought to their present perfection chiefly through the ingenuity and skill of Penn. Murdock, in 1785, attempted an oscillating engine, but the accuracy of our present fitting shops, and the skilful contrivances of modern machinists, were not at his command, so there is no wonder he could not perfect his ideas.

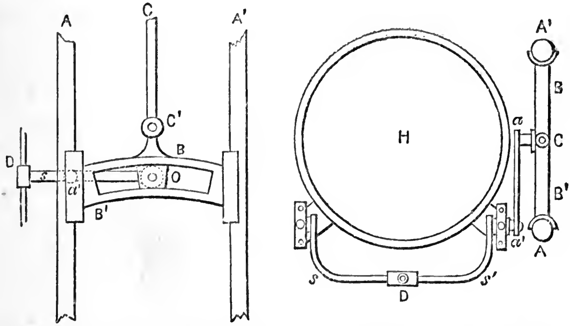


OSCILLATING ENGINES.

In oscillating engines, instead of the connecting rod oscillating to the motion of the crank, the cylinders oscillate and the connecting rod is dispensed with. It possesses many advantages; among others, it occupies but little space, consists of but few parts, and is easily accessible for repairs.

The two cylinders A B and C D vibrate, each upon two trunnions, only one of which, *a*, is shown in the figure. These trunnions are placed about the middle of the outside. The steam enters through the outside trunnions, or those nearest the sides of the vessel, whilst the exhaust steam escapes at the opposite sides, or into the condenser placed below and between the two cylinders. The air pump is within the condenser, and is worked by a crank on the "intermediate shaft." The shaft that stretches over the engines from cylinder to cylinder is called the intermediate shaft, the slide valves are worked by eccentrics on this shaft, but the particular mode of working is explained in the next paragraph. We must not omit to mention, that the steam first passes into a belt *c d* on the cylinders; and then, after going partly round, enters the ports at the proper time. E and F are the piston rods, G H and K H the cranks turning the main shaft H.

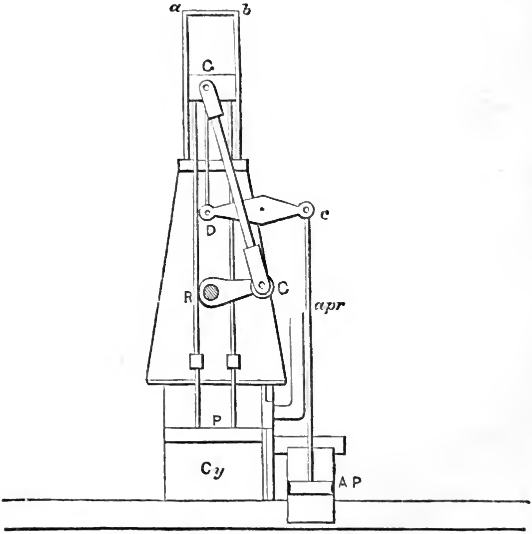
93. How the Slides in Oscillating Engines are Worked.—In oscillating engines of small power, the oscillations of the cylinder are made to work the slide valve.



WORKING OF THE SLIDES IN OSCILLATING ENGINES, AND DETAILS OF SLIDE GEAR.
(The letters in each figure correspond.)

In oscillating engines it will not do to connect the eccentric rod on to the slide valve rod, on account of the motion of the cylinder. The difficulty here encountered is overcome by having a sector B B′ sliding in between two upright rods A A′. The eccentric rod C C′ is attached to the sector by means of a pin C′, so that motion is given to the sector by the eccentric. Within the sector slides a block O, to which is fastened the gab-lever *a a*′ (right hand figure), the spindle of which rests on a bearing *a*′ attached to the side of the cylinder H; to this also is attached the valve lifter *s s*′, which gives motion to D, the slide valve rod, so that the movement of the eccentric is thus transferred to the slide valve. The slotway in the sector is an arc, the centre of which is the centre of oscillation of the cylinder. The motion of the cylinder cannot, therefore, have any effect on the slide valves if the block of the gab-lever pin move freely in the sector, which it does. In this manner, therefore, the eccentric works the slide valves as in ordinary cases.

94. Steeple Engine.—Steeple engines have been introduced largely on the Clyde, they also find much favour in America. They are direct acting engines, and are very serviceable and compact, and found to answer very well as river steamers.

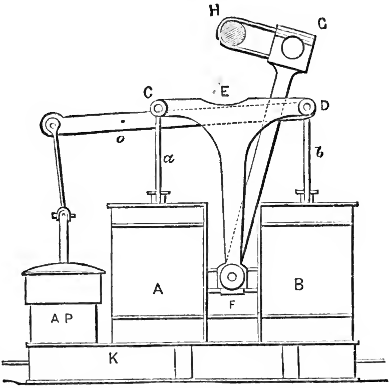


STEEPLE ENGINE.

They have not, in consequence of the high erection they require above the deck, found any favour as sea going vessels, but the objection against them from this cause seems more theoretical than practical. They do certainly present a surface to the action of the wind, but this action may very often be in favour of propulsion, while the surface is but small. They acquire their name from the high erection *a b*, which serves as a guide for the end of the connecting rod, which is above the crank.

Cy is the cylinder; P the two piston rods, as shown in the figure, move the guide block G up and down, between the guides *a b*. G C is the connecting rod converting the reciprocating rectilinear motion of G into a continuous circular motion by means of the crank C R, which is thus conveyed to the shaft marked dark in the figure. A P is the air pump, *a p r* air pump rod, worked by means of the air pump lever C D, which receives its motion from the guide block.

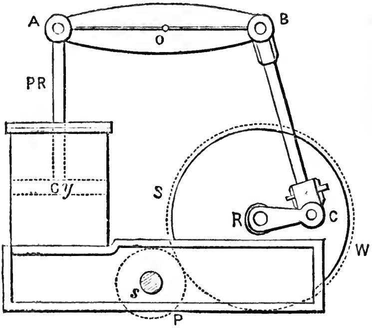
95. Maudslay's Twin Engine, or Siamese Engine, or Double Cylinder Engine.—There are two cylinders, A and B, and two piston-rods, *a* and *b*. These rise and fall simultaneously, carrying with them the large crosshead C D in the form of the letter T. The part E F descends between the two cylinders, the sides of which serve as a guide, so that the guide block F is compelled to move perpendicularly, and so preserve the parallelism of the piston-rod. To F is attached the connecting rod F G, which moves round the crank G H, carrying the main shaft H.



DOUBLE CYLINDER ENGINES.

The air pump A P is worked by the lever D *o*, reciprocated by the piston rod *b*, and moving on its centre *o*. The condenser is low down at K; this has proved an objection under certain circumstances. This engine is only fitted for driving a paddle wheel.

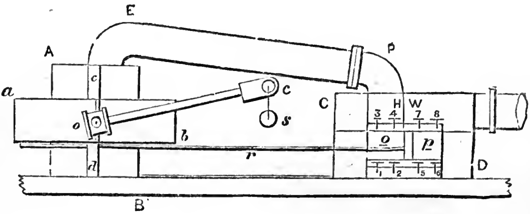
96. Beam and Geared Engine.—Some engineers do not admire driving their engines at a high speed of the piston, although it is necessary to have a high speed at the screw. A beam engine is often put into the ship which works a large spur wheel, from which is driven a smaller pinion. A moderate speed of the crank shaft may be kept up, which will give a very fast speed to the screw, on account of the smaller size of the screw shaft pinion compared with the driving wheel.



GEARED ENGINE WITH BEAM

Cy is the cylinder, the piston rod (P R) of which gives the necessary reciprocating motion to A B, moving on its centre O. B C is the connecting rod, R C the crank turning the spur wheel S W, which works the pinion P, which is keyed on to the main shaft *s*. It will thus be seen that one revolution of the spur wheel S W (or one stroke of the engine) will give several revolutions to the pinion P, or to the main shaft.

97. Trunk Engine.—Watt first gave the idea of a trunk engine, but it was not fully developed till Penn produced the



TRUNK ENGINE.

direct acting horizontal marine screw engine. Each engine is generally worked by two cylinders. The cylinder A B is laid on its side; and down the centre, passing through both ends of the cylinder, goes a large trunk *a b*, on which (all in one piece) is cast the piston *c d*, so that the effective working part of the piston is an annulus or ring. The trunk is fitted steam tight by means of stuffing boxes. The connecting rod is attached to a pin at *o*, fixed in the middle of the trunk, while the other end engages and works the crank *c s*, where *s* is the main shaft.

C D, the rectangular figure to the right, the condenser, is divided into the condenser proper, the hot well, and the pump barrel. The large pipe E P is called the eduction pipe; its purpose is to bring the exhaust steam into the condenser, where it is condensed at the bottom, after which the double acting pump *p* delivers the water into the hot well H W.

98. Double Acting Pump.—A double acting pump is one that delivers water both by the forward and backward stroke. Penn's trunk engine is always fitted with two of these air pumps, one to each cylinder; each is worked by a rod which passes through the piston and cylinder cover, and there are, of necessity, two suction (foot) valves, and two forcing (delivery) valves, on the same principle as the India-rubber disc valve, explained under its proper heading. The feed and bilge pumps are worked in the same manner.

Let us suppose the air pump piston is at the end of its stroke to the right, then the space in front of it, or near the cylinders, will fill with water from the foot of valves 1 2; when the piston moves to the left it will carry with it the air pump piston by means of the rod *r* to the left, so that the water filling *o* will be forced through the delivery valves 3 and 4. As the piston moves to the left a vacuum is left behind it in *p*, so that water rushes through the suction valves 5 6, while forcing valves 7 8 close by pressure from above. In a similar manner, but by opposite action, the stroke delivers water into the hot well H W, as the piston moves from left to right.

Another kind of double acting pump is a simple arrangement by which the same pump can be made to force water either in or out of the ship, or in or out of the boiler. The pump is worked by the usual arrangement of valves; but there are two key heads placed on the valve box which turn two circular spaces. When turned in one direction, the suction acts to bring water into the ship; but when turned in an opposite way, water is forced out by simply changing the direction from whence the water can get beneath the valves.

99. Launch Engines.—Launch engines generally consist of a small pair of engines either working vertically behind the boiler, or else diagonally or vertically in front. They are employed to propel very small river or harbour steamers. Being first used in the Royal Navy to propel the "launch," they are so named. They give a large number of revolutions per minute, and always work a *screw*. Both engines work the same shaft by means of cranks. The cylinder is at the top, and they work a shaft down close to the keel of the vessel. There is no point in their construction calling for explanation, as they differ in no way from a marine engine of the ordinary type, with cylinder, connecting rod, and crank.

100. Comparison of Engines.—Engines are compared with each other by considering their relative performance. A purchaser orders an engine of such and such horse-power. An engine of 100 horse-power is calculated to do the work of one hundred horses (but it will generally do a vast deal more). When Watt undertook to construct an engine for any of the mines in Cornwall, he always guaranteed it to do the work of so many horses. He allowed that a horse can do 33,000 units of work per minute, or lift in a minute 33,000 lbs. 1 foot high, or 33 lbs. 1000 feet high, or 1000 lbs. 33 feet high. This is generally considered too much. We have the *horse-power* and the *nominal horse-power*. The nominal horse-power is the commercial or selling power of an engine; or the horse-power, reckoning the pressure in the piston to be only *seven* pounds. For further information on this important point, the reader is referred to the questions at the end, where the formula for the calculations will be found.

101. Duty of an Engine.—The duty of an engine is the work it does in relation to the fuel consumed. The average duty of the Cornish pumping engines is generally stated to be 60,000,000 lbs. raised one foot high by 112 lbs. of best Welsh coals. Some have reached a duty of 100,000,000 lbs.

The following from the *Engineer*, Vol. XXXI., will give a good idea of what is meant by the duty of the Cornish engines:—

"It will be observed in the table inserted below that from the period when the work performed by the engines was commenced to be publicly reported, in 1811, there was a continuous improvement up to 1843, when an average performance of 67,000,000 lbs. lifted one foot high, by the consumption of 112 lbs. of coal, was reached. Since 1843 there has been an equally continuous retrograde course; so that at this time *the average duty of the engines has fallen off about 26 per cent.* Or, to put it in other words, at this time full *one quarter part more coal is consumed by the engines*, on the average, *than was necessary in 1843 to do the same work*, an item of no small importance, especially in such a period of depression as the mining interest has been passing through.

"TABLE OF THE AVERAGE DUTY PERFORMED BY THE CORNISH ENGINES PER 112 LBS. OF COAL, AT THE END OF EACH PERIOD OF FIVE YEARS, COMMENCING WITH 1811.

Year.	Duty.
1811	20·4 mils.
1815	24·4 ,,
1820	34·1 ,,
1825	38·1 ,,
1830	51·5 ,,
1835	56·9 ,,
1840	64·8 ,,
1843	67·0 ,,
1845	66·1 ,,
1850	61·8 ,,
1855	54·8 ,,
1860	51·6 ,,
1865	50·2 ,,
1870	(say) 50·0 ,,

"The cause of the decrease of duty which has taken place of late years must be attributed chiefly to the careless manner in which the engines and boilers are attended to; the mines have not been in a prosperous state, and in consequence the engines have, many of them, been worked in a wretched condition, perhaps after having been removed from place to place several times; and in many places where new engines are badly wanted, the old ones, which have worked some of them for thirty years, are made to answer the purpose, to obviate a large outlay in putting down new ones. There is also a certain carelessness on the part of the mine managers in having their engines 'reported,' so that many of the best engines are excluded from the duty records. The writer has found the best engines very lately doing from sixty-three to sixty-five millions with four-fifths expansion in constant work."

EXERCISES CHIEFLY FROM EXAMINATION PAPERS.

1. Describe the general arrangement of the trunk engine for driving a screw propeller. Describe also that of an oscillating engine suitable for a paddle wheel steamer (1869).

2. Define the duty of a steam engine. What is the average duty of the pumping engines in Cornwall? How do you explain the increased duty obtained from such engines by employing steam at a higher pressure and by working expansively (1869)?

3. In a steam engine the steam is used at 20 lbs. pressure, and is cut off at half stroke, find approximately the percentage of gain in the work done by the consumption of a given quantity of steam by reason of expansive working (1870).

We will find approximately the total work done. Let us suppose the stroke is 5 feet, and divided into 10 half feet to obtain a nearer approximation.

1st	half foot	pressure is	35	lbs. on the	sq. in.
2nd	,	,,	35	,,	,,
3rd	,,	,,	35	,,	,,
4th	,,	,,	35	,,	,,
5th	,,	,,	35	,,	,,
6th	,,	,,	$\frac{5}{6} \times 35 = 29\frac{1}{6}$	,,	,,
7th	,,	,,	$\frac{5}{7} \times 35 = 25$	,,	,,
8th	,,	,,	$\frac{5}{8} \times 35 = 21\frac{7}{8}$	,,	,,
9th	,,	,,	$\frac{5}{9} \times 35 = 19\frac{4}{9}$	,,	,,
10th	,,	,,	$\frac{5}{10} \times 35 = 17\frac{1}{2}$	,,	,,
∴ Total pressure,			10)288	lbs. on sq.	in. nearly.
			28·8	,,	,,

i.e., steam whose pressure is $17\frac{1}{2}$ lbs. has been made to do all the work of 28·8 lbs. of steam by giving it a great initial velocity. If therefore $17\frac{1}{2}$ lbs. does the work of 28·8 lbs., what is the gain per cent.?

As $17\frac{1}{2} : 100 :: (28·8 - 17·5)$ or 11·3 to Answer.

Ans. 64·57 per cent.

Other methods for this and 5 are given at the end.

4. What is meant by the nominal horse-power of an engine, and how is it determined for paddle wheel vessels (1867)?

5. The initial pressure of steam in a cylinder whose stroke is 5 feet 4 inches is 45 lbs., and expansion commences when 2 feet 3 inches have performed, find the pressure at the end of the stroke. Find also the horse-power, if the area of the cylinder is 2218 square inches, and the number of strokes per minute 30 (1867).

The terminal pressure will be found to be $18\frac{63}{64}$ lbs.; but, by allowing the port to be opened one inch before the end of the stroke to the exhaust, and neglecting cushioning, the terminal pressure will be found to be 19·2 lbs.

Dividing the piston into spaces 3 inches in length, as was done in example 3, the average pressure will be found to be 35 lbs. Taking the length of the stroke as $5\frac{1}{3}$ feet, area of cylinder 2218 inches, and number of strokes per minute 30, then we have

$$\text{Horse-power} = \frac{d^2 \times \cdot 7854 \text{ (area of piston)} \times \text{speed of piston} \times 35}{33{,}000}$$

Ans. Horse-power$=752 \cdot 3$.

6. Give a sketch and explanation of the oscillating engine (1867).

7. Describe with a sketch Maudslay's double cylinder engines (1869).

8. Give a sketch and explain the working of trunk engines (1866).

9. Find the nominal horse-power of an engine of the following dimensions:—Diameter of cylinder $57\frac{1}{2}$ inches, stroke of piston $5\frac{1}{2}$ feet, number of revolutions 25 (1866).

$$\text{Nominal horse-power} = \frac{d^2 \times \text{speed of piston}}{6000}$$
$$= \frac{57 \cdot 5 \times 57 \cdot 5 \times 5\frac{1}{2} \times 2 \times 25}{6000}$$

Ans. 151·5.

10. Describe generally the side lever marine engine. What is the object of the blow through valve, and where is it placed? Which parts of the engine are made of brass, and which of cast or malleable iron respectively (1870)?

11. What is the distinction between a single and a double acting air pump? Sketch both forms of air pump, showing the valves necessary in either case. Describe the India-rubber disc valve (1870).

12. What is meant by a steeple engine, and to what particular service are they generally devoted? Give a description of one.

13. Describe the general arrangement of a pair of oscillating engines in a paddle wheel steamer. How would you start the engine (1865)?

14. What is meant by the nominal horse-power of an engine, and how is it determined for paddle wheel vessels (1865)?

15. Find the nominal horse-power of an engine of the following dimensions (1865):—Diameter of cylinder $53\frac{1}{2}$ inches, stroke of piston $5\frac{1}{2}$ feet, number of revolutions 22. *Ans.* H.P. 115·44.

16. Find the horse-power of an engine whose mean steam pressure is 15 lbs., and vacuum pressure 2·4 lbs., the length of the stroke 4 feet 6 inches, the diameter of the cylinder 44 inches, and the number

of revolutions 31 per minute, the usual allowance being made for fricton (1866).

The pressure is $15 - 2{\cdot}4 = 12{\cdot}6$ lbs., on this the usual allowance has to be made for friction, which is $1\frac{1}{2}$ lbs., leaving an effective pressure of only $12{\cdot}6 - 1{\cdot}5 = 11{\cdot}1$ lbs.

$$\therefore \text{H.P.} = \frac{d^2 \times {\cdot}7854 \times \text{pressure} \times \text{speed of piston}}{33000}$$

$$= \frac{44 \times 44 \times {\cdot}7854 \times 11{\cdot}1 \times 4\frac{1}{2} \times 2 \times 31}{33000} = 142{\cdot}69.$$

17. What is the nominal horse-power of a pair of engines? Given diameter of cylinder 60 inches, stroke of piston 5 feet 4 inches, number of revolutions 38 (1867). *Ans.* H. P. = 486·4.

18. Why is the crank balanced in some engines? State clearly the general idea as to its effect. Give your reasons for or against the practice.

19. Give a sketch and explanation of the oscillating engine (1863).

20. Find the nominal horse-power when the diameter of the cylinder is $55\frac{1}{2}$ inches, stroke of piston 5 feet, and number of revolutions 21 (1863). *Ans.* 107·81.

21. The diameter of each of the engines of a steamer is $91\frac{1}{2}$ inches, the length of the stroke is 6 feet 8 inches, assuming the number of revolutions to be 16, and the indicator pressure 16 lbs., find the horse-power of both engines (1863). *Ans.* 1360·27.

22. What is meant by the terms cushioning and clearance? Does the amount of clearance above the piston in a side lever engine usually increase or diminish as the engine wears (1865)?

The side rods and the connecting rod are shortened by wear, therefore the clearence must diminish.

23. The air pump is commonly double acting in screw engines; explain the action of such a pump. Sketch roughly in section the condenser air pump and valves in Penn's trunk engine. How is each separate valve made and fitted (1871)?

24. What is meant by a hammer engine? state clearly its distinctive features.

25. Give a sketch of a compound engine, commonly called high and low pressure engine.

26. Describe Humphrey's engine.

27. What is meant by continuous expansion? To what engines is it particularly applied?

28. State distinctly what is meant by (1) a beam engine; (2) a side lever engine; (3) a geared engine; (4) a compound engine.

29. What engines are launches and small river steamers generally fitted with?

30. What method is adopted for comparison as to the power of different engines?

CHAPTER V.

METHODS OF PROPULSION.

Paddle Wheels—Immersion of Paddle—Disconnecting Paddle—Centre of Pressure—The Screw—Definitions—Slip—Propellers—Thrust—Hydraulic Propulsion.

THERE are various methods of propulsion, but up to the present time only two have done good work—

(1) PADDLE WHEELS.
(2) THE SCREW.

In addition to these two, the "Waterwitch" is driven by a kind of turbine or hydraulic propulsion, which shall be explained.

Vessels in every case are propelled through the water by leverage. The only fulcrum obtainable is the water itself, which cannot offer any resistance to the slightest pressure applied to it without yielding to a certain extent. The amount of yielding will vary with the pressure and the quantity of water acted upon. Without this yielding property of the water, no vessel could progress through it at all. The problem to be solved in marine propulsion, is to arrange the floats, screw, etc., that with the least amount of slip we may attain the highest speed of progression.

102. Paddle Wheels consist of two large wheels moving on the end of the engine shaft. They are made with iron arms attached to two large rings, on to which are bolted the paddles or floats. As they are turned round, the resistance offered to them by the water causes the vessel to move, acting precisely on the same principle as a boat oar, by them the inertia of the water is made a means of locomotion. In using this appliance as a motive power, its advantage greatly depends upon the amount of immersion. When the water approaches the centre, or reaches above, it is obvious that the greatest waste of power will ensue. It is quite as obvious that the greater the diameter of the wheel the greater the leverage, and the greater is the effect obtained. The floats are generally made of elm or pine. There are various kinds of paddle-wheels, such as (1) the ordinary radial wheel; (2) the Cycloidal; (3) Morgan's feathering paddle.

103. (1) The **Ordinary Radial Wheel** has the floats fixed on the radial arms. It is to be observed that in this arrangement the floats enter the water with the whole of their faces presented to it; the same action takes place as they come out. From this arises a great loss of power, for they should evidently offer the greatest resistance to the water when at their lowest point, and none when entering or leaving. From this cause, and the yielding of the water, the ship does not move as fast as the wheel. The loss is called slip, and is generally allowed to be 20 per cent.

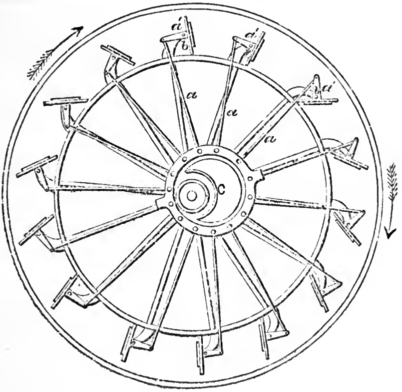
Slip is the difference between the speed of the wheel and the speed of the ship. The percentage is calculated on the speed of the wheel.

104. (2) **Cycloidal Wheels.**—To obviate the difficulties and disadvantages of the ordinary wheel other forms have been suggested, as the Cycloidal, which merely consists of dividing the float into two strips longitudinally. The one farthest from the centre is behind the radius, and the other in front of it. The intention of this arrangement is, that the floats may meet the water with more uniformity. It is a very good form of wheel for large vessels.

In order that the floats may enter and leave the water with the least possible resistance, they should enter in a tangential direction to the curve which is being described by any point in the wheel. This is, as is well known, the cycloidal curve.

105. (3) **Morgan's Feathering Paddle.**—A wheel of this kind was first patented by Galloway in 1829.

The figure at a glance gives us a good idea of the principle of the feathering paddle. The floats are seen supported on spurs attached to the rim of the wheel. The long levers *a a a*, etc., move the short ones *a′ a′ a′*, etc., on their centres *b b b*, etc., fixed in the spurs. The levers *a a a*, etc., proceed to a centre C, while *o* is the *centre* of the *wheel*. Thus the centre of the floats is not coincident with that of the wheel. The



MORGAN'S FEATHERING PADDLE.

centre C is either driven by an eccentric on the ship's side, or "by a rigid bar which springs from a solid ring."* By this plan the floats are always moved on their centres, so as to enter and leave the water very nearly perpendicularly, and also offer the greatest resistance at the lowest point. The floats are, in fact, constantly at right angles to the surface of the water when immersed.

106. Immersion of Paddles.—The great difficulty with paddle wheels is to secure a proper immersion. As the ship proceeds on its voyage and consumes its store of coals, the vessel becomes lighter, and, consequently, its draught of water decreases. Therefore, supposing a paddle is properly immersed at the commencement of a voyage, it will be nearly out of the water at the end. At the commencement of a voyage the paddles *must be* too deeply immersed, at the middle the proper immersion will perhaps be attained, while there will be too little towards the end of the voyage. It is usual to allow from twelve to twenty-two inches of water over the top of the floats, according to the size of the ship; but in river

* Goodeve's *Mechanism*, p. 251.

steamers the usual plan is to allow only about one inch over the floats, or that they should be just awash. A system of reefing the paddles exists, *i.e.*, at the commencement of the voyage the floats are reefed, or unbolted, and fixed nearer the centre, and as the coal is consumed they are shifted outwards to the end of the radii.

107. Disconnecting the Paddle.—When the wind is fair for sailing, and the ship is placed under canvas, it is usual to disconnect the paddle wheels from the engines, and allow them to revolve in their bearings by the resistance of the water. Several plans have been proposed to permit this action, as Maudslay's plan of sliding the paddle shaft with the nearest crank out of the crank pin by means of a worm wheel.

Braithwaite's, which consists of a cast iron disc keyed on to the paddle shaft; surrounding the cast iron disc is a strong wrought iron hoop, which will slide round the disc. A projection, into which is bored an eye for the crank pin to pass through, is forged on to the hoop; on the opposite side of the hoop it is enlarged to cover a brass cushion; this cushion is driven by a key tightly against the cast iron disc, when the friction is so increased as to cause the disc to carry round the hoop, and with it the crank, and so motion is communicated to the wheels. Of course, if the key be driven out, then the hoop and disc revolve independently, and the wheel is free to move by the resistance of the water.

108. The Centre of Pressure.—In Morgan's feathering paddle, as each paddle is always perpendicular to the water, they progress with the same horizontal velocity, therefore we may safely say that the point of maximum resistance, or centre of pressure, is in a line passing longitudinally along the centre of the float. But in the radial wheel this cannot be the case, for the outside edge of the float moves much faster than the inside; the point where these two average each other is taken at a distance of *one-third* the depth of the board from the outer edge.

109. The Rolling Circle is that circle described by the point in the wheel whose velocity is equal to the velocity of the ship. It is evident that the centre of pressure moves faster than the rolling circle; the resistance which this difference of velocity gives, is that which propels the ship.

"To the full power of the steam engine, and a certain draught of the vessel corresponds a certain rolling circle, which indicates the maximum performance of the vessel. Under no circumstances whatever can this maximum efficiency be obtained if the centre of the float of a paddle wheel is placed on the rolling circle. Wherever beyond the rolling circle the floats of a paddle wheel may be placed, and however great the slip of the float, so long as the rolling circle is kept at this maximum, slip, under such circumstances (as, for instance, in a small float placed at a distance from the rolling circle), is no loss of power, and does not lessen the efficiency of the engine."*

Paddle-wheel steamers are best adapted for propulsion on shallow rivers and lakes, where the draught of water is limited.

110. The Screw.—It need scarcely be said that the paddle wheel was the first mode of propulsion used, and that paddles possess certain advantages, under peculiar circumstances, by which they still retain a strong hold upon marine engineers. The comparative value of each will be considered presently.

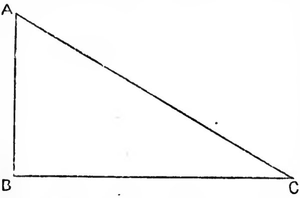
111. The Screw or Propeller, or Screw-Propeller.—The form is that of the screw of Archimedes, or it is a spiral similar to the geometrical staircase. It acts at right angles to the paddle wheel, and is fixed in the dead wood at the stern of the vessel, a large rectangular hollow being constructed on purpose for its reception.

The propeller is of the same construction as the common screw, but the narrow thread of the latter is expanded into the large thin plate in the former, while the central cylinder of the screw becomes small, and only a very small part of a convolution is taken, as it has been found that one-sixth part of a convolution is much more effective, and will do more work than the whole. Propellers are generally made with two blades, but they have been used with three, four, and six blades. The former are found to answer best, being fixed on a spindle passing through a boss.

112. Pitch, Thread, Angle, Length, Blade, Diameter,

* *Engineering.*

Slip.—We may suppose a screw to be formed thus:—Take a piece of paper in the form of a right-angled triangle,



as A B C, and wrap it round a cylinder, such as a large lead pencil or ruler. Let us suppose that when it is wrapped round, the point C touches B, or the side B C exactly fits round once. Then A B is the *pitch*, B C is the *circumference*, A C the thread, and A C B the angle. The thread on our supposed screw is only a line; let us imagine this, as was said above, to become a wide flat plate wound round, and that the cylinder becomes small, and that of the whole thread only two bits are taken opposite each other, we shall then have as good an idea of a screw as can be given.

The **Pitch** is the distance that a complete convolution takes upon the cylinder; or the pitch, as in the common screw, is the distance between two threads; or, thirdly, the pitch is the distance that the screw would go if turned once completely round in some unyielding substance.

The Thread is the distance along the edge of the blade.

The Angle is the inclination of the thread of the screw to the horizon.

The Length is the fraction of the pitch actually used.

Blade.—Each propeller consists of two or more parts, which are called blades. The *area* is the surface of the blade.

Diameter is the diameter of the cylinder from which the screw is taken, or it is the perpendicular distance between the extreme outside points of the blade.

Positive Slip is the difference between the speed of the ship and the speed of the screw. (See slip of paddle wheels, page 98.) Slip varies from 10 to 30 per cent.

Negative Slip.—It is a curious fact that vessels have been propelled *faster by the screw*, than the screw would have gone had it been working in an unyielding substance. The difference between the velocity of the ship and the screw under this circumstance is called *negative slip*. It has been suggested that the lines of the ship were such, that a large body of water followed the vessel and re-acted upon it, assisting the screw to send the ship forward. If we consider the condition of the water around the screw and behind it, we shall see a better reason for this singular fact. The water is thrown outwards and backwards by the propeller in the form of a *hollow cone.* Obeying the usual laws of nature, the water follows to fill up this hollow, and it thus comes again to the screw in two directions. First, that which follows in the wake of the vessel; and second, that which attempts, as it were, to fill up the vacuum near the centre, caused by the centrifugal action of the propeller. Both these bodies of water will impinge upon the screw, and cause an additional thrust. From this we can conceive that negative slip may exist when these two forces reach a maximum, and act under peculiar circumstances.

There are many varieties of screws, such as Griffiths', who bends the ends of his blades forward a little, and makes them broad at the boss. He discovered, in commencing a series of experiments, that when he placed a hollow globe, one-third the diameter of the screw, as the boss, that thereby a positive gain was effected. The blades of his propeller do not spring from the shaft, but from this hollow sphere. The reason for such an apparently anomalous arrangement will be found in what follows. To move the central portion of the screw and blades, absorbs through their inertia and resistance nearly twenty per cent. of the power of the engines, while these parts do little towards the propulsion of the vessel. For they are nearly in a line with the shaft, or at right angles to the water, and so cannot effect such a displacement of water as shall react on the ship. Griffiths constructs his blades to incline forward, the curve beginning from the centre of the length of the blade, and reaching to its point towards the ship.

Different engineers have given their blades the most varied shapes. The object has been to get rid of the vibration which communicates itself to the hull of the ship, and is the cause of that disagreeable tremulous motion experienced in screw vessels. This vibration must result from the screw striking the water at intervals, and not acting as it should with a continuous pressure. The unequal pressure is frequently caused by the blade being too wide across the top. Were the speed of the ship the same as that of the screw, this "shivering" would not occur. Engineers round off and spoil their screws to make them cut the water instead of striking it, when they should make the pitch finer in relation to the diameter, and the blades narrower, but retaining their natural form. The greatest resistance of the water is "across the propelling side of the front surface just across the middle, and the forward side of the leading edge of the back surface."

113. Feathering Screws.—Several methods have been proposed to feather the screw, such as Maudslay's and Bevis' methods. To feather the propeller is to resort to such an arrangement that the two blades can be turned into a line with the keel of the ship, or in a fore and aft direction when she is under canvas. Bevis' method feathers the screw by means of two levers working in a boss on the screw shaft; the levers are moved by a sliding rod passing through the *hollow* stern shaft. The sliding rod is worked by a nut on the shaft, while the whole apparatus is easily accessible in the shaft tunnel.

114. Twin Screws.—Twin screws are simply the use of two screws, one on each side of the rudder, instead of one screw in the dead wood in front of the rudder. One screw turns to the right hand, the other to the left. It is claimed for this arrangement that the ship can be very quickly turned within a small space.

115. Woodcroft's Screw is a screw of increasing pitch, *i.e.*, supposing two threads to be wound round a cylinder, and the distance between the threads to continually increase, we shall have a screw of increasing pitch. Under Griffiths' propeller, it was said that the centre does little or nothing towards propelling the ship, so therefore nearly all the work must be done by the extremities of the blade. For this reason, Woodcroft sought to increase the pitch of his blades at the ends, and thus gain power.

116. Ericsson's Propeller.—Ericsson fixed a number of blades on a drum, so that his propeller had a hollow centre, and the ends only of several blades were used to drive the ship.

117. Hodgson's Parabolic Propeller differs from the others, in that the two blades are hollow on their face, forming portions of two similar parabolas. The other propellers send away the water parallel to the axis of the screw, in the shape of a cone, but the parabolic curves throw it to a focus in a line with the axis. Hence, theoretically, as the action of a screw depends upon the comparative immobility of the water, it is evident the screw will have the greatest power when its action is centralized towards one point.

118. Beattie's Screw Propeller.—Beattie's propeller is placed beyond the rudder, instead of in the dead wood before the rudder. The object of this arrangement, and it succeeded, was to reduce the vibratory motion of the stern which is experienced to the chagrin of all amateurs on board sea going steam-boats.

119. The Advantages of Screw Propellers over Paddles.—Under favourable circumstances there is but little difference between screws and paddles. In running before the wind the paddle has the advantage; but when the wind is ahead it is not so, for the wind acts on the paddle-boxes, which offer great resistance, and so retard the ship. Fastened stern to stern, as tried with the Rattler screw and Alecto paddle, and Niger screw and Basilisk paddle, the screw dragged the paddle. The superiority of the screw is shown in long voyages; for whereas the lightening of the ship may prove detrimental to the paddle, it cannot be so to the screw, the screw being more deeply immersed. As a vessel rolls from side to side the immersion varies, and the paddle loses its power. In men-of-war the screw gives a clear broadside, while the paddle occupies the room of several guns. In passenger vessels the paddles are more pleasant than the vibrating motion of the screw, while the former will roll more than the latter. The paddle-boxes act as outriggers, and raise the centre of gravity so as to make the vessel move more evenly in the water. In lakes and rivers the screw requires deeper water, while the weeds and plants will be much more likely to clog the screw than the paddle. In screw vessels the engines may be below the water line, or at the very least much more out of the reach of shot than those of paddle wheel steamers. With the screw the upper deck is clear; so guns, etc., can be moved from end to end, and there is a much better chance of arranging the masts, sails, etc., so as to make the screw a more efficient sailing vessel than the paddle wheel.

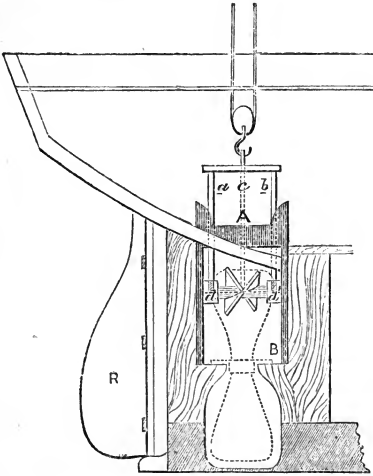
120. Disconnecting and Raising the Screw.—We have stated that Maudslay makes provision for feathering his paddle, or for arranging it so that when the ship is under sail, it shall offer no resistance to the water. It has been found before now, that when a ship has been under sail and steam at the same time, that the velocity of the ship has outstripped the velocity of the screw; hence the screw has dragged or become an obstacle to the progression of the vessel. Cases have been known in which the screw has actually been broken off backwards or away from the ship by this dragging force. The screw also requires to be sometimes taken out for examination and repair, therefore a necessity exists for providing means both for disconnecting the screw from the engines, and for raising it out of its place. Merchant vessels are generally brought alongside a quay at high water, and at low water the screw is examined or taken out: the process often involving considerable expense from loss of time, etc. But in men-of-war more complete arrangements exist. The screw is fixed in the centre of a frame, supported on a short shaft. The main screw shaft can be withdrawn, and thus the screw is *disconnected* from the shaft, and is at liberty to revolve; by an arrangement of slots, it and its frame are also perfectly free to be lifted out vertically. This is effected by means of ropes and other appropriate tackle, or by a rack and worm.

Admiral Hall has proposed a simpler and less expensive plan for shipping or unshipping the propeller in any harbour without entering a dry dock.*

The screw is fixed in a frame A B, and the screw shaft can be withdrawn. A is the crosshead of the frame through which pass two rods, *a* and *b*, which are screwed into the tops of the bearings at *d d'*; *c* is a strong chain to hold the screw. First of all, the propeller is raised as high as possible from the place shown by the dotted lines to the position as seen in the figure by means of the screws. Then tackling is

* A full description will be found in *Engineering*, Vol. VIII., p. 34.

fixed to each end of the blade, and *c* is also fastened on. Next the rods *a* and *b* are unscrewed and taken out, when *c* sustains the propeller. The tackling fixed to the ends of the blades is supported by guys, so as to run clear of the sides



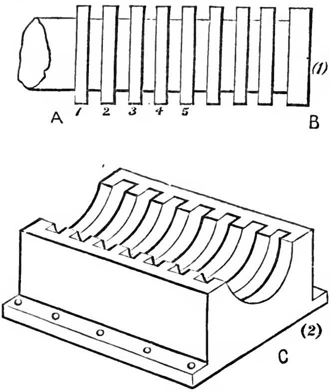
ARRANGEMENT FOR LIFTING SCREW.

of the vessel. Next *c* is let go, and as the right chain-tackle is slackened, the left is wound up, bringing the propeller out sideways and carrying it on to the deck. To ship the screw, these proceedings are reversed.

The same figure will also give us an idea where and how the screw is fixed in the dead wood, and its position as regards the rudder R.

121. Thrust of the Screw.—When we consider that the screw acts by the resistance offered to the surface of the blades by the inertia of the water, which is driven sternwards by the screw, we perceive at once that the whole force moving the vessel is transmitted to the end of the screw-shaft. Methods must therefore be provided to prevent the force or motion from being converted into heat by the enormous amount of friction necessarily transmitted. The more heat we allow the end of the screw shaft to generate, the more power we lose. The dynamical and modern theory of heat is, that heat is *motion*, and therefore the more heat we allow to waste or develop at the end of the shaft the more motion we lose.

The thrust of the shaft, or the reaction of that force which pushes the ship through the water, is received on a series of metal discs completely immersed in oil. Several discs are employed to distribute the friction, and should two or more set fast, by two pure metallic surfaces coming in contact, others may be still free to move. By far the best arrangement for receiving the thrust consists of a long plummer block having in it a series of circular depressions, with a square section, into which fit a series of collars turned on the end of the shaft.



(1) THRUST END OF SHAFT.
(2) LOWER END OF THRUST BLOCK.

A B is the end of the shaft; 1, 2, 3, 4, 5, etc., are the collars turned on it. These fit into the plummer block C. This figure C is a representation of the bottom half only of the plummer block. The cap which is removed is similar in section, and contains the corresponding semicircular spaces to fit the collars. The plummer block is often hollow, water circulating within.

122. Thrust of Screw Continued.—If two pieces of lead have their pure metallic surfaces laid bare, and are then put together with a slight pressure and twist, they unite and become almost as one piece; so will dissimilar metals, as iron and lead, or steel, brass and lead, or even two pieces of steel, or two pieces of glass truly flat and clean. When lead bullets (as they are made at Woolwich, entirely by compression, by driving the dies into the solid lead) are being manufactured, the lead will unite to the steel die, unless oil or grease be employed to interpose between the two metals: the *pure metallic surfaces* unite under pressure by the power of cohesion. Before the thrust of the propeller was received on a thrust block, as indicated above, it was received on a fixed piece of steel, against which the shaft directly worked. After wear, when the oil had been worn off, and the two surfaces had scraped each other so as to present mutually to each other pure metallic surfaces, the two perfectly united, and united so firmly that the shaft twisted and broke, not directly where the thrust was received, but elsewhere.

123. Hydraulic or Jet Propulsion.—A few years ago attempts were made by Mr. Ruthven and others to introduce water-jet propulsion, the main feature of which was, that a jet of water driven out of the side of the vessel in one direction propelled it in the other. In H.M. sloop "Waterwitch" three horizontal cylinders are arranged so that their connecting rods are coupled to a crank, which works the shaft of a turbined wheel placed in a case on the floor of the engine-room. The water is led to the centre of the turbine through openings formed in the bottom of the ship, and is driven by the centrifugal force imparted to it by the wheel through pipes, whose nozzles are placed outside the vessel on its side just above the water line; or it may be explained more exactly thus: from the circumference of the turbined wheel, the water escapes into the surrounding casing, and is led thence by two tangential pipes to the sides of the vessel. There are four nozzles or jets at the ends of the pipes; one pair pointing forward to drive the ship sternways, the other pointing aft to drive it forward. The water is discharged parallel to the keel of the vessel. Four valves, that can be worked from the deck very much like common cocks, allowing a free passage of water, are fixed in the pipes. By these the vessel can be started, stopped, backed, or moved round, according to which valves are opened or closed, without reversing the engine. By directing a jet of water forward on one side and aft on the other, the vessel is turned round.

The water jet propeller has found no favour with engineers, because it is palpably evident that there is a great loss of power. Out of 750 H.P. of the "Waterwitch," only about one-quarter seems to be utilized in propulsion, so that whilst offering advantages in manœuvring over existing methods, it is not economical. This arises from the inevitable losses from friction, in pumping efficiency, and the small sectional area of the jet.

124. Theory of Jet Propulsion.—The theory of jet propulsion is precisely that of "Barker's mill;" the same principle is used to propel the Congreve and other rockets. The fluid in a vessel presses horizontally and equally, and as long as it is equal there is no tendency to communicate motion to the vessel. But if an aperture be opened, the pressure upon that portion of the surface is removed, and the pressure upon the opposite portion of the surface is unsustained, and will tend to produce motion in that direction. Therefore, when water is issuing from the nozzles of the jet-propeller, the opposite portions are unsustained, and the ship moves.

EXERCISES CHIEFLY FROM EXAMINATION PAPERS.

1. Show how a helical surface is generated. What is meant by a screw of increasing pitch? How is the pitch of a screw measured (1865)?

2. The pitch of one of the blades of a screw propeller is 20 feet 8 inches, and the number of revolutions is 42; if there were no slip, what would be the speed of the ship in knots? Again, the pitch of the other blade being 21 feet 7 inches, if the speed of the screw be that already found, what would be the slip per cent., reckoning from the latter blade (1865)?

$$\begin{array}{c}\text{Speed in knots}\\ \text{from first blade}\end{array} = \frac{\text{Speed per minute} \times 60}{\text{Length of a knot}} = \frac{20\frac{2}{3} \times 42 \times 60}{6080}$$

$$= 8\tfrac{43}{76} \text{ knots} = 8{\cdot}565.$$

$$\text{Speed in knots from second blade} = \frac{21\frac{7}{12} \times 42 \times 60}{6080} = 8{\cdot}945$$

$$\therefore \text{ Slip} = {\cdot}3807.$$

$\therefore$ Slip per cent. is found thus,

As 8·945 : 100 : : ·3807 : 4·256, *Ans.*

3. Describe some form of engine adapted for driving a screw propeller. Define the terms pitch and length as applied to the screw propeller (1870).

4. Describe some form of screw propeller. Define the terms pitch, length, and angle of the screw. What is the slip of the

screw propeller? The speed of a vessel is 12 knots, the pitch of the screw is 20 feet, the engines make 70 revolutions per minute, find the amount of slip in percentage of the speed (1870).

Ans. 15 per cent.

5. Define a screw surface, and the length and breadth of a screw propeller. Describe the general arrangement of the boilers, engines, screw, shafting, and propeller in a vessel. How are the engines relieved from the thrust which propels the ship (1871).

6. How is a screw surface generated? Define the pitch and length of a screw propeller, and apply your knowledge of the geometrical properties of a screw surface to deduce an approximate method of estimating the area of the driving surface of a screw propeller by measurement (1871).

See examples at the end.

7. Find the area of the blade of a screw propeller either by calculation or approximately by measurement. In the latter case you must explain fully the steps of the operation (1871, Honours).

See examples at end.

8. The length of a screw propeller is 3 feet, the pitch 20 feet, and the diameter 16 feet, required the area of each blade (1867).

Ans. 42·48 sq. ft.

9. The pitch of a screw is 15 feet, the diameter 17 feet 6 inches, the number of revolutions is 85 per minute, find the rate of the screw in knots and the distance traversed by a point in the circumference of the screw (1867).

Ans. Rate, 12·58 knots; distance, 58·69 knots.

10. Find the slip of the screw of a steamer, number of revolutions 60, multiple of gearing 4 to 1, pitch of screw 8 feet, speed of ship 12 knots (1861). *Ans.* 5 per cent. nearly.

11. The number of revolutions of a crank is 73, find the pitch of the screw if 25 per cent. be allowed as slip, and the speed of the ship is 14 knots (1866). *Ans.* 25·91 feet.

12. Describe a screw propeller, and explain the terms pitch, length, angle, and diameter (1866).

13. A screw ship's engine makes 65 revolutions per minute, the pitch of the screw is 24 feet, and the rate of the ship is 14·5 knots. Find the slip in knots, and the amount per cent.

Ans. Slip ·894 knots; 5·809 per cent.

14. Find approximately the area of the blade of a screw propeller, the diameter being 15 feet, the pitch 24 feet, and the length $\frac{1}{6}$th of the pitch (1866). *Ans.* 46·84 sq. ft.

15. What advantages do screw propellers possess over paddle wheels?

16. Describe the common screw propeller. Define the terms pitch, length, and angle, of the screw and slip. A ship is required to steam at the rate of 12 knots and the engine crank is to make 76 revolutions, what must be the pitch of the screw if 20 per cent. be allowed for slip (1868)? *Ans.* 20 feet.

17. Explain a method of feathering the floats of a paddle wheel steamer (1869).

18. Distinguish between (1) the ordinary radial paddle wheels; (2) cycloidal wheels; (3) Morgan's feathering paddle.

19. What is the proper "immersion for paddles?" and state how they are disconnected.

20. What is meant by "negative slip?" Can you give any explanation of it?

21. Describe four different kinds of screws used in steam vessels; stating clearly their distinctive features.

22. What is meant by hydraulic propulsion? Give the theory to explain its action.

23. What do you mean by double screws, and what advantage is claimed for them?

Two screws are placed one behind the other on the same screw shaft; it is asserted that by this arrangement a better grip or leverage is obtained upon the water.

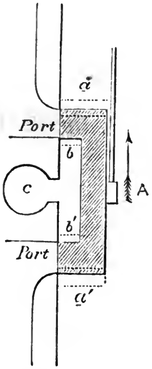
CHAPTER VI.

SLIDES.

Slides—Long D Slide—Short D—Seaward's—Cylindrical—Gridiron—Motion of Slide—Lap—Lead—Valves of Special Pump—Rotatory Valve.

125. Slides.—The *locomotive slide* has been already partially described, when speaking of the beam engine and the way the steam is admitted to the cylinder. The various slides used are the long D, short D, Seaward's, Cylindrical, Gridiron, etc.

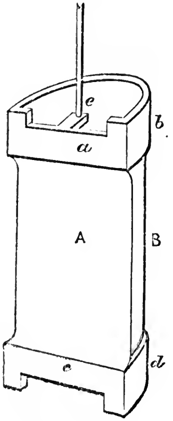
126. The Locomotive Slide is represented in the annexed figure, in which the dark shaded parts are the slide, and the ports are marked *port;* *c* leads to the condenser. The whole of the drawing is covered over by the slide casing, and steam is brought to the back of the slide at A by the steam pipe, not shown. When the steam is acting, it is clearly seen that it presses with great force against the back of the slide at A. The valve rod is shown attached to the back of the slide. When in the position as given in the figure, it is quite evident no steam can pass into the ports and go to the cylinder, as they are both covered over; but when the slide rod moves the valve up, the steam can pass into the lower port, and drive the piston up, while the steam that is in the upper part of the cylinder can come out at the upper port, when the form of the slide compels it to pass into *b b′* and through *c*, which leads to the exhaust, hence *c* is called the exhaust port. When the slide comes down again, both ports are first



LOCOMOTIVE SLIDE.

closed, then the upper one is open to steam and the lower one to the exhaust, precisely the reverse of the first case. As there are three ports, two steam ports and the exhaust port, this valve is sometimes called the "three-ported slide."

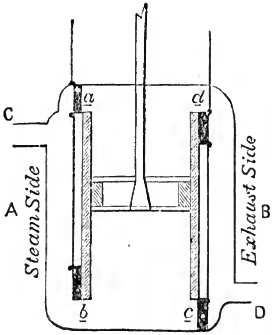
127. The Long D Slide is so called because its cross section forms the letter D. The two faces, *a* and *c*, fit against the ports. The body, or waist, A B, is smaller than the parts *a b* and *c d*. The steam comes along the steam-pipe, and can pass freely round the waist of the valve, and pressing against both back and front it is almost an equilibrium valve. The steam cannot pass by *b*, *d* nor *a*, *c*, because the two former parts fit closely to the slide casing, and the two latter press against the ports; only when the valve A is lifted or depressed can the steam enter the cylinder from round the valve. When the steam comes out of the upper port it passes right down the slide at *e* to the exhaust. This is the peculiarity of the slide, that the exhaust passage from the upper port is through the valve.



LONG D SLIDE.

128. Short D Slide may be described as consisting of the upper and lower portions *a* and *c* of the long D, but the passage is closed, and they are joined together by a rod. The steam is still brought to the waist, but cannot pass either *a* or *d* unless the slide be lifted up. Its action is somewhat similar to that of the long D, excepting that the way to the exhaust is not through the slide. There are separate exhaust passages from the top and bottom ports.

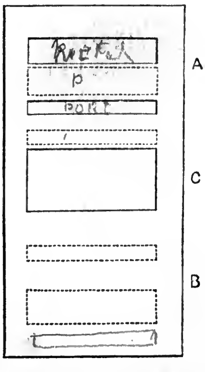
129. Seaward's Slides were first used by the inventor, after whom they are named. There are four slides, two for the exhaust and two for steam. A is the steam side of the cylinder, and B the exhaust side. When they are in the position in the figure, the piston is ascending. Steam enters at C; the upper port *a* being closed it cannot enter the top of the cylinder, but it can enter at the lower port *b*, and drive the piston up. As the piston ascends, *c* is closed and *d* open, so that the steam which drove the piston down is escaping through *d*. When the piston is descending, *a* and *c* are open, and *b* and *d* closed. D is the way to the exhaust, and B is called the exhaust side of the cylinder; *a* and *b* are called the induction ports, *c* and *d* the eduction. The slides are kept against the face of the ports by springs, so that any water that enters the cylinder through priming can easily escape.



SEAWARD'S SLIDES.

130. Cylindrical Slide.—These slides have been introduced and fitted to engines by Maudslay & Field. They are cylindrical in shape. The slide faces are hollowed out concave, and fit on convex nozzles. They are placed between the two cylinders, being used in double cylindered engines, and when raised the steam is admitted to the top of the cylinders, and the down stroke follows; and when depressed, steam enters beneath the piston, and the up stroke is effected.

131. The Gridiron Valve.—The gridiron valve is one of the most effective contrivances to give a large opening for steam by a very short movement. Each port is sub-divided into two or more narrow ports, while the valve face has openings to correspond. The principle is the same as that of an air grating in the floor, we have only to give the top plate a slight motion when it is open or shut; the same with this valve, except that the motion is rectilinear and not circular. If A B represent the ports of the cylinder, and the dotted lines the slide face, it is seen that by simply lowering the slide (face) the smallest amount, that the



GRIDIRON VALVE.

upper ports, A, are immediately open, and the lower, B, closed; the exhaust is not shown. When the slide is pushed back, the lower ports will be opened and the upper closed.

Full Steam is the position of the valve when fully open, and the piston is continuing its motion.

Cut-off is the position of the valve when it has just closed the port against the admission of steam.

Angular Advance is the angular measurement of the arc described by the centre of the eccentric while passing from the place it occupies when the valve is at half stroke, to that which it occupies at the commencement of the stroke of the piston.

Linear Advance is the distance which the valve moves while the centre of the eccentric is describing the above angle.

132. The Motion of the Slide Valve.—The motion of the slide valve when driven directly by an eccentric, or in the ordinary gab motions, is simply rectilineal and reciprocating, and is precisely on a smaller scale what the motion of the piston is on a larger. This is manifest in considering that the eccentric is but a crank of a very small radius, which has, like the greater crank, its own circle of revolution, its own throw, and its own dead points, which terminate the reciprocations of the valve in the one case, and those of the piston in the other. The motion of the slide valve must therefore be considered in its relation to that of the piston. The relation of those motions is founded upon the uniform circular motions of the crank and eccentric. These being rigidly fixed on one shaft or axle have the same angular velocity. Their relations, and those of the piston and valve derived from them, may be established by following them through a complete revolution. The rectilineal motion of the slide valve, like that of the piston, is accelerated and retarded during the travel.

All that is imperatively required of a slide valve in governing the distribution of the steam, is that it be at least of sufficient extent to close both of the steam ports at the time of changing the admission of the steam, in order that it (the steam) may not enter at both ends of the cylinder at one time, and that it release the steam from one end of the cylinder at least as soon as it is admitted to the other end.

The valve, as shown in the next figure, meets these conditions. In this position its inner and outer edges coincide with those of the steam ports. The smallest motion either way opens one of the ports to the steam, and the other to the exhaust port *c*. The valve is now at half stroke, whilst the piston is at the end of its stroke; and to move the piston in the direction of the arrow, for example, the valve must move in the same direction, and the eccentric must be set on the shaft at right angles to the crank. From this description it will be seen that one end of the cylinder is open to the boiler throughout the whole of the stroke, while the other end is open to the exhaust—a most disadvantageous result, as far as the economical working of steam is concerned.

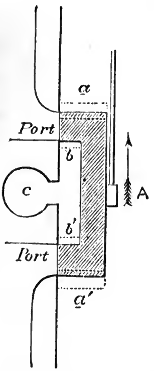
But these evils may be removed, to some extent, by causing the change of the distribution of steam to take place before the completion of each stroke; and this is effected by shifting forward the eccentric on the shaft, the motion of the valve being advanced in a like proportion. The arrival of the piston at the end of its stroke is anticipated by the change of distribution, and the steam has thereby gained time to re-arrange itself for the next stroke. The advantage of this is obvious, when we remember that by this arrangement the maximum time is afforded for these operations with the least motion of the piston and a minimum retarding effect. While by these arrangements a more efficient admission and exhaust are provided, nothing can be done with this valve to employ the expansive force of the steam in propelling the piston, which requires the confinement of the steam within the cylinder during the latter portion of the stroke; when using such a valve we find that the suppression and release of the steam take place at one and the same time.

Expansion is, however, attained by simply adding to the length of the valve, as shown in the figure, by the dotted lines *a a'*. Its two outer edges are, by the addition, set so much the further apart than the extreme edges of the steam ports, and by as much does the suppression, and, consequently, the commencement of expansion anticipate the exhaust during the travel of the slide valve, and while the valve describes this portion of its stroke, the piston is moving under the pressure developed by the expansion of the steam already in the cylinder.

133 Lap and Lead of the Locomotive Slide.—The width of the opening of the steam ports for the admission or for the release of the steam at the beginning of the stroke is known as lead. On the steam side of a locomotive slide, it is known as outside lead, or lead for the admission; on the exhaust side it is inside lead, or lead for the exhaust. When the valve is placed at half stroke over the ports, the amount by which it overlaps each steam port, either internally or externally, is known as lap. On the steam side it is named outside lap; on the exhaust side, inside lap. When the terms lap and lead are employed, they are understood to refer to outside lap and lead only.

The advance of the eccentric is a term used to denote the angle which it forms with its position at half stroke, and when the piston is at the commencement of its stroke.

The locomotive slide (figure annexed), as seen in section, has neither lap nor lead, but did it extend to the faint dotted lines *b b′*, it would have lap on the exhaust side to both ports; while, on the contrary, if it reached to the dotted lines *a a′*, it would have lap on the steam side. Lap is chiefly used on the steam side. To see what effect this will have, let us examine the top port, and suppose the slide going up. It is evident if the slide reaches to the dotted line *a*, as it rises from the bottom of the upper port, it will close it sooner against the admission of steam than it would be otherwise if the slide were constructed simply as drawn in the figure; therefore the steam that has had time to get into the cylinder has to perform the rest of the stroke expansively.



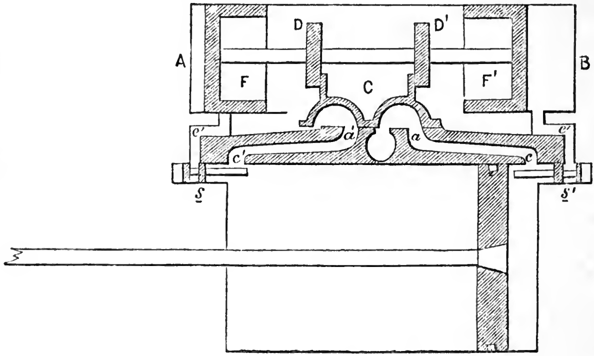
LOCOMOTIVE SLIDE.

Lap on the exhaust or eduction side, *b b′*, is always less than that on the steam side, and closes the port to the exhaust sooner than it would otherwise be, and thus prevents all the steam from rushing out to the exhaust; the steam remains behind, and the piston acts against it as against a cushion, and so all sudden jar and stoppage is avoided. Sometimes there is no lap, and even *less* than *none*, or negative lap; then the valve cannot cover both ports at once. When the slide has neither lap nor lead, the breadth of the slide face is equal to that of the steam port, and the travel of the slide twice the breadth of the port; but when the slide has lap, the travel of the slide must be double the lap with double the breadth of the steam port.

134. Lead.—Let us suppose that at the instant the piston is at the top of its stroke, that the slide is in the position shown in the figure of the locomotive slide, but that it extends only to the top darkly-dotted line, then the port at that instant would be open for the admission of steam: this is what is called the lead of the slide. Remember the *lap* is when the *slide* is at its middle position, but *lead* when the *piston* is at the end of its stroke. The lap and lead of the D slide are explained in precisely the same way, but the steam side is the inner and the exhaust the outer. There is always more lead required in engines that are driven at great speed, than in those which work slowly. Again, in engines that travel fast, it is best to open the exhaust passage before the end of the stroke, or else the cushioning will act injuriously.

135. Valves of the Special Pump.—We describe these valves, which are in a measure self-acting, as they seem to involve a mode of action which may be rendered still more effective and economical both in construction and wear and tear.

A B is the steam chest filled with steam, the valves and the contrivance for their working. There is a double set of steam passages, *a c* and *a′ c′*, the same as in the locomotive slide, and *e e′* leading from near the ends of the steam chest to the inner end of two small cylindrical chambers, *s* and *s′*, formed in each of the cylinder covers, Both the small chambers are fitted with a piston, as seen at *s* and *s′*, and kept in their places by the pressure of steam on their backs. C is an ordinary locomotive slide; as shown in the figure it is covering the ports, so that the right hand is open to the exhaust, and the left for the passage of steam, consequently the piston is moving to the right. (We have drawn it near the end of its stroke.) On the back of the valve are a pair of lugs, which fit between two collars, D and D′, formed on one

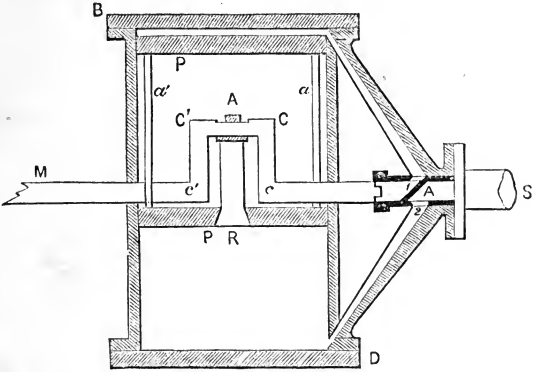


VALVES OF SPECIAL PUMP.

spindle; on the ends of the same spindle are two plungers, F and F′, which work in the ends of the steam chest. The steam chest is cast cylindrical on purpose for them to work in; but they *do not work steam tight*, but are fitted so as to allow a little steam to escape beyond the plunger, which thus gets shut up between the end of the plunger and the steam chest.

When the piston arrives at the end of its stroke, it strikes against the small spindle in *s*′, when the small valve is thrown off its seat, thereby opening the passage *e*′, and putting it in communication with the exhaust; so that the steam which has escaped beyond the plunger F′ runs to the exhaust, while the steam in the chest between F and F′ will obviously move the valve to the right, and alter the position of the slide, putting the right hand port in communication with steam, and opening the left to the exhaust. The stroke is then made towards the left, and the valve *s* thrown off its seat, when the steam from behind F escaping to the exhaust, the slide is moved to the left again.

136. Rotatory Valve.—A is a section of a rotatory valve as used in Ramsbottom's "Intermedial Steam-engines." M is the main shaft, a projection on the end moves the slide round and round; *the part marked black is the slide;* S is the steam pipe; the steam can freely enter A. As shown in the



ROTATORY VALVE.

figure, the port 2 is open for the steam to pass to the bottom of the cylinder to drive the piston up, which is now close at the top of its stroke. When the opening in A is turned round, we shall see then that steam will enter 1 and pass to the top to drive the piston down. The opening in the slide can be very wide, so as to admit a large quantity of steam; and it is evident that we can allow steam to pass into the cylinder during what part of the stroke we please. As the dark parts revolve with the shaft, the opening near A is alternately brought opposite to each steam passage 1 and 2, when steam will alternately pass to the top and bottom of the cylinder to drive the hollow piston P P.

CHAPTER VII.

OTHER VALVES.

Hornblower's Valve—Equilibrium—Escape—Snifting Valve—Communication Valve—India-rubber Disc Valves—Kingston's Valve—Blow-through Valve—Balanced Slides—Facing Valves.

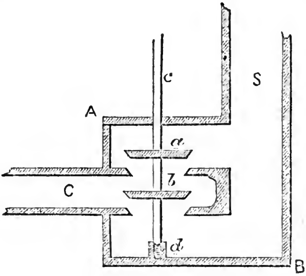
Beside slide valves, there are expansion valves,* such as Hornblower's, the equilibrium and Cornish double-beat; also the escape valve, India-rubber disc valves, Kingston's valves, etc., with communication or stop valve, safety valve, vacuum valve, and blow-through valve. Any valve will constitute an expansion valve, so long as it will suddenly give a large opening for steam, and as readily cut it off. When the throttle valve is used to regulate the steam supply, the steam is said to be wire-drawn; throttling is when you are using the valve to work the engines slowly.

137. Hornblower's Valve.—As soon as high-pressure steam came into use, a valve was wanted that would move easily, although the pressure of steam was very great. This valve has the "merit of affording any amount of expansion with a rapid cut-off and absence of wire-drawing, and a fully open passage to the condenser during the whole of the stroke." It consists of one tube sliding within another, like telescope tubes, with a valve fixed right across the tube; when the edge of the inside tube comes down on the valve no steam can pass, but directly the tube is lifted it can pass freely. It will lift easily, because the steam can press nowhere but upon the top circular edge of the tube.

138. Equilibrium Valves.—Equilibrium valves are those upon which the steam presses with equal force (or very nearly equal force) both upon the top and bottom, being ready to move easily when required. The following figure will give a good idea of an equilibrium valve:—

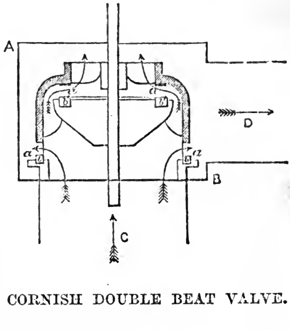
* For a good expansion valve, see *Elementary Steam.*

S is the steam-pipe, through which steam is introduced into the valve-box A B; *a* and *b* are two conical valves on one valve spindle *c d*, kept in its place by the socket *d*. The steam is required to pass at intervals along C. This it will do with full force when the valves are but slightly lifted upwards. It is seen that if *a* and *b* be very nearly equal, the valve is in equilibrium, and only a small force is required to lift it, for the pressure of steam on the top of *a* is counteracted by that on the bottom of *b*.



EQUILIBRIUM VALVE.

139. Cornish Equilibrium, Double-beat, Crown or Drop Valve.—A B is the valve-box. Steam enters it, let us say, from C, and is required to go along D, after passing the valve. It might with equal propriety be supposed to come from D and be passing down C. The part drawn with cross lines or section, is a cylindrical piece of iron fitting down on two rings, *b b* and *b′ b′*. The small squares are the sections of the rings; suppose these to go all round. It is evident that when the valve is down on the rings no steam can pass, but as soon as lifted it can rapidly pass through the two openings marked *a* in the paths indicated by the arrows. These openings extend all round in a circle. A very slight movement gives a large opening for steam. The seats *b b* and *b′ b′* are called the beats. Sometimes these valves are made with three or four beats.



CORNISH DOUBLE BEAT VALVE.

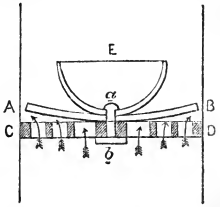
140. Escape Valve.—The escape valves should have been noticed when describing the cylinder. They are fitted in the top and bottom of the cylinder, being kept in their places by weights or springs. Water that gets into the cylinder through condensation or priming, as it is incompressible, would inevitably break something, were not provision made to allow it to escape through the escape valves. They are loaded with a weight or spring greater than the pressure of steam in the boiler. *Test* or *pet cocks* are also fitted to the tops and bottoms of the cylinders in marine engines for the same purpose. They are always opened on starting the engine, and shut when properly under way. The escape valves are *always* ready to act, and are held in their places by weights, which keep them closed only so long as the pressure in the condenser is below that in the boiler.

141. Snifting Valve or Tail Valve.—The *snifting valve* is placed in communication with the condenser, to allow the air to escape should the pressure of air become too great in the condenser. It was referred to in describing Newcomen's engine, and should have been shown in Watt's improvements at the bottom right hand corner of the figure. Before starting it is customary to "blow through," when the condenser is cleared out, and any air there may be in the condenser is driven out through the snifting valve, which is lifted on purpose. A snifting valve is not always fitted to an engine, because the air pumps take off the air.

142. Communication or Stop Valve.—The purpose of the *communication* or *stop valve* is to allow the steam to pass from the boiler to the engine. When it is wished to start, a handle is turned round, which lifts generally an ordinary conical valve from its seat, and the steam passes at once into the steam pipe to the slide casing, etc. A communication valve is fitted to each boiler, so that when an engine has several boilers, any one or more can be used without the others. The *regulator* in the locomotive corresponds to the communication valve in the marine and land engine.

143. India-rubber Disc Valves.—These are employed, especially in swift running engines, for air-pump valves, instead of the common butterfly or clack valves. They are constructed with a ring or disc of India-rubber covering a grating. A B is a circular piece of good thick vulcanized India-rubber;

C D is the grating over which it is fixed; the arrows show the direction in which the water passes. The grating is very similar in construction to those employed for air-gratings in floors. E is the guard to keep the India-rubber from collapsing into a heap. All these are bolted together by the bolt *a b*. When water has passed through the apertures in C D, and the pump ascends, the pressure of water on and above A B lays it flat on C D, so that none can return. But on the down stroke, the India-rubber being pliable it gives way, and the water passes above the valve. The guard has apertures in it.

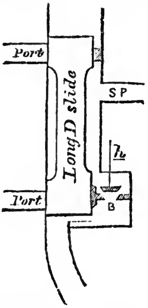


INDIA-RUBBER DISC VALVE.

144. Kingston's Valves are conical valves with the largest end downwards. They are fitted to every opening below the water line in a ship. The largest end is presented to the pressure of the outside water, so that in attempting to get into the ship through any orifice where they are fitted, the water actually closes it up more tightly, and so leakage is prevented. They are opened and shut by turning a screw by its handle; and when open the valves come outside the ship's bottom, but there is a guard to prevent them being opened too far.

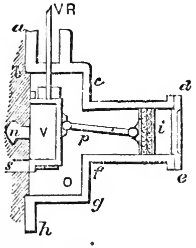
145. Blow-through Valve.—The blow-through valve of an engine is used to drive out all water from the cylinders, casings, and condensers before starting. It is placed at the bottom of the slide casing so as directly to communicate with the condenser. But sometimes one is placed at each end of the cylinder, and worked by a handle from the starting platform. Some engine-makers fit a small locomotive slide and ports for the purpose, which can also be used to start the engines. Before the engine is started, steam is admitted through the blow-through valve, and the cylinder first cleared of air and water; the steam passing on clears the condenser in the same way, so that as soon as the engine begins work a good vacuum is obtained in the condenser. This last is the chief object for which blow-through valves are fitted.

S P is the steam pipe; the steam having been brought to the back of the slide cannot enter the cylinder unless the long D slide be lifted up or down, neither can it go to the condenser unless the blow-through valve B be opened by means of the handle *h*. When the valve B is lifted off its seat, then steam can freely pass to the condenser, and blow out all air and water that may be in it; when no blow-through valve is fitted, by the tedious process of alternately letting the steam pass to the top and bottom of the cylinder, by raising and lowering the slide, the steam may be sent to the condenser, from which it will in time expel the air and water.



BLOW-THROUGH VALVE.

146. Balanced Slides.—When steam of a higher pressure began to be used in engines than was customary in the days of Watt, the general size of the slide rods, eccentric rods, bands, etc., were found to be too weak to perform their work; so that in large engines, such as those that were used in our large ocean boats, these parts were made enormously strong and out of all proportion to the rest of the engine, from which a great amount of power was taken to move the large slide valves, when their whole back surfaces were exposed to the pressure of the steam. Engine-makers seeing this took the matter into consideration, and arrived at results which relieve the slide valve of most, if not all, of the pressure; by these means the appearance of the engine has been greatly improved. The steam-hammer was the first engine in which it was attempted to fit a balanced valve, because, perhaps, the slide valve being worked by hand, the evil was felt too acutely to be longer neglected. A piston was fitted to a cylinder, which was placed above or at the back of the slide valve, to which it was connected by a rod. The area of the piston was made a little less than the area of the slide valve. *a b c d e f g h* is the slide casing; V is the valve, and V R the valve rod; to the back of the valve, by a ball and socket joint, is attached the rod *p*, which is fastened in a similar manner to the piston *i*. When steam enters the valve casing through O, it will press heavily against the back of the valve. It will also enter *f e d c*, and force the piston *i* in the opposite direction. Thus the valve is relieved of the pressure, and more readily moved to allow steam to pass through *s* or to the exhaust *n*.



BALANCED VALVE OF STEAM HAMMER.

It will thus be seen that there is just or nearly the same force pressing against the valve as against the piston, or the valve is balanced.

We will now explain another and one of the best plans yet adopted for balancing the slide. The back of the slide jacket cover is first planed. On the back of the slide valve is cast a large circular recess, which is further turned in the lathe, and into which is fitted a metallic ring. Several strong springs are placed at the bottom of the recess, which force the ring out against the planed surface of the jacket. It will thus be seen that at the back of the slide valve there is a large circular space on which the steam cannot press at all, only on the four corners of the valve. There is also a communication kept open between the space inside the ring and the condenser, by which means the condenser vacuum is in connection with the back of the slide, and is made to help to draw off the valve from the face of the ports, so as to counteract the pressure of the steam on the four corners. In fact, it has been calculated that when these engines are working with a low steam pressure and a good condenser vacuum, there is a good pressure tending to draw off the valve from the face of the cylinder ports.

Balanced valves have been shown to possess so many good qualities and advantages, that no large engine is made without them now by any engineer who wishes to get the greatest amount of work with the least possible outlay.

147. Facing Slide Valves.—The faces of the slide valves must be so prepared that steam will not be able to find its way between them and the nozzles of the cylinder into the latter. The valve being cast, the faces are first planed in the planing machine as true and smooth as that machine will make them.

Then a fine or smooth file is taken, and the faces are filed with it till all the marks made by the tool of the planing machine are taken out. The valve is next rubbed against a surface plate (a truly flat surface), on which is spread a thin covering of red lead and oil, this marks with red lead any inequalities that may now exist on the valve face. A scrape or scraper is then taken, which is simply a flat piece of steel with a very fine edge finely tempered and sharpened on an oilstone, it is held in the hand, and all marks of red lead are scraped off from the slide with it. This is repeated till the valve face bears all over on the surface plate.

The valve is now covered with the red lead and oil, and applied to the face of the port on the cylinder, when the red lead marks left on are scraped off as before, till in its turn the valve face bears all over the corresponding face on the cylinder. We thus get a perfectly steam-tight slide valve face.

In the American locomotive shops it is now the practice to put the slide valves in as they come from the planing machine, without any other preparation whatever; after a few days' working a very good bearing is found to have established itself.

There appears to be a general opinion that a large amount of time and money is wasted on the preparation of slide valve faces by making them fit so nicely; for when hot, the amount of expansion of the small thin part is unequal to the larger and thicker, and thus, it is averred, the truth of the slide valve is destroyed as soon as it is put to work.

EXERCISES CHIEFLY FROM EXAMINATION PAPERS.

1. Describe the long D slide (1867).

2. What is the use of the expansion valve? Show by a diagram the pressure of the steam in different parts of the stroke when worked expansively (1867).

For latter part of question see chapter on the indicator.

3. Give a short description of the common D slide, the short D slide, and Seaward's slide. What kind of slide is used for double cylinder engines (1867)?

4. The length of a gab lever is 10 inches, and the travel of the slide is 12 inches; find the travel if the gab lever be shortened 1 inch (1867).

The gab lever is the lever to which the eccentric rod is attached to work the slide.

If L and l be the length of the gab lever, and t and t' the travel of the slide respectively, we have the following inverse proportion :—

$$L : l :: t' : t.$$

The reason is obvious, for if the gab lever be shortened the eccentric rod, or the throw of the eccentric, remaining the same, will move the *short* gab lever through *more degrees of a circle* than the longer one. Hence the shorter the gab lever the longer the travel of the slide.

To solve the above question, since

$$L : l :: t' : t$$
$$\therefore 10 : 9 :: t' : 12$$
$$\therefore t' = \frac{12 \times 10}{9} = 13\tfrac{1}{3} \text{ inches.}$$

5. What is meant by lap? What is the difference in the working of two engines, one of which has lap to the slides and the other has not (1867)?

6. Describe an equilibrium valve. The upper side of an equilibrium valve is 9 inches in diameter, and the lower side 8 inches; find the power necessary to lift it when the steam is 16 lbs. above that of the atmosphere, if the space between the upper and lower valves be a vacuum (1867). *Ans.* 413·9 lbs.

7. Describe generally the side lever marine engine. What is the object of the blow-through valve, and where is it placed? Which parts of the engine are made of brass, and which of cast or malleable iron respectively (1870)?

8. Explain the principle of an equilibrium valve, and illustrate your explanation by referring to the Cornish double-beat or crown valve. In a double-beat valve the internal diameters of the two seats are 5 and $3\frac{1}{4}$ inches, and the weight of the valve 68 lbs., what head water could be held back by such a valve, before the pressure of the water would cause it to lift (1870)?

It will keep back a pressure of 5·99 lbs. on the square inch or 15·57 feet of water nearly.

Effective area of valve × pressure = weight of valve proper.

$$\left\{ 5^2 - (3\tfrac{1}{4})^2 \right\} \times \cdot 7854 \times \text{pressure} = 68 \text{ lbs.}$$
$$\therefore \text{pressure} = 5\cdot 99 \text{ lbs.}$$

9. What is the distinction between a single and a double acting air pump? Sketch both forms of air pump, showing the valves necessary in either case. Describe the India-rubber disc valve (1870).

10. Describe some form of slide valve as fitted to the steam cylinder of a double acting engine. Sketch the valve in section with the openings over which it slides, and give some account of lap on the steam side. How is the face of such a valve made truly plane (1871)?

11. For what purpose are escape valves fitted to the cylinders of marine engines? How are such valves kept closed, and what determines the least amount of load which must be put on them (1871)?

12. Show that a single slide valve will suffice to work a double acting engine, in the place of two steam and two exhaust valves. Explain with a sketch the action of any slide valve which you select (1871).

13. Define the lap of a slide valve. Explain the effect produced by adding lap, (1) to the steam side, (2) to the exhaust side of valve, showing what would occur if there were no lap on either side (1871).

14. A pump valve is made in the form of two rings, each 1 inch wide, and of internal diameter 6 and 12 inches respectively, what is the area of the openings of the seating, and what should be the lift when the valve is full open (1871)?

Ans. Area 29·8452 inches. Lift $\frac{1}{4}$ inch.

15. The safety valve on the boiler of a locomotive is held down by a lever and spring, sketch the arrangement. A safety valve 4 inches in diameter is constructed, so that each pound of additional pressure per square inch on the valve corresponds to 1 lb. pressure on the spring, what are the relative distances of the spring and valve from the fulcrum of the lever? After the valve is set, how much additional pressure per square inch will be necessary in order to lift it $\frac{1}{20}$ of an inch, the spring requiring 10 lbs. to extend it 1 inch (1871)?

Ans. Relative distances 2 : 25, nearly.
,, ·497 lbs.

16. Describe the locomotive or three ported valve, as applied in engines of short stroke. Why is its use restricted? Show that lap added to the valve produces an expansive working of the steam (Honours, 1871).

17. Describe the long D slide. The cover of a valve is $1\frac{1}{2}$ inches, whereof $1\frac{1}{4}$ inches is the lap on the steam side, and $\frac{1}{4}$ inch is the lap on the exhaust side; if $\frac{1}{8}$ inch is allowed for lead, what will be the amount of opening of the lower part to the exhaust when the piston is at the top of its stroke? Why is the lap on the exhaust side made so much less than that on the steam side (1870)?

Ans. $1\frac{1}{8}$ inches.

18. Describe some arrangement of expansion gear suitable for a marine engine. What form of valve should you employ (1870)?

19. Show how to find the proper length of the eccentric rod of an engine. The travel of a slide is to be increased from 13 to 15 inches; what alteration must be made in the length of the eccentric lever, whose original length was 12 inches (1863)?

Ans. Gab lever must be shortened $1\frac{3}{5}$ inches.

20. Describe the safety valve. If a circular inch be allowed on the area of a safety valve for every 200 square feet of heating surface, what must be the diameter of a valve for a boiler whose heating surface is 1,200 square feet (1868)? *Ans.* 2·45, nearly.

21. Describe the Cornish double-beat valve (1868).

22. Describe the Cornish double-beat valve with a sketch (1866).

23. There are two valves, the diameter of one is 2·5 inches less

than that of the other, and the sum of their area is the same as that of a valve of 11 inches diameter, find their dimensions (1866).

Ans. 6·4 and 8·9.

24. How is the slide of an engine placed in the middle of its stroke (when adjusting the slides) (1866) ?

25. What is the use of the cylinder escape valves? The steam pressure of a boiler is increased from 12 to 15 lbs., how much must the weight of the lead cylindrical weight on the valve be increased, its diameter being the same as that of the valve, and a cubic foot of lead weighing 710 lbs. (1866)? The question as it stands is absurd, the weight would be a yard high.

Ans. 7·3 inches in length.

26. In some double acting engines the valves connected with the steam cylinder are double-beat valves worked by cams. State the advantages of this system, and explain the principle of a double-beat valve (Honours, 1871).

27. Describe the locomotive and long D slides. The travel of a slide is 14 inches, depth of the port 6 inches, and the slide is short on the exhaust side $\frac{1}{4}$ inch; when at the middle of the stroke, how far does the slide go below the lower edge of the port on the exhaust side at the extreme of its stroke (1863)?

Ans. $1\frac{1}{4}$ inches.

28. Describe the long D slide, and show how it is worked by the eccentric. How is the packing of the slide at the upper and lower ends lubricated (1864).

29. Describe the safety valve of a locomotive boiler. Explain Bourdon's gauge for ascertaining the exact pressure of the steam in a boiler (1869).

30. How is the scale of the barometer gauge graduated? What error is introduced by having the scale fixed? To what extent will a thermometer, having its bulk inserted in the condenser, supply the place of a barometer gauge (1863)?

31. Give a sketch of a blow valve and a snifting valve, and show why these valves require no spring nor weights to keep them in their seat (1863 and 1864).

The blow valve has steam above and a vacuum below. The snifting valve, which is frequently kept in its place by a spring, has the atmosphere above and a vacuum below.

32. Explain the meaning of the terms cushioning, lead, and lap. On what is lead made to depend (1864)?

33. In what way is steam admitted into the cylinder? How is the apparatus worked (1865)?

34. Describe with a sketch some form of slide valve, as connected with the steam cylinder of an engine, and explain its action (1869).

35. Describe the method of working a slide valve by an eccentric (1869).

36. Describe Kingston's valve. Show how to ascertain the degree of saltness of the water in a marine boiler (1869).

See chapter X.

37. Describe some form of steam slide valve adapted for a double

acting engine. How are the faces of such a valve prepared so as to make it steam tight (1869)?

38. Define the lap of a slide valve. What is the object of putting lap upon a slide? What is meant by the lead of a valve, and what considerations determine the amount of lead (1869)?

39. Describe and explain some form of equilibrium valve. The diameter of a steam pipe is $12\frac{1}{2}$ inches, the upper and lower discs of an equilibrium valve being 12 and $10\frac{1}{2}$ inches in diameter respectively, what will be the lift of the valve when the pipe is fully open (1869)?

Ans. 1·736 inches.

40. Describe Kingston's valve. Sketch the arrangement of a feed pump and the valves connected with it. How are India-rubber annular valves made and fitted (1869)?

41. Describe the blow valve and the snifting valve, and why the former is not so important as formerly?* The diameter of a blow valve is 4·5 inches, and the steam gauge at 23 inches, what force is required to lift it before and after a vacuum has been created in the condenser, the barometer gauge in the latter case standing at 24 inches (1869).

Ans. 556·652 lbs.

42. Give a description of the gridiron valve. A gridiron valve has three openings for steam, each 16 inches by 3, find the total opening for steam. *Ans.* 144 inches.

43. Describe the short D slide; explain its action, and state in what respect it differs from the long D.

44. Give definitions of "full steam," "cut off," "angular advance," "linear advance," and "travel of slide."

The *travel of a slide* is the sum of the distances it moves up and down from its mid position.

45. How do Seaward's slides differ from others, and what is meant by the steam and exhaust side of the cylinder.

46. Describe any form of valve that is self acting.

47. What is meant by a "rotatory valve?"

48. Explain the term "balanced slide." Why do slides require balancing, especially those of the steam hammer?

49. Describe Hornblower's valve.

50. Give a sketch of a "snifting" and "blow-through valve.'

* Higher pressure steam is used, and therefore in starting the engineer has not to depend so much as formerly upon a good vacuum.

CHAPTER VIII.

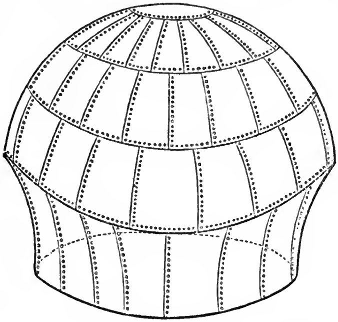
THE BOILER AND ITS APPENDAGES.

Definition—Haycock, Haystack, or Balloon Boiler—Waggon Boiler—Flue Boilers—Length and Diameter of Flue—Plates—Marine Flue Boilers—Blast Pipe—Steam Chest—Locomotive Boilers—Field's Boiler—Galloway's Tubes—Vertical Boiler—Cornish Boiler—Fusible Plugs—Clothing Boilers—Copper Boilers—Testing—Water Heaters—Surface Condensation—Circulating Pumps—Ejector Condenser.

The boiler is the vessel in which steam to drive the engine is generated. It has received various shapes from early and late engineers, such as haycock or balloon, waggon, sphere, hemisphere, ring or annular, flue, Lancashire, Cornish, and return-tubular, Field's, etc. The early boilers were very defective in their construction, being actually made of cast-iron with leaden or wooden tops, and even with wooden shells hooped like barrels, and often with flat surfaces—the weakest of all forms; but then no danger arose, for the pressure seldom or never exceeded twelve or fifteen pounds on the square inch; but now, when boilers have to submit to ten or twelve times that strain, care, thought, and diligent enquiry are absolutely necessary.

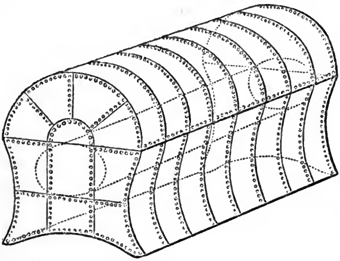
If, in the construction of steam boilers, strength alone were studied, the spherical form would be adopted, because it is the strongest of all forms in which a vessel can be made if it is to resist either internal or external pressure; but although such boilers have been used here and there they will never come into extensive use, because they have not a large amount of heating surface. The cylindrical form is next to the spherical in point of strength, and superior to it in respect of superficial area or heating surface, hence this form is very generally adopted.

148. The Haycock, Haystack, or Balloon Boiler, perhaps the earliest used, had for its lower part the frustrum of a cone, and its top a hemisphere. Some of these may still be seen at old mines. It is said that more explosions have occurred with these boilers than with any other class. Its shape is inherently weak.



BALLOON OR HAYSTACK BOILER.

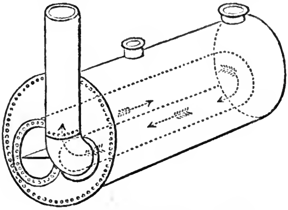
149. The Waggon Boiler has been more extensively used than the last. In shape it is somewhat like a carrier's waggon. The fire is placed beneath the bottom. It was employed very much by Boulton and Watt; being surrounded with brickwork flues in such a manner that the heated air and gases could run all round the lower part of the boiler. These are not strong boilers, they require much staying. When an explosion takes place, they generally give way at the bottom.



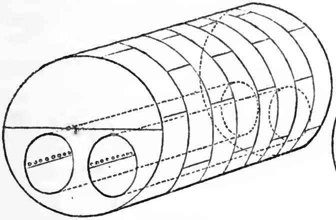
WAGGON BOILER.

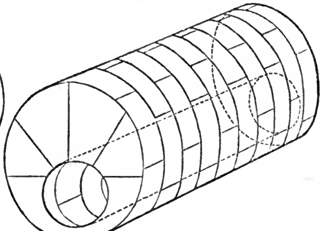
150. Flue or Cylindrical Boilers (external pressure).—These are a great stride beyond the last, and approach the true shape of a truly efficient boiler. They consist of a large cylinder with one or more flues passing through their whole length, which are generally built of plates of the same thickness as the other parts of the boiler, but experiments prove this to be a vicious system.

Flue boilers assume many different arrangements as regards the flues. The next figure shows the return flue boiler. At first the flue went right through, the fireplace at one end and the chimney at the other. It was a great improvement and early introduced, to let the flue curve round at the further end and return to the front, so that chimney and fireplace were both at the same end. The fireplace is seen to the left, and the chimney on the right of the front, while the dotted lines show the course of the flue in the boiler.

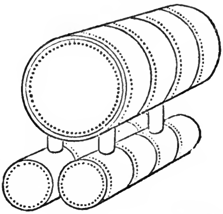

RETURN FLUE BOILER.

When the boiler has but one tube running from end to end, it is generally called a Cornish boiler, and when two it receives the name of Lancashire boiler; but we have explained a little further on with an illustration the real distinctive features of a Cornish boiler, and it must not be left unstated that we may


LANCASHIRE BOILER.


CORNISH BOILER.

speak of a two-tube Cornish boiler; but still it is a very common mode of distinguishing boilers of one and two tubes from each other, especially in the Midlands, calling them respectively Cornish and Lancashire boilers.


ELEPHANT OR FRENCH BOILER.

151. Elephant or French Boiler.—One of the most extraordinary forms given to boilers is shown in the annexed illustration, which is not only a very bad form of boiler, not being economical, but it is a dangerous one.

152. Length of Flues.—Sometimes flues are made to run the whole length of the boiler, twenty or thirty feet, without any supports. Three tubes were taken, four inches in diameter, of the same thickness of iron, supported at the ends by rings, but respectively nineteen, forty, and sixty inches long. Pressure was brought to bear upon them, and they collapsed at 137, 65, and 43 lbs. per square inch. This clearly demonstrates that the strength of similar tubes to a collapsing pressure, is in inverse proportion to their length. Two boiler flues forty-two inches in diameter, three-eighths of an inch thick plate, and twenty-five and thirty-five feet long, collapsed—the former at a pressure at 97, and the latter at 27 lbs. on the square inch.

153. Diameter of Flues.—The greater the diameter of a flue or cylindrical boiler, the weaker it is. Its strength varies inversely as the diameter, *i.e.*, double the diameter, the strength is diminished by one half. From experiments: three five feet tubes, four, eight, and twelve inches in diameter, about $\frac{1}{22}$ of an inch in thickness, collapsed at a pressure of 43, 20·8, and 12·5 lbs. on the square inch respectively.

154. Thickness of the Plates.—The *strength of flue* is augmented with the thickness of the plate in a little greater proportion than the square, *i.e.*, if a plate one-eighth of an inch thick bear a certain strain, then one double the thickness, or one-fourth of an inch thick, will bear a strain equal to $2^{2\cdot19}$, or more than four times as great. Then, because the greater diameter of a tube the weaker it is, and because, also, the strength of a plate increases with its thickness, therefore the thickness of a tube plate should be in proportion to the diameter of the tube; or, the plates of a two feet diameter flue should be, within certain limits, double the thickness of those of a one foot flue; or, if the plates of a one foot flue are one-fifth of an inch thick, those of a two feet flue should be two-fifths of an inch thick.

Mr. Fairbairn, to whom we are indebted for these important experiments, and from whose valuable work, *Useful Information for Engineers,* these facts are culled, proposes a remedy and modification in tubular boiler tubes, which have hitherto been constructed without a correct knowledge of the laws of nature. He proposes that strong rings of T or angle iron shall be riveted at intervals of 10 feet or less along the flues, thus practically reducing them to several tubes of short length, and, therefore, considerably increasing their strength. He also proposes that they should not be formed with the usual *lap joints*, but with riveted *butt joints*, and longitudinal covering plates.

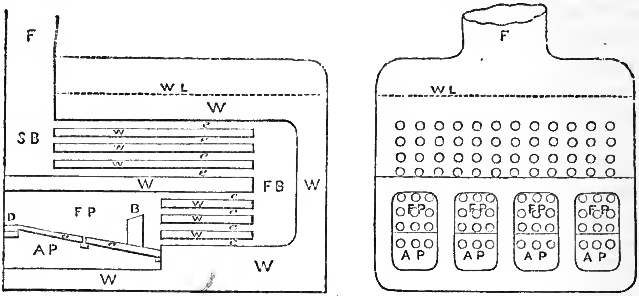
155. Boilers' Internal Pressure.—He also shows that the tensile strength of a boiler plate is nearly the same whether torn asunder in the direction of the fibre or across it; and that heat does not affect their strength up to 315° C., above which they rapidly become weaker. Riveting reduces the tenacity of a boiler or the bursting pressure from 23 tons per square inch to 15 tons. Cylindrical boilers made of the same thickness of plates throughout are more liable to give way along the sides than at the ends.

The external shell of a boiler is three or four times stronger than the flue, if both are constructed in the ordinary manner; or, the outside shell more easily resists the bursting pressure than the tubes can the collapsing. But if the flues are divided into lengths of 10 feet or less, by strong ribs of angle iron, their resistance is enormously increased. Cylindrical boilers must be strengthened in the same way, but are considerably weakened if made elliptical instead of cylindrical.

156. The Marine Flue Boiler.—In this boiler the fireplaces are within the shell, and the flues wind backwards and forwards until they discharge the remaining heat up the funnel, the furnace (or furnaces) being at the end of the boiler, below the middle of the water. The heat first descends to the bottom of the boiler and towards the farther end, it then winds back towards the furnace, and turning up and back comes now to the bottom of the funnel, near the centre of the boiler.

157. The Marine Tubular Boiler.—In tubular boilers the heat is allowed to pass into and through a series of tubes which run through the water. They are chiefly employed in locomotive and marine engines.

The figures on next page represent (1) a longitudinal section of a marine tubular boiler, (2) a front view—partly in section, to give a better idea of it, and showing four furnaces F P, with the ashpits A P. The small circles represent the ends of the tubes, W W is the water in the boiler, w w w the water around the tubes, the spaces between them are the tubes themselves, W L is the water level. In the left hand figure F P is the fireplace, B the bridge. The coal is first thrown on to the dead plate D to warm, it is then pushed on to the fire bars *a a*. The fire bars are in lengths,



1. *Longitudinal Section.* 2. *Front Elevation.*

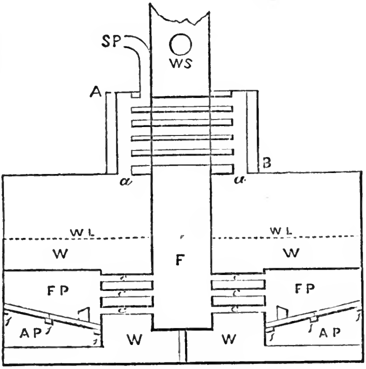
TUBULAR BOILER.

and the ends are not close together, to allow for expansion. B is the bridge to prevent the fire from getting too far back in the furnace; the bridge sometimes forms part of the boiler itself—a very bad practice—but is more frequently built of Stourbridge fire-clay bricks. The heated air and gases pass over the bridge through the lower tubes *c c c c* into the fire box F B, then through the tubes *e e e e* into the smoke box S B, and up the funnel or uptake F. The smoke box has a door opening into the engine room, so that the tubes may be cleared out should soot, etc., lodge in them. They also slant a little, the short ones towards the fire box, the longer ones towards the smoke box; so that the heat may receive more resistance in passing through, and have a better chance of communicating its motion to the water.

The next figure is another form of marine tubular boiler, which has been much used in compound engines. The boilers just described are not constructed to bear a very great pressure of steam, but those on this principle are.

In this figure the references are the same as in the last. F P is the fire place or furnace, A P is the ashpit, W the water, W L the water line, *c c c* the tubes, F the funnel—the bottom of which in this arrangement answers both for fire box and smoke box. Each fireplace has its own boiler, which can be kept perfectly distinct, as will be explained when speaking of the communication valve.

A B is the superheating apparatus; the steam leaves the *steam chest* by the passages *a a*, and passing in and out through the tubes within A B becomes further heated, by the heat passing up the funnel, and is carried off by the steam pipe S P to the cylinder. At W S the waste steam returns through the exhaust pipe, and rushing up the chimney creates a draught, answering better than a blast, and giving the engine-maker a chance of making his furnace small.



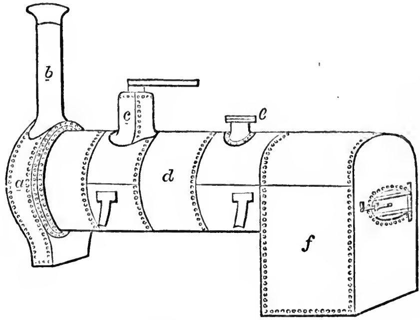
SECTION OF MARINE BOILER.

158. The Blast Pipe is a pipe leading from the boiler into the funnel to create a draught while getting up steam; but when the engine is moving (non-condensing engines), the waste steam passing through the waste steam pipe performs this office. The steam rushing up the funnel leaves behind a vacuum, when the air, rushing through the fire bars to supply its place, gives up its store of oxygen to combine with the other products of combustion, and intense heat is produced. It was this contrivance that so efficiently assisted Stephenson to win the prize of £500 at the memorable competition at Rainhill, when his engine, the Rocket, now in the South Kensington Museum, defeated the Novelty and Sanspareil. He also used coke and a tubular boiler.

159. The Steam Chest is either a dome above the boiler, or else the upper part of the boiler. It is a reservoir for steam, so that should the engines be using steam faster than the evaporation of the boiler, there is a supply to fall back upon.

The little squares marked with a dash (′) in the figure on page 139 are sections of the bearing bars which run across the fire places to support the fire bars.

160. Locomotive Boilers.—In the figure on page 138 suppose the fireplace reaches up higher, and that all the tubes are of the same length, but longer, and that the smoke box is where the fire box is, and the funnel above it, you have then a very good idea of a locomotive boiler. The fireplace is made of copper, being better adapted to bear the intense heat and a better conductor than iron, it therefore communicates the motion more readily to the water. Over the fireplace is a part of the boiler *quite flat.* This is theoretically the weakest part of locomotive boilers; and, therefore, it is well strengthened with angle iron, gussets, rods, etc.



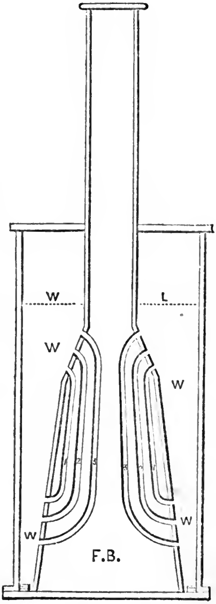
LOCOMOTIVE BOILER.

A full explanation of the locomotive boiler, with figures of the different details, is given under the proper headings in the chapter on the *Locomotive.*

161. The Field Boiler.—The Field boiler, named after its inventor, is an ordinary boiler, with the bottom, or part immediately over the fire, consisting of a series of vertical tubes—or rather two tubes, one inside the other. These come down towards the fire. The peculiar action or advantage of this boiler depends upon convection. The heat of the fire in contact with the tubes heats the water between the two tubes, which immediately ascends, while other water moves down the central tube to supply its place; so that, as the heated water and steam ascend, a constant circulation is promoted, and other water is brought in contact with the heat.

162. Galloway's Conical Water Tubes are an application of the same principle. They are exceedingly well adapted for flue boilers, being used to connect the bottom water with that above the flues; as the water in the tubes is heated it ascends by convection, and a constant circulation is kept up between the lower and upper water. They are of the same thickness as the boiler plates, and their seams are riveted; they are, therefore, not liable to leak or split, while they act as very strong stays.

163. Vertical Boilers.—Vertical boilers assume many shapes internally, although their outward appearance corresponds very much to the figure in the margin. Vertical boilers are used in steam cranes, hoists, and often in portable engines, and in Samuel's express locomotive. In this figure F B is the fire box; the letters W W show the water spaces, W L the water line. It is seen that tubes leave the boiler immediately above the fireplace, and rejoin the water at the crown of the furnace. Evidently from this arrangement the convected water will have a free rise, and a given quantity of heat will produce a fair amount of evaporation. In vertical boilers vertical tubes are used, as in Samuel's locomotive mentioned above; but vertical tubes by no means constitute a vertical boiler.

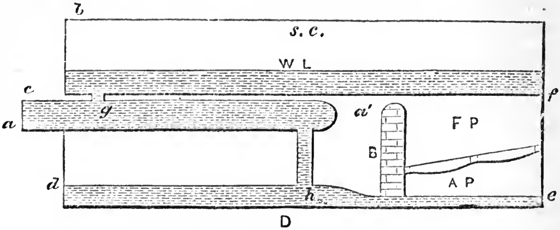


VERTICAL BOILER.

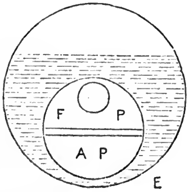
164. The Cornish Boiler.—The Cornish boiler is a long cylindrical one. Its peculiarity is in the internal arrangement of the flues, which can be best understood by well examining the following figures.

D is a longitudinal section, E a cross section. The lines of shading in both figures show the water. *c d e f* is the flue, in the right hand of which is the fireplace and ash pit.

Immediately behind the fire bridge B is a large tube *a'a* running beyond the end of the boiler to *a*, and suspended



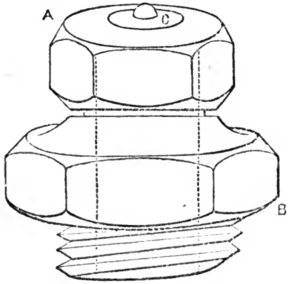
Longitudinal Section.
CORNISH BOILER.



Cross Section.

within the flame and burning gases. It communicates with the rest of the boiler at *g* and *h* by means of two copper pipes. Sometimes the pipe is not at *g*, but leads from the end *a* into the top of the boiler at *b*. W L is the water level, and it will be observed that there is a very large steam chest *s c*, and that the surface of the water is large. It is for this reason that there is no priming in Cornish boilers—the steam having plenty of room and a large surface to rise from. The fire and heat play everywhere within the flue, and are brought right round under the boiler, and pass along by D to heat the water in the bottom space *d h e*. The whole is set in masonry, and the arrangements are so good that very little heat can escape by conduction or radiation, while the heating surface is very great. From having such a large amount of heating surface it has been calculated that a pound of best Welsh coal in a Cornish boiler will evaporate $11\frac{1}{2}$ lbs. of water.

165. Fusible Plugs.—A precaution that should always be adopted to prevent boiler explosions will be found in the use of a fusible plug, or fusible metal plate, or a lead rivet placed in the boiler immediately over the fireplace. The lead rivet melts when the temperature of the plate is raised to a heat the steam does not reach, 338°C.; so giving vent to steam, the engineer knows of the existence of danger immediately. The fusible plug in the shape of A B has the part C consisting of an alloy of tin, lead, and bismuth, which melts when the heat of the steam is somewhere between 138° and 176° C., *i.e.*, as soon as the pressure becomes excessive.



FUSIBLE PLUG.

Boilers are generally fitted with man-hole and mud-hole doors. The *man-hole* is generally in the top of the boiler, and is fastened on with bolts and nuts. Its purpose is to give ingress to the interior of the boiler, so that any necessary repairs may be made. The *mud-hole door* is fitted in the bottom to allow of its being easily cleansed from accumulation of mud, salt, etc. This particularly applies to marine boilers, and boilers in river steamers. The mud-hole door should be fitted on *inside*, and the heads of the bolts should be *inside*, and the nuts outside. Through inattention to these points several accidents have happened. The nuts have become loose and the mud-hole door given way, when the whole body of water and steam have been driven into the engine-room and the men scalded to death.

166. Clothing of Boiler.—Instead of boilers being allowed to come in direct contact with the brickwork around them they are embedded in some non-conducting substance as wood, fine cinders, etc., so that a minimum amount of heat may escape by conduction from the boilers. For the same reason, cylinders are clothed and jacketed, while the top of the boilers are frequently covered, *i.e.*, clothed with wood, hair-cloth, etc., and painted to prevent radiation.

167. Copper Boilers.—Copper boilers are not so efficient as iron boilers. At one time they were used to a considerable extent, but it was found that, when leaky, salt acted injuriously, and they were soon damaged by sulphurous coal, and became weaker the more they were heated; but copper being a better conductor than iron, the heat more readily passes into the water, and consequently there is more economy exercised. They are not quite so strong as iron, in the proportion of 16 to 23, but they do not waste by scaling; and, therefore, they retain their original strength for a long time, while the iron ones are continually getting weaker and weaker. In consequence of its great conductibility and not wasting and burning at the joints, copper is used for the furnaces of locomotive boilers.

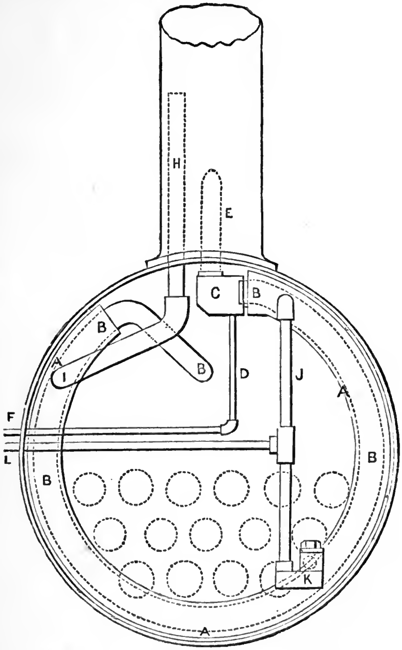
168. Testing Boilers.—Before a boiler is put to work its strength is tested by hydraulic pressure, also after it has been repaired. It is thus done: Every orifice is secured or else plugged up but one. The boiler is then filled with water, and an hydraulic pump attached to the opening left. A pressure gauge is attached to the pump and water is forced in, until the pressure gauge indicates a pressure three or four times that at which it is intended the boiler shall work. This will find out any leaks in the boiler, and should a part be too weak for the working strength, it is sure to be discovered.

I once saw a primitive way of testing a boiler. The boiler was filled by a pipe coming from a pool on a high ridge just behind the forge—the pipe being properly secured, no water could escape from the boiler; then as the pool was about 150 feet higher than the boiler, the pressure of water from the head severely tested its strength. 150 feet would give a pressure of 65 lbs. on the square inch.

169. Water Heater.—It is found very advantageous to heat the water before it enters the boiler, and if this can be effected by the waste steam and gases there is great economy and saving in fuel. This figure represents a very good method of carrying it into practice.* A A is a flat cast iron pipe fixed in the smoke box; through this pipe the exhaust steam passes along B B a second pipe inside A, heating the water lying between the two pipes A and B. The water is also heated by the waste heat round A A. The exhaust steam after passing round goes up the blast pipe and funnel E as usual. C is a chamber where the condensed steam water

* By Messrs. Cambridge, of Bristol. See *Engineer*, Aug. 5, 1870, Vol. xxx., page 87.

is stopped, and passes through tube D to be returned to the boiler by the pump, which forces the water through the



CAMBRIDGE'S FEED WATER HEATER.

tube H into the tank at I, after which it passes through J to boiler at K.

170. Water's Feed Water Heater is on rather a different principle to the above, and is said to produce a good result. A pipe brings the waste steam up through a reservoir for the heated water. The feed water enters at the upper part of the reservoir, being forced in fine spray through a sprinkler, so that a great surface in a small amount of water is presented to the steam to absorb its latent heat. At the top of the reservoir, above the sprinkler, is a deflector, which for a moment keeps the steam in contact with the water-spray from the sprinkler before it escapes through the top of the reservoir. It might be thought that part of the spray would fall down the exhaust passage, but this can scarcely take place to any injurious extent, because the force of steam will balloon the spray up again until it falls into the reservoir considerably heated. From the reservoir the water is taken in the ordinary manner into the boiler.

171. The Amount of Water Required for Condensation.— The proper temperature at which to keep the condenser is as near as possible 100° F. or 38° C. At this temperature the steam is sufficiently condensed, while the air pump has relatively the least quantity of water to raise; or, with a maximum amount of useful condensation, we have a minimum amount of water to lift.

Let us suppose the condenser is to be kept at 100° F., and the temperature of the condensing water is 50° F., then out of every unit of water $100° - 50° = 50°$ of cold are available to condense the steam.

Watt assumed the total heat in steam to be 1112°F. (latent and sensible heat of steam we have called 637°·2C. or 1147°F.); therefore there are 1112 units of heat to be overcome, which will take $\frac{1112}{50} = 22{\cdot}24$ units of water; or it will take $22\frac{1}{4}$ more times water than is turned into steam. As a cubic inch of water produces a cubic foot of steam, it will take $22\frac{1}{4}$ cubic inches of water to condense one cubic foot of steam. Watt allowed 28·9 cubic inches, or about a wine pint, for every cubic inch evaporated.

In this calculation we have given the result arrived at by Watt. We will now perform the calculation, using degrees centigrade, making allowance for *the heat which will be left* in the condensed steam, and using the more accurate number, 637°·2C.

Suppose the temperature of the condenser is to be maintained at 38°C., and the temperature of the condensing water is 10°C., what amount of water will be required for condensation?

The total amount of heat in a given unit of steam is 637·2 units C.

The amount imparted to each unit of water is $38 - 10 = 28$ units C.

Of the 637·2 units of heat in each unit of steam, it must give up $637{\cdot}2 - 38 = 599{\cdot}2$ units.

$\therefore$ the units of water required $= \frac{599{\cdot}2}{28} = 21{\cdot}4$.

Or, a cubic foot of steam as it is produced (very nearly) by a cubic inch of water, will require 21·4 cubic inches of water to condense it. More is always allowed, because it is impossible so to arrange the condenser, that every drop of water shall at once consume its allotted amount of heat.

The temperature of the condenser will always give an idea as to the vacuum. If the temperature of the condenser is above 100°F., then more water must be supplied for condensation; if it is below 100°F., then the cocks must be closed a little, as too much water is being used and the air pumps will have too much work thrown upon them. When the air pumps are labouring too hard, it is one sign that too much condensing water is being used. A thermometer therefore inserted in the condenser will show the state of the vacuum. Generally the engineman trusts to his vacuum gauge to tell him the state of his condenser. If the vacuum gauge is low, too little water is being used, and he must remedy the defect accordingly.

172. Surface Condensation.—Surface condensation consists in exposing the hot steam to large cold surfaces. Watt tried it. A few years ago Hall introduced his surface condensers. They did not answer originally on account of occupying so much space, adding more parts to the engine, and the pipes becoming furred up. They seem now to be coming more into use, being fitted in many of our iron-clad vessels, as the "Minotaur," "Lord Warden," "Lord Clyde," "Pallas," etc. The "Lord Clyde" has 13,000 vertical tubes for the condensation of steam. Hall's surface condensers consist of an immense number of vertical tubes or pipes placed in a large tank. The steam, after being used in the cylinders, passes through these pipes. Water surrounds the tubes, and is forced through the tank in among the tubes, either by pressure from behind or by creating a vacuum in front. The cold water enters at the opposite end to the steam, and goes out at the end where steam enters; thus the hot steam meets the warmer water first and the colder last, by which arrangement the water is made to carry off as much heat as possible.

173. Circulating Pumps.—The introduction of surface condensation has been necessarily followed by new arrangements for impelling the cold water *among* or *through* the tubes. To perfect the system circulating pumps are used. They are worked by eccentrics on the main shaft, and often directly from the piston by rods. Occasionally auxiliary engines have been employed with considerable advantage to circulate the water for the surface condensers. The water is forced through or around the tubes in the majority of cases, but is sometimes made to follow the vacuum.

174. Summary on Surface Condensation.*—The advantages of surface condensation are :—

(1) Freedom from injurious deposits in the boiler. This follows from using absolutely pure water, and not water that has been used for condensation. There is no necessity to scale the boilers or clean out salt.

(2) The boiler can be used with a higher pressure of steam. Scale and incrustations render it almost impossible to stay a marine boiler properly. Hence, when these evils are got rid of, we may use boilers of improved construction and higher pressure steam.

(3) The foulest water may be used for condensation without risking injury to the boilers or engine.

(4) A more regular supply of feed water can be relied upon. Under ordinary circumstances it requires constant watchfulness to regulate the feed and the brining.

(5) The load on the air pump is more regular, so that in heavy weather the engineer need not reduce the injection water.

(6) Fuel is saved, as no blowing out is necessary. This saving of coal may often amount to from 15 to 25 per cent., which is something very considerable on a long voyage.

(7) Being able to use high pressure steam, the economy of increased expansion can be fully realised.

(8) The boilers do not require cleaning so frequently, so labour is saved, and there is less wear and tear.

(9) When no scale forms on the boiler, the iron plates more readily communicate the motion of the heat to the water; so fuel is saved from the absorption powers of the boiler being unimpaired.

* From a paper by Mr. J. F. Spencer, read before the Institution of Engineers (Scotland), 5th February, 1862.

(10) With expansion at half stroke and superheated steam, one-half the usual boiler surface is ample, and the boiler power may be reduced one-fifth without any loss of indicated power.

The mechanical disadvantages of surface condensation are not insuperable, some existing more in imagination than reality. They may be classified under the following heads:—

(1) Additional pumps and machinery are required for circulating the condensing water.

(2) Additional space is required by the surface condenser itself and its appendages.

(3) It has been alleged that, under certain circumstances, the constant return of the same water to the boiler creates a tendency to corrosion in the boiler.

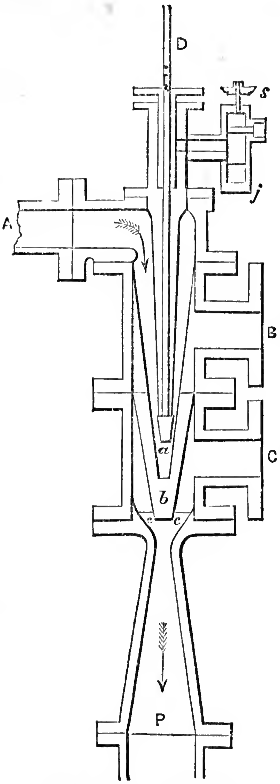
(4) The multiplicity of tubes in the surface condenser creates complication.

(5) There being so many tubes and joints in the surface condenser, there is a large increased liability to leakage.

(6) There is an increased first cost in the machinery of from 10 to 20 per cent., with an increased cost of repairs to additional machinery and condenser.

(7) A larger amount of condensing water is required for surface condensation than for injection condensers.

175. Moreton's or Barclay's Ejector Condenser.—The principle of the injector is modified to serve the office of a condenser. A glance at the figure will in a moment show the similarity of the two pieces of mechanism. The exhaust steam rushes from the cylinder into the condenser, and is met by a current of water which condenses the steam. The water rushes into the vacuum at a velocity of more than 40 feet per second, while that of the exhaust steam is many times greater. This force in the ordinary arrangement is lost in the condenser, either against its sides or in agitating the water, hence heat is developed and power lost. On an average this loss, together with that required to work the air pumps, is ·6 lbs., or a little more than half a pound per square inch. Now in the ejector condenser the power in the rush of steam and water is found to be sufficient to carry all the water, air, and uncondensed steam into the hot well at once without the intervention of an air pump.



MORETON'S EJECTOR CONDENSER.

The cold water passes from a tank through A to the nozzle *a*, which is surrounded by two more nozzles *b* and *c*, through which pass the exhaust steam by way of B and C from the two cylinders. Beyond the three nozzles is a gradually widening pipe P, which leads to the hot well. The condensation of steam takes place between *a* and *c*. The action is as follows: The water enters A at a pressure sufficient to make it flow with a velocity of 43 feet in a second, and rushes through *a* when D is screwed up; it is then met by steam at *b* at a much higher velocity; the water condenses the steam, but partaking of its impetus, both rush on to be joined by more steam at *c*, and again receiving more impetus, while *all* the steam is condensed, both water and .condensed steam rush on to the hot well by way of P.

Instead of the injection water being started from a tank to give it the necessary velocity, it may be set in motion by a small jet of steam. The part *sj* is on purpose for this. The rod is screwed up, when a jet of steam mingling with the water carries it forward to meet the exhaust. This jet can be shut off after the apparatus is fairly acting.

It is a remarkable circumstance that the ejector in its operation carries out all the air. This is doubtless on the same principle that the Trompe carries the air into a chamber to be afterwards used as a blast in smelting operations in the Catalan forges in the northern part of Spain.

CHAPTER IX.

APPENDAGES TO THE BOILER.

Safety Valve—Salter's Spring Balance—Bourdon's Gauge—Vacuum Gauge—Mercurial Gauge—Glass Water Gauge—Vacuum Valve.

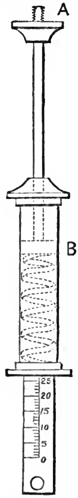
THE necessary appendages to a boiler are the safety valve, the gauge, which may be the old fashioned mercurial gauge, Salter's spring balance, or Bourdon's gauge; the reverse valve, the glass water gauge, or else gauge cocks.

176. **The Safety Valve** is a lever of the third kind, the fulcrum at one end, the weight at the other, while the power is exerted between the two.

It is a conical valve fitted steam tight on its seat and kept down by a weight. The weight is so proportioned that when the steam exceeds a certain pressure the valve will lift and the steam escape, and so prevent the boiler bursting, by keeping the pressure below a fixed maximum. Its area varies with different makers, but some engineers follow the rule of allowing half an inch of area to each horse-power of the engine. The weight is fixed by the engine-makers, and no increase should be allowed without their express sanction. Every boiler, when there are two or more to the same engine, must have its own safety valve. Some safety valves are kept on their seats by spiral springs.

177. **Salter's Spring Balance** is used especially in locomotives to exhibit the pressure of steam. Its principle is a steel spring, well tightened, which, according to the pressure of steam, extends after the manner of the spring steel yards used in public by our rag and bone merchants; or else the increased pressure of steam acts against the spring.

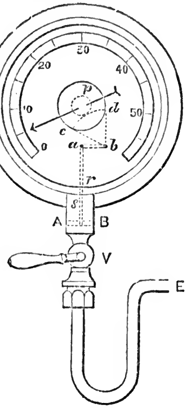
Another adaptation of the spring balance is shown by the figure on next page, where A is screwed into the boiler, or into a pipe in free communication with the steam, so that steam can enter the cylindrical body B; if we suppose the dotted lines at B are a piston, it will act against it to drive it down, which the pressure of the spring will not allow it to do until it overcomes its resistance. The greater the force of the steam the more will the spring be compressed, and the more of the graduated part be shown. Acting on this principle it is evident that, if it be properly graduated, the pressure of steam in the boiler will be correctly indicated by the scale. When used to keep down a safety valve, it acts at one end of the arm of a lever of the first class, and the steam pressure at the other in one arrangement. Thus Salter's spring balance is used in a simple manner for a *pressure* gauge, as well as to keep the safety valve on the seat.



SPRING BALANCE.

178. Bourdon's Gauge.—This gauge is produced in many shapes—we give one of the most portable and convenient in the figure on the next page. A B is a circular plate, fitting steam tight in *s*, but still readily moving with the least pressure. *s* is in free communication with the boiler, by way of E; therefore, the pressure of steam below will cause the plate to ascend, when the rod *r* will move the lever *a b* on its centre *b*, and with it the rack *c d*, which moves the pinion *p* from right to left, and with it the pointer P, which will indicate the number of pounds pressure in the boiler on the arc.

The use of gauges, it will be gathered from what precedes, is (1) to tell *accurately* the pressure of steam in boilers when water is hotter than 100°C.; (2) to indicate the *variation* in the pressure of steam from time to time. When we consider how much depends upon a knowledge of these facts, the following instance of, to say the least, carelessness and thoughtlessness will astonish us :—Out of 52 gauges tested for the Royal Agricultural Society, upon the occasion of their exhibition being held at Manchester, only 9 were correct. If this be a fair average, the deplorable fact comes to light that only 17·3 per cent. of the gauges in common use give correct indications of the state of the boiler pressure.



BOURDON'S GAUGE.

179. Vacuum Gauge.—The same figure will illustrate the vacuum gauge and its principle. This gauge is to show the state of the vacuum in the condenser, so is an appendage to the condenser and not to the boiler. E is fitted into the condenser. If A B be air tight, there being a vacuum in the condenser, when the cock V is opened the piston will *descend* by reason of the pressure of air above it. If the pointer be directed to a particular point when the air is acting freely on both sides of the piston A B, then, as the vacuum increases in the condenser, the pointer will move from left to right. When the gauge is used to show a vacuum the graduation only extends from 1 lb. to 15 lbs. The teacher must accustom his pupils to draw the figure clearly, pointing out the difference of action, when used as a vacuum gauge and as a steam pressure gauge.

180. Mercurial Gauges.—Mercurial gauges are and have been used to show the pressure of steam and the vacuum. But as they are very cumbersome, and nearly obsolete, it is useless to describe them, but we may say this much—

(1) **The Long Barometer Gauge.**—The pressure of air corresponds to very nearly 30 inches of mercury, which being about 15 lbs., 2 inches of mercury indicate 1 lb. pressure. A bent tube in the shape of a U, partly filled with mercury, was taken, and one end inserted in the boiler; as the pressure of steam increased it would drive the mercury down one part of the tube and up the other; a graduated scale of 2 inches to the lb. showed the pressure of steam in the boiler.

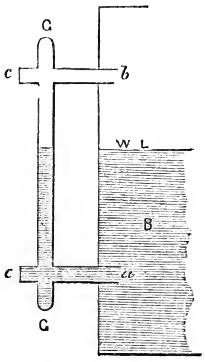
(2) When used as a vacuum gauge, the mercury would

follow the vacuum and rise up the part of the tube connected with the condenser.

(3) **The Short Barometer Gauge** was used to show the vacuum. It was of similar construction to the last; but between the legs, communicating with both, was a reservoir of mercury. As the pressure was taken off the reservoir the mercury fell down one arm, which was short; for as the vacuum between 10 and 15 lbs. only was wanted, the arm was made short, and would remain full of mercury till the pressure fell to 5 lbs. only; so that when the mercury stood 10 inches high, we should have a 5 lbs. pressure of air in the condenser; when 8 inches high, 4 lbs, etc.

The mercurial or barometer gauges are old-fashioned, and are hardly used now or fitted to new engines; therefore we have given no figures, merely a short description of them. To these gauges there are scales graduated to every two inches; so that by looking at them the engineman can tell at a glance the condition of his vacuum. If the mercury stand at 20 inches, then there is $\frac{20}{2} = 10$ lbs. vacuum, or $15 - 10 = 5$ lbs. pressure of air in the condenser. If the mercury stand at 24 inches, there is a vacuum of $\frac{24}{2} = 12$ lbs., or the pressure of air in the condenser is $15 - 12 = 3$ lbs. Another form of vacuum gauge is this: An iron tube is fixed into the condenser and bent upwards. At the bottom near the condenser is a cock, to open or close the communication with the condenser. Just above the cock is a small bowl for holding mercury, the tube passing right through the bowl, so that the mercury is round the bottom of the tube and outside it; the top of the tube is open. Now a glass tube open at the bottom and closed at the top, a little larger in the internal diameter than the outside diameter of the iron tube, is taken and placed right over the iron tube, the open end coming down into the mercury. When the communication with the condenser is opened, there being a vacuum within the iron tube, the pressure of the air on the outside pressing on the mercury will cause it to ascend between the two tubes; and, of course, the higher it rises the better the vacuum. It will ascend two inches for every pound. It is graduated, and a scale placed by its side; but as the mercury will sink in the bowl, a pointer or piece of wire is attached to the scale, the end of which bringing the scale lower with it, must be placed on a level with the mercury before the state of the vacuum is read off. Unless this precaution is taken, the reading is liable to error.

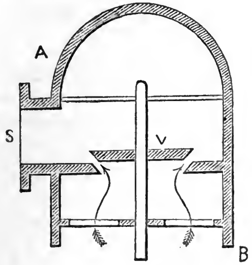
181. Glass Water Gauge.—The best contrivance to ascertain the height of the water in the boilers is the glass water gauge; whereby, at a glance, the engineer can see the height of the water in the boiler. Gauge cocks are also used; they consist of three ordinary cocks—the lower one placed below the level of the water, and from which water should always flow when it is turned; the middle on a level with the water, from which steam and water should issue; and the third above the level of the water, from which steam should always issue when turned. To bring the gauge cocks within reach of the engineman, they are placed low down or in a line, and tubes lead up inside the boiler to the required heights, and to a part of the boiler where the ebullition is least.



GLASS WATER GAUGE.

The figure simply shows the principle of the glass water gauge, which is often carried out by an elaborate system of cocks to prevent the gauge from choking, and to clean it out. B is the boiler and W L the water line, G G the glass gauge in communication with the boiler at *a* and *b*. It is seen that the height of the water in the gauge will show the level of the water in the boiler, and whether it be necessary to continue or discontinue the feed-water. There are frequently cocks at the two ends G and G, also at *c* and *c*, to clean out the gauge.

182. The Reverse Valve.—*Vacuum valve, internal safety valve,* or *atmospheric valve*—for it has all these names—is to prevent the boiler from collapsing through the external pressure of air. When a boiler has been in use, we will suppose the engine stops, and that the stop valve, safety valve, etc., are closed. Then, as the water cools down and steam condenses, a vacuum will exist in the boiler; and if means are not taken to prevent the external pressure of 15 lbs. on the square inch from taking effect, danger will ensue to it. A B shows the general appearance of the valve, S leads to the boiler. The air pressing upwards in the direction of the arrows will lift up the valve V and open it, when the internal pressure is at a certain stage below that of the atmosphere; then passing into the boiler through S, will restore equilibrium, or, at least, partial equilibrium. It is generally made of such weight that it will lift with an external pressure of 5 lbs. The pressure in the boiler can get below that of the atmosphere when the supply of steam is insufficient for the engines (if there be a good vacuum), or if a sea were to break over a ship and suddenly condense the steam in the boiler.



REVERSE VALVE.

EXERCISES CHIEFLY FROM EXAMINATION PAPERS.

1. Describe a cylindrical boiler with internal flues. State the advantages of this mode of construction. Which is the weakest part of the boiler, and how is it strengthened? Sketch the boiler in transverse action with the flues, showing the probable level of the water (1871).

2. Describe with a sketch the tubular marine boiler. Explain the necessity for a reverse or atmospheric valve. Point out the use of the stop valve in the steam pipe. How is this valve opened and shut (1871)?

3. What is surface condensation as applied to marine engines? One of the tubes used is of copper $\frac{5}{8}$ inch outside diameter, ·05 inch thick, 5 feet 10 inches long; find its weight, a cubic foot of copper weighing 550 lbs. What pumps are required when surface condensers are used (1871)? *Ans.* 2·012 lbs.

4. Describe the communication valve, and explain its use? If working with 3 boilers instead of 4, what would be the effect of opening all the communication valves (1865)?

Ans. The steam would pass to the disused boiler, and boil the water, so that a large amount of fuel would be wasted.

5. In the old-fashioned waggon boiler a vertical open tube, called

a stand pipe, passed through the shell of the boiler, and dipped below the surface of the water inside. If the steam pressure inside the boiler were 4 lbs. per square inch, at what height would the water stand in the pipe (1870)? *Ans.* $9\cdot0\dot{6}$ feet.

6. A cylindrical boiler with flat ends is 30 feet long, 6 feet in diameter, and has two internal flues, each $2\frac{1}{4}$ feet in diameter, the pressure of the steam in the boiler is 40 lbs. on the inch, what is the whole pressure on the internal surface in tons? How is the strength of a cylindrical boiler related to its diameter, the material being unchanged (1870)? *Ans.* 2596·95 tons.

7. Describe and explain some form of vacuum gauge, which would enable you to ascertain the pressure in the interior of the condenser of a steam engine (1870).

8. Describe with a sketch the glass gauge for showing the height of the water in a boiler. Point out the position and use of the three stop cocks. For what purpose are gauge cocks fitted to a boiler (1871)?

9. State the principal parts of a marine boiler connected with the generation of heat. Show the advantage of small tubes over large ones in giving a greater amount of heating surface (1865).

See question 13.

10. Give a description of the reverse valve. If kept in its place by a weight of brass, what must be its thickness that it may be opened when the pressure of steam within the boiler is $1\frac{3}{4}$ lbs. below the atmosphere? The weight of a cubic foot of brass is 525 lbs. (1871).

Ans. Area $\times\, 1\frac{3}{4}$ lbs. $=$ area $\times$ height $\times \frac{525}{1728}$ $\therefore h = 5\cdot76$ inches.

11. Describe a condenser gauge of an engine. The mean pressure on a piston being 12 lbs. above the atmosphere, and the mean vacuum pressure 13 lbs., what is the force exerted on a piston of 58 inches diameter? and what would have been the force had the engine worked without condensation of steam (1867)? The pressures are 25 and 12 lbs. *Ans.* 66052·14 lbs.; 31705·0272 lbs.

12. Name and give a short account of the gear connected with marine boilers requiring the attention of the engineer (1863).

13. A circular tube is replaced by four circular tubes of the same total volume, show that the heating surface is thereby doubled (1863).

Let $x =$ diameter of large tube.
$y =$,, small ,,
$x^2 \times \cdot7854 =$ area of large tube.

$$\frac{x^2 \times \cdot7854}{4} = \text{area of small one.}$$

Also $y^2 \times \cdot7854 =$,, ,,

$$\therefore y^2 \times \cdot7854 = \frac{x^2 \times \cdot7854}{4}$$

$$\therefore 4y^2 = x^2.$$

$$x = 2y.$$

Heating surface of large tube $= x \times 3{\cdot}1416 \times l$.
" " " $= 2y \times 3{\cdot}1416 \times l$.
" " small tube $= y \times 3{\cdot}1416 \times l$.
" " 4 " $= 4y \times 3{\cdot}1416 \times l$.

$$\therefore \frac{\text{Heating surface of large tube}}{\text{Heating surface of small tube}} = \frac{2y \times 3{\cdot}1416 \times l}{4y \times 3{\cdot}1416 \times l} = \frac{1}{2}.$$

$\therefore$ Heating surface is doubled.

14. The bottom of a steam boiler is 18 feet below the level of the sea; find the requisite steam pressure to force the water of the boiler through the blow out pipe (1863). *Ans.* 22·941 lbs.

15. What is meant by priming? Would you recommend in such a case that the safety valves should be kept open (1864)?

Ans. No; because the pressure being taken off the water, it will boil more furiously, and more spray will be thrown about the boiler, and therefore it is likely to increase the priming.

16. Describe the barometer gauge in common use. Why is the stop cock closed before blowing through (1864)?

17. Describe the steam gauge used in marine boilers (1865).

18. What are the advantages and disadvantages of tubular boilers? and what are the peculiarities of marine boilers when contrasted with land boilers (1866)?

19. What is meant by the grate surface of a boiler? If 1 square foot be allowed for each horse power, how much will be necessary for boilers to supply a pair of cylinders, each of 73 inches diameter, the piston moving at the rate of 240 feet a minute (1866)? Find nominal horse-power. *Ans.* 426·32.

20. There are 2400 tubes in a set of marine boilers, their external diameter being 3 inches, thickness of metal $\frac{1}{4}$ of an inch, and length 6 feet; find the amount of power developed, 16 square feet being equivalent to one horse-power (1866). *Ans.* 589·05 horse-power.

21. If the reverse valve of a boiler be a solid brass cylinder 5 inches long, what will be the pressure to collapse a boiler, when it is on the point of acting, the weight of a cubic foot of brass being 525 lbs. (1866)? *Ans.* 1·5 lbs.

22. What is the usual boiler used for marine engines? Describe it. Why is the arrangement peculiarly useful for marine purposes (1867)?

23. Describe the barometer gauge in common use (1867).

24. Give a description of the apparatus by which a boiler is prevented from bursting and collapsing. How is the pressure of the steam in the boiler ascertained? Can the same dependence be placed on an old gauge as on a new one (1865)?

25. Describe the safety valve of a locomotive boiler. Explain Bourdon's gauge for ascertaining the exact pressure of the steam in a boiler (1869).

26. Describe with a sketch the marine tubular boiler. What is the object of a reverse valve, and how is it fitted? How is a vessel protected from the heat of the funnel (1865)?

27. Describe the form of boiler first used, and how did it differ from modern boilers ?

28. What precautions should be taken to prevent boiler flues from collapsing? Give an idea of the pressure they have to sustain, and how should their thickness vary with their diameter ?

29. State the characteristics of the Field boiler and Galloway's tubes.

30. Describe a vertical boiler, and distinguish between a Cornish and Lancashire boiler. Give a section through any boiler with which you are familiar.

31. What provision is made for heating the feed water of a boiler? Why should the water be supplied as warm as possible ? Give any plan that has been adopted for heating the feed water.

32. What are the advantages and disadvantages of surface condensation ?

33. Describe Moreton's Ejector Condenser.

CHAPTER X.

SALT IN MARINE BOILERS.

Sea Water—Specific Gravity—Boiling Point—Blowing Out—Scale—Salinometer — Hydrometer — Priming — Feed Pumps—Giffard's Injector.

183. Pure Water Should be Used.—Boilers, both land and marine, are liable to become internally incrusted. If these incrustations are not carefully removed or guarded against great injury will ensue. All water contains solid substances, whether it be lime, flint, salt, or sulphur, all of which will either do, or be the means of causing, damage. Marine boilers are generally fed with salt water. Hence it is necessary to explain fully the constituents of sea water, and how their evil effects may be guarded against.

The deposits and incrustations which are the source of so much danger, are not likely to be retained as necessary evils. If surface condensation, which, as we have already said, has been introduced into some of our iron-clad vessels, be successful, the condensed water, being free from all such matters, will form no deposits. If the steam could be rapidly and effectually condensed without mixing it with impure water, it would itself supply almost enough water for feed, and that of the purest quality. All the evils of deposits, incrustations, priming from impure water, and much of the wear and tear of boilers, would be in many cases entirely and others greatly prevented. The consumption of fuel would be less than at present, and the air pump would be considerably reduced in size, and therefore less power would be required to work it, although of course we should have the circulating pumps instead, but still upon the whole there would be a gain. As the condensed steam would contain no air, the function of the air pump would be exclusively confined to the removal of the condensed steam.

184. Sea Water is both salt and bitter. Everywhere the sea holds in solution a large quantity of solid substances, chiefly common salt or chloride of sodium. The amount of salt is not constant in all seas, nor even in the same sea, nor at all depths, varying according to the amount of evaporation (*i.e.*, the heat of the climate) and the quantity of river water running into the sea. The Red Sea is salter than the Mediterranean, the Mediterranean than the Atlantic, the Atlantic than the Pacific. The water of the northern hemisphere is not so salt as that of the southern. The position of maximum saltness in the ocean is about 22° N. latitude and 17° S. latitude, and the belt of ocean lying between. We may incidentally mention that this is the region of greatest evaporation, and that therefore the saltness of the ocean follows from that circumstance. The Polar seas, Baltic, and White seas, contain very little salt. Ice is free from it, because water in the act of freezing parts with all its impurities. Out of every 1000 parts 34·4, or about $\frac{1}{30}$, of the whole consists of solid matter; out of the 34 parts nearly 24 are common salt. We may put it thus: out of 30 gallons of sea water, 1 gallon consists of solid matter, and of this solid matter $\frac{24}{34}$ or $\frac{12}{17}$ is pure salt; 24 parts out of 34·4 are pure salt, 4 parts chloride of magnesium, 4 parts sulphate of soda; 1 part in 1000 is carbonate of lime (chalk), and 1 part in 4000 silica (flint).

ANALYSIS OF SEA WATER.

Chloride of Sodium,	24·
Chloride of Magnesium,	4·
Sulphate of Soda,	4·
Carbonate of Lime,	·34
Silica,	·086
Other substances,*	2·
	34·426

* Bromine, Iodine, Boron, Silver, Copper, Iron, Potassium, etc.

Professor Forchammer* gives the following as his analysis of sea water :—

Chlorine,	19·	parts.
Sulphuric Acid,	2·26	,,
Lime,	·56	,,
Magnesia,	2·10	,,
All Salts,	34·04	,,
Total parts,	58·32	

Carbonic acid gas is ever present in sea water, and its quantity increases with the depth. There is also a trace of ammonia with atmospheric air to sustain life in the proportion of from $\frac{1}{40}$ to $\frac{1}{30}$ of its bulk. These facts, especially that relating to the different quantity of salt in different seas, go to explain the reason why the extent of the "brining" varies in different seas.

185. The Specific Gravity of sea water differs with every sea. In the North Atlantic Ocean it is about 1·02664, while in the South Atlantic it is greater, 1·02672. The Indian Ocean has a specific gravity of 1·0263; the Red Sea, 1·0286; the Mediterranean, 1·0289.

186. Boiling Point of Sea Water.—In consequence of some of the above solid substances being chemically combined and the others mechanically suspended in sea water, especially because of the latter, and its specific gravity being greater, it takes considerably more heat to boil it than to boil fresh, spring, or river water, and of course as ebullition continues and the steam is used the water will get salter and salter; no salt can possibly pass away with the steam, and therefore the amount of heat required to convert the water into steam will have to be increased in proportion to the density of the water, while the water itself will become saturated with salt, or it will be incapable of holding more salt, which will be precipitated, and form a crust on the boiler, separating the iron boiler plates from the water, so that the boiler plates can actually become red hot and danger is imminent, for the plates being softened they are liable to collapse.

187. Boiling Point of Salt Water.—Salt water containing $\frac{1}{30}$ part of salt (it has been usual in all works on steam

* See Ansted's *Physical Geography*, p. 141.

to say $\frac{1}{33}$), will boil at a temperature of 100° $\frac{2}{3}$ C.; if the proportion of salt be doubled, or $\frac{2}{30}$, it will boil at a temperature of 101° $\frac{1}{3}$ C., if $\frac{3}{30}$ or $\frac{4}{30}$ the boiling point will rise respectively to 102° C. and 102° $\frac{2}{3}$ C.; when there are $\frac{12}{30}$ of salt in the water the boiling point rises to 107° $\frac{7}{9}$ C. $\frac{12}{30}$ is the point of saturation, when the water is so full of salt that it will hold no more, and it is therefore rapidly precipitated. It will assist the memory perhaps to state that in each gallon of sea water there is more than four ounces of salt, and if two gallons be boiled down to one, it will contain double that amount, or more than eight ounces.

188. Blowing Out or Brining the Boilers.—Generally the saltness of water in the boilers must be kept below three or four thirtieths. To effect this, and to have them as free from salt as is consistent with the economical consumption of heat, the practice of "blowing out" is resorted to. For this purpose blow out cocks are fitted to the bottoms of all marine boilers, from the cocks pipes lead into the sea. Every two hours, but generally less, the blow out cocks are opened, and the supersalted water violently forced out of the boiler, by the pressure of the steam, into the sea. Much heat is lost by this blowing out, and many methods have been devised to save it. Before showing how this is accomplished, we must give other modes of getting rid of the impurities which collect in a marine boiler. The brine is sent overboard,

(1) By Blow Out Cocks (already explained).
(2) By Brine Pumps.
(3) By Surface Blow Out and Scum Cocks.

189. (2) **By Brine Pumps.**—To many engines are fitted brine pumps, and at every revolution of the engine a small portion of brine is extracted from the boiler. The size of the brine pumps must be such that the quantity of water drawn off added to that evaporated must be equal to the quantity introduced by the feed pump. If the water ejected from the boiler is to contain $\frac{3}{30}$ of salt, or three times as much as the feed water, then, if the feed pump supply n gallons in a given time, the brine pumps must extract $\frac{n}{3}$ gallons in the same time. The rule is, blow out from $\frac{1}{4}$ to $\frac{1}{3}$ the amount of feed water.

190. (3) Surface Blow Out and Scum Cocks.—The foreign substances in a boiler are always buoyed up to the surface, where they not alone prevent ebullition, but the formation of steam. The steam rises from and around them, and they remain at the surface for some time, when they gradually descend and form a scale upon the tubes and flues. It is therefore found quite as advantageous to blow out from the surface as from the bottom of the water. It is done by means of **scum cocks,** which are inserted on a level with the water, and are kept constantly about one-eighth open the whole of the time, so that as fast as dirty scum and other impurities rise to the surface they are expelled.

191. Lamb's Surface Blow Out Apparatus is a very efficient contrivance for effecting the same object. A float in connection with the bottom of the discharge pipe regulates the feed and discharge water. The apparatus ejects the scum and dirt at once; but in some boilers sediment collectors are employed, one, in shape and size somewhat resembling a sugar loaf, is placed in each boiler with the small end or apex downwards, it is connected to a pipe leading into the sea to carry the sediment away. The top or base of the cone stands out of the water, and the impurities enter through longitudinal tapering slits being ballooned into the cone, where the water is comparatively still, by the steam as it rises to the surface. The object of all this is to save heat.

192. Scale.—Whatever care and precaution are adopted, scale can hardly be prevented from forming on the boiler plates. A careful and attentive engineer can always reduce it to a minimum. When scale is formed on the boiler plates, it prevents the passage of heat into the water, for salt, gypsum, lime, etc., are exceedingly bad conductors of heat, and will not allow its motion to pass to the water, and therefore a waste of fuel must arise. When water is saturated with salt, etc., through negligence or otherwise, it becomes heavier, and therefore takes more heat to boil it, which is another waste of fuel; again, the scale is occasionally so hard and solid that the plates become red hot, and are liable to be burnt as well as to give way from internal pressure. Ammonic chloride and other chemical substances are sometimes put into marine boilers to prevent scale, but the utmost they do is to precipitate the foreign ingredients as powder, which must still be removed by blowing out. The more of these substances there are in the water, the more work the heat has to do to lift them, and therefore the more heat is required for ebullition, which is waste of motion and power.

A practical engineer, who has examined thousands of boilers, says: "Much mischief is often done by the injudicious use of compositions in the boiler which are designed to prevent incrustations, especially where there is no blow off cock or where its use is neglected. A hard deposit on the boiler plates is, in the writer's opinion, not so injurious as the soft and muddy deposit produced by the use of such compositions. A hard scale . . . is sufficiently mischievous, but the injury to the plates is much more rapid when a thicker but spongy deposit entirely prevents contact of the water, and impedes the transmission of the heat. The money spent in boiler compositions would be better applied in securing a supply of proper water, or in filtering and purifying the water before it enters the boiler. More attention to the purity of feed water would nearly always effect economy, and would be far cheaper than using chemical or other ingredients to neutralize the impurity after it is in the boiler. In many cases simply filtering the water in some ready way has produced very great improvement."*

A simple illustration of the formation of scale may be seen by examining the tea-kettle, where a scale (lime or chalk chiefly) is left on the sides and bottom of the kettle, because steam formed from impure water is perfectly pure; it can carry nothing away with it. We may also consider the boiler as, or compare it to, a great salt-pan. Just as in Cheshire and Worcestershire salt is made by the simple process of evaporating water in large pans, so does salt, etc., collect in marine boilers; but there is this difference, the scale formed on boilers is not soluble in water, while salt is. Here, of course, we draw a distinction between *salt* and *scale*.

An effective and expeditious, but not very good plan, to scale boilers is to throw in a few wood shavings

* From Marten's *Steam Boiler Explosions.*

all along the bottom, and set them on fire. They quickly heat the scale, which expands more than the shell of the boiler; the heat cannot reach the latter, so the scale is loosened from the plates. Precisely the same process is gone through, with a different result, when a glass tumbler is cracked by pouring hot water into it. The heat in the water suddenly expands the inside of the glass, which becomes too large for the outside, and so the glass is broken. Any scale that remains after this must be taken off with a hammer and chisel. This hard incrustation is formed in layers, and of course chiefly consists of carbonate and sulphate of lime, gypsum and chalk, with common salt. We have by us pieces of scale looking like pieces of iron; in their cross section they have the appearance of very thin alternate bands of iron and hard crystalline rock, while other pieces are *pure* salt. On this point Mr. Marten says: "The practice, especially in certain districts, of emptying the boilers immediately the engines are stopped, and before the flues have cooled, in order to loosen the scale by overheating the plates, has caused much more mischief than those who persist in doing it will believe, and has nearly ruined some otherwise good boilers."

193. Salt and the Boiling Point.—There are several methods of ascertaining the amount of saturation of the water in a marine boiler:—

(1) By the THERMOMETER.
(2) ,, HYDROMETER.
(3) ,, SALINOMETER.

From what has been said it will be gathered that the boiling point of water depends upon the quantity of salt in it, its specific gravity, and the pressure of the air. The strength of a solution of salt and water has always a fixed and well-ascertained relation to the boiling point and specific gravity.

For water with

$\frac{1}{30}$ or 1°	of saltness	in it boils at	$100°\frac{2}{3}$ C.
$\frac{2}{30}$ or 2°	,,	,,	$101°\frac{1}{3}$ C.
$\frac{3}{30}$ or 3°	,,	,,	102° C.
$\frac{4}{30}$ or 4°	,,	,,	$102°\frac{2}{3}$ C.
$\frac{5}{30}$ or 5°	,,	,,	$103°\frac{1}{3}$ C.
$\frac{10}{30}$ or 10°	,,	,,	$106°\frac{4}{9}$ C.
$\frac{12}{30}$ or 12°	,,	,,	$107°\frac{7}{9}$ C.

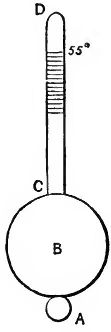
And also as fresh water when the oarometer stands at

27 inches boils at a temperature of				97°·2 C.
28	,,	,,	,,	98°·1 C.
29	,,	,,	,,	99°·1 C.
30	,,	,,	,,	100° C.
31	,,	,,	,,	100°·8 C.

we see at once the truth of what was previously said, that the boiling point of water depends upon its weight or specific gravity and the pressure of the air.

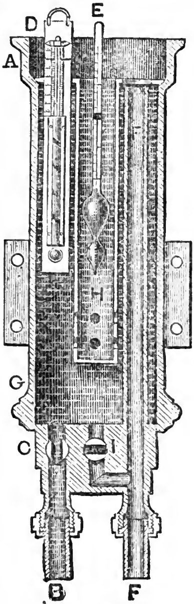
If, then, water be taken from the boiler, and boiled in the engine room under the ordinary barometric pressure of the air, and it is found by using the thermometer that its temperature at the boiling point is $103°\frac{2}{9}$ C., we must at once conclude that there are 5 degrees of saltness in the water, and that precipitation of impurities is commencing, and blowing out must be resorted to at once. But if by the same process it is ascertained that the water boils at $101°\frac{1}{3}$ C. (in the engine room), it is known that the boiler is comparatively safe and in good working condition. Salt does not really deposit till $\frac{12}{30}$.

194. The Hydrometer tells us the amount of salt in water by showing its specific gravity. The figure in the margin represents one. B is a hollow ball of brass or other metal, from which rises a stem C D, graduated; A is a second globe filled with mercury to make the whole swim uprightly in the water. A acts in precisely the same manner as the lead on a fishing line. The lead keeps the float upright, so does A the hydrometer. The stem C D is graduated that we may read off how far the stem sinks in the water. The greater the specific gravity of the water, or the more salt there is in it, the *less* it will sink, so the density is thus made a test to exhibit the amount of salt. We read off (not the density, but) the saltness of the water.



HYDROMETER.

Each hydrometer is graduated to a particular scale, generally 55°; *i.e.*, when placed in distilled water at a temperature of 55° the hydrometer sinks to the point marked 55°. This is much too low, for when water is taken from the boiler the experimentalist has to wait a considerable time for the water to cool down before he can test it. 90° C. would be a far better temperature to select. We now see the utility of the specific gravities of sea water given on page 163, and that the hydrometer is an imperfect instrument without the barometer; so useless is the one without the other, that we frequently see attempts made to combine the two, as in the *salinometer*.



HOW'S SALINOMETER.

195. Salinometer. — The salinometer has been presented in several shapes. In one it consists of a thermometer and hydrometer combined in a copper vessel, in another, Seaward's salinometer, of two pith balls. Mr. Seaward affixes a glass tube fourteen inches long, in a similar manner and in a corresponding place to the glass water gauge, so that when attached to the boiler the water rises up from the bottom of the boiler through the lower cock, and remains in the glass tube at the same level as the water in the boiler. The taps are then closed and the upper one opened, and two small balls of glass or metal are dropped into the water. The specific gravity of the first ball is such that it will sink when there are five degrees of saltness in the water and swim when more, the other ball will sink when there are less than three degrees of saltness, but swim when four or more. By this methcd the state of the boiler is soon ascertained.

How's salinometer consists of a cylindrical vessel, A G, connected with the steam boiler by the pipe B; the connection on the boiler being below the surface of the water. The quantity of water admitted to the salinometer is regulated by the cock C in pipe B. The salinometer is most usually fixed in the engine room, so as to be in constant view of the engineer, but it can be fixed in any other convenient place. A thermometer D is placed in the cylinder A G of the instrument, to show the temperature of the water. A hydrometer E floats in the water, at a height corresponding to the density or saltness which it indicates, and is protected by the metal guard H. An overflow pipe F takes away the surplus water, and prevents it running over the top. I is a cock for emptying the instrument through the pipe F. It should, of course, be emptied as often as the water is tested.

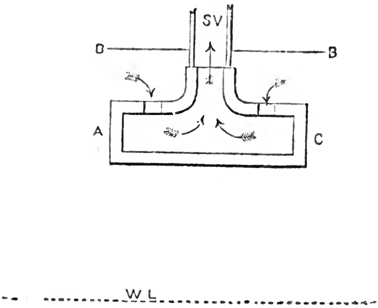
196. Priming.—When the steam comes from the boiler mixed with water, in the shape of spray or froth, it is said to be primed. Priming exists under most diverse circumstances; its cause cannot at all times be clearly traced.

197. Causes and Danger of Priming.—Priming takes place more in new than in old boilers; when there is but little water in the boiler; when the spaces between the tubes and flues are contracted; when there is fierce ebullition, this cause may be said to accompany all priming; in passing from fresh water to salt or salt to fresh; when the water used is muddy, dirty, or slimy; *when there is too small a steam chest;* when a safety valve, being situated near the steam pipe, is suddenly opened. The danger arising from priming is very great, and should therefore be most anxiously guarded against. We shall see its danger and injurious effect, if we but consider that when it gets into the cylinder, and there accumulates as incompressible water, something must give way should the test cocks and escape valves act improperly. Priming impairs the vacuum; in consequence of this, more water will have to be used for condensation, which will throw a greater load upon the air pump, and more feed water will also be required.

198. Remedy for Priming.—As priming is generally accompanied with great ebullition, obviously the most effectual remedy will be to enlarge the steam chest. It is found that boilers with plenty of water surface, or with a large steam chest, seldom or never prime. Cornish boilers with their large water surface give no trouble by priming. A remedy much practised with locomotive boilers, is to open a safety valve *remote from the steam chest and pipe.* Other temporary remedies are: to partly shut the throttle valve; to work the steam at a high pressure; to open the furnace door, thus checking the fierce boiling; to put down the stop valve so that the steam rushes against it, and the water is knocked out;

to inject tallow into the boiler by means of the donkey pump or a syringe fitted on purpose, this is the favourite remedy, but it is found in some boilers to increase the priming. Another remedy is to fit a steam pipe in the boiler full of small holes, and inside this another similar pipe, but to take care that the perforations of one pipe are not opposite those of the other. The steam in entering dashes against the inside pipe, and the spray falls out. Any thing that checks furious ebullition, or allows the steam plenty of space to rise, checks priming. When the steam chest has to be enlarged, it is better to fit a second on the top of the old one. Priming arising from the use of impure water may be obviated by liberally blowing off from the surface until the nuisance is abated.

A very good plan to prevent priming is one adopted in the engines constructed by Charles Powis & Co. Their arrangement is to fit the stop valve, opening to boiler, with a disc plate, arranged with orifices on its upper side so that dry steam only can find its way through the stop valve. A C is a section of the disc plate fitted inside the boiler; W L is the water line, and B B the top of the boiler, so that all steam passing to the stop valve, which is situated just above S V, must pass in the direction of the arrows, through the small perforations into which the top arrows are entering. The water will be thrown and knocked out of the steam before it can pass to the stop valve.



ENTRANCE TO STOP VALVE.

Boilers sometimes prime when the ship passes from salt to fresh water or fresh water to salt. It has been suggested that in passing from salt to fresh water the cause is this: fresh water being lighter than salt, is upon its admission to the boiler more easily thrown about by the ebullition, and therefore more spray is flying; but as the same boiler will also prime in passing from fresh to salt water, this reason evidently will not hold; we have yet to seek the true cause. May not the change of water cause a serious change in the existing condition of the boiler, and this change being accompanied by a general disturbance of the equilibrium of the water, much more spray is thrown off than usual, and priming follows.* When new boilers have primed, a good plan adopted, is to run into harbour and blow out the boiler several times in succession. This has often effectually prevented priming.

199. Fire Grate Surface, Heating Surface, Amount of Coal to Evaporate One Cubic Foot of Water.—In the majority of marine boilers, it is usual now to allow three-quarters of a square foot of fire grate surface, and about nineteen square feet of heating surface, to each horse-power, but some take these numbers at half a square foot and twelve square feet. It is also calculated that six pounds of coals should be consumed every hour for each horse-power of the engine; these proportions of fire grate, heating surface, and consumption of coal, evaporate one cubic foot of water per hour. Locomotive boilers are constructed with a much smaller amount of fire grate surface; to compensate for this, the waste steam pipe is introduced into the funnel, which causes a most intense heat in the furnace, and it is found, the more intense the heat, or the hotter the heating surfaces and the water are, the more heat will pass into the water. They consume one hundred weight of coke per hour on each square foot of grate surface, the proportion of heating surface to this is eighty square feet; on every five or six square feet of heating surface one cubic foot of water is evaporated per hour. Each horse-power requires a cubic foot of evaporated water per hour, but in high pressure work more. The quantity of water may be generally taken as one cubic foot per horse-power per hour, but it is in excess for such engines as those in which advantage is taken of the expansive force of steam. In Cornish boilers, where an enormous duty is obtained for each engine, not more than three and a half or four pounds of coal is burnt on each

* See Causes of Boiler Explosions—Spheroidal Condition of Water, and Water Purged from Air.

square foot of grate surface per hour. As well as a boiler having a due proportion of grate and heating surface to produce the necessary volume of steam, the furnace must be sufficiently roomy to consume all the products of combustion; the tube or flue surface, etc., must be adapted to abstract as large an amount of heat as possible, without too much passing away as waste, while at the same time the water spaces in the boiler and the distances between the tubes must be large enough to allow the steam freely to rise, or else priming may take place. Again, the furnaces should never be too long, for the stokers will find a difficulty in keeping the bars free from clinkers, the clinkers as well as the fire not being fairly within reach.

200. Feed Pumps.—The feed is supplied to the boilers in one of the following ways: (1) By boiler hand pumps; (2) by the donkey engine; (3) by the feed pump proper; or (4) by Giffard's injector.

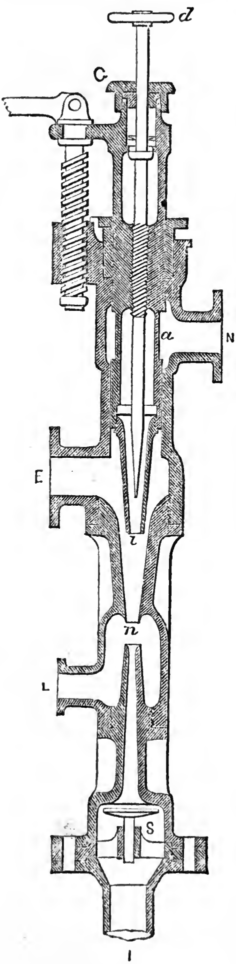
(1) The boiler hand pumps are fitted to marine boilers, so that when there is no steam up men may fill the boiler by hand, providing it is not sufficiently below the level of the sea for sea water to run in freely when the Kingston valve is opened.

(2) The donkey is a small steam pump in the engine-room that can be set to work to fill up the boilers when the engines are waiting for orders. The donkey has always the steam piston and pump piston at opposite ends of the same rod.

(3) The feed pumps which have been already explained.

In stationary engines part of the warm condensing water is driven into the boiler as feed; the rest, by far the greater quantity, being allowed to run away. But the feed pumps should at all times be capable of supplying much more water than the boiler in its normal state will use. The capacity of the feed pump is generally about $\frac{1}{240}$th that of the cylinder, so that it can supply more than *three* times as much as is required. While the steam pipe should be attached to the highest point of the steam chest, the feed pipe should be fixed as low down as possible, so that the cold water may gradually rise. In most Government vessels the feed and donkey pumps are made of brass.

201. Locomotive Feed.—In locomotives the feed pumps are made of brass and the plunger of iron or brass. They are worked either from an eye on the back of the eccentric (see fig., p. 70, G), or by the piston crosshead. The passage of the water from the tank to the boiler is governed by three ball valves and a cock or valve box close to the boiler. The lift of the valves must never exceed $\frac{4}{16}$ or $\frac{5}{16}$ of an inch. There are generally two pumps to each engine. The water, when directly admitted to the boilers, enters about the middle of the bottom, but sometimes a pipe passes it through the smoke box first to extract as much heat as it can from the heated gases before it gains admission to the boiler. So also in the marine engine, the water sometimes enters the boiler from round the funnel.



GIFFARD'S INJECTOR.

202. (4) **Giffard's Injector.**—This is a novel contrivance for feeding boilers, fast superseding all other methods of feed; but no convincing explanation of its action has yet been offered. The manufacturers claim for it these advantages:—

(1) It is as cheap as a pump and its connections; (2) it saves the wear and tear of pumps, which in locomotives and other high pressure engines are very considerable; (3) it saves the power required to work the pumps; (4) the water enters the boiler at a high temperature, so no heat is lost; (5) you can feed a boiler without setting the engine in

motion, thus saving donkey pumps; (6) it is free from risk of damage or stoppage by frost.

We will suppose it properly attached to the boiler, it then works in the following manner:—

G I is the injector, N is attached to the boiler. Steam can pass into the injector at N. When the handle *d* is moved up, steam rushes through *a i* at *i*, where it meets the water supply coming into the injector at E. The steam drives the water through *n*, and beyond the valve *s*, into the boiler. When there is sufficient water in the boiler, the valve *s* is forced upwards, and no more water can pass it; the waste water can then pass through the overflow pipe L. The steam to work the injector must be taken from the highest part of the boiler, and must not be primed. The water driven through it may be taken from a cistern overhead, or from a tank in the ground; but the distance from the level of the water below to E above must not exceed 5 feet. Now it is found that the pressure of steam will actually drive the water into the boiler, although it has to force it against the pressure of both the *steam and water* in the boiler.

A jet of steam moving with perhaps a velocity of 1700 feet per second, is instantly condensed in perhaps twelve times its weight of water. The combined jet will then move, by the momentum imparted to it by the steam, at one-thirteenth its former velocity, 131 feet per second—the motion of the steam being wholly imparted to the water. Thus the jet properly directed enters the boiler, and we can find an explanation of the action of the injector by simply considering that it acts solely by the momentum imparted to the water by the jet of steam.

EXERCISES CHIEFLY FROM EXAMINATION PAPERS.

1. Why is the hydrometer an imperfect instrument without the thermometer (1863)?

2. What quantity of water at 56° F. would be required to condense 1500 cubic feet of steam at a pressure of 35 lbs. per square inch above the atmosphere, so that the temperature of the whole should be 100° F. (1865)?

Temperature of injection water is raised $100° - 56° = 44°F. = 24°\frac{4}{9}C.$
$100°F. = 37°\frac{7}{9}C.$, and temperature at 50 lbs. pressure = 282°F.
Total heat in steam at $282°F. = 1082 + \cdot305 \times 282° = 1168°F. = 649°C.$
Relative volume at 35 lbs. above the atmosphere, or at 50 lbs., is = 552.

The relative volume may be taken as the number of cubic feet of steam produced from a cubic foot of water.

$$\therefore \text{ Number of feet of water} = \frac{1500}{552} = 2\cdot71.$$

The steam has to give up $649 - 37\frac{7}{9} = 611°\frac{2}{9}C.$
Since each unit gives up $24°\frac{4}{9}C.$

$$\therefore \text{ Injection water required} = \frac{611\frac{2}{9}}{24\frac{4}{9}} = 25 \text{ times the water evaporated.}$$

$$\therefore \text{ Quantity of water required} = 2\cdot71 \times 25 = 67\cdot75 \text{ cubic feet.}$$

3. When a boiler is filled with sea-water, it is the practice to test the degree of saltness from time to time; why is this? Describe the apparatus employed, and the method of using it (1871).

4. Describe Giffard's injector, and give some explanation of its action (Honours, 1871).

5. Describe the feed pump and valves necessary for supplying the boiler of a locomotive. What is the principle of Giffard's injector (1869)?

6. The brine pump of a boiler being choked, how is the brine to be got rid of, the steam gauge indicating 4 lbs. and the upper surface of the water being 2 feet below the level of the sea (1868)?

Ans. There will be nearly 1 lb. pressure per square inch to clear it.

7. Describe a method of ascertaining the degree of saltness of the water in a marine boiler (1870).

8. How is the degree of saltness of the water in a marine boiler ascertained?

9. Show generally how to determine the amount of fuel lost by the process of blowing out in marine boilers (Honours, 1871). See questions at the end.

10. Give an analysis of sea water, and state clearly what is the amount of solid matter in it.

11. How is the boiling point of salt water affected by the amount of salt in it?

12. Describe the manner in which the salt and impurities are "blown off" from the surface.

13. What is How's salinometer? also state the principle on which Seaward's salinometer is constructed.

14. What are the remedies against priming, and what do you mean by *priming?* can you account for it taking place?

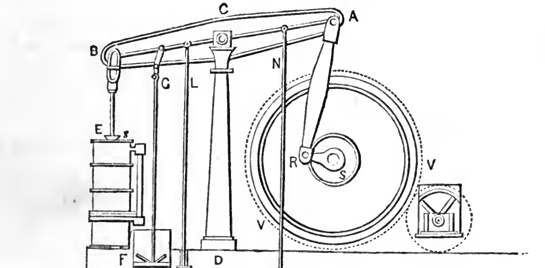
15. Give the relation between fire-grate surface, heating surface, and the evaporative power of the boiler in a marine engine.

CHAPTER XI.

LAND ENGINES.

The Beam Engine—Horizontal Engine—Vertical Engine—Table Engine—Portable Engine—Ramsbottom's Intermedial Engine—Gas Engine—Caloric Engine—Siemen's Regenerative Engine—Fire Engine—Cornish Pumping Engine.

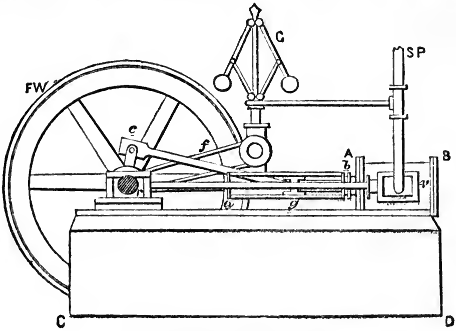
203. The Beam Engine has been already fully explained in Chapter III. It is the most general form of the land



BEAM ENGINE.

engine. We have now to allude to a few of the shapes, which for convenience, room, saving of expense, etc., have been adopted by various makers. Merely remarking that after the descriptions given of the beam engine, and of the marine engine generally, there is very little to which to direct attention, excepting the difference of arrangement.

204. Horizontal Engine.—In this, which is one of the most convenient and compact form of engine, the general arrangement is as illustrated in the figure given below, although they vary in detail with the caprice of the maker.

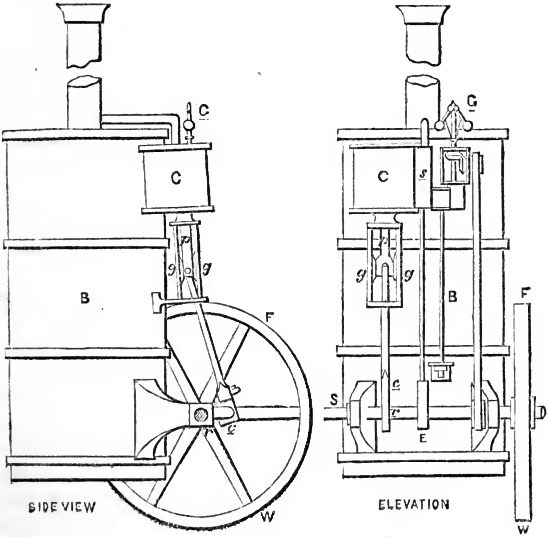


HORIZONTAL ENGINE.

A B is the cylinder lying horizontally on its side, *v* is the valve to admit the steam from the boiler by way of the steam pipe S P; the head of the piston rod is seen at *g*, the crosshead of which works within the guide or guide bars *a b*, and to the crosshead of the piston rod is attached the connecting rod *g c*, which works the crank *c r*. The main shaft is shown at *r*, darkened, this carries the *fly wheel* F W; *f* is the band working the governor G by means of pulleys, the driver being on the main shaft; of course the work is taken off the main shaft *r*. The whole is generally supported on firm masonry C D.

Advantages of Horizontal Engines.—The advantages gained by the use of a horizontal instead of a beam engine are: they require no "steadying stays" or supports, but can be bolted to foundations; they very snugly occupy but little space, and give out power as near the ground as is required; they can be made at considerably less cost, for the working parts are fewer, and less metal is required in their construction. The bottom parts of horizontal engines are liable to wear more than the rest—this is an objection. The cylinder occasionally becomes grooved out by the friction (gravity) of the piston. Engineers guard against these defects by providing suitable bearings, well balancing the several parts of the engine, and constructing it of the best material and workmanship.

205. Vertical Engine.—In many positions vertical engines are very much better fitted to accomplish the work required than horizontal. They seem especially adapted for cranes, and such like services.



VERTICAL ENGINE.

The letters in both figures correspond.

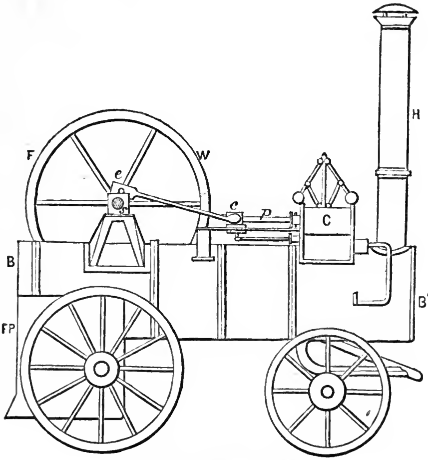
C is the cylinder, from which proceeds the piston-rod *p*. The head or crosshead, *g*, of the piston-rod moves in guides *g g*, the connecting rod is *g c*, working the crank *c r*. The shaft is *r*, which carries the fly wheel F W; the motion is taken from the end of the shaft at *s*, or sometimes F W is used as a drum, and the work is conveyed by an endless band; the governor is placed at G, and the manner in which it works is seen in the right hand figure. E is the eccentric working the slides at *s*; B is the boiler, to which the framing of the engine is attached, the boiler is generally a vertical tubular one. It is evident from the circumstance of the engine being attached to the boiler, that this class is not intended to give out powerful work.

Vertical engines are frequently used where space is an object, but they have to be rigidly supported to prevent vibration. The slides of vertical and horizontal engines are worked in the usual manner by eccentrics upon the main shaft. Horizontal engines have expansion valves very frequently, which are worked by separate eccentrics; of both kinds of engines the boiler and boiler appendages, such as safety valve, communication valve, pressure gauge, vacuum gauge, gauge cocks, and arrangement of the fireplace, are all the same. Vertical engines are generally non-condensing, and the escape steam is utilized for the blast. Horizontal engines are used both as condensing and non-condensing, but generally the former.

206. Table Engine.—Before the introduction of horizontal engines, these *table engines* were very common, but are now going out of fashion, chiefly because there is a good deal of extra gear connected with them, and they are therefore more expensive. The cylinder stands on the top of a large cast-iron plate or table, supported frequently by four columns, above the cylinder is a high erection or guide for the piston-rod to move upwards and downwards vertically, from the crosshead of the piston-rod two side rods come down by the side of the cylinder to work the crank which is below the cylinder. The additional parts as compared with plain vertical engines, are an extra connecting rod, crosshead, crosstree, and two side rods for slide valve, two guides and blocks for the same. As an engine it possesses great durability, but it has, as previously stated, a large amount of extra gearing; all its parts are well balanced.

207. Portable Engine.—A portable engine differs in no essential particular from an ordinary horizontal engine, excepting that provision has to be made to carry both boiler and engine on two pair of wheels.

C is the cylinder working the piston-rod *p*, the crosshead of which moves in guides or else is kept parallel by guide bars; *c e* is the connecting rod to work the crank *c s*, the main shaft being *s*, to the end of which is attached the drum or pulley F W, which also acts as a fly wheel; the slides are worked in the same manner as in ordinary horizontal or other engines by the eccentric; the fireplace is at F P,



PORTABLE ENGINE.

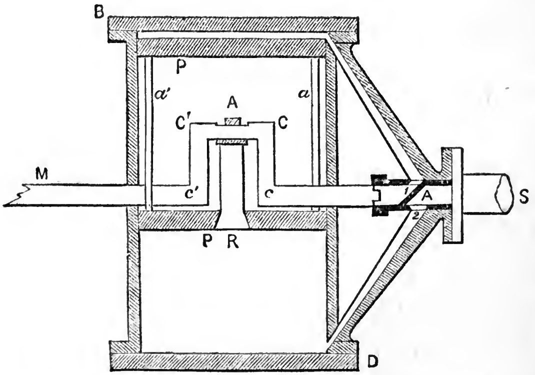
and beneath it is the ash box; B B′ is the barrel of the boiler, which is of the class multitubular; at B′ is the smoke box and H is the chimney. The boiler in a good many points resembles the locomotive; the waste steam is directed from the boiler to the funnel to create a draught, but the cylinder is generally on the top of the boiler and not under the smoke box; or else the cylinder with the pipes connected with it is placed inside the boiler, which certainly prevents rain, frost, etc., from condensing the steam in it. The shaft with its pulley or drum communicates the motion of the engine, by means of an endless band, to whatever machine it has to drive.

Distinctive Features of the Portable Engine.—Besides the distinctive features which may be seen at a glance, it is absolutely necessary that the machine should be as light as possible, to enable it to be easily and readily taken from place to place; hence no condensation of steam is attempted, but the waste arising from non-condensation is utilized as much as possible in increasing the draught. The *portable* must be plain and economical, so that being used by agricultural labourers, etc., it may not be liable to disarrangement, hence all its parts are very simple and light, it never being intended for *very* hard work. These engines are also very compact and cheap, requiring no expense for brick work, setting, etc. They are used for brick making, tile making, pumping, winding, thrashing, crushing, chaff cutting, and almost every other agricultural purpose.

The slides are worked by eccentrics, in the usual manner, and steadiness is given to its motion by a governor; it seldom or never does its work directly, but an endless band is always employed.

208. Ramsbottom's Intermedial Engine.—B D is the cylinder. The connecting rod A R and crank C *c*, as well as the piston P P, are all within the cylinder.

The piston is long and hollow, the ends P P being connected together, as seen in the figure, by *a* and *a′*, so that the



RAMSBOTTOM'S INTERMEDIAL ENGINE.

crank actually works *within the piston* as well as within the cylinder. The engine is evidently very compact, but is not adapted for heavy work. The stroke is very short. The shaft is seen at M, while the valves are explained in their proper place. The governor is placed on the top B of the cylinder, and "much of the straggling mechanism of the ordinary form is brought together." "This form of engine requires little fixing, and possesses a great range of speed."

209. Gas Engine.—A gas engine is one whose motive power is obtained by the explosion of a mixture of gas and air, either by an electric current, as in Lenoir's gas engine, or by external gas burners, as in Hugon's. The cylinder is furnished with a piston like an ordinary steam engine. It has passages on each side—one the inlet, the other the outlet passage—each covered by its slide worked by separate eccentrics. The mixture of gas and air, by the explosion of which the engine is worked, is admitted by the inlet valve. There is a recess in the valve where the gas becomes mixed with atmospheric air, the latter being introduced through an opening in the top of the valve. The proportion of air to gas used is as eleven to one. The outlet valve is very much like the inlet valve, but the ports through the back of it keep the recess in the valve in constant communication with the exhaust passage. The eccentric to work this valve is set on the crank shaft in such a position that it uncovers each port alternately, just before the piston has completed its stroke either way, and releases the vapour formed by the products of combustion. There are water spaces round the cylinder covers and exhaust valve, to carry off the heat generated by explosion. Forming part of the engine, there is what is called a distributor, which regulates the transmission of the currents of electricity to produce the sparks which explode the mixture of air and gas in the cylinder. An "igniter," consisting of a brass plug through which a china cylinder passes, having two separate insulated copper wires passing through it, is inserted at each end of the cylinder. At the end of the porcelain cylinder, within the engine, the two wires are brought nearly into contact, so that a spark can readily pass between them. The igniters are of course connected with the distributor, and batteries are employed for generating the electric current.

The Action.—In starting these engines, it is necessary to turn the fly-wheel round quickly two or three times by hand, then open the valves, and connect it with the distributor, etc. It should be well in motion before connected with the work it has to do. Let us suppose the engine in motion, and the piston just commencing its stroke from the crank shaft. The port leading to the end near the crank is uncovered by the inlet valve, the piston moves onward, and the mixture of air and gas runs in, filling the vacuum behind the piston. Just before the piston reaches the middle of its stroke, the inlet valve is closed, and the current of electricity having its circuit completed, produces a spark which ignites the explosive compound of gas and air. A little before the end of the stroke, the exhaust valve releases the enclosed vapour. From indicator diagrams taken by Mr. Smith, of the Patent Museum, South Kensington, it has been shown that, when running at 110 revolutions per minute, the indicated horse power was double the nominal.

210. Caloric or Hot Air Engine, or **Air Engine.**—Although we place the air engines in this chapter, it must be distinctly understood that Captain Ericsson's first attempt was to adapt the caloric engine for marine purposes.

Air Engines are very similar, in all their working parts, to the ordinary steam engine, but air expanded by heat is the motive power employed, and not steam. In the first attempt at a caloric engine, the air was heated to a high temperature, and having driven the piston within the cylinder, it was allowed to escape into the atmosphere; the great question has been how to save this heat, and economise the expenditure of fuel. Messrs. Stirling effect an economy of heat by using what they term a *regenerator* or *economising process.* It was discovered by Dr. Stirling that if heat be passed through a compartment filled with sieves of wire-gauze, or even minutely divided metallic passages, it will leave a large amount behind; this is precisely the plan adopted, the hot air, having driven the piston down in the cylinder, passes *outwards* through a chamber of fine wire-gauze, leaving a good deal of the heat behind in the sieves and narrow passages; other air which has to enter the cylinder next, is made to pass *inwards* through the same, having had added to it a little addition of heat, and gathering up heat also from the sieves and narrow passages, it effects the return stroke. This being repeated over and over again, it is evident that the same heat will be continually doing work.

In another kind of air engine compressed hot air has been used to give the reciprocating motion to the piston. While the name of Stirling is associated with the attempt to adopt air engines to land purposes, Captain Ericsson has worked to make the caloric a marine engine; although as regards the primary object of the inventors these engines have proved a failure, yet they have met with a certain amount of success. Small air engines have been extensively used in the United States for driving printing presses and other light work.

Motive Power of Air Engines.—The motive power of such engines is found in the circumstance that all bodies expand by heat and contract by cold, whether it be a gas, liquid, or metal, so therefore if they be subject to two extremes of temperature they will develop a certain amount of power, the only question is how to utilize it. In a steam engine, the extreme difference between the temperature of the boiler and condenser is not very great; now air can be subjected to greater extremes of temperature than water, and therefore is better adapted than water to act as a motive power. The practical difficulties have hitherto been so great, chiefly to prevent the enormous waste of power, and the high temperature to which certain parts of the engine are subjected, that their employment has been prevented, unless under very limited circumstances.

211. Siemen's Engine, or **Regenerative Engine.**—Mr. Siemen has invented an engine in which the conversion of heat into mechanical effect has been pretty successfully accomplished. He obtains his motive power by alternately heating and cooling steam, or by expansion and contraction. The *regenerative engine* is constructed on the same principle as the hot air engine explained in the preceding paragraphs. By the peculiar construction of the cylinders, receivers, etc., the steam takes up heat and gives it out as it passes from one cylinder to the others, of which there are three. Two cylinders, called the working cylinders, have plungers, and the other a piston. The steam is heated to a high temperature in the plunger or working cylinders, under each of which there is a fire. Part of the heat is consumed in doing the mechanical work of lifting the plungers, much of the rest is taken up by the *regenerators* as it passes to the third or regenerative cylinder. The *regenerators* have been explained in a previous page. In the regenerative cylinder, the steam acts in the ordinary way after its temperature has been reduced in the regenerators. It then returns to the plunger cylinders, where it receives additional heat and commences its round again; so that the same steam goes round and round, being continually employed. The regenerative or third cylinder communicates at one end with one working cylinder, and at the other extremity with the second.

In justice to others, it should be remarked that Siemen's engine resembles Stirling's, except that he uses saturated steam instead of air in the regenerator. Could the wear and tear caused by the heat to the heating vessels and cylinders be prevented, these engines would come into extensive use, as there is with them a remarkable economy of fuel, as high as 50 per cent.

212. Fire Engine.—The *fire engine* can be scarcely ranked as a distinctive engine. It is simply a steam pump on wheels; although, of course, there are several difficulties to be overcome in connection with them. The two essential qualities required are, that the steam shall be got up very rapidly, and that they shall be able to throw water to a good height.

Messrs. Merryweather & Sons have made these engines quite a success. The arrangements are such that the steam is raised in about ten minutes, while travelling to the fire. The boilers, with the blast pipe, are of steel, with copper tubes and large water spaces. They are fitted with the necessary safety valves, gauges, and Giffard's injector. The valves are arranged to allow foul and gritty water to pass, and steam can be conducted to them so that they cannot freeze by the winter's cold, and if they should become frozen they are easily thawed. The engine is direct acting, without fly wheels, cranks, or dead centres. The Sutherland will throw 1000 gallons per minute 200 feet high in a $1\frac{1}{2}$ or $1\frac{5}{8}$ inch stream. There is, of course, an air vessel to render the stream of water continuous, as in the common hand fire engine.

213. Cornish Pumping Engine.—Had this engine come under our notice in the earlier part of the work, it would have required many pages to fully describe it; but the chief points have been already illustrated under such headings as the *Beam Engine, Single Acting Engine, Cylinder, Connecting Rod and Crank, Cornish Double Beat or Crown Valve, Cataract, Expansion, Duty,* etc., to all of which headings the student is directed to acquire a full acquaintance with this engine. In a preceding page we remarked that the main object of early inventors was to produce a machine to lift the water from the mines of Cornwall and Devon, and perhaps it is no exaggeration to say that a large proportion of the engines of Boulton and Watt were sent into those counties.

Cornish Pumping Engines are generally single acting beam engines. Three slides are used to regulate the supply of steam in the cylinder, viz., steam or expansion, exhaust or eduction, and the equilibrium slide. The cylinder always has a jacket. The steam is worked at a very early " cut off," and the greatest advantage is taken of its expansive properties; consequently the engine moves slowly, its stroke being regulated by the *cataract,* although in its earliest form Watt used the governor to give it steadiness of motion. A fly wheel is generally employed, the steam being used to effect the down stroke of the piston, the weight of the pump rods, etc., performing the up stroke. The action of the steam is this: the steam valve admits the steam to the top of the piston, and after doing the duty of forcing it down, part of the stroke is done expansively; by means of the equilibrium valve, the same steam is allowed to pass to the bottom of the piston, and assist in the return stroke, after which it escapes to the condenser through the exhaust valve. See *Single Acting Engine.*

The beam is generally an unequal one, although equal beams are occasionally employed. It is supported on two cast-iron columns, but generally on walls of solid masonry. The reason for using an unequal beam is to give the piston a longer stroke without increasing the velocity at which the pump plunger works, and thus preventing the wear and tear of the latter. Again, high pressure steam may be used with a long stroke, without being obliged to strengthen the other parts of the engine in proportion to the stroke.

The slides are not ordinarily worked in the common manner by an eccentric, but by tappets on the air pump rod, or else on the plug rod. As the beam goes up carrying the air pump rod, a tappet or projection on the rod strikes the extremity of a simple lever, lifting it up; the other extremity opens the steam and exhaust valves, and closes the equilibrium, and in going down it reverses the process. Thus the slides are worked. The water is lifted on the down stroke of the piston by the extremity of the beam by means of a pipe passing down the mine shaft. It is not elevated right up to the top at once, but is driven from the bottom by an ordinary single acting valve, consisting of a plunger of suitable size, the water being forced into a cistern or tank at the first level, and not allowed to return by means of valves; the next stroke forces it up to another and higher level, and so on. If possible, they make the water drainage of each level run into its own tank.

To give an idea of their size, the following are the dimensions of one of the engines erected by Boulton and Watt:—

Diameter of cylinder,...............	28	inches.
Stroke,.................................	8	feet.
Number of strokes per minute,...	14	
Diameter of lifting pump,...........	$17\frac{1}{2}$	inches.
Stroke of lifting pump,..............	8	feet.
Water raised,..........................	126	feet.

The *distinctive features of the Cornish single acting pumping engines are:* the large employment of the principle of expansion, by which a very great economy of fuel has been realized; the use of the cataract to ensure a slow stroke, by regulating the supply of condensing water; the mode in which the valves are worked; the employment of steam for the down stroke, and the up stroke being performed by the weight of the rods, etc., at the other end of the beam; and a plunger is employed in the pumps, and not a lift or bucket.

The eduction valve allows the steam to escape to the condenser, when the down stroke is to be made; it is opened a little before the steam or expansion valve, so that it may have a longer time for condensation, and that the down stroke may take place the instant steam is admitted.

For a general description of this engine we may consider the figure of the beam engine, on page 177, as a Cornish pumping engine; but instead of the fly wheel *v v*, and the small geared wheel to the right at the bottom, we must imagine that from A descends a heavy pump rod down into the mine from which the water is to be raised. To the same end is attached the plug rod to work the cataract. At the other end of the beam is first of all the cylinder E F with the piston rod E B, while G H is the air pump rod, and H the air pump. L M is the hot water or feed pump rod and pump, as the air pump rod ascends and descends it works the valves. The water is elevated by the pump rod at the end A by first raising it from the lowest level to a higher, when it is delivered to the pump, then to the pump next above, and so on until the water reaches the surface.

EXERCISES CHIEFLY FROM EXAMINATION PAPERS.

1. Give a description of a beam engine. Upon what principle is it constructed, and how are the slides worked?

2. Describe a simple and effective form of horizontal engine. What advantages are gained by the use of such engines?

3. How does a vertical engine differ from a table engine? State the distinctive arrangements in each case. When may vertical engines be advantageously employed?

4. Describe a simple form of portable engine adapted for agricultural purposes. State clearly how the slides are worked, and how the work is taken off the engine.

5. What is the general form and principle of Ramsbottom's intermedial engine?

6. Describe the form of engine in which gas is used as the motive power. State clearly wherein they differ from a horizontal engine. Give a full description of the "igniter," and the theory of its action.

7. Describe a caloric engine, and show clearly how the motive power is treated. Can you tell what is meant by the "regenerator" as used in these engines, and describe clearly the principle on which it acts?

8. How does Siemen's engine differ from the hot air engine?

9. What are the distinctive features of a Cornish engine? How is the water elevated by these engines?

10. Explain the manner in which the steam acts in Watt's single

acting pumping engine. Why is this engine so much more economical in steam than the old atmospheric engine (1870)?

11. Explain the principle upon which the parallel motion of a beam engine is constructed (1870). See questions at the end.

12. State the principle of Watt's single acting engine as applied in pumping. What valves are necessary for the working of the engine? How is the number of the strokes to be made per minute regulated? Describe the cataract employed for that purpose (1871).

13. Define the duty of a steam engine. What is the average duty of the pumping engines in Cornwall? How do you explain the increased duty obtained from such engines by employing steam at a higher pressure and by working expansively (1867)?

14. Sketch in section steam cylinder and valves connected with it, as arranged in Watt's single acting pumping engine. Explain the object and use of each valve, showing at what periods of the stroke they should be respectively opened or closed (1871).

15. Give an account of the principal discoveries of Watt, and the advantages derivable from them (1867).

16. Describe the Cornish double beat valve (1867).

17. It was stated by Watt, that neither water nor any other substance colder than steam should be allowed to enter or touch the steam cylinder during the working of an engine. Show that this rule was not adopted in the case of the atmospheric engine, and describe the arrangements by which Watt gave effect to it (1872).

18. There are three valves connected directly with the steam cylinder in Watt's single acting condensing engine. Name them. During what portions of the up and down strokes of the piston should these valves be respectively open or shut, and for what reason (1872).

Several of these questions are repeated for the convenience of the students.

CHAPTER XII.

COMBUSTION AND PREVENTION OF SMOKE.

Definition—Foot Pound—Combustion—Analysis of Coal—Prevention of Smoke—Smokeless Coke—Rules to Avoid Smoke and Waste of Fuel.

214. Definition.—The combustion of a pound of coal produces 8000 thermal units of heat.*

A thermal unit of heat is the heat necessary to raise a pound of water one degree in temperature.

"The quantity of heat necessary to raise one pound of water 1° Fahrenheit in temperature is equal to that generated by a pound weight falling from a height of 772 feet against the earth, or it would raise 772 pounds 1 foot high.

215. "Foot Pound."—The term foot pound has been introduced to express in a convenient way the lifting of a pound to the height of a foot. Thus the quantity of heat necessary to raise the temperature of a pound of water 1° Fahrenheit being taken as a standard, 772 foot pounds constitute what is called the *mechanical equivalent of heat.* If the degrees be centigrade, 1390 foot pounds constitute the equivalent." †

216. Combustion.—*Combustion* is chemical combination attended with the evolution of heat and light.

A *flame* is gas or vapour raised to a high temperature by combustion. From this definition we see the reason why the direct impact of flame against the flues and tubes of a boiler should be avoided as much as possible.

* Ganot's *Physics*, p. 401.

† Tyndall's *Heat as a Mode of Motion*, 4th Ed., p. 40.

217. Analysis of Coal.—Caking or bituminous coal contains—

$75\frac{1}{4}$	per cent. of	carbon.
$4\frac{1}{4}$	,,	hydrogen.
16	,,	nitrogen.
$4\frac{1}{2}$	,,	oxygen.
100		

All analyses vary according to the coal taken. The quantity of carbon in different varieties of coal varies very materially; not only do the different kinds of coal, as caking, splint, cannel, anthracite, etc., differ in their constituents, but the coal from the same seam will vary considerably from the normal standard of that kind of coal. The heating powers of coal vary with the amount of carbon—the more carbon the more heat will be yielded. The best coals are the Lancashire, the Durham, the Staffordshire (locally called brown coal), and the Welsh anthracite, or stone and furnace coal. Lignite, as a rule, possesses two-thirds of the heating power of good bituminous coal. Peat contains on the average a little less carbon than lignite, or about 50 per cent. The Americans give analyses which lead to the conclusion that their anthracites contain more carbon than our best coals; but it must not be forgotten that anthracite requires an intense heat, a good supply of oxygen, and considerable time for its combustion; but we must set against this that when it does burn the heat is very fierce.

It is plain that the quantity of air necessary for perfect combustion will depend upon the fuel used. Caking coal, as Welsh, which fills up the spaces between the bars, will certainly require a greater admission of artificial air than the light burning coals from Staffordshire or Newcastle. A permanent opening of from 40 to 50 square inches behind the bridge has been found very effective to prevent the escape of carbon (smoke), and resulted in a saving of 33 per cent. in fuel.

When coal burns it throws off light carburetted hydrogen, heavy carburetted hydrogen, carbonic acid gas, carbonic oxide, etc., each of which, as it produces heat, will combine only with its proper proportion of oxygen; therefore, if more be supplied by introducing too much fresh air, it does injury not only by cooling the internal surface of the flues, but (remembering that a high temperature is necessary to produce combustion) by preventing combustion. It has been proved that hydrogen furnishes, weight for weight, four times as much heat as carbon; therefore the $4\frac{1}{4}$ parts of hydrogen in coal will produce $4\frac{1}{4} \times 4 = 17$ parts of heat, and the carbon $75\frac{1}{4}$; or out of 92 parts 75 are produced by the great preponderance of the carbon, and 17 by the small amount of hydrogen. In round numbers, we may say out of 100 lbs. of coal 80 lbs. are carbon and 5 hydrogen (which latter gives heat equal to $4 \times 5 = 20$). The 80 lbs. of carbon will require 2527 cubic feet of oxygen for its combustion, which will be supplied by 12635 cubic feet of atmospheric air. The hydrogen will require 473 cubic feet of oxygen, which will be found in 2365 cubic feet of air, making a total of $12635 + 2365 = 15000$ cubic feet of air for the combustion of 100 lbs. of coal.*

217. Prevention of Smoke.—Experience has proved that it is quite possible, with a carefully contrived furnace and skilful stoker, to prevent smoke almost entirely. In the Rainhill competition one condition was, that the engines were to consume their own smoke. Stephenson therefore used coke. In marine locomotion smoke is not a nuisance, except in river steamers, but it is a wasteful expenditure of fuel. Smoke is consumed by carrying out the principles of more perfect combustion; for this purpose, either an extra supply of atmospheric air (oxygen) is insured, or a jet of dry steam is sent into the mouth of the furnace. The chief object to which the fireman has to direct his attention is to spread his fire evenly, and when he introduces fresh fuel to keep it close to the fire door at first, so that the carbon may be brought in contact with sufficient heat, as it passes over the fire, for its perfect combustion. If the coals are at first placed near the furnace doors—this was Watt's plan for consuming smoke—they begin at once to give out their gases, these passing over the incandescent fuel, farther in the fireplace, are raised in temperature sufficiently for the carbon to combine with the oxygen. Coal gives out carbon and hydrogen, with nitrogen and oxygen, the carbon combining with the oxygen of the air gives

* See Colburn's *Locomotive Engineering* for a second calculation.

out carbonic oxide; but the hydrogen combining with the oxygen, gives intense heat, and sets the carbon free; but the carbon next unites with the oxygen, and as it passes from one to the other, we have intense light. The more the oxygen the greater the heat. Hence the reason for the construction of the Bunsen's burners, now so common in every house under the name of gas stoves. Mr. C. W. Williams of Liverpool has given great attention to the construction of fireplaces and furnaces that shall consume their own smoke. He admits air behind the firebridge into a mixing chamber, where the fresh and heated air enter into combination, and the smoke-laden flame is deprived of its carbon by more perfect combustion.

Some engineers consume the smoke simply by paying extra attention to the stoking. In Jukes' patent furnace the bars are arranged as an endless chain, passing over two rollers, which work the chain, the latter gradually carries forward the coal from the mouth of the furnace; as it passes under the door, the bottom of the door prevents the entry of too much coal at one time, or regulates the supply. A roomy furnace has a far better chance of consuming its own smoke than a small one. This will follow from what has been stated above. With a roomy furnace the smoke has a larger mass of incandescent fuel to pass over, so the gases can be better burnt as they go along to the flues. In Prideaux's furnace he supplies air only as long as smoke is being produced, by the peculiar arrangement of openings in, and plates of iron on the back of, the furnace door. These plates heat the air as it enters the fireplace, so that no cold air can gain admission. In practice it is found that if a continuous stream of cold air be allowed to enter, it acts injuriously upon the boiler plates, by causing oxidation through the excessive heat at one moment and sudden cooling at the next. When a jet of steam is introduced into the fireplace to promote the consumption of smoke, it enters from a pipe placed immediately across the top of and inside the door; then as it violently rushes over the burning fuel, it does this in two ways. Its synthesis is affected, and its own oxygen and hydrogen combine with the other products of the coal, and create heat, and at the same time the draught is considerably increased.

218. Smokeless Coal.—Anthracite coal burns without smoke and evolves no sulphur; for this reason it has been introduced on the Metropolitan line. In passing through the covered portions of the line, the exhaust steam is turned into the tanks and condensed, while the draught is maintained by the moderate use of a jet of steam.

Suppose we now throw together a few of the simple rules given under the heads Combustion of Fuel and Prevention of Smoke.

(1) It is best to heat the coals on the dead plate first after the manner of Watt, or else in commencing firing throw the first few shovelfuls toward the bridge, and gradually cover the fire evenly to the door. In all cases see that the bars are well covered.

(2) Knock out all clinkers as soon as formed, keep the fire from caking together, and admit a proper supply of air near the door.

(3) Regulate the draught either by the dampers or by the ash pit and furnace doors, or by an orifice behind the bridge. Clothe all parts of the engine and boiler that lose heat by radiation, such as steam pipe, cylinders, boilers, etc.

EXAMINATION QUESTIONS.

1. What is a foot pound?
2. Define combustion, and give an analysis of coal; also state how much air is required for the combustion of 100 lbs. of coal.
3. Give some simple directions to a stoker to effect the consumption of smoke when he is stoking.

CHAPTER XIII.

BOILER EXPLOSIONS.

Cause—Spheroidal Condition of Water—Water Purged from Air—Hydrogen Theory—Accumulated Pressure—Incrustations—Deficiency of Water—Collapsing—Bad Management—Mr. Colburn's and Professor Airy's Theory.

219. Cause of Boiler Explosions.—Many theories have been advanced to account for the sudden explosion of boilers: such as (*a*) the spheroidal condition of water; (*b*) water purged from air; (*c*) the hydrogen theory; (*d*) accumulated pressure; (*e*) incrustations; (*f*) deficiency of water; (*g*) from collapsing; (*h*) from bad management; (*i*) from faulty construction. The first three, *a*, *b* and *c*, are plausible theories. There can be no doubt that the majority of boiler explosions have originated in *excess of pressure*—the steam generated to cause that excess arising from several of the circumstances mentioned above.

Mr. Marten,* one of our most experienced engineers on boiler explosions, says steam boiler explosions may be classified under two heads:

1. "Faults in the fabric of the boiler itself as originally constructed, such as bad shape, want of stays, bad material, defective workmanship, or injudicious setting.

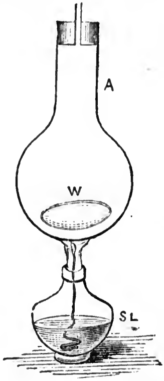
2. "Mischief arising during working, either from wear and tear, or from overheating through shortness of water or accumulation of scurf; or from corrosion, in its several forms of general thinning, pitting, furrowing, or channelling of the plates; or from flaws or fracture in the material, or injury by the effect of repeated strain; or from undue pressure

* See *Records of Steam Boiler Explosions*, by E. B. Marten, of Stourbridge, Spon.

through want of adequate arrangements for the escape of surplus steam."

Experience shows the need of greater care in construction to provide proper stays to ends; the want of stronger guards to man holes to prevent the edge of the plate cracking with the extra strain upon it, and the necessity of hoops or other means of strengthening weak internally fired tubes; and the greater care in executing repairs so as to restore the strength, and with sound workmanship to prevent the leakage from corrosion so often found in boilers repaired with rough screw patches.

220. (*a*) **The Spheroidal Condition of Water.*** — If a drop of water be thrown upon a very hot plate, as the top of a cooking stove, it will immediately assume a spheroidal shape, and roll about the plate; while if the plate be but warm, the water will spread upon it, and soon evaporate in steam. In the former case, the small spheres of water do not even reach the boiling point, but between them and the hot plate are small cushions of steam, which buoy up the spheres and keep them from coming in contact with the hot plate. Each sphere, as it were, projects from its surface vapour which repels the hot plate; but the moment they spread abroad upon the hot surface they disappear as steam. That steam in considerable quantities may be thus formed can be easily illustrated by experiment. Suppose that A is a copper vessel, with a small glass tube passing through the cork in the neck; place under it a spirit lamp S L; when the vessel is heated, pour a little water, W, into it, it will immediately assume a spheroidal condition, the small quantity of steam developed while it remains in that state passes through the tube. Let us remove the lamp, then the moment the copper is cooled down sufficiently the water loses its spheroidal form, spreads over the copper, and a large quantity of steam is developed, sufficient to drive out



* See Tyndall's *Heat as a Mode of Motion*, 4th Ed., pp. 154 to 162.

the cork with great violence. Applying this to the case of boilers, it will be seen that if from lack of feed the water in a boiler should assume a spheroidal state, that an explosion must inevitably follow; for as the furnace cools and the water spreads over the plates, a larger amount of steam will be developed than can pass the safety valve.

221. (*b*) **Water Purged from Air.**—All water holds air; boiling sets it free. We may see the air bubbles rise if we watch heating water; this air increases the ebullition. When air is removed the atoms of the water more firmly lock themselves together, or the cohesion of the particles is increased—the cohesion is so augmented that the temperature may be raised 30° or 40° C. above the ordinary boiling point without producing ebullition; but when ebullition once commences, the whole of the excess of heat is consumed in converting the water into steam, and an explosion follows. Many locomotive boilers have exploded on quitting the shed. It has been suggested that the cause of this may be found in the above statement. The water has been purged from air by previous boiling, and when the fires were got ready for a journey, they, instead of generating steam, stored up a large excess of heat in water possessing a high cohesive power, so that immediately the stop valve was opened, the equilibrium was disturbed, the cohesion gave way, and the excess of heat stored up produced steam sufficient to cause the explosion.

222. (*c*) **The Hydrogen Theory.**—Water consists of hydrogen and oxygen. One pound of hydrogen combining with eight pounds of oxygen would form nine pounds of water. It has been suggested that when water comes in contact with red-hot boiler plates, it is decomposed and separated into its constituents of hydrogen and oxygen, and that immediately the hydrogen is formed it explodes. There are serious objections to such a theory, not the least is that before the hydrogen explodes, it must be mixed with a due proportion of oxygen or air; again, it has never been proved that decomposition does take place under such circumstances. Water in contact with hot plates is converted into steam, which is quite capable of causing any explosion.

223. (*d*) **Accumulated Pressure.**—Accumulated pressure is the cause of ninety-nine boiler explosions out of a hundred.

An active fire under a boiler will generate a very large quantity of steam, and if proper provision be not made for its escape by means of the safety valve, etc., mischief must follow. If the safety valves should be too small—if they should get jammed on their seats—if they should be tied down or overloaded, for some enginemen have been found mad enough to do that—injurious results will certainly follow the excessive aggregation of steam. If, also, in getting the steam ready, time after time, the boiler should be put to an excessive strain by the safety valve being loaded too heavily or not acting properly, the time must come when the enormous elastic pressure of the steam will be greater than the tensile strength of the boiler, and an explosion will take place. A very large class of accidents have occurred through the safety valve not acting, or not being large enough in proportion to the evaporating power of the boiler. We have alluded in another place to the rapid manner in which steam pressure accumulates when an engine is standing still and the fires kept up as usual. When boilers burst from excessive pressure, the parts that give way are either those immediately over the furnace, the flat ends, or where water has been allowed to rust away the plates through faulty setting, etc. The best security against excessive pressure will be found in having boilers of maximum strength and the best form, with good appendages, as safety valves, etc.

224. (*e*) **Incrustations.** — Incrustations have been the cause of boiler explosions, as already referred to, when speaking of the salting of marine boilers. As gypsum, lime, salt, etc., are deposited internally upon the plates of a boiler, they form a solid hard crust. Let us suppose such a crust to be formed. It is sometimes deposited very rapidly; and consisting of earths, the incrustation is a very bad conductor of heat, consequently the boiler plates will become red-hot without transferring the motion to the deposit. When the boiler plates become red-hot, the incrustation will probably separate from the iron, through the latter expanding more than the former; the consequence will be that the water will reach the plates, and a sudden generation of highly elastic steam, in greater quantities than the safety valve will allow to pass, will cause a tremendous explosion, with consequent loss of life and property. It is of course quite plain that the part of the boiler likely to give way under these circumstances, will be the *softened plates* above the furnace. When heated like this, they lose five-sixths of their strength. In fact they will be driven into the furnace or collapse. The remedy against incrustation is a proper amount of blowing out and chipping off of the hard substance as it accumulates.

225. (*f*) **Deficiency of Water.**—From what was said under *b*, it is quite possible that from lack of a due supply of water that the remainder in the boiler may assume a spheroidal condition, which must result, when the heat decreases, in an explosion. Such a result can hardly be brought about if the least attention be paid to the water cocks, the feed pumps, and the glass water gauge. Sufficient water must always be kept in the boiler to cover every part in immediate contact with the heat. Should these parts get hot, as was mentioned above, they lose five-sixths of their strength, and only one-sixth of the ordinary strength of the boiler will be an insufficient safeguard against an explosion. Should the engineer lose his water, he must not attempt to open the feed valves or cocks—many a life has been thus needlessly thrown away to save a little scolding or dismissal. It is a thousand times wiser and more manly to face these consequences, than to risk life, limb, and far greater punishment. When the valves are thus opened, a great amount of elastic steam is immediately developed, and the softened plates give way. Therefore risk no life, open the fire doors and take out the fires, and then gradually ease the safety valves. Fusible plugs are a good preventative against accidents happening from a deficiency of water.

226. (*g*) **Collapsing.**—A boiler or flue is said to collapse when it gives way to exterior pressure, or from the air or steam acting against a vacuum or partial vacuum. In such cases the steam enters the flues, and scalds and destroys everything in the engine room. A partial vacuum has by some means been created in the flues, then the pressure of steam within the boiler has driven in the plates of the tube, and an explosion has followed, or the iron has become softened and worn, and the pressure being greater

than it can bear, the explosion has happened. To avoid danger from this cause, the flues must be properly constructed, stayed, and strengthened by rings of strong angle iron at every 10 feet. They must be round, not elliptical. The vacuum valve must be kept in working order to prevent boilers collapsing.

227. (*h*) **Bad Management.**—As long as ignorant and careless men can obtain charge of boilers, accidents will certainly happen. Let us hope that, as education spreads—it has perhaps now a fair chance—no such persons will find employment where so much depends upon their intelligence, care, and attention. When men cease fastening down the safety valve, either wilfully or by neglecting to raise it from its seat, and no more surreptitiously alter the weight, we shall have fewer accidents. Such things have been done, improbable as they may appear—the American phrase of sitting on the safety valve is too true. Ignorance leads to most accidents. It was only a few years ago in Plymouth Sound, that on board one of H.M.'s vessels the water was lost through the gauges not acting properly, when the engineer, aware of what was the matter, ignorantly turned on the feed instead of taking out the fires. The remedy for bad management exists in education. But excellent authorities say, that the introduction of cold water has nothing to do with the explosion when plates are overheated, for they say the water is introduced at the bottom, and only rises slowly over the surface, and gradually cools it. The experiment of putting cold water into red-hot boilers has been repeatedly tried without producing any explosion.

228. (*i*) **Mr. Colburn's and the Astronomer-Royal's Theory of Boiler Explosions** can hardly be called a theory on explosions, but rather a theory to account for the large amount of mischief that a boiler explosion creates. Mr. Colburn is of opinion that boiler explosions take place at but little above ordinary pressure by the rupture of a defective point close to the water line, the defect being generally caused by corrosion; that as soon as the rupture takes place, immediately part of the steam escapes; instantaneously, as the pressure is taken off the boiler water, the large store of heat in the water above the boiling point generates a large amount of steam, which is at once disengaged. This large quantity of suddenly formed steam forces off the upper shell of the boiler, and causes all the mischief that follows. So that the mischief is not done by the steam that was in the boiler at the moment of explosion, but is done by that which is created during the moment of explosion. This creating of steam takes place throughout the instant of explosion, its elastic force gradually diminishing till the water reaches 100° C. From careful investigations it may be stated roundly, that the explosive energy in every cubic foot of water in a boiler at 60 lbs. pressure equals that contained in a pound of ordinary gunpowder.

EXAMINATION QUESTIONS.

1. What are the chief causes of "boiler explosions?" What is the hydrogen theory?
2. State distinctly what you mean by the "spheroidal condition of water," and water purged from air. How have these theories been connected with boiler explosions?
3. Show how accumulated pressure and deficiency of water act to produce a boiler explosion.
4. Account for so much steam being generated and mischief done by boiler explosions.
5. What distinction is there between a boiler exploding and a tube collapsing; state the precautions to be adopted in either case.

CHAPTER XIV.

PRACTICAL WORKING.*

Duties to Machinery when in Harbour and Getting up Steam—Starting the Engines—Under Steam—Fires—Bearings—Engines in Port—Lap on Slide Valves—How to Set the Slides.

229. 1. Duties to Machinery when in Harbour before Getting under Steam.—When an engineer takes charge of the machinery of a boat, his first attention ought to be directed to his boilers; for, being the source of power, they may become the source of great danger if not properly looked after. In inspecting the boilers three things require especial notice:—(1) The thickness of the plates above the fires and other places of importance; (2) the state of the stays; (3) the position of the gauges, viz., the water gauge, cocks, and glass water gauges.

(1) Respecting the first, a general plan is to drill a small hole through the plate, and thus find its real thickness, for it is often the case that a boiler plate may be far thicker at the seams than in the middle. At the seams the proper thickness cannot always be correctly ascertained on account of the way in which they are caulked, by which a plate may appear considerably thicker than it really is. After the hole has served its purpose, it is tapped and plugged tightly up again.

(2) As regards the stays, they require a great amount of attention; for they are very apt to get eaten through near the plates by oxidation.

(3) The gauge cocks are often placed just above the highest row of tubes. Now this is a very dangerous practice, for it is possible for an engineer to lose his water, let him be

* Written by a Working Man.

ever so careful, when great danger follows; while if the cocks were placed a little higher, the loss of water would not be necessarily followed by so much danger.

230. 2. Duties to Machinery when Steam is Getting up.—The water in the boiler when the fires are lighted ought to be just above the bottom of the glass. In a large, or even moderate sized boiler, the water will expand, and there is also not so much water to heat at first; and we know, by reason of conduction and radiation, that small bodies of water are heated comparatively more rapidly than large. On first lighting the fires they should not be kept too large, but just sufficient to cover the bars. A large thin surface of fire is found to be the most effective on getting under weigh.

When the fires are lighted, and the steamer is going on a long voyage, it is the practice to rub the polished parts of the engine over with a composition of tallow and white lead. This prevents any rust forming on the rods, etc., from water dropping on them which may have been used for keeping the bearings cool.

The discharge valve is also opened now, or else on starting the engine something will give way. Several accidents have occurred by neglecting to do this.

The safety valves are now to be inspected to find out whether they are fast corroded to their seatings. If so, they must be freed and made ready to act before starting.

It is a good plan, and one much practised, to give the engines a good blowing through whilst the steam is getting up. This warms the cylinder, and tries any joints that may have been made since the engines were worked last. It also saves the steam, for if not done now (when the engine is starting), a great amount of steam is wasted in heating the cylinder instead of imparting its elastic force to the piston. It is thus that boilers are sometimes taxed beyond their powers, and the steam pressure reduced to perhaps a very dangerous point.

231. 3. Starting the Engines.—All ships are now fitted with the double eccentrics, or "Stephenson's Link Motion," by which the engines are started, or rather by this the slide valves are under the command of the engineer, and can be worked back or forward as command be given, by either a bar, lever, or generally, in large engines, by a wheel.

The handles, by which steam is turned on and off, with the injection cock handles, are placed beside the wheel, so that one man can now generally start the engine.

Some large ships have a steam piston so fitted that it rises and falls by steam admitted above or below, thus rising or lowering the link in its motion. This is what is called steam starting gear, and is very handy when the link is of great weight. There is always hand gear fitted as well, which can be used in cases of emergency. In giving injection to a common condenser, it should be opened just after the steam is turned on to the cylinders, or else if going slowly the condenser may become too full of water, and the air pump not able to perform its work properly.

In starting an engine that is fitted with surface condensers, the only thing requiring attention before going on, is to open both valves communicating with the sea above or below the condenser, viz., suction to the circulating pumps and delivery from them.

DUTIES WHEN UNDER STEAM.

232. The Boiler.—Always keep looking at the water level. This is oftentimes a source of great anxiety, for some boilers require the water to be kept at a certain fixed level. If water be too high they will not keep steam, and if too low the steam will generate too fast. Some boilers require a high water level, others a low one, in fact no general rule can be given for the water level, nothing but practice can determine it. A safe rule is to keep the glass water gauge about two-thirds full.

Blowing out marine boilers should be practised about every two or three hours. Practice has proved this to be a good rule, on account of not so much water being required to be blown out at a time, and therefore the steam pressure is not reduced to a very great extent.

In steamers fitted with surface condensers, a little sea water is supplied to the boilers to make up for the loss in the steam pipes, jackets, leaks in the condensers, etc. This in time may injure the boiler if not counterbalanced some way or other. The general plan is to blow out about two or three inches every twelve hours. The water in these boilers is never allowed to reach more than $\frac{2}{30}$ of saltness.

The fires require much consideration. A furnace is best worked with a heavy fire, but not too heavy, thicker towards the back than front. The fresh fuel should be placed in front, and then pushed back after being thoroughly heated. Every four hours (at the least) the fires should be cleaned out, as large clinkers or refuse of the coals adhere to the fire bars and prevent the draught, making the fires burn dead, especially towards the back of the furnace. Sometimes the slag will stick fast to a furnace bar, and cannot be removed from it. This causes a great amount of trouble, as in trying to remove it, the fire bars are occasionally pulled out of their places, and the greater part of the fire falls through, causing much waste and often danger.

The principal thing to pay attention to when the engines are under steam, is to keep the bearings cool and the glands steam tight. Oil is generally used for keeping bearings cool, but when larger ones are working hard, a jet of water is kept playing upon them. This is found to answer very well when the water is turned on before they have had time to heat. It should not be used after they have been allowed to get heated, for it may crack them by too sudden contraction. A good stream of water should be kept running on the thrust block from the time of starting, this with the tallow, which is always put into it before starting, keeps this all-important bearing cool. The cap of the thrust block requires great care in adjusting. If screwed on too tightly it is almost sure to heat or fire, as it is termed, and if not screwed down sufficiently tight, the unpleasant jumping shake so often experienced in our screw ships is sure to follow.

The packing of the gland at the stern tube should be well looked after, and kept quite tight and well tallowed.

In paddle wheel steamers there is frequently not sufficient care taken about the outer bearing of the shafts. In very few ships are proper means provided for lubricating these important parts. At the commencement of a voyage, the outer bearings are well tallowed, and often put down, screwed up, and left to look after themselves as best they may. Very few ships, indeed, being provided with tubes leading down from the paddle boxes to the oil holes of the blocks, or in which means are provided for their lubrication.

The coals in the bunkers must be carefully watched, to prevent spontaneous combustion. The stoppers over the holes should be kept open as much as possible, and care taken not to keep damp coals longer in the bunkers than can be avoided; for it is only damp coal that is liable to spontaneous combustion.

In new fast running engines castor oil is a very good thing to use on first starting. When new brasses have been fitted into the bearings, till they form a good bearing for themselves, the same should be used. It appears to have a much firmer body in it to lubricate than all other oils have. The difference in the cost of the oil is not very much, coarse castor oil being very little dearer than good machine oil.

233. Duties to Machinery when the Ship has Arrived in Port.—The white lead and tallow should be rubbed off with a piece of oily waste, and then the bright work of the engines will give no trouble by rusting.

The engines should have a good blowing through to drive out all water in the condensers, then the Kingston's valves, communicating with the sea, should be shut, next open the condenser drain cocks, which will drain out all the water left in them. This is allowed to run into the bilges, which can be pumped out by the donkey pump or the hand pumps if no steam is left in the boilers.

Some engineers always blow out their boilers after steaming, others do not, the latter only let the fires out and shut the valves in the steam pipes; both plans have their advantages and disadvantages. Perhaps the majority keep the water in the boilers, only blowing out when repairs or an examination of the boiler is required. An engineer should always examine for himself whether all the fires are properly out, and not take the word of the stokers for it. A great amount of damage may be done by the fire not being properly put out in the ash pits. A frequent practice is to get a heap of hot ashes together and dash some water over it; this makes it black outside and leaves it burning inside. The ashes should rather be spread out evenly, and then water thrown over gradually and gently to put the fire out effectually, and to create as little dust and dirt as possible.

234. To Find the Amount of Lap on the Slide Valve (before setting the slides).—Take a batten of wood, and place it on the cylinder slide face at right angles to and over the ports. Mark off on it the edges of the steam and exhaust ports with a square and scriber. By placing this on the face of the slide-valve, the amount of the lap can be at once found.

235. To Set the Slides.—Put the piston at the top or bottom of its stroke. If the eccentric is rightly fixed on the shaft, simply fasten the slide valve on the spindle with the required amount of lead. Then turn the engine to the other end of its stroke, and see if the lead is the same; or in some engines more lead is given at the bottom than at the top (as in vertical engines). If the engine is fitted with the link motion, the reversing eccentric is then connected and the valve tested in like manner. Also with the link motion, the slide rod is placed in the centre of the link; and although the position of the eccentrics on the shaft ought to destroy any motion of the valve, yet there is a little with a short link. This is tested to see that the steam ports are always closed, and thus the engines can be stopped, even if the full pressure of steam be admitted to the back of the slide by the stop or throttle valves.

EXAMINATION QUESTIONS.

1. Describe briefly the duties to the machinery when in harbour before getting under steam, that require the attention of the marine engineer.
2. To what must an engineer particularly direct his attention while getting up the steam?
3. When a vessel is under steam, what will then claim the especial attention of the engineer?
4. When a ship is to be laid up in harbour, how must the engines be left?
5. Show how to set the slide valves, giving the proper amount of lap and lead.

CHAPTER XV.

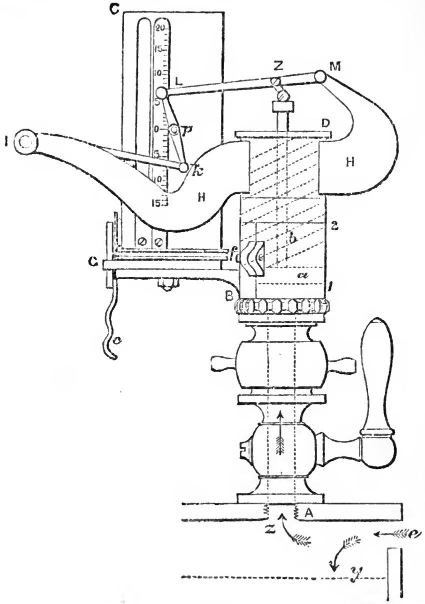
THE INDICATOR.

Description—Use—Diagram—Diagrams under Various Circumstances.

236. The Indicator, an instrument invented by Watt, is used to ascertain the internal condition of the engine, the state of the vacuum, the amount and variations in the pressure of steam at every point of the stroke, the cushioning, the condition of the slides, whether there be too much or too little lap or lead, whether they are leaky or properly set, whether ports are closed and opened at the proper time, in fact, it tells us the power and all the faults by which that power is impaired. It may also be attached to the air pump, the hot well, the condenser, etc., when it will tell us the nature of the pressures there existing. It has been very much modified since the time of Watt, to better adapt it to its purpose. The figure given of it is from one of Richard's indicators, which exhibits the latest improvements.

In its simplest form, the indicator consists of a cylinder with a piston, the top being open to the atmosphere, and a spring to keep the piston down to its work. A diagram is taken on a piece of paper to tell us all we wish to learn. This piece of paper is fastened round a barrel, which moves through nearly a whole revolution and back again as the engine makes one stroke.

The figure is a representation of Richard's indicator. A is a screw to fasten the indicator into the cylinder. The handle is to open the connection between the cylinder and the indicator, and thus allow steam to enter B D, the cylinder of the indicator. The piston *a* and piston-rod *b* of the indicator are shown by dotted lines. The slanting dotted lines are intended to show the spring which keeps the piston down, and against which the steam has to act in forcing up the



INDICATOR.

piston *a*. In the actual indicator, the piston is not so simple as shown here, but is conical and truncated; B C is the barrel round which the paper is wrapped. The graduated scale is to measure the pressure of steam and the vacuum. Within this barrel is a spring, so that when the barrel has moved nearly round once while the piston goes up, the force of the spring causes it to return as the indicator piston goes down. Round the pulley *f* G passes a string to give motion to the barrel. This string is attached to the crosshead of the cylinder (or the radius bar), and the motion is reduced in its travel to suit the card barrel. While the piston of the indicator moves up only one to two inches, the piston of the cylinder moves several feet. The barrel has to move round four or five inches in the same time. The motion is reduced by levers, when taken from the piston crosshead. If the length of the diagram be three inches, and the stroke three feet or thirty-six inches, we have only to proportion the levers as 3 : 36 or 1 : 12, and the required motion is found. The indicator barrel is moved round by the string (shown in the figure, being attached to its proper relative position on the lever, and) actuating the pulley *f* G and with it the barrel. The arm H H is to carry the parallel motion I *k* L M, the pencil being at *p*. The reason of this arrangement, *i.e.*, of having a parallel motion, is that while the stroke of the indicator is (say) only from 1 to 2, the pencil is required to move up and down from the lower 15 to (say) 25 on the scale. The head of the indicator piston-rod being attached to the lever M L at Z, multiplies the motion of the indicator in the proportion of M Z to Z L. In Richard's indicator this multiplier is about three and a half; in fact, this is the essential difference between Richard's and other indicators, such as M'Naught's, Maudslay and Field's, etc., that the motion is magnified, and therefore the pencil more sensibly indicates the least variation of pressure or action.

The action of the indicator must now be traced. Supposing the indicator is attached to the cylinder, but not placed in communication with it by turning the handle, and that the cord *c* is fastened to a lever at the head of the piston-rod, then it will move the barrel from right to left, and a straight horizontal line will be drawn by the pencil, as A B in next figure—it is generally customary to let the pencil mark this line several times. The line is called the atmospheric line, because it coincides with the atmospheric pressure; all parts of the diagram above that line show pressure above the atmosphere, all parts below it show the vacuum, hence the top part of the diagram is called the "steam" and the bottom the "vacuum." Again: supposing the barrel were still and the steam admitted to the indicator, the pencil would be driven straight up, or a vertical line would be traced. We see that if the barrel only move a horizontal line is traced, while if the indicator piston only move a vertical one is made; therefore when both move together we shall have a line compounded of the two motions, and if the one is continually changing, it will not be a diagonal motion.

Let us suppose the indicator is attached to the top of the cylinder, and that steam enters the upper port *e* as the piston comes to the top of its stroke. The moment steam enters the cylinder it drives the piston down, but at the same time it enters the indicator, and drives the piston of the indicator up.

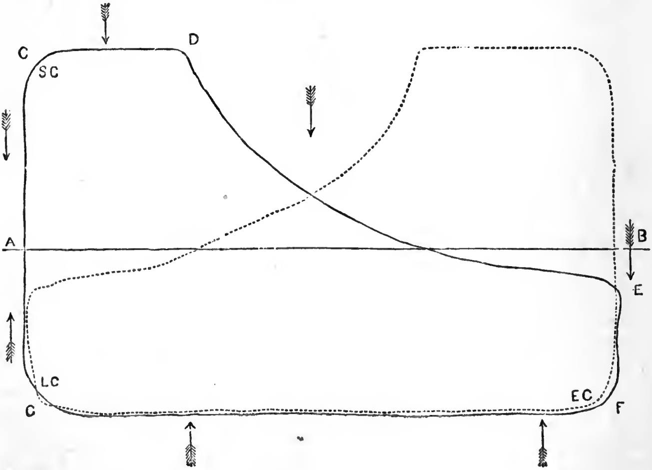


DIAGRAM.

Let us suppose the pencil (when air is in both sides of the piston) stands at A on the above figure, then the line A B, which will be traced by the barrel moving nearly the whole way round, is the atmospheric line. Now let us suppose the top port *e* opened at the instant the tap of the indicator is turned, then steam will rush in, in the direction shown by the arrows; in the direction *y* to drive down the piston, and in the direction *z* to drive up the piston of the indicator. Steam coming in instantaneously drives up the pencil, and the line from A to C will be drawn (C is called the starting corner). Now steam continues rushing in at its normal pressure and the piston of the engine goes down, while on the indicator piston the pressure is continuous, so therefore the pencil remains at the same height, and as the barrel moves round the line from C to D is drawn. When the pencil gets to D the slide has come down again and closed the port,* so that the steam is left to expand; and of course as it expands its pressure decreases, the engine piston continues to go down, and the pressure, becoming less and less in the indicator, the pencil gradually falls lower and lower to E. When it gets to E, the slide still falling, the upper port *e* is opened to the exhaust, and the steam rushes out in a contrary direction to the arrows, the pencil therefore immediately falls to F (the eduction corner). Now there is a vacuum above the piston of the engine, and below that in the indicator, and the engine piston begins to rise up, all the time it is rising there being no steam or pressure in the indicator (or less than no pressure), the pencil having fallen to its lowest point is still, and traces the vacuum line F G to the lead corner G. Against the pencil gets there, the piston has arrived at the top of its stroke, the cushioning then takes place, and the pencil rises at once to A, or else the lead comes into action by the rising of the slide, and drives the indicator piston, and with it the pencil, to A.

The action of the indicator has been traced through an up and down stroke, or a complete revolution of the crank, and we see that the varying pressure in the cylinder is faithfully translated by the indicator and rendered visible to the eye.

The indicator is absolutely necessary if we are to know the pressure of steam when it is performing its work. The Bourdon gauge or other contrivance, when correctly graduated, will always tell the boiler pressure, but it must be well understood that the boiler pressure seldom or never corresponds to that in the cylinder, it is less in the cylinder. This reduction of pressure is due (1) to the friction caused as the steam passes along the passages; (2) to radiation; (3) to loss of power which arises when the passages are contracted; (4) when there is a bend in the pipes and waste of steam: of course all these causes of loss may not exist in every engine, but some

* We are supposing a long D slide is used. In reading the paragraph, the student must consider both this figure and the last on page 210.

of them certainly do in all. This diagram (page 212) is supposed to be taken from the top of the cylinder, and the arrows show the direction in which the piston of the engine is moving when that part of the diagram is being traced. The dotted diagram shows one taken from the bottom of the cylinder.

The indicator diagram, as we have intimated before, is the only true way of ascertaining the action of the steam inside the cylinder. The corners of the diagram are the points to which attention must be directed to find out any defects. In the diagram from a non-condensing engine, the whole of the curve is above the atmospheric line; but in a condensing diagram part is above the atmospheric line and part below.

This is the normal slide diagram, and all condensing engines in good working order with slides properly set and rods of correct length, should give a similar diagram. We will note what the change would be under certain conditions.

If the curve in starting from A ran to the left of C instead of vertically, then we should know that the steam was late in its action, or the slide (the long D) was not high enough at the proper moment. If the curve at E were a little higher and a little farther to the left, the exhaust would take place too early, or the upper part of the slide would be too low. Both the changes would take place through the slides being too far down in the casing, or if the slide rod or eccentric *rod were too long.* Such an evil would also be shown by the diagram being fuller at G, or coming a little farther to the left, and the steam would be cut off too soon at D.

If the slide rod be too short we shall have the exact opposite effects, through it keeping the slide too high in the casing. The upper part from A C will fall to the left at the top and be longer from C to D, fall down lower at E, and a large amount of cushioning will take place at G, through the port being closed too soon, to the exhaust.

If the stop on the eccentric be too far forward we have a diagram something similar to that given when the slide rod is too short, because all the movements of the slide are too early, but the corners will be sharp and angular instead of round. There is a distinction between this case and the cases where the eccentric rod is too long or too short. In the case under consideration the *same fault* would exist in the diagrams taken from the top and bottom of the cylinder, but when the slide rod is in fault the *opposite defects* would exist at top and bottom.

If the stop on the eccentric be not sufficiently forward the diagram will be too full at every period, because all the motions of the slide will be too late.

237. Throttling and Expansive Working. — If two diagrams are taken from an engine under these two circumstances: first, when the steam is throttled; and second, when the expansion valve is used; it can easily be shown that it is far more economical to work steam expansively than throttling it; in other words, when the steam is throttled or wiredrawn, a greater quantity is used and less work is done by it. In throttling, hardly any of the curve will rise above the atmospheric line, while the vacuum will be pretty full, and show a large amount of cushioning; in expansive working the steam line will suddenly rise to a good height, and the expansion rapidly fall; and at the point E (p. 212), where the port is opened to the exhaust, it will be found that with throttling, the line is much higher than when the expansion gear is used, showing that there is more steam in the cylinder in the former than in the latter case. Hence, it is always more advantageous to use the steam at a high grade of expansion than to throttle it.

(*a*) Let us suppose, for instance, that the steam is too late for its action, or, in other words, that the piston commences its stroke by the momentum already imparted to the engine instead of the slide valve admitting steam through having the requisite amount of lead. We then have, instead of an upright line A C, a line A B slanting towards the motion of the indicator barrel. Therefore, whenever we find a diagram with a line in the direction A B instead of A C, we conclude immediately that the steam is too late for its action. This is corrected by advancing the eccentric a little farther in the same direction as the motion of the crank, or else giving more lead to the slide. When

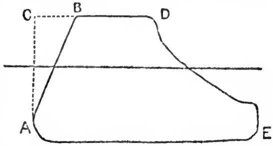


FIGURE 1.

the slide rod is too long we have almost a similar diagram, the steam line B D is too short while the exhaust line E A is too long, so that steam has too short a time for its admission and too long a time for eduction.

(*b*) Let us now examine the annexed figure, by looking at corner A, which is termed the lead corner, we can tell whether the lead be too great or properly proportioned. A defect is exhibited when instead of a vertical line A C being drawn a line B C is drawn slanting off from the motion of the barrel. Steam in this case enters too quickly. The rounding of the corner A generally exhibits the cushioning. To remedy the defect of steam entering too soon, less lead must be given to the slide. Had the steam line C D been too long as well as the exhaust line E B too short, the proper remedy would have been to lengthen the slide rod. For these are the two defects shown by a diagram when the slide rod is too short. A somewhat similar defect would exist if the stop on the eccentric were too far advanced, every action of the slide would commence too soon.

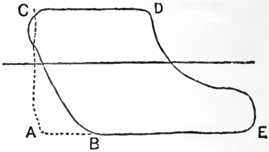


FIGURE 2.

(*c*) A good corner at the end of the full *steam* line, indicates a good arrangement for expansion, as point D in fig. 1. Too gradual a descent from it shows that some steam entered after it ought to have been totally cut off.

(*d*) A good horizontal line on the top of the diagram as far as the expansion point D (in fig. 1), shows that steam has free entrance to the cylinder, or, in other words, that the steam pipes are of good size and the ports properly proportioned. Should either of these be too small for the size of the cylinder, the full steam line A C will gradually decline from the steam corner A to the expansion corner B. Then a slanting line from A to B shows a defect in the ports or steam pipe, for the full steam line A C should be perfectly horizontal, or parallel to the atmospheric line, and not as shown by A B.

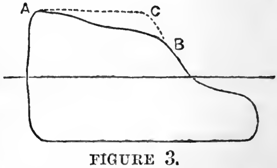
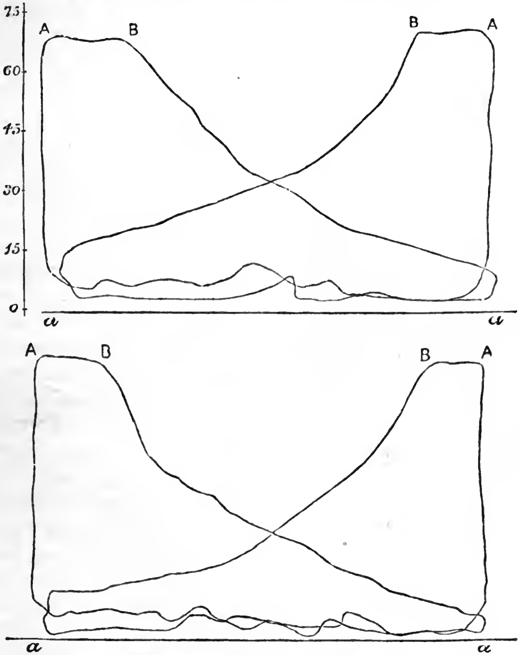


FIGURE 3.

(*e*) A curve at the end of the expansion line before it descends to the vacuum line, indicates that the slide valve is a little opened to, or slightly placed in communication with, the condenser, just before the piston has arrived at the end of its stroke, or in fact that there is *negative* lead.

The two pair of high pressure diagrams, or properly, diagrams from a non-condensing engine, below, are taken from a pair of high pressure cylinders of $10\frac{1}{2}$ inches in diameter.



HIGH PRESSURE DIAGRAMS.

Pressure of steam in the boiler, 75 lbs; length of stroke, 1 ft. 8 in., making 150 revolutions per minute.

The first or upper card was taken from the leading engine, which also works the pump; the full pressure A B was allowed for $3\frac{1}{2}$ inches of the stroke, after which it was cut off by an expansion valve at the back of the slide valve.

The second or lower card was taken from the following engine, in which the steam A B was cut off after $2\frac{1}{4}$ inches of the stroke were accomplished.

The leading engine is allowed $\frac{1}{16}$th of an inch lead by the slide valve, and the following one $\frac{1}{32}$nd.

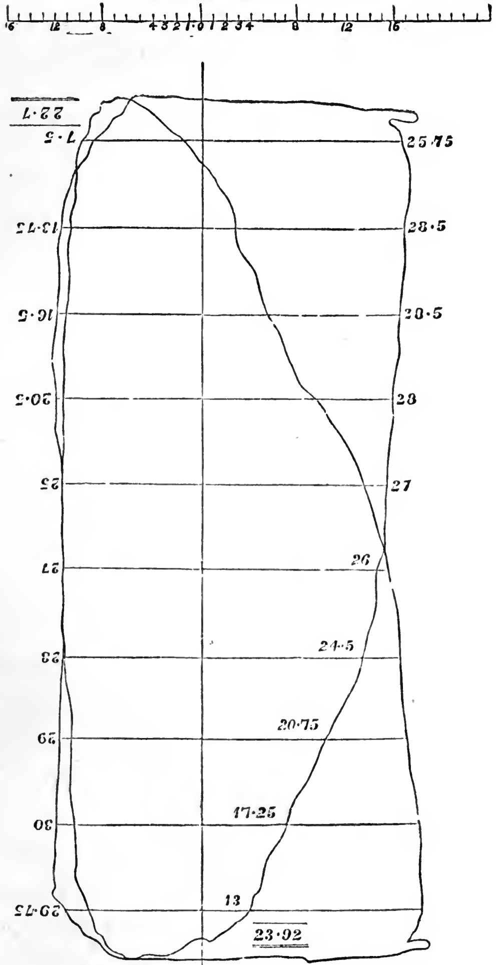
The escape or waste steam is allowed to escape into a pipe common to both engines, which accounts for the irregular exhaust line; but notwithstanding this, it is of ample size, which is clearly proved by the exhaust line being for steam of so high a pressure tolerably near the atmospheric line *a a*. Slackness of cord as well as bad exhaust would cause the irregularities in the lower lines.

238. Slide Diagram.—The slide diagram is omitted, as it is perfectly useless and seldom now taken. It will tell you nothing but what may be learnt from the diagrams taken from the top and bottom of the cylinder.

239. Continuous Indicator.—Canon Mosley, Mr Rigg of Chester, and others, have proposed continuous indicators. The portion of the indicator showing the pressure and vacuum in Mr Rigg's arrangement, is made exactly like the ordinary indicator, with its pencil resting on a continuous web of paper moving slowly. Suppose the pencil to have marked the atmospheric line: the tap is so arranged that it can be opened say during three strokes, and then remain closed for 100 or 1000, or any other pre-arranged number. The diagram so taken consists of a succession of short strokes, across the diagram runs one long line representing the atmospheric line, and at right angles again are short vertical lines showing the highest steam and lowest vacuum pressure at every 100th or 1000th stroke of the engine. The hours can be marked on the card, and the number of revolutions in the interval is easily ascertained according to the spaces into which the atmospheric line is divided. An ordinary diagram, whose steam and vacuum line correspond to any one stroke, will give the basis for the calculation of the horse-power.

To show how to find the horse-power of an engine from the indicator diagram.

This figure consists of a pair of diagrams, one taken from the top the other from the bottom of the cylinder by Richard's indicator. The engine is by Maudslay & Co. (600 H. P.):—



23·92
22· 7
46·62
Mean, - - - 23·31

2 cylinder, 76 inches in diameter, area = 4536·46; 3 ft. 6 in. stroke; 51 revolutions: 23·3 is the mean pressure as per diagram.

To find this mean pressure we have drawn across the diagram *ten* equi-distant lines. Then, in each case, taking the length of the perpendicular lying between the steam and vacuum lines, and applying them to the scale, we find the pressures are 25·75, 28·5, 28·5, 28, 27, etc., which give an average pressure of 23·92 lbs. for the down stroke, and 22·7 lbs. for the up stroke, and a mean of 23·3 lbs.

Therefore the indicated horse-power will be

$$= \frac{4536{\cdot}46 \times 23{\cdot}3 \times 51 \times 2 \times 3\frac{1}{2}}{33000}$$

$$= 1143{\cdot}9 \text{ for one cylinder.}$$

$$= 2287{\cdot}8 \text{ for two cylinder.}$$

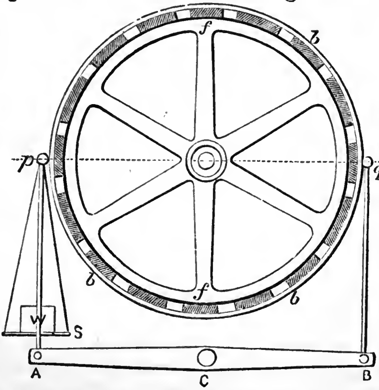
Notice here how widely different the nominal or mercantile horse-power 600 is from the indicated 2288.

240. Dynamometer.—The dynamometer is an arrangement for determining the power exerted by an engine. It exists in several forms. In one form it consists of two flat metal springs joined at the ends by links; the machine or engine is applied to separate the springs. The wider they are separated the greater the power of the machine. The power is indicated on a dial plate.

To ascertain the power exerted by the engines of a screw vessel, the thrust of the screw is made to bear upon the fulcrum of a lever of the second class; by receiving the force near the fulcrum, and having a long arm for the weight, the force exerted by the screw is thus decreased in a great and easily ascertained ratio, somewhat after the manner by which in the weighing machine a small weight in the machine house balances a considerable one on the platform. A pulley on the shaft turns a barrel on which is fixed a piece of paper, while a pencil, moved backwards and forwards by the varying thrust of the screw, exhibits to the eye the power of the engines.

The force driving a paddle wheel engine is measured by a dynamometer fixed on shore, a rope being carried from the vessel and fastened to the dynamometer, when the engines are set to work and their tractive force ascertained precisely as in the last case. The use of the dynamometer has greatly furthered the mechanical improvement of screw engines, by enabling us to estimate the thrust of the screw, and thus ascertain if any large amount of force is being wasted. General Morin states that a good dynamometer should have (1) sensibility properly proportioned to the intensity of the efforts to be measured; (2) the indications of the flexures should be placed beyond the chronic influences of the observer and must be given by the instrument itself; (3) the observer should be able to estimate the effect at every point of the path of any curve made by the instrument; (4) the apparatus should be constructed so as to easily give the total amount of work expended by the engine or machine under consideration.

241. Friction Dynamometer (Balk's). — The friction dynamometer is employed to ascertain the horse-power of an engine by the friction. "The strap or instrument used for producing the friction in Balk's dynamometer is connected with the ends of an unequally armed lever, which causes any shifting of the strap or instrument to increase or decrease its pressure on the friction wheel, thus adjusting it so as to produce the exact amount of friction necessary to keep the load up." The instrument consists of a drum, which receives its motion from a strap connected with the engine whose power is to be tested. On the same axis as the drum is affixed the friction wheel, the periphery of which is turned smooth and true, on it works the friction band, consisting of a hoop of thin copper. On the inside of this hoop is fixed a lining of wood (generally beech) in pieces; to the hoop is fastened two plates, from which two straps run to the ends of the lever. To



one of the plates is attached, by means of steel straps, a scale pan, into which is put the weights. Small weights are added to each end of the lever, until the friction of the band is so increased as to lift the scale pan with its weight. The instrument is tested with various loads, and a scale obtained.

f is the friction wheel, with the friction band *b* round it. The drum is not shown in the figure. The lining of wood attached to the friction band is indicated by the blocks in cross section. The lever is A B resting on its fulcrum C; the straps are seen connecting the plates *p* and *q* with the ends of the lever. The end A C of the lever must be slightly longer than C B. The scale pan is shown at S.

The point of suspension *p* of the weight W must be kept horizontal. The power required to maintain the weight in the position in the figure will be the velocity of the point *p* per minute multiplied by the weight, which will therefore be equivalent to the units of work done.

Let us suppose the radius of the friction wheel is 2 feet 6 inches, the number of revolutions 100 per minute, and the weight 100 lbs., we can then find what the horse-power will be.

Circumference of circle .... $= 5 \times 3{\cdot}1416.$

$\therefore$ Velocity per minute .... $= 5 \times 3{\cdot}1416 \times 100.$

$\therefore$ Units of work done per minute $= 5 \times 3{\cdot}1416 \times 100 \times 100.$

$$\therefore \text{ Horse-power} = \frac{5 \times 3{\cdot}1416 \times 100 \times 100}{33{,}000} = 4{\cdot}76.$$

To find what weight we must use to test an engine is evidently the reverse of this. The horse-power must be multiplied by 33,000, and the produce divided by the number of revolutions of the dynamometer multiplied by the circumference.

EXERCISES CHIEFLY FROM EXAMINATION PAPERS.

1. How can it be ascertained by the aid of a slide diagram if the stop of the eccentric is properly adjusted (1867)?
2. Describe the indicator. Show how it may be used to find the effective horse-power of an engine (1868).

3. Having given a normal indicator piston diagram, show what change would take place in its form if the injection water be shut off; or, secondly, if the steam be throttled (1868).

4. What kind of a diagram would be obtained if the gab lever be too long? What kind of a diagram is obtained by fixing one end of the string to the crosshead of the slide (1868).

5. Describe the indicator for ascertaining the horse-power of an engine. Draw the diagram which you would expect to obtain from a condensing engine in good working order. If the slide rod were a little too long, describe the changes which would probably occur in the diagrams taken at each end of the cylinder (Honours, 1869).

6. Show by an indicator diagram the advantage of working expansively over throttling (1864-5-7).

7. In what cases would you consider it necessary to take a diagram from the top and bottom of the cylinder, and how would you from that diagram get the work developed in the up and down strokes respectively (1865).

8. Give a description of Richard's indicator. Do you know anything of a continuous indicator?

9. Show clearly by an illustration how the horse-power of an engine can be found from an indicator diagram.

10. Describe the dynamometer.

11. Show by an indicator diagram the advantages of working expansively over throttling (1865).

12. Sketch a normal slide diagram, and also a slide diagram with the eccentric stop top advanced (1865.)

13. Explain the construction and principle of the indicator (1863).

14. Give an outline of a normal slide diagram, and show by a corresponding diagram the alternation that would take place if the slide rod were shortened (1863).

15. Give a sketch of a normal indicator diagram. What alternation would be produced in the upper and lower indicator diagrams if a portion of the lap were taken from the exhaust side of the upper slide face, and the same amount added to the lower exhaust side (1864)?

16. Explain the construction and principle of the indicator (1865).

17. Show by slide diagrams the advantages to be gained by expansive working over the throttling when making the same number of revolutions (1865).

18. By what apparatus can you obtain a diagram on paper which will inform you as to the amount of the pressure of the steam or uncondensed vapour in the cylinder during each portion of the stroke of the piston? what would be the probable form of the diagram in a condensing engine (1870)?

19. Draw the indicator diagram which would probably be obtained from the cylinder of a condensing engine, and explain how the changes in its form indicate what is occurring in the cylinder at different parts of the stroke. How would you calculate the horse-power from the diagram (1870)?

20. Draw the indicator diagram which you would expect to obtain from a condensing engine when the steam is cut off at one-fourth of the stroke?

21. Draw also the diagram which would be theoretically perfect, and show from it that the amount of work obtained from the expenditure of a given quantity of steam is somewhat more than twice what it would be if the full pressure were continued till the end of the stroke (1871).

22. Draw the indicator diagram which you would probably obtain from the cylinder of a condensing engine. How would the curve change if the steam passage were opened too late and the exhaust passage too soon? Draw also the indicator diagram which would be taken from the cylinder of a single-acting air pump. How would the diagram tell you when the water was being delivered (Honours, 1871)?

23. Describe the indicator with a sketch, and explain its uses. The steam pressure before expansion is 10 lbs. above the atmosphere, the steam is cut off at $\frac{3}{4}$ths of the stroke, the exhaust commences at $\frac{19}{20}$ths, the cushioning at $\frac{9}{10}$ths, and there is no lead; represent the diagram you would expect to obtain (1865).

24. For what purposes is the indicator applied to the cylinders of steam engines? Trace the peculiarities in the curve arising from expansion of the steam, eduction, cushioning, and lead (1866–7).

25. Explain the construction of the indicator, and show how it may be employed to obtain the horse-power of an engine (1866).

26. What kind of diagram would be obtained at the upper and lower ends respectively of the cylinder if the slide rod were shortened (1866)?

27. What is the use of the expansion valve? Show by a diagram the pressure of the steam in different parts of the stroke when worked expansively (1867).

CHAPTER XVI.

THE LOCOMOTIVE ENGINE.*

DIVISION I.

History—Trevithick's Model—Adhesion of Wheels to Rails, etc.—Tractive Force—Murray's Engine—Hedley's Locomotive—Stephenson's Engine: "The Rocket"—Blast Pipe—Trevithick's Claims—Contrast between "Rocket" and Modern Engines.

242. Its History.—No sooner had Watt made his improvements in the steam engine, than many thoughtful persons began to consider the practicability of turning the new invention to the purpose of locomotion on our common roads. Even Watt himself, although bitterly opposed to the scheme, because he thought such a high pressure of steam would be required, produced improvements upon steam engines which, in his own words, "are applied to give motion to wheel carriages for removing persons, or goods, or other matter from place to place, and in which the engines themselves must be portable." His boiler was to be of wood or thin metal, even earthenware and lead were used in early boilers, as they never dreamed of a pressure much above that of the atmosphere; his fireplace was to be within the cylindrical or globular boiler; the steam was to be discharged into the atmosphere, or else condensed by a curious arrangement for surface condensation. Two cylinders were to be

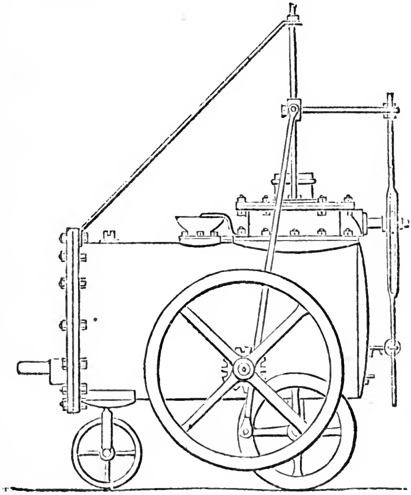
* For writing this chapter on the locomotive, the valuable work of Colburn on *Locomotive Engineering* has been freely and liberally placed at the disposal of the author by the publishers, Messrs. Wm. Collins, Sons, & Co., of London and Glasgow. The author has not scrupled to extensively avail himself of the privilege.

P

used, double acting, the pistons and rods of which, by the sun and planet wheels, converted the reciprocating rectilinear motion into rotative; toothed wheels communicated the motion to the axle of the wheels. Mr. Murdoch, the foreman of Boulton and Watt, better understood the locomotive than Mr. Watt himself. A small model made by him is still in existence. It is remarkable for its ingenuity. The piston-rod was connected to one end of a beam, vibrating upon a joint at the other, an arrangement known in a certain class of engines as the "grasshopper." The chief pioneers in the construction and invention of the locomotive were undoubtedly Trevithick in Cornwall, Hedley of Wylam, constructor of the "Puffing Billy," Murray, Hackworth of the Stockton and Darlington Railway, and Stephenson, who, with his "Rocket," won the £500 prize offered by the directors of the Liverpool and Manchester Railway in 1829 for the best locomotive. The conditions of competition were briefly these :—

(1) The engine must consume its own smoke; (2) if the engine weigh 6 tons, it must draw after it 20 tons 10 miles an hour; the pressure on the gauge not to exceed 50 lbs.; (3) there must be two safety valves, the engine and boiler must be supported on springs and rest on six wheels, the height of the whole not to exceed 15 feet to the top of the chimney; (4) it must not weigh more than 6 tons, less weight preferred, which may draw a less weight behind it, then it may have four wheels; (5) the price not to exceed £550.

243. Trevithick's Model.—Trevithick made and worked the first tramway locomotive. The annexed drawing represents a model locomotive made by him in 1802. The cylinder standing vertically is within the cylindrical boiler. The large wheel is a fly wheel, evidently worked by gearing all of which is not shown. The small hind wheel is the driving wheel, driven by the crank, as seen on the left side of this wheel, the connecting rod coming down from a guide and crosshead above the cylinder. Trevithick's arrangement for the fire was to place it within the boiler. He employed a "force draught" created by steam for working within the chimney. His engine worked simply by the adhesion of its spur-coupled driving wheels upon the smooth surface of the tramway. His flue returned from the back through the



TREVITHICK'S MODEL.

boiler, and the chimney went up by the side of the fireplace in front.

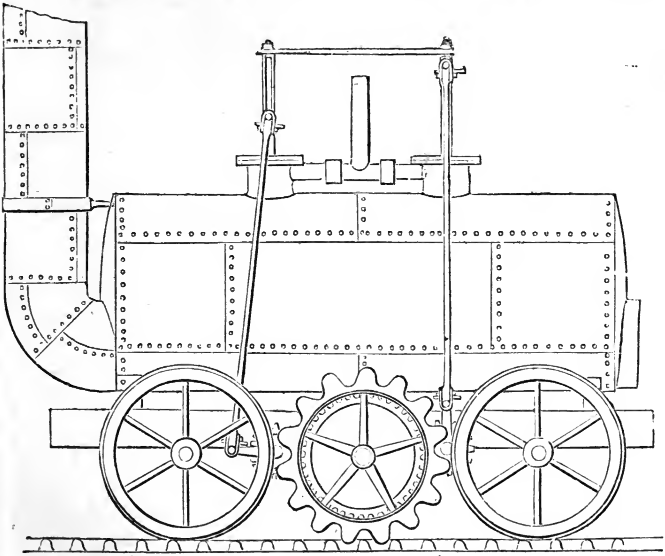
244. Adhesion of Wheels to the Rails.—It was a great difficulty with early locomotive engineers as to how they should secure a proper amount of friction between a smooth wheel and a smooth rail. Hence in early locomotive engineering we find geared wheels to the locomotives working in a rack on the tramway. A difficulty did or does exist, for at slow speeds with full pressure of steam on the piston, it is true that the ordinary adhesion of a single pair of wheels loaded with two or three tons only is nearly useless for any practical purpose. From Mr. G. Rennie's experiments on friction and the testimony of practical men, it is found that with extremely light loads upon the driving wheels there is not sufficient adhesion. Were we now to employ weights of only two or three tons upon the driving wheels of locomotive engines when working at slow speeds, means would have to be provided to prevent slipping. Who has not seen the driving wheel slip when the engine is starting? The adhesion of the wheels to the rails is reckoned at from $\frac{1}{5}$th to $\frac{1}{10}$th of the load, according as the rails are clean, perfectly wet, perfectly dry, or partly wet.

It has been found that a maximum adhesion upon a clean dry rail of three-tenths, and even three-eighths of the weight on the driving wheels is occasionally attained. This, of course, is much more than has been counted on by engineers. A better knowledge than was formerly possessed as to the amount of adhesion between the driving wheels and the rails has led to the working of steeper inclines, until, as an extreme case, loads have been taken in practice up *gradients* of one in ten, and no inclination less steep than one in forty is now considered a serious obstacle to the practical working of a large traffic.

245. Tractive Force.—The absolute tractive force required to draw a carriage over a good macadamized road is $\frac{1}{36}$ of the load, but in locomotives at slow speeds on level rails it is considered to be about $\frac{1}{300}$ of the load. But, of course, the more rapid the speed the greater the tractive force required. The resistance due to the atmosphere increases very rapidly. It is from 12 to 15 lbs. per ton on a train moving at the rate of 30 miles an hour. At 44 miles per hour the resistance to train and engine is about 24 lbs. per ton; at 60 miles, 29 lbs. per ton. On rough roads the resistance due to the atmosphere increases as the square of the speed.

The figure (p. 229) will show the arrangements practised by a few early engineers for securing adhesion. Mr. Blenkinsop, of the Middleton Colliery near Leeds, took out a patent for increasing the adhesion of the locomotive by gearing. The means he employed were a pinion working in a stout rack-rail running along one side of the line of railway. Murray's engine worked upon such a rack, as seen in our illustration.

The longer the crank of an engine, and the shorter the radius of the driving wheel, the greater the proportion of the pressure on the pistons which will be exerted as tractive force on the rails. The tractive force varies from 6000 lbs., in the case of an express engine, to 20,000 lbs. in the case of a goods engine, and these are not the extremes. Supposing the speed of the pistons to be the same, the express engine

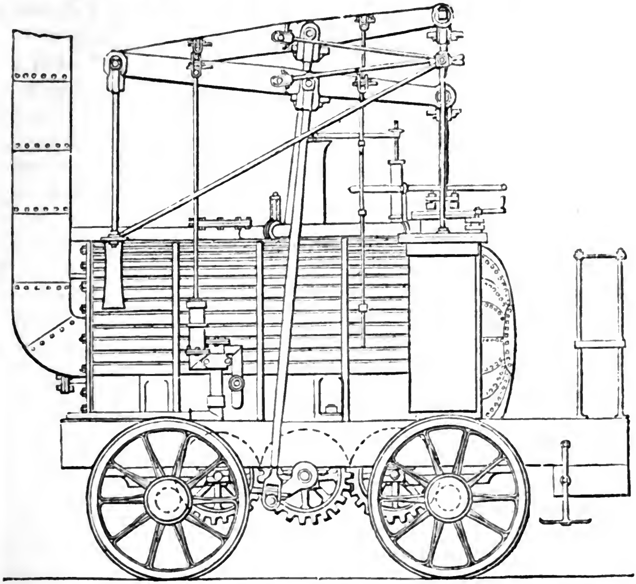


MURRAY'S LOCOMOTIVE UPON BLENKINSOP'S RAILWAY, 1812.

would move fastest, because its tractive force is quite sufficient and the driving wheel much larger in diameter than that of the goods engine. To exert a great tractive force the driving wheels of an engine must, by their friction upon the rails, have an adhesion equal to the tractive force. For instance, if an engine is to advance, the tractive force being 9 tons, the driving wheels must not slip until the resistance amounts to the same 9 tons. This adhesion is secured by providing sufficient weight upon the driving wheels. On a clean, dry rail as much as one-fourth, and even more, of the total weight on the driving wheel is available for adhesion. One-sixth is, considering the ordinary condition of the weather and other contingencies, quite enough to allow. When half wet the adhesion is less than when thoroughly wet. They are, in fact, what is termed greasy, and we must not reckon upon more than one-tenth, or even less; but see art. 244, p. 227.

246. Murray's Engine.—Here the boiler was cylindrical with ends slightly convexed. It had a single internal flue, with the fire at one end and the chimney coming out of the other. (To secure the greatest amount of evaporation the flue ought to have returned through the boiler.) It had two double acting steam cylinders, the ends of the piston-rods working in guides, while the connecting rods were coupled to cranks, which were made to work at right angles to each other—two on each side the engine. This is the arrangement adopted in modern locomotives, and Murray has the honour of first using it. The cylinders were upright, and are seen in the illustration half immersed in the boiler. The cranks drove a toothed wheel on each side the engine, each of these two wheels geared into another twice the diameter. On the axis of the larger toothed wheel was a coarse pinion (the one seen in the middle front of the figure) which worked in the rack laid along the railway. The rack rail was a clumsy affair, and the necessity for its use disappeared as soon as heavier engines were constructed, and it became thoroughly understood that considerable adhesion existed between a smooth loaded wheel and a smooth rail.

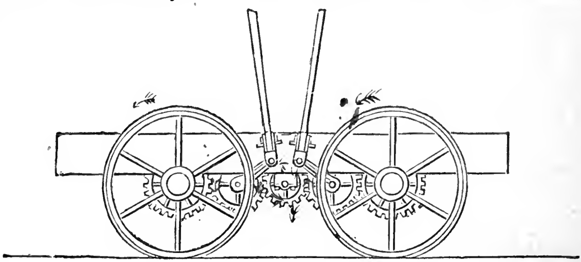
247. Hedley's Locomotive — "*The Puffing Billy.*" — Hedley, who had been employed at Wylam in altering one of Trevithick's engines, first made a series of experiments to ascertain whether the ordinary adhesion of the wheels of an engine upon the smooth rails would be sufficient to give the necessary amount of friction to ensure the useful application of the tractive force of the steam. It is claimed for Hedley that he was the first person "to adopt smooth wheels working upon smooth rails." It is evident Trevithick had done the same before him. Hedley constructed the following engine to draw coals on a colliery tramway; and here we would remark, just as the early steam engine was invented, improved, and developed to pump water from the mines of Cornwall and Devon, so the locomotive was introduced to draw coals from the mouth of the pit to towns, iron-works, and smelting furnaces at a distance. The engine under consideration had a wrought-iron boiler and a return flue—the chimney being placed at the same end as the fire door. Two



HEDLEY'S LOCOMOTIVE "PUFFING BILLY," 1813 (NOW IN SOUTH KENSINGTON MUSEUM).

vertical cylinders were used, one on each side of the farther end of the boiler. The piston-rods were at one end linked to beams, which were centred at the other end—an arrangement known as the "grasshopper." The two beams are seen on the top of our figure centred close to the chimney. The parallel motion may be noticed at the right end of the "grasshopper," and the connecting rods may be observed attached to the centre of the beams (nearly). These two connecting rods communicated the motion of the piston by means of the cranks and toothed wheels to four wheels of equal diameter. In this engine Hedley was the first (although Trevithick had previously suggested them) to embody two improvements of very great importance: (1) he employed the return flue boiler, which not only gave additional heating surface, but rendered the course of the flame more effective on any given area; (2) he adopted a small diameter, about one foot for the chimney, which rendered the draught quicker than those of 20 and 22 inches used at Killingworth. His waste steam passed up the chimney after being previously thrown into a cylindrical reservoir to keep down the noise.

248. Stephenson's Engine—"*The Rocket.*"—Stephenson's life is the history of the locomotive engine. He found it a small imperfect engine, and after many trials and much experience left it almost the perfect machine we see it to-day. His first engine, made to "lead" coals from the pit, was constructed at Killingworth in 1814; it was supported on four wheels three feet in diameter; it had a wrought-iron boiler with a single flue, the fireplace was within the boiler, and the two vertical cylinders were half immersed in the same. The motion was conveyed to the wheels in the same manner

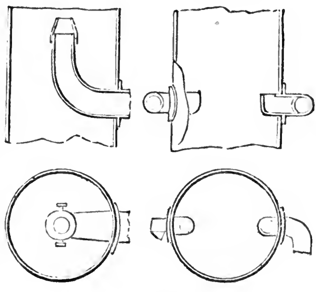


STEPHENSON'S DRIVING GEAR, 1814.

that Hedley had previously adopted, by the intervention of cranks and toothed gearing. The cranks worked at right angles to each other, and the pistons made two strokes for each revolution of the driving wheel. As seen in the figure, the axle of each pair of driving wheels had a 24-inch toothed wheel keyed on to it, and the axles being 5 feet from centre to centre they were geared together by three intermediate wheels of one foot in diameter. The centre wheel acted as a regulator, and preserved the two cranks at right angles, and thus kept the propelling power in equilibrium. This engine did not answer very well, its radical defects were the single flue and the wide chimney; the waste steam does not appear to have been sent into the chimney. Stephenson soon abandoned the toothed gearing to convey the motion to the driving wheels, and introduced springs to carry the weight of the engine. Springs were first used by Nicholas Wood.

249. Blast Pipe.—The discovery of the properties of the steam jet has been much disputed, some claiming it for one party, some for another. Its uses were fully understood before the year 1830.

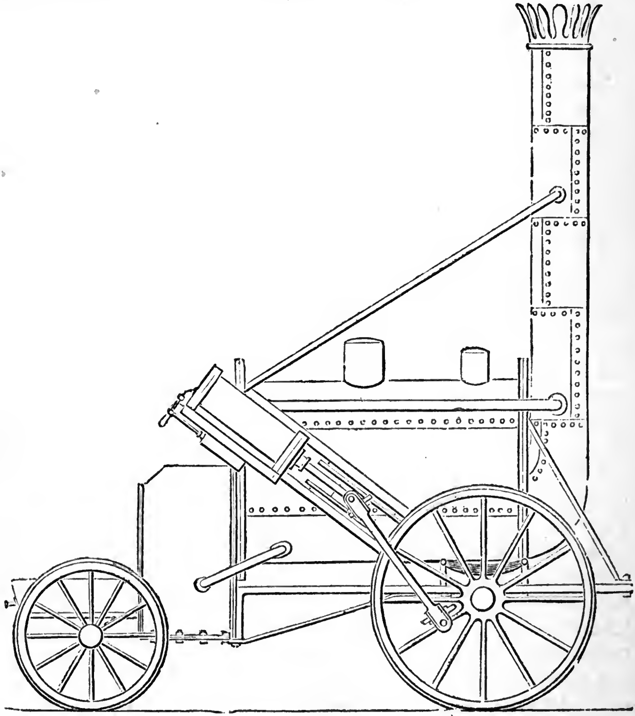
The annexed illustrations will show how the blast pipe was applied in the two cases of the "Royal George" on the Stockton and Darlington Railway, by Hackworth, and by Stephenson in 1827. The principle of the *blast pipe* has been previously explained. When the steam is introduced into the chimney, it causes a very powerful draught by rushing upwards and carrying with it the air, thus creating a partial vacuum, when the air rushes through the fire doors and bars to fill up the vacuum. In this act it carries a large amount of oxygen into the fire box, which assists in the more perfect combustion of the coke. The steam expands as it rushes out of the mouth of the blast pipe, and filling the chimney like a plug it not only drives all out before it, but drags with it the gases from the smoke box by mere contact. The degree of exhaustion in the chimney, or the vacuum, of a locomotive, is generally such as would support from 3 to 6 inches of water. The force of the blast greatly depends upon the amount of contraction given to the mouth of the blast pipe, as seen in the foregoing left hand figure. The contraction must not be carried too far, for it is evident that if the steam cannot freely run out of the cylinder, a back pressure will be thrown on the piston. As there are two cylinders, the exhaust steam is led by a forked pipe, sometimes called a breeches pipe, toward



BLAST PIPE.

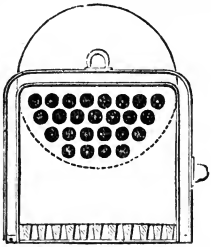
the chimney, which joins immediately before it enters the funnel, where it stands up vertically in the centre. As the vacuum increases in the smoke box, so there is an increase of blast pressure. This no doubt arises from the increase of speed, which means an increase in the rapidity at which one puff of blast succeeds another.

250. The "Rocket."—This locomotive has been already referred to. The annexed figure represents the engine as it appeared when it ran in the famous Rainhill competition.



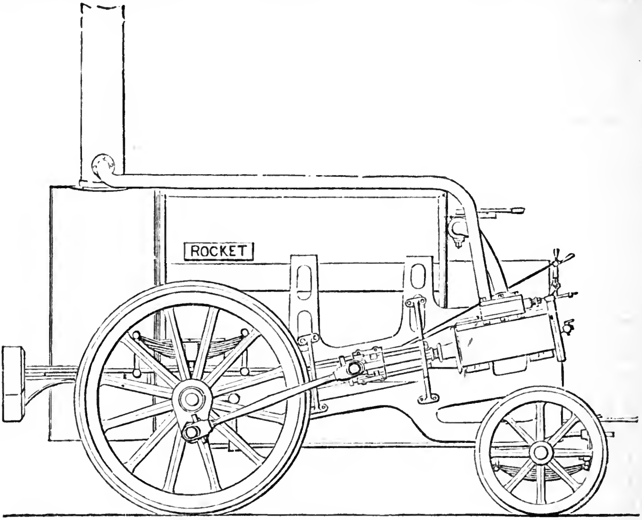
STEPHENSON'S "ROCKET." 1829.

It was a four-wheeled engine supported on springs, and with a supply of water in the boiler weighed 4 tons 5 cwt., with its tender loaded it weighed 7 tons 9 cwt. Its boiler, of which the accompanying figure is a section, was cylindrical, 6 feet long, with a diameter of 3 feet 4 inches; through it passed twenty-five copper tubes 3 inches in diameter; these conveyed the heated air, gases, and other products of combustion from the "fire box" at one end of the boiler to the tall chimney, 12 inches in diameter at the other end, after passing from end to end of the flue. The heating surface of this multitubular boiler was $117\frac{3}{4}$ square feet; the use of these tubes gained Stephenson his victory, and laid the foundation of his fame. The body of the figure on last page is the boiler barrel with the tubes inside. The fire box or furnace is represented on the left hand side close to the smaller wheel. It will be noticed that a small tube goes from the boiler barrel to the furnace, this was to allow water to run round the fire box casing; at the top of the fire box was another tube running into the boiler (in our figure it is omitted and hidden by the upper end of the cylinder), to allow the steam generated in the fire box casing to enter the boiler. The safety valve is the projection on the top of the boiler nearest the chimney. The cylinders were two, one on each side; one is seen to the left just above the fire box, inclining to the rails at an angle of 45°; this was a poor arrangement, as the pistons slightly lifted the boiler up and down on the springs. It is seen that the connecting rods worked on crank pins on one of the spokes of the driving wheels, and thus the motion of an ordinary connecting rod and crank was gained. The diameter of the cylinder was eight inches, and the stroke $16\frac{1}{2}$ inches. The exhaust steam from each cylinder was carried through a pipe and turned upwards into the chimney, but the exhaust orifice was not contracted.



"BOILER OF ROCKET."
1829.

The next illustration is the "Rocket" as altered after the trial in 1829, and as now preserved in the South Kensington Museum, London. A glance at it will show the improvements, and one or two things are plainer than in our previous figure. The long pipe running along the top of the boiler is the exhaust steam pipe. The short pipe to the right



STEPHENSON'S "ROCKET" IMPROVED.

is the steam pipe, to allow the steam to pass from the boiler to the slides and cylinder. The springs and crank are more plainly visible.

251. Trevithick's Claims.—"As a true inventor no name stands in so close connection with the locomotive engine as that of Richard Trevithick. It was he who first broke through the trammels of Watt's system of condensation, and low if not negative pressure. It was he who first employed the internal fireplace and internal heating surface; he was the first to create or promote a chimney draught by means of exhaust steam; the first to employ a horizontal cylinder and cranked axle, and to propose two such cylinders with the cranks at right angles to each other; the first to surround the cylinder with hot air; the first to draw a load by the adhesion of a smooth wheel upon a smooth iron bar; and the first to make and to work a railway locomotive engine. Trevithick and

George Stephenson were contemporaries.* The first locomotive seen by the latter was constructed by the former, and a personal acquaintance was afterwards established between them. Although irrelevant to the present purpose, it may be added that Trevithick patented the screw propeller, and specified several forms of that instrument, and various modes of applying it, in 1815—years before those to whom the invention is more commonly ascribed had turned their attention to it. Justice exacts the truth, however, that Trevithick's genius, brilliant as it certainly was, was of an impracticable kind, and scarcely capable of conferring any direct benefit upon society.

"The next most deserving name in connection with locomotive improvement is that of Timothy Hackworth. If he discovered no important principles, he stamped a character upon the structure of the locomotive engine which it still retains. What he did in this respect should be ever acknowledged. It does not appear, however, that Hackworth was ever placed in a position where he had to struggle against and overcome the once strong prejudices of the public against locomotive conveyance upon railways. It is as the champion in that great contest that the name of George Stephenson must ever shine above all others; and even Trevithick and Hackworth might have felt pride in having provided directly or otherwise the most important aids in the final achievement of the great victory of 1829." †

252. Contrast between the "Rocket" and Recent Locomotives.—The cost of the "Rocket" was not to exceed £550; modern engines cost upwards of £2000. It weighed 7 tons 9 cwt. with its tender; the working weight of some modern engines and tenders exceeds 45 tons. The driving wheel was 4 feet 8½ inches in diameter, and cylinders 8 inches, and stroke 16½ inches. Engines are now running with a driving wheel 9 feet in diameter, and cylinders 18 inches, and stroke 24 inches. The greatest speed attained by the "Rocket" on its trial was 24 miles an hour, for a distance of one mile and a half. Some of the express engines on the

* Trevithick was born April 13, 1771, and died April 22, 1833; George Stephenson was born June 9, 1781, and died August 12, 1848.

† Colburn's *Locomotive Engineering*.

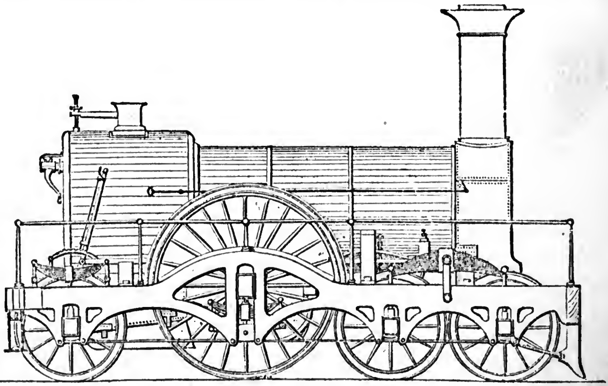
London and North-Western Railway have attained a speed of 73 miles per hour between Holyhead and London. The pressure on the boiler was not to exceed 50 lbs. on the square inch when working, although the company were to be at liberty to test the boiler, etc., up to a pressure of 150 lbs. on the square inch. Now new locomotive boilers work at a pressure rarely less than 120 lbs. on the square inch, and many cases 140 and 150 lbs.

The student is invited to compare the "Rocket" with the engine on opposite page.

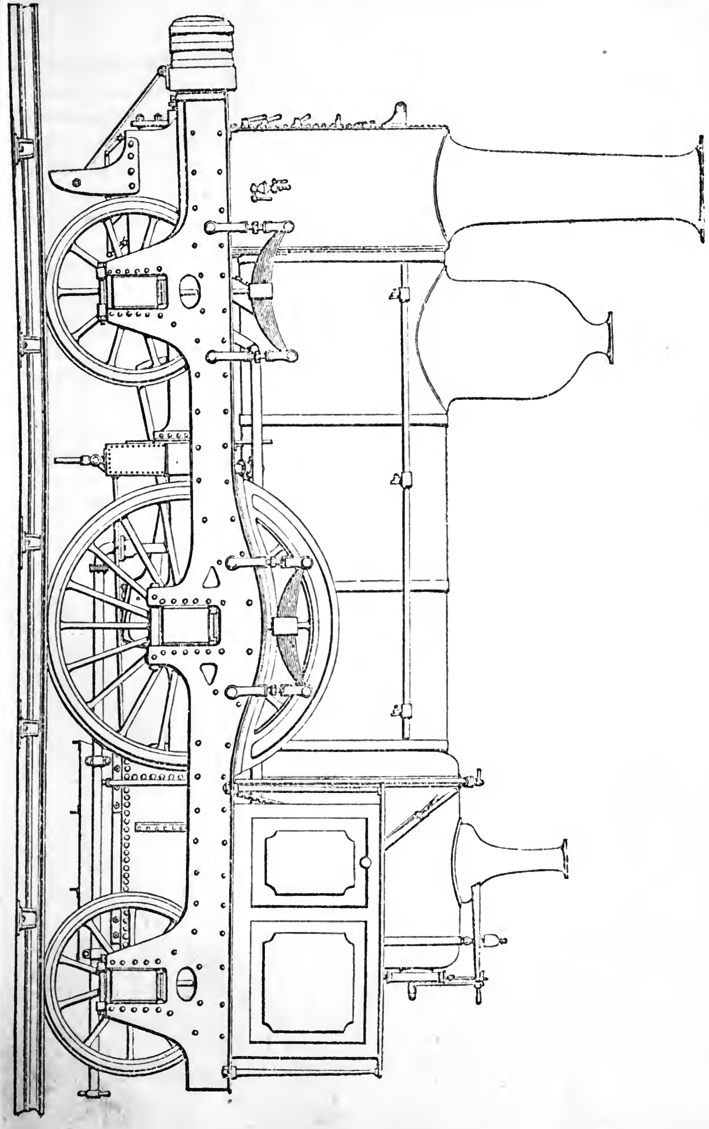
DIVISION II.

General Description of a Locomotive—Crampton's Engines—Tank Locomotive — Bogie — Locomotive Boiler — Shell of Boiler — Through Tie Rods—Tubes—Clearance—Fire Box—Staying the Furnace—Fire Bars—Ash Pan—Smoke Box—Heating Surface —Safety Valves — Chimney — Damper — Steam Dome — Man Hole—Regulator—Whistle—Pressure Gauges.

253. General Description of a Locomotive.—This is one



of the Great Western express engines, running on eight wheels; the large wheel is the driving wheel, the others are

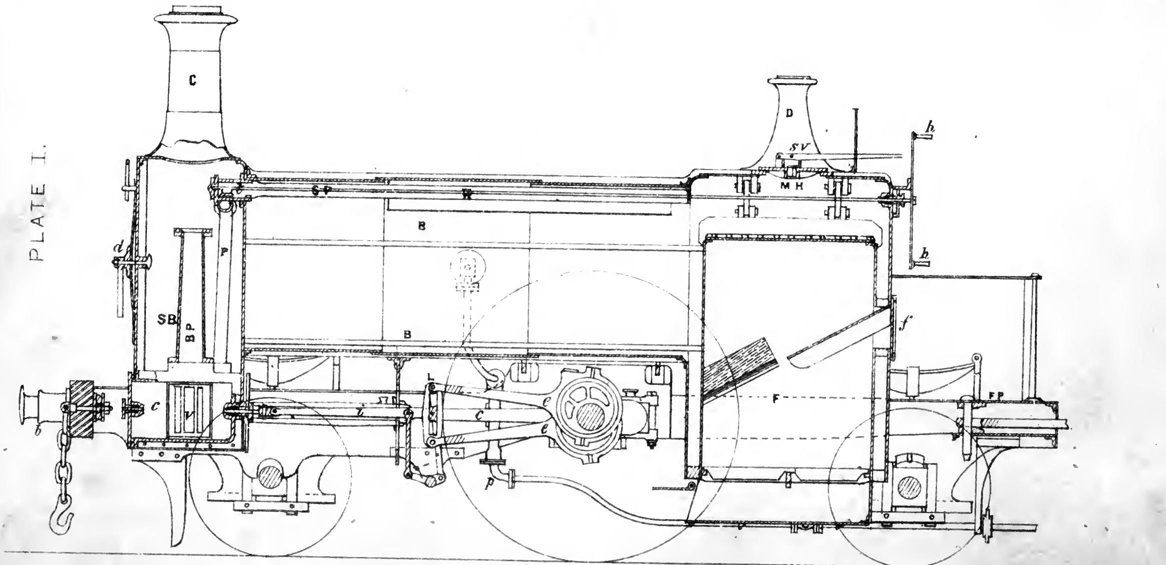


called the leading and trailing wheels; the chimney is seen on the right hand, the furnace on the left, and the barrel of the boiler with the tubes in the middle. Upon the top of the furnace is the steam dome and the safety valve. The springs for carrying the weight of the whole may also be noticed.

The annexed illustration will give a much better idea of the locomotive engine and boiler than the last one.

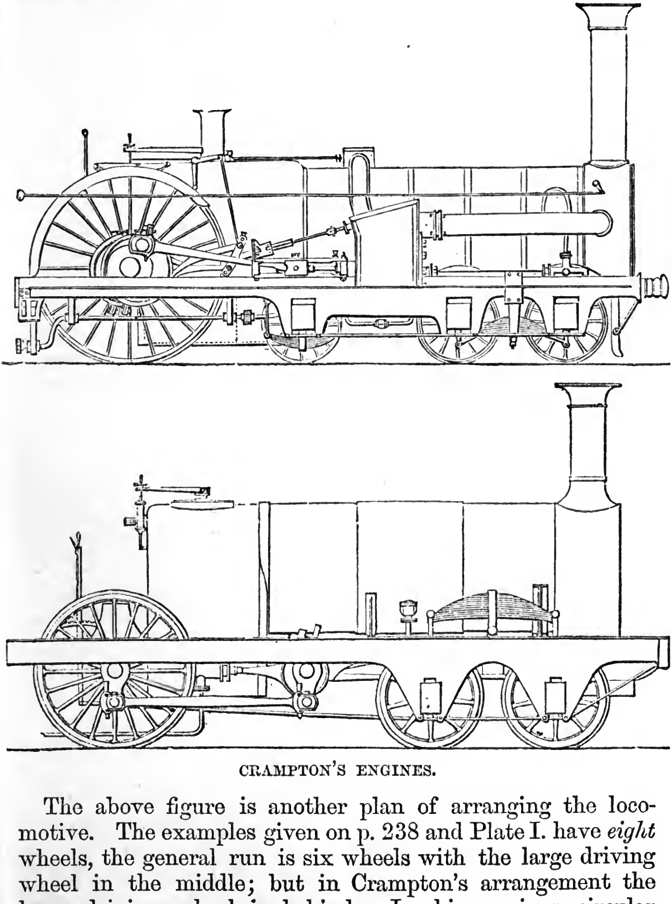
In this sectional elevation F is the furnace, with *f* the furnace door; the furnace is seen surrounded by the outer fire box, but the screwed stays are omitted. Above and below B are the tubes running from the inner fire box to the smoke box S, one only is shown; around the tubes and above them is the water; the level of the water is called the water line. Admission to the smoke box is gained by a door at *d*; this door is fitted as closely as possible to exclude all cold air. At the top of the smoke box S, is seen the chimney C, and within the smoke box is the waste steam pipe or blast pipe, B P, the mouth of which can generally be closed, or at least partially closed, to regulate the blast. The dome is at D, the steam from the boiler passes up D to the mouth of a pipe in it, this is the mouth of the steam pipe S P, generally closed by the regulator, which admits the steam to the cylinder; the regulator being opened, the steam passes along S P down the smoke box by way of P to the cylinder C, and sets the piston reciprocating; thus the engine is worked. In our figure the handle of the regulator is at *h*, and the regulator itself at *r*, the handle of course being worked by the engineman, who stands on the foot-plate, F P, at the back of the furnace; the whistle is also close to his hands, whilst one of the safety valves, *s v*, or S V, is under his control, generally *s v*, and the other he cannot interfere with. The man hole and man hole door are seen at M H, below the dome; the man hole door is taken off when it is wished to enter the boiler for examination, or to tighten the stays, etc. The large wheel in the middle is the driving wheel, turned by the crank, which is moved round by the connecting rod *c*, which is attached to the piston rod *i*, the latter in its turn is firmly fixed to the piston. The front wheel next the chimney is called the leading wheel,

PLATE I.



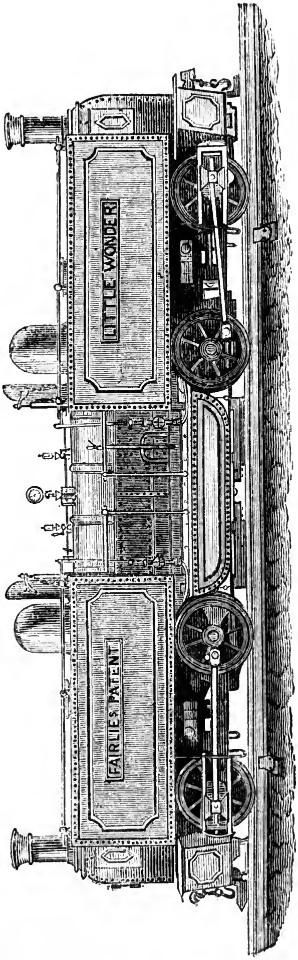
SECTION OF LOCOMOTIVE ENGINE

securely fixed on the leading axle, and the wheel to the right the trailing wheel.



CRAMPTON'S ENGINES.

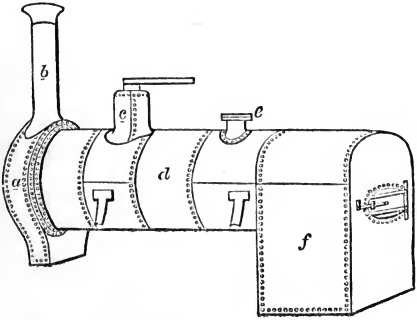
The above figure is another plan of arranging the locomotive. The examples given on p. 238 and Plate I. have *eight* wheels, the general run is six wheels with the large driving wheel in the middle; but in Crampton's arrangement the large driving wheel is behind. In his engines circular motion is first given, by inside cylinders, to a cranked shaft, supported on bearings fixed upon the frame in the usual manner, and motion is communicated from this shaft to the driving wheels behind the fire box by side rods. When outside cylinders are used they are placed midway in the length of the boiler, and connected directly to the driving wheel. The upper figure is Crampton's arrangement for outside cylinder, the lower for inside cylinders.



254. Tank Locomotive.—*Tank locomotives* are advocated in opposition to those of excessive weight to save the enormous dead weight, and are generally very light. They are constructed with a tank usually over the boiler, and occasionally at the sides, so that they can carry their own water, without being compelled to drag a tender after them, being independent of that seemingly fixed appendage.

255. Bogies.—The bogie is a truck on four wheels that will swivel round. Bogie carriages generally run on eight wheels. They were invented to meet the necessities of the American traffic, where, in passing through streets, it was sometimes necessary to turn round very sharp angles. Mr. Stephenson constructed the first bogie for America. "The engine was made two-wheeled, and a small truck on four low wheels supported the front end, being swivelled to it by a centre pin, or what the high road people call a perch bolt. This kind of truck, known in many places as a lorry, a trolly, and many other names, was, it appears, called in Newcastle a bogie, and the engine was therefore shipped as a bogie engine. It became the pattern or type for American locomotives."* When the engine or carriage is long, two bogies are employed with four wheels each.

In the example here given, the engine is on two trucks. The one end can be turned so that the double sets of wheels are not in the same straight line. In practice it is found that bogie carriages bring a great strain on curves. In the "Little Wonder," which works on the Festiniog Railway, constructed to a gauge of 1 ft. 11½ in., or the two foot gauge, the boiler is double, with two fire boxes, two barrels and two sets of tubes, and two chimneys. A bogie or swivelling truck is placed under each barrel, and each bogie has two pairs of wheels coupled together, working independently by a pair of steam cylinders to each.



LOCOMOTIVE BOILER.

256. Locomotive Boiler.—All locomotive boilers are of the class termed multitubular: they consist essentially of the barrel filled with tubes, while the two ends are named respectively the furnace, or fire box, and the smoke box. Boiler plates should be rolled from the best iron to about

* Clark's *Railway Machinery*.

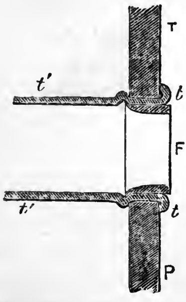
three-eighths or half an inch in thickness; these form the barrel, which has a diameter varying from three feet to four feet three inches in different boilers, and consists of three or six plates for each boiler, and their joints are arranged to give as much strength as possible.

d is the barrel of tubes. *f* is the fire box. The fire door is seen at the end, in front of which stands the driver and fireman, the latter supplying the engine with coke by throwing it into the furnace; the fire door is always oval. *e* is the safety valve; there is also a second safety valve sometimes placed on the top of *c*, the steam dome or chest. *b* is the chimney, bolted on to the top of the smoke box *a*.

The shell of the boiler is usually made of best Yorkshire, Staffordshire, or Lowmoor iron. The thickness of the plates varies from $\frac{3}{8}$ to $\frac{1}{2}$ of an inch, according to the diameter of the barrel of the boiler, which rarely exceeds 4 ft. 3 inches inside. The joints are either lap or jump joints; if the first mode is adopted they are made to lap 2 inches or $2\frac{1}{4}$ inches for single riveting; when jump joints are employed, 4 or $4\frac{1}{4}$ inch welts are applied to the seams, and secured to the boiler plates by two rows of rivets: the plates are or ought to be planed at the edges. The riveting is usually single, but for strength it should be in double rows in a zigzag course. The rivets in size are from $\frac{3}{4}$ inch to $\frac{7}{8}$ inch in diameter, being placed at a pitch (from centre to centre) of from $1\frac{3}{4}$ inches to $1\frac{7}{8}$ inches. The barrel of the boiler is usually joined to the fire box and smoke box tube plate by a three inch angle iron. In the fire box shell the front and back plates are joined to the others either by three inch angle iron, or by flanges turned on them to a four or five inch radius; the former is the simpler process, but the latter the stronger, fixing them more securely, and is the plan generally followed.

257. Through Tie Rods run from the smoke box tube plate to back of fire box; they are about one inch in diameter and four inches from centre to centre. Their number depends upon the size of the boiler. They are put in to stay the boiler, and to assist the tubes in preventing the two ends from being blown out by the force of the steam.

258. Tubes.—The tubes may be of brass or iron; copper is too soft, brass is also better than iron for several reasons. It conducts the heat better, or communicates the motion of the fire more readily to the water than iron, and also resists the abraiding action of the small coke carried through the tubes by the draught; it resists the action of impure water outside better, springs more easily under extra expansion, and is not so liable to break as iron is. Economically, brass tubes are at least as cheap as iron, as they will fetch when worn out half their original price for old metal. Tubes are fixed in the tube plates by widening with a mandril to fill the holes completely, turning over their protruding ends upon the plates. At the fire box end, ferules of wrought-iron, and in some cases of cast-iron, about an inch in length, slightly tapered, are inserted, and should, when driven, be left with about a $\frac{1}{4}$ inch projection into the fire box, so that should any of the tubes spring a leak on the road they may be tightened by a tap or two from the end of a pinch bar. Ferules at the smoke box end are frequently omitted, which gives a free passage for small coal and cinders into the smoke box. Tubes are either of equal thickness throughout, or of a tapering thickness, from No. 9 wire-gauge at the fire box to No. 14 at the smoke box. Tubes wear unequally on the inside, and mostly at the fire box end. The first foot or eighteen inches should therefore be a little thicker than the rest of the tube. The number of tubes in a locomotive boiler varies from about 130 to 220. The distance between the tubes, called the *clearance*, is from $\frac{5}{8}$ths to $\frac{7}{8}$ths of an inch; but the larger the tubes the greater the clearance. The size of the tubes varies from $1\frac{3}{4}$ to 2 inches in diameter; they must not be too small, for fear of being choked, nor too large, for then the heating surface is diminished. If too small they are perhaps too numerous and crowded, when the water spaces are not of sufficient size to prevent priming, which is a serious evil if not effectually prevented in time, neither must they be too long, as the evaporative power of the heated gases rapidly diminishes as they recede from the fire box.



END OF TUBE AS SEEN IN FIRE BOX.

259. The Manner in which the Tubes are Fastened into the Tube Plates.—This has just been explained, and we illustrate it here:—T P represents a piece of the tube plate; *t′ t t t t′* is the brass tube, which, when driven in, projected a little beyond the tube plate, then the end was turned over on the plate as we see it at *t* and *t*; thus they are all left at the smoke box end, but at the fire box end they are further secured in their places by the ferules F.

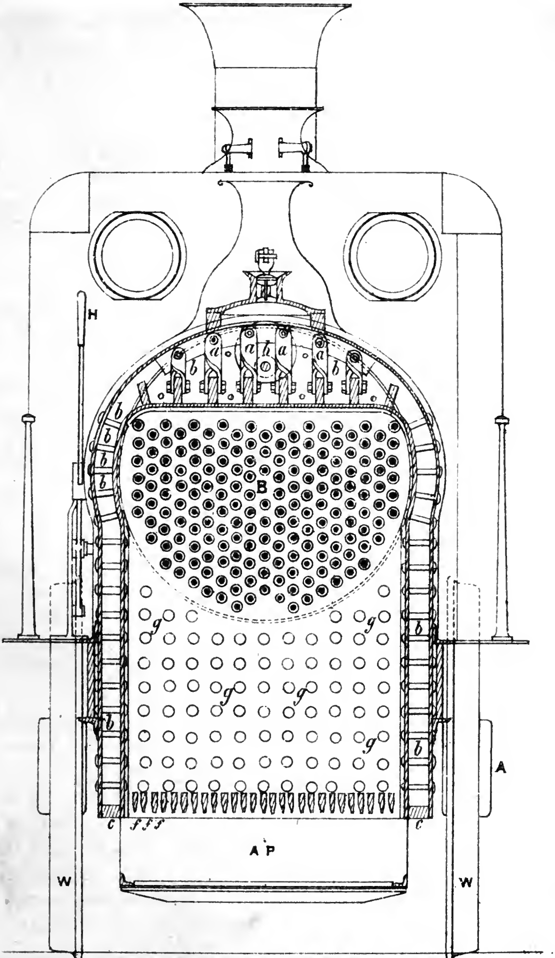
260. Clearance.—*Clearance* is the space between the tubes, and between the tubes and the boiler shell. It is required to allow a proper circulation of the water and steam around and between the tubes, and to give the steam plenty of room to rise, instead of remaining in contact with the tubes.

261. Fire Box or Furnace.—The *fire box* consists of two distinct parts, the external fire box, always made of wrought iron, and the internal fire box, or furnace proper, of copper. The staying of the fire box is a question of the greatest importance, especially of that part immediately above the fire. Occasionally the internal rectangular fire box is of iron, but copper is found to answer better, because it resists the intense combustion and conducts the heat more rapidly, and is not so liable to be burned away and ruptured at the thick lap joints and places where the sediment collects. The internal fire box is fastened to the external by screwed stays, screwed through both plates, and their heads left and riveted over. The space between the two is a *water* space.

In this figure (Plate II.) the part marked *b b*, etc., is the space between the internal and external fire box, the latter is seen in section on the outside, the former is seen inside the other; the short bolts running across are the screwed stays, many of the ends of which are seen at the front* of the fire box at *g g*, etc. The tubes B are marked by double circles above, there are about 178 of them in this boiler. The water spaces between the two fire boxes completely surround the inner fire box; it will be seen closed at the bottom by a square bar

* The front of the fire box is what would be generally termed the back, *i.e.*, the *front* is the part *nearest the tubes*, so that the other side, where the *door* is, is the *back*. The engineman stands at the back of the fire box.

PLATE II.

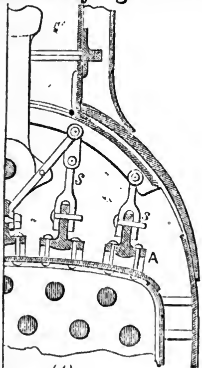


TWO FIRE BOXES, FIRE BARS, ASH PAN, AND SUPPORTS FOR TOP OF FIRE BOX.

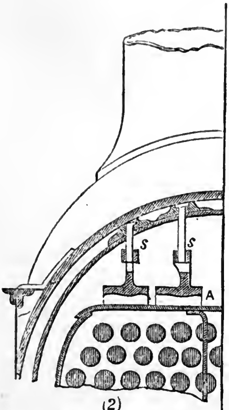
c c, which is bent and welded to the proper form, to extend round the bottom of the inside fire box, and is rivetted and tightly caulked to both fire boxes. The water in the water spaces is in free communication with the rest of the water in the boiler.

The *fire bars* are seen at *f f*, etc., and the manner in which the top of the furnace is stayed is seen at *a a a*, etc.

262. Staying of the Furnace.—The staying of the furnace renders this end the strongest part of the boiler. The *flat* top is, of course, equally bad with the flat sides without the stay bolts, for all flat surfaces in a boiler are inherently weak. The top cannot be satisfactorily secured by stay bolts. The following plan is adopted:—Across the roof of the fire box are placed nine or ten *roof stays*, or *cross stays;* A B (fig. 3) is one of them, they are placed four inches from centre to centre, these roof stays are firmly bolted to the top of the boiler, as seen at *a a a*. The roof stays are further secured by *suspension stays*, or hanging stays *s s*, to the outer fire box, in the manner shown very clearly in the figure at C C. Those in the upper figure are a little differently arranged to those in the lower, but the principle is the same in both. The roof stays are firmly bolted to the roof of the furnace, then suspension stays extend from the fire box roof stays to the top of the outside fire box.



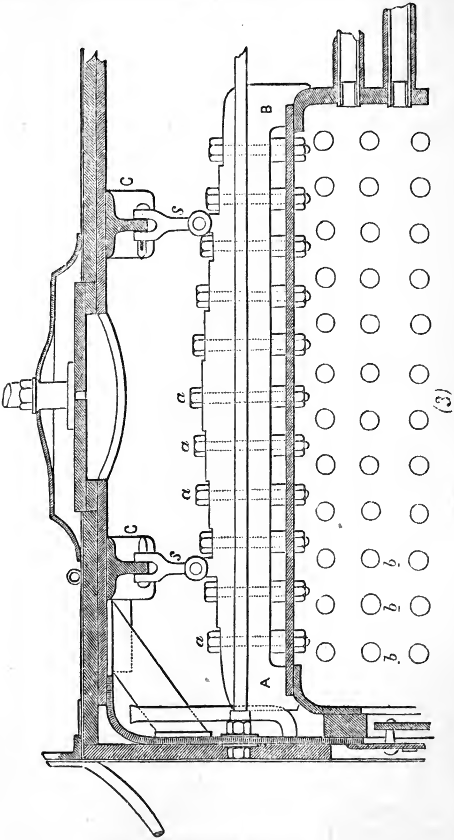
(1)



(2)

263. Fire Bars.—Fire bars of wrought iron support the fire and separate the fire box from the ash pan. They are laid on a frame which rests on bolts or brackets in the side of the fire box.

It is found that thin deep fire bars, laid close together, are much better adapted for the purpose of a locomotive than larger ones. The fire bars, from the intense heat of the



FURNACE STAYS.

furnace, wear or burn away very rapidly. They are frequently bent—this arises from the softening of the iron from intense heat—when they drop, because they are not capable of sustaining the weight of the fire. Fire bars are about 4 inches deep, $\frac{3}{8}$ of an inch thick on the lower edge, and double that thickness at the upper, so that they are more widely separated on the side next the ash pan than on that on which the fire lies; they are so placed that the top of the bars are above the bottom of the water spaces by $2\frac{1}{2}$ or 3 inches. The fire bars are marked distinctly on Plate II., page 246, at *f f f*, just above the ash pan A P.

264. Ash Pan.—The ash pan is placed directly under the fire bars, and is a simple wrought iron tray about ten inches deep, the bottom being nine inches above the level of the rails. It must be carefully fitted and closed all round, so that the draught shall not be impeded, while the engine driver can use it as a damper to regulate the supply of air. Again, it should be so arranged that when the engine is running the air impinging against it shall be directed into the furnace. Its purpose is to prevent cinders and live coals from falling upon the line, for this, in early locomotion, caused several fires. There is another reason for it, as hinted above. When the engine is standing still it is often important to stop the generation of steam, this is partly done by allowing as little air as possible to gain access to the furnace, hence the ash pan is made to fit tightly to the fire box on all sides; but the front side can be opened and closed at pleasure, like an ordinary damper, which is adjusted by a rod worked from the foot plate. When the engine is running rapidly with the damper opened, advantage is gained by the air rushing into the ash pan, and thence into the furnace. At sixty miles an hour the pressure of air would be nine pounds per square foot, hence its advantage is at once apparent. The ash pan is at A P in the illustration on Plate II., page 246.

265. Smoke Box.—The smoke box is at the farther end of the engine to where the driver stands, or at the front of the engine exactly under the chimney. The heated air and products of combustion pass from the internal fire box through the tubes into the smoke box, and then are carried up the chimney. Access is given to it by means of a door, generally swinging on two hinges, which is kept fixed in its place as air-tight as possible, by means of bars, catches, and handles. Sometimes the door is in two parts, folding or overlapping in the middle, and closed by a bar, handles, and catches also. In the smoke box is placed the blast pipe, and the steam pipe runs down it to the cylinders at the bottom. Its use is to contain these, and to allow the tubes to be cleaned out, and to gather the soot, bits of coke, etc., that may be carried through the tubes. The smoke box is seen at S B.

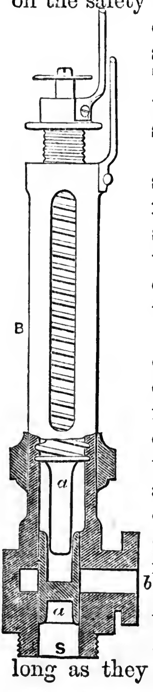
266. Heating Surface of Fire Box and Tubes, and Grate Surface.—It has been most distinctly proved by experiments, that most of the heat passes into the water from the fire box and the first foot or two of the tubes, and very little indeed from the further end of the tubes, and that long boilers do not attain any economy of fuel. Taking an average consumption of fuel, the evaporation due to the first quarter of the length of tubes is 21 per cent.; that of the second quarter of the length of tubes, 16 per cent.; of the third, 12 per cent.; and the last quarter length 8 per cent, leaving 43 per cent. for the fire box. In the working of railways, from 100 to 200 cubic feet of water, or from 2·8 to 5·6 tons, must be evaporated per hour to produce the necessary steam to move an ordinary train at the usual speed. A square foot of heating surface cannot, under any circumstances, transmit more than sufficient heat to evaporate one cubic foot of water in an hour; altogether nearly a square yard of heating surface is requisite for the evaporation of one cubic foot of water per hour in locomotive boilers. The total heating surface is from 1000 to 1500 square feet. In the fire box itself there are about 90 square feet of heating surface, and in practice from six to twelve times this heating surface must be provided in the tubes. The fire grate surface varies from 12 to 30 square feet, but about 15 square feet is the usual rule. It is easily proved that the smaller the diameter of the tubes, by so much the more is the proportion of their heating power increased. By doubling the diameter of a tube we double its heating surface, but we increase the space it occupies fourfold. In proportioning the number and diameter of the tubes to the area of the fire box surface, it is best to keep them to a definite proportion; it is also considered that there should be a certain proportion between the area of the fire grate of the furnace and the area of the opening through which the hot gases escape from the fireplace. The size of this opening is named the *calorimeter*, which is sometimes taken as showing the evaporative power of the boiler, but this is not a wise test, as a large calorimeter can easily be procured by a few large tubes.

The top row of tubes—they are generally about 2 inches in diameter, from 10 to 12 feet long, and number from 100 to 200 or more—is covered by from six to eight inches of water. It must also be remembered, in arranging the fire box, that more heat passes into the water from the top of the furnace than from the sides, because the convected water and steam can rise up more readily in the one case than in the other. It is sometimes the practice to incline the fire box a little.

267. Fuel and Evaporation per Hour.—The highest rate of combustion may be taken as *one hundredweight of coke per hour on each square foot of grate surface; this evaporates, at the maximum rate, sixteen cubic feet of water per square foot of grate surface per hour.* (Taking a pound of coke to evaporate nine pounds of water.)

268. Safety Valves.—Two openings are made in the upper part of the boiler, which are covered by discs or valves. These valves are held down on their seats by levers; one arm, the shorter one, is secured directly to the boiler, while the other arm, the longer one, is held down by a stout spring balance, so screwed down that the valve can only rise when the pressure of the steam in the boiler becomes greater than the spring can resist. These valves are named safety valves, because by rising when the pressure of the steam exceeds the intended limit, they allow it to escape, thus preventing any excessive accumulation of pressure whereby the safety of the boiler and persons around are endangered. The safety valve does not show how much the pressure of the steam may be below or above the proper limit; this is shown by the steam or pressure gauge. The safety valve of a locomotive should be placed as far from the dome as convenient, in order to prevent priming.

There are two generally fitted, one placed beyond the control of the driver and the other near him. They are kept in their places, one by a Salter's spring balance, and the other is held down directly by a spring secured to the top of the valve, and hence it has no lever; weights are inapplicable to the case of the locomotive, because they would jerk up and down with the vibration of the engine. The safety valves vary in size from $1\frac{1}{4}$ inches in diameter to 4 inches; but the general size is about 3 inches. Large safety valves are not so likely to set on their seats as smaller ones. The lever by which the Salter's spring balance presses the valve on to its seat is generally graduated, according to the area of the valve. If the valve be 10 inches in area, the lever is divided into 11 parts; the safety valve lever presses on the valve at the first division, leaving 10 divisions on the long arm and one on the short arm; thus the pressure per square inch on the safety valve is exhibited. They vary in shape in some engines; annular valves are used in which the steam escapes round the edges of two circles. The annexed figure illustrates a very good valve used by Mr. Gooch. It is constructed somewhat on the principle of the steam indicator.



To the above valve there is no lever; the spring balance is placed on the top of the valve itself, which is $1\frac{3}{16}$ inches in diameter. The steam enters at S, when acting on *a a* against the spring in the barrel B; the force of steam compresses it until it acts by allowing the steam to pass through *b*.

269. Chimney.—It is usual to term it a chimney, not a funnel. The height must not exceed fourteen feet above the level of the rails; they are made of wrought iron, and proceed directly from the top of the smoke box to which they are bolted. Their relative sectional area to that of the fire grate is about one-tenth, or they should properly be a little less in diameter than one of the two cylinders, which is considered a good proportion. Their draught does not depend upon their height; or, rather, the draught depending upon the rush of waste steam, it matters little what height they are, so long as they convey the steam, smoke, etc., away from the driver and fireman. A damper is generally provided, as seen in our figures, near the end of the blast pipe; but the damper is so arranged that the nozzle of the blast pipe passes through it. It consists of a disc of metal.

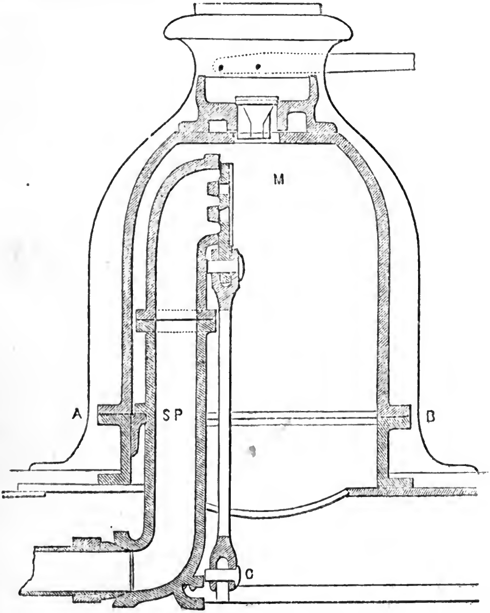
270. Dampers. — Besides the disc damper referred to above, placed across the chimney, the front of the ash pan is always so arranged as to act as a damper, by regulating the supply of fresh air to the fire. The most effectual dampers are those placed at the smoke box end of the tubes, consisting either of a perforated plate with circular holes corresponding to the number and end of the tubes, which slides so to either completely close or leave open the ends of the tubes, or else it consists of thin strips of metal arranged and acting on the principle of the Venetian blind, by these the tubes can be left fully open or closed, or partly closed, so as to check the draught according to the judgment of the driver.

271. Steam Dome and Prevention of Priming. — The position of the steam dome varies, but it is always bolted to its seating, which is riveted on to the top of the boiler, sometimes immediately over the external fire box, and sometimes towards the middle of the barrel of the boiler. Within the steam dome is placed the end of the steam pipe, and it is here placed so that the steam shall enter it as far from the water as possible. It is sometimes known under the name of the **Separator,** because by the steam entering the steam pipe within the dome, a better chance is given for the spray produced by ebullition to separate from the steam—thus priming is prevented. Sometimes the safety valve is placed on the top of the steam dome, but this is considered an objectionable practice, as it should be as far away as possible from the steam pipe. A baffle plate of brass, shown by the line A B in the figure (p. 255), is fixed above the water line at the entrance to the steam dome—it is thoroughly perforated; as the steam runs towards the mouth of the steam pipe M, it impinges against this perforated plate, and in rushing against the plate and passing through the holes, the water that has come away with the steam is knocked out—the whole arrangement is thus found effectually to prevent priming. Another mode of preventing priming is by placing the steam pipe as near the top of the boiler as possible, and allowing the steam to enter through holes in the top, before which are placed a smaller baffle plate; this has been already explained. The dome is bolted to its seat, which is riveted on to the top of the boiler or fire box—the former is the more preferable plan by far—and the joint is made steam tight, as explained under the next heading *Man Hole.* Its form varies as much as its position, depending upon the taste of the maker, but the majority are either hemispherical or have hemispherical tops. It is usually worked out of one plate, with a spherical top, or finished with a dished cover of plate, or cast-iron.

272. Man Hole.—The man hole is to gain an entrance to the interior of the boiler. No special man hole is required, as the dome can be taken off, and admission thus gained to the boiler; but when fitted, it is frequently over the top of the fire box, or near the chimney, or on the dome seating. Near the fire box is the best place, as the stays can easily be reached. It is about 15 inches in diameter, sufficiently large to admit a man's body. The door of the man hole must be attached with a steam-tight joint to the top of the boiler; it is rendered steam-tight in the ordinary way, by the use of canvas and red lead. Sometimes the molecular force of expansion is made to render the joint steam-tight thus:—Soft copper wire is laid on the joint, then the cover is brought down on to it and screwed up as tightly as possible, then, when the steam is up the heat causes the copper wire to expand; the greater the heat, which, in this case, may represent pressure of steam to escape, the greater the expansion of the copper, and the more steam-tight the joint. It is made with a necking formed of thicker metal than that of the boiler, and flanged to join it. The upper flange is planed to receive the cover or dome.

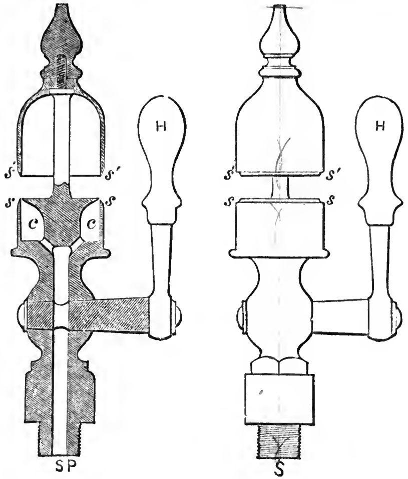
273. Regulator, or Steam Regulator.—This contrivance is to regulate the admission of steam to the cylinders from the boiler. They are made in various forms, but are chiefly of two classes: (1) Those formed on the principle of a conical valve and seat; (2) those constructed like an ordinary locomotive slide valve.

C is a lever, or else an eccentric worked by *the regulating* *handle,* which is close to, or within easy reach of, the engine-driver. This lever, or eccentric C, being moved, the slide M is brought down, and free exit is given to the steam in the boiler, so that it can readily pass down the steam pipe S P to the cylinders. Sometimes these valves are arranged precisely on the same plan as a ventilating grate in the floor of a building, where a very slight turn gives a large passage for air, in this case steam.



DOME AND STEAM REGULATOR.

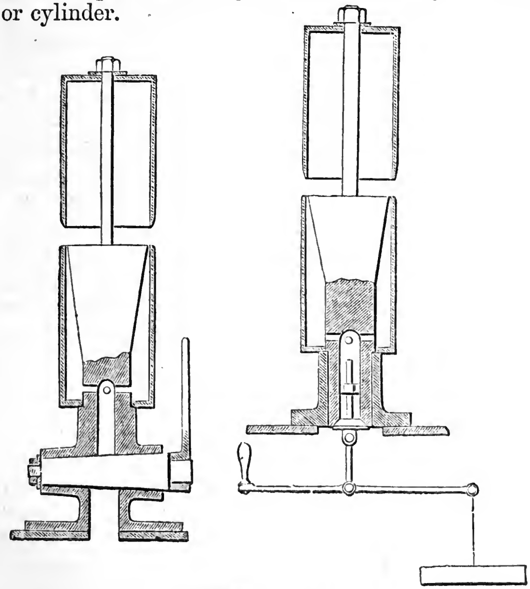
274. Steam Whistle.—The steam whistle is a device attached to locomotives for giving warning that the train is approaching, moving, etc. It mainly consists of a pipe fastened into the top or end of the boiler, with a cock within easy reach of the engine driver. When the steam is turned on, it issues violently out of a circular opening and strikes the rim of a bell-shaped piece of brass (its edge being placed exactly over the circular opening), with sufficient force to make the whistle heard at a very long distance. The principle is simply this:—When the handle H is turned, the steam coming from the boiler passes up S P, and out all round the edge of *s s* through the circular opening *c c*, then impinging with great force upon the edge of *s′ s′* it sets it vibrating, the vibrations communicate their motion to the air and mould it into a series of sonorous waves, giving us a high note of so shrill a pitch that it can be heard at a very considerable distance.



STEAM WHISTLE.

There are generally two whistles—the shrill one for ordinary purposes, and a deep-toned one to attract the guard's attention. It is usual now to arrange the guard's whistle, so that both the driver and guard can sound it. The cord that runs along from one carriage to another is in connection with this whistle, and if the passenger pull this cord he will sound the deep-toned whistle.

By comparing the steam whistle we have just explained with the next two, it will be seen that no difference in principle exists between the first used and those with modern improvements attached. The left hand one is a sectional view of the first locomotive whistle ever used. It was made in 1835; the right hand one is a section of the first steam whistle ever employed, which was at the Dowlais Iron Works in 1833, where it is supposed to have been invented by William Stephens, a working man. It will be observed that the steam is made to pass round a tapering funnel with its wide mouth upwards, and as it comes out it is compelled to impinge upon the edge of an inverted hollow cylinder. Experience has given a thinner edge to the upper part or cylinder.



STEAM WHISTLES.

275. Pressure Gauges.—The reader is referred back to the gauges used in the marine steam engine, as described on page 153, *et seq.*

But we would add a few remarks to these. The general use of the steam gauge has not only given additional security in the working of all steam engines; but, serving as a guide to the enginemen, it has been the means of effecting a considerable saving of fuel, by enabling them to maintain the proper pressure without, as in old times, letting the steam vigorously escape at the safety valves. Engine drivers once held it to be a good sign that they were properly attending to their fires when the safety valves were continuously roaring, and De Pambour estimated the total steam lost on the Liverpool and Manchester Railway, by this blowing off at the safety valves, as one-quarter of the whole steam generated.

When steam is raised, the safety valve fixed, and the fire under the boiler, the pressure and temperature increase very rapidly, hence the necessity for continual watchfulness, to see what pressure the gauges indicate, and to ascertain whether the safety valves are properly acting. In some experiments made with a locomotive boiler, the pressure being at 32 pounds, and temperature $133\frac{1}{3}$°C., and the fire kept as regular as possible, in three minutes the pressure was $44\frac{1}{4}$ pounds, temperature $141\frac{1}{3}$°C.; in three minutes more, pressure was $57\frac{3}{4}$ pounds, temperature 149°C.; in three minutes more, $74\frac{3}{4}$ pounds, temperature $155\frac{5}{9}$; or in nine minutes the pressure increased from 32 to $74\frac{3}{4}$ pounds, or much more than double its pressure—a most astonishing increase. This will, perhaps, explain a few boiler explosions that have happened while engines were stationary.

276. A Fusible Plug is screwed into the crown of the fire box (for description, see page 143). These plugs are not always to be relied on, as they sometimes become encrusted and do not operate; but, with a properly kept boiler, they are a useful precaution against accidents.

DIVISION III.

THE WATER FOR A LOCOMOTIVE.

Water Tanks—Water Cranes—Feed Pump—Giffard's Injector—Gauge Cock—Glass Water Gauge—Screw Plugs—Scum Cocks—Blow-off Cocks—Heating Cocks.

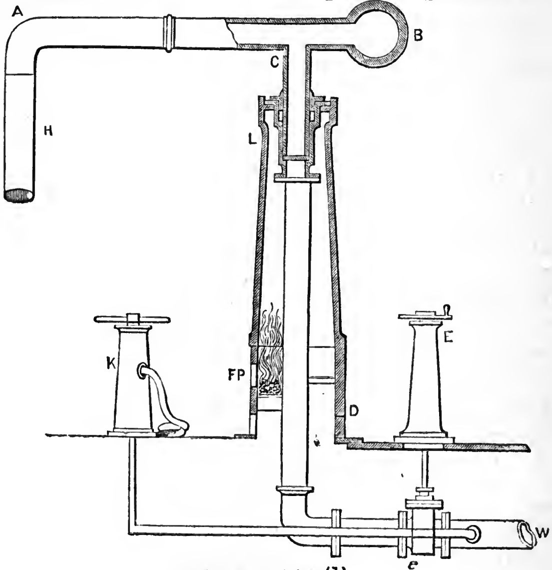
277. Water.—The boiler of a locomotive engine is filled so that the water stands a few inches above the top of the fire box. It is admitted to the boiler by means of pumps and ball valves, or by Giffard's injector.

278. Water Tanks.—Walls, or small buildings of substantial masonry, supporting a large tank for water, are generally seen by the side of a railway station; they supply the engine with water. Water tanks are usually rectangular, from five to nine feet deep. They are, at the bottom, at the least, twelve feet above the level of the rails, so that there is constantly a sufficient pressure of water to fill the *tender* quickly. Tanks are either filled by allowing the water to run into them from a higher level, or by pumping up the water by means of an engine from a lower level. This is the general plan when the engine, boiler, pumps, etc., are housed under the tank. The water tanks are made of boiler-plate iron, and supported by cast-iron beams running in a row under each seam of the tank. They are also made of cast-iron, supported by cast-iron beams across the tank from side to side. The engines preferred for the purpose are *vertical*, and the pumps double-acting.

279. Water Crane.—The water is drawn from the tank at the bottom, and passes through a cast-iron pipe to the *water crane.* It is allowed to pass into the mouth of this cast-iron pipe by a valve which has the fulcrum of its lever on the side of the tank, the valve is lifted for the discharge of water by a chain hanging down outside within reach.

Fig. 1. is a water crane of the usual construction. A B is the *swing pipe,* balanced on a vertical pivot at C, within the cast iron column C D; it will, therefore, swing round into any position convenient for filling the *tender with water.* H is a leather hose at the extremity of the swing pipe for the convenience of the engineman. E is a shut-off screw valve, to allow the water to pass up the column D C when the handle is turned, and to stop the supply when sufficient has been delivered into the tender; the valve *e* is screwed up when water can pass from W. It will be seen that its action is exceedingly simple. Water passing from the tank by way of the pipe W is allowed to run through the valve *e* by turning the handle at the top of the shut-off screw E, it then goes upwards through D C, along C A, and into the tender by H. B is a weight to counterpoise that of A C, so that no undue strain comes on the vertical pivot C; also, by its momentum, it assists in turning the arm A C. It will be observed at C that the pivot has a brass bearing, which has to

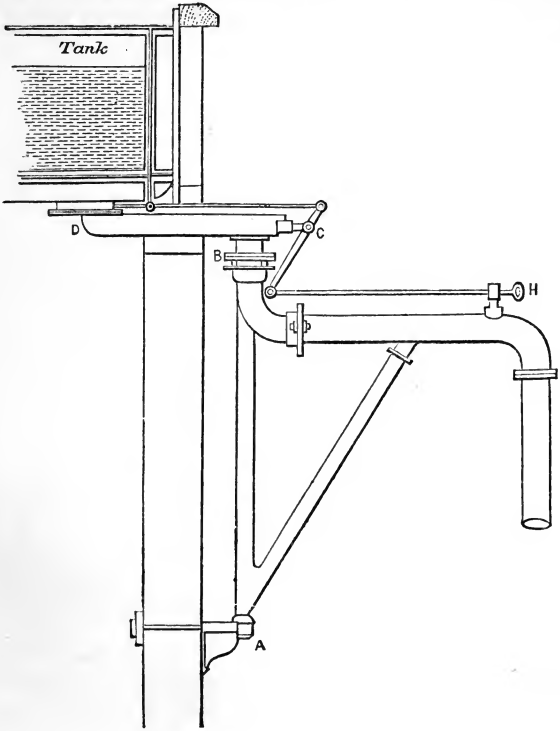
be fitted with considerable care. F P is a fire place, so that in winter the column can be warmed and the water unfrozen, or prevented from freezing; the products of combustion pass out through a number of small apertures provided for the



WATER CRANE (1).

purpose at L. K is a pillar fountain, from which water can be taken, by turning the handle at the top, for cleansing and other purposes; an hose can be attached to it for the convenience of watering and cleaning.

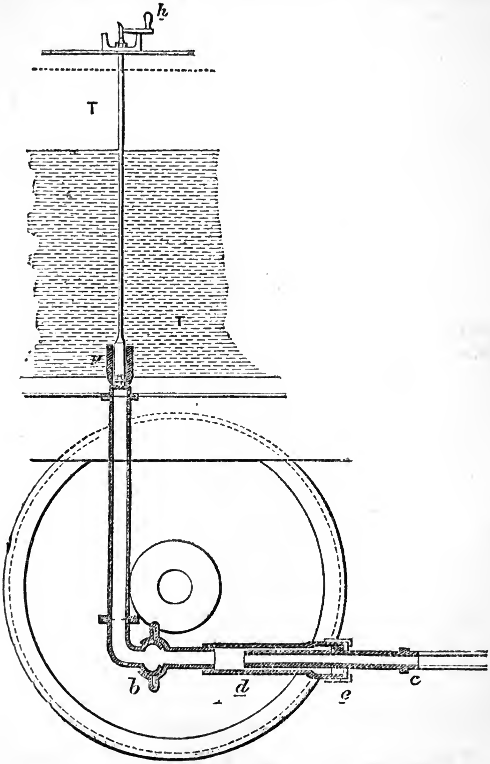
The *wall water crane* is simpler in its details than the one just described, but not always so well adapted for its purpose, as it makes no provision for the extreme cold of winter. It swings at the bottom A on a bracket bolted to the wall, and at the top B it is supported by the supply pipe D C, into which it is pivoted. The engine driver pulls the handle H, when, by means of lever C, a sluice valve is pushed back within D, when the water runs along the supply pipe D C, and into the swing pipe, as before, to the tender through the leather hose at the extremity of the supply pipe. The tank is seen in its proper position.



WALL WATER CRANE (2).

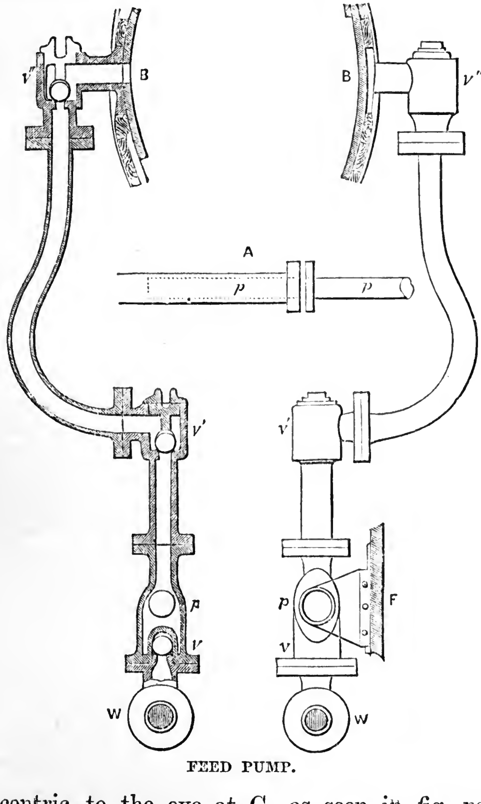
280. Feed Pumps.—The feed is either supplied by *Giffard's injectors,* fixed to the fire box, and of which a description has been already given, or else by an ordinary double-acting pump worked off the crosshead of the piston-rod, or from one of the eccentrics on the crank axle. When the former method is adopted, the ram is about $1\frac{7}{8}$ or 2 inches in diameter; but in the latter arrangement the ram must necessarily be of greater diameter, about 4 inches, as the stroke is so much shorter.

The water is kept in the tender T. The handle at *h* is turned, when the plug *p* is lifted and the water runs down



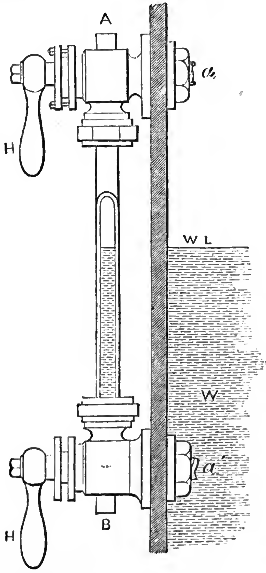
BALL AND TELESCOPE VALVE ON TENDER.

p b c by gravity. At *b* is a ball and socket joint, so that the pipe *b c* (this part is generally called " bags") is capable of a slight vertical and lateral motion. From *d* to *e* is a telescopic joint, which admits of a longitudinal motion in and out. It is thus that all the motions of the train are provided for, and that the joint is rendered water tight. At *c* it is screwed on the pipe leading to the engine and boiler. This tube leads the water to W in the next figure, which gives us two views of the feed pump. *p* is the plunger, a side view of which is shown at A. The eye of the plunger rod is fastened to the crosshead of the piston, but sometimes to the back of



FEED PUMP.

the eccentric to the eye at G, as seen in fig. page 279. The plunger is very small, not more than 2 inches in diameter. As it moves to the right a vacuum is left behind it, and the water rises through the valve v; next, as it comes back, the water is forced along the delivery pipe from v' to v'', through the ball valves v' and v'', into the boiler at B. The object of the third valve at v'' is to prevent the pressure of the steam from forcing the water back upon the other valves. The lift of the valves is very small, not more than $\frac{1}{4}$ to $\frac{5}{16}$ of an inch. Above each valve is a guard to keep it down to its seat; for, if allowed to rise too high, the force of concussion would be sufficiently great to destroy the valve seating. When no feed is required the water is shut off at the tender. These feed pumps only work when the engine is moving. Sometimes it may be noticed that engines are running backwards and forwards a short distance near a railway station. It is that water may be pumped into the boiler. When Giffard's injector is fitted, there is no necessity for this. It was a custom to fit a small donkey pump for the purpose of forcing water into the boiler when the engine was stationary. The capacity of the pump, *i.e.*, the area of the plunger or ram, multiplied by the length of the stroke, should be from $\frac{1}{70}$ to $\frac{1}{80}$ of the contents of the cylinder. Each pump or injector should be capable, singly, of keeping up the feed. Two are fitted in case one should be disabled.



GLASS WATER GAUGE.

281. Gauge Cocks.—When the boiler is first filled with water, it is made to stand a few inches above the fire box. In order to know when the water is at the proper height in the boiler, there are fixed in the back or side of the fire box two brass gauge cocks. One is a few inches above, and the other as much below, the proper level of the water in the boiler. The cocks are connected with a glass tube, the whole forming the **Glass Water**

Gauge. Both cocks are kept open in communication with the boiler, so that the water can freely pass through the bottom cock into the glass tube, and the steam as freely through the top one. The water within the gauge has thus the same level as that in the boiler, and the driver has only to look at the glass to see the height of the water in the boiler. When the feed pumps are at work, he watches it till there is a sufficient supply in the boiler, and afterwards he has to notice that it does not get too low through the evaporation of the water. In addition to this there are fitted three *gauge cocks* at the back or side of the fire box at different heights, between the extreme limits admissible for the water level. By trying these cocks successively, the engineman can judge, according as steam or water issue from them, at what height the water stands in the boiler.

W is the water in the boiler, W L is the water level. The water passing from the boiler enters at a', and stands the same height in A B, the glass water gauge. The handles H and H, when turned, allow water or steam to issue from the boiler, and clean the gauge out. It is the duty of the engineman to turn these handles now and then, for fear the gauge may be choked at a, or a', or at B and A.

282. Screw Plugs.—To facilitate the washing out of the boiler, a screw plug, about 2 inches in diameter and slightly tapered, should be fitted at each corner of the fire box, with as large square heads as the plugs will admit, to bear the strains of the screw key. The plugs should be of hard brass, and threads cut to a fine pitch, to give them a good hold on the metal; sometimes a lining plate is inserted at the corner to increase the hold of the plug, and reduce the liability to leakage.

283. Scum Cock.—This cock is fixed on the back of the fire box at the ordinary water level, with $1\frac{1}{2}$ inch copper pipe, carried down below the foot plate, to draw off the impurities which rise to the surface of the water, and which, whilst there, frequently cause the boiler to prime.

284. Blow-off Cock is also fixed at the back or side of the fire box, but at the level of, or as near as practicable to, the ring at the bottom of the water space between the internal and external fire boxes, and is for the purpose of blowing the water out of the boiler when required. There are two other cocks fitted to all locomotive boilers, viz., the blower and the warming cock; the former being connected by a pipe with the chimney, for the purpose of getting up the steam rapidly, the latter for warming the feed water in the tender. It is generally opened while the engine is stationary, when by suitable pipes the steam passes to the tender, where it heats the water instead of blowing off to waste. This practice was adopted in the very earliest days of locomotive engineering. It is also a common practice to heat the water by other methods before it enters the boilers; in fact, this should always be done.*

285. Warming Cocks.—Warming cocks are employed to let any surplus steam pass into the tender to heat the water. They are fixed near the top of the fire box, and are connected with the feed pipes by an inch copper pipe. In tank engines the pipe goes directly into the tank.

DIVISION IV.

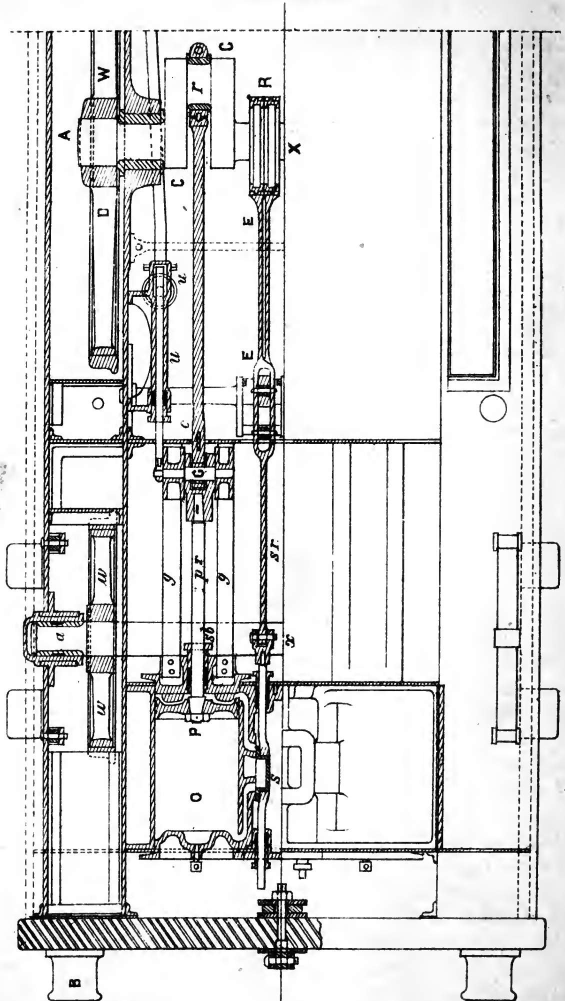
DETAILS.

The Cylinders—Water Cocks—Grease Cocks—Piston and Piston-Rod—Connecting Rod and Crank—Coupling Rod—Strap Gib and Cutter—Sector—Driving Wheel Tire—Counterweight to Wheels—Sand Cocks—Axle Boxes—Springs, Buffers, and Buffer Springs—Brakes—Draw Bar.

286. The Cylinders of locomotives are generally placed immediately beneath the smoke box, where all condensation from external cold is entirely prevented. Sometimes they are fixed on the outside of the engine, such engines receiving the name of Outside Cylinder Engines. In early locomotives the cylinder was placed vertically. The horizontal cylinder was finally adopted about 1830. It is unnecessary to enter into the details of the cylinder. The student is referred to what has been said concerning those of land and marine engines generally, as the arrangement is the same.

* For a method of carrying out this idea, see Article on Cambridge's Feed Water Heater.

PLATE III.



PLAN OF CYLINDER & DRIVING GEAR

Of course they are made of good hard cast-iron. Sometimes, from the weight and friction of the piston, there is a tendency to groove. They are generally constructed so that both the top and bottom of the cylinder may be removed. The piston-rod works through a stuffing box and gland in the ordinary manner. It is always usual to allow one-quarter of an inch, or less, clearance at both ends of the stroke.

In Plate III., the cylinder is seen at O with its piston P. The piston-rod is *p r*, and two guide blocks are at G, which move backwards and forwards between the guide or motion bars *g g*. The piston crosshead is also at G. Into the guide blocks comes the end of the connecting rod *c r*. C C is the crank moved round by the connecting rod, and carrying with it the axle A X, and with it the driving wheel D W. R is the eccentric, and E E the eccentric rod working the slide rod *s r*, which in its turn gives the reciprocating rectilinear motion to the slide *s*. The slide *s* is seen in front of the ports, the bottom port being open to the exhaust and the upper to the steam. The piston is just going to commence its stroke to the left. The manner in which the connecting rod is attached to the crosshead of the piston and to the crank is explained by the illustration. *a x* is the axle of an ordinary leading wheel *w w*; the part marked *a* is the journal.

287. Water Cocks, Drain Cocks, Relief Cocks, or Cylinder Pet Cocks.—Two drain cocks are fixed to each cylinder, one at each end, and at the lowest part, to relieve the cylinder from any water that may arise from condensation of steam or priming. They should be opened just before starting, after the engine has been standing still, to get rid of any water that may have become condensed while waiting. They are worked by rods and levers from the footplate. Sometimes, often after repairs, the water is greasy, and until it is properly got rid of the engine will often prime, hence the value of these relief cocks.

288. Grease Cocks.—A grease cock is fixed on to each cylinder; it communicates with the slide valve and lubricates it; part of the tallow, as the slide moves backwards and forwards, enters the cylinder and lubricates it also. It is generally fixed on the valve-jacket, so that the slide valve and cylinder are lubricated as well.

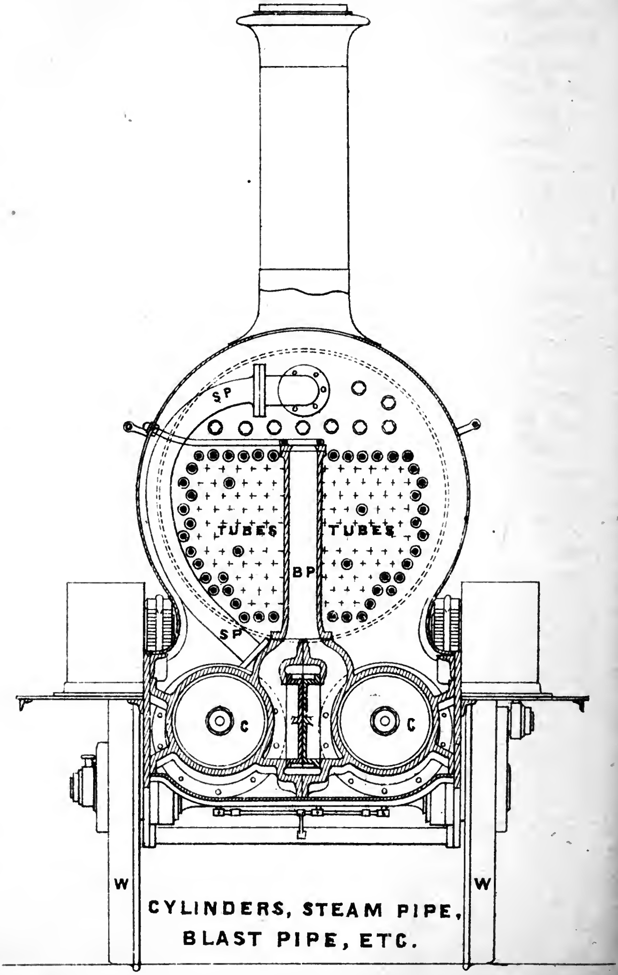
289. Piston and Piston-Rod.—The crosshead is the part to which the farther end of the piston-rod is fitted, to this also is attached the connecting rod, the crossheads move in guides or between motion bars, which are two or four parallel bars.

Pistons for locomotives are fitted and packed in many various ways. The piston-rods are made of steel or iron, while the piston itself is of cast-iron or brass; brass is the better substance, because it is lighter and does not so readily break; some makers forge the rod and piston in one piece. The top of the piston-rod is fastened by a cutter into a socket with jaws; G is the socket, the jaws are a little to the right and left of G; the whole is named the piston cap. Between and into the jaws comes the small end of the piston-rod *p r*, which is kept in its place by the pin of the crosshead; the two ends of this pin are fastened into two blocks, which move in guides or motion bars, to preserve the parallelism of the piston-rod. The pin of the crosshead is seen running under G, while the guides are marked *g* and *g*, and the two guide blocks may be observed above and below G at the end of the guide bars. The piston-rod works steam-tight through the cylinder cover; between P and *s b* is a short tube cast on the cylinder, with an opening a little larger than the diameter of the piston-rod, this is called the stuffing box, the gland is the part close to *s b*. The piston-rod being in its place, the stuffing box is first filled with hemp soaked in melted tallow, or else with other packing; the gland is then brought down on to it and screwed forcibly against the packing, so as to press it tightly against the piston-rod. Whenever any sliding rod has to work into a space filled with steam, or with water under pressure, a similar method is adopted to prevent any escape at the side of the rod.

"The maximum economical speed of the piston has not been ascertained, but it appears that, with a high speed of piston, small driving wheels and light engines are preferable to the very large ones which are now frequently seen. Small wheeled engines have been found to start a train more rapidly, and to draw it with greater regularity of motion, than engines with from $6\frac{1}{2}$ feet to 8 feet driving wheels."

290. The Connecting Rod and Crank. — By the inter-

PLATE IV.

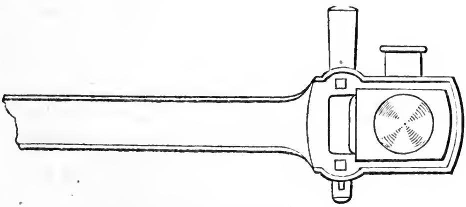


CYLINDERS, STEAM PIPE, BLAST PIPE, ETC.

vention of *the connecting rod and crank*, the rectilinear motion of the piston is converted into a circular motion. The connecting rod is *c r*, crank C C, and axle A X (Plate III.), which move the driving wheel D W. The crank, or rather the cranks—for there are two, as there are two cylinders and pistons—are forged on the axles of the driving wheels. The cranks are placed at right angles to each other; only one is seen in the figure, the other half is precisely similar to A X, but the crank is at right angles to C C. In our illustration C C is lying horizontally, so that when the piston P attempts to move to the left, it will only pull the crank in a straight line, as it were, and cannot move it, hence we see the necessity for two cranks; the one not shown, being at right angles to C C, is just in that position where the piston will have the greatest effect upon it; hence the driving wheel can be moved, which could not happen if the engine stopped exactly as seen in the figure, and there were only one crank. Such an axle as we have here is called a cranked axle, and is made of wrought-iron or steel. It must be understood from what precedes, that when one piston is at the end of its stroke the other is in the middle.

291. View of Fire Box, etc.—In Plate IV., C C are the ends of the two cylinders, S P the steam pipe, B P the blast pipe.

292. Coupling Rod.—A coupling rod is very similar in its form to a connecting rod, but it is not so large or heavy. Its use is for coupling the driving wheels to the leading or trailing wheels, or both, when of course the wheels must all be of the same diameter, as in the case of goods engines.

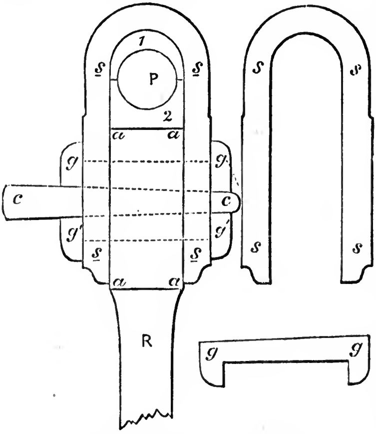


They are attached to cranks fixed on the outer ends of the axles, or else to crank pins inserted in the arms of the wheels

—the former method applies to engines with outside bearings, and the latter to those with inside bearings. They are always outside the wheels. Generally they are made with ends forged in one piece, and the cutters so arranged as to preserve their length constant as the bushes wear. An oil cup is shown in the figure; it is forged on and has a small tube in the centre, in which to insert the wick to lubricate the bearing.

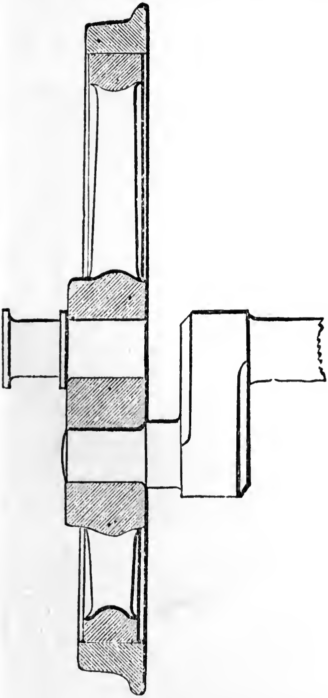
293. Strap, Gib, and Cutter.—The ends of the connecting rod are not, as it were, part of the rod, but are built up upon the end of the rod itself.

Let us take the annexed illustration, which is the smaller end of a connecting rod; *a a a a* is the end of the rod with a hole in it; first upon the end are placed the two brasses 1 and 2, in which a circular hole is left for the crosshead pin to pass through; round the whole is placed the strap *s s*; then into the hole is placed the *gib g g* (in this case we have two gibs, *g g* and *g′ g′*); then the *cutter* or *key c c* is driven in tightly, so that the whole is held firmly together. Sometimes *c* is also held in its place by a screw and nut.

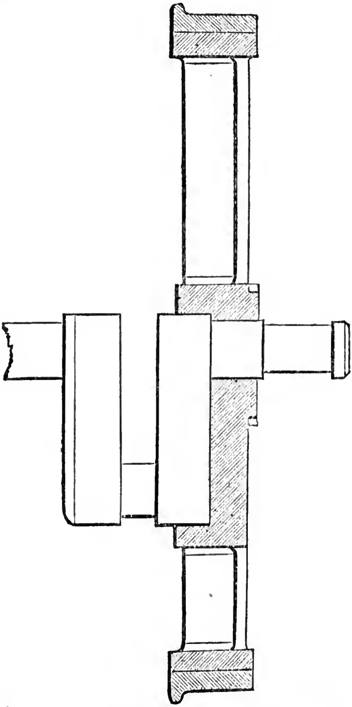


STRAP, GIB, AND CUTTER.
SMALLER END OF CONNECTING ROD.

294. Driving Wheel.—The wheels attached to the crank axle are called the driving wheels; the front pair of wheels of the engines, are called the leading wheels; and the hind wheels, or those close to the fire box, the trailing wheels. They are nearly always made of wrought-iron, and are kept upon the rails by a flange formed on the tire. The driving wheels in passenger engines are always made large, to increase the speed, and the power of the engine must be increased in the same ratio; but in goods engines they are not so large, and consist of four or more coupled together by coupling rods. The object in employing coupled driving wheels is simply to distribute the great weight necessary for adhesion, where great tractive force is to be exerted at moderate speed, such as with a goods engine. The wear of wheels amounts to about the twelfth of an inch per annum with wrought-iron tires. A good idea of a locomotive wheel can be obtained by referring to the following figures.



BALDWIN'S "HALF-CRANK."



DUNHAM'S CRANK.

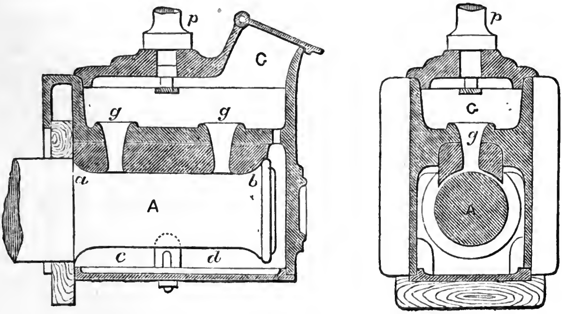
Wheels are made upon various systems, the object of all being to give strength to the tires and prevent wear. The tires are not cylindrical, *i.e.*, they have not the inner and outer edge both the same diameter, but are made slightly conical, which plan keeps the carriage in the centre of the railway, and the flanges do not come in contact with the rails unless under exceptional circumstances; in fact, conical wheels have a self-adjusting action, which preserves the carriages in their proper position on the rails. Again, if the wheels be thrown into such a position that one flange is close against the outer or large curved rail, the wheels being conical, a larger circumference of the outer wheel will move on the rail than on the smaller wheel (for we must recollect that the wheel only rests on *one* point), consequently the larger wheel will quickly restore the carriage to its proper position.

295. The Tire is a distinct part of the wheel, composed of a ring of metal, either wrought-iron or steel, which is shrunk on to the wheel, and further secured to the rim by bolts or rivets. It forms the conical part of the wheel and the flange. When worn, they are re-turned in the lathe to a true surface. This is required after an engine has been running from nine to twelve months. The tires, when new, are usually about $2\frac{1}{2}$ or $2\frac{5}{8}$ inches thick, and are not allowed to be worn down to less than $1\frac{1}{4}$ to $1\frac{1}{2}$ inches.

In each of the above wheels the tire is seen at the top and bottom, with the flange formed on one side. Here we have two methods differing from the ordinary one of forging the crank on the axle. In Baldwin's half-crank, we see a simple and cheap way of forming the crank. In the second example, or Dunham's crank, while we have the same position of the crank wrist, the crank is completed by adding the second arm, or cheek, this cheek being bedded in the cast-iron driving wheel itself.

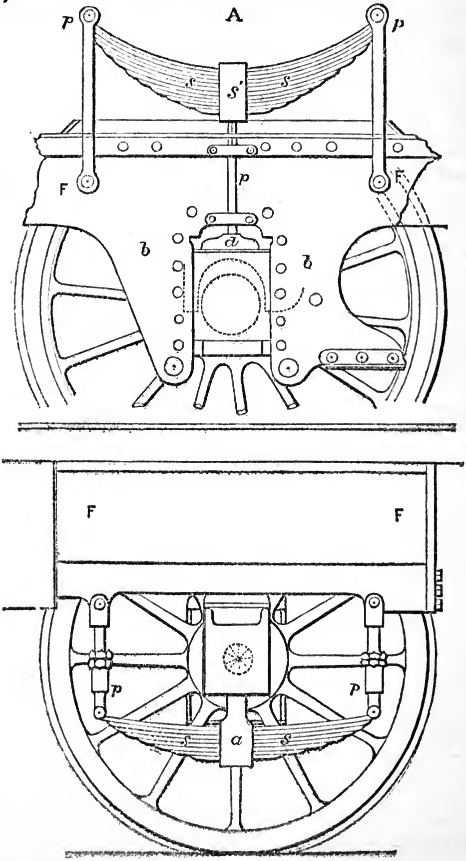
296. Counterweights to Wheels.—The momentum of the piston-rod, guide blocks, connecting rod, etc., is very great; this has to be counterbalanced by the application of a weight to the wheel. These weights are put into the rim of the wheels between the spokes. If the student will notice the driving wheels of a locomotive, he will see the balance weight partially filling up the space between three or four of the spokes. This weight depends upon the speed at which the engine is intended to run, and the weight of the moving parts; with the engine-maker this is a matter of nice calculation. Seven-eighths of the whole disturbing weight is allowed with outside cylinder engines, and for inside cylinder three-fourths. Counterbalancing is done to give the engine greater stability on the rails. It is said that engines, without counterbalancing, will not attain the speed they will when counterbalanced, the resistance being greater. They must be sufficiently heavy, not only to balance the crank and connecting rod, but the piston and its appendages.

297. Sand Cock.—To every engine there is a small sand box, fitted either on the top of the tank, in front of the engine on the buffer beam, or by the side of the footplate. In connection with it is a small pipe from $1\frac{1}{4}$ to 2 inches in diameter, leading to within two inches of the rail in front of both driving wheels, or in front of the whole if connected by coupling rods. The cocks are opened in slippery or damp weather, when the engine is starting, to assist the wheels in biting the rails, so that they may not run round without giving motion to the engine. The engine being fairly started they are closed. Whenever the wheels begin to slip, the cocks are opened till the nuisance is abated; and are, as occasion may require, brought into use on inclines.



AXLE BOX.

298. Axle Boxes.—The wheels are fixed securely upon their axles, which revolve in boxes, upon which the weight of the boiler and machinery is carried through stout springs. The axle boxes can rise and fall freely, as far as the springs will permit. The axle boxes are guided vertically by suitable guides or *axle guards*. The part of the axle which revolves in contact with the axle box is called the journal. When the journals are inside the wheels they are called inside bearings, and when outside the wheels outside bearings.

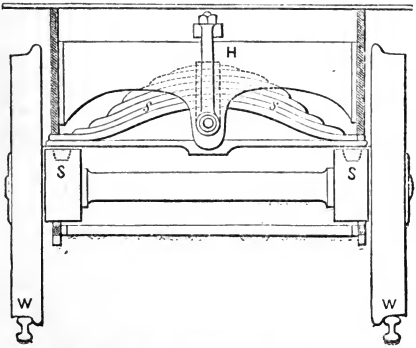


B

SPRINGS.

A is the journal (p. 273), the whole weight rests on the spring, of which *p* is the spring pin, therefore the weight of the engine rests on the top of the axle (and wheel) from *a* to *b*; *c d* is hollow, although sometimes a sponge, or some cotton waste, is laid in to soak up the oil or grease. In the cross section it is seen more clearly, where the weight rests upon the axle.

299. Springs.—The weight of the engine, boiler, etc., is sustained by springs resting upon the axle boxes. They are formed of steel plates from three-eighths to half-an-inch in thickness, of a number proportioned to the weight they have to carry. Each spring of the driving axle has often to carry from four to six tons. The plates are connected at the centre, and slide on each other at their extremities. If we examine the spring A (p. 274), we shall notice a rod proceeding from the centre of the spring *s'* to the top of the axle box at *a*. The middle of the spring thus rests upon the axle box. At *p* and *p* are two eyes, the ends of the spring pass into the jaws of a bridle at *p* and *p*, and through them passes a pin to keep the spring firm at *p* and *p*. Sometimes, as in figure B, the springs are placed below the framing, when the weight of the engine is made to rest upon the ends of the springs. In figures A, B the weight of the engine is carried by the springs

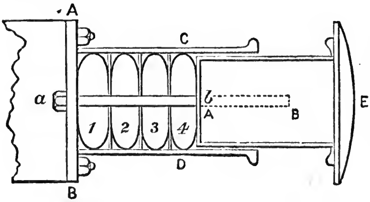


TRANSVERSE SPRING.

s s, the framing F F resting on the spring pins *p p*, the springs then bear up the weights. They are fastened to the axle box in figure B by means of a pin passing through the eye of a strap *a* round the middle of the spring. In the upper figure *b b* are the horn plates, or axle guards, of wrought-iron, forming part of the frame of the engine. They form a guide, with the cast-iron slides riveted on to the wrought-iron horn plate, for the axle box to move up and down in, as the springs give way to the weight and jerks of the train. The strain of the engine and carriages comes on the horn plate.

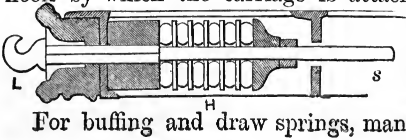
This is another method of arranging the spring:—A transverse spring is attached to the framing at H, and carries the weight on its centre. The ends of the spring *s s* resting on the top of the axle boxes at S and S. Their use is to receive the jerks, oscillations, etc., as the engine runs, so that the motion of the engine may be smooth, just as we know, and can feel, the difference between riding in a cart and a carriage, so the springs act in keeping the engine, etc., still.

300. Buffers and Buffer Springs.—Buffers are to receive any sudden shock or strain, so as to give the passengers as little shock as possible.



A B is bolted to the buffer beam; within C D are four or more cushions of India-rubber, or India-rubber springs, 1, 2, 3, 4, separated from each other by $\frac{3}{16}$ iron plates, all of which will admit of lateral motion. The bar *a b* passes through all the plates and India-rubber springs. When a shock is received by the buffer E, the springs are compressed and the bar runs up A B, but it is sometimes arranged to drive from right to left. Steel springs are as frequently employed as India-rubber.

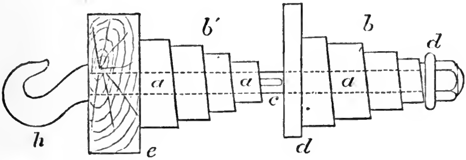
Here we see the arrangement of the *draw bar* and spring for a carriage. At H are the India-rubber springs, L is the hook by which the carriage is attached. The pull of the



carriage acts on *s* and draws the bar towards L, so that the springs are compressed.

For buffing and draw springs, many kinds have been employed. India-rubber springs are formed of circular discs, the buffing and draw-rods running through them; helical and spiral springs, made of steel, and rods acting upon ordinary steel springs, are also used.

301. Draw Bar with Springs.—The draw bar with springs is fitted to engines to receive and take up sudden shocks and strains.

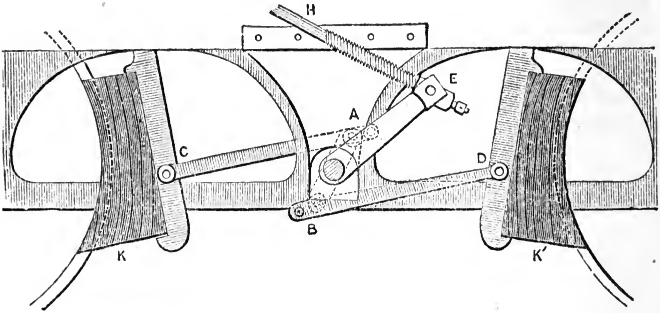


DRAW BAR WITH SPRINGS.

h is a crook or hook, to which the carriages are coupled on; *a a a* is the *draw bar*, chiefly shown by dotted lines; *b′ b* are two steel springs; *d* and *e* are two transverse pieces of the frame, firmly fixed at the same constant distance; *e* is the buffer beam; *c* is a cutter to bring up the spring *b′*, while the spring *b* is brought up by *d*, a washer close against a nut, as seen in the figure. The action is this, if a pulling strain comes upon the *draw bar*, then the spring *b′* acts, and is compressed by the cutter *c*; at the same time, the washer *d* compresses the spring *b*, thus assisting *b′* to counteract the strain. The traction spring or draw bar modifies the force of sudden snatches by the engine, which are liable to snap the couplings between the carriages. A plan adopted to resist the strain on carriages, is for the two buffers to act each on the end of an ordinary carriage spring, say from left to right, while the draw bar, to which the carriage is coupled, acts on its centre from right to left.

302. Brakes.—*Brakes* are employed to bring the train to a standstill. They are generally worked by the fireman, although there are *brake vans* with brakes worked by the guards as auxiliaries.

Suppose the handle H pulled to the left (by a screw), then the lever E is drawn towards the left, and with it the lever A B. As A goes to the left, the arm A C jams the brake K against the wheel, while the arm B jams K′ against the other wheel, when, friction preventing the revolutions of the wheel, the train is brought to a standstill.



BRAKES.

The brake, which is essentially a screw and lever apparatus, is generally of wrought-iron, except the part which embraces the wheels, which is of wood. Sometimes two or more sledges slide on the rail under the engine. The power developed by the screw and levers is enormous, reaching as much as 500 : 1, so therefore if a man turn the screw with the force of half a hundred weight, it acts upon the wheels with a force of more than twelve tons. It does not do to make the leverage excessively great, because the force coming on the frame of the engine, it is liable to be wrenched. The frame must be adapted to bear such extra strains. To save the frame, the force should be thrown on the levers as much as possible, and not on the screw, or the screw should be coarse in its thread, and have a short handle.

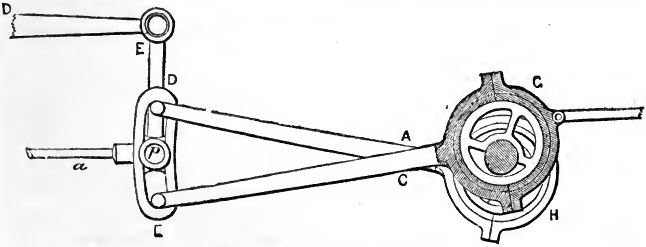
A brake used on the North London Railway is a very good one, bringing the train to a standstill in a very short distance. "To each vehicle two pairs of pendulous brake blocks are hung in the usual way. The brake is worked by a $\frac{5}{8}$ inch chain, carried on sheaves along the centre of the train, united by coupling hooks at each carriage. In the centre of each carriage the chain hangs down like a festoon, and passes under two pulleys attached to pulling rods fitted to the block hangers. When the chain is tightened, the centre pulleys are raised, and the blocks pulled on the wheels with a collective force of about 3 tons for each vehicle. When the chain is slackened, the pulleys, assisted by a back weight, descend by gravity to their normal position, and free the brake blocks. The chain is tightened from either end of the train by means of two transverse axles, driven by steel-faced friction wheels 20 inches in diameter, screwed by manual power against the van wheels. The momentum of the van is thus made to retard the whole of the train, and is so powerful that a train of eight vehicles can stop the largest engine under full steam."

DIVISION V.

SLIDE VALVE AND COMBUSTION.

Stephenson's Link Motion—Sector—Single Eccentric—Slide Valve and its Motion—Temperature of Furnace Gases—Transmitting Power of Metals—Coke and Coal Burning in Locomotives—Air Required for Combustion—Steam Blow Pipe—Beattie's Fire Box —Conclusions on Combustion.

303. Stephenson's Link Motion.—The advantage of this



STEPHENSON'S LINK MOTION.

contrivance is, that the engine can be reversed without any more trouble than is entailed by moving a handle. It consists of two eccentrics H and G, each having its own rod C E and A D. When the forward eccentric works the slides, the engine goes forward; when the backward eccentric works them, it is reversed. D E is named the link, and it is moved up or down by the lever D E D. *a* is the slide rod attached to the block *p*. The link motion is not used to work the steam expansively; it merely alters the travel of the slide, when the engine moves slowly or quickly. It reverses the engine by reversing the travel of the slides.

To obtain the greatly varying power required in the locomotive at different times, it is necessary to be able to vary the times at which the steam shall be cut off from the cylinder. This is effected by the link motion, which consists merely of two eccentrics, as has been already explained (page 70).

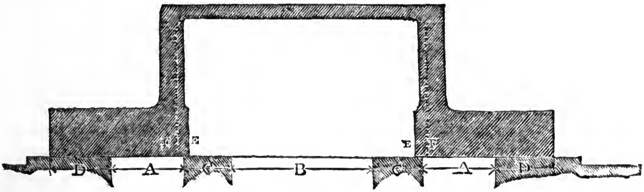
304. Single Eccentric.—The single eccentric, which is loose on the shaft, acts on the same principle as the double eccentric with the slot link. With the double eccentric and link, one eccentric only works the valves at a time, or acts on the slide valve spindle. The single eccentric is fitted with a weight to balance it, to keep it steady on its stop. Were it not so, it would come away from the stop on the shaft. Were no weight fitted, when the centre of the eccentric and centre of the shaft came in a straight line with the valve spindle, it would have a tendency to pass too quickly over the centre, and cause a knock or back lash at every stroke.

305. Sector.—The *sector* is in the form of a sector of a circle, and is an adjunct to the link motion. In it is a series of notches to hold the reversing handle. When the locomotive is started, the handle is dropped into full throw, or into the farthest notch. By doing this, the forward eccentric at once works the slides, or the eccentric rod comes direct on to the valve spindle, and all the strength of the steam is at once given to the piston. When the engine is fairly under way, the handle is brought back a notch or so to economize the steam. There are about five notches from the centre down, or ten altogether. The nearer the reversing handle is to the centre of the sector, the less steam is used.

306. Slide Valve and its Motion.—The manner in which the steam is admitted to and released from the cylinder, and the points of the stroke at which the events take place, can be varied in three ways: (1) By altering the form of the valve; (2) by variation in the valve gear which drives the valve; (3) by altering the relative proportions of the connecting rod and crank.

307. Action of the Single Eccentric and the Slide Valve.—The annexed is the form of valve generally employed. It is called a locomotive or "three-ported" slide.

A and A are the steam ports or passages, by which the steam enters the cylinder. B is the exhaust port, by which the communication is kept up with the exhaust pipe; C C



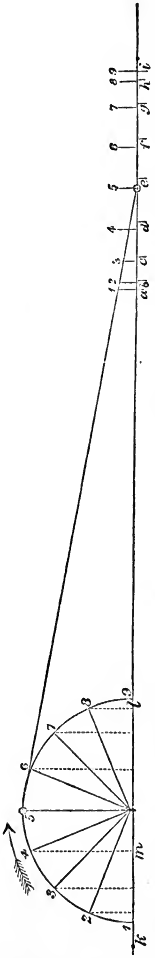
SLIDE AND PORTS.

are termed the *bars* or *bridges.* In the position shown in the figure, the valve is at half-stroke, and the parts D of the valve, extending at each end beyond the ports, is termed the *outside lap* or *outside cover;* and the part E, or the distance the inner edge extends beyond the ports A A, is called *inside lap* or *cover.*

Should the valve extend only to the dotted lines on its inside, it would not entirely cover the ports at half-stroke on the inside, but leaves them both partly open to the exhaust. This is called *inside clearance.* Lead has already been sufficiently illustrated on page 118.

When a slide is driven by a single eccentric, its motion is a compound of two others: (1) Of that given by the centre of the eccentric moving round that of the crank shaft; (2) this motion is retarded and accelerated by the varying inclination of the eccentric rod. As the eccentric is nothing but a crank, we can determine the various positions of the slide in relation to such a motion as a crank will give.

The manner in which the position of the piston is influenced by the action of the connecting rod, is shown by our figure, in which are represented the relative positions occupied by the crosshead and crank, at nine points in a half revolution of the crank shaft. In this diagram the length of the crank is taken at 12 inches, and that of the connecting rod at 6 feet. The short lines, numbered 1 to 9 on the upper side of the centre line, represent the positions of the crosshead corresponding to the similarly numbered positions of the crank. The other lines below the centre line, lettered *a* to *i*, show the places the crosshead would occupy if the connecting rod were of infinite length; and the spaces into which these lines divide the stroke of course agree with the spaces into which the diameter, *k l*, is divided by the ordinates drawn to it from the points denoting the position of the crank pin. This diagram at once shows that if the crank shaft rotates in the direction of the arrow, from *k* to *l*, the motion of the piston will, during the first half of the stroke, be retarded by the action of the connecting rod, while during the latter half it will be correspondingly accelerated. The effect of this is, that, during the whole of the stroke *from* the crank shaft, the piston is in arrear of the position which it would occupy if the connecting rod were of infinite length; whilst, during the stroke *towards* the crank shaft, it is correspondingly in advance of such position. In the example before us, the piston travels 10·99 inches, while the crank moves from position 1 to that marked 5, and 13·01 inches as it rotates from 5 to 9.



308. General Principles.—The slide valves admit and release the steam. By the *lap*, means are provided for the suppression of the steam before the end of the stroke, and the eccentric is so set that the valves shall open before the commencement of the stroke, and thus release the steam before that period. It is usual also to give a certain amount of lead to the valve, in order that the steam may be promptly admitted, and the port opening be wide enough as the piston advances to allow the pressure to be well sustained. The amount of this varies with the speed of piston at which it is intended the engine shall work, also to a certain extent with the opinions of engineers, $\frac{1}{4}$ inch being the usual amount in this country, and $\frac{1}{8}$ inch, or even as little as $\frac{1}{6}$ inch, in America. In some cases a small amount of inside lap is given for the purpose of preventing the escape of steam too early in the stroke; in other cases, inside lead is adopted in order that the steam may have a freer escape. The former would be suitable for goods engines exerting large tractive force at slow speeds, and the latter for express engines working at a high speed of piston. The amount of either is rarely over $\frac{1}{8}$ inch at the most.

309. Motion of the Slide — *Continued.* — By these five figures we wish to show the relation between the travel of the slide and the path of the centre of the eccentric pulley. The motion of the eccentric is here communicated to the valve through a rocking shaft. This was the old method; it is now customary to attach the eccentric rod directly to the slot link, which is brought down or up to the end of the valve spindle.

"In figure 1, the piston is shown at the commencement of its stroke by the amount due to the angular advance of its eccentric, which, as there is no outside lead, corresponds in this instance to a movement of the valve, equal to the lap, which is here $\frac{1}{16}$th of an inch. At the same time the steam passage, communicating with the end of the cylinder farthest from the piston, is uncovered to the exhaust by the amount of the inside lead, which, as there is no inside lap, is also $\frac{1}{16}$th of an inch. Here the centre of the crank is seen in a position at right angles to the piston rod and below it. In fig. 2, the crank has performed one-eighth of a revolution, and both the steam ports are partially open, the one for the admission of steam and the other for its egress. The centre of the eccentric has moved on in the same direction; but notice in every case that the crank moves on in advance of the eccentric, which is the very reverse of what would take place if there were no rocking shaft. In all cases now the crank of the slide rod is in advance of the larger crank. In fig. 3, one-fourth of a revolution has been accomplished, and both ports are fully uncovered. In fig. 4, the crank having

FIG. 1.

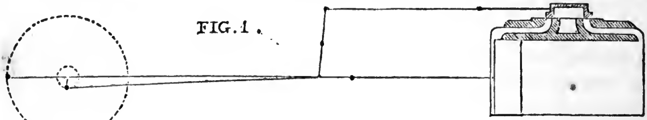


FIG. 2.

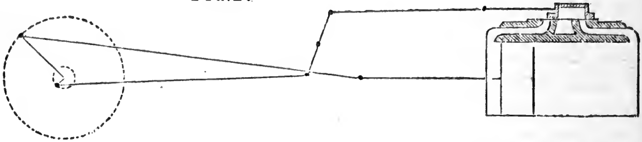


FIG. 3.

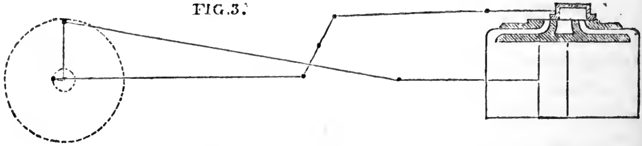


FIG. 4.

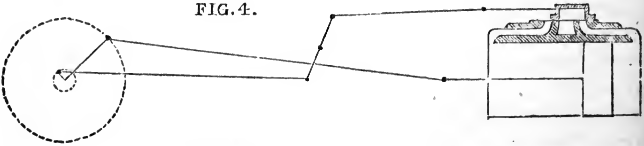
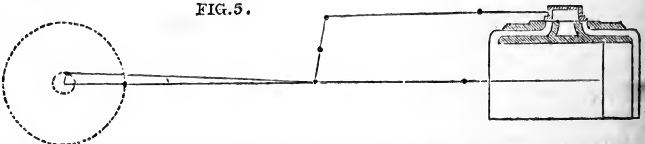


FIG. 5.



made three-eighths of a revolution, the ports are again partially closed, the valve having assumed a position almost similar to that which it occupied in fig. 2. In fig. 5, the piston has reached the end of its stroke, and the steam port, which has hitherto been receiving steam, is uncovered $\frac{1}{16}$th of an inch on the exhaust side, the other steam port being entirely closed."

310. Temperature of Furnace Gases.—The heat transmitted by a solid body from a hotter medium to a colder one, is in direct proportion to the difference of the temperature of the two. The evaporation by any given heating surface will therefore be increased as the temperature of the furnace gases increases. Hence it is that coke is superior to coal, for its products of combustion come off at a higher temperature than those of wood or coal. In this matter we must consider the boiler temperature as the lower. It is not a fact that the greater the pressure of steam the less the evaporative power of the boiler, for the gases in this case simply escape at a higher temperature, and the pressure has nothing to do with the transmission of heat.

311. Time of Contact.—The transmission of heat is not alone directly proportional to the *extent of heating surface* and *the temperature of the furnace gases*, but also to the time of contact and the *conducting power of the solid metal in contact.* In a locomotive, as the gases run along the tubes their temperature rapidly diminishes; small tubes with the blast make the gases move rapidly, with larger ones they move more slowly in inverse proportion. Products of combustion always take the nearest and shortest way to the chimney. Hence many different arrangements are adopted to keep these gases in contact with the heating surface, as inclining the fire box and tubes, making the distance greater from the back of the fire box to the tubes, than from the front part of the grate to the tubes. In this latter arrangement the great bulk of the air, being drawn in at the front end of the grate, would pass through the lowest row of tubes, because it is the shortest route, and here meets with least resistance. The grate is inclined towards the front of the fire box; to counteract this by equalizing the distance, more fuel is thrown on the front of the grate, for the air, entering at the front to pass through, is thus retarded.

312. Specific Heat Transmitting Power.—We have to consider (1) the way in which the boiler plates and tubes receive the heat; (2) the conducting powers of the metal; (3) the emission of heat by the metal.

Let A = the *absorbing unit*, or the heat absorbed by one square inch of boiler surface per minute in a locomotive.

Let B = the *unit of conducting power*, or the heat transmitted through the boiler surface on a square inch per minute through the *thickness of one inch.*

Let C = the *emission unit*, or the quantity of heat given up by one square inch per minute to the water in contact.

Let t = thickness of the plate; then while A and C will remain constant, B must be divided by t, for the quantity of heat transmitted or conducted by the metal is inversely proportional to the thickness of the boiler plate.

Suppose the heat within the fire box to be given off in constant quantities, the plate will soon come to a stationary temperature, and all the heat absorbed by it will be instantly transmitted to the water, when the following equation will exist :—

$$A = \frac{B}{t} = C = H \text{ (say total heat transmitted).}$$

Taking the reciprocals

$$\therefore \frac{1}{A} = \frac{t}{B} = \frac{1}{C} = \frac{1}{H}$$

$$\therefore \frac{1}{A} + \frac{t}{B} + \frac{1}{C} = \frac{3}{H}$$

$$\therefore H = \frac{3}{\frac{1}{A} + \frac{t}{B} + \frac{1}{C}}$$

This equation shows three things :—

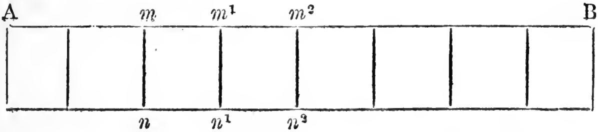
(a) That the heat-transmitting power of a boiler plate increases with the heat absorbing, conducting, and emitting power, (b) and decreases with its thickness, (c) but the heat transmitting power is *not inversely* proportional to the thickness of the plate.

In practice, it is not the thickness of the metal that is of importance in the conduction of heat, but the heat transmitting *capabilities of the surface.* The boiler plates become coated with rust or oxide of iron and soot on one side, and scales on the other; these lessen the absorbing and emitting power of the boiler surfaces. Hence it is that thick plates have but little influence, although thin plates with clean surfaces will give the greater evaporative effect. Again, thick boiler plates are objectionable, because they get hotter on the outside next the fire than inside, hence burn, and their liability to become injured by excessive heating is well known.

313. Transmission of Heat, with Decreasing Temperature of the Furnace Gases, or Transmission of Heat in Tubes.—In showing that

$$H = \frac{3}{\frac{1}{A} + \frac{t}{B} + \frac{1}{C}}$$

we assumed that, during the time of contact, the temperature of the furnace gases remained constant. This condition only exists over very small areas of the boiler plate, in tubes as the gases pass along, we must consider that the temperature diminishes.



Let this represent a boiler tube surrounded with water, and through which the gases pass.

Let us suppose $n\,m$ is a very small section taken at any particular place.

Let G = the quantity of gas in pounds passing $m\,n$ per minute.

Let t = the temperature of the gases at $m\,n$ above the water in the boiler, which depends upon the distance of $m\,n$ from A.

Let x = the distance from $m\,n$ to $m^1\,n^1$.

After passing through the small space $n\,m^1$, the gases will have lost a certain amount of heat, which will be in proportion to the length of $m\,m^1$ and the difference between the temperature of the gases and water.

Suppose we take for the unit of absorption, the heat which would be absorbed on one inch in length in one minute from gases 1° hotter than the surrounding water.

Then the heat absorbed by the small space $n\,m^1$ is

$$H_1 = x\,t \text{ (units of absorption).}$$

Let the gases pass through the next small space $n^1 m^2 = x$, then since the loss of temperature is proportionate to the distance they travel, they enter $n^1 m^2$ with a temperature $t_1 = t - tx = t(1-x)$ $\therefore$ heat taken by second length will be equivalent to

$$\begin{aligned} H_2 &= (t - xt)\,x = tx - x^2 t, \text{ and} \\ t_2 &= t_1 - H_2 \\ \therefore\ t_2 &= t - tx - tx + x^2 t \\ &= t - 2tx + x^2 t \\ &= t(1 - 2x + x^2) \\ &= t(1-x)^2 \\ &= \text{temperature when it enters at } m_2\, n_2. \end{aligned}$$

In the third length we shall have

$$\begin{aligned} H_3 &= t(1-x^2)\,x = t(x - 2x^2 + x^3) \\ \therefore\ t_3 &= t_2 - H_3 = t(1-x)^2 - t(x - 2x^2 + x^3) \\ &= t(1-x)^3 \end{aligned}$$

Hence we see the law for the decrease of temperature as the gases pass along the tubes: the temperature falls in a geometric ratio. In passing through the first, second, third, etc., unit of length, the temperature falls in proportion to $1-x$; $(1-x)^2$; $(1-x)^3$, etc.

These numbers are represented by hyperbolic logarithms, thus:—

Let x_m = unit of length from front end of the tube.
,, t_m = the temperature of the gases above the water, less the unit of absorption.
,, x_n = whole length of tube = L
,, t_n = temperature of smoke box.

Then since

$$\frac{\text{Log.}_\varepsilon\, t_m}{\text{Log.}_\varepsilon\, t_n} = \frac{x_m}{x_n} = \frac{1}{L}$$

$$\text{Log.}_\varepsilon\, t_n = L \times \log._\varepsilon\, t_m.$$

314. Coke and Coal Burning in Locomotives.—It is usual to employ coke in locomotives, so that no smoke shall be produced. In coal the three elements of importance in combustion are carbon, hydrogen, and oxygen. Anthracite contains 91·44 per cent. of carbon, 3·46 of hydrogen, 2·58 of oxygen; the rest is nitrogen, sulphur, and ash. Good average coal contains 73·52 per cent. of carbon, 5·69 of hydrogen, and 6·48 of oxygen; the rest as above, ash, etc. Anthracite produces 92·9 per cent. of coke; average coal, 57·8 per cent. A hundred pounds of coal will give out more than a million units of heat, but the products of combustion carry away nearly one quarter of this, and require $246\frac{1}{2}$ lbs. of oxygen for their consumption, or about $1068\frac{1}{2}$ lbs. of atmospheric air; but as all the air cannot be made to give up the whole of its oxygen, the supply required is about $1355\frac{1}{2}$ lbs. The total evaporative power of this 100 lbs. of coal is 858 lbs. of water. We have, in a former page, given a similar estimate. The student must carefully consider the two, and notice where they agree, and how they differ. Both estimates are taken from leading authorities.

315. A Pound of Good Coal will in practice evaporate 7·4 lbs. of water, and its heat is distributed in the following manner:—

7400	units or	62·2	per cent. go to form steam.
2172	,,	18·3	,, are wasted with products of combustion.
2375	,,	19·5	,, are waste.
11947	,,	100	

It is calculated that the combustion of a pound of coke produces 14,000 units of heat, and requires $2\frac{2}{3}$ lbs. of oxygen, or 12 lbs. of atmospheric air, or 160 cubic feet, for its complete combustion The 160 cubic feet become 200 in practice, and theoretically the pound of coke should evaporate 12·16 lbs. of water.

316. One Pound of Coke.—In practice the greatest evaporative power of a pound of coke is $9\frac{1}{2}$ lbs. of water, and its heat is distributed in the following manner:—

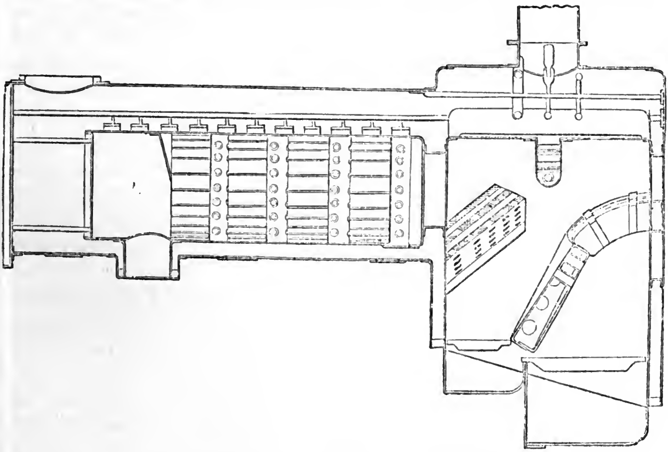
10920	units or	78	per cent.	go to form steam.
2365	,,	$16\frac{1}{2}$	,,	are lost by products of combustion.
715	,,	$5\frac{1}{2}$	,,	are wasted by ashes, etc.
14000	,,	100		

Coke has the advantage over coal as a fuel for locomotives, because the temperature of its products of combustion is considerably higher than that of coal in the proportion of about 14 : 12.

317. Coal Burning.—When coal is burnt in the locomotive furnace, it requires that the air shall be admitted in a peculiar manner to perfect the combustion. As soon as fresh coal is thrown on the fire, a gas is set free which, when mixed with air, burns with a clear bright flame of great heating power. It is therefore of importance that this gas shall at once have its due supply of air at the spot where it is generated, or else the draught will draw it through the tubes, and the heating power will be lost. The air for coal-consuming locomotives is admitted in two ways, partly through the grate, and partly by special contrivances, but the exact quantity depends upon the kind of coal used. An insufficient quantity of air is exhibited by dense black smoke issuing from the chimney. With just enough or too much air no smoke will come out, so it requires great care and practice. A second requisite is necessary for the complete combustion of coal: the temperature should be sufficiently high within the furnace in order to effect the proper combination of the oxygen and carbon. In practice, to prevent smoke in locomotives, engine-drivers have chiefly relied on the ash pan, the damper, and the fire door, with careful firing. "They have endeavoured to prevent the formation of smoke by controlling the admission of air through the grate, and adjusting it precisely to the requirements of the fuel, by similarly manœuvring the fire door for the admission of air above the fuel, by stoking with large pieces of coal and deep fires for heavy duty, and smaller coals with shallow fires for lighter duty, by firing more frequently to lighten the duty, and at all times by keeping the bars covered with fuel to prevent excessive local draughts through the grate." The fire door should be pitched low; fresh coal must be thrown on under the fire door directly inside, and, when partly burned, pushed forward towards the tubes; but when the grates are inclined, it will find its way down by gravitation, and thus with good stoking a very efficient system of coal burning may be carried out. It is the usual practice now not to depend upon the stoking, but to adopt one of these two methods: (1) A current of air is introduced through tubular and other openings in the sides of the fire box, and thus uniformly distributed over the surface of the fuel; (2) a body of air introduced through the doorway is deflected upon and over the surface of the fuel by a baffle plate. Large and spacious fire boxes are also introduced with extensive grate surface. In addition to the above, a third method has found considerable favour. It may be described as follows: A steam-induced current of air is made to pass over the incandescent fuel, thus air currents are admitted just above the fuel by tubes or otherwise through the sides of the fire box, and are then forcibly accelerated by means of jets of steam directed from the outside through the openings into and across the fire box.*

318. Steam Blow Pipe.—The steam blow pipe in a locomotive corresponds to the blast pipe in a marine engine. All engines that consume coal are fitted with the blow pipe or auxiliary jet in the chimney, to continue the draught when the engine is standing, and to assist in getting up the steam when the fire is first lighted.

319. Beattie's Coal Consuming Fire Box.—In this boiler,



BEATTIE'S COAL BURNING BOILER.

designed for the use of coal only, the fire box was divided by an inclined water partition into two compartments, each having its own door, fire grate, ash pan, and damper. The principal fire was maintained in the box nearest the foot-plate. The gases arising from the coals were met by a great

* For a further explanation, see chapter on Combustion and the Prevention of Smoke.

number of fine streams of air entering through the perforated door, and both the gas and air rose through a grating of fire-clay tiles into the upper part of the second fire box, on the grate of which coal was burnt only slowly, with a slight and carefully regulated admission of air through the front damper. The mingling of air and gases was further deflected downwards by a hanging water bridge, and passed over a fire-brick arch and through a series of fire-clay tubes into a combustion chamber, from which the boiler tubes led into a smoke box; most of the arrangements are seen in the figure. In these furnaces, arrangements are made for a sufficient admission of air, for the intimate mixture of the air and gases, and for the maintenance of a high temperature to complete the combustion of the gases. The grating of fire-clay tiles is seen at the lower right hand side of the figure, the hanging water bridge is hanging down from the top of the fire box, the fire-brick arch is seen to the left, the combustion chamber is on the right hand of what looks like the barrel of the boiler, the entrance to which is through a series of fire-clay tubes not shown (as they cannot be without putting the boiler in section).

320. Conclusions and Facts on Combustion in Locomotives.—The following are the practical conclusions as to the combustion of *coke, coal,* and *wood* in a locomotive furnace:—

"1. Successful practice requires the complete combustion of the carbon and hydrogen available in the fuel.

"2. To find the quantity of free carbon and hydrogen, it is necessary to deduct one part by weight of hydrogen, or six parts of carbon from the total contents of the fuel for every eight parts of oxygen contained in the same.

"3. One pound of coke requires about 200 cubic feet of air for combustion: the air may be admitted through the grate only.

"4. One pound of coke is capable of evaporating 9·5 lbs. of water at $15°\frac{5}{9}$ C.; in common practice, its evaporative power is $8\frac{1}{2}$ lbs. of water.

"5. The temperature produced by the combustion of coke in the hottest part of the fire box, may be estimated at 1666°C.

"6. The gases produced by the combustion of coke carry $16\frac{1}{2}$ per cent. of the total heat generated into the smoke box, which they leave at a temperature of 333°C.

"7. The complete combustion of coal requires the admission of air both through and above the grate; the relative proportion and the total quantity of air admitted in both ways depends upon the percentage of gaseous components in the coal.

"8. Insufficient admission of air causes smoke and the loss of heating effect by incomplete combustion. A surplus of air reduces the temperature of flame, and causes waste of heat.

"9. The evaporative duty of coal per pound weight averages about 6 lbs. of water; in regular practice the maximum being about 8 lbs.

"10. The temperature produced by coal in the fire box is lower than that obtained from coke.

"11. The products of combustion from coal have a higher specific heat than those from coke: they carry off a quantity of heat equal to 18·3 per cent. of the total heat produced. This percentage varies with the amount of hydrogen in the coal.

"12. The combustion of coal must be made as nearly uniform as possible by skilful firing.

"13. Coal, when completely and properly burned in a locomotive, affords greater economy, as compared with the coke produced from the same.

"14. The evaporative power of dry pine wood is in practice $2\frac{1}{2}$ lbs. of water, the maximum having been found at 4 lbs. One pound of coke is equivalent to $2\frac{1}{2}$ lbs. of wood.

"15. The temperature produced by wood is generally less than 1111°C."

DIVISION VI.

THE ROAD.

Tramway—Railroads—Curves—How the Carriages are Kept on a Curve—Rails—Fish Joint—Gradients—Ballast—Cuttings and Embankments—How Rails are Laid—Two Ways—Broad and Narrow Gauge—To Adapt one Gauge to the other—Fell's Railway—Turn Tables—Traversers—Switches and Crossings.

321. **The Tram or Tramway** is a roadway consisting of long pieces of wood or iron laid down in lines, and prepared

to receive the wheels of waggons or trams. They were first used in the North of England and South Wales for the convenience of carrying coals from the mouth of the pit to seaport and other towns. The way in which they were originally formed may be thus described: First, pieces of oak, 5 or 6 feet long, called *sleepers*, were laid transversely across the track about two feet apart; next, longitudinal beams or rails, in lengths of 5 or 6 feet, of sycamore or larch, were laid upon these sleepers, and secured to them by wood pins or trenails; next, these longitudinal pieces of wood were supplanted by rails formed of wrought-iron plates, next cast-iron rails were used. The trams were drawn by horses. Some tramways are constructed of hard stone, as granite, for sills, and flat iron bars laid upon them for rails. A good idea of one of the earliest form of rails may be obtained by taking a sheet of paper the size of this sheet; first double down one-third of the page longitudinally, turn over the paper and double down the other side in a similar manner; now stand the two pieces perpendicularly to the middle, one will be above and the other beneath. Imagine that the lower one enters the longitudinal rail, and the middle one lies on and is bolted to it, then the wheels of the carriage must be supposed to run on, or within, the one standing perpendicularly. Each part was about three inches wide, and of iron one inch or three-quarters thick.

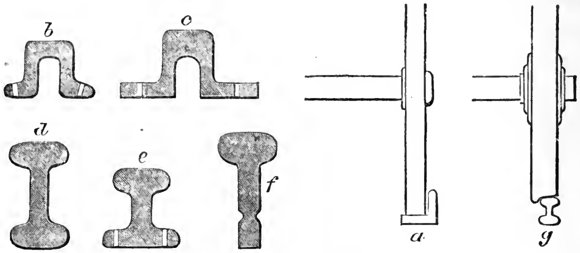
322. Railroad.—Railroads are improved tramways. The London and Birmingham Railway is about 30 feet wide on the embankments, and 33 feet in the cuttings; it is wider in the cuttings, because two drains are necessary, one on each side of the line. The average breadth of formation is 18 feet for a single line, and 28 for a double. Space has to be allowed for fencing and ditching. The width on the narrow gauge lines is 4 feet $8\frac{1}{2}$ inches, as North-Western, South-Western, Eastern Counties, etc., and 7 feet on the broad gauge, Great Western. The space between the two lines of rails is 6 feet 6 inches, and is often spoken of as the "six foot way." The sleepers are laid transversely across the road at a distance of from three feet to three feet six inches apart. To the sleepers are fixed the chairs, which are cast-iron supports for the rails. Sleepers are frequently creosoted, or else kyanized, to resist the action of the atmosphere, water, etc. On the broad gauge system, the line is laid with longitudinal sleepers and bridge rails, but the narrow gauge with cross or transverse sleepers and double-headed rails; the rails in the former case being secured directly on to the longitudinal sleepers, whereas those of the latter are supported by cast-iron chairs secured to the cross sleepers. Longitudinal sleepers have been tried on the narrow gauge system, but have not been found to answer so well as the transverse. At least this is the opinion of some experienced engineers.

Railways are *single* or *double*. The double consist of two lines of rails—a *down* line and an *up* line. The down line leads from London, the up line goes to London. To a person looking towards London, the down line is the right hand pair of rails, the up line the left hand pair. Single lines consist of a single pair of rails used both for the up and down lines. There are double lines at intervals to allow one train to pass another. Lines are constructed on this system for cheapness. The lines should be as level and straight as circumstances will permit.

323. Curves should be of as large a radius as possible; there are but few curves of less than three-eighths of a mile, or 30 chains' radius. The exterior rail of the curve is always elevated — the generic term is *super-elevated*— to counteract the centrifugal force, or otherwise the train might leave the rails. Sharp curves should never be on steep inclines, for the tendency to leave the rails at a curve is as the square of the speed; as a rule, they should be out in the open where they can be well seen, and not in cuttings.

324. How the Carriages are Kept on a Curve.—As an object moves round in a curve, the centrifugal force has a tendency to make it fly off in a straight line. Hence railway carriages, in passing curves, have a tendency to run off the line at the outside. To prevent this, and to keep the flanges of the wheels from the rails, the larger, or outer curve, is raised higher than the inside one, so by this means the carriages are thrown to the opposite side to that on which the centrifugal force would keep them. The *super-elevation* of the outer rail and the conical wheel are thus made to balance the centrifugal force. On the narrow gauge lines, with a wheel three feet in diameter, no super-elevation need be made, unless the curve have a less radius than 1400 feet; on the broad gauge line, with a four feet diametered wheel, the least radius that can be used without super-elevation is double this. The quicker the trains pass a curve the greater must be the elevation of the outer rail.

325. Rails.—The rails are made in many shapes, as seen by the following figures; all these forms are in use, but generally those marked *d* and *c* are preferred. There are many other forms as well as these. At *a* is shown one of the earliest, a plate of iron turned up; the same figure also shows the difference in the arrangement for the running of the wheels on the tramway and railway. At *a* the purpose of

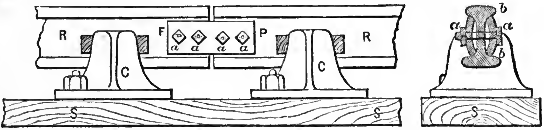


FORM OF RAILS.

one part of the rail is to confine the wheel to the track, and it is evident that much tractive force might be expended in the wheels grating against the rail; but at *g*, the modern arrangement, we see that the wheel is kept on the rail by a flange on the wheel. To the sleepers are fixed the chairs, or chocks, of cast-iron, into which fit the rails, kept in their places by iron spikes. The ends of the rails are secured to each other by a *fish* or *fish plate*, two being used, one on each side, and bolted together by four bolts.

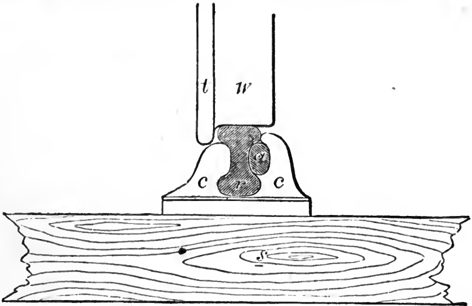
326. Jointing of Rails: The Fish Joint.—The two ends of any two adjoining rails are not placed close together, but a small space is left between for expansion. The joint is obviously the weakest part of the rail. The fish joint is intended to give it stability.

Rails are "fished" by having four holes — *a a a a*— punched in them, and then the fish plate F P is fastened on with four bolts; the holes are larger than the bolts, to allow a slight motion caused by the changes of temperature. The



fishes are made of wrought iron, and bear against the top and bottom of the web of the rail, as seen in the section at *b* and *b*. Close to each fish, on either side, are two chairs, C and C, firmly bolted to the sleepers S S. The fish joint is found to answer so well that its use is extending rapidly.

327. Chair, Sleeper, and Rail.—The following simple figure will show how the rail *r* is fixed in the chair *c c*, by



CHAIR, SLEEPER, AND RAIL.

means of the wedge *a*; it also shows the manner in which the flange *t* of the wheel *W* clears the chair without touching it, and how it runs on smoothly and evenly without the chair offering any resistance or obstruction.

328. Gradients should not exceed *one* foot rise in a *sixty* feet length, although there are gradients double this, or that rise two feet in sixty. Gradients are very expensive, as extra power, which means fuel, time, and labour, is required to ascend them. When very steep, stationary engines are employed to haul up the trains. Gradients should rise, where practicable, on each side towards a station, for then the weight or gravity of the train will assist the brakes in bringing it to a standstill, while, when leaving, such an arrangement will help to set the train moving. On long inclines there are occasionally level spaces, or benches, to assist the ascending and check the descending train. It is not allowable to place a station on an incline.

329. Ballast.—After the railway is cut, and embankments made, the road is covered with broken hard stones, flint, dry gravel, etc., called ballast, upon this the sleepers are laid. The ballast serves two purposes, it allows all water to drain away, and so the sleepers are kept dry; it also keeps them firm and steady.

330. Cuttings and Embankments.—To save expense, the sides of a cutting should be as steep as possible, for then less earth is moved, but this can scarcely ever be done; no general rule can be given as to what slope should be used, everything depends upon the strata that is being cut through, and not alone upon the top strata, but the bottom strata have frequently to be considered. Most kinds of hard rock will stand vertically, chalk requires a slope of one in three, sand and gravel three feet in two, clay two to one; but there are very great exceptions to every rule. The most troublesome cuttings are where soft clay or wet soft strata, come under others that are harder and drier, the soft and wet give way, or else the others slip over them, thus giving an enormous amount of trouble, and adding to the expense of the permanent way.

331. How the Rails are Laid.—Two plans, already mentioned, are followed in laying down rails:—(1) That with longitudinal sleepers, which gives a continuous bearing; (2) that with transverse sleepers, in which the sleepers are laid about three feet apart, and the rails supported on chairs.

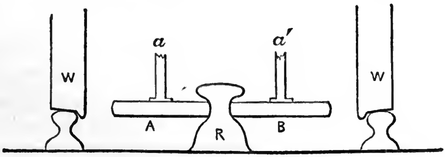
(1) *The Continuous Bearing.*—Here the rails are firmly secured to long baulks of timber laid in parallel lines, each line inclines a little towards the middle. They are kept at the proper distance apart by transverse pieces of timber, the ends of which are let into the baulks, and then secured by angle plates or wrought-iron knee straps. Sometimes these longitudinal sleepers are laid on transverse or cross sleepers, and thus the advantages of both systems are secured.

(2) *The Transverse Sleeper Bearing.*—This is the system that has been most generally adopted. Sleepers of good strong timber, twelve feet long and six or eight inches thick, properly prepared (see page 294), are laid at intervals of about three feet or three feet six; on each sleeper is securely fixed two chairs at the proper distance, in which the rails are firmly fastened, and so kept in their places steadily, and at a continuously equal distance. Formerly, where stone was plentiful, large blocks of stone were used to fix the chairs to, and thus support the rails.

332. Broad and Narrow Gauge.—The *broad gauge* has a distance of *seven feet* between the two rails on which the carriages run, while the narrow gauge rails are 4 feet 8½ inches apart.

333. To Adapt Broad Gauge to Narrow Gauge.—Great interruption and expense are entailed through railways being of a different gauge. Instead of passengers and goods in bulk being conveyed from the starting place to their destination in the same carriage, much trouble and cost are incurred in changing from one line of rails to another. So much is this inconvenience felt, that gradually on the Great Western and other lines a third line of rails is being laid down, so that the inner line of rail and the third serve for the narrow gauge carriages.

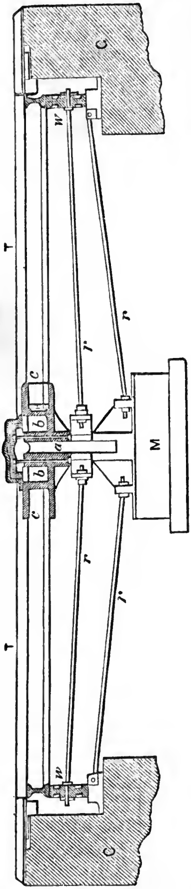
334. Fell Railway.—The progress of railway locomotion has compelled engineers to turn their attention to steep gradients, and how best to drive an engine and its carriages up and down steep inclines. Practically, we have returned to Blenkinsop's rail rack. The first plan proposed was to have a middle rail up the steep incline and a pair of wheels on vertical axes gripping the rail on each side, and which,



by their forcible revolution, would carry up the train where the ordinary driving wheels would slip without effect. Mr.

Fell, for the Mount Cenis Railway, patented a locomotive with horizontal cylinders and two pair of coupled gripping wheels driven direct without the intervention of bevel wheels, the connecting rods that turn the gripping wheels working in a horizontal plane. Powerful springs press the gripping wheels against the centre rail.

W and W are the wheels of the engine, R the middle rail, A and B the gripping wheels, *a* and *a′* their axes.



TURN TABLE.

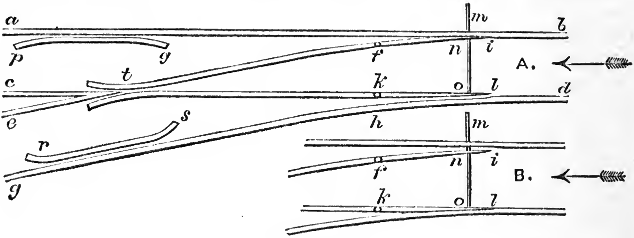
335. Turn Tables.—Turn tables are useful and necessary adjuncts to a terminal station, especially when it is remembered that every engine upon completing a journey has to be turned round; for the engine has to drag the train of passengers and face any danger first. Turn tables are divided into two classes: (1) Those employed to turn the engine and its tender, which of course must be firm and strong, and are generally turned by gearing or hydraulic force; (2) those employed for reversing carriages, which are not so strong, and are worked by hand.

In the annexed figure we have a section of a turn table. T T is the floor for carrying the rails, and on which the engine or carriage stands that has to be reversed. *a* the pivot, and *w w* the wheels or rollers on which the whole turns, and by which it runs round. *a* carries the centre of the floor, and *w w* carry the outside circumference; *r r r r* are stay rods to bind the whole together, and to give strength and stability to the structure. M is the sole or sole plate, resting on a solid foundation; the sole plate and the wheels receive the whole weight of the turn table and whatever is placed on it. C represents solid masonry. Turn tables are required to be strong and steady, and to work with little friction. They are constructed partly of cast-iron, and partly of wrought. In some arrangements the wheels *w w* run similarly to common railway carriage wheels. The whole is bedded on some solid foundation, such as stone or brickwork. Turn tables for engines and tenders have many wheels or rollers, and are made exceedingly strong. They are turned by gearing attached to one of the rollers. The roller path frequently consists of an ordinary flat-footed rail inverted, so as to present its upper table as a bearer to the rollers.

336. Traversers.—By means of a traverser, a carriage can be taken directly across a station from the side of one platform to that of the other. The *traverser* is a convenient and cheap substitute for the turn table, consisting of a low flat table which runs on a line of rails laid transversely to the lines of railway. It is fitted with a line of rails on itself, the rails overhanging at the sides, and are placed as low as possible, so as to just clear the fixed lines. When a carriage is run on to the top of a traverser, a process which is rendered easy by the aid of short incline planes attached to the ends of the table, it is then run or traversed over any number of lines of rails, and then run off and deposited on another line. The wheels of traversers are placed in pairs, one a little behind the other, to enable the traverser to pass the gaps in the traverse rails without shocks.

337. Switches and Crossings.—Switches and crossings, or, as they are more commonly termed, *points* and *crossings*, are used for the purpose of allowing the trains to pass or cross over from one line of rails to the other. Several different methods have been devised for doing this. One of the simplest plans, and that most frequently adopted, is to lay down a short line of rails connecting the other two, and thus establishing the desired communication. It is, however, necessary to have ready and expeditious means of connecting and disconnecting this short line with the main line, according as it is intended that the trains shall leave or continue upon the latter; this is effected by the contrivance termed a *switch*, which is shown in our figure.

a b and *c d* are portions of the rail of the main line, and *e f* and *g h* portions of the short line branching from it. All these parts are immovably fixed in the ordinary manner, with the exception of the two rails *f i* and *k l*. These, which are termed the tongues of the switch or points, are only fixed at one of their ends *f* and *k*, on which they turn as centres; the other ends are tapered away to nearly a point, a slight recess being sometimes cut in the other lines, as at *i* and *l*, into which they fit. These tongues are connected together by a bar *m n o*, by means of which they are preserved at such a distance apart, that when either tongue is in contact with the rail near it, the other shall be removed from the one opposite a sufficient space to allow the engine or



SWITCHES.

carriage wheels to pass between. (Suppose the train to come in the direction of the arrow.) In order to keep the train on the main line, or to leave the same and enter the branch line, it only becomes necessary to move the bar *m n o*. When *m n o*, or the bar which moves the switch, is in the position as shown at A, the carriages will leave the main line; but if shifted into the position shown at B, then they will continue on their course along the main line. It will assist the student to understand what has been said, if he will consider that the flange of the wheel bears against the inside of the rail. It is usual to have the points so arranged that they are kept in the position shown at B (where the main line is not interrupted) by a self-acting weight, the attendance of a pointsman being necessary to move them into the position A, if it is desirable that the train should go off the main line. Two guard rails, *p q* and *r s*, are employed to prevent the flanges of the wheels from striking against the point where the two lines intersect each other at *t*.

DIVISION VII.

THE INDICATOR AND DIAGRAM.

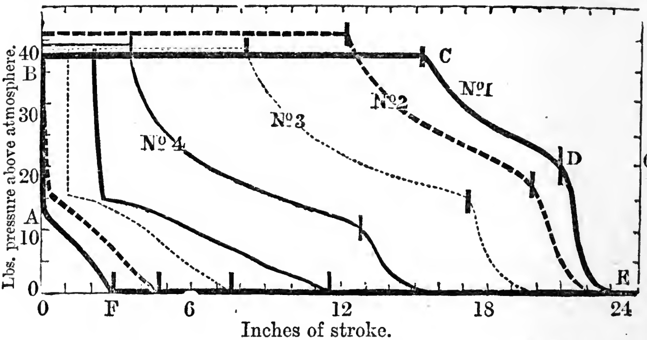
Richard's Indicator — Diagram of Locomotive — Conclusion to be Drawn from Diagrams—Examples of Diagrams—Questions and Examinations.

338. Richard's Indicator, and the slide diagrams given on the marine engines, must be studied and mastered now. In what is here said on the non-condensing or high pressure diagrams of the locomotive, we have supposed the student has mastered the early lesson there given, and that, having some knowledge of the indicator and its action, he is now prepared to study the locomotive diagram.

339. Indicator Diagram of the Locomotive.—The action of the valve in the distribution of steam, as we have already hinted, is regulated by the lap, lead, and travel. When these are given, a diagram will show us at what point of the stroke the steam is admitted, cut off, exhausted, and compressed or shut in. When the link motion is fitted, the steam is cut off earlier by shortening the travel of the slide. This is done in such a manner that, however much the travel of the slide is reduced, the lead is always the same, or at least as at full gear. With the shifting link, it is a little more. When the travel is shortened, not only is the steam cut at an earlier point of the stroke, but it is exhausted earlier, admitted earlier, and the exhaust port is closed earlier during the return stroke. Thus shortening the travel of the slide causes everything connected with the distribution of steam to be done earlier.

No. 1 was taken with the shifting link in full gear in the first notch of the sector, No. 2 in the second notch, etc.

Taking No. 1 first, we must understand that the port began to open for the admission of steam at the point A, about $\frac{3}{16}$ of an inch before the beginning of the steam stroke, the line runs up instantaneously to B in time to commence the steam stroke at the full pressure. While the pencil runs from B to C the steam is at a continuous pressure of 38 lbs., as shown by the scale at the side. At C the steam is suppressed or cut off, and while the piston moves the per-



pendicular distance between C and D ($4\frac{1}{2}$ inches), the enclosed steam expands behind it, rapidly decreasing in pressure, as indicated by the falling line C to D. At D, when the piston has yet to travel the perpendicular distance from D to G, the port is opened to the exhaust, *i.e.*, it is opened when the piston has yet to travel *three* inches, the pressure therefore quickly decreases, as shown by the falling line from D to E. During the return stroke, the steam continues to exhaust into the atmosphere, and the atmospheric line E F is traced; but ordinarily the diagram seldom coincides with the line, as we have it here, for there is a certain amount of back pressure. When the piston gets to F, within three inches of the end of the return stroke, the exhaust port is closed, and the piston continuing its motion, the cushioning takes place, and the pressure of the pent-up steam increases, as shown by the rising curve F to A; when at A the steam is re-admitted, and the curve traced again. We may, following the suggestion of Mr. Colburn, adopt the following terms and points of distinction :—

A is the *point* of admission of the steam.

B to C is the *period* of admission of the steam.

C is the *point* of cut off or suppression.

C to D is the *period* of expansion.

D is the *point* of exhaust or release.

D to E is the *period* of exhaust during the steam stroke.

F is the *point* of compression.

E to F is the *period* of exhaust during the return stroke.

The portion of the stroke described while A B is traced is the period of pre-admission, or during which the *lead* is taking effect.

The portion between F and A is the period of compression or cushioning.

The same definitions apply to all four diagrams, taken with four different notches of the sector.

(1) By considering the diagrams here given, it is obvious that the sooner the port is closed to the admission of steam, the sooner it is opened to the exhaust, as well as the exhaust occupying less time, and also the sooner it is opened to admit steam.

(2) Although every change takes place earlier, there is less difference in the positions of the points of exhaust, cushioning, and admission than in the cut off. Therefore the period of admission being shorter, the period of expansion is longer.

(3) By shifting the link motion, the steam may be cut off at from $\frac{1}{6}$ to $\frac{1}{7}$ of the stroke.

(4) When we increase the expansion, though the exhaust takes place earlier, it never commences within the first half of the stroke.

(5) The period of cushioning, increasing as the admission is reduced, amounts to one-half the stroke at mid gear.

(6) That the lead increases from 1 to 10 per cent. in passing from full gear to mid gear.

Let the student carefully compare these six assertions with the diagrams, and not leave the subject until he has mastered them, when he will have learnt a really useful lesson. We will take *two* and *five*, and try and explicitly restate them.

The period of cushioning, increasing as the admission is reduced, amounts to one-half the stroke at mid gear.

In the first notch, the cushioning is from A to F, or measuring from F to O it is 3 inches. With the second notch it is measured by the thickly dotted line at the corner just above A F, and takes place during $4\frac{3}{4}$ inches of the stroke, reckoning from O along the atmospheric line to where the line starts away from it. The cushioning is longer in the proportion of the line A F and the darkly dotted line near it, or in proportion of 3 to $4\frac{1}{2}$. With the third notch, the cushioning is shown by the fine dotted line at the same left hand corner, and takes place during $7\frac{2}{3}$ inches of the stroke. When at mid gear the cushioning is shown by the line commencing at 12, or it takes place during the last half of the stroke. Thus the cushioning or compression at the

Inches.
1st notch : 2nd : 3rd : 4th : : 3 : $4\frac{3}{4}$: $7\frac{2}{3}$: 12.

Illustrating the second proposition: "Although every change takes place earlier, there is less difference in the positions of the points of exhaust, cushioning, and admission than in the cut off Therefore the period of admission being shorter the period of expansion is longer." The straight horizontal lines along the top of the diagram vary in length, that taken with the first notch being longer than the second, the second than the third, and so on. "The period of expansion is longer, for from C D is shorter than the corresponding line on No. 2, and the one on No. 2 is shorter than the one on No. 3, etc., therefore we see the expansion increases. Again, as regards the first part of the proposition, there is less difference between the four points corresponding to D on the diagrams, than between the four points corresponding to C on the diagrams.

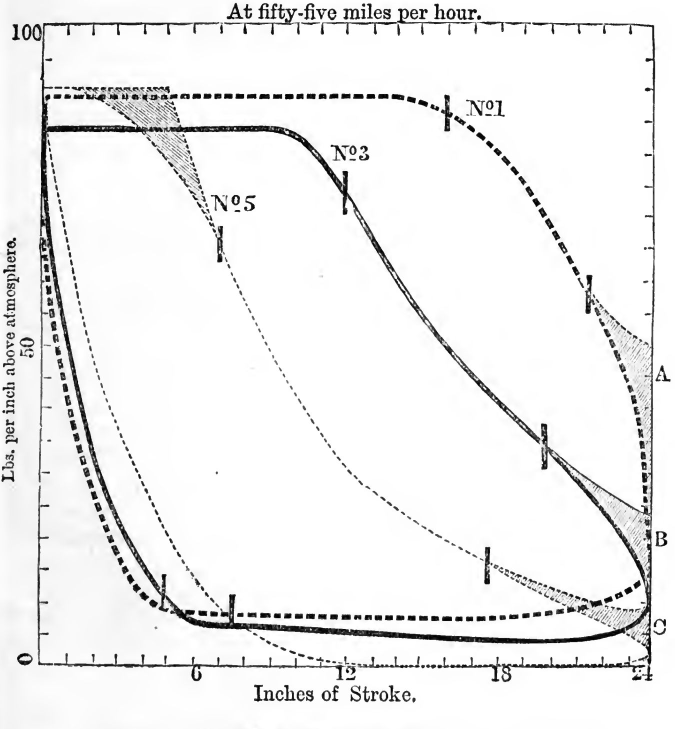
The diagrams show that nearly all the time of the exhaust (D E) is employed for the complete evacuation of the steam, and if this be so for slow speeds, it must be, in a greater degree, the case when the piston is running at ordinary speeds.

The following diagrams were taken when the Great Britain was running at a velocity of 55 miles per hour under the first, third, and fifth notch of the sector.

No.		Lbs.		Lbs.		Lbs.
1.	Mean pressure of steam	80.4,	Exhaust	10.8,	Effective	69.6
3.	,, ,,	62	,,	11.2,	,,	50.8
5.	,, ,,	40.9,	,,	11.5,	,,	29.4

Cylinder 18 by 24, driving wheel 8 feet, lap $1\frac{1}{4}$ inches, travel in full gear $4\frac{3}{4}$ inches, lead $\frac{3}{8}$ inch, blast orifice $5\frac{1}{2}$ inches diameter.

The marks on these diagrams show where the steam is cut off, and where the exhaust commences. The diagrams prove



INDICATOR DIAGRAM FROM GREAT BRITAIN LOCOMOTIVE.

that the steam pressure falls very gradually during the exhaust, especially at high speeds. The mean pressure on the first diagram, by examining the scale and drawing equidistant lines, as shown in the case of the marine diagram, amounts to 80 pounds; now, if we examine the curve at the bottom, we find that the pressure of steam does not descend to the atmospheric pressure, but remains above it, or near the bottom line; by taking the average of these distances from the line, the back pressure is found to be 10·8 pounds, leaving an effective pressure of $80 \cdot 4 - 10 \cdot 8 = 69 \cdot 6$ pounds. The loss yielded by the early exhaust, when the link motion is used, is of no consequence, for an early exhaust, at high speed, is essential to a perfect exhaust during the return stroke.

EXERCISES CHIEFLY FROM EXAMINATION PAPERS.

1. Describe the feed pump and valves necessary for supplying the boiler of a locomotive. What is the principle of Giffard's injector (1869)?

2. How is a locomotive engine reversed by the use of a double eccentric and link motion. What is the object of the sector with notches cut in it, whereby the starting lever can be held in intermediate positions (1869)?

3. State the leading features of Stephenson's invention of the locomotive engine and boiler, pointing out the difficulties which were overcome by this construction (Honours, 1869)?

4. The boiler of a steam engine should be strong enough to support the pressure of steam, the heat of the fire should not be wasted unnecessarily, and a sufficient supply of air should be provided for the burning of the fuel. State particularly the manner in which you would design and set up a boiler so as to fulfil, as nearly as possible, these requirements (Honours, 1871).

5. Describe the general construction of a locomotive boiler. Why is the fire box made of copper? How is it attached to the iron shell which surrounds it? How is the roof of the fire box strengthened (1871)?

6. Describe, with a sketch, the feed pump of a locomotive boiler. What form of valves are used, and for what reason (1871)?

7. What form of packing rings should you prefer for the piston of a locomotive engine? How are the brasses of the connecting rod tightened (1871)?

8. The stroke of the piston of an engine is 24 inches, and the diameter of the driving wheel is 8 feet, what is the mean velocity of the piston when the engine is running at 40 miles an hour (1871)?

At each revolution the wheel goes $8 \times 3 \cdot 1416$ feet.

Forty miles per hour is $40 \times 1760 \times 3$ feet.

$\therefore$ The train moves in feet per minute $\frac{40 \times 1760 \times 3}{60}$

$\therefore$ Number of revolutions of wheel per minute $= \frac{40 \times 1760 \times 3}{60 \times 8 \times 3 \cdot 1416}$

But in each revolution of the wheel the piston moves $2 \times 2 = 4$ ft.

$$\therefore \text{Speed of piston} = \frac{40 \times 1760 \times 3 \times 4}{60 \times 8 \times 3.1416}$$
$$= 560 \text{ feet per minute.}$$

9. How does a railroad differ from a tramroad? Describe the method of supporting rails upon cross sleepers, and of joining them securely (1871).

10. State what you know in respect of the arrangement and construction of springs for the three different purposes for which they are fitted to a passenger carriage, viz., as buffer, draw, and bearing springs (1871).

11. Describe the link motion employed in reversing a locomotive engine. Upon what principle is the power of the engine regulated by the position of the starting lever (1871)?

12. Describe some form of regulation valve for admitting steam into the pipe leading into the cylinders. Where is this valve placed (1871)?

13. Describe, with a sketch, the locomotive boiler. Why is the fire box made of copper? Why is it essential to discharge the waste steam up the chimney (1869)?

14. Describe the safety valve of a locomotive boiler. Explain Bourdon's gauge for ascertaining the exact pressure of the steam in a boiler (1869).

15. Sketch and explain the arrangement of the feed pump and valves connected with it, as fitted to a locomotive boiler (1869).

16. Describe generally the construction of a railroad. How are the tires of the wheels of the carriages shaped, and for what reason? Describe the fish joint (1869).

17. Explain generally the nature of Stephenson's invention of the locomotive engine and boiler. Point out the advantages resulting from this form of construction (1869).

18. The safety valve on the boiler of a locomotive is held down by a lever and spring; sketch the arrangement. A safety valve 4 inches in diameter is constructed so that each pound of additional pressure per square inch on the valve corresponds to 1 lb. pressure on the spring, what are the relative distances of the spring and valve from the fulcrum of the lever? After the valve is set, how much additional pressure per square inch will be necessary in order to lift it $\frac{1}{20}$th of an inch, the spring requiring 10 lbs. to extend it 1 inch (1871)? *Ans.* 2 : 25; ·497 lbs.

19. State the differences in the construction of the driving axle of a locomotive engine when inside or outside cylinders are employed. Mention some of the advantages belonging to either mode of arranging the engine (1871).

20. In driving a locomotive, if the valve gear were reversed before stopping the engine what would occur, and what injury might follow (1871)?

21. Describe generally the locomotive engine and boiler (1870).

22. When two equal and parallel cranks are connected by a link attached to the end of each crank, as in the coupling link which connects two driving wheels in a locomotive, will the rotation of one crank cause the other also to rotate? In what way does this kind of coupling accomplish its object (1870)?

23. Explain the method of reversing a locomotive engine (1870).

24. Describe the safety valve of a locomotive boiler, and the method of adjusting it so as to blow off the steam at different pressures. Explain the principle of any form of steam pressure gauge which you would prefer to use (1870).

25. Explain the importance of balancing the cranks in a locomotive engine. The leading wheel of an engine is $3\frac{1}{2}$ feet in diameter, what would be the pull on the centre of the wheel caused by an unbalanced weight of 9 lbs. upon the rim, when the engine was running at 20 miles an hour (1870)?

$$\text{Centrifugal force} = \frac{\left(\frac{v}{4 \cdot 01}\right)^2}{D} \times 9 = 137 \cdot 5 \text{ lbs.}$$

v = velocity per second.

26. Describe the construction of a locomotive boiler. How is the fire box attached to the barrel of the boiler? In what way is the draught obtained? In a locomotive boiler there are 156 tubes, each 2 inches in diameter and 127 inches long, what amount of heating surface do they give (1870)? *Ans.* 864·4636 square feet.

27. Show with a sketch the method of fitting a safety valve to a locomotive boiler. The safety valve is 5 inches in diameter, and the bearing faces are inclined at 45° to the axis of the valve. What should be the lift in order that the available opening for the escape of steam may be $\frac{7}{10}$ths of a square inch? How do you account for the fact that the pressure in such a boiler may often rise above the amount for which the safety valve is adjusted (1870)?

As the angle is 45°, when raised the lift of the valve is equal to the breadth of the circular space open. Hence if x = diameter of part of valve flush with the opening, we have

$$(5^2 - x^2) \cdot 7854 = \tfrac{7}{10}$$
$$\therefore x = 4 \cdot 91$$
$$\therefore \text{lift} = 5 - 4 \cdot 91 = \cdot 09 \text{ inches, } Ans.$$

28. Show how you would allow for the weight of the lever in adjusting the weight of the safety valve.

29. Explain the principle of construction adopted in a locomotive boiler. How is the crown of the fire box strengthened (1870)?

30. How much air is required for the combustion of 1 lb. of coke? Describe the arrangements for obtaining a sufficient draught of air in a locomotive boiler (Honours, 1870).

31. Describe Giffard's injector, and give some explanation of its action (Honours, 1871).

32. Suppose a train of 60 tons is drawn up an incline of 1 in 100, and the friction is 8 lbs. per ton, find the work due to gravity, friction, and the total power required to draw the train up the incline.

If it rises 1 in 100, the force due to gravity $= \frac{1}{100}$

$$\therefore \text{Force due to gravity on a 60 ton train} = \frac{60}{100} = \tfrac{3}{5} \text{ tons}$$
$$= 1344 \text{ lbs.}$$

Also as friction is 8 lbs. per ton
force due to friction $= 60 \times 8 = 480$ lbs.
∴ Force to draw it up the incline $= 1344 + 480$
$= 1824$ lbs.

33. With what force would it descend the incline?
Force of gravity impels the train downwards $= 1344$ lbs.
,, ,, friction resists this downward motion $= 480$ lbs.
∴ There is left $1344 - 480 = 664$ lbs. to move it down the incline.

34. A stationary engine of 40 horse-power is situated on the top of an incline rising 1 in 6, what weight would it draw up such an incline (disregarding resistance of air) at a velocity of 220 feet per minute? A horse exerts a force of 9 lbs. to move a ton on a level road.

Work of engine per hour $= 40 \times 33000 \times 60$

Rise of incline in a mile $= \frac{5280}{6} = 880$ feet

Work due to gravity in a mile $=$ tons $\times 2240 \times 880$
$= 1971200 \times$ tons (a)
Work due to friction on a mile $=$ tons $\times 9 \times 5280$
$= 47520 \times$ tons (b)

By adding a and b.
∴ Total work on a mile $= 2018720 \times$ tons

Now 220 feet per minute $= \frac{220 \times 60}{5280} =$ miles per hour

∴ Work to be done in one hour $= 2018720 \times$ tons $\times \frac{220 \times 60}{5280}$
$=$ Work of engine per hour

$$\therefore \text{Tons} \times 2018720 \times \frac{220 \times 60}{5280} = 40 \times 33000 \times 60$$

$$\therefore \text{Tons} = \frac{40 \times 33000 \times 60 \times 5280}{2{,}018{,}720 \times 220 \times 60} = 15{\cdot}69 \text{ tons.}$$

Or thus:
Work of engine per hour $= 40 \times 33000 \times 60$

Rise of incline in one mile $= \frac{5280}{6} = 880$ feet

Rate of work $= \frac{220 \times 60}{5280}$ miles per hour

$$\left.\begin{array}{l} \text{Work due to gravity on a ton p. mile} = 2240 \times 880 = 1971200 \\ \text{,, ,, friction ,, ,,} = 9 \times 5280 = 47520 \end{array}\right\} = 2018720$$

$$\text{Total work on a ton per hour} = \frac{2018720 \times 220 \times 60}{5280}$$

∴ Since work on a mile × miles per hour = work of engine

$$\therefore \text{Total number of tons} = \frac{40 \times 33000 \times 60 \times 5280}{2018720 \times 220 \times 60} = 15{\cdot}69.$$

35. An engine is required to draw 20 tons up an incline of *one* in

ten, at a velocity of 300 feet per minute; supposing the resistance due to friction to be 8 lbs. per ton, what is the horse-power of the engine?
Ans. $42\frac{2}{11}$.

36. An engine of 60 horse-power draws 100 tons up an incline at the rate of 12 miles an hour; what is the gradient when friction is 10 lbs. per ton? *Ans.* 1 in 256.

37. Find the horse-power of a locomotive engine which, running 40 miles per hour on a level track, draws a train weighing 70 tons, taking the friction at 8 lbs. per ton, and neglecting the resistance of the air.

$$\text{Distance train moves per minute} = \frac{40 \times 5280}{60} = 3520 \text{ feet.}$$

$$\text{Resistance due to friction} = 70 \times 8 = 560 \text{ lbs.}$$

$$\therefore \text{ Work of friction per minute} = 3520 \times 560.$$

This must equal the horse-power in units of work.

$$\therefore \text{ Horse-power} \times 33000 = 3520 \times 560.$$

$$\therefore \text{ Horse-power} = \frac{3510 \times 560}{33000} = 59{\cdot}56.$$

38. Find the horse-power of a locomotive to run 40 miles per hour, to draw a train of 70 tons, while ascending a gradient of 1 in 500, allowing 8 lbs. for friction, and neglecting the resistance of the air.

From above work of friction per minute = 3520×560.
,, ,, ,, ,, hour = $3520 \times 560 \times 60$
= 118272000

We next show how the work of ascending the gradient is calculated.

$$\text{Rise of incline in a mile} = \frac{5280}{500} = 10{\cdot}56 \text{ feet.}$$

Work due to gravity in a mile = $70 \times 2240 \times 10{\cdot}56$
,, ,, ,, 40 miles = $70 \times 2240 \times 10{\cdot}56 \times 40$
= 66232320.

Total work in one hour = $118272000 + 66232320$
= 184504320

$$\text{Horse-power} \times 33000 \times 60 = 184504320.$$

$$\text{Horse-power} = \frac{184504320}{33000 \times 60} = 93{\cdot}18.$$

39. A locomotive drew a train of 60 tons on a level line of rails at a speed of 50 miles per hour, allowing friction at 8 lbs. per ton, what was the horse-power? *Ans.* 64.

40. With what speed will an engine, whose effective horse-power is found to be 64, draw a load of 60 tons, the rails being laid on a level, and the usual allowance for traction assumed?
Ans. 50 miles an hour.

41. A locomotive engine drew a train of 60 tons at a speed of 50 miles an hour up an incline of 1 foot in 440; if we neglect the resistance of the air and allow 8 lbs. per ton for friction, what was the effective horse-power of the engine? *Ans.* $104\frac{8}{11}$.

42. A locomotive engine of 100 horse-power drew a train of 60 tons at a speed of 50 miles per hour up an incline; allowing 8 lbs. per ton for friction and none for the resistance of the atmosphere, what was the gradient? *Ans.* 1 in 498 nearly.

43. Find the horse-power to draw the train of 100 tons up the incline of 1 in 80 at the rate of 20 miles per hour, allowing 8 lbs. per ton for the friction. *Ans.* 192 H.-P.

44. A train of 75 tons descends an incline of 1 in 400 at the rate of 60 miles per hour; find the horse-power, the friction being 8 lbs. per ton. *Ans.* Horse-power = 28·8.

45. The stroke of an engine is 24 inches, it is making 70 revolutions per minute, and the diameter of the driving wheel is 6 feet; what is the speed of the train.

In one stroke (forward and backwards) the wheel goes round once, or $6 \times 3{\cdot}1416$ feet.

In one minute the train goes $6 \times 3{\cdot}1416 \times 70$ (feet).
,, hour ,, ,, $6 \times 3{\cdot}1416 \times 70 \times 60$ (feet).

$$\therefore \text{ Speed per hour} = \frac{6 \times 3{\cdot}1416 \times 70 \times 60}{5280} = 14{\cdot}994 \text{ miles.}$$

46. What is the speed of the piston?

The speed of the piston is the velocity at which it moves per minute, or the distance it moves in one minute.

In 1 stroke the piston moves $2 \times 2 = 4$ feet.
In 70 strokes ,, ,, $4 \times 70 = 280$ feet.

47. An engine is running at the rate of 29·09 miles per hour, the diameter of the driving wheel being 5 feet, and the stroke of the piston 16 inches; what is the speed of the piston?

The simplest way to solve this question is first to find the number of revolutions of the driving wheel per minute.

Train goes $29{\cdot}09 \times 5280$ feet per hour.

,, ,, $\frac{29{\cdot}09 \times 5280}{60}$,, minute.

Wheel in one turn goes $5 \times 3{\cdot}1416$.

$$\therefore \text{ Wheel turns } \frac{29{\cdot}09 \times 5280}{60 \times 5 \times 3{\cdot}1416} \text{ times per minute.}$$
$$= 163 \text{ nearly.}$$

Since each time the wheel goes round the piston travels
$16 \times 2 = 32 = 2$ feet 8 inches $= 2\frac{2}{3}$ feet.
$\therefore$ Speed of piston $= 163 \times 2\frac{2}{3} = 434\frac{2}{3}$ feet.

48. Suppose the same engine to move at a velocity of 20·34 miles per hour, what is the speed of the piston? *Ans.* 298 feet nearly.

49. The stroke of an engine is 25 inches, the diameter of the driving wheel 6 feet 6 inches, what number of revolutions must it make per minute to give a speed of 40 miles per hour, and what will then be the speed of the piston?

Ans. 172·3 strokes, and 718 feet.

50. The diameter of each of n small cylinders is d, for them the en-

gineer substituted *one* large cylinder; show that the rubbing surfaces or the friction was diminished, the length of the stroke being the same.

Rubbing surface of n small cylinder $= d \times \pi \times l \times n$

Contents of small cylinder $= d^2 \times \frac{\pi}{4} \times l$

,, n ,, cylinders $= d^2 \times \frac{\pi}{4} \times l \times n$

But this is the contents of the large cylinder.

Let D = the diameter of the large cylinder.

$\therefore D^2 \times \frac{\pi}{4} \times l =$ contents ,, ,,

$\therefore D^2 \times \frac{\pi}{4} \times l = d^2 \times \frac{\pi}{4} \times l \times n$

$\therefore D = d\sqrt{n}$

$\therefore$ rubbing surface of large cylinder $= d\sqrt{n} \times \pi \times l$

Hence, considering the friction the same as the rubbing surface,

$$\frac{\text{Friction of large cylinder}}{\text{Friction of small cylinders}} = \frac{d\sqrt{n}\,\pi\, l}{d\,\pi\, l n} = \frac{1}{\sqrt{n}}$$

$\therefore$ by decreasing the number of cylinders we diminish the friction. Suppose *one* cylinder be substitued for *four*, then the friction is diminished one half; for in that case twice the friction of the large cylinder is equal to the friction of the small ones.

51. Required the horse-power of a locomotive engine which moves at a steady speed of n miles per hour on a level railway, the weight of the train being W tons, and the friction $\frac{1}{f}$ of the weight of the train, the resistance of the air not being considered.

The resistance to motion $= \frac{2240 \times W}{f}$

If n be the number of miles per hour the train moves

$\therefore \frac{n \times 5280}{60}$ is the ,, feet ,, min. ,, ,,

$\therefore$ The number of units of work done per min. $= \frac{n \times 5280}{60} \times \frac{2240 \times W}{f}$

$\therefore$ H.-P. $= \frac{n \times 5280 \times 2240 \times W}{33000 \times 60 \times f}$ but $f = 280$ or 8 lbs. per ton.

$$= \frac{n \times 5280 \times 2240 \times W}{33000 \times 60 \times 280}$$

$$\therefore \quad = \frac{128 \times n \times W}{100 \times 60}$$

CHAPTER XVII.

DE PAMBOUR'S THEORY.

Introduction—Work Done on One Square Inch—Horse-Power—The Load—The Pressure—De Pambour's Theory—Relation between the Temperature and Pressure of Steam in Contact with the Water—Relations between the Relative Volumes and Temperatures of Steam—Velocity of Piston under a Given Load and Horse-Power—To Determine the Evaporative Power of a Boiler—Maximum Useful Effect—Examples—Hyperbolic Logarithms.

340. To find the Units of Work Done on a Piston in One Stroke, when the length of the stroke is given, the point of cut-off, and the pressure of steam on admission.

Let l = the length of the stroke in feet

,, q = the distance moved by piston when the steam is cut off

,, p = the pressure at which steam enters the cylinder.

,, s = the number of feet described at any part of the stroke

,, p' = the corresponding pressure

$$\therefore p' : p :: q : s \qquad \therefore p' = \frac{p\,q}{s}$$

Dividing the length of the stroke into an indefinite number of parts, and taking their sum, we must have as near an approximation as possible to the average pressure

$$= \frac{q\,p}{s}\,d\,s$$

Integrating this between the limits l and q, we get

$$\int_q^l \frac{q\,p}{s}\,d\,s = q\,p \int_q^l \frac{d\,s}{s} = q\,p\,(\log. l - \log. q)$$

$$= q\,p \log._e \frac{l}{q}$$

This is the work done by the expanding steam; we must add the work done before expansion if we wish for the total units of work: the work done before expansion is evidently qp.

$$\therefore \text{ Total work} = qp + qp \log._{\varepsilon} \frac{l}{q} = qp \left(1 + \log._{\varepsilon} \frac{l}{q}\right)$$

Let us take an example and show the application of this formula.

Ex.—The length of the stroke of an engine is 6 feet, the steam is cut off at 1 foot, or $\frac{1}{6}$ the stroke, the pressure of steam is 60 lbs. on the square inch when admitted. Find the work done on each square inch of the piston.

We have to substitute in $qp\left(1 + \log._{\varepsilon} \frac{l}{q}\right)$

$$= \tfrac{1}{6} \times 6 \times 60 \left(1 + \log._{\varepsilon} \tfrac{6}{1}\right)$$
$$= 1 \times 60\,(1 + 1{\cdot}791759)$$
$$= 167{\cdot}50554.$$

From this we will proceed and find the horse-power. Given diameter of piston 35 inches, and speed of piston 25 strokes per minute.

$$\text{Area of piston} = 35 \times 35 \times {\cdot}7854$$
$$\text{Units of work done} = 35 \times 35 \times {\cdot}7854 \times 167{\cdot}50554 \times 25$$
$$\therefore \text{ Horse-power} = \frac{35 \times 35 \times {\cdot}7854 \times 167{\cdot}50554 \times 25}{33000}$$
$$= 122{\cdot}09.$$

Rule to find the work done on each square inch of the piston in one stroke:

Divide the length of the stroke by distance moved through by the piston before the steam is cut off, take out the hyperbolic logarithm of this, and to it add *one*, then multiply this sum by the steam pressure, and by the part of the stroke performed before the steam was cut off.

The rule for horse-power is—multiply the area of the piston by the number of strokes, and by the pressure thus found, and divide by 33000.

341. To find the load

Let L = the load on the square inch.

$\therefore$ $L \times l$ = the work done on a square inch in each stroke by the load, and as this must equal the work of the steam

$$\therefore \ Ll = qp\left(1 + \log._{\varepsilon} \frac{l}{q}\right)$$

$$\therefore \ \text{L or Load} = \frac{qp}{l}\left(1 + \log._{\varepsilon} \frac{l}{q}\right)$$

Rule to find the load:

(1) Divide the length of the stroke by the part of the stroke at which the steam is cut off, take the hyperbolic log. of this and add unity to it, then multiply this by the part of the stroke and by the pressure of steam, dividing this result by the length of the stroke we have the load.

Ex.—The length of the stroke is 6 feet, the steam is cut off at 1 foot, the pressure of steam is 60 lbs. on the square inch when admitted; find the load.

Before $\quad qp\left(1 + \log._{\varepsilon} \frac{l}{q}\right) = 167{\cdot}50554 = \text{work done.}$

Dividing this by l we have $\frac{167{\cdot}50554}{6}$

$$\therefore \ \frac{qp}{l}\left(1 + \log._{\varepsilon} \frac{l}{q}\right) \quad . \quad = 27.91759$$

$$= \text{Load.}$$

342. Pressure.—*Given the load, the stroke, point where steam is cut off, to find the* PRESSURE *at which the steam must be admitted.*

$$\text{From formula } \frac{qp}{l}\left(1 + \log._{\varepsilon} \frac{l}{q}\right) = \text{L}$$

$$\therefore p = \frac{\text{L}\, l}{q\left(1 + \log._{\varepsilon} \frac{l}{q}\right)}$$

From which we deduce the following rules to find the pressure of steam:

(1) Multiply the length of the stroke by the load.

(2) Divide the length of the stroke by the part of the stroke, take out the hyperbolic logarithm of this, and add unity to it, multiply this by the part of the stroke.

(3) Divide the quantity obtained in the first rule by that in the second, and the pressure is found.

Ex.—The load of an engine is 28 lbs., the length of the stroke 6 feet, steam is cut off when one foot of the stroke has been performed; required the pressure at which the steam was admitted.

Rule I.

$6 \times 28 = 168$

Rule II.

$6 \div 1 = 6$

Hyperbol. log. $6 = 1{\cdot}7917594$

$1 + 1{\cdot}9717594 = 2{\cdot}7917594$

$2{\cdot}7917594 \times 1 = 2{\cdot}7917594$

Rule III.

$$\frac{168}{2{\cdot}7917594} = 60{\cdot}17 \text{ lbs. pressure.}$$

The horse-power can be also expressed in terms of the same formula.

Let d = the diameter of the cylinder.

„ n = the number of strokes per minute.

$$\therefore \text{H.-P.} = \frac{d^2 \frac{\pi}{4} n q p \left(1 + \log. \frac{l}{q}\right)}{33000}.$$

343. De Pambour's Theory.—Steam on its first admission to the cylinder moves the engine but slowly; the motion gradually accelerates till the engine attains a certain velocity which it does not surpass, the steam being incapable of sustaining a greater velocity. So long as the resistance remains constant, it has to move the same mass. To attain this velocity requires but a short time, and, when reached, the *power* is strictly in equilibrium with the *resistance.* Were the power to vary, the motion must accelerate or retard in proportion. The pressure in the cylinder is less than that in the boiler, therefore the steam changes its pressure in passing from the latter to the former, because in going from the boiler along the pipes to the cylinder, the pressure decreases, or the steam is allowed to expand; in the cylinder also the steam dilates, because the area of the cylinder is larger than the pipes and ports. The area of the cylinder is ten or twenty times that of the pipes. At first the piston does not move; when it does, steam continues to flow in, and the balance is partly restored. As the piston acquires a quicker motion and develops a greater space before the steam, the latter dilates, till in time the piston moves as quickly as it possibly can under the supposed pressure of steam, and equilibrium is established between the moving power and the load or resistance. The pressure in the cylinder can never exceed that of the resistance of the load, and it is clear that the pressure of steam in the cylinder is regulated by the resistance on the piston alone. Therefore, if P′ represent the pressure on each unit of surface, and R the resistance against the piston for each unit of surface, the first equality is established, that

$$P' = R.$$

But as the piston is in motion, the velocity as well as the intensity of the force is to be considered. The rate at which steam is generated in the boiler will obviously affect this velocity, and there is necessarily an equality between the quantity of steam used and that produced. If we let S equal the volume of water evaporated in the boiler in a unit of time, and m the ratio of steam formed under the pressure P in the boiler, then m S will represent the volume of steam generated under the pressure P in a unit of time, this pressure P becomes P′ in the cylinder. But steam in passing from pressure P to P′ will increase its volume in the inverse ratio of the pressures, therefore the volume m S of steam from the boiler will increase in the cylinder to a quantity whose volume

$$= m\,S\,\frac{P}{P'},$$

Now if v is the velocity of the piston and A the area of the cylinder in square feet, therefore A v is the number of cubic feet of steam expended in the cylinder in each unit of time. We therefore get the equality

$$A\,v = m\,S\,\frac{P}{P'},$$

since the production of steam must be equal to the consumption.

But before it was shown that P′ = R, substituting R for P′, the equation stands thus:—

$$A\,v = m\,S\,\frac{P}{R}$$

$\therefore v = \frac{m\,S}{A} \cdot \frac{P}{R}$ which is the velocity of the piston under the resistance R.

$\therefore R = \frac{m\,S\,P}{A\,v}$ which is the resistance with the given velocity v.

$\therefore S = \frac{A\,R\,v}{m\,P}$ which is the evaporative power of the boiler, with a certain load and given velocity.

These equations are sufficient to determine all questions relative to the effect of steam engines. But they have been still further adapted to meet the requirements of different engines under their varying conditions.

344. Relation between the Temperature and Pressure of Steam in Contact with the Water.—Steam generated under the pressure of 15 lbs. per square inch has a volume always 1700 times that of water. If two volumes of steam of the *same weight* be compared, we institute a comparison between their relative volumes; for, being of the same weight, they are produced from the *same quantity of water*. The *relative* volume of steam being the absolute volume divided by the volume of water from which it was produced, the ratio of any two relative volumes of steam is the same as the ratio of their absolute volumes.

When steam remains in contact with the water in the boiler, the same pressure exhibited by the gauge corresponds to the same temperature in the boiler, and the same temperature in the boiler will always give the same corresponding pressure of steam. So, therefore, if we increase the temperature we increase the pressure and density, and we, of course, get the greatest pressure and density that steam can have at that temperature.

But if the steam be taken from the generator and further heated in another vessel, we may increase its pressure or elasticity as we increase the temperature to almost any extent, but the state of greatest density ceases, for there is no water from which to increase its density; also, we may increase the one without augmenting the other. *The constant ratio between temperature and pressure does not exist. This is the great distinction between steam in contact and not in contact with the water.* We can determine the elastic force if we know the temperature when steam is in the boiler, and *vice versa,* but such is not the case when *not* in contact with the water. To determine these pressures and temperatures of steam, when in contact with the water, has required a great number of expensive and delicate experiments. The true *theoretic* law connecting the two has not been ascertained; but several formulæ have been proposed that give the relative connection within certain limits of temperature.

There is a direct relation between the relative volumes and the pressures, as long as the steam is in the boiler or in contact with the water.

We must remember that steam in contact with the water has its maximum density and pressure for that temperature. The formula proposed (for the true theory has not been yet precisely determined) is the following :—

Let p = pounds pressure per square foot,
and v' = the relative volume : then

$$v' = \frac{1}{n + qp}$$

where for condensing engines

$$n = \cdot 00004227$$
$$q = \cdot 000000258$$

while for non-condensing engines

$$n = \cdot 0001421$$
$$q = \cdot 00000023.$$

From this formula the relative volume of steam generated under different pressures can be calculated.

For instance, take two atmospheres 30 lbs., the relative volume for condensing engines will be

$$\frac{1}{\cdot 00004227 + \cdot 000000258 \times 30 \times 144} = 864 \cdot 4.$$

For non-condensing engines we shall have it

$$= \frac{1}{\cdot 0001421 + \cdot 00000023 \times 30 \times 144} = 880 \cdot 5.$$

The volume calculated by the ordinary method is 882.

345. Relation between the Relative Volumes and Temperatures in Steam Taken from the Boiler.—When steam is separated from the water, its temperature may be varied without changing its pressure, or the pressure without altering the temperature. The density increases or diminishes according as the elasticity or temperature is affected.

Mariotte's law is, that if the volume of a given weight of steam be increased, the elastic force diminishes; or if the volume be diminished, the pressure increases; or it is affected in an inverse ratio, *i.e.*, if v and v' be two volumes of the same weight of steam, and p and p' their pressures, then

$$p : p' : : v' : v \quad (a)$$

Hence if $r\,v$ and $r'\,v'$ be their relative volumes, we have by the same reasoning,

$$r\,v : r'\,v' : : p' : p \quad (b)$$
$$v : v' : : r\,v : r'\,v' \quad (c)$$

Gay-Lussac has shown that if the temperature of steam not in contact with the boiler-water be increased in temperature, for every degree centigrade the volume receives an increment of ·00364; the co-efficient of expansion is more correctly ·00366 $= \frac{1}{273}$.

Hence if v and v' be two volumes of the same weight of steam and at the same pressure with the temperatures t and t', and V the original volume,

$$\frac{v}{v'} = \frac{V + V \cdot 00366\,t}{V + V \cdot 00366\,t'} = \frac{1 + \cdot 00366\,t}{1 + \cdot 00366\,t'}$$

Hence from equation (c)

$$\frac{r\,v}{r'\,v'} = \frac{1 + \cdot 00366\,t}{1 + \cdot 00366\,t'}$$

This law cannot, of course, possibly apply to steam in contact with the water, since the pressure varies with the temperature.

346. To Find Pressure of Steam taken from the Boiler.— The formula for the relative volume is—

$$v = \frac{1}{n + q\,p}$$

If we, as before, suppose a volume of water S to be evaporated into steam at a pressure p, whose absolute volume is V, we have—

$$\text{Relative volume} = \frac{\text{absolute vol.}}{\text{vol. of water}} = \frac{V}{S} = v = \frac{1}{n + q\,p}$$

If the same body of steam, by passing into the cylinder, etc., have its pressure changed to p', its volume will alter to, suppose, V′. Then, again, we have—

$$\frac{V'}{S} = \frac{1}{n + qp'} \quad (2) \qquad \text{but } \frac{V}{S} = \frac{1}{n + qp}$$

Dividing (1) by (2)—

$$\frac{V}{V'} = \frac{n+qp'}{n+qp} = \frac{\frac{n}{q} + p'}{\frac{n}{q} + p}$$

so, therefore, the volumes of the steam are *not* in the inverse ratio of the pressures, but in the inverse ratio of the pressures plus the same constant quantity $(\frac{n}{q})$.

Finding p from the equation $\frac{V}{V'} = \frac{n + qp'}{n + qp}$

$$p = \frac{V'}{V}\left(\frac{n+p'q}{q}\right) - \frac{n}{q}$$

$$= \frac{1}{q}\left\{\frac{V'}{V}(n+p'q) - n\right\}$$

We now proceed—

347. To Find the Useful Load when Working Non-Expansively :—

From above $\qquad \frac{V}{S} = \frac{1}{n+qp}$

Let L = the length of the stroke.
c = the clearance.
A = as before, the area of a section of the cylinder.
N = the number of strokes per minute.
∴ L + c is total length of cylinder filled with steam.
A (L + c) is total volume of one cylinder full of steam.
A N(L + c) is the quantity or volume of steam used per minute.

If v be the velocity of the piston in feet per minute

$$\therefore v = N \times L \quad \therefore N = \frac{v}{L}$$

$$\therefore \text{ Steam used per minute } = \frac{v}{L} A(L + c) = \frac{vA(L+c)}{L} = V$$

$$\therefore \frac{V}{S} = \frac{vA(L+c)}{LS} = \frac{1}{n + qp}$$

$$\therefore n + qp = \frac{LS}{vA(L+c)} \qquad (a)$$

but the pressure p must equal the total resistance, which is composed of R the useful load, f the friction of the unloaded engine, α R the addition friction for the loaded engine, and let p' be the pressure of the uncondensed steam.

$$\therefore p = R + \alpha R + p' + f = R(1+\alpha)+p'+f$$

substituting in (a) above

$$n + q\left\{R(1+\alpha)+p'+f\right\} = \frac{LS}{vA(L+c)}$$

solving the equation

$$R = \left\{\frac{LS}{vA(L+c)} - [n+q(p'+f)]\right\}\frac{1}{q(1+\alpha)} \qquad (b)$$

348. To Find the Horse-Power: Working Non-Expansively.—Let the whole resistance = R′, this must equal p in equation a, by substituting R′ for p we get

$$n + qR' = \frac{LS}{vA(L+c)} \quad \therefore \quad R' = \frac{1}{q}\left\{\frac{LS}{vA(L+c)} - n\right\}$$

Multiply each side by A v

$$\therefore AR'v = \frac{\frac{1}{q}\left\{\frac{LS}{L+c} - nAv\right\}}{33000} = \text{H.P.} \qquad (c)$$

or this is the horse-power required.

349. To Find the Velocity of Maximum Useful Effect when Working without Expansion.—This means that we are to find at what speed the engine should run, so that we may get most work out of it.

This velocity will evidently be attained when the pressure of steam in the cylinder becomes equal to that in the boiler, and therefore is equal to p.

From our first equation (a)

$$n + qp = \frac{LS}{vA(L+c)}$$

$$\therefore v = \frac{LS}{A(L+c)} \times \frac{1}{n+qp} \qquad (d)$$

which is the equation required, giving the velocity of maximum useful effect.

350. To Find the Useful Load when Working Expansively.—Taking the same notation as when working without expansion, and letting

l = the length of the stroke traversed when expansion begins, or the distance travelled by the piston before steam is cut off.

Let l' be the distance at any point of the stroke when the steam is expanding and its pressure falls to p'.

Now from what precedes at pressure p the relative volume is $\frac{S}{n + p\,q}$

$$\therefore \text{ At pressure } p' \text{ it is} = \frac{S}{n + q\,p'}$$

$\therefore$ If V is the relative volume at the pressure p and
V′ " " " " " p'

$$\therefore \frac{V}{V'} = \frac{n + q\,p'}{n + q\,p} \quad \therefore\ n + q\,p' = \frac{V}{V'}\,(n + q\,p)$$

$$\text{but } \frac{V}{V'} = \frac{A\,(l + c)}{A\,(l' + c)} \quad \therefore\ n + q\,p' = \frac{l + c}{l' + c}(n + q\,p)$$

$$\therefore\ p' = \frac{l + c}{l' + c}\left\{\frac{n}{q} + p\right\} - \frac{n}{q} \qquad (e)$$

but the pressure may be assumed as constant for a very short space of the stroke $(d\,l')$, and, therefore, the work done while the piston traverses that small distance is =

$$A\,p'\,(d\,l').$$

$\therefore$ The whole work done during expansion must be that given by the following equation, which we must integrate between the limits L and l to obtain the work done during expansion :—

$$A\int_l^L p'\,(d\,l') = A(l + c)\left(\frac{n}{q} + p\right)\int_l^L \frac{(d\,l')}{l' + c} - A\,\frac{n}{q}\int_l^L d\,l'$$

$$= A\,(l + c)\left(\frac{n}{q} + p\right)\log._\varepsilon \frac{L + c}{l' + c} - A\,\frac{n}{q}\,(L - l)$$

but the work done before expansion, which is $A\,p\,l$, must be added to this to give the total work done.

$$\therefore \text{ Whole work} = A\,(l + c)\left(\frac{n}{q} + p\right)\left\{\frac{l}{l + c} + \log._\varepsilon \frac{L + c}{l + c}\right\} - A\,\frac{n}{q}\,L\,(f)$$

but this is, of course, the resistance $= R' \times L$

which from what precedes $= \left\{R\,(1 + \alpha) + p' + f\right\}L$

$$\therefore AL\left\{R\,(1 + \alpha) + p' + f\right\} = A(l + c)\,\left(\frac{n}{q} + p\right)\,C - A\,\frac{n}{q}\,L \qquad (g)$$

where C is substituted for $\frac{l}{l + c} + \log._\varepsilon \frac{L + c}{l + c}$

$$\therefore A\left\{R(1+\alpha)+p'+f\right\}=\frac{A(l+c)}{L}\left(\frac{n}{q}+p\right)C-A\frac{n}{q}$$

$$\therefore R=\frac{1}{1+\alpha}\left\{\frac{l+c}{L}\left(\frac{n}{q}+p\right)C-\left(\frac{n}{q}+p'+f\right)\right\}$$

$$\text{Now }\frac{NA(l+c)}{S}=\frac{L}{n+qp}\quad\therefore n+qp=\frac{LS}{Av(l+c)}$$

$$\therefore R=\frac{1}{q(1+\alpha)}\left\{\frac{SC}{Av}-[n+q(p'+f)]\right\}\qquad(h)$$

which is the useful load when working expansively.

351. To Find the Horse-Power when Working Expansively.—From equation (g) the whole work done in one stroke is

$$A(l+c)\frac{n+qp}{q}C-A\frac{n}{q}L$$

but if we let R' represent the whole resistance

$$\therefore AR'L=A(l+c)\frac{n+qp}{q}C-AL\frac{n}{q}$$

$$\therefore AR'=\frac{1}{q}\left(\frac{SC}{v}-An\right)$$

$$\therefore AR'v=\frac{1}{q}\left(\frac{SC-Avn}{33000}\right)=\text{H.P.}\qquad(i)$$

this equation will give the horse-power when working expansively.

352. To Find the Velocity of Maximum Useful Effect when Working Expansively.—The volume of steam used per minute when working expansively is =

$$V=A(l+c)\,N=\frac{Av(l+c)}{L}$$

$$\therefore\frac{V}{S}=\frac{Av(l+c)}{LS}=\frac{1}{n+qp}$$

$$\therefore v=\frac{1}{n+qp}\left\{\frac{LS}{l+c}\cdot\frac{1}{A}\right\}\qquad(k)$$

where v is the velocity of maximum useful effect required?

353. To Find the Diameter of the Cylinder to Give a Certain Power, etc., when Working Expansively.—Equation (h) was

$$R=\frac{1}{q(1+\alpha)}\left\{\frac{SC}{Av}-Z\right\}\qquad\text{where }Z=n+q(p'+f)$$

Solving this equation we find

$$A = \frac{S\ C}{v \left\{ R\ q\ (1 + \alpha) + Z \right\}} = \frac{\pi}{4} d^2 \qquad (m)$$

from which equation the diameter is known.

354. To Find the Evaporation when Working Expansively.—From the last equation (m)

$$S = \frac{A\ v \left\{ R\ q\ (1 + \alpha) + Z \right\}}{C} \qquad (n)$$

355. To Find the Point at which Steam must be Cut Off to Attain the Maximum Useful Effect.—Since

$$A\ R\ v = \frac{1}{q\ (1 + \alpha)} \left\{ S\ C - [n + q\ (p' + f)] \right\} A\ v$$

$$= \frac{1}{q\ (1 + \alpha)} \left\{ S \left(\log._\varepsilon \frac{L + c}{l + c} + \frac{l}{l + c} \right) - A\ v\ [n + q\ (p + f)] \right\}$$

and v or velocity of maximum useful effect

$$= \frac{S\ L}{A\ (l + c)} \cdot \frac{1}{n + q\ p}$$

substituting this for v in the second member of the equation we get

$$\therefore A\ R\ v = \frac{S}{q\ (1 + \alpha)} \left\{ \left(\log._\varepsilon \frac{L + c}{l + c} + \frac{l}{l + c} \right) - \frac{L}{l + c} \cdot \frac{1}{n + q\ p} \left(n + q\ \overline{p' + f} \right) \right\}$$

Differentiating with respect to l to find the value which makes A R v a maximum, we have

$$\frac{d\ (A\ R\ v)}{d\ l} = \frac{S}{q\ (1 + \alpha)} \left\{ \frac{-l + L \left(\frac{n + q\ \overline{p' + f}}{n + q\ p} \right)}{(l + c)^2} \right\} = 0$$

$$\therefore l = L \cdot \frac{n + q\ (p' + f)}{n + q\ p}$$

We now proceed to apply the equations found. The first three, being of no practical importance, are lightly passed over, as engines do not work without expansion.

In equation f we have $\log._\varepsilon \frac{L + c}{l + c}$

$\text{Log.}_\varepsilon \frac{L + c}{l + c}$ can be found from the common logs. by multiplying by 2·350285 ; thus,

$$\text{Log.}_\varepsilon \frac{L + c}{l + c} = 2{\cdot}302585 \times \text{Log.}_{10} \frac{L + c}{l + c}$$

To save trouble it is customary to give the log. $\frac{L+l}{l+c}$ to the grade of expansion $\frac{L}{l}$ in a table, but it may be observed that it is far better to give the length of stroke, clearance, and cut off—then all that the student has to remember are the values of n and q in the formula $\frac{1}{n+qp}$, instead of burdening his mind with constant logarithms, or employing unnecessary tables.

Equation c gives the horse-power when not working expansively, if we make the proper substitutions for q c, etc., as previously indicated, and dividing by 33000, we have

$$\text{H.-P.} = \frac{3238686{\cdot}5\ S - 555{\cdot}6154\ d^2 v}{33000}$$
$$= 98{\cdot}14\ S - {\cdot}0168\ d^2 v$$

Hence the rule for finding the horse-power when not working expansively.

(1) To the log. of evaporation of number of cubic feet per minute, add log. of 98·14.

(2) Find the natural number of this.

(3) To log. of ·0168 add twice log. diameter in feet, and log. velocity of piston per minute.

(4) Find the natural number corresponding to the sum of this log.

(5) Then subtract the one natural number from the other, the remainder is the horse-power.

We give no practical illustrations of these rules, because no engineers are now so injudicious as to work their engines without expansion.

356. To Find the Evaporation of a Boiler *when we know the horse-power, velocity, and area of piston (not working expansively).*

$$\text{H.P.} = \frac{3238686{\cdot}5\ S - 555{\cdot}6154\ d^2 v}{33000}$$
$$\text{H.P.} = 98{\cdot}14\ S - {\cdot}0168\ d^2 v$$
$$\therefore\ S = \frac{\text{H.P} + {\cdot}0168\ d^2 v}{98{\cdot}14}$$

Equation i gives the horse-power when working expansively.

$$A\,R'\,v = \frac{1}{q}\left(\frac{S\,C - A\,v\,n}{33000}\right)$$

making the proper substitutions, as in page 321, etc., De Pambour's *rule for finding the horse-power* when working expansively becomes

$$\text{H.-P.} = \frac{3399968{\cdot}74\ \text{SC} - 555{\cdot}6154\, d^2v}{33000}$$
$$= 103{\cdot}029\ \text{SC} - {\cdot}0168\, d^2v.$$

Hence we obtained the following rules for finding the horse-power of an engine under this condition:—

(1) To the log. of 103·029 add log. evaporation of cubic feet per minute, and the log. of $\left\{\frac{l}{l+c} + \log._\varepsilon \frac{\text{L}+c}{l+c}\right\}$

(2) Find the natural number corresponding to the sum of the above logs.

(3) To the log. of ·0168 add twice the log. of the diameter in feet, and log. velocity of piston in feet per minute.

(4) Find the natural number corresponding to the sum of these logs.

(5) The difference between the natural numbers found in (2) and (3) will give the horse-power required.

Note.—Log. $\left\{\frac{l}{l+c} + \log._\varepsilon \frac{\text{L}+c}{l+c}\right\}$ must be calculated by itself. We have indicated above how $\log._\varepsilon \frac{\text{L}+c}{l+c}$ may be found, after which no difficulty ought to be found in finding the correct result.

Ex.—The boilers of an engine evaporate 4 cubic feet of water per minute, the diameter of the piston is 6 feet, the length of the stroke 5 ft., and the number of strokes per minute 20; if the steam is cut off at ½ the stroke find the horse-power.

S or evaporation = 4 cubic feet per minute.
Speed of piston = 5 × 2 × 20 = 200 feet per minute.
Let the clearance at each end be 2 inches, then

$$\frac{l}{l+c} + \log._\varepsilon \frac{\text{L}+c}{l+c} = \frac{\frac{1}{2}\text{ of }5}{\frac{1}{2}\text{ of }5+\frac{2}{12}} + \log._\varepsilon \frac{5+\frac{2}{12}}{\frac{1}{2}\text{ of }5+\frac{2}{12}}$$
$$= \frac{15}{16} + \log._\varepsilon \frac{31}{16}$$
$$= {\cdot}9375 + {\cdot}657520$$
$$= 1{\cdot}59502.$$

* Take out log. 31, subtract log. 16 from it, multiply this by 2·302585, will give ·657520.

$$\therefore \text{H.-P} = 103{\cdot}029 \times 4 \times 1{\cdot}59502 - {\cdot}0168 \times 36 \times 200$$
$$= 657{\cdot}5 - 120{\cdot}9$$
$$= 536{\cdot}6$$

Or it may be done thus by logarithms:

Rules I and II.	Rules III and IV.	Rule V.
Log. 103·029 = 2·012958	Log. ·0168 = $\bar{2}$·225309	657·5
Log. 4 = ·602060	Log. dia. 6 = ·778151	120·9
Log. 1·59502 = ·202897	·778151	H.-P. = 536·6, *Ans.*
Log. 657·5 = 2·817915	Log. 200 = 2·301030	
	Log. 120·9 = 2·082641	

Ex.—The boilers of an engine evaporate 270 cubic feet of water per hour, the diameter of each piston is 66 inches, the length of stroke 6 feet, the steam is cut off at 2 feet, and the number of revolutions of the crank is 20, allowing 2 inches for clearance determine the horse-power.

$$\text{S or evaporation is } \frac{270}{60} = 4{\cdot}5 \text{ cubic feet.}$$

Speed of piston is $6 \times 2 \times 20 = 240$ feet per minute.

$$\therefore \frac{l}{l+c} + \log._{\varepsilon} \frac{L+c}{l+c} = \frac{2}{2+\frac{1}{6}} + \log._{\varepsilon} \frac{6+\frac{1}{6}}{2+\frac{1}{6}}$$
$$= \frac{12}{13} + \log._{\varepsilon} \frac{37}{13}$$
$$= {\cdot}923 + 1{\cdot}040276 = 1{\cdot}963276$$
$$\therefore \text{H.-P.} = 103{\cdot}029 \times 4{\cdot}5 \times 1{\cdot}963276 - {\cdot}0168 \times 5{\cdot}5^2 \times 240$$
$$= 910{\cdot}2 - 121{\cdot}9$$
$$= 788{\cdot}3, \textit{ Ans.}$$

Or it may be done thus by logarithms:

Rules I and II.	Rules III and IV.	Rule V.
Log. 103·029 = 2·012958	Log. ·0168 = $\bar{2}$·225309	910·2
Log. 4·5 = ·653213	Log. dia. $5\frac{1}{2}$ = ·740363	121·9
Log. 1·963276 = ·292980	·740363	H.-P. 788·3, *Ans.*
Log. 910·2 = 2·959151	Log. 240 = 2·380211	
	Log. 121·9 = 2·086246	

Equation m gives the area of the piston, and hence its diameter, so that with a certain *evaporation*, *horse-power*, *velocity*, etc., we may find the required dimensions of the cylinder.

$$\frac{\pi}{4} d^2 = \frac{S\,C}{v \left\{ R\,q\,(1+\alpha) + Z \right\}}$$

making the proper substitutions and reducing down we obtain the

$$\text{H.P.} = 103{\cdot}029\ S\ C - {\cdot}0168\ d^2v. \qquad (r)$$
$$\therefore\ {\cdot}0168\ d^2v = 103{\cdot}029\ S\ C - \text{H.P.}$$
$$d = \left(\frac{103{\cdot}029\ S\ C - \text{H.P.}}{{\cdot}0168 \times v}\right)^{\frac{1}{2}}$$

RULE I.—To logarithm of 103·029 add logarithm evaporation of cubic feet per minute, and logarithm C, then take out the natural number.

RULE II.—To logarithm of velocity in feet per minute add log. ·0168, then take out the natural number.

RULE III.—Subtract the horse-power from the number found by Rule I., and divide this by the number found in Rule II., extract the square root of the quotient, and the result is the diameter in feet.

Ex.—The stroke of an engine is 5 feet, number of revolutions per minute 50, horse-power 1600, the evaporation of the boiler 390 cubic feet per hour, the steam is cut off after the first foot of the stroke, allowing the clearance to be $\frac{3}{8}$ of an inch, find the diameter of the cylinder.

The evaporation per minute = 6·5 cubic feet.
The speed of the piston is 5 × 2 × 50 = 500 feet per minute.
Clearance $\frac{3}{8}$ of an inch = $\frac{1}{32}$ of a foot.

C or $\left\{\frac{l}{l+c} + \log._{\varepsilon} \frac{L+c}{l+c}\right\}$ will be the same as in the examples on page 333, we therefore write it down as 2·554636.

$$\therefore\ d = \left(\frac{103{\cdot}029\ S\ C - \text{H.P.}}{{\cdot}0168 \times v.}\right)^{\frac{1}{2}}$$
$$= \left(\frac{103{\cdot}029 \times 6{\cdot}5 \times 2{\cdot}554636 - 1600}{{\cdot}0168 \times 500}\right)^{\frac{1}{2}}$$
$$\therefore\ = \left(\frac{1714{\cdot}74 - 1600}{8{\cdot}4}\right)^{\frac{1}{2}} = 3{\cdot}69,\ Ans.$$

Or thus by logarithms :

RULE I.		RULE II.	
Log. 103·029	= 2·012958	Log. 500	= 2·698970
Log. 6·5	= ·812913	Log. ·0168	= $\bar{2}$·225309
Log. 2·554636	= ·407329	Log. 8·4	= ·924279
Log. 1714·74	= 3·234200		

$$d = \left(\frac{1714{\cdot}74 - 1600}{8{\cdot}4}\right)^{\frac{1}{2}} = \left(\frac{114{\cdot}74}{8{\cdot}4}\right)^{\frac{1}{2}} = 3{\cdot}69 \text{ feet.}$$

Ex.—Find the diameter of a cylinder to give 200 horse-power when the evaporation is 1·09 cubic feet per minute, the length of the stroke 5 feet, and number of revolutions 21, the steam is cut off at $\frac{1}{5}$, and the clearance $\frac{3}{8}$ inch.

The evaporation per minute is 1·09 cubic feet.

" Speed of the piston $5 \times 21 \times 2 = 210$ feet per minute.

" Clearance $\frac{1}{32}$ of a foot

$$C \text{ or } \frac{l}{l+c} + \log._\varepsilon \frac{L+c}{l+c}$$ will be the same as in next example.

We therefore omit this calculation altogether, merely writing it = 2·554636.

Rule I.

Log. 103·029...........	= 2·012958	Log. 210..........	= 2·322219
Log. 1·09................	= ·037426	Log. 0168.........	= $\bar{2}$·225309
Log 2·554636...........	= ·407329	Log 3·528........	= ·547528
Log. 286·888..........	= 2·457713		

$$\therefore\ d = \left(\frac{286 \cdot 888 - 200}{3 \cdot 528}\right)^{\frac{1}{2}} = \left(\frac{86 \cdot 888}{3 \cdot 528}\right)^{\frac{1}{2}} = 4 \cdot 962 \text{ feet.}$$

$$= 5 \text{ nearly.}$$

Equation n gives the evaporation when we know the grade of expansion, horse-power, etc., working expansively.

$$S = \frac{A\,v\left\{R\,q\,(1+\alpha) + Z\right\}}{C}$$

without taking the trouble to substitute, we may find from (r) above.

$$\text{H.P.} = 103 \cdot 029\ S\ C - \cdot 0168\ d^2 v$$

$$\therefore\ S = \frac{\text{H.P.} + \cdot 0168\ d^2 v}{103 \cdot 029\ C}$$

We have, therefore, the following rules for finding the evaporation required to produce given results when the steam is used expansively:—

Rule I.—To log. ·0168 add twice the logarithm of the diameter and the logarithm of the speed of the piston in feet per minute. Take out the natural number.

Rule II.—To log. 103·029 add log. C, found as before, and take out the natural number.

Rule III.—Add the horse-power to the number found by Rule I., and divide the sum by the number found in Rule III. This gives the evaporation per hour.

Ex.—The stroke of an engine is 5 feet, number of revolutions per minute 50, the horse-power 1600, the diameter of piston 42 inches, and the grade of expansion $\frac{1}{5}$, and the clearance $\frac{3}{8}$ of an inch. Find the evaporation.

Velocity of piston is $5 \times 2 \times 50 = 500$ feet per minute.
Clearance $\frac{3}{8}$ of an inch $= \frac{1}{32}$ of a foot.

$$C \text{ or } \left\{ \frac{l}{l+c} + \log._\epsilon \frac{L+c}{l+c} \right\} = \frac{1}{1+\frac{1}{32}} + \log._\epsilon \frac{5+\frac{1}{32}}{1+\frac{1}{32}}$$
$$= \frac{32}{33} + \log._\epsilon \frac{161}{33}$$
$$= \cdot 9697 + 1 \cdot 584936$$
$$= 2 \cdot 554636$$

$$\therefore S = \frac{\text{H.-P.} + \cdot 0168\, d^2 v}{103 \cdot 029\ C.}$$
$$= \frac{1600 + \cdot 0168 \times 3 \cdot 5^2 \times 500}{103 \cdot 029 \times 2 \cdot 554636}$$
$$= \frac{1600 + 102 \cdot 9}{263 \cdot 2} = 6 \cdot 47, \textit{ Ans.}$$

Or by logarithms, which is a much easier method, it is done thus—

Rule I.

Log. ·0168	=	$\bar{2}$·225309
Log. (dia.) $3\frac{1}{2}$	=	·544068
		·544068
Log. 500	=	2·698970
Log. 102·9	=	2·012415

$$S = \frac{\text{H.-P.} + \cdot 0168\, d^2 v.}{103 \cdot 029\ C.}$$

Rule II.

Log. 103·029	=	2·012958
Log. 2·554636	=	·407329
Log. 263·2	=	2·420287

Or Rule III.

$$= \frac{1600 + 102 \cdot 9}{263 \cdot 2} = \frac{1702 \cdot 9}{263 \cdot 2} = 6 \cdot 47 \text{ cubic feet per minute.}$$

Ex.—The diameter of a cylinder is 5 feet, the number of strokes per minute 21, and the stroke 5 feet; if the steam is cut off at 1 foot, find the evaporation, allowing $\frac{3}{8}$ for clearance, the horse-power being 200.

Velocity of piston $= 5 \times 2 \times 21 = 210$ feet per minute.
Clearance $\frac{1}{32}$ feet.

$$\frac{l}{l+c} + \log._\epsilon \frac{L+c}{l+c} = 2 \cdot 554636, \text{ as in the last problem.}$$

Rule I.

Log. ·0168	=	$\bar{2}$·225309
Log. (dia.) 5	=	·698970
		·698970
Log. 210	=	2·322219
Log. 88·2	=	1·945468

Rule II.

Log. 103·029	=	2·012958
Log. 2·554636	=	0·407329
Log. 263·2	=	2·420287

$$S = \frac{\text{H.P.} + \cdot 0168\, d^2 v.}{103 \cdot 029\ C.}$$
$$= \frac{200 + 88 \cdot 2}{263 \cdot 2} = \frac{288 \cdot 2}{263 \cdot 2}$$
$$= 1 \cdot 09 \text{ cubic feet.}$$

Equation k gives the velocity of maximum useful effect, and may be thus applied—

$$v = \left\{ \frac{L\,S}{(l+c)} \cdot \frac{1}{\bar{A}} \right\} \frac{1}{n+q\,p}$$

$$= \frac{S}{d^2 \times \cdot 7854} \times \frac{L}{l+c} \times \frac{1}{n+q\,p}$$

Ex.—The evaporation is $8\frac{1}{2}$ cubic feet per minute, the pressure at which the steam is admitted to the cylinder 31 lbs., the diameter of the cylinder is 7 feet, and the length of the stroke $6\frac{1}{2}$ feet, the steam is cut off at half-stroke. Find the speed of the piston or maximum useful effect Clearance $\frac{1}{32}$ feet.

Evaporation per minute in 8·5 cubic feet.

Clearance, $\frac{1}{32}$ feet. Diameter, 7 feet.

Now

$$v = \frac{S}{d^2 \times \cdot 7854} \times \frac{L}{l+c} \times \frac{1}{n+qp}$$

$$= \frac{8 \cdot 5}{7 \times 7 \times \cdot 7854} \times \frac{6\frac{1}{2}}{3\frac{1}{4} + \frac{1}{32}} \times \frac{1}{\cdot 00004227 + \cdot 000000258 \times 144 \times 31}$$

$$= \frac{8 \cdot 5}{38 \cdot 4846} \times \frac{208}{105} \times \frac{1}{\cdot 00119392}$$

$$= \frac{1768}{4 \cdot 823} = 366 \cdot 4 = \text{No. of revolutions.}$$

Log. 8·5	= ·929419	Log. 38·4846...........	= 1·585286
Log. 208	= 2·318063	Log. 105.................	= 2·021189
	= 3·247482	Log. 00119392..........	= $\bar{3}$·076973
	·683448	....	·683448
Log. 366·4	= 2·564034		

∴ Speed of piston = 366·4 feet per minute.

∴ No. of revolutions: $\frac{366 \cdot 4}{2 \times 6\frac{1}{2}}$ = 28 nearly.

EXERCISES CHIEFLY FROM EXAMINATION PAPERS.

The clearance allowed in finding the answers to the following problems is in all cases $\frac{3}{8}$ths of an inch, which is about the proper quantity. The student must not use the special tables given in some works on steam, for $\frac{l}{l+c} + \log_{\epsilon} \frac{L+c}{l+c'}$, the clearance there allowed is out of all proportion in some cases, and the true relation between L and l is too often a matter of average, instead of proper calculation. In every answer here given, the true quantities have been substituted in the formula last named, and the hyperbolic logarithm used, either taken from a table of hyperbolic logarithms, or calculated by employing the ordinary logarithms as indicated on page 327.

1. Investigate the relation between the useful effect of a steam engine, the evaporation, speed, and area of the piston (1), when the engine is not, and (2), when it is, working expansively (1863).

2. What is meant by the nominal horse-power of an engine? and show how it is determined for paddle-wheel vessels. Find the nominal horse-power when the diameter of the cylinder is $55\frac{1}{2}$ inches, stroke of piston 5 feet, and number of revolutions 21. Find the effective evaporation of the engine whose dimensions are given above, if the horse-power be supposed to be 120 (1863), steam cut off at $\frac{1}{5}$.

Ans. 107·8 and ·6962 cubic feet.

3. Wishing to construct an engine of 250 horse-power, what must be the diameter of the cylinder that the length of the stroke may be 5 feet 10 inches, and the number of revolutions 21 (1863)?

Ans. 78·24.

4. Find the quantity of water evaporated by a boiler if the initial indicator pressure be 16 lbs., the diameter of the piston being 3 feet 6 inches, length of stroke 4 feet, and number of revolutions 25 (1863), steam cut off at $\frac{1}{2}$.

First find the horse-power = 113·72
Next find the evaporation = ·904 cubic feet per minute.

5. Find the nominal horse-power of an engine of the following dimensions:—

Diameter of cylinder .... $53\frac{1}{2}$ inches
Stroke of piston............................ $5\frac{1}{2}$ feet
Number of revolutions.................. 22. *Ans.* 115·44 H.-P.

6. Find the effective evaporation of the engine whose dimensions are given above, supposing the horse-power to be 110·6 (1865), steam cut off at $1\frac{1}{2}$ feet. *Ans.* 82.

7. Given the evaporation of an engine, the speed and area of the piston, investigate an expression for the horse-power (1865).

8. Investigate, according to De Pambour's method, an expression the work done in a condensing engine when working expansively (Honours, 1870).

9. Find an expression for calculating the effective evaporation of a condensing engine of given dimensions and horse-power, the piston moving with a given velocity, when working expansively (1866).

10. In a pair of engines the diameter of the cylinder is 60 inches, length of stroke 4 feet 6 inches, the number of revolutions 63, find the nominal horse-power, and the evaporation of a set of boilers to supply the engines, the steam being cut off at $\frac{1}{3}$ of the stroke (1866).

Ans. 680·4 N H.P.; 2·288 cubic feet.

11. Find the quantity of water evaporated by a boiler, if the initial indicator pressure be 18 lbs., the diameter of the piston 4 feet 6 inches, length of stroke 4 feet, and the number of revolutions 31 (1866), steam cut off at one half stroke. *Ans.* 2·014 cubic feet (H.P. $262\frac{1}{4}$).

12. The diameter of the cylinder of an engine is 56 inches, the stroke of the piston 5 feet, the number of revolutions 33, find the

effective evaporation, the horse-power being 150·8 (1867), steam cut off at $\frac{1}{5}$. *Ans.* 1·031 cubic feet.

13. Investigate a formula for finding the diameter of a cylinder to work at a given speed, knowing the evaporating power of the boiler (1867 and 68).

14. Investigate an expression for the horse-power of an engine (1) working without expansion, (2) with expansion (De Pambour's method), (1867 and 1868).

15. Find the effective evaporation of the boiler for a pair of engines of 750 collective horse-power, the diameter of the piston being 88 inches, the length of the stroke being 5 feet 2 inches, the number of revolutions per minute 60, the steam being cut off at one-fourth of the stroke (1868). *Ans.* 2·714 cubic ft. for each engine.

16. Upon what principles is De Pambour's theory of the steam engine founded? (Honours, 1869).

17. Knowing the evaporation of an engine, the speed and the area of the piston, show how to calculate the horse-power (Honours, 1869).

18. Prove De Pambour's rule for finding the horse-power of an engine, knowing the evaporation, and speed, and area of the piston (1865).

19. What determines the nominal horse-power of an engine? What evaporating power should a boiler have for a pair of engines of 560 collective horse-power, the diameter of the cylinder being 88 inches, length of stroke 5 feet 9 inches, and making 17 revolutions per minute (1865), steam cut off at $\frac{1}{8}$? *Ans.* 1·191 cubic ft. for each.

20. Calculate the work done by the steam in one stroke of the piston, taking clearance into account, the steam being cut off at one-twelfth of the stroke (Honours, 1871).

HYPERBOLIC LOGARITHMS.

1 = ·000000	$4\frac{1}{4}$ = 1·446918	$7\frac{1}{2}$ = 2·014903	6·9 = 1·7917520
$1\frac{1}{4}$ = ·223143	$4\frac{1}{2}$ = 1·504077	$7\frac{3}{4}$ = 2·047692	1·9375 = ·6575042
$1\frac{1}{2}$ = ·405465	$4\frac{3}{4}$ = 1·558144	8 = 2·079441	$\frac{37}{13}$ or
$1\frac{3}{4}$ = ·559615	5 = 1·609437	$8\frac{1}{4}$ = 2·110212	2·846 = 1·060276
2 = ·693147	$5\frac{1}{4}$ = 1·658228	$8\frac{1}{2}$ = 2·140066	3·612 = 1·2842680
$2\frac{1}{4}$ = ·810930	$5\frac{1}{2}$ = 1·704748	$8\frac{3}{4}$ = 2·169053	3·929 = 1·3684170
$2\frac{1}{2}$ = ·916290	$5\frac{3}{4}$ = 1·749199	9 = 2·197224	$\frac{161}{32}$ = 1·5848968
$2\frac{3}{4}$ = 1·011600	6 = 1·791759	$9\frac{1}{4}$ = 2·224623	$\frac{129}{65}$ = ·6854265
3 = 1·098612	$6\frac{1}{4}$ = 1·832581	$9\frac{1}{2}$ = 2·251291	$\frac{185}{24}$ = 2·0423030
$3\frac{1}{4}$ = 1·178654	$6\frac{1}{2}$ = 1·871802	$9\frac{3}{4}$ = 2·277265	
$3\frac{1}{2}$ = 1·252762	$6\frac{3}{4}$ = 1·909542	10 = 2·302585	
$3\frac{3}{4}$ = 1·321755	7 = 1·945910	$\frac{351}{32}$ = 2·395049905	
4 = 1·386294	$7\frac{1}{4}$ = 1·981009		

QUESTIONS.

1. Reduce 39° Fahrenheit to centigrade and 4° C. to F.
Ans. $3^\circ\frac{8}{9}$ C.; $39^\circ\frac{1}{5}$ F.

2. Reduce -12° F. to C., and -12° C. to F. *Ans.* $-24^\circ\frac{4}{9}$ C.; $10^\circ\frac{2}{5}$ F.

3. Reduce 25° R. to F. and C. *Ans.* $88^\circ\frac{1}{4}$ F.; $31^\circ\frac{1}{4}$ C.

4. Express 40° C. as F., and 40° F. as C. *Ans.* 104° F.; $4^\circ\frac{4}{9}$ C.

5. Convert 12° F. to C., and 40° R. to F. *Ans.* $-11^\circ\frac{1}{9}$ C.; 122° F.

6. Express -15° C. in the scale of Fahrenheit. *Ans.* 5° F.

7. In 55 circular inches how many square inches?

A circular inch is a circle having one inch for its diameter,

$\therefore$ 55 circular inches $= 1^2 \times \cdot7854 \times 55 = 43\cdot197$ square inches.

8. Convert 200 square inches to circular inches.

$$200 \text{ sq. in.} = \frac{200}{\cdot7854} = 254\cdot6 \text{ circular inches.}$$

$$\because x \times \cdot7854 = 200 \;\therefore \text{etc.}$$

RULES:

To reduce circular inches to square inches, multiply by ·7854.
To reduce square inches to circular, divide by ·7854.

9. Convert 120 square inches to circular.
Ans. 152·7 circular inches.

10. How many square inches are equivalent to 300 circular inches?
Ans. 235·6 sq. in.

11. A pound of water at 60° C. is mixed with a pound at 100° C., what is the resulting temperature? *Ans.* 80° C.

12. A pound of ice at 0° C. is mixed with a pound of water at 100° C., what is the result? *Ans.* 2 lbs. at 10°·3 C.

To melt the ice will consume 79°·4 C., as this is the latent heat of water. This will leave $100^\circ - 79^\circ\cdot4 = 20^\circ\cdot6$. This residuum will be 2 lbs. of water at a temperature of $\frac{20^\circ\cdot6}{2} = 10^\circ\cdot3$ C., *Ans.*

13. 2 lbs. of ice are mixed with 2 lbs. of water at a temperature of 79°·4 C., what is the result? *Ans.* 4 lbs. of water at 0° C.

14. 9 lbs. of ice are mixed with 10 lbs. of water at 100°C., what is the result? *Ans.* 19 lbs. of water at 15°·02C.

15. What weight of ice at zero must be mixed with 12 lbs. of water at 25°C., in order to cool the water down to 10°C.?

Each pound of ice in liquefaction will consume 79°·4, and as this has to be raised 10°, ∴ each pound of ice requires 89°·4C. Each pound of water will give up 25° − 10° = 15°C.

∴ Total heat to be extracted from the water = 15° × 12 = 180°.

$$\therefore \text{No. of lbs. of ice required} = \frac{180^\circ}{89^\circ{\cdot}4} = 2{\cdot}013 \text{ lbs., } Ans.$$

16. 60 lbs. of ice at 0°C. are mixed with 100 lbs. of water at a temperature of 45°C., will this melt the ice?

Ans. No. It will require 264°C. more.

17. How many pounds of water at the above temperature would have been just sufficient to melt the ice? *Ans.* $105\frac{13}{15}$ lbs.

18. I mix 4 lbs. of ice at 0°C. with 8 lbs. of water at 95°C., what is the resulting temperature? *Ans.* 12 lbs. of water at 36°·8̇6C.

19. How many pounds of ice must I mix with 30 pounds of water at 80°C., so that the result may be water at a temperature of 35°C.? *Ans.* 11·8 lbs.

20. How many pounds of water at 27°C. must be mixed with 2 lbs. of steam at 100°C. to reduce the temperature of the steam to 45°C.?

Latent heat of steam is 537·2.

∴ Each pound of steam has to give up 637°·2 − 45° = 592°·2C.

Each pound of water takes up 45° − 27° = 18°.

$$\therefore \text{No. of lbs. of water to condense 1 lb. of steam} = \frac{592{\cdot}2}{18} = 32{\cdot}9 \text{ lbs.}$$

$$\therefore \quad \text{,,} \quad \text{,,} \quad \text{,,} \quad \text{,,} \quad 2 \quad \text{,,} \quad = 32{\cdot}9 \times 2 = 65{\cdot}8 \text{ lbs.}$$

21. How many pounds of water at 40°C. must be mixed with a pound of steam at 100°C. to convert it into water at the boiling point? *Ans.* 8·95 lbs.

22. How many pounds of water at 50°C. must be mixed with 21 lbs. of steam to condense it, so that the result shall be water at a temperature of 80°C.? *Ans.* 390·04 lbs.

23. The temperature of steam is 100°C., and that of the condensing water 10°C., what will be the proportion of condensing water to steam if the condenser is to be kept at a temperature of 38°C.? *Ans.* 21·4:1.

24. A pound of steam is converted into water by ice at 0°C., how much ice will it just melt? *Ans.* 8·02 lbs.

25. How many pounds of steam at a temperature of 100°C. will be required to melt 40 lbs. of ice at −4°C.?

Each pound of ice consumes 4 + 79·4 = 83°·4 units of heat.

∴ 40 lbs. of ice will require 83°·4 × 40 = 3336° units of heat,

$$\therefore \text{No. of lbs. of steam} = \frac{3336}{637{\cdot}2} = 5.23 \text{ lbs.}$$

26. The temperature of steam is 105°C., and $5\frac{1}{2}$ lbs. of steam melted 42 lbs. of ice, what was the temperature of the water remaining? *Ans.* 4°·15C.

27. What weight of steam at 100°C. is necessary to raise the temperature of 210 lbs. of water from 15°C. to 33°C? *Ans.* 6·25 lbs.

28. A pound of mercury at 40°C. is mixed with a pound of water at 156°C., what is the resulting temperature?

The specific heat of water is 1.
,, ,, mercury ·033.

Hence 1° from the water will raise the mercury $\frac{1}{\cdot 033} = 30°\cdot 3$.

The difference of heat is $156° - 40° = 116°$.

Evidently to find the number of degrees of heat to be added to the 40°, as mercury takes ·033 and water 1, we shall get $\frac{116}{1 + \cdot 033} = 112°\cdot 3$.

∴ The temperature of the mixture will be $40° + 112°\cdot 3 = 152°\cdot 3$.

Or we may reason thus:—

Every 30°·3 given to the water out of the 116° we must add 1° to the mercury, which will raise it 30°·3.

∴ The increase of temperature above the $40° = \frac{116 \times 30\cdot 3}{30\cdot 3 + 1} = 112\cdot 3$.

∴ Temperature = 152°·3, as before.

29. A pound of mercury at 10°C. was mixed with a pound of water at 100°C., the result was found to have a temperature of $97°\frac{1}{8}$ C.; find from this the capacity for heat of mercury.

The temperature of the water was lowered $2°\frac{7}{8}$ C.
,, ,, mercury was raised $87°\frac{1}{8}$ C.;
and since the specific heat of water is 1, we have this proportion—
As $87°\frac{1}{8} : 2°\frac{7}{8} :: 1 : \cdot 033$, *Ans.*

30. A pound of mercury at 160° C. is placed with a pound of water at 20° C., what is the resulting temperature?

Every 30·3 given up by the mercury will only heat the water one degree, as it also requires 1° for itself, the difference (160° − 20°) divided by (30°·3 + 1°) will give what is required.

$$\text{Hence } \frac{140}{31\cdot 3} = 4°\cdot 47$$

Hence resulting temperature is $20° + 4°\cdot 47 = 24°\cdot 47$ C.

31. A pound of mercury at 200° C. is placed with 5 lbs. of water at 20° C., what is the temperature of the mixture?

Ans. 21°·18 C.

32. How much mercury at a temperature of 120° C. will be required to melt 10 lbs. of ice? *Ans.* 200·48 lbs.

33. A pound of iron at 200° C. is put into a pound of water at 10°, both acquire a temperature of 28°·8 C., find the specific heat of iron.

Ans. ·1098.

34. A pound of iron at 500° C. is put into 10 lbs. of water at 24° C., what is the temperature of the water? *Ans.* 29°·34 C.

The specific heat of iron between 0° and 100° C. is ·1098, between 0° C. and 300° C. it is ·1218. In this question we have taken it as ·1138. (See Tyndall *On Heat.*)

35. 12 oz. of iron at 600° C. are placed in 8 oz. of water at 50° C., how much water is converted into steam, supposing no heat lost in the process? *Ans.* ·526 oz.

To leave iron at 100° C. it gives up $500 \times 12 = 6000°$.

To raise water to 100° C. it takes up $50 \times 8 = 400°$.

Specific heat of water is $\left(\frac{1}{\cdot 1138} =\right)$ 8·787 times greater than that of iron.

∴ These 400 units will take $(8{\cdot}787 \times 400)$ of those in the iron, 3514·8 units.

∴ There are left *from the iron* $6000 - 3514{\cdot}8 = 2485{\cdot}2$ units of heat to generate steam.

To find how many units of heat from the iron will convert an ounce of water into steam, we have $537{\cdot}2 \times 8{\cdot}787 = 4720{\cdot}37$ units.

$$\therefore \text{Number of ounces converted into steam} = \frac{2485{\cdot}2}{4720{\cdot}37} = {\cdot}526 \text{ oz. } \textit{Ans.}$$

36. If 16 oz. of iron at 500° C. are placed in 10 oz. of water at 60° C., and the specific heat of iron is considered as ·1138, how much water will be converted into steam? *Ans.* ·611 oz.

37. Suppose 4 lbs. of copper at 210° C. are placed in 2 lbs. of water at 60°, and that the temperature of the water is raised to 84° C., what is the specific heat of copper? *Ans.* ·0952.

38. I heat 40 cubic feet of air from 30° C. to 50°, what is the increase of volume, and what is the present volume?

1 cubic foot on being heated 1° expands $\frac{1}{273}$ of its volume,

∴ 40 ,, ,, ,, $\frac{40}{273}$

∴ 40 ,, ,, 20° ,, $\frac{40 \times 20}{273}$

$= 2{\cdot}93$ cubic feet, ∴ Vol. $= 42{\cdot}93$ cubic feet.

39. 40 feet of gas lose 25° C. of heat, what is the volume remaining?

An approximate answer is obtained by the same method as above.

$$= \frac{40 \times 25}{273} = 3{\cdot}663.$$

$$\therefore \text{Volume remaining} = 40 - 3{\cdot}663 = 36{\cdot}337 \text{ feet.}$$

But if the quantities are large the annexed is a more correct method.

Let $x =$ volume remaining.

If the 25° of heat be applied to x its increase is $\frac{25x}{273}$

$$\therefore x + \frac{25x}{273} = 40$$

$$\therefore x = 36{\cdot}64.$$

40. If 900 feet of air be heated through 75° of heat, what is the increase of volume? *Ans.* 247·2 cubic feet.

41. If 500 feet of gas have their temperature lowered through 60°, what is the volume remaining? *Ans.* 409·9 cubic feet.

42. Suppose the boiling point of water on the summit of Mont Blanc is 85°·14 C., what is the height of the mountain? The boiling point of water decreases 1° C. for every 1062 feet perpendicular height. *Ans.* 15,781 feet.

43. The summit of Monte Rosa is 15,000 feet above the level of the sea, what is the boiling point of water? *Ans.* 85°·88 C.

44. On the 3rd August, 1858, the temperature of the boiling point on the summit of the Finsteraarhorn was 187° F., what may we infer the height of the mountain to be from this fact? *Ans.* 14,750 ft.

The exact height is 14,100 feet; we may account for the discrepancy by the reading of the barometer not being properly taken into account.

45. The specific heat of air is ·237

,, gravity ,, $\frac{1}{770}$.

A cubic foot of water loses 1°C., how many cubic feet of air would this heat 1°C.

The specific heat of water is ($\frac{1}{.237}$=) 4·219 times greater than that of air, ∴ heat will do 4·219 times the work on air it will on water. But as the same weight of air will fill 770 times the same space as the same weight of water, ∴ this cubic foot of water will heat 4·219 × 770 = 3248·6 cubic feet of air.

46. 40 cubic feet of water loses 10° of heat; how much air will this heat 20°? *Ans.* 64972·6 cubic feet.

47. 1,000,000 cubic feet of air *has its* temperature depressed 10°C., of how much water will this increase the temperature 3° if all the heat is communicated to the water? *Ans.* 1026·08 cubic feet.

48. Steam at 24 lbs. pressure is admitted into a cylinder above the piston 50 inches in diameter; find the total pressure on the piston (1) when there is a vacuum below; (2) when the air is freely admitted below. *Ans.* 47124 lbs. : 17671·5 lbs.

49. Steam of 30 lbs. pressure is admitted below a piston 80 inches in diameter, and the atmosphere admitted to the top; find the number of tons pressure to force the piston up. *Ans.* 33·66 tons.

50. Steam of 30 lbs. pressure is admitted (1) to one side; (2) to the other, the diameter is 45 inches, and diameter of piston-rod 5 inches, find the difference between the pressures on the upper and lower side of the piston. *Ans.* 589 lbs.

51. The steam pressure is 40 lbs. per circular inch, what is the pressure in tons on a 36 inch cylinder? *Ans.* 23$\frac{1}{7}$ tons.

52. If the pressure in the last question had been 40 lbs. on the square inch, find the total pressure. *Ans.* 18·1764 tons.

53. If the pressure be 60 lbs. on the square inch, how much is that on the circular inch? *Ans.* 47·124 lbs.

54. The pressure of air is 14·7058 lbs. on the square inch, the specific gravity of mercury is 13596; find the height of a column of

mercury, whose base is one square inch, to correspond with the pressure of the atmosphere.

Let x = height of the column in inches.

$$\text{Weight of 1 cubic inch of mercury} = \frac{13596}{1728} \text{ ounces}$$

$$\therefore \quad ,, \quad x \quad ,, \quad ,, \quad = \frac{13596x}{1728}$$

$$\therefore \frac{13596 \times x}{1728 \times 16} = 14{\cdot}7058$$

$$\therefore x = \frac{14{\cdot}7058 \times 16 \times 1728}{13596} = 29{\cdot}9048 \text{ inches.}$$

55. Answer the same question as above, but substitute pure water for mercury, or assume a cubic foot of water to weigh 1000 ounces. *Ans.* 33·88 feet.

56. Answer the same question, but substitute salt water, the specific gravity of which is 1·0267. *Ans.* 33 feet, nearly.

57. An air pump is 20 inches in diameter, and the length of the stroke 2 feet 3 inches; the engine makes 40 revolutions per minute, and its piston is covered with water at each stroke to the depth of $\frac{2}{3}$ of the stroke; find the number of tons of fresh water lifted in an hour.

Capacity of pump $= 20^2 \times {\cdot}7854 \times 27$.

Quantity raised at each stroke $= 20^2 \times {\cdot}7854 \times 27 \times \frac{2}{3}$.

Quantity raised in an hour $= 20^2 \times {\cdot}7854 \times 27 \times \frac{2}{3} \times 40 \times 60$.

$$\text{Number of cubic feet raised per hour} = \frac{400 \times {\cdot}7854 \times 27 \times 2 \times 40 \times 60}{3 \times 1728}$$

$$\text{Weight of this in tons} = \frac{400 \times {\cdot}7854 \times 27 \times 2 \times 40 \times 60 \times 1000}{3 \times 1728 \times 2240 \times 16} = 219{\cdot}14 \text{ tons.}$$

58. You are required to answer the same question, but suppose it to be a marine engine using salt * water. *Ans.* 224·4 tons.

59. The air pump of a land engine is 24 inches in diameter, its stroke is 20 inches, and it is $\frac{3}{5}$ full at every plunge; find the weight of water lifted in an hour when the engine is making 55 strokes per minute. *Ans.* 289·26 tons.

60. In question 59 we will suppose it to be a marine engine; how many more tons would it have lifted in the time? *Ans.* 6·9427 tons.

61. The air pump of a marine engine is 32 inches in diameter, and is $\frac{3}{4}$ full at each stroke; find the weight of salt water lifted in 6 hours, when the strokes are 50 per minute, and the length of the stroke 4 feet. *Ans.* 8616·96 tons.

62. What must be the diameter of an air pump with a stroke of 39 inches, $\frac{3}{5}$ full at each stroke, and 45 revolutions per minute, to lift 300 tons of salt water per hour? *Ans.* 19·12 inches.

* A cubic foot of salt water weighs 64 lbs., or more exactly, as the specific gravity is 1·0267, it is 64·16875 lbs., but it is customary to call it 64 lbs.

63. An air pump is 15 inches in diameter and $3\frac{1}{2}$ feet stroke, and $\frac{2}{5}$ full at each stroke; what must be the number of revolutions per minute to lift 220 tons of salt water per hour? *Ans.* 74·6,

64. The water level in a boiler is 12 feet below the surface of the sea, (*a*) What is the pressure to force water into it? (*b*) If the pressure of steam is 5 lbs. how high will the water rise?

33 feet of water = 14·7058 lbs. on the square inch.

It will be more convenient to say, in round numbers, that a column of water 33 feet high, gives a pressure of $14\frac{3}{4}$ lbs. on the square inch. The usual rule is to allow 34 feet, but it is evident from question 56 that the correct number is 33 feet when salt water is in question.

(*a*) As 33 : 12 : : 14·75 : $5{\cdot}36\dot{3}$ lbs., *Ans.*

(*b*) When the steam presses with 5 lbs., there is left only $\cdot 36\dot{3}$ lbs. hydrostatic pressure to force in water—

∴ As 14·75 : $\cdot 36\dot{3}$: : 33 : ·812 feet, *Ans.*

65. A boiler or water level in a boiler is 10 feet below the surface of the sea, the pressure in the boiler is 8 lbs. of steam, what is the force acting against hydrostatic pressure in blowing out.

Ans. 3·53 lbs.

66. The bottom of a boiler is 9 feet below the level of the sea, suppose 2 feet of water have entered it, what is the pressure to still force water into it? *Ans.* 3·128 lbs.

67. Water enters a boiler by means of a pipe from a tank, the surface being 35 feet high, what must be the pressure of steam to exactly counteract the pressure of the water? *Ans.* 15·18 lbs.

68. A boiler 5 feet in diameter is fed by an inch pipe, from a head 30 feet above the level of the top of the boiler; find the hydrostatic pressure on each circular inch on the bottom of the boiler when it is full.

Ans. 11·92 lbs.

69. A brine pump is 3 inches in diameter and 13 inch stroke, it makes 15 strokes per minute, how much water will it extract from the boiler in an hour, being $\frac{3}{5}$ full at each stroke?

Ans. 1837·83 lbs.

Capacity of pump, ... $3^2 \times \cdot 7854 \times 13$.
Quantity brine pump lifts at each stroke, $3^2 \times \cdot 7854 \times 13 \times \frac{3}{5}$.
Quantity per hour in lbs., ... $\dfrac{3^2 \times \cdot 7854 \times 13 \times \frac{3}{5} \times 15 \times 60 \times 64}{1728}$

$\doteq 1837{\cdot}836$ lbs.

70. Find the volume of water that will be lifted in 5 hours by a brine pump under the following circumstances: $3\frac{3}{4}$ inches in diameter, length of stroke 12 inches, and 10 strokes per minute, $\frac{4}{5}$ full.

Ans. 153·398 cubic feet.

71. The level of the water in a marine boiler is 10 feet below the surface of the sea, the pressure of steam is 24 lbs., (*a*) What force will the steam have to expel the brine? (*b*) Can it drive out all the water, if water in boiler is 3 feet deep?

Ans. (*a*) 4·78 lbs. (*b*) Yes.

(*a*) At 10 feet deep pressure of water is—

As 33 ft. : 10 ft. : : 14·75 lbs. : 4·469 lbs.

But pressure if column of air is 14·75 lbs.

∴ Total pressure at 10 ft. is = 19·219.

∴ Force to expel brine,...... = 24 − 19·219 = 4·781 lbs.

(*b*) At 3 feet deeper or at 13 feet pressure of water is—

As 33 ft. : 13 : : 14·75 : 5·81 lbs.

∴ Total pressure at 13 ft., = 20·81.

∴ Force to expel brine is = 24 − 20·81 = 3·19 lbs.

72. The surface of the water in a marine boiler is 9 feet below the sea, the steam pressure is $17\frac{1}{2}$ lbs.; when the blow out cocks are opened, will water enter or will the brine be expelled, and what is the force to do this, (1) at the commencement of the action? (2) at the end? How long will it act?

Ans. Water will enter with a pressure of 1·27 lbs., and will continue till it rises 2·84 feet.

73. The pressure in a boiler is 14 lbs. above the atmosphere, what is the force to blow out when the level of the water in the boiler is 8 feet below the surface of the sea? *Ans.* 10·42 lbs.

74. The lever of a safety valve is 16 inches long, and the spindle acts at 4 inches from the fulcrum, the diameter of the valve is 4 inches; find the weight that will allow the valve to begin to act when the steam pressure in the boiler is 45 lbs.

Area of valve,.. $= 4^2 \times \cdot7854$.

Pressure to oppose the atmosphere, ... $= 45 - 15 = 30$ lbs.

Pressure on the valve,.............................. $= 4^2 \times \cdot7854 \times 30$.

Moments of the pressure about the fulcrum $= 4^2 \times \cdot7854 \times 30 \times 4$.

" " weight " " $= W \times 16$.

By the condition of the question these two are equal—

$\therefore W \times 16 = 4^2 \times \cdot7854 \times 30 \times 4$.

$\therefore W = 94\cdot248$ lbs.

75. The lever of a safety valve is 30 inches long, the spindle of the valve acts at 3 inches from the fulcrum, while the diameter of the valve is $3\frac{1}{2}$ inches the weight is 45 lbs., find the pressure of steam above the atmosphere when the valve begins to act.

Area of the valve, ... $= 3\cdot5^2 \times \cdot7854$.

Moments, if pressure is x lbs., $= 3\cdot5^2 \times \cdot7854 \times x \times 3$.

" of weight............ $= 45 \times 30$.

$\therefore 3\cdot5^2 \times \cdot7854 \times x \times 3 = 45 \times 30$.

$$\therefore x = \frac{45 \times 30}{3\cdot5^2 \times \cdot7854 \times 3} = 46\cdot7 \text{ lbs.}$$

76. Find what weight must be attached to the lever of a safety valve 28 inches long, weighing 5 lbs., when the valve is $1\frac{1}{2}$ lbs. weight, with a diameter of 3 inches, and its spindle acting at 4 inches from the fulcrum. Pressure of steam in the boiler being 55 lbs.

Moments of steam acting on valve,............ $= 3^2 \times \cdot 7854 \times 40 \times 4$.
,, valve,.................................. $= 1\frac{1}{2} \times 4$.
,, lever acting at its centre of gravity, $= 5 \times 14$.
,, the weight,.......................... $= W \times 28$.

$$\therefore W \times 28 + 5 \times 14 + 1\tfrac{1}{2} \times 4 = 3^2 \times \cdot 7854 \times 40 \times 4.$$

$$\therefore W = \frac{9 \times \cdot 7854 \times 40 \times 4 - 76}{28} = 37 \cdot 67 \text{ lbs.}$$

77. Find the diameter of a safety valve which acts at $3\frac{1}{2}$ inches from the fulcrum, the arm is 24 inches long, and the weight 80 lbs., and pressure of steam 75 lbs. *Ans.* 3·4 inches.

78. The lever of the safety valve is 26 inches long, the area of the valve 16 square inches, the weight is 75 lbs.; at what distance should the valve spindle act, so that the valve shall lift with a pressure of 55 lbs. of steam? *Ans.* 3·047 inches.

79. The lever of a safety valve is 30 inches long, the diameter of valve $3\frac{1}{2}$ inches, and spindle acts at 3 inches. The weight is 60 lbs., what will be the pressure of steam when it begins to act? *Ans.* 77·3 lbs.

80. Find the weight that must be attached to a safety valve at 21 inches from the fulcrum, when the valve weighs $1\frac{1}{2}$ lbs. and acts at $3\frac{1}{2}$ inches, while its diameter is $3\frac{1}{4}$ inches, the lever of the safety valve weighs 6 lbs., and pressure above the atmosphere is 40 lbs. *Ans.* 52·05 lbs.

81. A $3\frac{3}{4}$ inch valve weighs $2\frac{1}{2}$ lbs., and acts at $4\frac{1}{4}$ inches from the fulcrum, while the pressure is 5 atmospheres and the lever 21 inches long, weighing $6\frac{1}{2}$ lbs.; required the weight that shall just begin to act under these circumstances. *Ans.* 130·35 lbs.

82. The pressure in a boiler is 36 lbs. above the atmosphere on the circular inch, required the weight to be attached to the arm weighing 8 lbs. and 30 inches long, when the 4 inch valve acts at $3\frac{1}{2}$ inches and weighs $3\frac{1}{2}$ lbs. *Ans.* 62·79 lbs.

83. Find the nominal horse-power of an engine of the following dimensions: the diameter of the cylinder is 25 inches, the length of the stroke 3 feet, and the number of revolutions 55. In calculating the nominal horse-power of an engine the pressure is taken at 7 lbs.

Area of piston,.....................	$25^2 \times \cdot 7854$
Pressure on the piston,...........	$25^2 \times \cdot 7854 \times 7$
Number of units of work in one revolution,......................	$= 25^2 \times \cdot 7854 \times 7 \times 3 \times 2$
Number of lbs. lifted 1 foot high per minute,............. Or, number of units of work done per minute,............	$= 25^2 \times \cdot 7854 \times 7 \times 3 \times 2 \times 55$
	$= 1133921 \cdot 25$

It is allowed that a horse can do 33000 units of work per minute, or can lift 33000 lbs. 1 foot high per minute,

$$\therefore \text{H.P.} = \frac{1133921 \cdot 25}{33000} = 34 \cdot 36, \textit{ Ans.}$$

84. The rule for finding the nominal horse-power of an engine is: multiply the square of the diameter by the speed of the piston, and divide the product by 6000. Prove this.

Let d = diameter of the piston,
l = the length of the stroke in feet,
n = the number of revolutions per minute.

The speed of the piston is $= l \times 2 \times n$.

Area of piston $= d^2 \times \cdot 7854$

$\therefore$ Units of work done per minute $= d^2 \times \cdot 7854 \times 7 \times (l \times 2 \times n)$

$$\therefore \text{H.P.} = \frac{d^2 \times 7854 \times 7 \times (l \times 2 \times n)}{33000}$$

$$= \frac{d^2 \times \cdot 7854 \times 7 \times \text{speed of piston}}{33000}$$

$$= \frac{d^2 \times \text{speed of piston}}{6000} \text{ (very nearly)}$$

For $\cdot 7854 \times 7$ will go into 33000 (very nearly) 6000 times.

Hence the rule.

85. Find the horse-power of a direct acting blowing engine, with 4 cylinders, diameters 4 feet, stroke 6 feet 6 inches, pressure 60 lbs., number of strokes per minute 15.

Area of pistons (4),........... $= 48^2 \times \cdot 7854 \times 4$
Speed of piston per min., $= 6\frac{1}{2} \times 2 \times 15$
Total pressure on the pistons,........................ $= 48^2 \times \cdot 7854 \times 4 \times 60$
$\therefore$ Units of work done per minute,..................... $= 48^2 \times \cdot 7854 \times 4 \times 60 \times 6\frac{1}{2} \times 2 \times 15$

$$\therefore \text{H.P.} = \frac{48^2 \times \cdot 7854 \times 4 \times 60 \times 6\frac{1}{2} \times 2 \times 15}{33000}$$

$= 2566 \cdot 28$, *Ans.*

86. A portable engine has two cylinders, with $9\frac{1}{2}$ inch diameters and 14 inch stroke, the pressure of steam at which it is usually worked is 42 lbs., and the number of strokes per minute 60; find the horse-power. *Ans.* 25·25 H.P.

87. A marine engine has four cylinders, each of 50 inches in diameter and 4 feet stroke, the number of revolutions is 52 per minute, and the engine is worked at a pressure of three atmospheres; find the horse-power. *Ans.* 4455·36 H.P.

88. An engine with one cylinder of 3 feet diameter, 5 feet stroke, and 25 revolutions per minute, is worked at a pressure of 30 lbs. on the circular inch; find the horse-power. *Ans.* 294·54 H.P.

89. An engine with two 18 inch cylinders and 2 feet 6 inch stroke is required to do work equal to 150 horse-power, when the number of revolutions is 40 per minute; what should be the steam pressure? *Ans.* 48·6 lbs.

90. What must be the diameter of a cylinder to develop 100 horse-power with 4 feet stroke, 45 revolutions, and 80 lbs. pressure? *Ans.* 12·07 inches.

91. Fine the nominal horse-power of a pair of engines, diameter of cylinder $10\frac{1}{2}$ inches, stroke $1\frac{5}{8}$ feet, number of revolutions 120.

Ans. 14·7 H.P.

92. The diameters of the two cylinders of a marine engine are 60 inches each, the length of the stroke 4 feet 4 inches, and the number of strokes per minute 40; find the nominal horse-power.

Ans. 416 H.P.

93. If the cylinders of a locomotive are 12 inches in diameter, 18 inches stroke, and make 40 strokes per minute, while the pressure is 70 lbs. per square inch; what is the horse-power? *Ans.* 57·57.

94. Steam at 60 lbs. pressure is admitted into a cylinder 6 feet long, and cut off after 2 feet of the stroke have been performed: (1) find the terminal pressure; (2) the average pressure throughout the stroke.

We have always this proportion—

$$\frac{\text{Initial pressure}}{\text{Terminal pressure}} = \frac{\text{Whole stroke}}{\text{Part of stroke}}$$

$$\therefore \frac{60}{x} = \frac{6}{2} \qquad \therefore x = 20$$

Or we may take the following rule for finding the terminal pressure: The terminal pressure is always equal to the initial pressure multiplied by the grade of expansion.

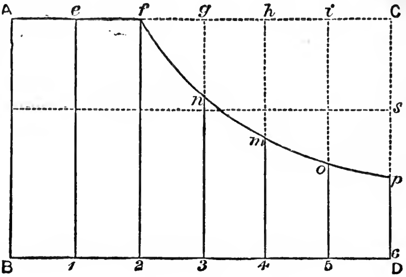
To find the average pressure—

1.	Pressure	during	1st	foot	of stroke	$=60$
2.	,,	,,	2nd	,,	,,	$=60$
3.	,,	,,	3rd	,,	,,	$=\frac{2}{3}\times 60=40$
4.	,,	,,	4th	,,	,,	$=\frac{2}{4}\times 60=30$
5.	,,	,,	5th	,,	,,	$=\frac{2}{5}\times 60=24$
6.	,,	,,	6th	,,	,,	$=\frac{2}{6}\times 60=20$
						6)234
						39 lbs.

The average pressure is therefore 39 lbs.
,, total ,, ,, ,, 234 lbs.
,, terminal ,, ,, as before 20 lbs.

We may also find the steam pressure by Simpson's rule, which is a nearer approximation.

Let A D represent the cylinder in this question, B D the length of the stroke, 6 feet. Let A B represent 60 lbs., then e 1 and f 2 represent 60 lbs. pressure of steam. When the piston gets to g 3, the steam expanding from f to g will fill a space half as large again, $\therefore$ the pressure will be $\frac{2}{3}\times 60=40$ lbs. So take $n\ 3=40$ it will represent the pressure of steam. When the piston gets to h 4, it will fill double the space, $\therefore$ the pressure will be $\frac{1}{2}$ of $60=30$. Let $m\ 4=30$. On the same principle o 5 and p 6 are respectively 24 and 20. Draw the curve through the points, it will represent the falling pressure of steam. The curve itself is an hyperbola. We also see that by giving the steam a great initial velocity, the actual pressure of which is only p 6 or p D, it has been made to do work equivalent to 39 lbs. of steam, or, say, *s* 6. These ordinates, then, now represent our steam pressures. To find their sum we have—



Simpson's Rule: To the sum of the extreme ordinates add four times the sum of the even ordinates and twice the sum of the odd ordinates. This sum, multiplied by one-third the common distance between the ordinates, will give the area (of the figure $f\,p\,D_2$, and therefore the total steam pressure).

$$\text{Area} = \tfrac{1}{3}\left\{60+20+4\,(40+24)+2\times 30\right\} = 132.$$

$$\text{Work done before steam was cut off} = 2\times 60 = 120.$$

$$\therefore\ \text{Total work done} = 132+120 = 252.$$

$$\therefore\ \text{Average work done} = \frac{251\frac{1}{3}}{6} = 42 \text{ lbs.}$$

In the chapter on De Pambour's theory we gave some rules for finding the work done on a piston on one stroke. To show what a near approximation Simpson's rule gives we work the same question by those rules.

$$\text{Units of work done on stroke of piston} = q\,p\left(1+\log._{\epsilon}\frac{l}{q}\right)$$

$$= 2\times 60\left(1+\log._{\epsilon} 3\right)$$

$$= 120 \times 2{\cdot}0986123$$

$$= 251{\cdot}833476$$

95. In a compound twin screw engine steam is admitted into the smaller cylinder 44 inches in diameter, and cut off when $1\frac{1}{2}$ feet of the stroke are performed: the length of the stroke is 4 feet. The steam then enters the larger cylinder, 50 inches in diameter, and in which we will suppose the average pressure is 43 lbs. Find the horse-power when steam at 80 lbs. initial pressure enters the first cylinder. The revolutions are to be 40 per minute.

$$\text{Grade of expansion} = \frac{1\frac{1}{2}}{4} = \tfrac{3}{8}.$$

$$\text{Terminal pressure} = 80\times\tfrac{3}{8} = 30.$$

To find average pressure in the smaller cylinder—

		Lbs.
Work done in the 1st half foot of the stroke		=80
,, ,, ,, 2nd ,, ,, ,,		=80
,, ,, ,, 3rd ,, ,, ,,		=80 (1)
,, ,, ,, 4th ,, ,, ,,	$=\frac{3}{4}\times 80$	=60 (2)
,, ,, ,, 5th ,, ,, ,,	$=\frac{3}{5}\times 80$	=48 (3)
,, ,, ,, 6th ,, ,, ,,	$=\frac{3}{6}\times 80$	=40 (4)
,, ,, ,, 7th ,, ,, ,,	$=\frac{3}{7}\times 80$	$=34\frac{2}{7}$ (5)
,, ,, ,, 8th ,, ,, ,,	$=\frac{3}{8}\times 80$	=30 (6)

By Simpson's rule the total pressure will be*

$$=80\times 3+\tfrac{1}{3}\left\{80+30+4\ (60+40)\ +2\ (48+34\tfrac{2}{7})\right\}$$
$$=240+224\tfrac{6}{7}=446\tfrac{6}{7}.$$

$$\therefore\ \text{Average pressure}=\frac{446\frac{6}{7}}{8}=55\tfrac{6}{7}\text{ lbs.}$$

Although half a foot is the common distance between the ordinates, the relative unit of distance is *one*, so we therefore multiply by $\frac{1}{3}$ and not $\frac{1}{6}$. Consider the stroke as 8 feet, and the reasoning is seen perhaps better.

Secondly, we have the average pressure in the larger cylinder given as 43 pounds. The reason why we assume it so high is, that the vacuum is always exceedingly good in the larger cylinder, and each cylinder is generally arranged so as to give the same horse-power. Of course the steam will enter the second cylinder at about 30 pounds pressure, which, with the vacuum and not cut off, would give something about the pressure we have assumed, namely, 43 lbs.

Thirdly, to find the horse-power developed in each cylinder.

$$\text{H.-P. of smaller cylinder}=\frac{44^2\times\cdot 7854\times 2\times 4\times 55\frac{6}{7}\times 40}{33000}=823\cdot 589$$

$$\text{H.-P. of larger cylinder}=\frac{50^2\times\cdot 7854\times 8\times 43\times 40}{33000}=818\cdot 72$$

$$\therefore\ \text{Total H.-P.}=1642\cdot 309.$$

96. A compound engine has two cylinders of 60 and 90 inches in diameter, the stroke is 5 feet, and the number of revolutions 60 per minute; find the horse-power, pressure being 84 lbs., cut off at one foot in smaller cylinder, and allowing the average pressure to be 23 in the larger cylinder.

The average pressure (to be found by the student) is 44·4 very nearly. *Ans.* 2282·51+2660·36=4942·87 H.-P.

* This is not a case in which Simpson's rule should be applied, as there should properly be an *odd* number of ordinates when the rule is used; but we have ventured to apply it here, as the error cannot possibly amount to more than a very small fraction.

97. Suppose we have a compound engine of the following dimensions, etc., find the H.-P. :—

Diameter of cylinders,	40 in. and 70 in.
Length of stroke,	42 in.
Number of *revolutions*,	40
Initial pressure of steam,	60 lbs.

Steam is cut off in the smaller cylinder at $1\frac{1}{2}$ feet, and we will allow the average pressure to be 20 lbs. in the larger cylinder.

Ans. Pressure is $47\frac{32}{45}$ lbs., say 48 ; horse-power $511{\cdot}79 + 653{\cdot}07 = 1164{\cdot}86$.

98. A stationary engine has a cylinder 24 inches in diameter, the stroke of the piston is 3 feet, pressure 100 lbs., and number of revolutions 80. Find the H.-P. when the grade of expansion is $\frac{1}{3}$.

Ans. 463 or 460·1 H.-P.

99. Find the nominal horse-power of a pair of engines 6 feet stroke, 36 inches in diameter, 46 revolutions. *Ans.* 119·23.

100. In a locomotive engine the steam is cut off at $\frac{1}{4}$ stroke, the length of stroke is 24 inches, the diameter of each cylinder is 15 inches, number of revolutions of crank 50, and initial pressure of steam 80 lbs. ; find the horse-power.* *Ans.* $89\frac{1}{4}$.

101. A blowing engine has 4 cylinders, diameter 40 inches, stroke 5 feet, grade of expansion $\frac{1}{5}$th, number of strokes 18, and pressure of steam 25 lbs. ; find the horse-power. *Ans.* 359·47.

102. A cylindrical boiler with flat ends is 25 feet long, 5 feet in diameter, and has two flues running through its whole length, each 2 feet in diameter ; find the whole pressure of steam on the internal surface of the boiler when the steam gauge stands at 40 lbs.

The surface of the shell is $= 5 \times 3{\cdot}1416 \times 25$.

" " two flues $= 2 \times 3{\cdot}1416 \times 25 \times 2$.

" " " ends $= (5^2 - 2 \times 2^2) \times {\cdot}7854 \times 2$.

$\therefore$ Whole internal surface $= 25 \times 3{\cdot}1416(5+4) + 17 \times {\cdot}7854 \times 2$.

$= 25 \times 3{\cdot}1416 \times 9 + 34 \times {\cdot}7854$.

$= 733{\cdot}5636$ ft.

$$\therefore \text{ Total pressure in tons,} = \frac{733{\cdot}5636 \times 144 \times 40}{2240} = 1866{\cdot}3064 \text{ tons.}$$

103. A cylindrical boiler of 3 feet in diameter, 14 feet long, has an internal tube of $1\frac{1}{2}$ feet diameter. If the steam pressure is 30 lbs., find the whole internal pressure in tons.

Ans. 402·15 tons.

104. A cylindrical boiler is 40 feet long and 8 feet in diameter, it has two internal flues running through its whole length each $2\frac{1}{2}$ feet in diameter. Suppose the water averages a pressure of $1\frac{1}{2}$ lbs. over the whole surface, and the steam $40\frac{1}{2}$ lbs., find the total internal pressure in tons.

Ans. 4629·226 tons.

* Pressure is found as in Ex. 94. Simpson's rule does not apply.

105. In a tubular boiler there are 144 tubes, each $2\frac{1}{4}$ inches in diameter, and 10 feet long, find the amount of heating surface if the heating surface around the fire box be 40 feet.

$$\text{Heating surface of} \quad 1 \text{ tube} = \frac{2{\cdot}25 \times 3{\cdot}1416 \times 10}{12} \text{ feet.}$$

$$,, \quad ,, \quad ,, \; 144 \; ,, \; = \frac{2{\cdot}25 \times 3{\cdot}1416 \times 10 \times 144}{12}$$

$$= 848{\cdot}232 \text{ feet.}$$

To this add surface around the fire box $= 888{\cdot}232$ feet.

106. In a locomotive boiler there are 160 tubes 96 inches long and $1\frac{1}{2}$ inches in diameter, find the total heating surface of the tubes.

Ans. 502·656 ft.

107. Steam is used by an engine at 30 lbs. pressure, and cut off at $\frac{1}{4}$, find approximately the saving per cent. by working expansively.

Let us suppose stroke is 8 feet, we must find (1) terminal pressure, (2) average pressure.

Terminal pressure $= \frac{1}{4} \times 30 = 7\frac{1}{2}$ lbs.

1.	Pressure during	first	foot		30	
2.	,, ,,	second	,,		30	(1)
3.	,, ,,	third	,,	$\frac{2}{3} \times 30$	$=20$	(2)
4.	,, ,,	fourth	,,	$\frac{2}{4} \times 30$	$=15$	(3)
5.	,, ,,	fifth	,,	$\frac{2}{5} \times 30$	$=12$	(4)
6.	,, ,,	sixth	,,	$\frac{2}{6} \times 30$	$=10$	(5)
7.	,, ,,	seventh	,,	$\frac{2}{7} \times 30$	$=8\frac{4}{7}$	(6)
8.	,, ,,	eighth	,,	$\frac{2}{8} \times 30$	$=7\frac{1}{2}$	(7)

$$\text{Total pressure} = 30 \times 2 + \frac{1}{3}\left\{30 + 7\frac{1}{2} + 4\left(20 + 12 + 8\frac{4}{7}\right) + 2\left(15 + 10\right)\right\}$$

$$= 60 + 83\frac{11}{42} = 143\frac{1}{4} \text{ (nearly).}$$

$$\therefore \text{Average pressure} = \frac{143\frac{1}{4}}{8} = 17\frac{29}{32}.$$

Now had steam been admitted throughout the whole stroke, its average would have been 30 lbs.

$\therefore$ Out of 30 there is saved $30 - 17\frac{29}{32} = 12\frac{3}{32}$.

To find gain per cent—As $30 : 100 :: 12\frac{3}{32} : 40\frac{5}{16}$, *Ans.*

There was no necessity to have found the average pressure, we might have reasoned thus:

If steam had been continuously admitted, total pressure would have been $30 \times 8 = 240$. But by expansive working, total pressure $= 143\frac{1}{4}$.

$\therefore$ Out of 240 we gain $240 - 143\frac{1}{4} = 96\frac{3}{4}$.

As $240 : 100 :: 96\frac{3}{4} : 40\frac{5}{16}$, as before.

108. Steam at 50 lbs. pressure is admitted into a cylinder 6 feet long, and cut off at $\frac{1}{3}$ stroke, find approximately the gain per cent. by reason of expansive working. *Ans.* 30.

109. Steam at 45 lbs. pressure is admitted into a cylinder 4 feet long, and cut off at $\frac{1}{2}$ stroke, find the gain per cent. by working expansively. *Ans.* 15·5.

110. The terminal pressure is 40 lbs., what was the initial pressure if the stroke is 5 feet and steam is cut off at $\frac{1}{4}$ stroke?

Ans. 160 lbs.

111. The stroke is 8 feet long, the initial pressure 120 lbs., and terminal pressure 50, at what point of the stroke was steam cut off?

Ans. $3\frac{1}{3}$ ft.

112. What was the length of stroke when initial pressure was 80, terminal pressure 45, and steam cut off at 2 feet?

Ans. $3\frac{5}{9}$.

113. The pitch of a screw propeller is 20 feet, and the diameter 18 feet, find the angle.

$$\text{Tan. of angle} = \frac{\text{Pitch}}{\text{Circumference}} = \frac{20}{18 \times 3{\cdot}1416} = \frac{10}{28{\cdot}2744}$$

$$\begin{aligned} &\text{Log. } 10 \ldots\ldots\ldots\ldots = 1{\cdot}000000 \\ &\text{Log. } 28{\cdot}2744 \ldots\ldots = 1{\cdot}451393 \\ &\text{Log. Tan. } 19^\circ\, 28' = \overline{9{\cdot}548607} \end{aligned}$$

114. Find the angle of the screw propeller of the "Simoon," when the diameter is 16 feet, and the pitch 20 feet. *Ans.* 21° 41′.

115. Find the angle of a screw when the pitch is 20 and the circumference $20\sqrt{3}$. *Ans.* 30°.

116. What angle has that screw whose pitch is equal to the circumference? *Ans.* 45°.

117. The thread of a screw is to the pitch as 2 : 1, find the inclination of the screw. *Ans.* 60°.

118. The circumference of a screw is to the pitch as $\sqrt{10+2\sqrt{5}} :: \sqrt{5}-1$. Find the angle. *Ans.* 18°.

119. The pitch of a screw is to the thread as $\sqrt{5}-1$ is to 4, find the angle. *Ans.* 18°.

120. Find the pitch of a screw propeller when the angle is 20° and the diameter 16 feet.

$$\text{Tan. } 20^\circ = \frac{\text{Pitch}}{\text{Circumference}} = \frac{\text{Pitch}}{16 \times 3{\cdot}1416}$$

$$\therefore \text{Pitch} = \text{Tan. } 20 \times 16 \times 3{\cdot}1416$$

$$\begin{aligned} &\text{Log. } 16 \ldots\ldots\ldots\ldots = 1{\cdot}204120 \\ &\text{Log. } 3{\cdot}1416 \ldots\ldots = \ {\cdot}497076 \\ &\text{Log. Tan. } 20^\circ \ldots = 9{\cdot}561066 \\ &\text{Log. } 18{\cdot}29 \ldots\ldots\ldots = \underline{\underline{1{\cdot}262262}} \end{aligned}$$

121. Find the pitch of a screw propeller, when the angle is 25° and diameter 15 feet.

Ans. 21·97 ft.

122. If the diameter of a propeller be 16 feet, and the angle 21° 10′, what is the pitch?

Ans. 19·46 ft.

123. The pitch of a screw is 18 feet, and the number of revolutions 70, how many knots will the ship go per hour, making no allowance for slip?

The length of a knot is 6080 feet.

At each turn of the screw the ship advances 18 feet.

$\therefore$ The ship advances in one minute 18×70.

$\therefore$,, ,, ,, hour $18 \times 70 \times 60$.

$\therefore$ Number of knots per hour $= \dfrac{18 \times 70 \times 60}{6080} = 12{\cdot}43$.

124. A ship has a propeller making 55 revolutions per minute, the pitch of the screw is 20 feet, the slip 15 per cent., find the speed of the ship.

The speed of the screw per hour $= 20 \times 55 \times 60$ feet.

,, ,, ,, in knots $= \dfrac{20 \times 55 \times 60}{6080.}$

Taking off 15 per cent., leaves $\frac{85}{100}$.

$\therefore$ Speed of the ship per hour $= \dfrac{20 \times 55 \times 60 \times 85}{6080 \times 100} = 9{\cdot}22$ knots.

125. A ship is required to steam 12 knots per hour when the screw is making 75 revolutions, what must be the pitch of the screw?

Let x = pitch of the screw.

The velocity of the screw per hour $= x \times 75 \times 60$ feet.

,, ,, ,, $= \dfrac{x \times 75 \times 60}{6080}$ knots.

$$\therefore \frac{x \times 75 \times 60}{6080} = 12.$$

$$\therefore x = \frac{12 \times 6080}{75 \times 60} = 16{\cdot}21 \text{ feet, } \textit{Ans.}$$

126. Find the pitch of a screw to propel a vessel 10 knots per hour, when the screw is making 72 revolutions per minute, after 12 per cent. has been deducted for slip.

The slip is calculated on the speed of the screw.

To obtain these 10 knots, 12 per cent. or $\frac{12}{100} = \frac{3}{25}$ have been taken off the speed of the screw.

$\therefore$ This 10 is only $\frac{22}{25}$ of the speed of the screw.

$\therefore$ Speed of the screw $= 10 \times \frac{25}{22} = 11\frac{4}{11}$ knots.

Then as above

$$\frac{x \times 72 \times 60}{6080} = 11\tfrac{4}{11} \quad \therefore x = 16 \text{ feet (nearly).}$$

Or we may reason thus:

$$\frac{x \times 72 \times 60}{6080} = \frac{12 \times 100}{88}$$

i.e., we take the 12 from 100, which leaves 88 or $\frac{88}{100}$.

127. Required the pitch of a screw propeller to drive a ship 14 knots per hour, when the engine crank is making 40 revolutions, and the multiplying gear is 2·3, and the slip is 20 per cent.

Ans. 19·27 feet.

128. What must be the pitch of a screw to drive a ship 13 knots

per hour, slip 15 per cent., number of revolutions of crank 42, when in the multiplying gear the larger wheel has 120 teeth and smaller 55? *Ans.* 16·9 feet.

129. Required the speed of a ship when the pitch of the screw is 20, the number of revolutions 65, and the slip 25 per cent.? *Ans.* 9·63 knots.

130. The diameter of a paddle wheel should be four times the length of the stroke; find the diameter of the paddle wheels worked by engines with 4 feet 3 inches, 5 feet 4 inches, and 3 feet 10 inches stroke. *Ans.* 17 feet, 21 feet 4 inches, 15 feet 4 inches.

131. The crank of an engine is 3 feet 2 inches, find the velocity of the ship in knots when the paddle wheel is properly proportioned to the crank, the number of revolutions 15 per minute, and the width of the paddle boards 2 feet 3 inches. The centre of pressure is situated at one-third the width of the float from the outer edge.

$$\text{Diameter of effective working wheel} = \overset{\text{Ft. In.}}{3\ \ 2} \times 8 - 2 \times \tfrac{1}{3} \times \overset{\text{Ft. In.}}{2\ \ 3}$$

$$\text{,,} \quad \text{,,} \quad \text{,,} \quad \text{,,} \quad = \overset{\text{Ft. In.}}{25\ \ 4} - \overset{\text{Ft. In.}}{1\ \ 6} = \overset{\text{Ft. In.}}{23\ \ 10}$$

$$\therefore \text{Speed of ship per minute} = 23\tfrac{5}{6} \times 3{\cdot}1416 \times 15.$$

$$\therefore \text{Speed of ship per hour in knots} = \frac{23\frac{5}{6} \times 3{\cdot}1416 \times 15 \times 60}{6080}.$$

$$= 11{\cdot}08, \textit{ Ans.}$$

132. The diameter of a paddle wheel is 24 feet, and the number of revolutions 15 per minute; find the speed of the ship when the width of the paddle boards is 2 feet 6 inches. *Ans.* 10·4 knots.

133. The crank of an engine is 4 feet, the paddle wheel is properly proportioned to it, the revolutions are 12 per minute, and the width of the paddle boards 2 feet; find the speed of the ship. *Ans.* 11·4 knots.

134. The diameter of a paddle wheel is 21 feet, the width of the boards 1 foot 6 inches, number of revolutions 20; find the speed of the ship when slip is 15 per cent. *Ans.* 10·5 knots.

135. Suppose the diameter of a paddle wheel is 24 feet, the width of the boards 4 feet, number of revolutions 16; find the speed of the ship when slip is 12 per cent. *Ans.* 9·31 knots.

136. A steamer is going up a river down which the tide is coming at 3 miles an hour, how fast must she steam?

Ans. The most economical speed is half as fast again as the tide,

$\therefore$ Speed $= 3 \times \frac{3}{2} = 4\frac{1}{2}$ miles, and progress $1\frac{1}{2}$ miles per hour.

137. A boat is steaming up a river down which a flood is coming 4 miles an hour, how fast must she steam? *Ans.* 6 miles an hour.

138. The level of the water in a marine boiler is 9 feet below the surface of the sea, the pressure of steam is 21 lbs., the depth of water in the boiler is 5 feet; what depth of water will be driven out by the force of steam if blow out cocks are left open?

Ans. There will be ·58 feet left in.

139. The steam pipe leading to one of Hornblower's valves is 9

inches in diameter; find the lift to allow a free passage of steam if the valve be 9 inches in diameter.

Here the area of steam pipe is $9^2 \times 7854$; and this volume of steam must have free passage round the *circumference* of the valve.

$\therefore$ Circle for passage of steam $= 9 \times 3{\cdot}1416$.

Let h be the height, then

$$9 \times 3{\cdot}1416 \times h = 9^2 \times {\cdot}7854$$

$$\therefore\ h = \frac{9^2 \times {\cdot}7854}{9 \times 3{\cdot}1416} = 2\tfrac{1}{4} \text{ inches.}$$

140. One of Hornblower's valves is 10 inches in diameter, and the steam pipe leading to it is 11 inches in diameter, how high must the valve be lifted to allow the steam to pass freely?

Ans. $3\frac{1}{40}$ inches.

141. Find the lift of a Hornblower's valve, the inner diameter of steam pipe being 8 inches, to allow a free flow of steam.

Ans. 2 inches.

142. The feed water of a boiler was supplied at a temperature of 15° at the rate of 85 gallons per hour; a feed water heater was introduced, and then it was supplied at a temperature of 85°; find the units of heat saved in 24 hours.

To each gallon is supplied $85° - 15° = 70°$.
A gallon of pure water weighs 10 lbs. (salt 10·27 lbs. nearly).
$\therefore$ As each lb. of water is raised in temperature 70°, the saving in each gallon is ....$10 \times 70 = 700$ units.
$\therefore$ In 85 gallons, or in one hour,
the saving is .... $= 85 \times 700 = 59500$.
$\therefore$ In 24 hours the saving is $59500 \times 24 = 1{,}428{,}000$ thermal units.

143. If the engine in the last question works 10 hours per day, six days a week, how many pounds of coals are saved in a week?

The combustion of a pound of coal produces 8000 thermal units and as a thermal unit is the heat necessary to raise a pound of water 1° C., we have from above—

Heat saved in 1 hour .... = 59,500 units.
,, ,, 10 hours or 1 day .... = 595,000
,, ,, 6 days .... = 3570,000 ,,
$\therefore$ lbs. of coals saved .... $= \frac{3570}{8} =$ 446·25 lbs.
= 4 cwt. nearly.

144. The feed of a boiler was 15 cubic feet per hour, find the saving effected in a week of six days, 10 hours per day, by using a feed water heater that raised the temperature of the water 60° C.

Ans. $421\frac{7}{8}$ lbs.

145. A boiler evaporates 20 cubic feet of water per hour, the feed water heater raises the feed through 75° of heat, find the saving in 100 days of 12 hours each. *Ans.* 14062·5 lbs.

146. To find the specific gravity of steam and weight of a cubic foot of steam.

An inch of water produces 1669 cubic inches of steam at atmospheric pressure.

$$\text{Weight of an inch of water} = \tfrac{1000}{1728} = \text{oz.}$$

$$\therefore \text{ Weight of 1669 cubic inches of steam} = \tfrac{1000}{1728}$$

$$\therefore \quad ,, \quad 1 \quad ,, \quad ,, \quad = \tfrac{1000}{1728 \times 1669}$$

$$\therefore \quad ,, \quad 1728 \quad ,, \quad ,, \quad = \tfrac{1000}{1669}$$

$$= \cdot 5991 \text{ oz.}$$

Now, as water is 770 times heavier than air, and the specific gravity of gases have air for their standard, $\therefore$ specific gravity of steam will be found thus:—

A cubic foot of air weighs $\frac{1000}{770} = 1 \cdot 2987$ oz.

If specific gravity of air weighing 1·2987 oz. is 1, what is the specific gravity of steam weighing ·5991 oz.?

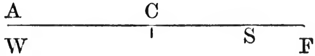
As 1·2987 : ·5991 : : 1 : ·4613 specific gravity of steam.

Bourne gives specific gravity of steam as ·481.

147. The diameter of a steam-pipe is 10 inches, the two equilibrium valves measure 9 and $9\frac{1}{2}$ inches in diameter, find the lift when fully open to steam.

Ans. 1·35 inches.

148. Give a general proof of the rule for finding the weight to be applied to a safety valve,—the length of the valve, the distance of the spindle from the fulcrum, the weight of the valve, and the weight of the lever being known.



Let A F be the lever of the valve, with its centre of gravity at C and fulcrum at F.

Let S, between C and F, be where the valve acts on the lever.

Taking the moments about F, and supposing d to be the diameter of the valve, and p the pressure of steam above the atmosphere, we have—

Letting W be the weight, and w that of the lever, and w' that of the valve.

$$\therefore W \times AF + w \times CF + w' \times SF = d^2 \times \frac{\pi}{4} \times p \times SF$$

$$\therefore W = \frac{\left(d^2 \times \frac{\pi}{4} \times p - w'\right) SF - w\,CF}{AF}$$

Or given the other elements, the quantities d or p may be found.

149. Show generally that the most economical speed to run in a tide way, or against a stream, is half as fast again as the stream.

Let $x =$ the speed of the ship per hour.

,, $v =$ the velocity of the tide or current per hour.

$\therefore x - v =$ the progress made by the ship per hour.

Now the consumption of fuel varies as the cube of the speed, or as x^3.

Let the consumption be $c\,x^3$.

$\therefore$ Consumption for each mile $= \dfrac{c\,x^3}{x-v}$; this is to be the most economical consumption.

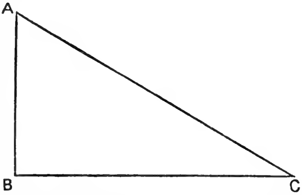
$$\therefore \frac{cx^3}{x-v} = \text{min.}$$

Differentiating and equating to zero.

$$\frac{3\,c\,x^2\,(x-v)\,d\,x - c\,x^3\,d\,x}{(x-v)^2} = 0$$
$$\therefore\ 3\,c\,x^2\,(x-v) - c\,x^3 = 0$$
$$\therefore\ 3\,(x-v) - x = 0$$
$$2\,x = 3\,v$$
$$x = \frac{3\,v}{2}$$

150. Find approximately the surface of a screw blade.

In taking A B as the pitch, B C as the circumference, and A C as the thread, it is very evident that if we consider the blade to be made up of a very large number of triangles, placed side by side, and that the part A B C is then taken away, leaving A C to form the blade, that if we could find the lengths of all the lines corresponding to A C, their sum divided by their number would give an average length, which, multiplied by the radius, must be the approximate area of the blade. In practice, it is usual to find only three of these lines, and then dividing by *three*, and multiplying by the radius, gives the area of the blade. A B may be considered as the length of the screw to obtain the approximation.



In the above figure let us suppose B C is bisected in D, and A D joined; then A C represents the longest line on the surface of the blade, A B the shortest, and A D an intermediate one.

$$\therefore\ \text{Area} = \frac{A\,B + A\,D + A\,C}{3} \times r.$$

151. The diameter of a propeller is 12 feet, the pitch 14 feet, and the length 2 feet; find the surface (1) of one blade, (2) of two blades, (3) of a complete screw.

$$B\,C = 3{\cdot}1416 \times 12 = 37{\cdot}6992.$$
$$A\,B = 14 \text{ and } D\,B = \tfrac{1}{2} \text{ of } 37{\cdot}6992.$$
$$A\,C^2 = A\,B^2 + B\,C^2 = 196 + 1421{\cdot}2296 = 1617{\cdot}2296.$$
$$\therefore\ A\,C = 40{\cdot}214.$$
$$A\,D^2 = A\,B^2 + B\,D^2 = 196 + \tfrac{1}{4} \text{ of } 1421{\cdot}2296.$$
$$\therefore\ A\,D = 23{\cdot}479.$$

$$\begin{array}{r} AB = 14 \\ AD = 23{\cdot}479 \\ AC = 40{\cdot}214 \\ \hline 3)77{\cdot}693 \\ \hline 25{\cdot}897 \\ 6 \\ \hline \end{array}$$

Sq. ft. $\underline{\underline{155{\cdot}38}}$ = area of complete screw.

As the length is 2 feet, the area of one blade $= \frac{2}{14}$ of the whole.

$\therefore$ Area of one blade $= \frac{1}{7} \times 155{\cdot}38 = 22{\cdot}19$ sq. feet.
$\therefore$,, two blades $= 44{\cdot}39$ sq. feet.

152. Find the area of the two blades of a propeller of the following dimensions:—

Diameter = 15 feet.
Pitch = 20 feet.
Length = 3 feet.

Ans. 76·57 square feet.

153. Find the area of the two blades of a propeller and of the complete screw, when diameter is 16 feet, pitch 20 feet, and length $2\frac{1}{2}$ feet. *Ans.* 70·8 and 283·2472 square feet.

154. Find approximately the area of the blade of a propeller, 18 feet in diameter and 21 feet pitch, when the length is $\frac{1}{7}$ of the pitch. *Ans.* 49·94 square feet.

155. Find the horse-power of an engine of the following dimensions:—

Diameter of two cylinders, 70 inches.
,, trunks, 20 inches.
Length of stroke 6 feet, cut off at $\frac{1}{3}$.
Pressure 60 lbs., number of revolutions 45.

Ans. 4241·16 or 4854·68.

156. Obtain the usual expression for the locomotive performance of marine engines, viz., $\frac{D^{\frac{2}{3}} v^2}{I}$.

Show from your investigation with what limitations you may apply it to measure the performance of different ships (1863).

Here v is the speed of the vessel.
,, D ,, displacement.
,, I ,, indicator horse-power.

When a steamer goes from place to place, she excavates, as it were, a canal between the two places, the transverse section of which is the immersed *midship section* of the vessel. For similar vessels the work done on a mile, or per hour, must bear a relation to this immersed midship section. Let M be the midship section of the vessel, and W the work done in foot pounds, and R the resistance against M; then $R = M v^2$; and therefore the work done $= M v^3$.

This holds good for similar vessels only. The midship section may be expressed in terms of the length l, breadth b, or height h, l^2, b^2, h^2, for the area of the midship section varies as the square of these quantities.

It is evident that the whole displacement, depending upon the *length, breadth,* and *height* of the vessel, will vary as the cubes of l, b, or h.

$$\therefore \text{ M varies as } l^2 \therefore l \propto \text{M}^{\frac{1}{2}} \qquad (a)$$

$$\text{while D} \quad ,, \quad l^3 \therefore l \propto \text{D}^{\frac{1}{3}} \qquad (b)$$

$$\therefore \text{ from } (a) \text{ and } (b) \text{ M}^{\frac{1}{2}} \propto \text{D}^{\frac{1}{3}} \therefore \text{M} \propto \text{D}^{\frac{2}{3}} \qquad (c)$$

so that now we can put $\text{D}^{\frac{2}{3}}$ for M, where D is the displacement. It is very evident that if a vessel go from one place to another at *double* the usual speed, she goes in *half* the time, and therefore has *four* times the work to do in half the time, and hence there must be eight times the power employed, or the horse-power varies as the cube of the speed. If at three times the velocity, nine times the work will be done in one-third the time, and therefore the power is multiplied by 27. $\therefore a\text{I} = \text{M}v^3$ where I is the indicator horse-power; but as M varies as $\text{D}^{\frac{2}{3}}$, the measure of the locomotive performance will be

$$= \frac{\text{D}^{\frac{2}{3}} v^3}{\text{I}}$$

In the latter part of this theorem we might have reasoned thus:—

The locomotive performance depends upon the fuel used, the fuel used gives an approximation of the indicator horse-power (I).

$$\therefore \text{ Work done by a unit of fuel} = \frac{\text{M}v^3}{\text{I}}$$

$$= \frac{\text{D}^{\frac{2}{3}} v^3}{\text{I}}$$

as before.

157. Reasoning as we have in this last question, we see that if C and C′ be the consumption of fuel, and K and K′ the speed or velocity.

$$\therefore \text{C} : \text{C}' : : \text{K}^3 : \text{K}'^3;$$
$$\text{also H.P.} : \text{H.P.}' : : \text{K}^3 : \text{K}'^3;$$

also, if n and n' be the number of boilers,

$$n : n' : : \text{K}^3 : \text{K}'^3;$$

also, if r and r' be the number of revolutions,

$$r : r' : : \text{K}^3 : \text{K}'^3.$$

158. The degree of saltness of the water entering a boiler is read of as $\frac{1}{30}$, and that of the water in the boiler is kept at $\frac{2}{30}$, the

temperature of the feed water is 100°F. ($37°\frac{7}{9}$C.), and that of the water in the boiler is 248°F. (120°C.), what percentage of the total heat given to the boiler is wasted by blowing off?

The total heat in steam at 248° is 1157°·64. See example 177. Substitute in next formula. *Ans.* 6·5 per cent.

Formula for finding the loss of heat by blowing out and the loss per cent.

Let x = the number of feet of water blown out every 3 hours.
Let y = ,, ,, ,, evaporated ,,
$\therefore x+y$ = ,, ,, ,, entering ,,
Let t = the temperature of the feed water.
Let t' = ,, ,, ,, boiler ,,

To turn y feet of water into steam will require $(637{\cdot}2-t)\,y$ of heat.
To boil the x feet of water blown out will require $(t'-t)\,x$ of heat.

$\therefore$ The total loss is $(t'-t)\,x$.

$\therefore$ Total quantity of heat employed $=(637°{\cdot}2-t)\,y+(t'-t)\,x$.

Since out of $(637°{\cdot}2-t)\,y+(t'-t)\,x$ there is lost $(t'-t)\,x$.

$$\therefore \text{Loss on } 1\ldots\ldots = \frac{(t'-t)\,x}{(637°{\cdot}2-t)\,y+(t'-t)\,x}$$

$$\therefore \text{Loss per cent.} = \frac{100\,(t'-t)\,x}{(637°{\cdot}2-t)\,y+(t'-t)\,x}$$

159. A marine boiler is blown out every 3 hours, in the proportion of 1 gallon blown out to 3 evaporated. At each time 1000 gallons are expelled, and the boiler evaporates 3000 gallons per hour. The temperature of the feed water is 6°C. Find the loss per cent., if temperature of water in boiler is 113°C.

Ans. 5·3 per cent.

160. A marine boiler is blown out every hour. On each occasion 33 gallons are expelled, while 132 gallons are evaporated in the same time. Find the loss per cent. when the temperature of the water in the boiler is 115°C., and that of the feed 5°C.

Ans. 4·1 per cent.

161. If a be the number of cubic feet of feed water, b the quantity blown out, e the quantity evaporated, supposing the water is to be maintained at $\frac{s}{30}$ of saltness; find the quantity blown out.

Since the feed water $=e+b=a$,
and also since the feed water has $\frac{1}{30}$ of saltness in it,

$$\therefore \tfrac{1}{30}(e+b)=\tfrac{s}{30}\,b$$

$$\therefore e+b=s\,b$$

$$\therefore b=\frac{e}{s-1} \quad (1)$$

If the quantity evaporated is required $e=b\ (s-1)$

Since $a=e+b$

$\therefore\ a=s\,b\quad \therefore\ b=\frac{a}{s}$

162. The boiler water is to be kept at $\frac{4}{30}$, or 4 degrees of saltness, how much must be blown out?

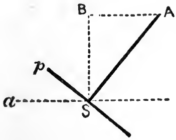
From last example, $b=\frac{a}{s}=\frac{a}{4}$

$\therefore$ Quantity blown out must be $\frac{1}{4}$ the feed.

163. A marine boiler is to be kept at 3 degrees of saltness, how much water must be blown out? *Ans.* $\frac{1}{3}$ feed.

164. If 900 gallons of water be converted into steam, what quantity of brine must be blown out that the water in the boiler may be maintained at $\frac{4}{30}$ of saltness? *Ans.* 300 gallons.

165. Prove that when a vessel is heeling over, the load on the safety valve becomes L. Cos. *h*.



Let S be the safety valve. Let S A represent the load. Then when the vessel heels over, the load A S will be resolved into the two forces, A B acting horizontally and B S perpendicularly; the part B S only is effectively acting to keep down the valve.

Angle B S A is the heel *a* S *p*. Let A S = L or load.

$$\text{Cos. heel}=\frac{\text{B S}}{\text{A S}}\ \therefore\ \text{B S}=\text{A S Cos. heel.}$$

$$=\text{L. Cos. heel.}$$

166. A boiler is loaded to 20 lbs. on the square inch; the vessel heels over 25° when the steam issues from the valve; find the steam pressure in the boiler.

When boiler begins to blow off, force of steam = Cos. heel × load on the safety valve.

$\therefore$ Pressure = Cos. 25° × 20.

	log Cos. 25°	= 9·957276
	log 20	= 1·301030
Ans.	log 18·12	= 1·258306

167. A boiler is loaded at 50 lbs. on the square inch; the vessel heels over 12°; what force will the steam have in blowing off?

Ans. 48·9 lbs.

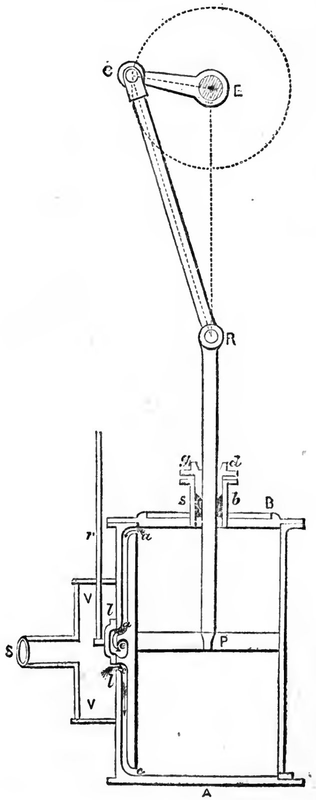
168. A ship heels over 15°, and the boiler blows off at 40 lbs., what is the load of the valve when the ship is on an even keel?

Ans. 41·4 lbs.

169. A marine safety valve is loaded to 35 lbs., and blows off at 34, when the vessel inclines at a certain angle; find the heel.

Ans. Cos. 13° 44′.

170. To investigate a formula for finding the position or angle of the crank at any point of its stroke.



Let the length of the connecting rod R C $= l$
,, ,, crank C E $= r$
,, θ be the angle R C E between the connecting rod and crank
,, h ,, height of the stroke made.
The length of the upstroke or down stroke $= 2r$
If the piston were at the bottom of its stroke, E R would $= r + l$

Since h is the portion of stroke made

$$\therefore \ ER = r + l - h$$

$$\text{Cos. } \theta = \frac{RC^2 + CE^2 - RE^2}{2RC.CE} \qquad (1)$$

$$\therefore \ \text{Cos. } \theta = \frac{l^2 + r^2 - (r + l - h)^2}{2rl} \qquad (2)$$

From equations (1) or (2) we can find the angle at any point of the stroke.

Let $h = r$, or suppose the piston is halfway up or down, then equation (2) becomes

$$\text{Cos. } \theta = \frac{l^2 + r^2 - l^2}{2rl} = \frac{r^2}{2rl} = \frac{r}{2l}.$$

Let angle $\theta = 90°$, or let the crank be at right angles to the connecting rod.

$$\therefore \ \text{Cos. } 90° = \frac{l^2 + r^2 - (r + l - h)^2}{2rl}$$

$$\text{And Cos. } 90° = 0.$$

$$\therefore \ l^2 + r^2 - (r + l - h)^2 = 0$$

$$\therefore \ l^2 + r^2 = (r + l - h)^2$$

$$\therefore \ (l^2 + r^2)^{\frac{1}{2}} = r + l - h$$

$$\therefore \ h = (r + l) - (l^2 + r^2)^{\frac{1}{2}}$$

171. When the crank is at right angles to the piston rod, prove that

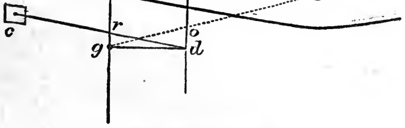
$$h = r + l - \sqrt{l^2 - r^2}.$$

172. The length of the crank is 2 feet, and the connecting rod 6 feet; find the angle between the connecting rod and crank, when the piston is in the centre of the cylinder. *Ans.* 80° 25′.

173. The crank is $2\frac{1}{2}$ feet long, connecting rod $7\frac{3}{4}$ feet: find the angle at half stroke. *Ans.* 80° 43′.

174. The angle at half stroke is 78° 27′, the piston has moved up 4 feet, find the length of the connecting rod.

Ans. 10 feet.



PARALLEL MOTION.

175. On page 62 it has been been proved that

If we divide $C\,h$ in e so that

$$C\,e : c\,d :: d\,o : o\,e$$

then by similar triangles $g\,d\,o$ and $o\,e\,C$

$$\therefore g\,d \text{ or } h\,e : C\,e :: d\,o : o\,e$$

$$\therefore h\,e : C\,e :: C\,e : c\,d$$

$$\therefore c\,d = \frac{C\,e^2}{h\,e}$$

which gives the length of the bridle rod $c\,d$.

To find o, the point where the air pump rod must be attached, when the length of the bridle rod and back link are known.

$$C\,e : c\,d :: d\,o : o\,e$$

$$\therefore \frac{c\,d}{C\,e} = \frac{o\,e}{d\,o} \text{ add } \textit{one} \text{ to each side}$$

$$\therefore \frac{c\,d + C\,e}{C\,e} = \frac{o\,e + d\,o}{d\,o} \text{ inverting, etc.}$$

$$\text{or } \frac{C\,e}{c\,d + C\,e} = \frac{d\,o}{d\,e}$$

$$\therefore d\,o = \frac{C\,e.\,d\,e}{c\,d + C\,e}$$

176. If 40 lbs. of water are heated from 20° to 100°, how many thermal units are required? *Ans.* 3200.

177. The steam in a boiler is at a temperature of 245° F., find the total amount of heat in it, and the latent heat.

$$1082° + {\cdot}305\ \text{T} = \text{units of heat}$$
$$1082° + {\cdot}305 \times 245° = 1156°{\cdot}525\ \text{F.}$$
$$= 643°\ \text{C. nearly.}$$

$\therefore$ Latent heat $= 1156°{\cdot}525 - 180° = 976°{\cdot}525$, which is $(976°{\cdot}525 - 966°{\cdot}6 =)\ 10°$ in excess of the law as usually stated.

178. The temperature of steam in a boiler at a pressure of 6·12 atmospheres is 320° F.; find the total amount of heat in the steam and the latent heat. *Ans.* $\begin{cases} 1179°{\cdot}6\ \text{F.} = 655°\tfrac{1}{3}\ \text{C.} \\ 999°{\cdot}6\ \text{F.} = 555°\tfrac{1}{3}\ \text{C.} \end{cases}$

179. The pressure in a boiler is 10 atmospheres, and the temperature 356° F.; find the latent heat of the steam. *Ans.* 1010° F.

180. How many units of work are done in raising a cylinder weighing two tons from the hold of a vessel 16 feet deep? *Ans.* 71680.

181. An iron ship 300 feet long, when in water at a temperature of 2°C., proceeds from Norway and meets the Gulf Stream off C. Hatteras at a temperature of 27°C.; find the increase in the length of the ship, co-efficient of iron being ·0000123. *Ans.* 1·107 inches.

182. A locomotive boiler 16 feet long is increased in temperature from 0°C. to 180°C., find the linear increase. *Ans.* ·425088 inches.

183. The stroke of the piston of an engine is 24 inches, and the diameter of driving wheel is 8 feet; what is the mean velocity of the piston when the engine is running at 40 miles per hour?

Ans. Strokes 140; 560·2 feet per minute.

184. A shaft in a marine engine was making 20 revolutions, and the speed was 8 knots; what will be the speed if the revolutions, by means of the multiplying gear, be increased to 25?

The revolutions of the crank vary as the cube of the speed.

Let V be speed required.

$$\frac{V^3}{8^3} = \frac{25}{20}$$

$$\therefore V^3 = \tfrac{25}{20} \times 8^3 = 640.$$

$$\therefore V = 8·617 \text{ knots.}$$

185. The revolutions of the crank of a marine engine are 24 per minute, and the speed 10 knots. The multiplying gear was put into action, and the revolutions increased to 30; find the increase of speed. *Ans.* ·77 knots.

186. The revolutions of a crank are 30, and the speed 12 knots, to what number of revolutions must the multiplying gear raise this 30 to increase the speed to 13 knots. *Ans.* 38·1 revolutions.

187. The horse-power of a pair of engines is 400, and the speed 10 knots; it is required to give a speed of 12 knots to the ship, what power engines must be put in?

The rule "cube of speed" applies to this and all similar questions.

$$\frac{10^3}{12^3} = \frac{400}{x}$$

$$\therefore x = \frac{400 \times 12^3}{10^3} = 691·2 \text{ H.-P.}$$

188. A pair of engines of 850 horse-power, which give a speed of 9 knots, are replaced by others which give 11 knots, what is the horse-power of the new engines? *Ans.* 1552 nearly.

189. If a pair of engines 1000 horse-power give 11 knots per hour, what is the speed that will be given by 1200 horse-power?

Ans. 11·68 knots.

190. A ship has 4 boilers. With 2 boilers the speed is 7 knots per hour, what is the speed with 3 boilers?

$$\frac{x^3}{7^3} = \frac{3}{2} \therefore x^3 = \frac{3 \times 7^3}{2} = 514·5$$

$$\therefore x = 8·013 \text{ knots.}$$

191. What will be the speed when all 4 boilers are used?

Ans. 8·819 knots.

192. To find the length of the pendulum and height of pendulum governor.

The usual formula, as found in all works on mechanics, is that the time of one oscillation in seconds is $= \pi \sqrt{\frac{l}{g}}$, where $g = 32$ feet. l is the length feet, and $\pi = 3·1416$; and height of a pendulum governor is $h = \dfrac{g}{(2\pi n)^2} = \dfrac{8}{(\pi n)^2}$

We have also this proportion deduced from the same equation:

$$n : 60 : : \sqrt{39 \cdot 1393} : \sqrt{l}$$

where 39·1393 is the length in inches of a seconds pendulum in the latitude of London.

193. Required the vertical height of a governor to revolve 80 times per minute. *Ans.* nearly 5·4 inches.

194. Required the height of a pendulum governor to revolve once every half second. *Ans.* 2·43 inches.

195. How often will a pendulum 2 feet long vibrate in a minute? *Ans.* 76·6.

196. To find the density of the air under the receiver of an air pump after the piston has ascended any number of times.

Let A be the capacity of the receiver.
,, B ,, ,, ,, barrel.
,, d ,, density of atmospheric air.
,, d_n ,, ,, after n ascents of the piston.

After one ascent the air which fills A fills A + B.

$$\therefore \; d_1 (A + B) = d A \;\therefore\; d_1 = \frac{d A}{A + B}$$

After two ascents we shall get by similar reasoning

$$d_2 (A + B) = d_1 A \;\therefore\; d_2 = \frac{d_1 A}{A + B}$$

$$\text{Substituting for } d_1 = \frac{A}{A + B} \times \frac{d A}{A + B}$$

$$= \frac{d A^2}{(A + B)^2}$$

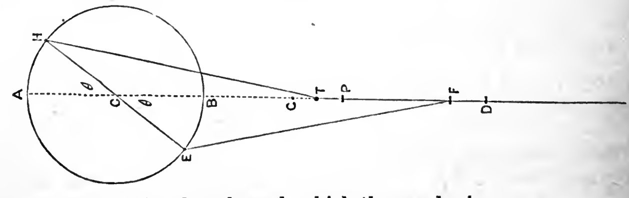
After the third ascent we have

$$d_3 (A + B) = d_2 A \;\therefore\; d_3 = \frac{d_2 A}{A + B} = \frac{d A^3}{(A + B)^3}$$

Generally after n ascents we have

$$\text{Density of remaining air} = \frac{d A^n}{(A + B)^n}$$

197. To find the height through which the head of the piston-rod has moved at any part of its stroke:—



Let the circle be that through which the crank pin moves.
Suppose the piston head to move from D to F.

In triangle F E C

$$EF \text{ is the connecting rod} = l$$
$$EC \quad ,, \quad \text{crank} = r$$
$$\text{Let angle } ECF = \theta$$

$$\text{Now } FE^2 = EC^2 + CF^2 - 2\,EC,\,CF,\,\text{Cos.}\,\theta$$

Adding EC^2 Cos.$^2\,\theta$ to each side, and transposing

$$CF^2 - 2\,EC.\,CF\,\text{Cos.}\,\theta + EC^2\,\text{Cos.}^2\,\theta = FE^2 - EC^2 + EC^2\,\text{Cos.}^2\,\theta.$$

Extracting the square root

$$CF - EC\,\text{Cos.}\,\theta = \pm\sqrt{FE^2 - EC^2\,(1 - \text{Cos.}^2\,\theta)}$$
$$\therefore\; CF = EC\,\text{Cos.}\,\theta \pm \sqrt{FE^2 - EC^2\,(1 - \text{Cos.}^2\,\theta)}$$
$$\text{or } CF = r\,\text{Cos.}\,\theta \pm \sqrt{l^2 - r^2\,\text{Sin.}^2\,\theta} \qquad (1)$$
$$\text{Now } CD = r + l \;\therefore\; DF + CF = r + l$$
$$\therefore\; CF = r + l - DF \qquad (2)$$

Equating (1) and (2)

$$\therefore\; r + l - DF = r\,\text{Cos.}\,\theta \pm \sqrt{l^2 - r^2\,\text{Sin.}^2\,\theta}$$
$$\therefore\; DF = r\,(1 - \text{Cos.}\,\theta) + l \mp \sqrt{l^2 - r^2\,\text{Sin}^2\,\theta} \qquad (3)$$

The negative sign of which will give what is required.

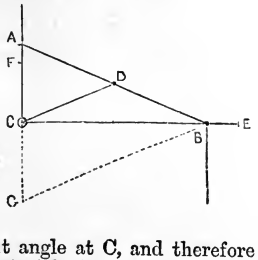
$$\left.\begin{array}{l} \text{If } \theta = 90^\circ \text{ then } DF = r \\ \text{If } \theta = 0^\circ \text{ then } DF = 0 \\ \text{If } \theta = 180^\circ \text{ then } DF = 2\,r \end{array}\right\}$$

198. Prove that if the crank pin move through the same angle θ from A to H in the last figure, that the piston descends through a space equal to D F.

199. Show fully that equation (3) in Example 197, will give the correct height of the piston when at the top, bottom, and middle of its stroke.

200. Show how to construct an exact parallel motion (Honours).

This figure represents the parallel motion first suggested by Mr. Scott Russell, and fitted by Mr. Seaward to the Gorgon engines.



The lever or bridle rod C D turns about its fixed centre C, and carries jointed to it at D the link A D B, called the rocking beam, and is so arranged that A D = D B = C D; if this be so, we know by the third book of *Euclid* that the angle A C B is the right angle in a semi-circle. If we compel B to move in a straight line towards C, say from E to B, as the three lines are equal, we shall always have the right angle at C, and therefore point A must move from F to A in the straight line C A continued. Hence we have an exact parallel motion, *i.e.*, constrain point B to move in a straight line, point A will do the same. In the Gorgon engines point B oscillates at the end of another bar, called the rocking standard, which describes a small arc nearly coinciding with a straight line.

C D is a mean proportion between A D and D B. This we see in a moment. If a proof be necessary, consider that in one position C D must be perpendicular to A B, and then by *Eu.* vi. 13, the fact is established that it is a mean proportional. As the lengths of the lines never vary, therefore in all other positions it is a mean proportional. In fact, either A D, D B, or C D is a mean proportional between the other two.

The distance through which the point B slides, or

$$BE = AB - \sqrt{AB^2 - \frac{s^2}{4}}$$

where s is the length of the stroke of the engine, which may be represented by A G.

$$CB^2 = AB^2 - AC^2.$$

$$= AB^2 - \frac{s^2}{4} \left(\text{since } AG = s \therefore AC^2 = \frac{s^2}{4}\right)$$

$$\therefore CB = \sqrt{AB^2 - \frac{s^2}{4}}$$

But C B = A B − B E.

Consider A B to coincide with C B, then to rise gradually from it, and we see C B=A B−B E.

$$\therefore AB - BE = \sqrt{AB^2 - \frac{s^2}{4}}$$

$$\therefore BE = AB - \sqrt{AB^2 - \frac{s^2}{4}}$$

The parallel motion of the side lever engine is not given, as such engines are seldom or never constructed now. But if the reader wishes to make himself acquainted with it, it is to be found in Rankine's *Applied Mechanics*, Bourne on the *Steam Engine*, or Goodeve's *Mechanism*.

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