THE STEAM ENGINE

CHAPTER I.

INTRODUCTION.

The elementary conception of a steam engine—The essential elements of steam engines—Description of a simple form of modern steam engine and boiler—Distribution of steam by an ordinary slide valve—The use of the fly wheel—Various purposes for which steam engines are employed—Importance of the accurate study of the engine in all its bearings—The natural subdivisions of the subject.

THE complete study of the steam engine is, in its nature, somewhat complex, involving as it does an acquaintance with the sciences of heat, of chemistry, and of pure and applied mechanics, as well as a knowledge of the theory of mechanism and the strength of materials. It is proposed, therefore, to begin this work by showing, in a very simple case, how steam can be used to do work, and then to proceed to describe an actual steam engine of the most modern construction, but one which at the same time is remarkably free from complexity. When studying this description, the student will soon find out how it is that the perfect knowledge of the steam engine involves an acquaintance with so many branches of science; and the order in which these subjects must be studied, so far as they bear on the matter in hand, will naturally be suggested by the description.

Take a hollow cylinder (fig. 1) of indefinite height, the bottom of which is closed while the top remains open, and fill this cylinder to the height of a few inches with water.

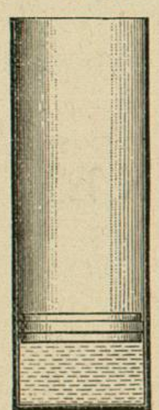

Fig. 1.

Next cover in the water by means of a flat plate, or piston, which fits perfectly the interior of the cylinder, and then apply heat to the water; we shall witness the following phenomena. After the lapse of some minutes the water will begin to boil, and steam will accumulate at its upper surface between it and the piston, which latter will be raised slightly in order to make room for the steam. As the boiling process continues, more and more steam will be formed, and the piston will be raised higher and higher, till the whole of the water is boiled away, and nothing but steam is contained in the cylinder. Now this apparatus, consisting of cylinder, piston, water, and fire, is an elementary form of steam engine of the simplest kind. For a steam engine may be defined as an apparatus for doing work by means of heat applied to water; and it is manifest that the appliance just described, inconvenient and clumsy though it may be, perfectly answers to the definition; for the piston is a weight, and this weight has been raised to a certain height by the formation of steam from the water. Now the raising of a weight through a height is a particular form of doing work, and consequently this combination is an apparatus capable of doing work by means of heat applied to water.

If, instead of a simple piston, we had taken one loaded with weights, and applied heat as before, the result would have been similar but not precisely the same. The water would not have begun to boil so soon, and when it was all boiled away the loaded piston would not have risen to the same height as did the simple one. The reason of this will be amply explained in the chapters on heat. Supposing

that, having raised the weight to the utmost height it would go, we then removed it from the piston, and wished to employ the apparatus in order to raise a similar weight to the same height, we should have to bring back the steam to its original condition of water. This we could do by removing the fire and by surrounding the cylinder instead with cold water. The result would be that the steam would all condense into water, and fall back to its original place, the piston following it, and everything would be ready for a fresh start. Now, though this apparatus answers the definition of a steam engine, it is, nevertheless, a very bad one, for the following reasons. The only kind of work it can do is the raising of weights through certain heights. When we want to repeat the operation we have to remove the fire and surround the cylinder with cold water, and then replace the fire, which is a most cumbrous process. While condensing the steam we made the cylinder cold, and a large quantity of heat is wasted in warming it again. Moreover, when, at the cost of a considerable amount of fuel, we have heated the water and turned it into steam, we allow the whole of the heat in the steam to escape into the cold water, and thus become wasted, though it is capable of doing much more work if properly used. Thus we see that our elementary engine is limited in its scope, clumsy in use, and extremely wasteful of fuel. It is in obviating these disadvantages that actual engines differ from the one we have described.

It will have been observed that this engine consists of four principal elements, viz.: the fire, or source of heat; the water, or medium to which the heat is applied, and by the conversion of which into steam the work is done; the cylinder with movable piston, which contains the water and steam, and which prevents the latter from escaping into the air when formed and becoming lost; and, lastly, the source of cold, or the water by means of which the steam was condensed and brought back to its original condition. The great majority of actual engines consist of precisely the same elements, more advantageously arranged, with the addition of certain mechanism for changing the straight line movement of the piston into circular, or any other kind of motion. This mechanism has also to effect other subsidiary objects which will be fully described hereafter. It should also here be mentioned that if, instead of condensing the steam by means of cold water, we had opened a temporary communication between the steam space inside the cylinder and the open air, we should have equally well succeeded in bringing the piston back to its original position, when, by introducing into the cylinder a fresh quantity of water, we could have again raised the weights.

In practice the arrangement adopted is as follows :—

1. The source of heat, and the vessel containing the water to be boiled, are kept quite separate and distinct from the cylinder. These parts of the apparatus are called respectively the furnace and boiler. The steam is supplied from the boiler, where it is generated, to the cylinder where it is used, as it is wanted, by means of a pipe, called the steam pipe.

2. The steam, after doing its work in the cylinder, is led away through a second pipe, called the exhaust pipe, into the open air, or else to be condensed in a separate vessel kept quite apart from the cylinder, and which is called the condenser.

3. The cylinder, instead of being open at one end, and of indefinite length, is closed at both ends, and in length seldom exceeds twice the diameter of the piston.

4. The steam, instead of being used only on one side of the piston, is admitted alternately to and exhausted from each side in succession, so that when the engine is in use, the piston is constantly travelling backwards and forwards from one end to the other of the cylinder.

5. Suitable openings are made at each end of the cylinder, to allow the steam alternately to enter and escape, and valves driven by suitable mechanism are provided in order to ensure that the admission and escape of the steam shall take place at the proper moments.

6. Instead of placing the weights to be lifted directly upon the piston, a cylindrical bar or rod called the piston rod is attached firmly to the centre of the piston, and is continued through one end of the cylinder to the open air, so that the outside end of the rod moves backwards and forwards in a straight line, exactly as the piston does. By means of suitable mechanism, which will be fully described hereafter, this straight line motion of the piston rod end is changed into rotatory or circular motion, so that the engine can be used, not only for lifting weights up in a vertical direction, but for doing any kind of work which may be required of it.

The manner in which all this may be accomplished in practice will be shown in the following description and drawings of an engine and boiler, which are here selected for description on account of their simplicity of construction. We will commence with the source of heat, and apparatus for turning the water into steam ; then go on to the engine proper, i.e. the cylinder with the mechanism belonging to it. The abstracter of heat, or condenser, will be considered in a separate chapter. Fig. 2 is an elevation of the boiler, fig. 3 a vertical section through its axis, and fig. 4 a horizontal section through the furnace bars.

The type of steam generator here exhibited is what is known as a vertical tubular boiler. The outside casing or shell is cylindrical in shape, and is composed of wrought iron or steel plates riveted together as shown in fig. 2. The top, which is likewise composed of the same material, is slightly dome-shaped, except at the centre, which is cut away in order to receive the chimney, *a*, which is cylindrical in shape and formed of thin wrought-iron plates. The interior is shown in vertical section in fig. 3. It consists of a furnace chamber, *b*, which contains the fire. The furnace is formed like the shell of the boiler of wrought iron or steel plates in the form of a cylinder, the top of which is covered by a flat circular plate, *cc*, firmly attached to the cylindrical

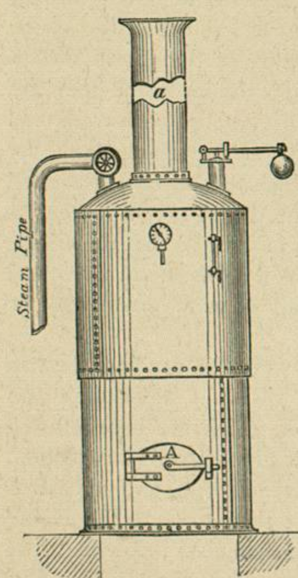

Fig. 2.

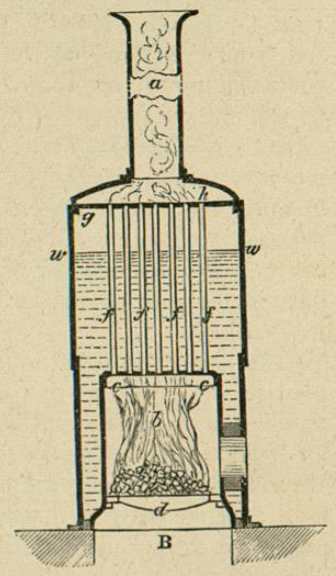

Fig. 3.

portion by flanging and riveting. The bottom is occupied by the grating, on which rests the incandescent fuel. The grating consists of a number of cast-iron bars, *d* (fig. 3), and shown in plan in fig. 4, placed so as to have interstices between them like the grate of an ordinary fireplace. The bottom of the furnace is firmly secured to the outside shell of the boiler in the manner shown in fig. 3. The top covering plate, *cc*, is perforated with a number of circular holes of from one and a half to three inches diameter, according to the size of the boiler. Into each of these holes is fixed a vertical tube made of


Fig. 4.

brass, wrought iron, or steel, shown at *fff* (fig. 3). These tubes pass through similar holes, at their top ends in the plate *gg*, which latter is firmly riveted to the outside shell of the boiler. The tubes are also firmly attached to the two plates, *cc*, *gg*. They serve to convey the flame, smoke, and hot air from the fire to the smoke box, *h*, and the chimney, *a*, and at the same time their sides provide ample heating surface to allow the heat contained in the products of combustion to escape into the water. The fresh fuel is thrown on to the grating when required through the fire door, A (fig. 2). The ashes, cinders, &c., fall between the fire bars into the ash pit, B (fig. 3). The water is contained in the space between the shell of the boiler, the furnace chamber, and the tubes. It is kept at or about the level, *ww* (fig. 3), the space above this part being reserved for the steam as it rises. The heat, of course, escapes into the water, through the sides and top plate of the furnace, and through the sides of the tubes. The steam which, as it rises from the boiling water, ascends into the space above *ww*, is thence led away by the steam pipe to the engine. Unless consumed quickly enough by the engine, the steam would accumulate too much within the boiler, and its pressure would rise to a dangerous point. To provide against this contingency, the steam is enabled to escape when it rises above a certain pressure through the safety valve, which is shown in sketch on the top of the boiler in fig. 2. The details of the construction of safety valves will be found fully described in Chapter IX., which is devoted exclusively to the consideration of boilers and their fittings. In the same chapter will be found full descriptions of the various fittings and accessories of boilers, which it would be out of place here to describe in detail, such as the water and pressure gauges, the apparatus for feeding the boiler with water, for producing the requisite draught of air to maintain the combustion, and also the particulars of the construction of the boilers themselves and their furnaces,

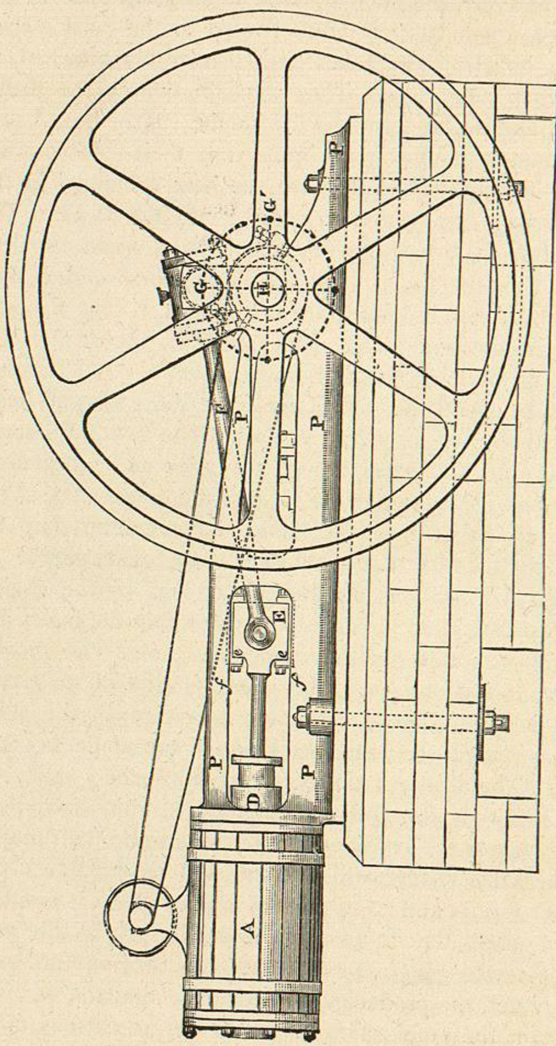

Fig. 5.

and the principles on which their strength is determined, and their various parts proportioned, so as to fully realise the effects intended.

We now come to the description of the engine, and the type selected for illustration is that usually called horizontal single cylinder, direct acting.

Fig. 5 is an elevation of the exterior. Fig. 6 is a hori zontal section of the cylinder, piston, and valve box. Fig. 7 is a plan. The cylinder is shown at A, figs. 5, 6, 7; its construction is best seen from the section, fig. 6. It is formed of cast iron, the ends being flanged to allow of the cylinder cover or end plate, *aa*, and the frame, PP, being

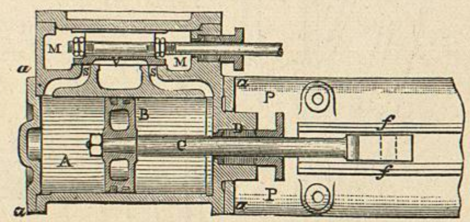

Fig. 6.

bolted to it. The piston is shown at B; it is a circular cast-iron disc, made to fit the cylinder in a steam-tight manner. Into the piston is fixed the piston rod, C, which passes through the front cylinder cover, the place where it passes through being made steam-tight by the stuffing box, D. The front end of the piston rod is fastened to the crosshead, E (fig. 5), which is a joint used for connecting the piston rod to the connecting rod, F, in such a manner as to allow the latter to swing in a vertical plane as the piston travels backwards and forwards. The crosshead is also provided with two slides, *ee* (fig. 5), which move between the guide bars, *ff* (figs. 5 and 6), and which prevent the piston rod from being bent, and from moving otherwise than in a straight line. The connecting rod, F (figs. 5 and 7), joins the end of the piston rod to the crank pin, G. The crank axle in which

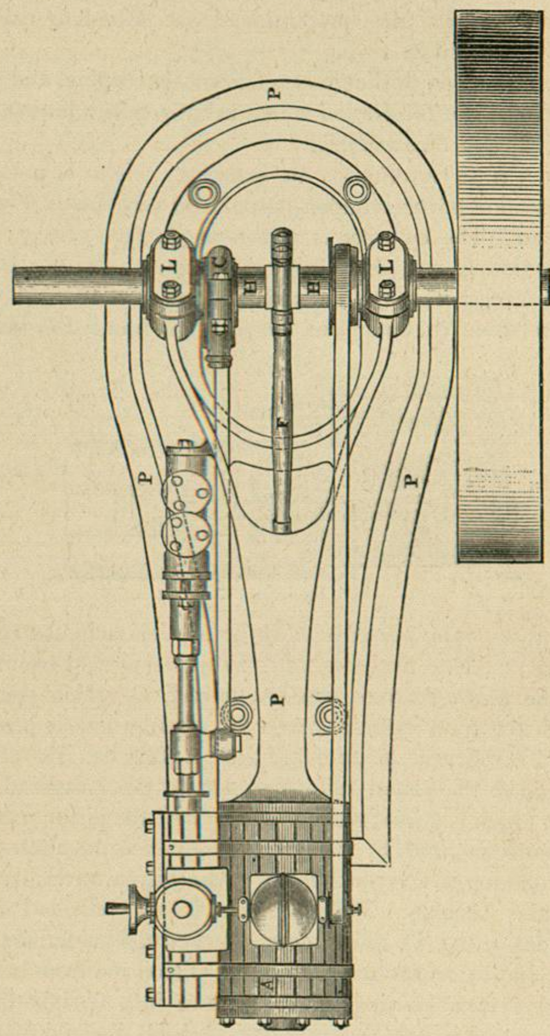

Fig. 7.

the crank is formed is shown in section at H (fig. 5), but is seen more clearly in the plan, fig. 7, where it is shown passing through the two bearings, LL. The distance between the centre of the crank pin, G, and the centre of the crank axle, H (fig. 5), is called the length of the crank arm, and is exactly equal to half the distance which the piston moves from one end to the other of the cylinder.

Supposing now that steam were allowed to flow from the boiler into the cylinder in such a manner as to obtain admission behind the piston, B ; this latter would commence to travel towards the front cover of the cylinder, and in doing so would push forward the piston rod and the crosshead. The end of the connecting rod next the crosshead would also be pushed forward, but the other end of the connecting rod which encircles the crank pin, not being free to move simply forward, would describe an arc of a circle round the centre of the crank axle, H, and in so doing the direction of the rod would become inclined so as to form an angle with the axis of the cylinder. By the time the piston has travelled to the front end of the cylinder, the crank pin will have been turned round into the position G′ (fig. 5), diametrically opposite to its initial position. Suppose that, just before this takes place, the steam is shut off from the back of the piston, and the steam already in the cylinder is allowed to escape, while at the same time fresh steam from the boiler is allowed to enter the cylinder at the *front* side of the piston, this latter will commence to travel back to its original position,[1] and in doing so will cause the crank pin to revolve from the position G′ (fig. 5), through a semicircle, till it reaches its original position, it having thus described a complete revolution round the centre of the crank axle, while the piston was making a double stroke backwards and forwards. This operation may be repeated as often as we like provided we have a suitable apparatus

[1] For the sake of simplifying the description, no account is here taken of the action at the dead centres. See p. 14.

for admitting the steam alternately on each side of the piston, and then allowing it to escape either into the open air or a condenser.

The manner in which the steam admission is regulated is as follows. By referring to the section (fig. 6), it will be seen that a box-like casing, MM, is cast in one piece with the cylinder and on one side of it. This box contains the valve, V, which controls the flow of the steam. It will be noticed that the side of the cylinder next the valve box contains two passages, *ss*; these are called the steam ports because the steam by means of them gains access to and escapes from either end of the cylinder. For the sake of clearness the following diagram, fig. 8, is given, showing the

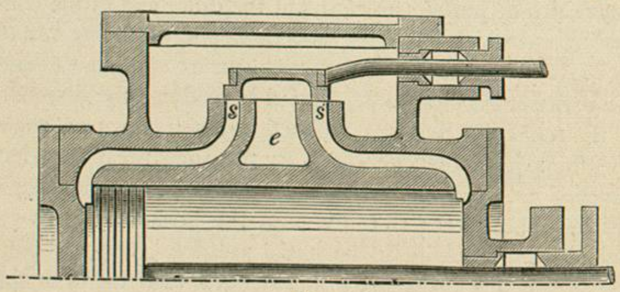

Fig. 8.

valve and side of a cylinder to a larger scale. The cast-iron box containing the valve is always filled, when the engine is at work, with steam from the boiler. If the valve occupies the position shown in fig. 8, the steam cannot enter the cylinder at all, because both ports are covered up by the valve. If the latter, however, be moved a little to the right so as to uncover the steam port *s*, two things will happen. The steam will be enabled to pass through the port *s* into the cylinder, and push the piston forward from left to right, while at the same time the port *s′* will be uncovered by the inner edge of the valve, and any steam which may be contained in the cylinder on the right-hand side of the piston

will be enabled to escape through the port *s′* into the interior hollow of the valve, and thence into the exhaust passage *e*, whence it can escape to the air of the condenser. This condition of things is shown by fig. 9.

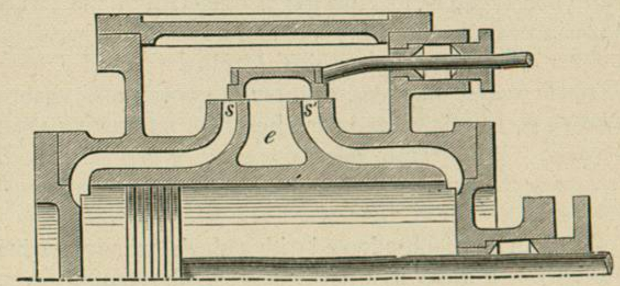

Fig. 9.

If when the piston has reached the end of its forward stroke the valve be moved backwards into the corresponding position on the other side, the steam port *s′* will then be uncovered and will allow the boiler steam to enter the cylinder, and force the piston back from right to left, while the steam on the left-hand side of the piston will be enabled to escape into the exhaust passage.

The foregoing remarks must be looked upon as merely an elementary sketch of the working of this particular sort of valve (which is commonly called the D slide valve). The proper way of proportioning the parts of the valve, the widths of the steam ports, and the methods of driving the valve so as to admit and cut off the fresh steam and release the exhaust steam precisely at the right moments during the stroke of the piston, are points of the greatest nicety and require the most careful study, and are fully described in Chapter VII.; but enough has been now said to illustrate the method of working in a general way without going into complexities.

It will be noticed that the valve is connected by a rod (see fig. 7) with a cam, C, fixed to the crank axle of the engine. This cam, which is called an eccentric, drives the valve backwards and forwards; its manner of working will be found described in the chapter already referred to.

When the centre of the crank-pin occupies either the point G′, fig. 5, or the diametrically opposite position, the centre line of the crank is in the prolongation of the axis of the cylinder and connecting rod, and it is evident that when in either of these positions, which are called the dead centres, the steam would only tend to press the crank axle against its bearings, LL, fig. 7, and would exercise no rotating effect whatever. Consequently unless some means can be devised for getting the crank over the dead centres the engine will stick fast.

The plan invariably adopted with a single cylinder engine is to provide a heavy fly-wheel, shown in elevation in fig. 5, and in plan in fig. 7. The momentum acquired by this fly-wheel during the stroke carries the crank over the dead centre. In addition to the above the fly-wheel exercises other useful functions which are explained in Chapter V., but which need not be dwelt upon at present.

The engine which has been described above is mounted on the heavy combined bed plate and frame PPP, shown in elevation fig. 5, and in plan fig. 7. The bed plate is bolted down to a solid mass of masonry as shown in fig. 5.

For our present purposes it is not necessary to examine into the other details of the mechanism, such as the governor and feed pump shown on fig. 7.

The engine which we have just described belongs to a type which is very much employed to drive machinery on land. It must not be supposed, however, that the steam engine, as originally invented, was anything like so simple a machine. On the contrary, it has taken two centuries of time to attain its present degree of perfection. We have no intention of entering into the history of the steam engine; indeed, the limits of this volume would preclude any such idea; moreover, the historical part of the subject has been dealt with over and over again in special

books, and in the biographies of the great engineers. At present we are only concerned with the engine as we actually find it, and with its possible future. The past will only be referred to for the purpose of showing what increase in efficiency has been attained in more modern times.

The importance of the accurate study of the steam engine will not be disputed when it is remembered to what purposes the engine is applied now-a-days, and to what an extent this manufacturing and sea-trading country is dependent upon its efficiency. Foremost among these purposes are:—

1. Locomotion on railways. The steam engine is employed in effecting nearly the whole of the internal goods and passenger traffic of the country. At the present moment there are in this country over 18,000 miles of railway opened for traffic, and the various railway companies employ between them many thousands of locomotives.

2. Marine locomotion. For this purpose the engine is employed in propelling the numerous steam vessels, which effect the greater part of the ocean-carrying trade of the world. Another important use of marine engines is the propulsion of those ships of war on which we depend for the protection of our coasts and our mercantile navy from foreign enemies.

3. The driving of machinery in our factories. The importance of the engine for this purpose can hardly be over-estimated, when it is remembered that we depend on our factories, and on the export of our manufactures, for the means of maintaining our present population, which is far too large to be supported by the produce of the country.

4. The winding of coal and other minerals, and the pumping of water out of mines.

5. The tillage of the soil, and the preparation of its produce for the use of mankind. This is a comparatively novel purpose for which the steam engine is employed, but one which is daily increasing in importance.

Each of these purposes requires a different type of engine for itself. In a small volume like this, it would be out of the question to describe every variety of engine at present in use. It will only be possible, at best, to explain the principles on which they should all alike be designed. The great importance of an accurate study of the subject is this: that without this study we cannot make our engines economical in the use of fuel. This economy should be one of the first objects of every constructor of a steam engine; for even if our supply of fuel at present prices were inexhaustible, nevertheless in many cases economy is of paramount importance. Take only the case of steam vessels which have to make long voyages. Up to a comparatively recent period it was not found commercially practicable to run merchant steamers on the longest trade routes, such as to China; for the mere coal required to develop the power necessary for propulsion would have occupied so much of the carrying capacity of the vessel as to leave insufficient room for a remunerative cargo. Thanks, however, to the fuel economies introduced during the last twenty years, steamers can now be employed with advantage on the longest voyages. Similarly the magnificent passenger steamers which now cross the Atlantic owe their high speed mainly to the modern improvements which have enabled great power to be attained with a comparatively moderate weight of machinery and fuel.

The ultimate object of all study of the steam engine is this:—to enable us to attain the maximum economy in the use of fuel with the greatest efficiency of the machinery. Hence the theoretical portion of the subject naturally divides itself into two principal parts. First, the study of the engine as a heat engine; that is, as an apparatus for the conversion of the heat supplied to it into mechanical work. Second, the study of the engine as a piece of machinery.

The study of the heat engine involves a knowledge of the nature of heat, and the laws of its conversion into mechanical work; hence we shall have the following divisions:—

A chapter (II.) in which is explained the nature of heat, and the mode of measuring it. This chapter will only deal with the subject so far as it bears directly upon the heat engine, and all reference to other branches of this science will be avoided.

A chapter (III.) which deals with the conversion of heat into mechanical work, by its application to gas and water. This chapter will give an exact account of the physical properties of these bodies, and an explanation as to how the heat supplied to them under given circumstances is actually spent. It will also contain a description of the theoretically perfect heat engine, and show what proportion of the total heat supplied to it can, under the most favourable circumstances, be in theory turned into work, and also the conditions to be observed in order that this ratio of work done, to heat supplied, may be realised. It will, lastly, show how to apply the principle of the theoretically perfect heat engine to actual steam engines, and will explain why these latter are comparatively wasteful of heat.

We now come to the consideration of the engine, as a piece of machinery, and the student will require to study in detail, both theoretically and practically, the nature of the mechanical means, or mechanism, by which the pressure of the steam is transformed into work. The study of this part of the subject is contained in the following divisions.

Chapter IV. shows the connection between the size of the cylinder, the pressure of the steam, the velocity of the piston, the useful work to be done, and the incidental resistances which have to be overcome; and will show practically how to proportion the size of the cylinder to the work it has to do.

Chapter V., on the laws of motion, as applied to the separate moving parts of an engine, so that the effects of their weights, velocities, and directions of motion, on the working of the whole may be understood.

The practical part of the book contains descriptions of the various organs of which different types of engines and boilers are made up, and the rules for proportioning them to their several purposes.

Chapter VI. is on the practical details of the mechanism employed. This chapter will contain illustrations of the working parts of various sorts of engines.

Chapter VII., on a part of the mechanism—viz., the valves and valve gear—which, on account of its importance and complexity, requires a separate detailed description.

Intimately connected with the subject of valve-gearing is the instrument which is used in practice in order to ascertain if the valves are effecting a proper distribution of the steam. This instrument is called the indicator, and it is used not only for the above-mentioned purpose, but also to measure the power which is being exerted by the engine. The indicator records the performance of the engine by inscribing a geometrical figure called an indicator diagram on a piece of paper.

Chapter VIII. is devoted to the consideration of indicators and the interpretation of their diagrams, and is illustrated by numerous diagrams taken from actual engines, each of them being remarkable for some peculiarity.

Chapter IX. deals with the means of generating steam in practice, and contains an account of the nature of combustion, the constituents of fuel, and the various descriptions of furnaces, boilers, and their fittings.

The subject of the condensation of steam, and the various forms of condensers, air and circulating pumps, are dealt with in Chapter X.

In the chapters containing descriptions of the mechanism of steam engines, several arrangements, which may be looked upon in the light of refinements, have been omitted. Most of these contrivances have been designed with the object of minimising the losses of efficiency of actual engines, as compared with those which are theoretically perfect. These

sources of loss are enumerated at the end of Chapter III., and a special chapter (XI.) is devoted to the various remedies, and contains an examination into the merits of steam jackets, super-heating, and the compounding of engines.

Students who approach this subject for the first time, or those who wish only to acquire a general knowledge of the construction of engines and boilers, are recommended to omit Chapters III., IV., V., and the latter part of Chapter VII.