THE AGE OF MACHINERY

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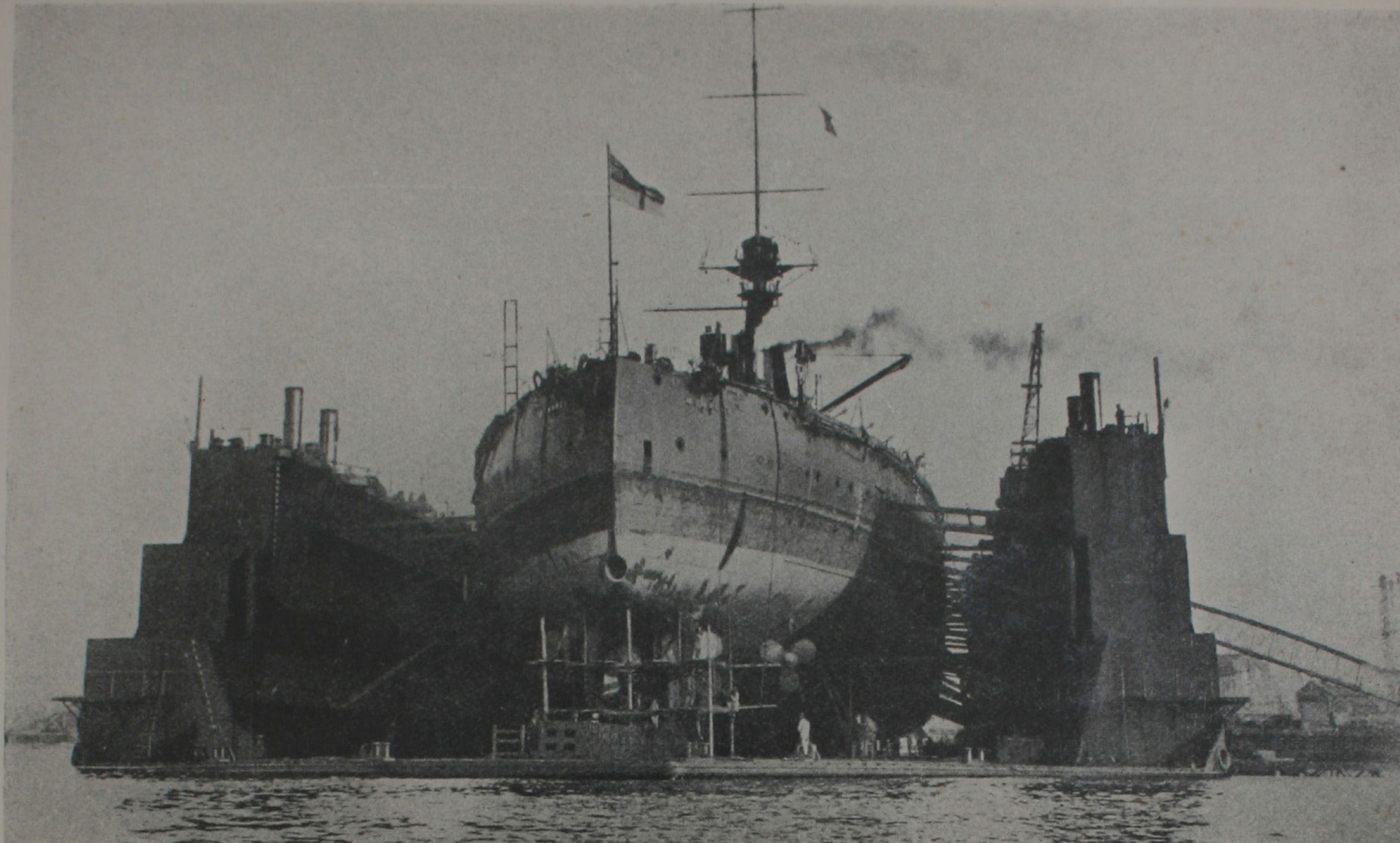

Photo. Stephen Cribb

H.M.S. MONARCH IN FLOATING DOCK

THE AGE OF MACHINERY

The Forces of Nature turned to the Service of Man

BY

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PREFACE

In this book some ordinary useful applications of the sciences are explained in simple language. It is hoped that it may help the young people for whom it is intended to realize what is possible to those who, often through failure, have persevered and studied. The book is not intended to give either a scientific or a technical treatment of the subjects with which it deals; its purpose being to convey to the reader a general knowledge of the more common machines, and of the materials from which they are constructed.

The author desires to acknowledge his indebtedness to the firms who have supplied photographs from which certain of the plates have been reproduced.

A. R. H.

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THE AGE OF MACHINERY

1

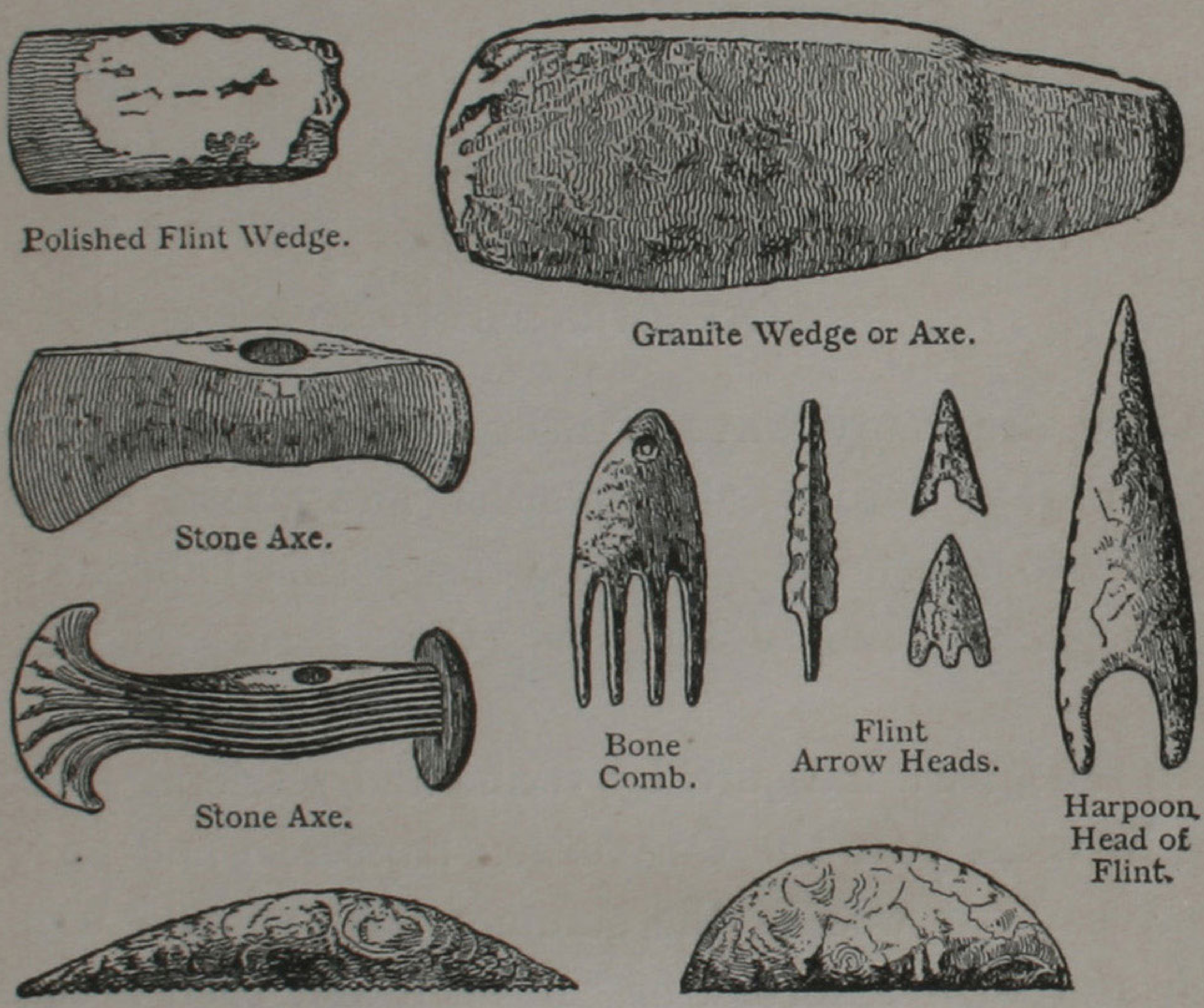
INTRODUCTION

There are many ways of measuring time. We count off our days into weeks, months, and years, and our years into centuries. We say that "this happened in the reign of King John", or "that during the Civil War".

At school we measure by terms and sessions. Ask a boy in what year the Coronation happened and he will likely say "it was in the summer term when I was in such and such a form", or "in such and such a class".

The early days of man, before the beginning of history, are measured in much the same way, for at that time man had not yet learned to number the years. He had other things to learn. Like the young apprentice he had first to learn the use of his tools. And so, just as the child counts his first school years by his form or class, we speak of the *bronze age* when man used bronze weapons, and the *stone age* when his weapons were made of stone.

The early dwellers in Britain are known to have done their hunting and fighting with arrows and lances pointed with stone, and to have used stone-headed hatchets and hammers. Many of these stone tools and weapons have been found in our days and are to be seen in our museums. For countless years man used those stone implements, and we speak of that time as the Stone Age.



Early Implements

Later, men found that by melting tin and copper together over a fire they could make bronze. With this metal they were able to make better tools and weapons than with stone, and they grew so clever at working in bronze that they gave up using stone. The Bronze Age had begun.

In course of time, however, man found a better metal than bronze. Weapons made of bronze were no match for swords and spears made of this new metal. For the new metal was iron, which was harder and could take a sharper edge than bronze. So iron drove out bronze. The Bronze Age gave place to the Iron Age.

The lives of these early peoples were simple. With their rude weapons and tools they hunted animals and killed them for food; they tilled the ground; they went to battle with their neighbours.

Since these far-off times man's way of living has changed. The smith with his metal-work is only one of the many craftsmen who from early days have given their skill to the service of the race. As man grew in knowledge old ways gave place to new. Instead of the bronze-tipped arrows we now have powerful guns with which to go to war; and for the hoe and the sickle we now have ploughs and reaping machines driven by steam or by oil power. The oldfashioned boats, moved by oars and sails, have given place to vessels of great size and power driven by machinery. In fact modern machinery is to us what the ancient stone and bronze tools were to our forefathers. They lived in the Ages of Stone, of Bronze, or of Iron, while we live in the Age of Machinery.

We are so accustomed to travel in railway trains and electric cars, to see motor cars and steamships, and to hear of submarines and aeroplanes that we are apt to forget that all these things were unknown little more than a century ago. Some of them, in fact, are of very recent birth.

We owe more of our comfort to machinery than one would at first suppose. It has brought our cities closer together. The locomotive, which was first used to draw a passenger train in 1825, enables us to travel between the capitals of England and Scotland in about eight hours instead of spending weary days in a stage coach as our forefathers had to do.

Villages and towns are linked together by our tramways, and continents are brought nearer to one another by vessels driven by machinery. We can go to America in fewer days than our forefathers required weeks in the days of the sailing ship, before Henry Bell built the first seagoing steamship—the *Comet*—in 1812.

Our newspapers and our books, printed by machinery on machine-made paper, bring the farthest-off lands to our firesides; while the light by which we read them in winter evenings, whether it be gas or electricity, is produced by machinery.

Machines prepare much of our food. They shape the stones and the bricks of which our homes are built. They make the cloth from which our clothing is fashioned. They raise our coal from the mine and sometimes even dig it for us. And these are only a very few of their countless uses.

2

COAL—WHAT IT IS AND HOW IT BURNS

Coal is one of the many minerals which make up the crust of the earth, and it is found in all parts of the world. It is usually so far below the surface that mines have to be sunk in order to get it out; but sometimes, as for instance in France and Spitzbergen, it is dug out in much the same way as stone is quarried in this country.

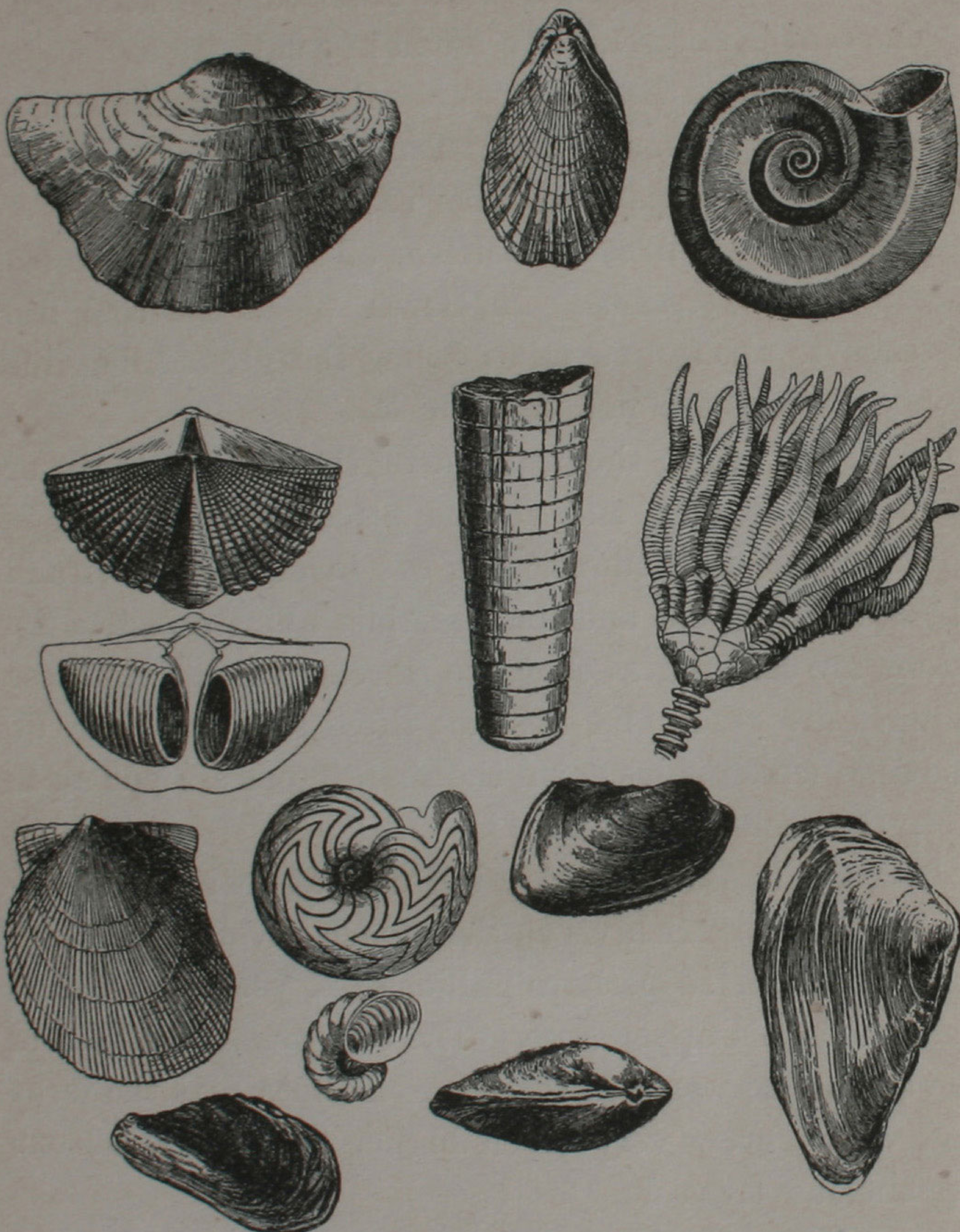
The coal is not generally found in solid masses, but in layers. Some of these layers are only a few inches thick, while others are many feet. The seams of coal, as they are called, are separated from each other by seams of stone or clay. In some districts oil shale is found between the coal seams. In South Wales the coal bed extends to about two miles below the ground, but the layers of coal are not very thick.

In order to get the coal out of the earth a shaft, or deep hole, is dug, and at the places where it passes through the coal, tunnels are cut in all directions and the coal is dug out and the materials which separate the seams are left, unless they are of some value. As these tunnels are made and the coal lifted to the surface by the cage which is let down the shaft, props are put up to keep the roofs from falling in.

Those who study geology tell us that coal is what remains of a very rich vegetation which covered the earth many thousands—perhaps millions—of years ago, before man made his appearance. The soil was so fertile and the climate so warm in those far-off times that the ferns and weeds grew very much higher than many of our present-day trees do.

In course of time earth-movements caused great changes. What was once dry land, thickly covered with trees and undergrowth, sank and became the bed of the sea. Then the rivers carried down sand and weeds just as they do to-day and laid them upon this bed.

As the sand and weeds were heaped up, their great weight, aided by the heat of the earth, caused the trees



Fossils found in Coal

and shrubs underneath to be compressed into the solid masses which we call coal.

As the rivers continued to heap up more sand the earlier of the sand-deposits were compressed into stone. Shells and fossils of sea animals are now found in this stone, and this proves to us that the coal bed was once covered by water.

Not very long ago an explorer discovered, in Baffin's Land, two great coalfields. The coal was so near to the surface that it could be dug out with a shovel.

Baffin's Land lies between Greenland and the north of Canada, and it is intensely cold there. No trees are to be found within a thousand miles of it. Yet this explorer discovered, buried beneath the surface of the earth, an immense forest in perfect preservation. The trees were found lying upon their sides just as if they had been blown over by a gale. Even the cones from the tree-tops were as fresh as the day they fell. All this shows us that at one time Baffin's Land must have been much warmer than it is now.

Plants like animals are made up chiefly of four substances—Carbon, Hydrogen, Oxygen, and Nitrogen. The amount of nitrogen is small. The leaves absorb carbonic acid gas from the air around them. Carbonic acid gas is made up of carbon and oxygen. The plant retains the carbon and uses it to build up its body, and it gives part of the oxygen back to the atmosphere.

The hydrogen is obtained from the water which the plant sucks in by means of its roots; for water is made up of oxygen and hydrogen.

Now, since coal is formed of decayed plants, we should expect that it too would be made up of carbon, hydrogen, oxygen, and nitrogen; and so it is. In decaying, the plant loses most of its oxygen and nitrogen. A piece of average coal weighing one pound contains about twelve ounces of carbon, one half ounce of hydrogen, and two ounces of oxygen and nitrogen.

Carbon and hydrogen give out a large amount of heat when they are burned. Although there is much less hydrogen than carbon in coal it is just as important, because, weight for weight, it gives out a great deal more heat than carbon does.

Coal cannot burn without a supply of oxygen, and this is generally taken from the air, which is made up of oxygen and nitrogen. There is a continual burning going on in our own bodies. We draw air into our lungs and our blood absorbs the oxygen from it and carries it through our bodies and brings it into contact with the tissues. These are burned up and carbonic acid gas is formed. This gas is then carried back to our lungs, where it is exchanged for more oxygen and breathed out. It is by this burning process that we are kept warm, and from it also we get the energy to walk and talk and think.

If we were to remain for a time in a small, badly-ventilated room, the oxygen would very soon be used up and the carbonic acid gas would poison us. It is much the same with burning coal. Coal requires a continuous supply of oxygen in order that it may be kept alight.

When coal is heated, the hydrogen and some of the carbon combine to form a gas. There are really a number of different gases, each of them mixtures of these substances in different proportions. They are called hydrocarbons, and they are very important.

When we sit by the fire and watch the stream of gas which issues from the coal and sometimes bursts into flame we see those hydrocarbon gases. But some of the hydrocarbons do not pass off as gas, for the coal is not hot enough. Some of them appear in the form of a soft, tarry substance upon the surface of the coal.

It is usually because the top of the fire is not sufficiently hot to burn these hydrocarbons that smoke and soot are formed. In this way a great deal of what would be useful heat is wasted.

3

COAL—WHAT IT IS AND HOW IT BURNS (*Cont.*)

There are many kinds of coal, and they are generally distinguished from one another by the amount of hydrocarbon or "bituminous" matter which they give off. Those coals which contain a large amount of hydrocarbon are called bituminous coals. They are generally very smoky. They are used in ordinary house fires, and also for the manufacture of coal gas. We shall learn later that coal gas is simply this hydrocarbon gas which has been purified.

In the south of Wales coal is found which contains almost no bituminous matter, and so, when it is burned, it gives hardly any smoke. This kind of coal is called "anthracite". It is used in the navy, because smoke would help the enemy to detect the presence of a vessel. It is also used for making a particular kind of gas for driving engines.

Bituminous coals very often give off gases in the mine, because it is always hot far down in the earth. The miner calls this gas "firedamp". The latter part of this word means "gas", and it has nothing to do with dampness. It is this gas which, when mixed with air, explodes with great force when a naked light is brought near it, causing great destruction and loss of life either by burning, or by suffocation from the carbonic acid gas, or "after-damp", as the miner calls it, which is formed by the burning.

In some parts of Germany a kind of coal is found called "brown coal" or "lignite". It is the remains of plants which grew at a later period in the earth's history than those which have formed the coal as we know it, and so it has not had so long a time to become pressed together. It stands, as it were, between wood and coal, and it contains a large amount of water and ash. It does not give out so much heat as ordinary coal does. But since it is much cheaper it is used in the neighbourhood in which it is found either for making steam to drive steam engines or gas for working gas engines.

Peat is another kind of fuel, which is simply decayed vegetable matter. It has been formed in districts at one time covered by lakes. These lakes have dried up and left the great peat bogs. It is because of this that these bogs are always wet and marshy. Some of these marshes give off a gas called "marsh gas". It is exactly the same as the "firedamp" found in mines.

Peat contains a large amount of water and so it has to be dried before it can be used as a fuel. This is

CHARGING FLOOR OF RETORT HOUSE

Operation of filling a retort (*See p.* 18)

From "Proceedings", 1908 Inst. of Mech. Engineers

DISCHARGING FLOOR OF A RETORT HOUSE

The gas producer, which is below the floor, is being filled with coke from the retorts. (*See p.* 18)

generally done by cutting it into brick-shaped pieces and stacking these so that they will be exposed to the air. Sometimes the blocks of peat are pressed by machinery; but even when great pressures are used it is found to be impossible to get rid of all the water.

It is said that if all the peat in Europe was collected and laid out in a layer ten yards thick it would cover an area of one hundred thousand square miles.

Peat is used in some parts of Scotland and Ireland as a fuel; and in Germany it is usually made into blocks or briquettes. It, too, can be made to give up its hydrocarbons and so form a gas which can be used to drive gas engines.

These, then, are the solid fuels which we have at our disposal for driving machinery.

4

THE MANUFACTURE OF COAL GAS

We have seen that for making coal gas we use bituminous coal, a kind which is rich in hydrocarbon matter, and with this coal gas we set gas engines to work and so drive the machinery in our mills. A visit to the gas-works is interesting. not only because gas is made there, but also because after the coal has given up its gas the stuff that is left over can be put to so many uses.

As gas-making is the chief business of the gas-works, gas is called the *product*, while the other things that are made in the course of the manufacture are called *by-products*.

The coal is placed in a kind of oven called a retort, like a low tunnel about twenty feet long with a flat bottom. These retorts are made of fireclay so that they will not burn away by the heat from the furnace, which is placed below. After being filled with coal, the doors of the retorts are fixed tightly so that no air can enter. As the heat from the furnaces below reaches the coal in the retorts the hydrocarbons are driven off in much the same way as they are given off when fresh coal is placed on a hot fire. There is this difference, however, that while the gases from the fire are allowed to mix with air and so are burned, those from the retorts are kept from contact with the air until they issue from the burners and are burned to give light and heat; or until they enter the gas engine, where they explode and drive the piston backwards and forwards (p. 16).

A pipe is led up from each retort, and its upper end is turned down so that it dips under water in a long horizontal trough or box called the "hydraulic main". The hot gas, as it passes up this pipe, carries with it a quantity of tar in the form of a gas which has been formed by the heating of the coal. On entering the water the gas is cooled and the tar becomes liquid and falls to the bottom of the trough. The tar is drawn off from the trough at intervals.

After this, the gas passes slowly through a number of pipes which are surrounded by the air and so it is cooled still further. In this way more tar is deposited, and it falls into a tank underneath which contains water.

Ammonia gas, which is also carried over from the retorts, is absorbed by this water. The pipes and tank form what is called the condenser.

At the end of the condenser there is a fan or "exhauster" which is used for sucking the gas through the pipes and also for forcing it through the remaining parts of the purifying apparatus beyond.

On leaving the fan, the gas passes first through one or more circular towers which contain coke. A stream of water continually flows over this coke, and in this way any ammonia which remains mixed with the gas is absorbed. The dust in the gas is left in the pores of the coke, and so the gas is partly purified when it leaves.

After going through this "scrubbing" process, the gas is led through very large boxes which contain lime, oxide of iron, and other substances which are placed on trays having a large number of holes in them. In this way the gas is split up, and the purifying materials absorb the carbonic acid gas and the foul-smelling sulphur compounds, and now the gas is pure.

The gas is then conveyed through more pipes to the gasholder, where it is stored until required. This well-known part of the equipment of a gas-works is often called a "gasometer". Gasometer is quite a wrong name, however, as the word means gas-meter or measurer, while the gasholder does not measure the quantity at all. It is merely a storage tank. The large bell of the gasholder rises in the daytime when the gas is being made more quickly than it is being consumed; and it falls during the night when the demand is greater than the supply.

The lower edge of the bell dips under water, which really forms the bottom of the vessel. In this way the bell can rise and fall and so adjust itself to contain the surplus gas without allowing it to escape.

When the gas is to be used for lighting it has to be enriched with another gas which is made from oil. This oil gas is made by forcing the oil into a highly-heated brick chamber through which air and steam pass.

5

THE MANUFACTURE OF COAL GAS (*Cont.*)

The by-products of gas-making are many, and very valuable. When the gas has been given off from the coal, coke is left. Coke is simply carbon mixed with ash. It can be burned and it gives out a great amount of heat. Since all the hydrocarbon has already been taken away from it no smoke is produced.

Coke is used in the manufacture of iron and steel, and for heating many kinds of furnaces. Within recent years it has also been used for heating rooms by burning it in a special kind of enclosed grate instead of in an ordinary open fireplace. This kind of fire has the great advantage that no smoke is formed, and the dust or ash cannot fly about the room.

The tar which is collected from the purifying apparatus gives us many useful things, such as carbolic acid, creosote oil, which is used for preserving wood, naphtha, which is valuable because it dissolves indiarubber, and saccharine, which is about five hundred times as sweet as sugar and is much used in its stead by those who suffer from certain diseases.

In addition to all these, the tar yields a great number of brilliant dyes. Ammonia is obtained from tar. Pitch, too, is got from it, and is useful for many purposes. Coal briquettes are made by mixing together very small coal and pitch and then compressing the mixture into moulds.

The water which has absorbed the ammonia gas is treated with sulphuric acid (commonly called vitriol) and in this way a substance called sulphate of ammonia is made. This is one of the most valuable manures we have, for it contains a large amount of nitrogen, and nitrogen is one of the principal foods of plants.

In the process we have been reading about, the gas is the product and the coke and other substances are by-products. Sometimes, however, these change places, and then the coke becomes the principal product, and the gas a by-product. But the method of manufacture is not very different in the two cases.

One of the best examples of coke-making is to be seen at a colliery in South Wales. It is very interesting because of the large amount of machinery which is used for handling the coal. In fact the coal is never touched by hand from the time it is taken from the mine until it is carried away in trucks in the form of coke.

The coal is brought from the mine in wagons and is emptied on to a travelling belt which carries it to a large storage bunker. From the bunker it is taken by another belt, as required, to the riddles or "screens" which separate it into piles of different sizes. The larger coal is then washed to get rid of dust, and is afterwards sold.

Next, the small coal is crushed and carried in buckets along a thick wire rope suspended in the air to another bunker. Then it is fed into the ovens and formed into coke by driving off the hydrocarbons in the way we have already described.

When the coke is made, it is pushed out of the ovens by large rods or "rams" worked by electricity. It then falls, while still hot, on to a number of travelling steel plates, and water is poured over it to cool it. Then it is carried to the screens where it is separated according to size. From the screens the coke is emptied into trucks, and taken away and sold.

The gas which has been given off in the retorts is purified, and the tar and sulphate of ammonia are recovered and sold. The engines are supplied with the gas as they require it.

These engines drive the machines which make electricity, and the electricity is used to work the many machines required in the manufacture, and also for lighting. All this energy is got from a by-product which was at one time wasted by being allowed to burn at the mouths of the retorts.

6

OIL AND ITS USES

In place of coal or gas, oil is rapidly coming into favour for driving engines. We have only to think of the motor car to realize this.

Oil was not used for producing power until about the middle of last century, and then only for very small engines. But as a fuel, oil has been known for thousands of years. Herodotus, the historian, who lived about four hundred years before the beginning of the Christian era, tells us that there were oil springs in the island of Zante off the west coast of Greece. The Romans, too, we know, got the oil they burned in their simple lamps from Sicily.

Oil is found in nearly every part of the world; but at present more than half of the total supply comes either from the Pennsylvania district of America or from Baku on the Caspian Sea in the south of Russia.

In Pennsylvania oil was discovered almost by accident. In making salt it had been the custom to bore small holes down into the earth until the sand was reached. This layer, or stratum, of sand was generally about half a mile below the surface, and immediately the point of the boring tool reached it, the imprisoned salt water flowed out at the top of the hole. This brine, as the salt water is called, was then boiled and the salt was left behind.

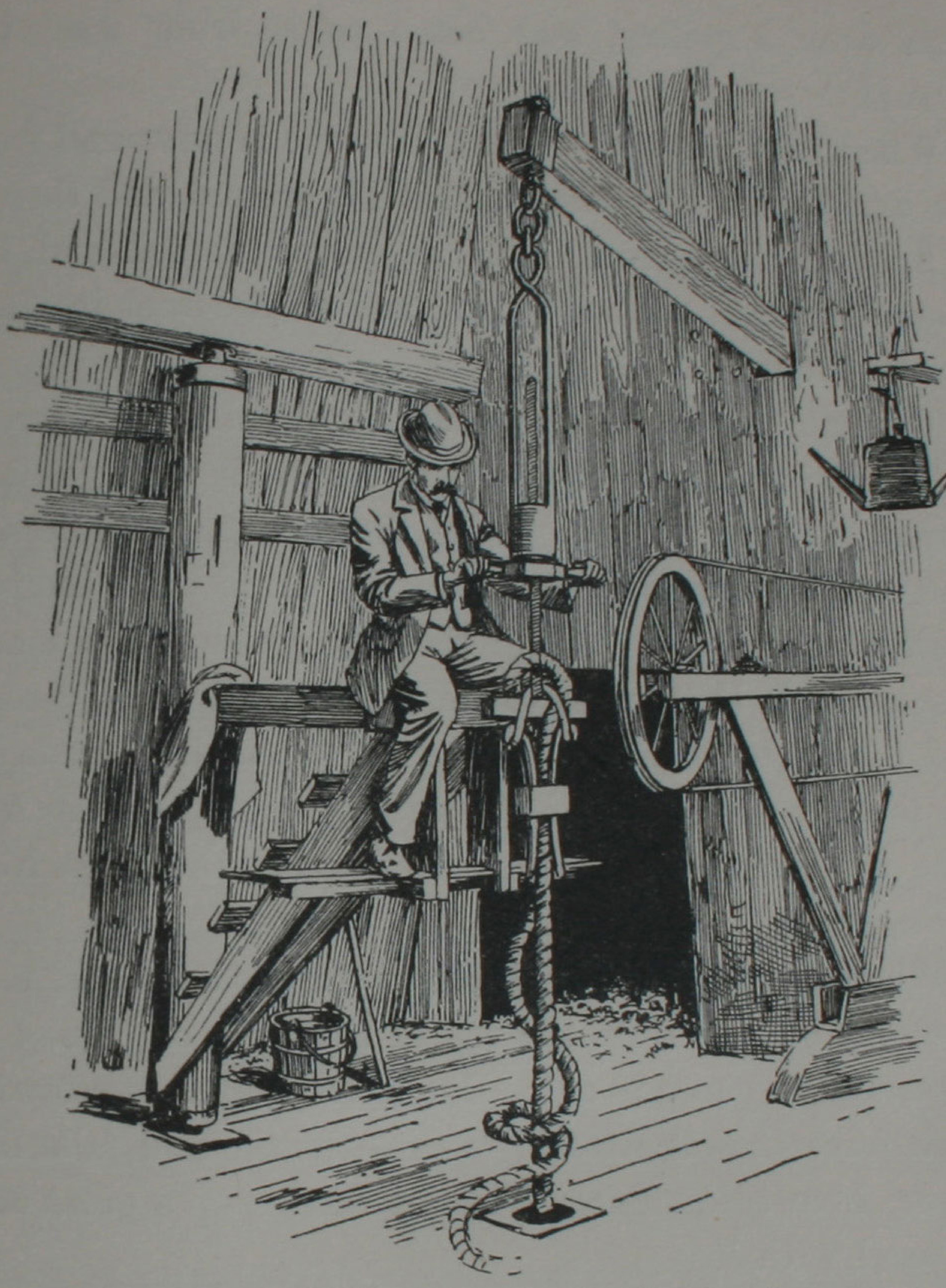
Very often the brine was found to contain so much oil that it could not be used, and then the money which had been spent in sinking the well was lost.

People at that time did not know the value of petroleum, as the oil that flows from the earth is called. About the year 1830 a well of this kind was being bored, and, to the surprise of the workmen, it was neither brine nor even a mixture of brine and oil which flowed out, but pure petroleum. It came out at intervals with a great rush as if it were forced up by a series of explosions. It is said that this well alone yielded about one hundred and fifty tons of petroleum every day for some time after it was opened, and that it continued to give many barrels daily for about thirty years.

Before the year 1850 nearly all of the oil which was used in lamps was made from coal, but it was found that petroleum was better. So the great oil industries of America and Russia were begun.

It was not until about twenty-five years after this that oil engines were first made, and they were very small. But by experience and invention the oil engine has now been made so perfect that we have good reason to wonder whether it will not by-and-by take the place of the steam engine both on land and sea.

When an oil-well is to be sunk, a "derrick" is first erected over the spot. The derrick is made of four posts. The lower ends of these posts are placed on the ground, and their upper ends are connected together to form a tower about seventy feet high in the shape of a pyramid. The posts are tied together by spars of wood. A long beam is mounted on a pivot which is supported between two of the posts, and it forms a sort of seesaw. The outer end of this beam is made to move up and down by an engine. The other end of the beam, which



Sinking an Oil-well

This arrangement differs from that described. The rope suspending the tool does not pass up over the top of the derrick, but is simply attached to the bottom of the screw. The derrick is here shown covered in with boarding, in order to form a store. The end of the beam moves up and down, as explained in the text.

is right above the place where the well is to be sunk, has a long screw hung from it. The bottom of this screw is made to grip a rope from which the boring tool is hung. This rope passes up to the top of the derrick.

then over a pulley, and down to a drum near the ground.

When a hole is to be bored, the rope is unwound from the drum until the tool touches the ground, and then it is fixed to the screw. The engine is started and the beam is moved up and down, and so the tool is alternately lifted and let fall.

The tool is fed downwards by turning the screw. When the screw is let down as far as it will go, it is turned back again. Its grip of the rope is then released. The rope is now unwound from the drum until the tool again touches the bottom of the hole which it has made. The screw is then made to take a new grip of the rope, and the engine is again started. The cuttings made by the tool are forced out of the hole by a pump, and an iron tube is driven into the hole to prevent the sides from giving way.

When the oil-bearing layer is reached the oil may flow out quietly from the top of the well, or it may be necessary to pump it out. But it very often issues with such force that it rises high into the air and falls like water from a fountain. Then it carries up a great deal of sand with it.

We are told of a well at Baku where the rush of oil destroyed the derrick. Twenty-four hours after the well was opened, the ground was covered with a layer of sand about six feet thick, and upon the top of this there flowed many thousands of tons of petroleum.

If the oil does not come away freely, a charge of nitroglycerine is put down into the well and exploded. This loosens the sand and increases the flow of oil.

7

OIL AND ITS USES (*Cont.*)

The crude or impure oil, as it comes from the wells, is stored in tanks, and the sand soon settles at the bottom. The crude petroleum can be used in certain kinds of oil engines, but it is unsuitable for most purposes. It cannot be used for burning in lamps or for oiling machinery until it has been purified or refined.

This crude oil is really not a simple substance, but it is made up of a number of different kinds of oil. Some of them are light and clear, while others are heavy and thick. Any kind of oil, if it be heated to a sufficiently high temperature, will boil and change into a vapour just as water boils and becomes steam. But the boiling-points of different oils are very different, and it is upon this fact that the process of oil refining is based.

The crude petroleum is placed in a metal vessel or "still". Steam is first passed over the oil, and this provides sufficient heat to change the lightest of the oils into vapours. These vapours are then carried to a number of pipes which are surrounded with water, and so they are cooled and become liquid again. Petrol, which is used for motor cars and motor boats, is a mixture of these lighter products of the oil.

The still is now heated, and as the temperature rises, the heavier portions of the oil are in turn changed into vapours, and these too are led to the pipes or condensers, where they are liquefied and stored in tanks. First come the oils which are suitable for burning in lamps;

and after them, those which are used for lubricating or oiling machinery. Then follow the oils from which gas can be made. Last of all the solid products, paraffin wax and vaseline, are given off.

The separate products are now treated with sulphuric acid and soda, in order to purify them and to remove the disagreeable smell of the unrefined oil.

The thick substance which remains in the still was at one time of no value, but now it is used in place of coal for heating steam boilers.

In the year 1850 the late Dr. Young, the founder of the large oil-works in Linlithgowshire which bear his name, discovered that paraffin oil, which is very like the oils got from petroleum, could be obtained from the shale which abounds in that district.

This shale, after it is taken from the ground, is placed in a retort and heated. It yields many kinds of burning oils and, like bituminous coal, it also gives off a gas. This gas is very often used for lighting the oil-works.

Sulphate of ammonia, the manure which we read of in the last chapter, is also a by-product of oil manufacture.

8

HOW IRON IS MADE

Iron has been made from very early times, and perhaps it was first used for the tips of arrows and spears. Later, when man came to be more expert in forging iron, he used it for making pillars and beams.

Iron is found nearly in the pure state in the stones which have been thrown off from meteors and buried in the earth's crust. It may have been from these stones that the ancients got their iron; but the supply of ironstone from this source is very small.

Iron is made from iron ores, which are mixtures of iron and other substances. Iron ores are found in most parts of the world, notably America, Germany, and our own country.

One pound of the richest iron ore contains about three-quarters of a pound of iron, while in the poorest varieties, a little more than half of the ore is made up of impurities.

There are two kinds of iron. One is cast iron, which is poured into sand moulds, and the other is wrought iron, which is hammered or rolled into shape. Steel is really a special kind of iron.

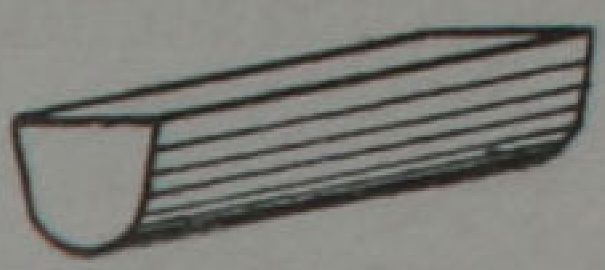
Although these kinds of iron are very much alike in composition, they are very different in character. Cast iron is very brittle; wrought iron, on the other hand, can be hammered and bent, even while cold, without injury. Steel can be made of any degree of toughness. Some kinds of steel are as brittle as cast iron, but they are much stronger. Other varieties are even tougher than wrought iron.

All kinds of iron and steel contain carbon; in fact it is the amount of carbon in them which mainly decides the characters of these metals. Cast iron has the most, yet there is seldom more than half an ounce of carbon in each pound of cast iron. Steel has much less than this, and wrought iron has only a very small amount of carbon in it.

The manufacture of iron can be divided into two stages. First, there is the separating of the iron from the oxygen and other impurities contained in the ore, by which "pig iron" is got; and second, there is the adjustment of the amount of carbon in the iron, so that the product may have the strength and toughness required.

In the first process, after the iron ore has been taken from the ground, it is heated in a stove or "kiln" in order to drive off the moisture, and also the sulphur and carbonic acid gas which it contains. It is then put into a "blast furnace", which is a steel shell of from sixty to ninety feet in height lined with firebrick. There are three openings near the bottom of this furnace. The lowest one is used for drawing off the molten metal; the highest for getting rid of the impurities; and through the one in the middle hot air is forced. The pipe which carries the air is surrounded with water to keep it from being burned by the great heat of the furnace (p. 32).

The iron ore is put into the furnace in layers with coke between, and limestone is added. The oxygen of the air which is forced into the furnace enables the carbon of the coke to burn. In this way the iron is melted, and it runs to the bottom of the furnace. On its way it absorbs some of the carbon of the coke. The limestone which forms the lining of the furnace combines with the impurities in the ore, and together they form a scum or slag which floats upon the top of the molten iron.

The furnace is "tapped" now and again, and the molten metal is allowed to run out on to a bed of sand in front of the furnace. This bed slopes downwards from the furnace, and it has a large number of moulds or impressions of this shape  made in it.

Each of these moulds holds about one hundredweight of iron. The moulds are connected together by little channels made in the sand to a point just below the opening in the furnace. The iron flows into them, and when it cools the bars of iron, or "pigs", are separated from one another. We have now got Pig Iron.

If we were to break one of these pigs we should find that the surface looks as if it were made up of a great many small crystals. The colour of the surface may be grey or white, depending upon the amount of carbon which the iron contains. The colour helps the iron-founder to judge of the quality of the metal.

9

HOW IRON IS MADE (*Cont.*)

When a part of a machine is to be made of iron, a pattern of the part is made, generally in wood, but sometimes in iron or plaster of Paris. This pattern is buried in a particular kind of sand which is rammed tightly round it.

The sand mould is made in two or three pieces which can be separated from one another, so as to allow of the pattern being taken out. When it is removed the mould is put together again (p. 33).

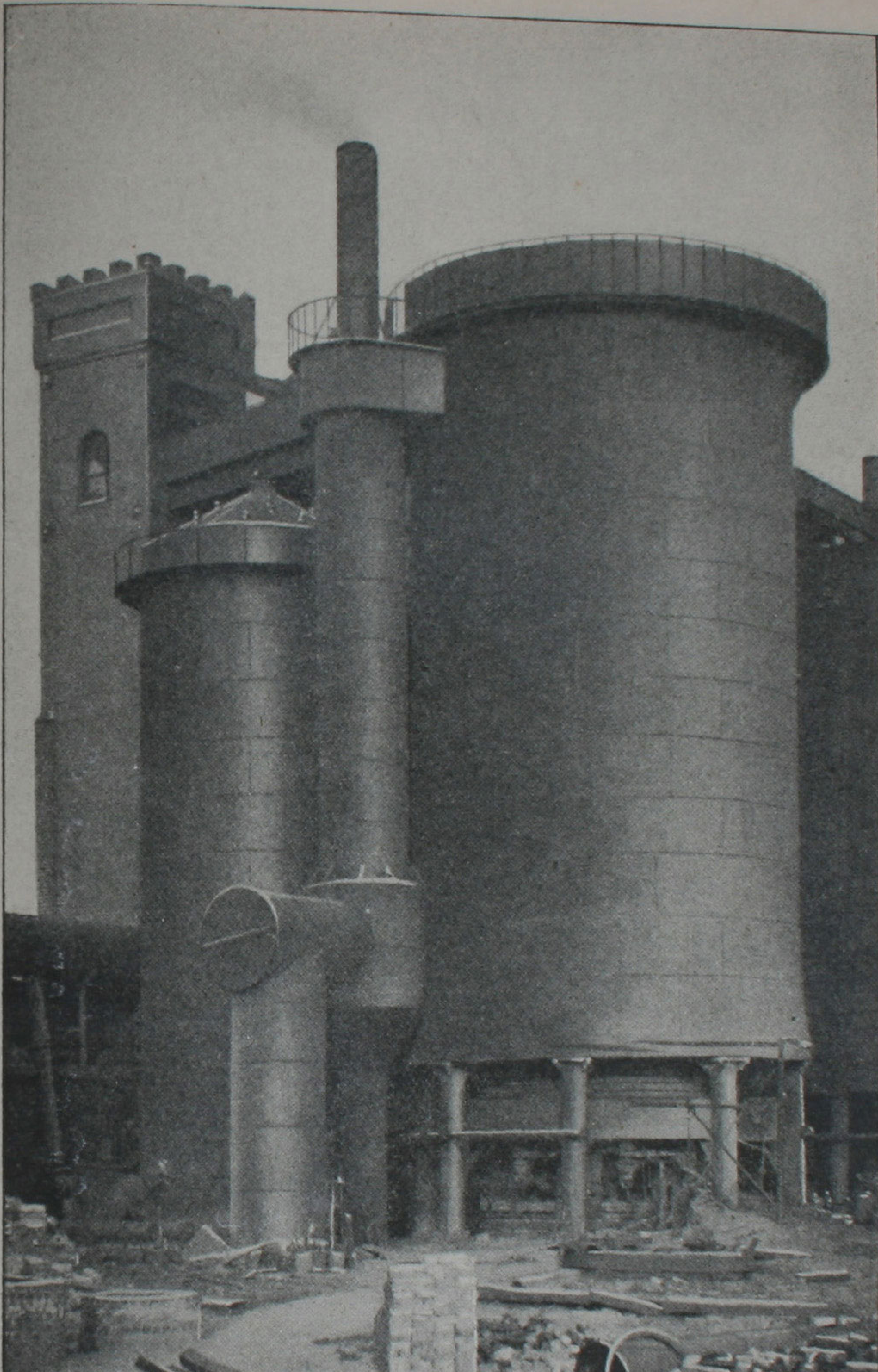
Several openings are made in the sand, some of them to admit the molten metal and others to allow the air to escape. If the air were shut in, the casting would be found full of holes; and as some of these would not be on the surface of the metal, they might not be detected until the machine was set to work, when it would probably break. The iron is then poured, and when it has cooled the mould is broken up and the casting is left.

The iron which is used for making these castings is usually a mixture of pig iron and scraps of wrought iron from old or disused machinery. These are melted together in a vessel which is very like a small blast furnace, and it is called a "cupola".

Many of the more complicated pieces of machines must be cast in this way, for it would be almost impossible to form them from wrought iron by hammering. Even if this could be done, it would take too long, and would therefore be too costly.

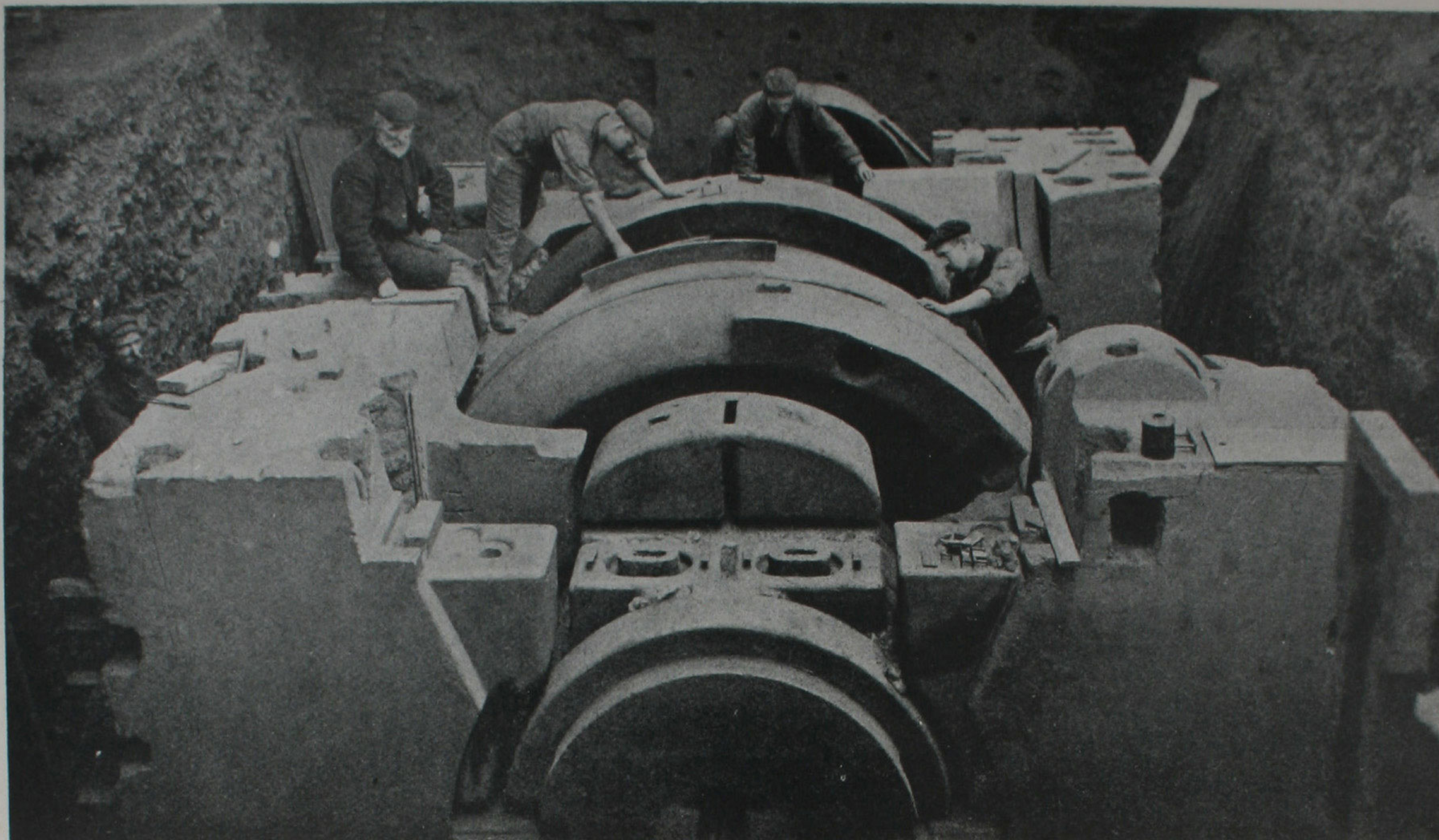
There are a great many parts of machines for which cast iron is quite unsuitable because it is not sufficiently strong, and because it is too brittle. Then wrought iron or steel must be used.

Wrought iron is made from pig iron by removing as much of the carbon from it as possible. To do this, the pigs are broken into pieces and placed in another kind of furnace called a "puddling" furnace, of which there are many kinds. The furnace is lined with iron ore. Gas or oil vapour is continually burned over the top



BLAST FURNACE

(See p. 30)



Vickers Limited, Barrow-in-Furness

PREPARING A MOULD IN WHICH THE OUTER CASING OF A STEAM TURBINE IS TO BE CAST

(*See p.* 32)

of the metal. This melts the metal and burns up the carbon in the pig iron, and so leaves it pure.

As in the case of the blast furnace a slag is formed, and as the metal loses its carbon it becomes pasty. When it reaches this state long rakes are pushed into the furnace, and by moving them about, the pasty metal is formed into lumps or "blooms". These blooms always contain some of the slag. They are then taken out of the furnace and placed under powerful presses which squeeze out most of the slag.

While still hot, the blooms are passed between heavy rollers, and these help to force out more of the slag, and the metal is formed into bars. These bars are then cut into pieces which are piled together and either hammered or rolled again.

The two rollers between which the iron is passed have a number of grooves cut round them. As we pass from one end of the rollers to the other we find that these grooves become smaller. The space between the last groove in each roller is made of the shape which the finished bar is required to have (p. 36).

The block of iron passes first between the largest grooves, where it is made thinner and longer. Then it goes through the next space, when it becomes still thinner and still longer, and so on until it reaches the last groove. When it has gone through the last it may be ten or twelve yards long, or even more; and it may be square or round, or like a tramway or railway rail.

Sometimes the bars are made of the shape of a large L; sometimes they are T-shaped, or they may resemble an H. The bars are then cut into the required lengths by a saw which rotates at a very high speed and resembles the circular saws which are commonly used for cutting wood.

Plates are made in the same way, only the rollers used in making plates do not have grooves in them. After the metal has passed between the rollers the space separating the rollers is made less and then the plate is passed through in the other direction. This process is continued until a plate of the required thickness is obtained.

It is of these bars and plates that our ships and our bridges are built. Boilers, too, are made of them. They are also used in modern buildings as pillars and beams for carrying the floors. We very often see iron beams placed over the tops of doors and windows of a building to support the weight of stone above.

When used in buildings, the iron beams are very often covered with concrete, which is a mixture of cement and broken stone. In the event of a fire, this covering protects the metal from the intense heat. This is a very great advantage, for metal beams become twisted when they are heated.

10

THE MAKING OF STEEL

Steel, since it is a good deal stronger, is very often preferred to iron for making machinery. It can be cast into moulds like cast iron, or be rolled into bars or plates in the same way as wrought iron is.

The amount of carbon in steel is less than in pig iron and more than in wrought iron, so steel can be made from either of these. It is usually made from pig iron.

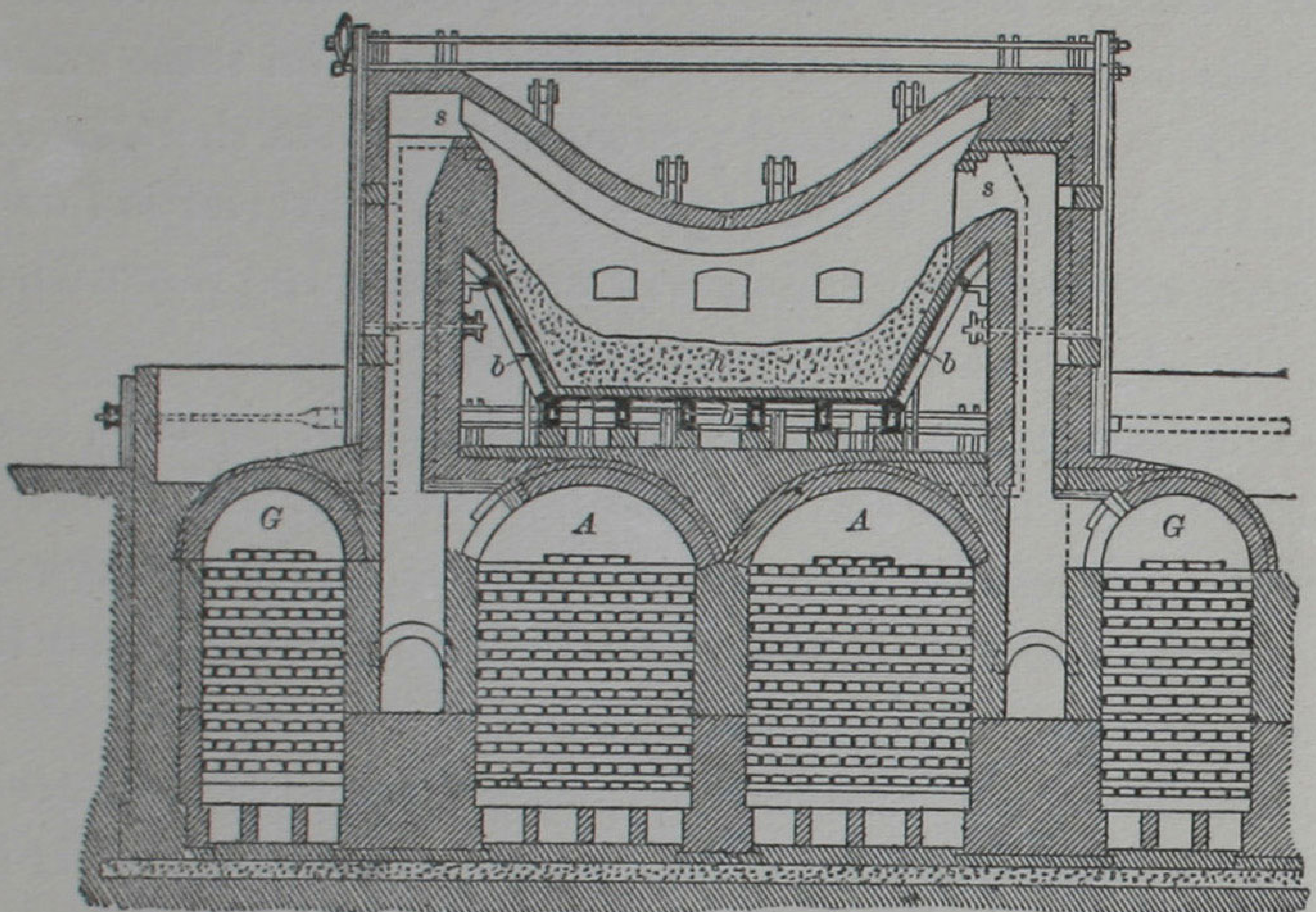
Henry Bessemer invented a way of making steel from pig iron. The iron is placed in a large bottle-shaped vessel called a "converter", which is mounted on two hollow axles placed about halfway up. When the furnace is to be filled or emptied, it is turned on these axles until it is in a horizontal position; but when the steel is actually being made it is upright. The converter is lined with some material which will unite with the impurities in the pig iron and form a slag (p. 45).

The converter is partly filled with molten pig iron, and air is then forced through the hollow axles and bubbles up through the metal. In this way a supply of oxygen is provided which enables the carbon in the pig iron to burn, and so pure iron is produced.

It is not pure iron, however, that is required, but steel. So some of the carbon must be put back again. This is done by adding just the correct quantity of some material which contains carbon. Spiegeleisen is generally used for this purpose. The word spiegeleisen is made up of two German words which mean "mirror-iron", and it gets its name from its bright appearance.

The air blast is now shut off, and the contents of the converter are emptied into a large iron ladle. Sometimes this ladle is supported at the end of a very strong arm. This arm is turned round until the ladle is over a steel mould. A valve in the bottom of the ladle is then opened, and so the mould is filled. The arm and ladle are now turned round a little farther and another mould is filled, and so on until the ladle is emptied. In some cases the ladle is carried from mould to mould by a crane.

There is another way of making steel. It was invented by Sir William Siemens. Burning gas passes over the surface of a mixture of molten pig iron, iron scraps, and

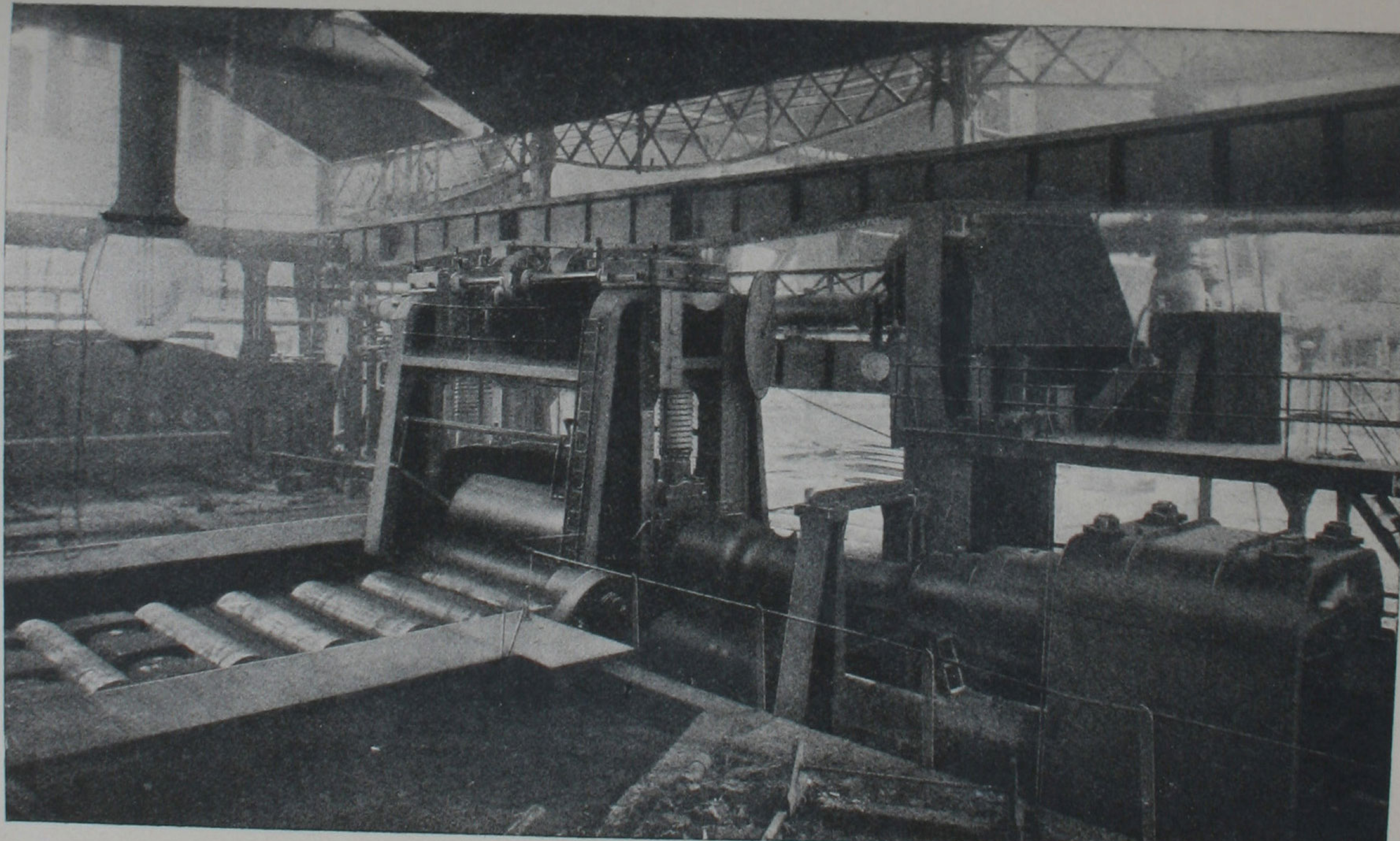


Siemens Furnace

Air and gas enter the upright passage from the chambers *A* and *G* on the left (say). They then pass over the metal in the upper chamber, burning as they go, and leave by the passage on the right. The brickwork in the chambers *A* and *G* on the right take up much of the heat which remains in the gases. The flow is then reversed, and the incoming air and gas now entering on the right become heated by this brickwork. This reversal of flow saves much heat which would otherwise be wasted.

iron ore. The heat causes the carbon in the iron to burn, and the flow of gas is stopped just when the metal is found to contain the proper amount of carbon. The steel is then cast in moulds in much the same way as is done in the Bessemer process.

The moulds into which the steel is poured are wider at the bottom than at the top, so they can be readily



Wm. Beardmore & Co.

ARMOUR-PLATE ROLLING MILL

(*See p.* 33)

lifted off by the aid of a crane. This is done very soon after the metal has become solid and while it is still red-hot. The ingots, as these blocks of steel are called, are then carried by a crane or in steel trucks to the "soaking pit", where they are reheated. Then they pass to the rolling mill, where they are rolled into plates or bars in the manner described for iron.

11

THE MAKING OF STEEL (*Cont.*)

When steel is to be made from wrought iron, bars of iron surrounded with charcoal or other material which contains a large amount of carbon are placed in boxes made of firebrick. A cover is then placed on the top of the box and sealed up so that no air can enter. The box is kept very hot for a number of days, and the carbon gradually enters the wrought iron and so turns it into steel. The steel which is to be used for making all kinds of cutting tools is manufactured in this way.

Sometimes the carbon does not reach the centre of the bar. This is an advantage, for the inner part is then tough and able to withstand shocks and jars; while the outer surface is very hard, and so it does not wear readily when rubbed. Many small parts of machines, such as the spindles or axles of bicycles, have their surfaces "case-hardened" in this way.

Some of the ingots or blocks of steel made by the

Bessemer or Siemens process weigh as much as sixty tons. The thick steel plating used to protect some parts of our men-of-war is rolled from these ingots, and has its outer surface hardened that it may offer a very great resistance, even to the heaviest shell. If the metal were hard right through, the plate would break up when struck by a shell in much the same way as a pane of glass splinters if hit with a stone. But the metal behind is softer, and after the shell has had most of its energy destroyed in breaking the skin or outer surface of the plate, the softer metal soon brings it to rest. These armour plates may be likened to a sheet of glass with a thick layer of sand behind; for we know that if a bullet is fired into a bag of sand it is very soon stopped.

The surface of cast iron or steel is sometimes hardened by pouring it into cold iron moulds. The metal next the mould cools very quickly, and this rapid cooling makes it very hard. This process is known as "chilling". For example, the surfaces of the rollers used in the manufacture of paper are hardened in this way.

Some of the rarer metals, if mixed with ordinary steel, even in very small quantities, have a very great effect upon its strength and other properties. The most important of these is nickel. A small quantity of nickel makes steel much stronger, and also prevents it rusting. For these reasons this nickel steel is now used in the building of bridges, but it is much more expensive than ordinary steel.

Our methods of making iron and steel are very different from those practised by our forefathers. Some time ago a mass of iron was found beside an old furnace near Newcastle. An examination of this block of metal told that the ancient ironmakers must have smelted their iron ore in very small quantities, perhaps over an ordinary fire. They then put these small pieces together by hammering them while hot, and in this way they managed to build up large beams and pillars.

Several very large beams and pillars have been found in India. The most noteworthy of these is the pillar of Delhi, which is about twenty-four feet high and sixteen inches in diameter.

The ancient peoples of India are supposed to have worshipped iron, and there is a tradition about this Delhi pillar. It is said that a rajah was once told by the priests that so long as this pillar remained standing his people would be successful in battle. It was explained to him that when the pillar was put down into the ground it had pierced the head of the serpent which was supposed to support the earth. He did not believe this story, and so he had the pillar removed, and it is said that he found the bottom of it to be covered with the blood of the serpent. He put the pillar back again, but the serpent had escaped. Tradition says that no matter what he did he could not get the pillar to stand steady; and that from the fact that it remained loose in the ground the city took its name. Nevertheless, the pillar of Delhi stands firm in the ground to-day!

12

OTHER USEFUL METALS AND ALLOYS

While iron and steel are by far the most important metals used in the making of machinery they are not the only ones. The engineer also uses copper, tin, zinc, and aluminium, either by themselves or mixed with one another.

Tin ore, or "tin-stone" as it is often called, is a mixture of tin and oxygen with earthy impurities. It also contains sulphur and the very poisonous substance, arsenic. In order to obtain pure tin the ore is first roasted, and then it is heated in a brick-lined furnace along with powdered coal. The coal, as it burns, uses up the oxygen in the ore and so leaves the tin pure.

Tin by itself is of little use in the construction of machinery. But it is very useful as a coating to protect iron, for it prevents rusting, at least as long as the surface remains unbroken. Unfortunately, however, if the skin be once broken, the iron and the tin together form a little electric battery, and this causes the iron to rust more quickly than it would do if the tin were not present.

The iron is coated by dipping it into molten tin. When a plate of iron is coated in this way it is called "tin-plate".

Zinc is obtained from its ore in much the same way as tin. Zinc like tin is often used as a coating for iron plates. When iron is covered with zinc it is said to be "galvanized". The corrugated or "wavy" plates which are so often used to form the roofs of sheds and small buildings are made of galvanized iron.

Zinc, by itself, is also used for the roofing of houses and for lining wooden tanks which are to contain water or other liquid. But zinc is not used alone for the construction of machinery, because it is too soft, and it has very little strength.

Next in importance to iron and steel comes copper, which has been known from very early times. Copper is found almost pure on the shores of Lake Superior, and combined with sulphur it occurs in granite and among the old rocks in many parts of the world. About half the world's output of copper comes at present from America. Spain, Mexico, Japan, and Germany also produce large quantities. Very little copper is found in Britain; but our colonies Australia and Canada have large deposits.

Copper, in its pure state, is used to a very large extent by engineers, because it is such a good conductor of electricity. The cables or wires which carry the electric current from the station in which it is produced to the street lamps and tramway cars are made of copper. It is also used for making pipes for conveying water and steam. Copper wire is made use of for many purposes.

In order to form copper plates, the ingots or blocks are rolled in much the same way as iron and steel ingots are. From these plates, some of which are very thin indeed, all sorts of vessels are made. Sometimes the insides of these vessels are coated with tin, because copper compounds are all poisonous, especially the compounds of copper and arsenic. The tinning prevents the poisonous arsenical compound from coming in contact with the contents of the vessel.

Copper pipes are made in several ways. One way is to roll a piece of plate round an iron rod or "mandrel", whose diameter is the same as the inside of the pipe required. The edges are allowed to overlap, especially if the plate is thin. When the plates are thick, the edges may be made to butt against one another. The joint is then "brazed".

Brazing is very like soldering. But instead of ordinary solder, which is a mixture of about two parts of tin with one of lead, a harder substance is used. This is called "spelter", and it is made from equal parts of copper and zinc.

After the edges of the plate have been thoroughly cleaned they are rubbed with a solution of borax. Strong heat is then applied, either by a furnace or a blowpipe, and the rod of spelter is rubbed into the joint, sometimes with the assistance of a wire. If the joint is properly made it will be very nearly as strong as the plate itself.

In addition to being much stronger than ordinary solder, spelter can withstand a much higher temperature without melting. Soft solder would melt if used for making the joints of steam pipes.

Pipes, when made in this way, must have a joint in them; but they can be made solid by another process. A block of the metal is forced through a steel plate or "die" which has a hole in it just the size of the outside of the pipe required. A hard-steel pin of the same size as the bore of the required pipe projects into this hole. Very great pressure is required to force the metal through the space between the block and the pin. This is supplied by a hydraulic press, which can be made to give a force of many tons.

Copper wires are made in very much the same way, but then there is no pin in the centre of the hole. Electricity has given us another way of making copper plates and pipes, but to understand it we must wait until we have read something about electricity.

13

OTHER USEFUL METALS AND ALLOYS (*Cont.*)

Metals are mixed together to form alloys. Solder and spelter, for example, are alloys. So are bronze and brass, for they are mixtures of copper, tin, and zinc in varying proportions, according to the character of the metal required; but copper is always the chief substance.

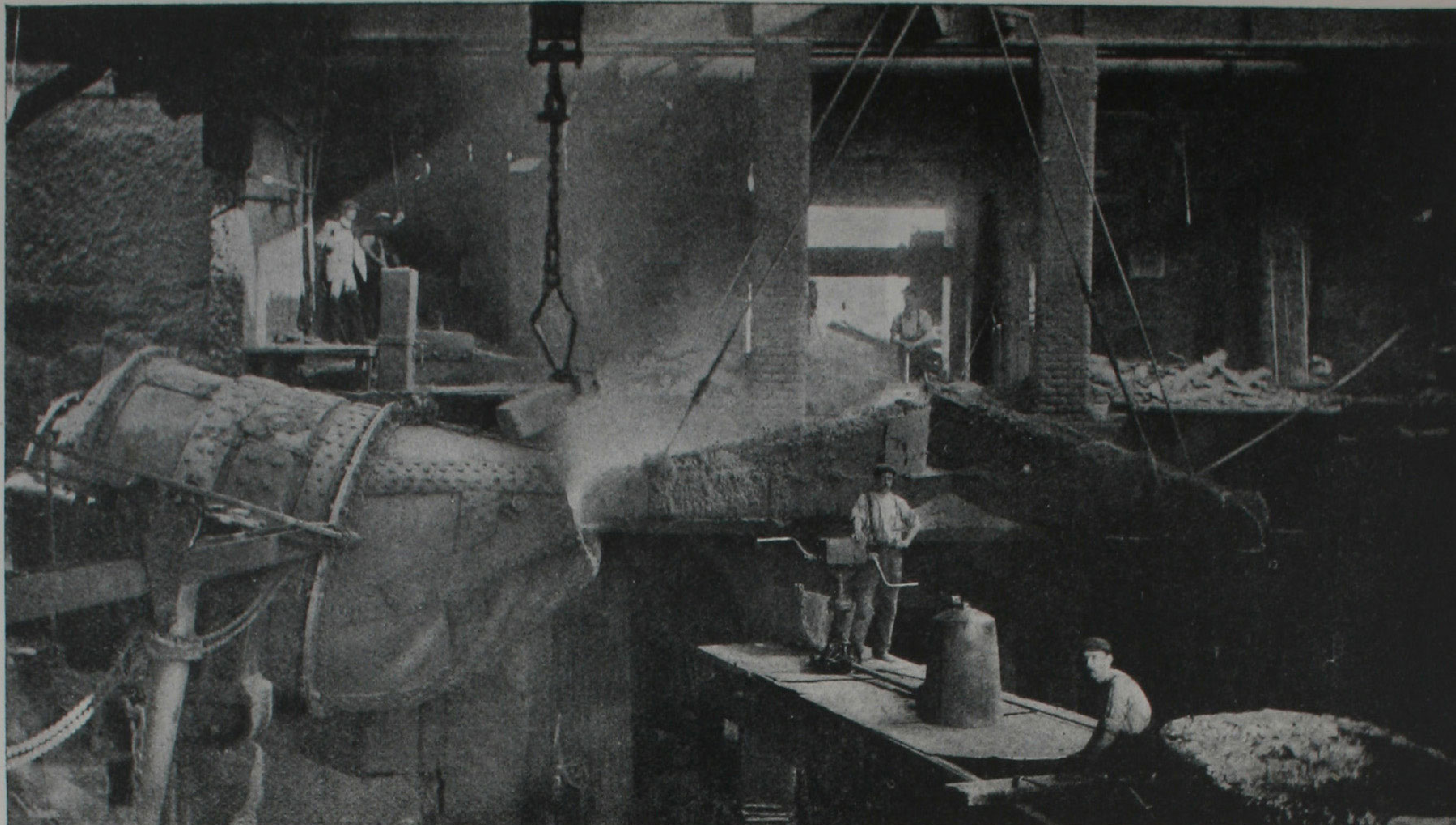
Bronze is often used for making valves and cocks, as it is stronger and tougher than cast iron. The screws which propel ships through the water are sometimes made of bronze, but bronze propellers are expensive. They have an advantage over steel in that they are very slightly affected by sea water.

The uses to which brass is put are very numerous. In everyday life we see countless articles made of brass. In machinery, too, brass is much used. The brackets which support the revolving shafts which are used to drive machines are generally lined with this metal, for then the shafts run much more smoothly than they would do if the bearings which carry them were made of iron.

The brackets themselves, however, are usually made of cast iron, for it is so much cheaper than brass. In course of time the rubbing wears down the bearings, and if the bracket were made all in one piece, then it would be necessary to renew the whole of it. This would be very expensive and wasteful, for there is no advantage in having brass except where the rubbing takes place. This is the reason why only a lining of this metal is provided. When this lining wears out, a new one can be supplied at a very small fraction of the cost which would be required to renew the whole bracket.

Aluminium is another very important metal. It has many properties which make it of great value to the engineer. Although it is not nearly so strong as iron or steel, it has the great advantage of being much lighter. Unlike iron, too, it does not rust. It is on account of its lightness that it is so much used in the construction of motor-car engines and fittings in motor launches and small ships, and especially in flying machines. In the manufacture of all kinds of electrical apparatus aluminium is largely used.

Aluminium was discovered almost a century ago, but it was not manufactured on a large scale until about the year 1890. Like the other metals we have been reading about, it is found in nature combined with oxygen and other impurities. It is purified by passing a strong electric current through a molten mineral called "cryolite", in which the aluminium, and the oxygen with which it is



BESSEMER CONVERTER

Iron from the Furnace being poured into the Converter to be afterwards made into steel. The ladle is seen in the bottom right-hand corner. (*See p.* 35)

combined, are dissolved. The current gives out a very great deal of heat, and this heat serves not only to keep the mixture in a molten condition, but also to separate the metal from its oxygen.

The manufacture of aluminium is carried on by the side of Niagara Falls. The power required to drive the machines which produce the electric current is obtained from the falls. It is also made in this country at the Falls of Foyers in Inverness-shire, at Conway in North Wales, and at Wallsend-on-Tyne.

Aluminium is sometimes mixed, in small quantities, with other metals, for it has a great influence upon their properties. For example, it makes steel harder, and it helps to prevent the formation of little pinholes which often occur in castings of this metal and of brass. A small quantity of aluminium added to bronze makes a very strong alloy.

There is another metal, called "nickel", which, when added to steel, increases its strength and toughness. It is obtained from some iron ores, and is very expensive. Another advantage of adding a little nickel to steel is that it prevents it from rusting. Its great strength and freedom from rusting make nickel steel a very suitable material for the building of bridges.

14

HEAT, AND WHAT IT CAN DO

We have now some knowledge of the metals of which machines are made, and also of the fuels which are used for driving them. We have learned, too, that these fuels give out heat. But what has heat to do with the energy which a machine gives, or with the work which it does? This is just the question that troubled many scientific men up to the middle of last century, and it was first answered by Dr. Joule of Manchester.

When a man carries a number of bags of coal up a flight of steps, we say he is working, or that he is expending energy. Now, we very often wish to measure the amount of work which is done by an engine when it raises weights. The engine may, for instance, be drawing coals up out of a mine, or it may be pumping water.

We are told exactly the amount of work which a man or a machine is doing if we multiply the weight of the body which is lifted by the height through which it is raised.

But it is not necessary to actually lift weights in order to do work. If we coil up a spring, as we do when we wind up a watch, then we do work. The spring then becomes, for the time being, a storehouse of energy, and it slowly gives up this energy to the watch. Or, again, we may do work by drawing a heavily-loaded sledge along a level road. But what becomes of the work which we do in this case? It is not stored up in the sledge as it was in the watch spring, for we cannot get it back again. Yet we have done the work, and it must have gone somewhere.

If we have pulled the sledge quickly, we shall find that the runners have become heated. Here we have a clue to the energy which has apparently disappeared. The truth is that we have been overcoming the friction between the runners and the surface of the road, and in this way the energy which we have expended has been changed into a new form. It has been transformed into heat.

We are told that once when a man called Count Rumford was boring a gun, he discovered that the metal became very hot. Before this time, people had never thought seriously about what became of the energy which was used up in cutting the metal. If you had asked them they would probably have said that it disappeared.

But what is heat? We know that when we supply heat to a body it becomes warmer, or, as we say, its temperature rises. But temperature does not tell us how much heat a body contains. It simply measures the effect of that heat. Temperature has very often been compared to water level. If we were to pour a gallon of water into an upright tube which has been closed at the lower end, it would rise to a considerable height in the tube; but if we were to empty it into a bath, it would little more than cover the bottom. In the same way, if we were to put equal quantities of heat into a pound of lead and one hundredweight of iron, their temperatures would not be increased by equal amounts, because the piece of iron can hold more heat than the lead can.

Temperature is measured by a thermometer. There are many kinds of thermometers, but the simplest one consists of a very fine glass tube with a bulb at one end. The other end is closed, so that no air can enter. The bulb and part of the stem is filled with mercury. The stem is afterwards divided by lines, and the spaces between those lines are called degrees. When the mercury is heated it expands and so rises in the tube, and the temperature of the substance in which the thermometer is placed is read off from the scale.

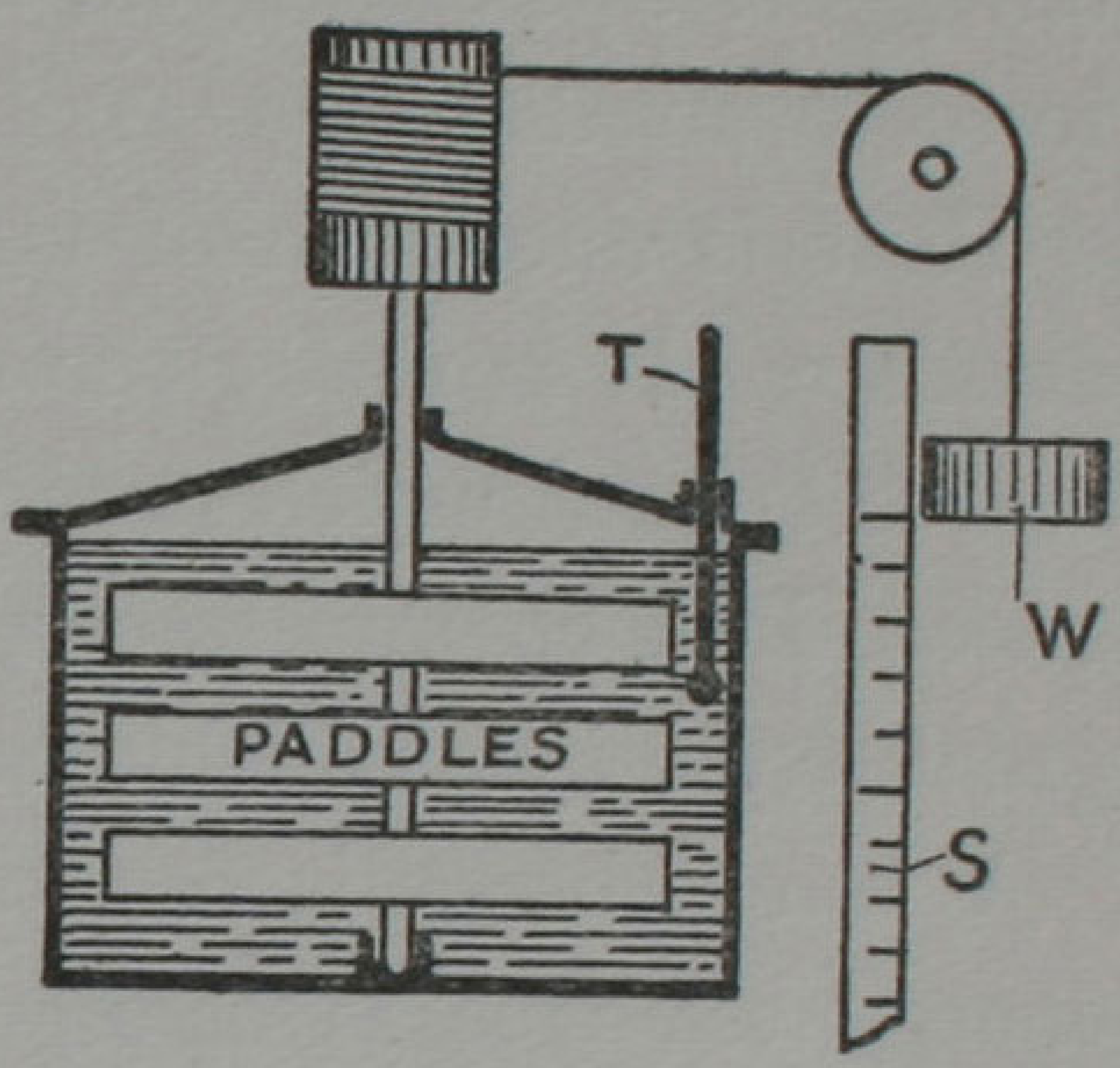
If a thermometer be placed in a vessel which contains one pound of water, and the water be heated until its temperature rises exactly one degree, then we say that the water has received one "unit of heat". This is the way in which we measure quantities of heat. For example, if a quantity of water weighing four pounds has its temperature raised by five degrees, we say that it has received four multiplied by five, or twenty units of heat.

15

HEAT, AND WHAT IT CAN DO (*Cont.*)

In the year 1864 Dr. Joule set himself to discover whether there was any connection between work and the heat which that work could produce. If a weight be lifted from the ground, it can be made to do work as it falls. For instance, the weights of an eight-day clock, as they descend, do the work necessary to turn wheels.

The apparatus which Dr. Joule used consisted of a tank containing a known weight of water. Inside the tank he placed an upright rod which had a number of vanes or paddles attached to it, and it also had a little pulley or drum at the top. A cord was wound round this pulley, and it passed over another one which served to guide it. A known weight was then suspended from the end of the cord. A thermometer was placed in the water, and the temperature was carefully noted. The weight was then allowed to fall through a measured distance, and in this way work was done. This work was used up in churning the water. This was repeated several times, and it was found that the temperature of the water had risen, for the work done by the falling weight had heated the water by churning it.



Dr. Joule's Apparatus

W, Falling weight. S, Scale.
T, Thermometer.

The work done by the falling mass was easily measured by multiplying its weight by the distance through which it had fallen; and the amount of heat given to the water was found from the product of the weight of water and its increase in temperature.

After many similar experiments Dr. Joule came to the conclusion that a certain amount of work always produced the same amount of heat. In fact, he gave a number which expressed the relation between those two forms of energy. He proved that it would be necessary to let a one-pound weight fall through a distance of nearly twenty-seven miles to heat one pound of ice-cold water to the boiling-point.

This discovery is one of the greatest that has ever been made in science. It proves to us that what we call energy is not destroyed, but is only changed from one form to another.

Heat is one form of energy, and chemical energy is another. It is really the chemical energy set free when coal is burned which produces the heat of the fire or furnace. It is chemical energy, too, that gives force to the great explosions which occur when gunpowder is ignited.

When a charge is fired in a gun, some of the chemical energy set free is changed into heat energy, and the remainder is stored up as mechanical energy in the moving shell. When the shell strikes a target its mechanical energy is again changed in form. Some of it reappears as heat, and some of it is spent in distorting the material of the target. So we learn the very important fact that energy is changed from one form to another, but is not lost.

Electricity is another form of energy. The electric current can be produced by making use of the energy possessed by flowing water, by the heat stored in steam, or by the chemical energy set free when gas or oil vapour is exploded in order to work an engine. In fact, all kinds of engines exist simply for the purpose of changing one form of energy into another.

Now Dr. Joule, in his experiment, changed mechanical energy into heat. Our steam engines and our gas and oil engines work in the opposite way, for the steam engine changes the heat which the steam has received from the coal burned in the boiler into mechanical energy, and for the same purpose the gas engine or oil engine makes use of the heat given out when the gas or oil has exploded or burned.

We have learned how to measure work, but this is not all we require to do. Two men may do equal amounts of work, but one may take much longer to do it than the other. This is equally true of two engines. A small engine will do as much work as a large one, if it is given sufficient time. But the power of an engine is the *rate* at which it can do work, and this is, after all, the most important thing.

It was James Watt, the great improver of the steam engine, who first attempted to measure the power of a machine, and he did it for a very good reason. He wished to sell his engines to men who had been accustomed to get their work done by horses, so he stated the power of his engine by saying how many horses it was equal to. And so to-day we speak of an engine being of so many horse-power.

Watt was an honest business man, and so he wished to make sure that he did not claim too much for his engine. So when he decided how much work a horse could do, he chose the most powerful one he could find.

16

ABOUT GASES

In the last chapter we learned that heat really did the work in engines, and that some medium was required to store up the heat and give it out again when the work was to be done. The medium is generally a gas of some kind. It may be water vapour, or steam as we call it; or it may be coal gas or the vapour of oil. It may even be air, for we are all familiar with the hot-air engine.

To begin with, we may take the gas to be air. Let us imagine that we have a tube or cylinder with one end closed, and that inside of it there is a disk or piston which fits it so closely that the air enclosed in the cylinder cannot escape. At the same time the piston must be easily moved. Perhaps if we think of a bicycle pump we shall follow the reasoning better.

Imagine that we have already pumped up a tyre until it is very tight, so tight, in fact, that we have to push very hard in order to move the piston of the pump—for that is what we do when we inflate the tyre.

We first pull the piston out, and the valve on the tyre prevents the air already inside from escaping. In this way we fill the cylinder of the pump with fresh air. If we now press the piston in again we find that we very soon come to a point beyond which we cannot move it. The reason for this is that we are trying to squeeze the air already in the tyre into a smaller space. The air resists this; it reacts, as we might say, and opposes the force which we apply by our hand. We see, then, that if we compress the air into a smaller space we increase its pressure.

If now we unscrew the valve so that the air is no longer locked in the tyre, and then reduce the pressure of our hand on the piston very slightly, the piston will be forced back, for the air tries to return to the volume it occupied before it was compressed.

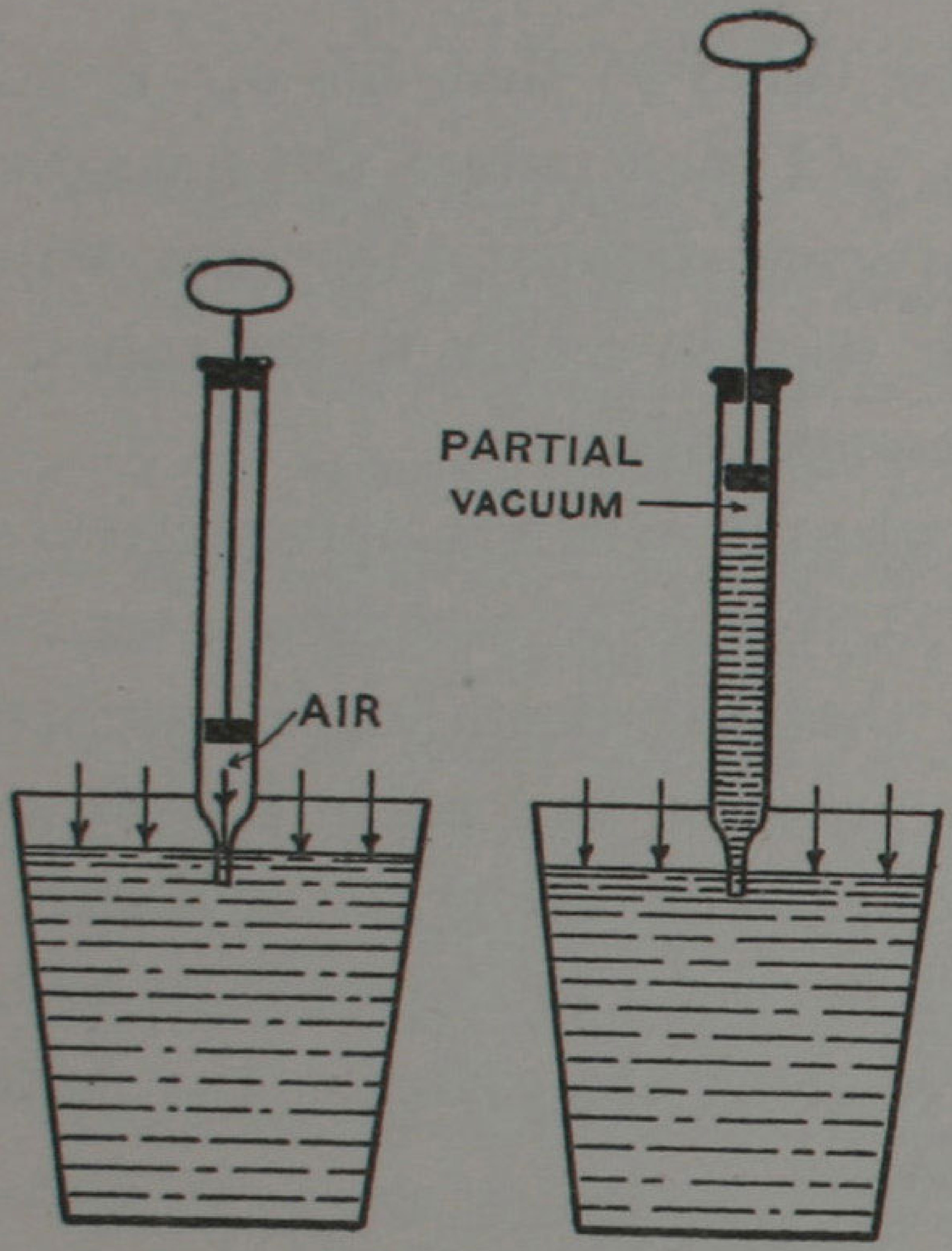
So we learn that a gas when it is in a compressed state exerts a pressure, and so it is able to overcome a resistance. It is in this way that the steam engine works. The steam is under high pressure, and so, in its efforts to free itself, it pushes the piston along the cylinder.

The piston is connected by links to the shaft in such a way that, when it moves along the cylinder, the shaft or axle of the engine is turned.

There is a very simple law which connects the pressure and the volume of a gas. If we hold the piston in some position and mea ure the pressure and volume of the gas and multiply them together, and then move the piston into a new position and measure these quantities again and find their product, the two answers will be equal. For example, if we double the space which a gas occupies, it will exert only one-half of the pressure which it did before.

The air around us exerts a pressure. Think of what happens when the piston of a syringe is drawn outwards. If the nozzle of the syringe is open to the air then the barrel will be filled with air; but if it be placed just under the surface of water in a bucket the water will rise in the barrel as the piston is pulled out.

We say that the water is sucked up; but this is not the real explanation of how a syringe works. The truth is that the small amount of air which was enclosed in the barrel, between the surface of the water and the piston, has its volume increased when the piston is withdrawn, so its pressure is reduced. But the pressure of the air on the surface of the water outside remains the same, and so now there is an excess of pressure there which forces the water up into the barrel.



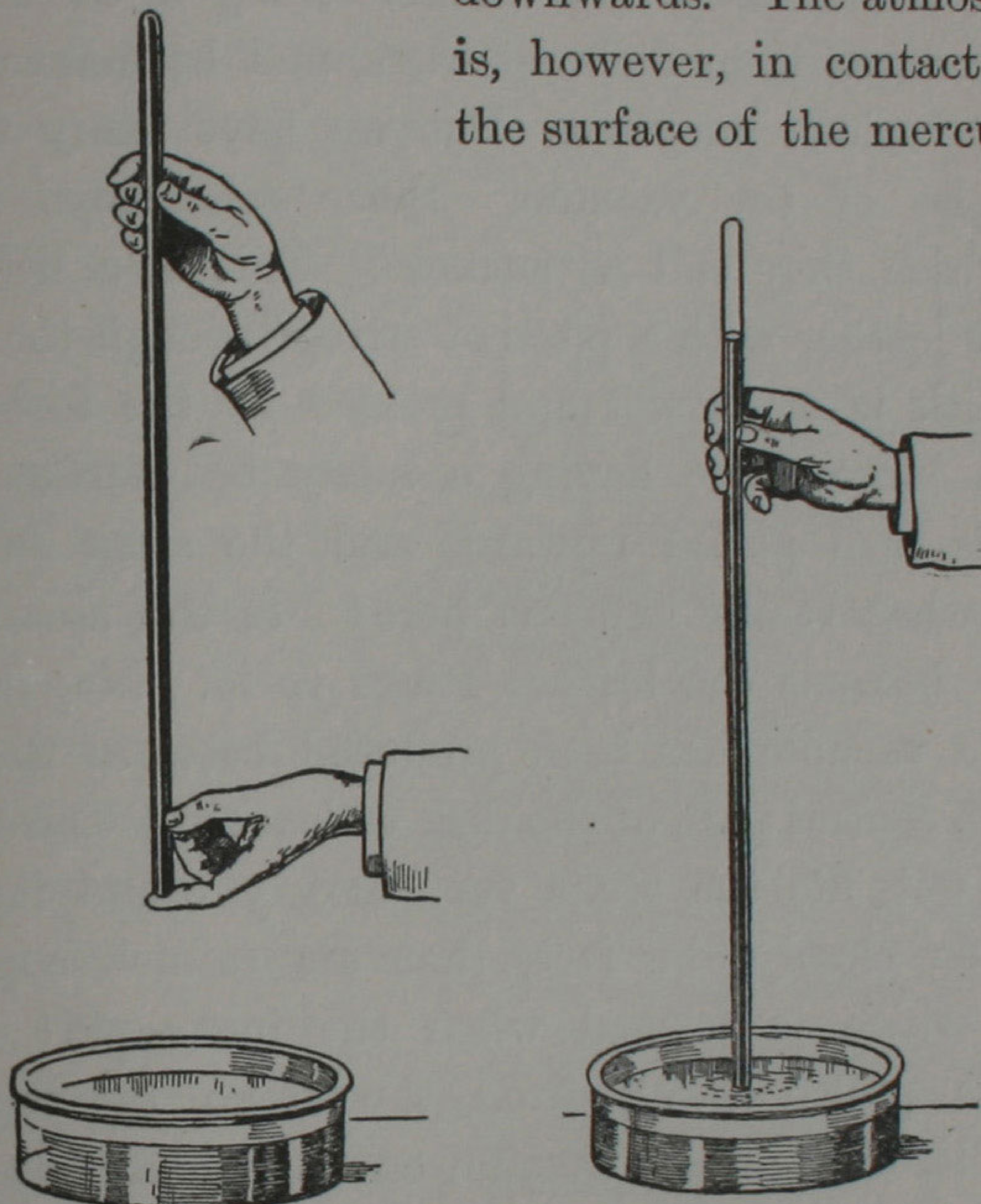
Filling a Syringe

17

ABOUT GASES (*Cont.*)

The pressure of the air which forms our atmosphere is measured by a barometer. The simplest form of barometer consists of an upright glass tube about a yard long; one end of the tube is sealed and the other dips under mercury in a dish. When making the barometer the tube is first held with the open end upwards and completely filled with mercury. The opening is then covered with the finger, the tube is now turned upside down and the lower end is dipped into the mercury in the dish without taking the finger away.

When the finger is removed the column of mercury drops a little, but there is no air above it to push it downwards. The atmosphere is, however, in contact with the surface of the mercury in



Mercurial Barometer

the open dish, and the pressure which it exerts is able to support inside the tube a column of the liquid about thirty inches long. The length of the column varies from day to day according to the weather conditions. The pressure which the atmosphere exerts on every square inch of surface exposed to it is very nearly fifteen pounds.

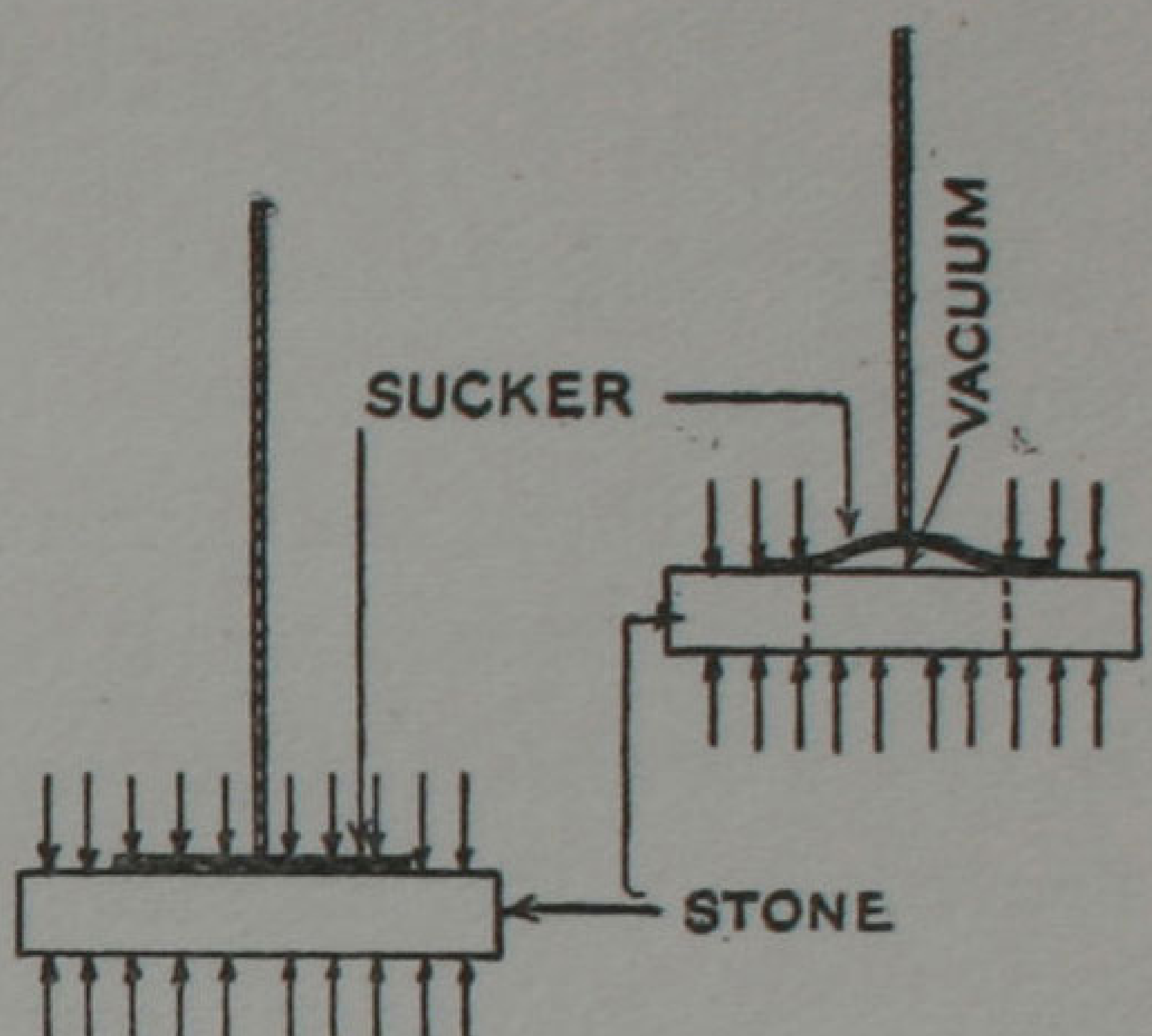
We learn, then, that the atmosphere can be made to lift, or support, a column of mercury if we reduce the pressure at the top of the column; or, as we say, if we create a "vacuum" there.

The vacuum is a very valuable thing to the engineer. He produces it in different ways, and he makes use of it for various purposes. But we have many familiar examples of the vacuum. Some schoolboys have a toy which they call a "sucker". This is a little disk of soft leather with a piece of string through the centre. The disk is made wet and pressed by the foot on to, say, a large stone having a fairly flat surface. The cord is then pulled upwards and the stone is lifted. Now, what really happens here? Is the stone lifted simply because the leather sticks to it? No; it is because a vacuum has been produced between the stone and the central part of the disk of leather. The leather, being wet, fits the stone very closely round its outer edge, so closely, in fact, that air cannot enter the space which is formed when the inner part of the disk is pulled away from the stone by the cord. There is, therefore, a vacuum on the under side of the leather.

Now, before the cord is pulled up, the pressure of the atmosphere is the same on the top as on the bottom of the stone. But when the cord is pulled and the central part of the leather is lifted, the total downward pressure of the atmosphere on the top of the stone is reduced, for now there is a vacuum over that part which is covered by the leather.

The pressure on the under side of the stone, however, remains the same, so there is now a force pressing the stone upwards. As we continue to pull the cord, more of the leather leaves the stone, and so the pressure on the top is relieved until the excess of pressure on the lower side of the stone is sufficient to lift it.

Sometimes a pump is used to lift water from a well. The piston of the pump sucks the air out of the pipe, which dips below the surface, and the atmosphere presses the water upwards, just as it pressed it into the syringe when the nozzle was placed in it.



The "Sucker"

The left-hand figure shows the stone before the sucker is pulled up. The pressures of the atmosphere are then equal on top and bottom of the stone. The right-hand one shows the sucker pulled up. There is a vacuum in the space between the sucker and the stone. There is now no pressure on the top of the stone between the dotted lines. But there is still the same pressure on the under side; so the excess of pressure lifts the stone.

The engineer sometimes uses a vacuum in order to boil liquids at low temperatures. Water, for instance, when placed in an open vessel has to be made very hot before it will boil. But if the vessel be sealed, and the air be sucked out from above the water, it will boil at quite a low temperature.

In an earlier chapter we read about the refining of oil. The very light oils can be made to boil off at a low temperature by simply producing a vacuum in the still. It is sometimes necessary to do this, because the high temperature which would be required to change the oil into vapour when exposed to the pressure of the atmosphere, would destroy it. It is in the steam engine, however, that most use is made of the vacuum.

18

STEAM BOILERS

In the oldfashioned steam engine the boiler and the engine were made in one, but nowadays they are quite separate. There are a great many kinds of boilers, each suited to the special work required. One of the simplest is the "Cornish" boiler, which like others is made in many sizes; for engines of different powers require different quantities of steam (p. 64).

In the Cornish boiler there is an outer shell or tube of steel plates. This tube is sometimes thirty feet long, and it may measure eight feet across. It is impossible to get a single plate large enough to make this shell, and so several plates have to be fixed together by means of strong rivets. The shell is closed by a plate at each end, which must be strengthened by brackets fixed to the plates and to the shell, to keep the pressure of the steam inside the boiler from bending them. Rods or stays are also passed through the boiler from front to back, and these help to prevent the ends from bulging outwards.

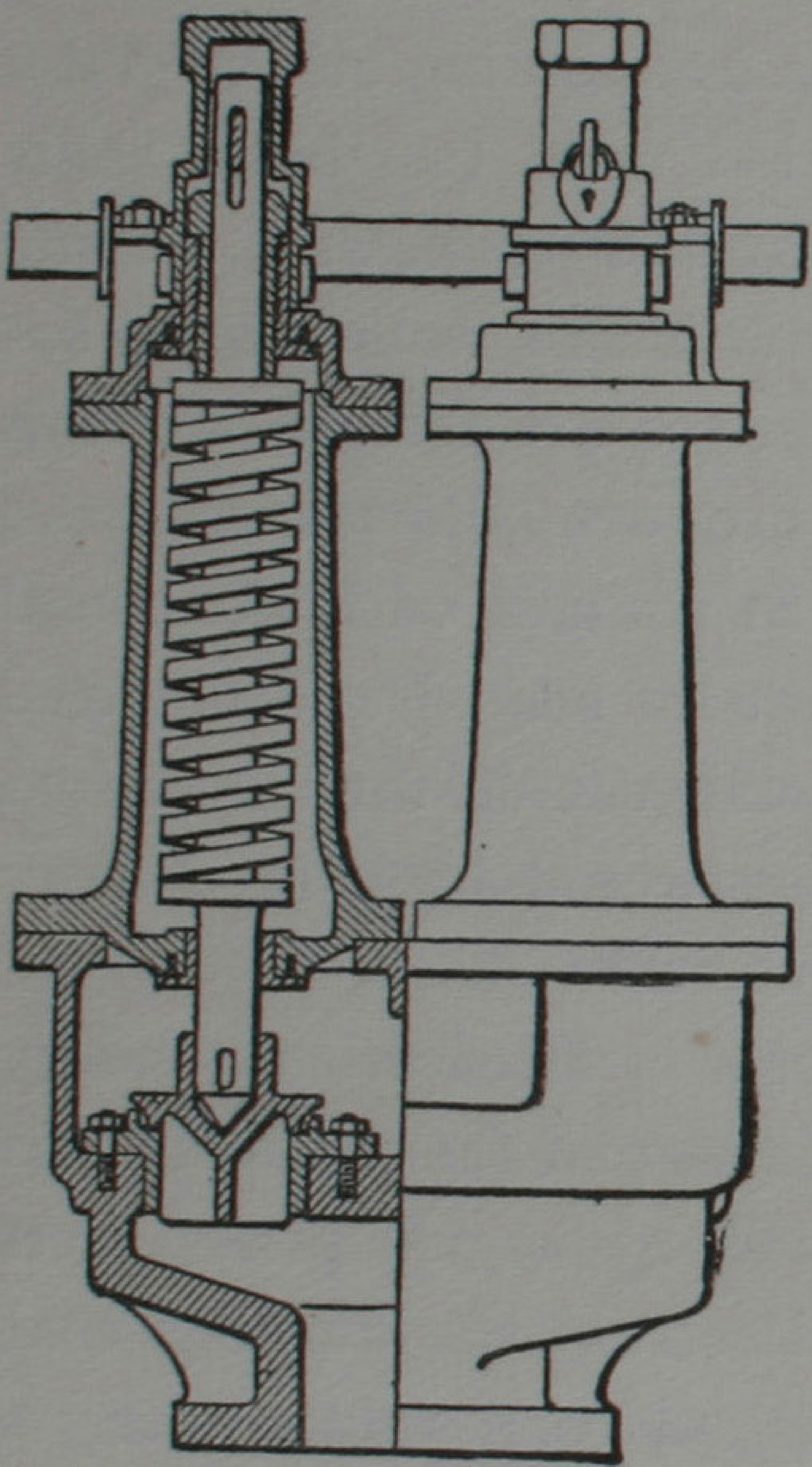
Inside this shell there is another about three feet in diameter which extends the whole length of the boiler. It is securely fixed to the end plates, and each piate has a hole cut in it so that this inner tube is open right through. The front end of this tube is used for the furnace. The grate is made of iron bars about six feet long. At the front they rest upon a bracket which is fixed to the front plate of the boiler, and their other ends are supported upon a brick wall, or bridge, which is built inside the tube. The top of this wall is a little above the bars, and this prevents the coal from falling off the grate.

The whole boiler is supported upon two brick walls which run from the front to the back, and is surrounded by other brick walls. These walls are so arranged that a number of passages are formed through which the gases from the fire are allowed to pass; and as they do so they are in contact with the metal plates, and so the water inside is heated and changed into steam. Ordinary bricks will not do for the insides of these passages, because they would be burned away very soon; so a lining of firebrick is used.

The front of the inner tube is fitted with a heavy door, in which there are openings; and the amount of air going into the fire is regulated by a grid placed over these. The gases, as they rise from the burning coal, pass along the furnace tube, and then return along a passage under the outer shell. In this way they reach the front end of the boiler, where they divide and pass by two side passages to the back of the boiler again. From there they go away to the chimney. By this time the gases have been cooled down, but they are still hot when compared with the air outside, and so some of the heat of the coal is lost.

The boiler is not filled quite full of water, for then there would be no room for the steam; but the water must be high enough in the boiler to cover the furnace tube, else the plate would become red-hot and collapse. Many serious explosions have occurred on account of the water being allowed to get too low.

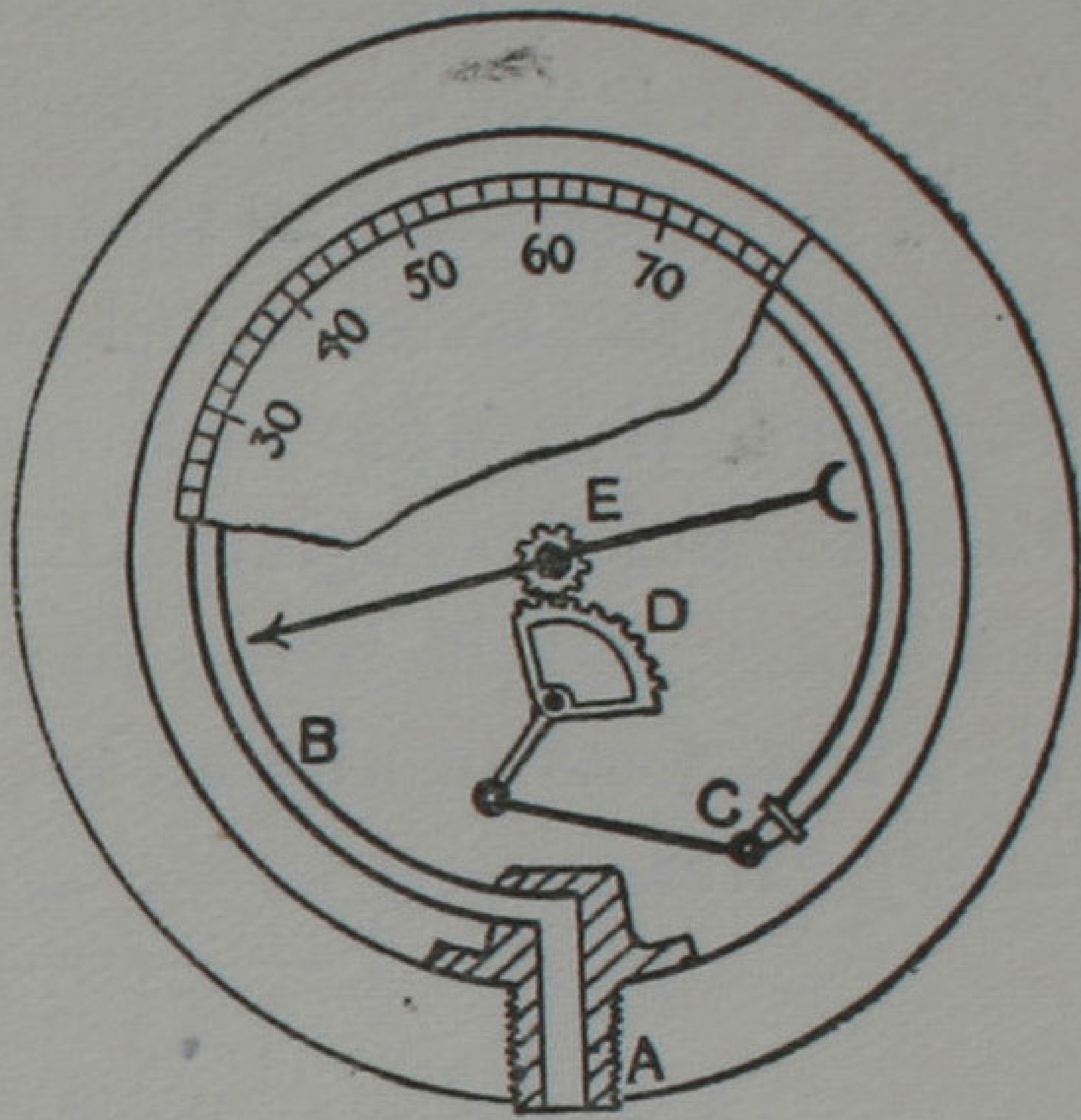
To let the fireman know at what level the water stands, two cocks are fitted to the front of the boiler, one above the other. These cocks are connected together by a strong glass tube. The middle of this tube is on about the same level as that at which the water inside the boiler ought to be, and so the fireman can tell when he has to feed in more water.



Safety Valve loaded by Springs

It must be remembered that the pressure of the steam in the boiler is very great, and so it is necessary to force the water in. This is done by a pump. A valve is always fitted in the pipe which leads from the pump to the boiler, and it is so made that it can open to admit the water to the boiler when the force produced by the pump is sufficient to overcome that of the steam; but should this force not be great enough to do this, the steam pressure closes the valve, and so the contents of the boiler cannot escape.

Now let us imagine that the water has been put into the boiler, and that the pipe which leads from the boiler to the engine has been closed. The fire is lit, and in course of time the water boils just as it does in a kettle, but with this difference that the steam cannot get away. The steam very soon fills the space above the water. As the fire continues to burn, more steam is formed, but it has to squeeze itself into the space already filled with steam. This really means that the steam is compressed, and so its pressure increases.



Pressure Gauge

The steam from the boiler enters the curved tube B by the opening A. The pressure in B tends to straighten it, so moving point C to the right. The greater the pressure the farther does C move. The motion of C is transmitted to the pointer, which moves over the graduated scale by the toothed quadrant D and the wheel E.

The pressure inside the boiler would go on increasing in this way until even the strong steel plates could not stand it, and an explosion would occur. Explosions do actually happen on account of the steam pressure becoming too great. A valve must be fitted on the boiler which will open when the pressure reaches what is known to be the greatest that it is safe to allow. This is called the "safety valve", and is loaded by heavy weights or forced down by a spring.

When the pressure rises too high, the valve is driven open and the steam escapes until the pressure falls again to the proper value, when the weight, or spring, closes it again.

A gauge is also placed at the front of the boiler to show what the pressure is. It has a pointer which, as the pressure increases, moves over a dial with marked numbers. These numbers tell the force with which steam is pressing on each square inch of the boiler.

If the valve which connects the boiler to the engine is open and the engine started, then the fire must be kept going at such a rate that the amount of steam formed in the boiler is just sufficient to keep the engine running. If the fire is burned too slowly the pressure will fall, and the engine will not be able to drive all the machinery. If it burns too briskly, the pressure will rise, and some of the steam will be lost through the safety valve.

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STEAM BOILERS (*Cont.*)

The coal can be shovelled into the boiler by the fireman, or stoker as he is called; or it may be fed in by a machine known as a "mechanical stoker". These are of many kinds. One is a tube with metal plates projecting from it on each side and a slot along the top. Inside the tube there is an apparatus like a very large corkscrew. This screw is turned by an engine or electric motor. Coal is fed into the front of this tube either by hand, or from another tube which conveys the coal from the bunkers above the boiler. As the screw turns, the coal is driven forward, and it rises and spreads itself over the flat plates, where it burns.

Another kind is the chain-grate stoker. In it the grate is made up of a large number of links. The chain may be as many as six feet broad—think of a cycle chain, and imagine that the pedals represent the engine at the front of the boiler. If the pedals be turned the wrong way round we have a model of this kind of stoker.

The hub of the back wheel corresponds to the drum which is placed at the inner end of the grate. Coal is fed on to the chain above the crank, and it is slowly carried forward and burns as it moves along. The speed is regulated so that when the coal has reached the hub of the back wheel it is completely burned. It then falls over the end into the ashpit, and the chain returns to the front again, where it receives a fresh charge.

Mechanical stokers have many advantages over firing by hand. They need very little attention; and one man can look after several boilers without trouble, so the cost of labour is reduced. It is no simple task to fire a boiler properly. An inexperienced man will very soon allow the fire to burn into holes and a stream of cold air will enter and cool it down, and so waste the coal. But the machine keeps the fire at a uniform thickness.

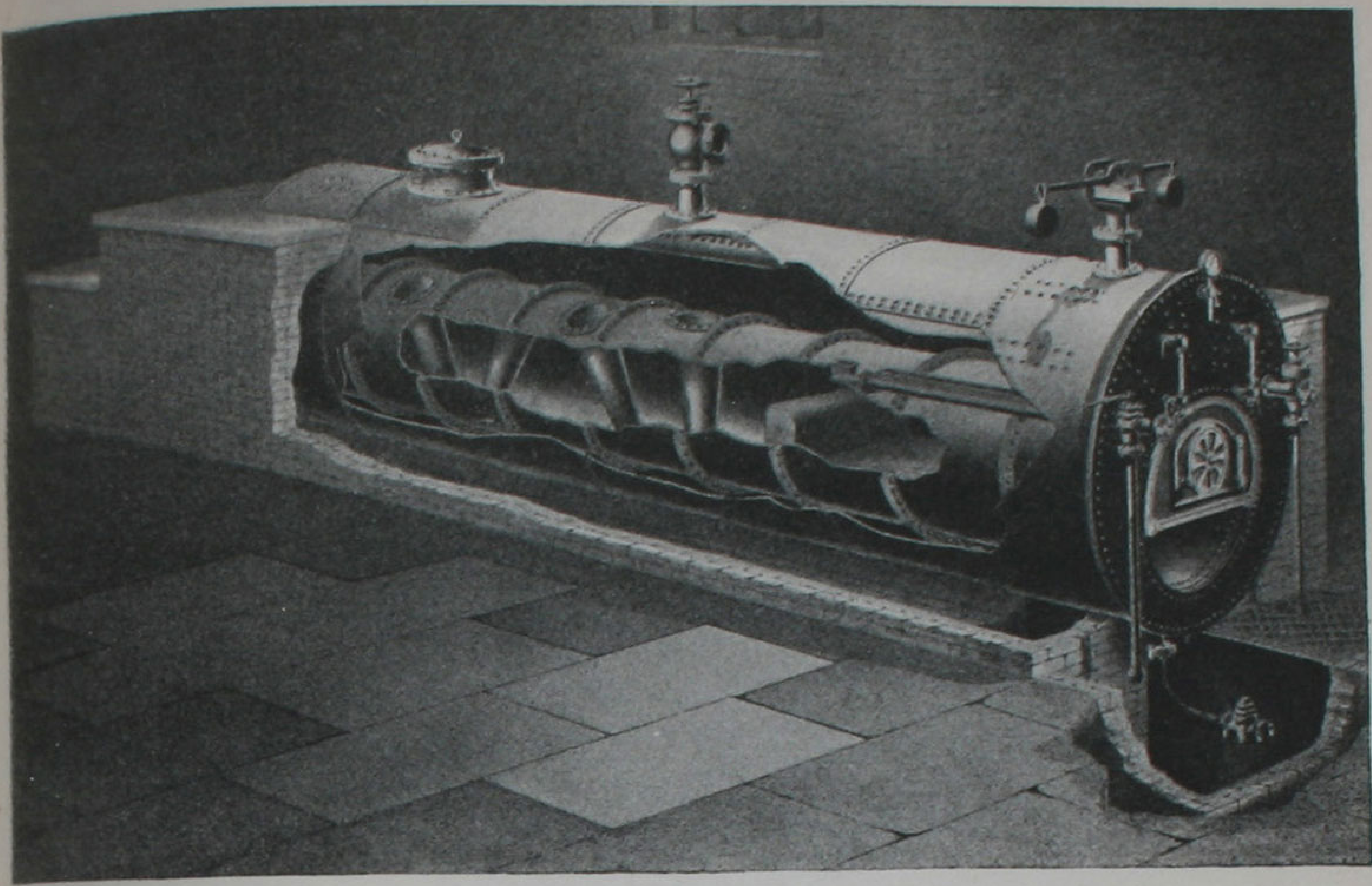
At sea, where the amount of steam required varies very often and very rapidly, these machine stokers are not suitable, for it is a difficult matter to regulate their speed properly. The rolling of the ship, too, makes it impossible to use them.

The Lancashire boiler is very like the Cornish boiler, but it has two furnaces, placed side by side, instead of one. Lancashire and Cornish boilers are used very largely on land, but they are unsuitable for use on board ship, because the rolling and pitching of the vessel would soon break down the brick walls upon which they have to be supported. The marine boiler has a shell very like that of the Cornish boiler, but it is fixed down to the hull of the ship. It has two, three, or sometimes even four furnaces. The gases, after they have passed through the furnaces, return to the front of the boiler again through a large number of small tubes which are below the level of the water in the boiler. In this way they give up some more of their heat. They then enter a box-shaped chamber called the smokebox and from there they pass up to the funnels (see opposite).

There is another kind of boiler which is used both on land and sea. In it there are a number of drums, some of them placed low down and others at a high level. These drums are connected to one another by a large number of tubes. The water fills the lower drums and the tubes, and it reaches to about the level of the centre of the upper drums. The space above this level is reserved for the steam. This whole structure is enclosed either by brick walls, when used on land, or by steel plates lined with firebrick, at sea.

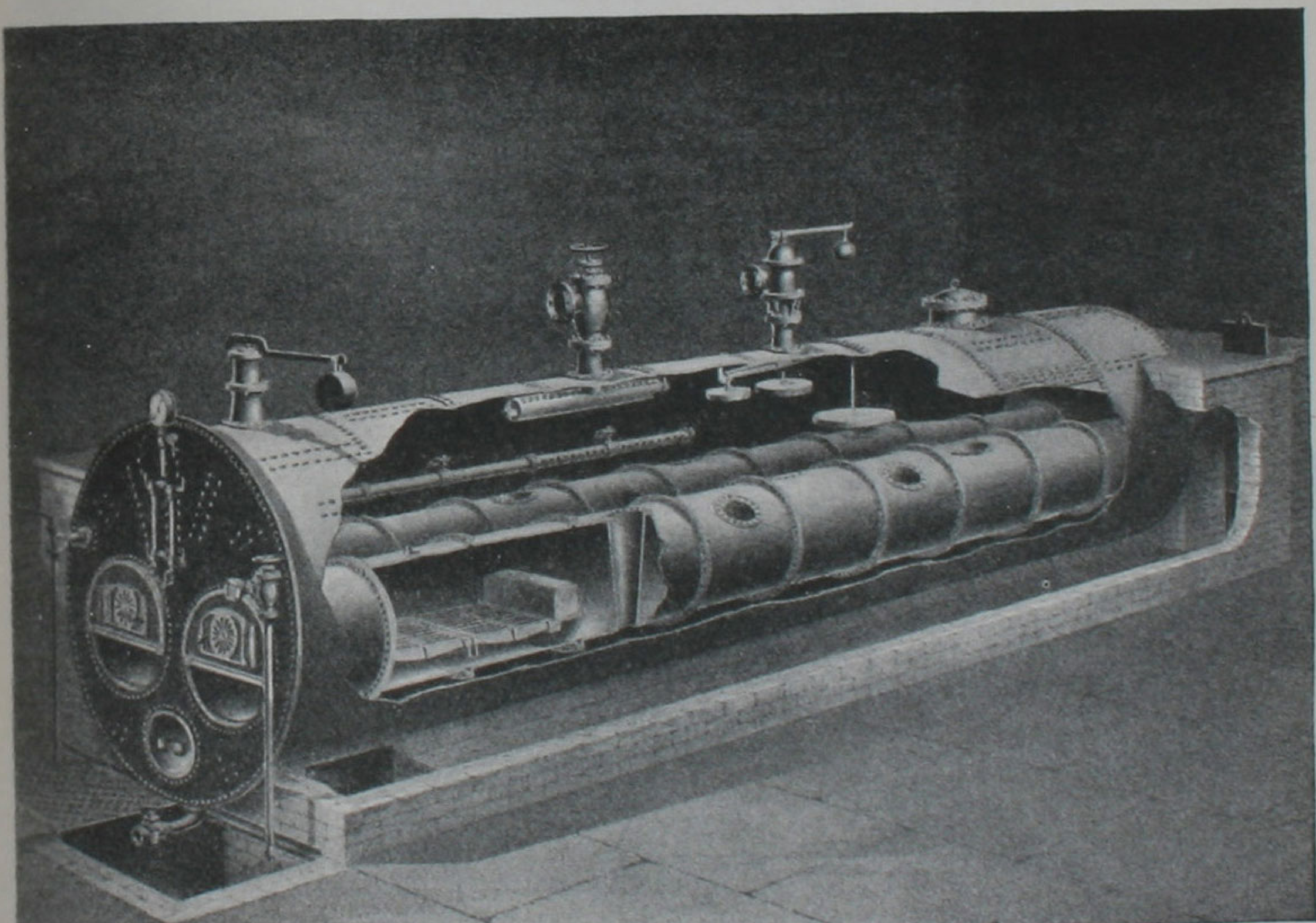
The grate is at the front of the boiler, and the gases which arise from the burning coal pass between the tubes, and so the water within them is heated and turned into steam. The gases then pass away to the chimney. One great advantage of this "water-tube" boiler is that steam can be raised much more quickly in it than in a Cornish or Lancashire boiler.

The gases when they leave the boiler are still very



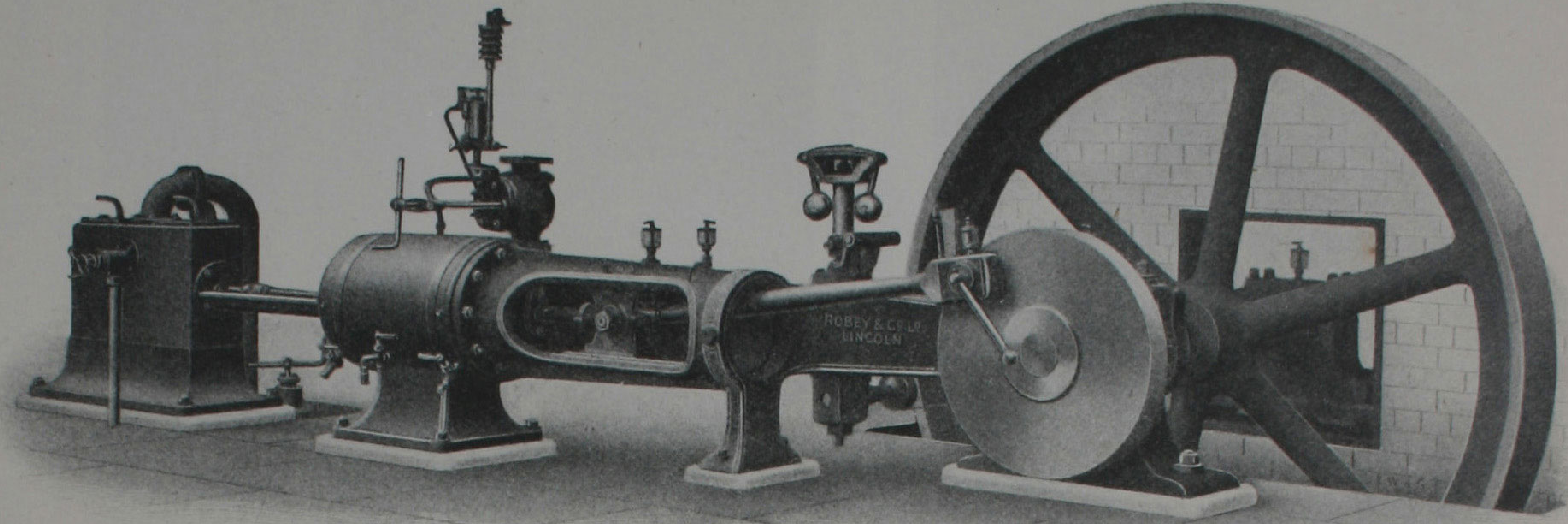
CORNISH BOILER

(See p. 58)



LANCASHIRE BOILER

(See p. 64)

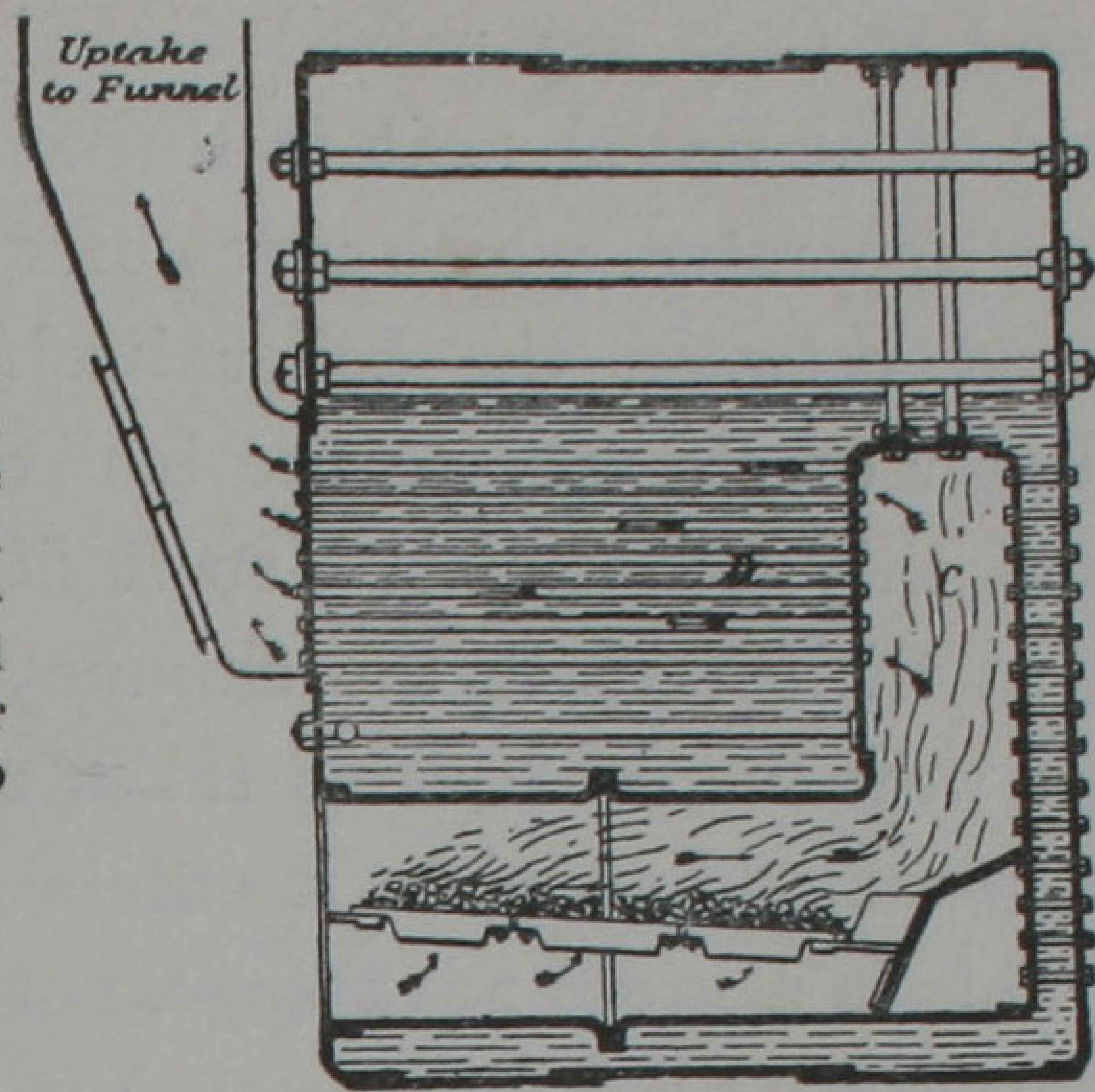


Condenser — Cylinder — Governor — Crank disk — Flywheel

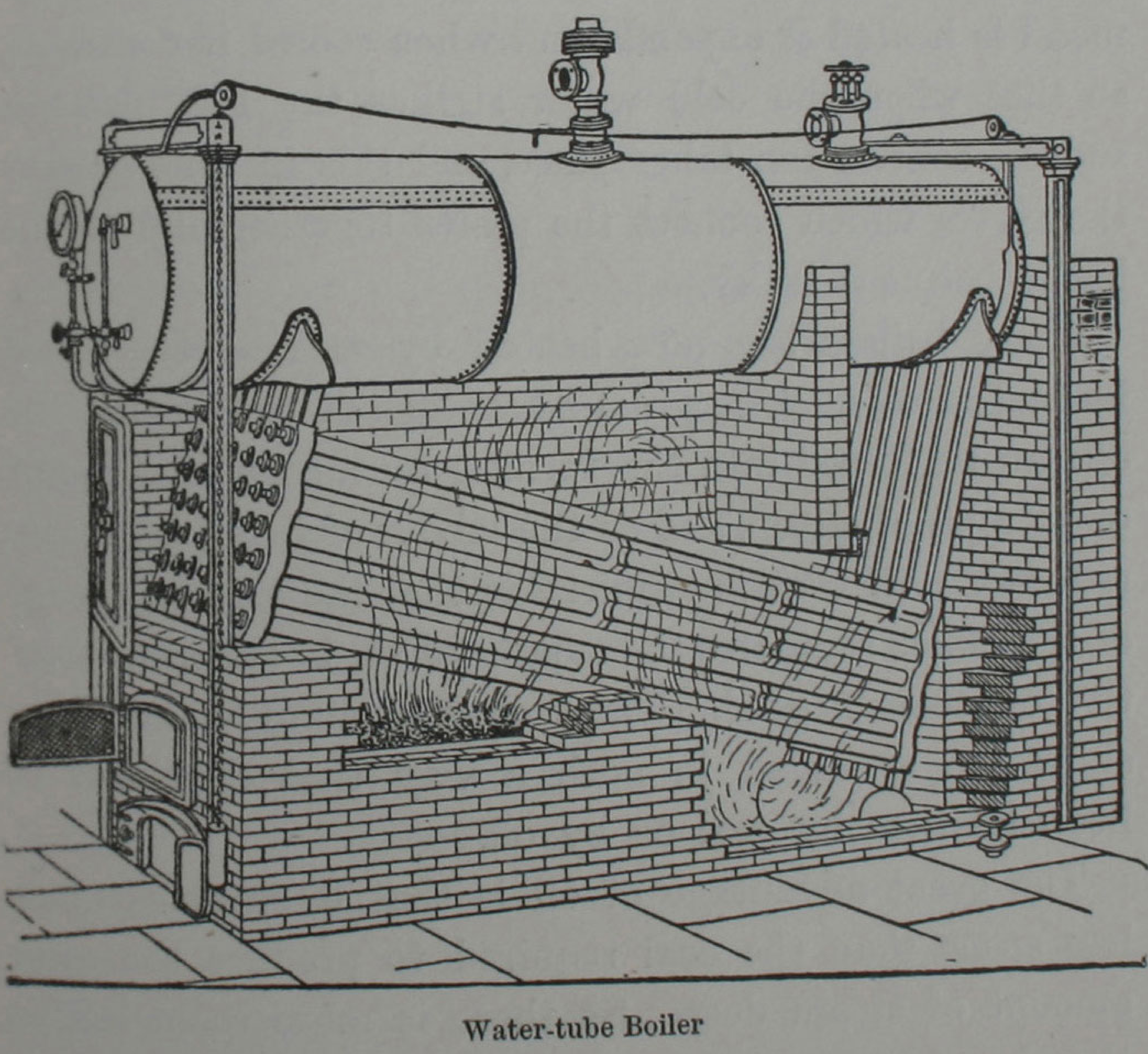
STEAM ENGINE

(*See p.* 68)

The hot gases from the fire pass through the chamber *C* and the tubes *D*, and so reach the funnel. The water-spaces at the bottom and the back of the boiler are necessary to keep the plates cool.



Marine Boiler



Water-tube Boiler

hot, and if they are passed directly to the chimney a great deal of useful heat is thrown away. Sometimes another apparatus, which resembles a water-tube boiler, is placed between the boiler itself and the chimney. The water on its way to the boiler passes through the tubes of this "economizer", as it is called, and the hot gases on their way to the chimney pass around them. In this way the cold water takes up some of the heat of the gases, and so when it enters the boiler it is very hot. This is a great advantage, not only on account of economy of coal but also because it is a very bad thing to allow very cold water to come into contact with the hot plates of the boiler. We must remember that when metal is heated it expands and when cooled it contracts, so that when the cold water strikes the hot plates a sudden contraction takes place, and this in time loosens the rivets which connect the plates together and so the boiler becomes leaky.

Many boilers are now heated by means of oil fuel instead of coal. One great advantage of this is that the oil can be forced into the furnace by means of a pump, or by a jet of steam, and so the labour of firing is greatly reduced. All that is required is that the man in charge of the boiler regulates the supply of oil to suit the quantity of steam needed. The boilers of many of our warships are arranged in such a way that they can be heated either by coal or by oil.

The great advantage of oil is that it occupies much less space than the coal required to produce the same amount of steam does. So there is more room left in the ship for cargo.

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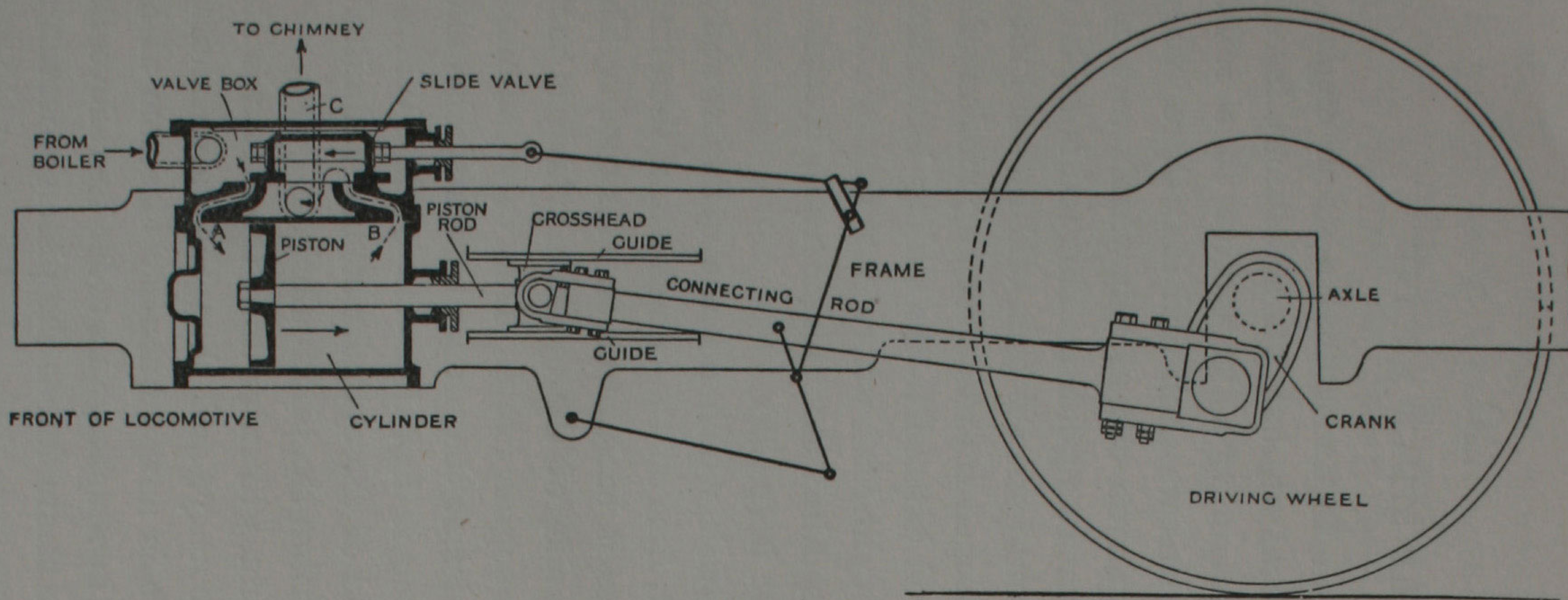
THE STEAM ENGINE

It is very difficult to understand a steam engine by merely reading about it, but we sometimes have an opportunity of examining a locomotive at a railway station. If we do this we shall find that there is a rod which connects a pin on one of the wheels to a block which slides between two guides. This rod is called the "connecting rod", and by it the back-and-forward motion of the block is changed into the turning motion of the wheel. Another rod is fixed to the sliding block, and it passes into the "cylinder" where the steam does its work. This rod is called the "piston rod", because the "piston" is fixed to it (p. 65).

The piston is a disk which fits the cylinder, and the steam presses on it, first on the one side and then on the other, and so drives it backwards and forwards. There is a valve on one side of the cylinder which is moved to and fro by the engine itself. This valve admits the steam to the cylinder at the proper time and also allows it to pass out after it has done its work. When the piston is at one end of the cylinder steam is admitted to that end, and it pushes the piston along.

The steam continues to enter until the piston is about halfway on its journey, and then the valve shuts off the supply. There is now a quantity of steam at high pressure enclosed in a space. In order to relieve itself of its pressure, the steam forces the piston onwards, and as it does so, its pressure falls. In this way the steam



Engine of Locomotive

Steam from the boiler enters the valve chest or box. It then passes down the passage A into the cylinder. Its pressure drives the piston forward, and the spent steam upon the other side of the piston is forced up the passage B, under the slide valve, and away up the chimney. When the piston reaches the end of the cylinder, the valve has moved over so that fresh steam from the valve box now enters from the passage B, driving the piston back again. The steam on the left side now escapes under the valve and away to the chimney. In this way the piston is driven backwards and forwards continuously.

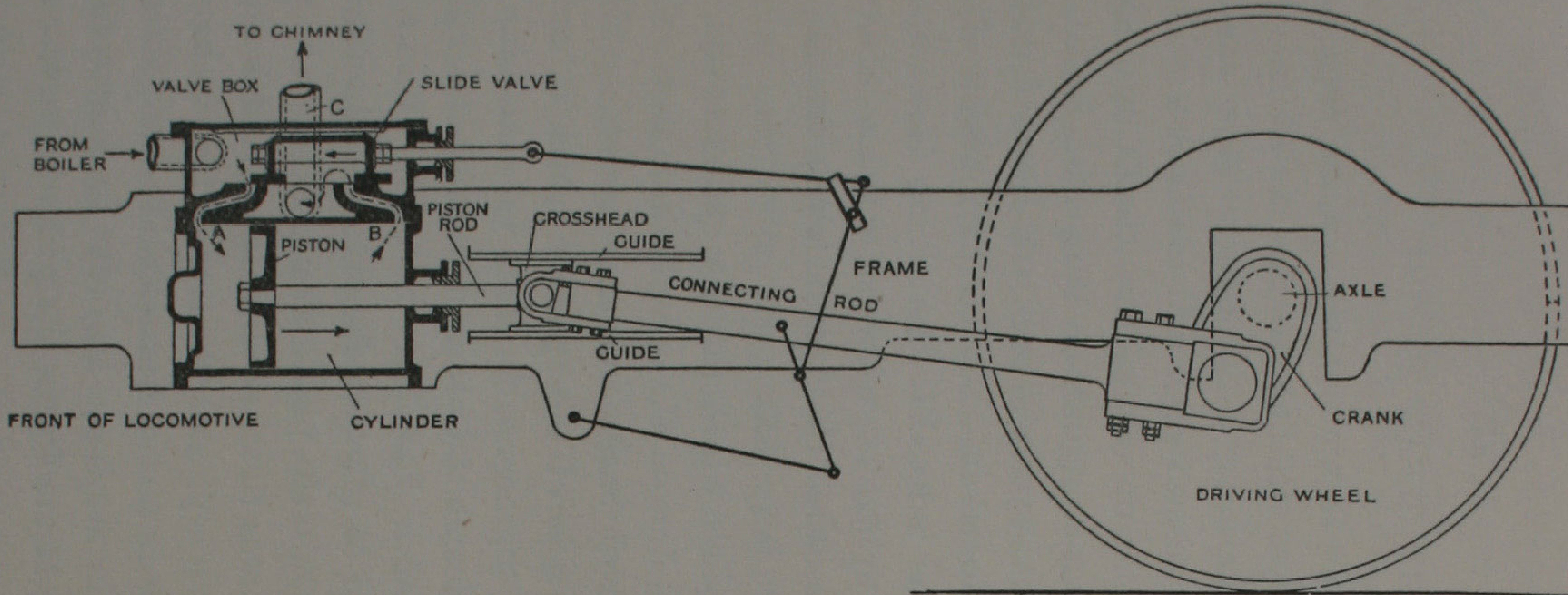
The piston rod connects the piston to the crosshead, which slides between the guides. The motion of the crosshead is transmitted to the crank on the axle of the driving wheels by the connecting rod. The other wheels of the engine are left out, as they would confuse the diagram.

is cooled, and some of the heat which it contained is changed into useful work.

Very soon the piston reaches the other end of the cylinder and by that time the valve has moved into a position which allows this spent steam to pass out into the air. In the locomotive it passes up the chimney, and it is seen coming out in a series of puffs. Steam now enters at the other end of the cylinder and drives the piston back again. All this takes place in a very short time. When a locomotive is going at sixty miles an hour, the piston travels from one end of the cylinder to the other and back again in about one quarter of a second.

When the steam passes away from the engine it still has a large amount of heat in it, for it gives up only about one-tenth of the heat which it received from the coal in the boiler, while passing through the engine. This means that for every ten pounds of coal burned, nine are really lost, because the heat which they have given to the steam is carried away to the atmosphere. So we see that a steam engine is not economical.

When the steam is forcing the piston in one direction, it has to drive the steam which has done its work on the other side, out into the atmosphere. But we have learned that the atmosphere exerts a pressure of nearly fifteen pounds on each square inch of surface exposed to it. In some of the large engines used on board ship, the cylinder may measure as many as one hundred inches across. This means that the pressure of the atmosphere upon it is more than fifty tons. If, then, this atmospheric pressure which acts against the motion



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This can be done in a very simple way. Imagine that we have a vessel filled with steam and that we plunge it into another containing water. The steam inside the vessel will be immediately turned into water, and so it will occupy a very much smaller space than it did before; for a very small volume of water makes a very large volume of steam. What, then, is the remaining space filled with? There must be a vacuum above the water.

The apparatus in which the steam is turned into water is called a "condenser". The steam, after it has done its work in the engine, is not allowed to pass away to the atmosphere, but it is led by a pipe into this condenser, and in this way the pressure behind the piston is reduced.

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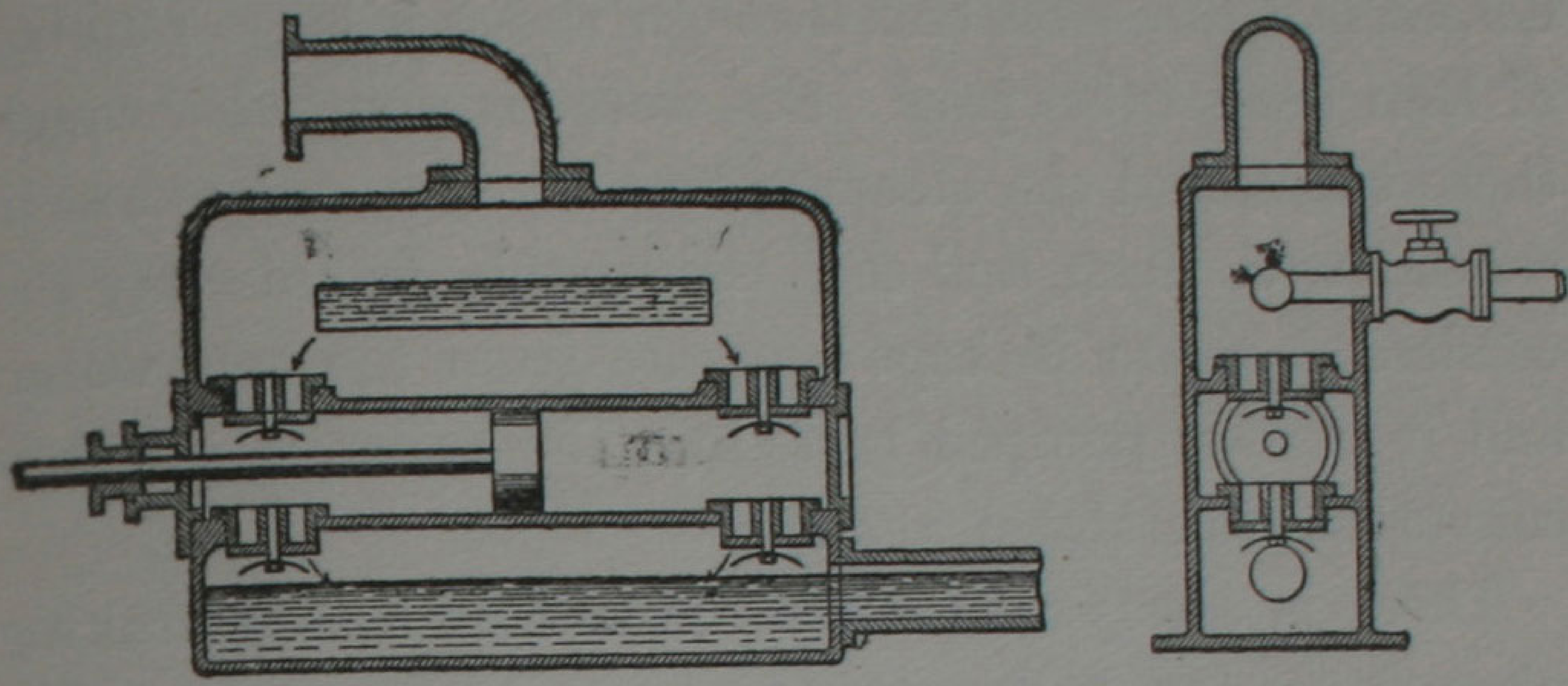
THE STEAM ENGINE (*Cont.*)

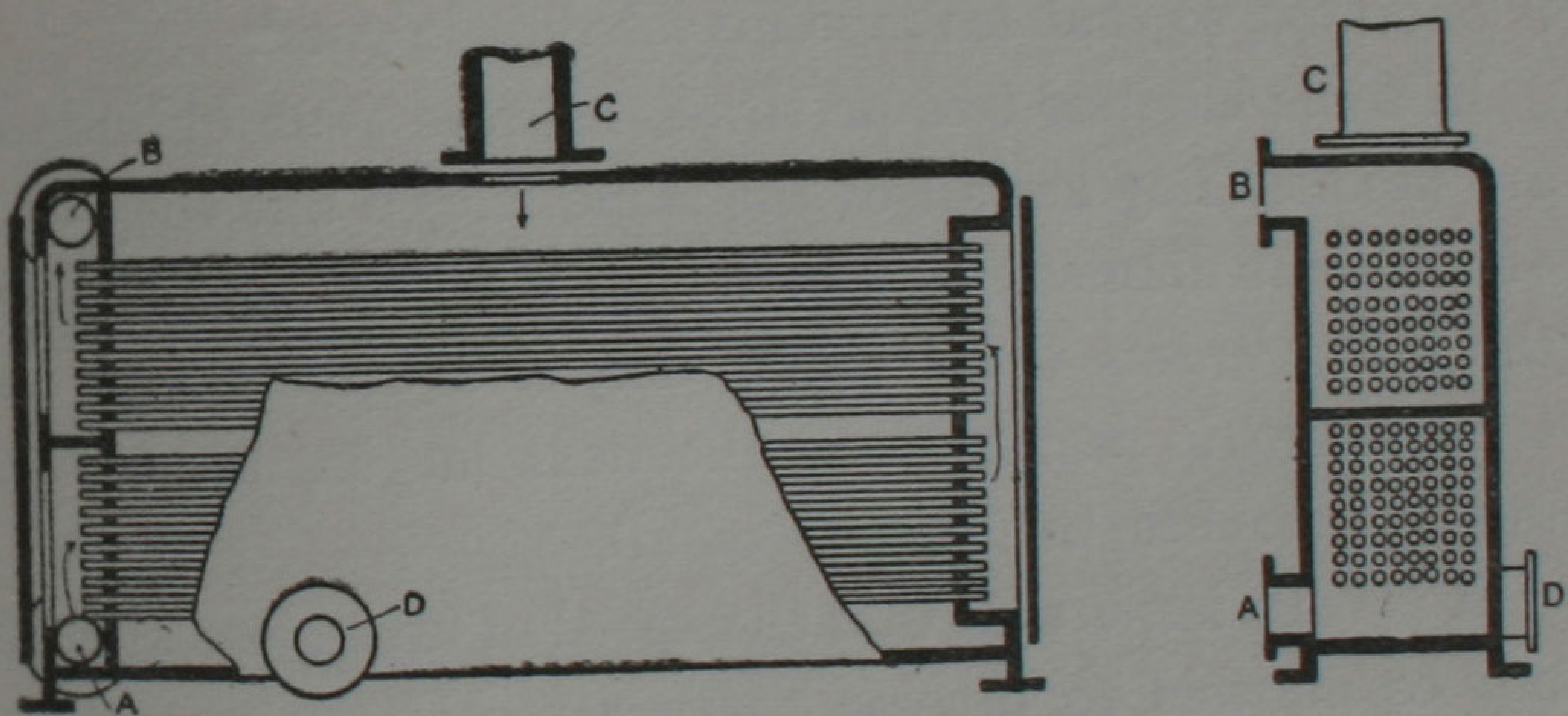
There are many kinds of condensers. In one form the steam is led into a box where it meets a continuous stream of water which is sprayed in, in the form of a cone. The steam is immediately cooled and turned into water, and it passes away from the bottom of the box along with the water which forms the spray. This is a very simple kind of condenser, but it is not always convenient to use this type.

At sea fresh water is very scarce, so sea water is used for condensing the steam. But salt water must not be put into the boilers, because if it were then when the



Jet Condenser

steam was formed the salt would be left behind in the form of a crust on the steel plates. This crust would in



Surface Condenser

Cold water enters at A and passes through the lower tubes. It then returns by the upper tubes and leaves at B. The steam from the engine enters at C, and, coming in contact with the cold tubes, is condensed to water. A vacuum is therefore produced. The condensed steam is drawn out at D by means of a pump.

time cause the plates to become burned and explosions might take place.

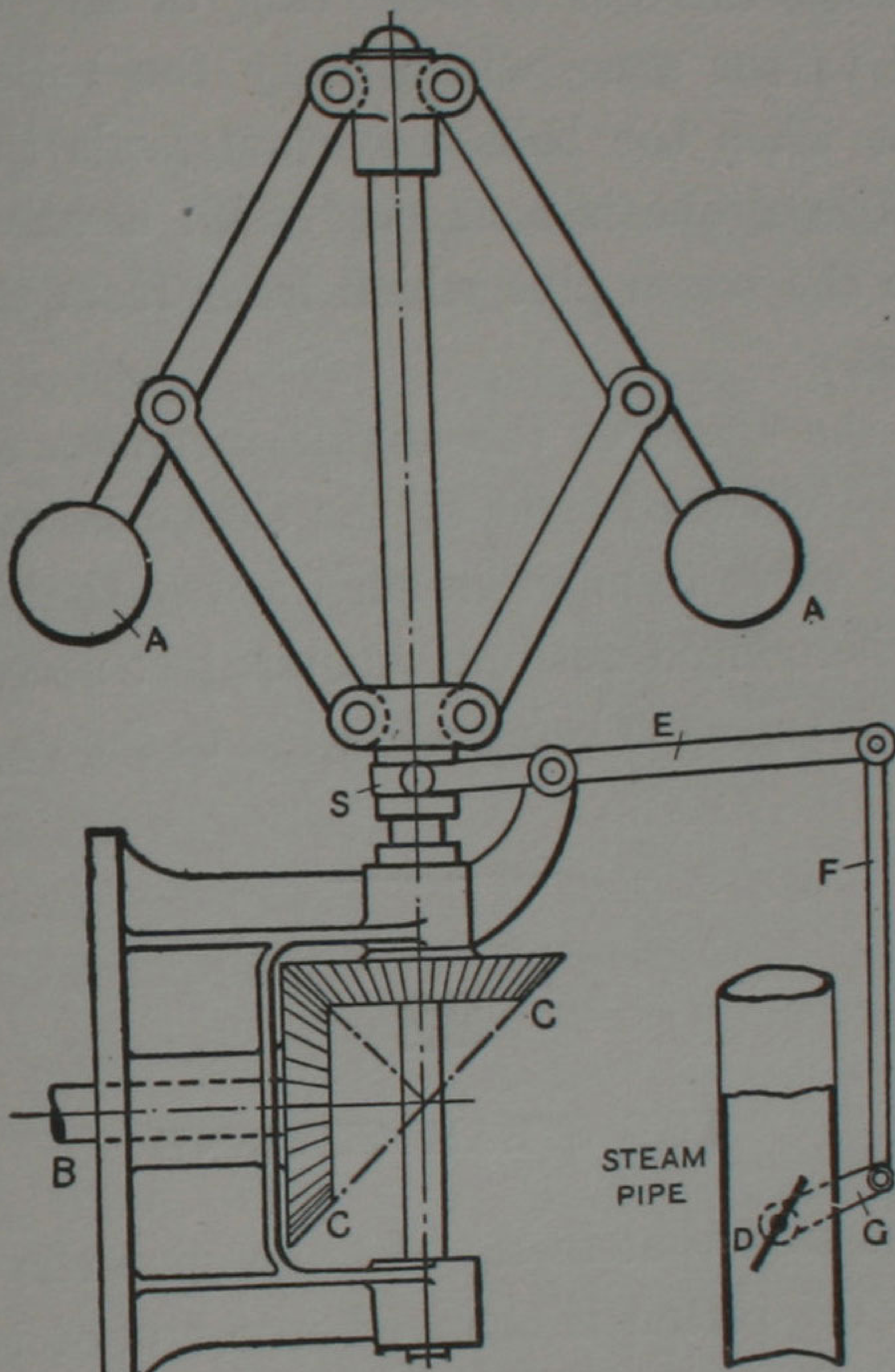
The same fresh water must therefore be used over and over again. This is done by filling the boiler to the proper level with fresh water before starting on a voyage and by using a special kind of condenser. This condenser is a cast-iron box through which a large number of thin brass tubes pass. Sea water is pumped through these tubes, and the steam enters the box and comes in contact with them, and so is condensed. In this way the condensed steam is kept separate from the salt water, and it is then pumped back into the boiler, where it is converted into steam again.

There is always a certain amount of leakage taking place from the boiler, the pipes, and the engine. To make up for this, ships are fitted with an "evaporator" which boils the salt sea water, and the steam formed is condensed. In this way a reserve stock of fresh water is obtained, so that leakage may be made good.

In some engines two or three, or even four cylinders are used. They are all of the same length but they are of different diameters. The steam when it comes from the boiler enters the smallest one, and after doing its work there it passes on to the next larger, and so on until it reaches the largest of all.

It is very important that the speed of an engine should not be allowed to become too great. If the engine is driving a number of machines and a few of them are suddenly disconnected the engine will go faster, because the steam still does the same amount of work as before, while less is now being required by the machinery. To prevent this increase in speed a "governor" is fitted to the engine. The governor was invented by James Watt, and it is used to regulate either the pressure or the supply of steam to suit the work to be done.

In order that we might better understand how the governor acts, let us imagine that we have a heavy ball or stone suspended from the end of a piece of cord. If



Steam-engine Governor

The governor is driven round by the engine, through the axle B and the toothed wheels C C. When the speed of the engine increases, the balls A A move outwards. The sleeve S rises, the rods E, F, and G are moved, and the valve D is partially closed. In this way the amount of steam passing to the engine is reduced, and so the engine slows down again.

the upper end of the cord be held in the hand and the ball caused to move in a horizontal circle, we shall find that the faster the ball revolves the larger will be the circle in which it moves. This is exactly what happens in the governor. There are two arms, each of which carries a heavy ball at its lower end. Their upper ends are pivoted on a rod which is rotated by the engine. On this rod there is a loose ring or sleeve, and it is attached to the arms which carry the balls in such a way that when the balls move outwards the sleeve is lifted. The sleeve is connected with a valve which is placed in the steam pipe which leads from the boiler to the engine.

When the speed of the engine increases a little, the balls move outwards and so the sleeve is raised. This causes the valve to move in such a way that the supply of steam is reduced until an amount just necessary to do the work required is being admitted to the engine.

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THE STEAM TURBINE

We have seen that in the steam engine the to-and-fro motion of the piston is changed into one of turning by the aid of the connecting rod. The steam turbine is quite different from the steam engine. In it the steam causes the parts upon which it acts to rotate, so that there is no back-and-forward motion. This is one of the many advantages of the turbine. Energy is lost when the back-and-forward motion has to be changed into one of turning, since a great deal of friction has to be overcome at the joints which connect the various links which are needed to bring about this change (p 80).