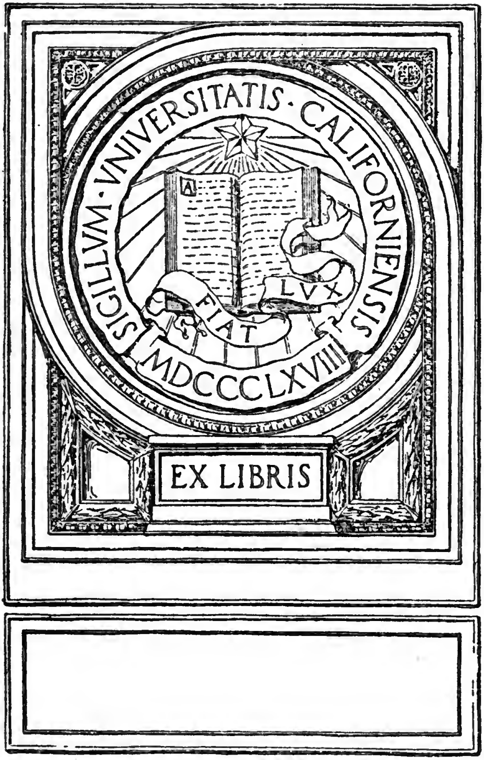
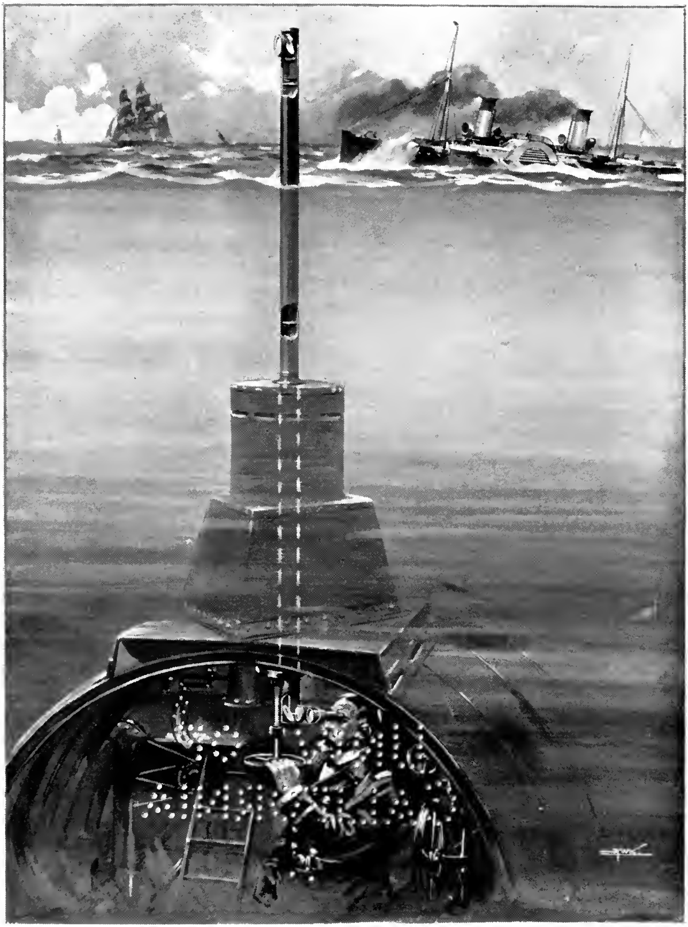


A

ENGINEERING OF TO-DAY



THE "EYE" OF THE SUBMARINE BOAT

When moving under water the "man at the wheel" sees his way by means of the periscope, which projects above the surface, but is so small that it cannot itself be seen. At the top of the tube is an artificial eye, and what that eye sees is reflected down the tube and into the real eyes of the man below.

ENGINEERING OF TO-DAY

A POPULAR ACCOUNT OF THE PRESENT STATE OF THE SCIENCE, WITH MANY INTERESTING EXAMPLES, DESCRIBED IN NON-TECHNICAL LANGUAGE

By

THOMAS W. CORBIN

With 39 Illustrations & Diagrams

PHILADELPHIA
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PREFACE

ENGINEERING is now recognised as one of the sciences, and therefore naturally finds its place in a series of volumes dealing with the Science of To-day. It is really the science of applying the older sciences to the ordinary affairs of mankind. The chemist investigates the causes of the explosion of gas ; the engineer makes the explosions drive engines. The geologist studies the structure of the earth's crust ; the engineer makes use of this acquired knowledge in obtaining a water supply. The mineralogist examines the properties of earths and ores, and through his researches the engineer is enabled to devise a new method of building.

Engineering is so closely connected with the concerns of daily life that it cannot fail to interest the general reader if presented to him in a way that he can readily understand, free from the technical terms which are unintelligible to him. I have attempted this in the present volume, and out of the many topics well worthy of discussion, I have selected those which I believe to be of most general interest, and those which are most typical of the problems with which the engineer has to deal. I have not written for the professional reader, to whom many of my descriptions would necessarily appear inadequate and incomplete.

The illustrations in the text are, in most cases, not exact drawings, but diagrams intended to make the reader understand with the least possible trouble the main features of the things represented.

Preface

Engineering is essentially a modern science. As we know it now it is not much more than a century old, and the rapidity of its progress seems to be increasing as time goes on. It already does for us many things which our immediate ancestors had to do for themselves, and what it holds in store for us and our children it were vain to conjecture. There are, however, certain guiding principles which underlie the latest as well as the earliest inventions, and I have tried to make these so clear that the reader may find in the following pages not merely a review of the past, but a key to the meaning of new developments.

My sincere thanks are due to those who have kindly supplied the photographs from which many of our illustrations are taken, and to several friends who, being specialists in certain departments, have perused and criticised those passages of my MS. which relate to their particular subjects. I wish also to acknowledge my indebtedness to *Engineering*, the invaluable journal which is studied by every one who wishes to keep in touch with the various activities of his profession.

T. W. C.

WESTMINSTER, *July* 1910.

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ENGINEERING OF TO-DAY

CHAPTER I

THE ENGINEER AND THE PUBLIC

THE engineer is a much-abused man.

One of the greatest of English writers and thinkers argues that his countrymen are not a great nation because they have "turned every quiet valley into a highway of rushing fire," a gibe at one of the greatest achievements of engineering; and there are thousands of less eminent people than John Ruskin who, in less eloquent language, denounce the engineer as a spoiler of natural beauty, a pure utilitarian who gives us smoke for pure air, grime instead of verdure, and straight hard lines in place of the soft lines and graceful curves of nature.

Yet the people who speak thus do not refuse to go by train; they are not content with candles, but must have gas or electric light; if they have to cross the ocean they do not seek for an old wooden sailing-ship, but go by the latest and fastest steel vessel with the most modern engines; they do not draw water from an old (and probably contaminated) well, but use the pure water which some maligned engineers have brought from distant hills, and delivered, clean and pure, into their houses. In short, while abusing the engineer they are glad to take advantage of his work.

The truth is that the engineer is like the doctor—a necessary evil, perhaps, but necessary all the same; only the public do not do the same justice to the engineer that they do to the doctor. A man with one arm is looked upon as a monument to the beneficent skill of the surgeon; but a railway or an aqueduct, still more a factory chimney, is regarded simply as a blot on the landscape.

Yet the engineer does not build his railway or his chimney for the fun of the thing, any more than does the doctor amputate a man's arm. Both do their work because it needs to be done. The medical man operates because the safety of his patient depends upon it, and the engineer builds and constructs because the needs of the community call upon him to do so.

There are remote districts in India which, in the event of a failure of the harvest through drought, suffer all the horrors of famine. There is grain in existence in plenty, but one of the great difficulties is to get it transported into the famine-stricken districts. More railways would go far to prevent these distressing periods.

Indeed, without the railways and steamships of the present day there would be some parts of Europe in a chronic state bordering on famine, and it almost seems as if the railway and the steamship had been brought into existence by an over-ruling power just at the "psychological moment" when they became necessary to carry food-stuffs to the densely populated areas.

Then, apart from the carrying of food, who can estimate the sum of human happiness which is entirely due to the modern facilities for travel? There are the visits of children to the old folks at home; the pleasant trips into new and strange lands; the mingling together of the nations—the last of which is probably the most potent of all the influences tending to bring about that era of universal peace and friendship among the peoples of the earth, which men have hoped for for centuries, and which now really seems to be approaching.

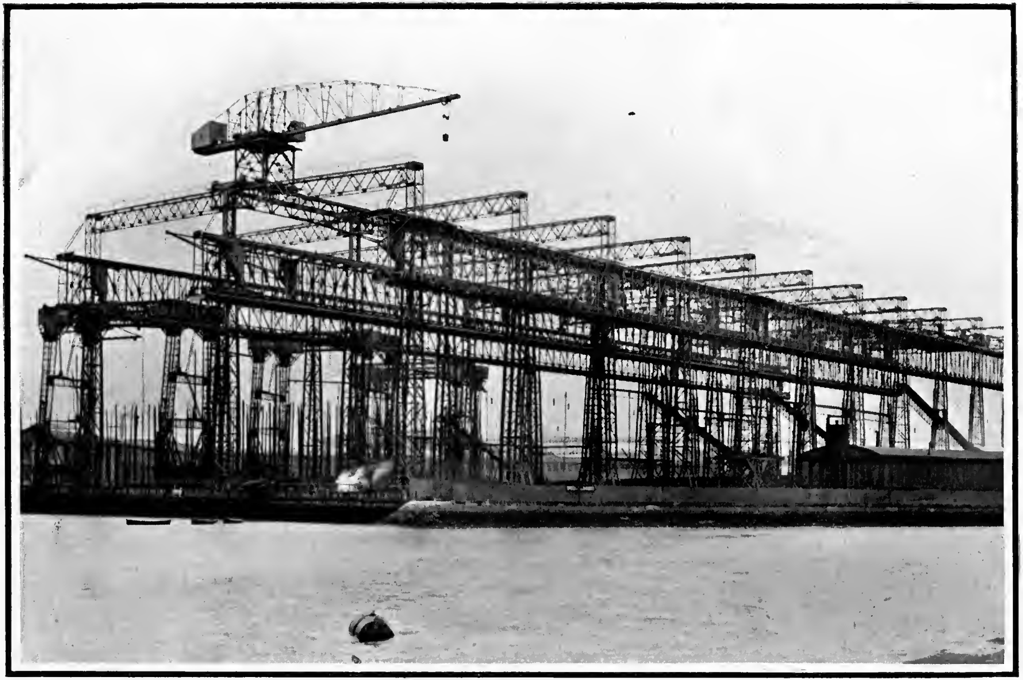
And facilities for travel and transport are but one branch of the engineer's work. There are others in which his efforts are almost as beneficent. Is it too much, then, to claim that the benefits conferred upon mankind by the labours of the engineer far outweigh an occasional spoiling of a landscape or the shutting out of a favourite view?

Then there are people who look for infallibility in an engineer, and, failing to find it, write down him and all his kind as "frauds." A business man, for example, has clerks who keep his accounts, involving thousands of transactions and hundreds of thousands of pounds, and who make them balance at the end of the year to a penny. He therefore expects the same freedom from error in an engineer, forgetting that copying figures from one book to another and adding them up is a very different matter from wrestling with the forces of nature. In an engineering undertaking of any magnitude the questions involved are so complex that, in Mr. Gladstone's historic phrase, it "passes the wit of man" to anticipate and provide for them all. Consequently things are bound to "crop up" unexpectedly as the work proceeds, and those concerned in the enterprise then blame the engineer for not having thought of them earlier, a state of things which is constantly arising, particularly in municipal undertakings.

Another reason why the public are apt to undervalue the skill of the engineer is because they do not realise the great gulf between theory and practice. A scheme may be theoretically perfect; but since there is no such thing as a perfect material, and as the perfect workman has yet to be discovered, it may, *in practice*, be quite the reverse. Now the engineer has learnt from experience that allowance must be made for these practical imperfections, while the layman has not.

I know of an instance which illustrates this. A certain firm built a large furnace of brickwork, held together by a steel frame. After a short time the steelwork gave way, and the structure fell to pieces. The firm happened to be at that moment without a technical adviser, so the commercial men attempted to deal with the matter themselves. They reasoned thus. The design is the same as other furnaces, which are standing well; the bricks are the same, and the same men laid them; everything is exactly the same in this furnace as in the others, except the steelwork, which was supplied by a different maker; therefore it *must* be the fault of the steel. That sounds, on the face of it, and undoubtedly is theoretically, a perfectly sound proposition, as conclusive, apparently, as a proposition in Euclid, and on the strength of it the firm claimed damages against the steelmaker; but any engineer would know in a moment that it is as weak as water. For no one can say that two such structures, even if built to the same drawings, of similar materials, and by the same men, will be exactly alike. A few defective bricks, a pailful of badly mixed concrete, a difference in the weather when the work was done, an unknown fault in the ground under the foundations, any of these things may make a difference.

In this case an arbitrator was ultimately called in to decide where the responsibility lay. He examined the broken piece of steel and found no flaw. He found, however, signs that it had been subjected to intense heat, and further minute investigation revealed



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GIGANTIC CRANES USED IN SHIPBUILDING

Shipbuilding Cranes at Messrs. Harland and Wolff's Yard, Belfast. There are three parallel "gantries" supporting many cranes of different sizes, while between the gantries are two slips for building large ships. These were specially constructed for the purpose of building the largest ships in the world.

the fact that the foundations had settled unequally, cracked the brickwork, and laid the steel open to the full heat of the furnace. That, becoming softened by the heat, gave way and the whole affair collapsed. The apparently perfect proposition, as to the responsibility, likewise collapsed when the matter was thus subjected to thorough examination.

The theoretical perfection which some people expect to be attained with the imperfect materials and methods which alone are available in this world, has been cleverly satirised by Oliver Wendell Holmes in his humorous little poem "The Wonderful One-Hoss Shay." In this he tells of a man who observed that carts always broke down and never wore out, which he attributed, rightly, to the fact that some parts are relatively weaker than others. He decided, therefore, to build himself a carriage in "a perfectly logical way," in which every part should be of exactly the correct relative strength. This marvellous vehicle ran for one hundred years exactly without showing any sign of wear, and then, in a moment, every part broke at once and the carriage fell into small pieces "as if it had been ground in a mill." It only needs to be related to be laughed at, yet it is simply the views of many people in regard to engineering matters carried to their logical conclusion.

It will be noticed that, above, I have used the conventional conception of theory as opposed to practice, but in reality there is no opposition between the two. We often say that a thing is perfect in theory but will not work in practice, but that is only because in forming our theory we have omitted to take into account some factor the presence of which makes our theory a false one. If we do not realise this, we are apt to discredit theory and fall back upon methods usually described by the term "rule of thumb," whereas the real lesson to be learnt from this apparent conflict between theory and practice is that by study and investigation we should seek to make our theories more perfect.

Nowadays there are few people who do not come more or less into touch with engineering matters. Business men, from the directors of great companies to the owners of very humble shops, must needs, if they wish to succeed, accept the engineer's help.

The up-to-date grocer has his electrical coffee-roaster, the baker his mechanical dough-mixer, while the laundryman does nearly everything by machinery, and these are but a few of the trades which the engineer helps; and there is not one of them but will be the better off for a little more intimate knowledge of engineering matters, for without it they are apt to fall into curious blunders.

I heard of an amusing case the other day. A firm starting a new factory purchased a steam-engine and boiler of which they were very proud, but they unfortunately entrusted its care to a rather careless attendant. This man allowed the water in the boiler to get too low, with the result that the "fusible plug" melted and put the fire out. This "fusible plug," which will be explained more fully in a later chapter, is a safety device, and *is intended to melt* under these circumstances, in order to avoid more serious disaster. The plug was replaced; but a few weeks later, again through carelessness, the same thing occurred again, whereupon the firm sent a sharp letter to the makers angrily demanding to know what they meant by supplying "fusible plugs" which burnt out so often. They did not know it, but they might just as reasonably have complained of their boiler being fitted with a safety-valve, on the ground that it let a certain amount of steam out.

Then there is a large section of the public who are by nature interested in engineering. Many of them feel that they ought to have been engineers, only an unkind fate, such as a paternal business, decreed otherwise. They feel attracted by any example of engineering that they may meet with; but unfortunately they are often unable, through insufficient knowledge, to understand what they see. They are like amateurs whom I have observed at engineering exhibitions, wandering round endeavouring in vain to understand the exhibits, and delighted beyond measure if some friendly engineer will take the trouble to initiate them into the mysteries.

It is to such that this book is particularly addressed. The various branches of the engineer's work are here exhibited not with descriptions merely, but explanations, where possible, of the underlying principles, the methods of design, and the reasons why different problems are attacked in different ways. These will help the amateur engineer to understand more easily what he sees, and enter more intelligently into the questions with which his professional brother is engaged.

CHAPTER II

SOURCES OF POWER

THE STEAM-ENGINE

It will be evident to every one that, without some means of generating power, most of the industries of modern life would be impossible.

The force which man is able to exert by the exercise of his own muscles is only trifling ; but, fortunately for him, the mental powers with which he is endowed enable him to turn to his own use the vast stores of energy which are locked up in nature. For many centuries the force of the wind has been utilised, while the idea of a wheel turned by the power of falling water is of still greater antiquity, but the greatest of all the natural sources of power, Heat, has only been tapped in comparatively modern times.

Ages ago, when parts of the earth now known as Britain and America were covered with vast tropical forests, the heat of the sun enabled the vegetation to perform a certain chemical process. The carbonic-acid gas in the air was separated into the two elements of which it is composed. One of these, the carbon, was built into the structure of the trees and plants, while the other, the oxygen, was liberated into the atmosphere.

Now none of the energy in the universe is ever lost. It may be changed from one form into another, as when the energy expended in rubbing out a pencil-mark is converted into heat which can be felt in the india-rubber, but it is still in existence. So the energy of the sun which was expended all those thousands of years ago is still in existence in the coal which was ultimately formed out of that tropical vegetation. The coal has only to be dug up and subjected to a certain amount of heat in the presence of oxygen for the reverse process to be set up. The carbon and oxygen once more combine together into carbonic acid, and the heat which was used up in the dim past in separating them is given back. It is this which accounts for the heat of a coal fire.

We are thus in possession of enormous stores of energy which can, if proper means are employed, be converted into mechanical motion and used for driving machinery of all kinds, and one of the most important functions of the engineer is to devise the most efficient way of doing this.

The machines which have been invented for effecting the conversion of heat into power fall naturally into two classes, steam-engines and gas-engines. Of these the former is the older and the most largely used, so we will give that our first consideration.

When a substance is heated it almost invariably expands with great force. I heard only a short time ago of an incident which illustrates this. One of the engineers employed in the building of the Forth Bridge told me how the bridge used to bend if the sun happened to be shining on one side of it. The slight increase in temperature caused that side to expand more than the other, bending the whole span as much as one foot out of the straight. Every passing cloud made a difference, by more or less shielding the sun's rays and so varying the temperature.

If the variation of a few degrees is able to bend a huge structure like the Forth Bridge, it is evident what an enormous power is to be obtained from the fierce energy of a furnace.

Of all the substances which may be expanded thus by the application of heat, one of the most convenient for our purpose is water. Not only does it expand gradually as solids do, but on reaching (if unenclosed) a temperature of 212 degrees, it suddenly changes into steam, increasing its volume as it does so 1600 times.

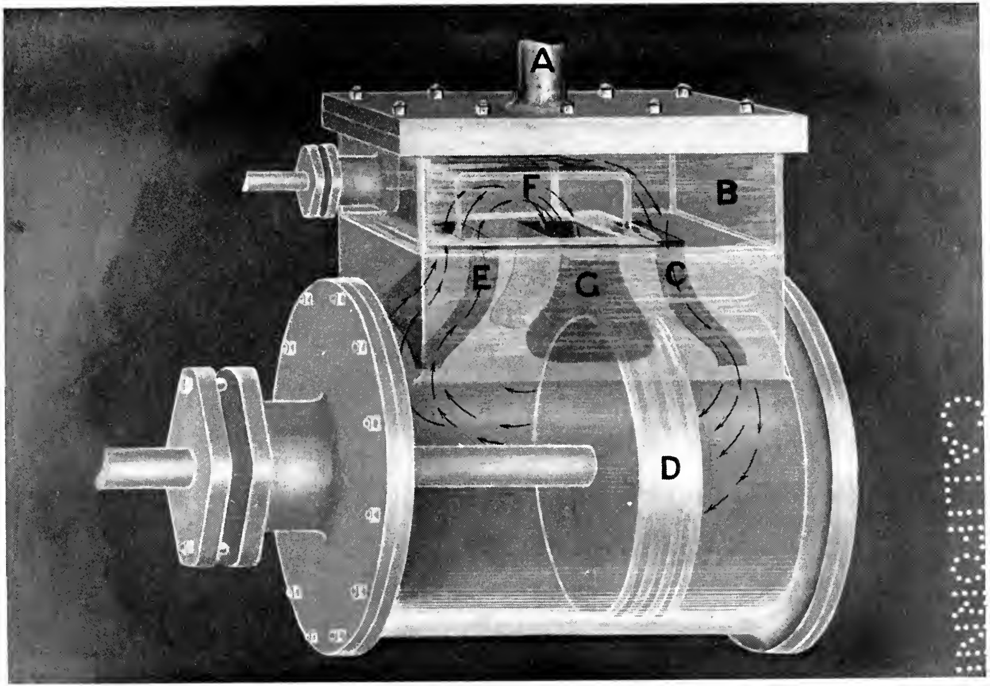
When it is enclosed in a boiler it cannot of course expand ; but its effort to do so produces a great pressure —so great indeed that, if it were allowed to continue, it would burst the strongest boiler that could be constructed.

Here, then, we have a ready means of turning the energy of coal into a powerful moving force, and it only remains to harness this energy of steam and turn it to the work that we require to be done.

It is curious that whereas, now, the work generally required of an engine is to turn something round, the steam-engine had been in existence for pumping water by an up-and-down movement for seventy years before any one thought of making it turn a crank and so produce a rotating motion. In fact there is a case on record in which a cotton-mill in Lancashire was driven by a steam-engine pumping water on to a water-wheel so as to produce a rotary motion.

The steam-engine consists of one or more cylinders, each of which has a piston sliding inside it. The steam enters first at one end and then at the other, in that way pushing the piston backwards and forwards. This motion is conveyed to a rod, called the piston-rod, one end of which is attached to the piston, and which slides in and out through a hole in the end of the cylinder.

The other end of the piston-rod is connected to



THE SOUL OF THE STEAM-ENGINE

This unique drawing shows the interior of a steam-engine cylinder. The steam enters through the pipe A into the steam-chest B; it finds the mouth of the port C uncovered, so passes through it into the cylinder, pushing the piston D to the left. The old steam left in after the previous stroke finds its way out through the port E into the *inside* of the slide-valve F, and thence out through the exhaust port G. As the piston moves to the left the slide-valve moves to the right until port C becomes connected to the exhaust port, and port G open for the fresh steam. Then the piston starts back from left to right.

a part called the cross-head, a block of metal of a suitable shape which slides between guides, and whose function is to keep the motion of the piston and piston-rod in a straight line.

In pumping-engines, which do not require to have a rotary motion, the piston-rod is sometimes continued straight to the pump-barrel, but in most engines the movement of the cross-head is communicated by means of a rod, called the connecting-rod, to a crank which turns the shaft or spindle just as the crank of a bicycle turns the chain-wheel.

On the shaft there is generally a heavy wheel, called the fly-wheel, the purpose of which is to ensure the steady running of the engine. We are all familiar with the fact that anything that is spinning round tries hard to maintain a regular speed and strenuously resists any attempt to increase or diminish it. In this way the fly-wheel of an engine tends to prevent any sudden variation in the speed owing to variations in the power of the steam or in the load on the engine.

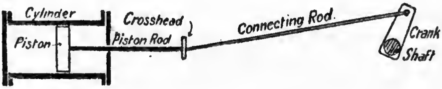


FIG. 1.—The essential parts of a Steam-engine.

The speed is further regulated by a governor, which generally takes the form of two weighted levers suspended from a revolving spindle, which is turned by the motion of the engine. If the speed be increased these tend to fly outwards owing to the centrifugal force, and, in doing so, slightly close a valve which controls the supply of steam to the engine. In this way the speed is brought back to the proper number of revolutions per minute. If, on the other hand, the speed should diminish, they close together and open the valve, giving the engine more steam and so increasing the number of revolutions.

The valves which regulate the admission of the steam first to one end of the cylinder and then to the other, and at the same time permit the exit of the used-up steam, are worked by the engine itself. The most usual form is the "slide-valve," a kind of box which slides to and fro inside a steam-tight chest, called the "steam-chest," on the side of the cylinder. As it moves it covers and uncovers the mouths of certain passages, or "ports" as they are called, in that way permitting fresh steam to pass from the steam-chest through the ports into the cylinder, and allowing the escape of the steam which has already done its work.

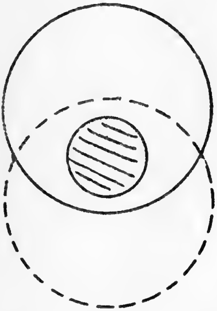


FIG. 2.—The full-line circle shows an eccentric at one part of its revolution. The dotted circle shows its position half a revolution later. The shaded part is the shaft on which it turns.

The valve is moved by a small rod called the valve-spindle, which passes out through a hole in the end of the steam-chest, and is connected by the eccentric rod to the eccentric on the shaft.

The eccentric is a round disc of metal, like a pulley, which is fixed on the shaft and revolves with it, about a point which is not its centre, so that it "wobbles." A strap encircles the circumference of the disc, and, as the latter turns round (sliding freely inside the strap), it pushes the strap to and fro a distance equal to twice its eccentricity. The eccentric rod is attached to the strap, and so the revolution of the eccentric works the valves.

Steam is not, like water for instance, incompressible. On the contrary it is very elastic, and consequently, when under pressure, it contains an amount of force stored up within itself which it would be foolish to waste. This can best be understood by picturing what would happen were one to lift a weight at the end of an elastic cord. In that case the hand would have to move some distance, before the weight would be lifted, during which time the elastic would be stretching. The force used in stretching the elastic would become stored up in it, and under certain circumstances a part of it, at any rate, could be recovered. For suppose that the weight having been lifted some distance, one-half of it could be detached ; the elastic alone, without any further help from the hand, would raise the remaining half of the weight; and if that could be again halved, it would raise the remainder a further distance, and so on until the cord had resumed its normal length.

In just the same way, if the supply of steam to an engine cylinder be cut off when, say, one-half only of the stroke has been made, that which has already entered will expand and push the piston the rest of the stroke. As it expands it will lose in pressure until, when the piston reaches the further end of the cylinder, the steam (since it will have doubled its volume) will have only half the pressure that it had to start with.

By this arrangement we do not therefore get quite so much power out of our engine as we should do by letting in steam at full pressure all along, but the loss of power will be less than a quarter, whereas the saving in steam will be one-half. The importance of this to the man who has to pay for the coal, is at once evident.

But if the steam is cut off at half-stroke, or even earlier, it is evident that there is still a lot of force left in it which does not get used. The puffing of a steam-engine, which is such a familiar sound to us all, is simply a sign of this useful energy being wasted.

It is impossible, however, for reasons which we need not go into in detail, to use up all this expansive force of the steam in one cylinder, but the difficulty is largely overcome by taking the steam through two, three, or even four cylinders in succession. Each of these is larger in diameter than the preceding one, so that the steam is able to expand. Of course it loses pressure as it does so ; but, having at each stage a larger piston to push against, it is able to do useful work.

Such engines are called compound, triple-expansion, or quadruple-expansion respectively, according as the steam passes through two, three, or four cylinders.

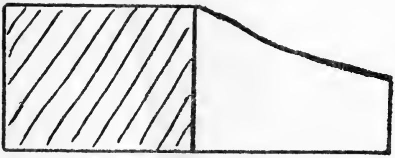


FIG. 3.—The advantage of "cutting-off" the steam. The whole figure represents the amount of push given to the piston. The shaded part shows the amount given by the new steam. The unshaded part indicates the amount of force which is got "for nothing."

There are many different varieties of steam-engines. For instance, there are the imposing-looking machines to be seen at the water-works for pumping water for the supply of our towns. These are generally of enormous size since, having to move vast quantities of a heavy and inelastic substance like water, they have to work slowly, and an engine which works slowly needs to be of large size if it is to do much work.

At the other extreme are the small high-speed engines used for generating electricity. They are generally coupled direct to the dynamo—that is to say, the shafts of the two machines are connected end to end, and, as a dynamo works well at a high speed, these engines are comparatively small but designed for speed. Whereas a pumping-engine usually works at about 20 to 30 revolutions per minute, the electric-light engine goes at 200 to 300.

These high speeds necessitate very high-class workmanship, and special attention has to be given to lubrication.

The marine steam-engine is in principle just the same as the others, only it is made as compact as possible so as to take up the minimum of room in the ship. Enormous power is sometimes concentrated in a small space.

As we shall see, in a subsequent chapter, the tendency of the present day is to supersede the steam-engine in favour of the gas-engine; but there is one particular in which the steam-engine appears to be likely to make inroads into a region which has been almost entirely occupied until recently by the petrol-motor, which is of course a form of gas-engine.

There are steam-engines now on the market which work at a very high pressure (1000 lbs. per square inch) and at a very high speed, so that they are very small in themselves and suitable for motor-vehicles. They have no boiler in the ordinary sense of the word, but the water is injected in the form of a spray on to a hot surface, and "flashes" instantly into steam, hence the vessels in which this takes place are usually called "flash-boilers" although vapouriser would seem to be the better term. In the opinion of many competent judges, these high-pressure steam-engines with "flash" boilers will ultimately be the type of engine most used on motor-vehicles. They certainly have the enormous advantage that they will start readily, will reverse easily, and the speed can be regulated from full speed down to a crawl, without any need for complicated gearing. The speed is regulated by simply varying the amount of water injected into the boiler at each stroke.

Another essentially modern form of steam-engine is the steam-turbine. How modern it is will be realised from the fact that it was only in 1884 that

Mr. Parsons made the first one, and it was not until 1891 that the turbine became a serious competitor with the reciprocating engine.

It is true that in 1629 an Italian named Branca invented a little wheel blown round by steam escaping from a pipe; but it was only a toy, and lacked the features that make the modern turbine a success, so that we may fairly attribute to the Hon. C. A. Parsons the credit of being the inventor of the steam-turbine.

FIG. 4.—This shows the principle of the Parsons Turbine. The curves represent end views of a number of blades. The steam coming from the left is split up into jets, and deflected by the fixed blades as shown by the *curved* arrows. The jets then strike the inside surface of the moving blades, and drive them in the direction shown by the *thick* arrow. Finally the steam rebounds off the moving blades, in the direction shown by the dotted arrows, to the next row of fixed blades.

The Parsons turbine consists of a steel drum, called the rotor, which revolves inside a cylindrical cast-iron casing. Round the rotor there are rows of small blades, in shape very like that part of a pen-nib which fits into the holder. Fixed to the inside of the casing there are also rows of blades similar to those on the rotor, except that they are set the opposite way, and the rows are so placed that when the rotor is put in the case and the latter closed they come alternately. First there is a row of blades fixed to the casing, then a row fixed to the rotor, then another row fixed to the casing, and so on.

The steam enters at one end of the casing, and, seeking an outlet, passes on towards the other end. It first encounters a row of casing blades, which split it up into jets and direct these jets on to the first row of rotor-blades. Off these the steam rebounds on to the second row of casing blades, and from them on to the second row of rotor-blades, and so on. Thus, as it passes along the whole length of the turbine the steam is continually being directed on to the blades upon the rotor, and the combined effect of the impact of the steam upon a large number of these small blades (for there are thousands of them in a large turbine) is to push the rotor round with great force.

The rotor and casing are enlarged by steps towards the end at which the steam escapes, so that it has room to expand, and thus the elastic force within it is utilised in the same way as it is in a compound or triple-expansion engine. Indeed, it is one of the great features of a turbine that it can extract and use the whole of the expansive force of the steam, so that when it comes out it has no more force left in it than has that which we see rising from the spout of a kettle. For this reason a turbine can be made to work efficiently with the steam which has already been used in a reciprocating engine. Such turbines are called "exhaust-steam turbines," and are often used in large works for generating electricity by means of waste steam from the other engines.

It seems strange at first sight that a machine like this, in which the steam simply blows against something, should be so effective. Of course the blades are set very close together; but it appears as if a lot of steam must escape past them without doing any good, and that an ordinary steam-engine, with its steam-tight piston, must be better. It is not so, however, as the turbine gets more work out of the steam than the reciprocating engine does.

Yet it has one great defect for many purposes. From its nature it has to work at a high speed, generally well over a thousand revolutions per minute. It can be made to work more slowly, but then it loses some of its efficiency.

This high speed does not matter much when it is used for driving electrical machinery, as a dynamo itself works well at a high speed, but for propelling ships it is a very serious defect.

A ship's propeller, if it be turned too fast, simply churns up the water and so loses its pushing effect. It is quite easy to see that the ideal would be for the propeller, which is of course simply a screw, to push against perfectly still water. This is of course quite impossible to attain—there must always be some disturbance of the water; but, when the speed of the screw reaches a certain point, the disturbance becomes so great that power is actually lost instead of gained by any further increase in the speed. The most effective speed depends upon several things, such as the shape of the boat, the size and shape of the propeller itself; but for most ships it is well under a hundred revolutions per minute, which is much less than the most effective speed of a turbine.[1]

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[1] In very fast steamers it is possible to arrive at a compromise between the best speed for the turbine and the best speed for the screw without seriously sacrificing efficiency, but this is out of the question for boats of moderate speed.

It is suggested that this trouble may be got over by making the turbine drive a dynamo, the current from which could be used to work an electric motor. The latter can be designed for any desired speed. This would also get over the reversing difficulty, for a turbine will not reverse, whereas a motor will do so easily. An arrangement of tooth-wheels is also being tried, but there are practical difficulties in the way of making tooth-wheels which will stand the wear and tear of conveying such large power.

Arising out of this remark, the question will probably occur instantly to the minds of many readers, How does a turbine steamer go astern if the turbine will not reverse?

The answer is that it has separate "astern" turbines. A very usual arrangement is this. Many steamers have three propellers, each of which is fixed to the end of a propeller-shaft which passes through the ship to the engine-room. The centre one is worked by what is called the "high-pressure" turbine. This is simply an ordinary turbine, but reduced in length so that when the steam has passed through there is still a good deal of force left in it. This partially exhausted steam is then divided and goes half to each of two "low-pressure" turbines, as they are called. These again are just ordinary turbines, only shorter than usual, and each of them turns one of the two outer propellers.

Then on each of these two outer propeller-shafts there is also a second turbine, in which the blades are set the opposite way, so that the steam will blow it round in the reverse direction. These are the "astern" turbines.

As a matter of fact, the two low-pressure turbines and the reverse turbines are generally combined inside one case. The ahead blades are at one end of the rotor and the astern blades at the other, the outlet for the steam being in the middle. Thus, if steam be admitted at one end, the shaft will be turned one way ; while, if it be admitted the other, the direction will be reversed. I have explained this point at length because if any of my readers should ever see the engine-room on a turbine steamer and see apparently only one turbine for each propeller, they would be puzzled as to what had become of the astern turbines.

The centre propeller, I ought to explain, does not usually reverse, as two are sufficient for going astern.

For the propulsion of ships, the Parsons turbine is almost invariably used, but for driving electrical and other machinery there are a number of others. Of these the best known are the Curtis, the Westinghouse, the De Laval, and the Rateau. They are all, in the main idea, similar to the Parsons, the variations being in the details, which I fear would simply weary my readers were I to attempt to describe them.

When the steam-engine was first invented, the boiler was simply a large iron kettle. The steam was allowed to escape when the pressure reached 1 lb. per square inch. In fact, the force which drove the early engines was the pressure of the atmosphere, and not the direct power of the steam at all. The purpose of the latter was merely to push the air out of the cylinder, and then, being itself condensed, leave a vacuum. It was ultimately found, however, that still greater force could be got by having a strong boiler, generating the steam at considerable pressure, and using the direct power of the steam.

So, as advances in the manufacture of steel and iron plates made it possible, the strength of boilers increased and the pressures used grew higher and higher, until it is no unusual thing nowadays for a boiler to be made to withstand a regular working pressure of 200 lbs.

per square inch, being actually tested with hydraulic pressure to one and a half times that amount.

The most common form of boiler is what is called the Lancashire. It consists of a large cylinder or shell, sometimes as much as 9 feet 6 inches in diameter and 30 feet long, built up of steel plates riveted together, with two large flues, also made of steel plates, running through it from end to end.

It is set in brickwork in which other flues are formed, one underneath the boiler and one on each side. The fires are made in the front ends of the two cylindrical flues, and the heat passes through them to the back, then dives downwards and returns through the underneath flue to the front. On reaching the front, it divides and returns to the back along the two side flues. Thus there is a great amount of surface exposed to the heat of the fires, and through which the heat can pass into the water. At the back the fumes enter the chimney and pass up into the atmosphere.

The purpose of a tall factory chimney is not, as is often supposed, simply to carry off the smoke to regions where it will do the least harm. Its main duty is to create a strong draught. Sometimes, therefore, a tall chimney is dispensed with, and a fan or a jet of steam is made to force air through the furnace. An existing engine and boiler can often be made to generate a considerably greater power by adding a fan or steam-jet to increase the draught.

Although, as we have just seen, the hot gases after they leave the fire are made to travel a long distance through the various flues in contact with the surface of the boiler and so give up a great deal of their heat, they are still at a very high temperature when they reach the chimney, and so a sad waste of heat occurs. In order to save some of this an apparatus called an "economiser" is often used.

In this there are a number of cast-iron pipes, around which the hot fumes pass just before they enter the chimney, and the water for feeding the boiler is passed through these pipes. Some of the escaping heat is thus captured and carried back into the boiler.

There is also an appliance called a "superheater," which is placed at the back of the boiler too. It is formed of a number of tubes through which the steam passes on its way from the boiler to the engine. These tubes, like the economiser, are heated by the hot gases going to the chimney, and so a considerable amount of heat is added to the steam.

The advantage of this "superheating," as it is termed, is not at once apparent. Ordinary steam, as soon as it comes into contact with a surface cooler than itself, such as the pipes or the cylinder of the engine, begins to condense, and in consequence rapidly loses force. If, however, it has been superheated, it has a certain amount of heat which it can part with before condensation begins. Therefore the use of some of the waste heat from the fires in this way effects a considerable saving in the amount of steam used.

Still, when all is done, with the most up-to-date boiler, and with superheaters and economisers, the amount of heat which is put to a useful purpose is only some 25 per cent. of that which the coal gives out, while 75 per cent. goes up the chimney.

There is another kind of boiler called the Cornish. This is similar to the Lancashire, except that it has only one flue through it instead of two, and is generally rather smaller.

On board ship the boilers are somewhat different. The shell is much shorter, and there is of course no brickwork. Instead, the flues pass at the back into a steel box called the combustion chamber, and from thence the hot fumes return through a number of small tubes which run through the boiler from back to front above the flue. These discharge into a steel chimney, which is fixed to the front of the boiler above the furnace-doors.

In locomotives the boiler is entirely tubular—that is to say, there are no large flues at all. The fire is made in a chamber at the back called the fire-box. From this there are some hundreds of steel tubes, about 3 inches in diameter, which pass right through the boiler into another chamber, called the smoke-box, at the extreme front of the boiler. The heat from the fire therefore passes through these tubes, which are entirely surrounded with water.

The most modern type of boiler is the "water-tube" boiler. In this the water is in tubes, and the heat from the fire passes around them. These have many advantages. For one thing the tubes, since they are small, can be very thin compared with the plates of a cylindrical boiler, and so the heat can the more easily penetrate through them to the water. Then if anything should burst, it would probably only be a small tube and not the shell of the boiler itself, and so the danger is much reduced. It must not be understood from this that cylindrical boilers are in the habit of blowing up, for they are not; but where such enormous forces are kept in thrall there is bound to be the possibility of an accident, and, if it should happen, less damage is likely to result if the boiler is of the water-tube variety.

To describe all the different kinds of water-tube boiler would fill a whole book, so I will only explain them in general terms. There are always one or more drums, like small cylindrical boilers, at the top. Then there are a number of tubes, more or less vertical in direction, connected to the underside of these. The whole thing is enclosed in a chamber formed of brickwork or steel plates, and the fire is at the bottom of this chamber. The heat thus rises and travels among the tubes, heating them as it does so. It is always arranged so that some of the tubes are heated more than others, with the result that a circulation of the water is set up—up the hot ones and down those that are less hot. This adds greatly to the efficiency of the boiler.

Water-tube boilers are very much used on war-ships, and also in electric generating-stations, since they are able to get up steam very quickly, an important fact in an emergency.

Probably most readers will think that they could stoke a boiler-fire without any difficulty. It seems to be simply a matter of taking a few shovelfuls of coal and throwing it into the furnace. So long as the coal does not miss the door altogether and scatter on the floor of the boiler-house, there does not seem to be any skill required.

This, however, is quite a mistake. The coal must be put in in a thin layer so that every particle may be completely consumed, and the new coal must be placed near the front of the furnace so that the smoky gases which are given off in the early stages of combustion shall be burnt by having to pass over the glowing fire beyond. Thus unskilful stoking causes smoky chimneys, perhaps followed by trouble with the local authorities, to say nothing of the wasteful use of fuel. If you watch an experienced stoker at work you will notice that he does not throw the coal in promiscuously, but studies his fire and then throws the coal in, giving his shovel a dexterous little twist as he does so, in order to spread it on that part of the fire which needs it.

Still, with the utmost care and experience this operation cannot be done quite satisfactorily, and it needs the opening of the furnace-door, letting in a flood of cold air which lowers the heat of the fire.

Mechanical stokers are therefore often used now. In these the coal falls down from the bunker above, through a pipe, into a little hopper. From this it is fed continuously in very small quantities into the furnace through a small opening, and as it is fed in, the whole of the fire is automatically moved backwards so that there is always a thin layer of burning coal, the fresh coal being always at the front. These conditions are almost the ideal for getting the full value out of the coal, and the loss of heat through the inrush of cold air when the furnace-door is opened is avoided. Mechanical stokers need, of course, to be driven by some power, which is often an electric motor.

In some parts of the world where oil fuel is plentiful, it is used instead of coal, and the same thing is being done more and more on naval ships owing to the ease with which the fires can be fed with liquid fuel as compared with coal. In this case the oil is generally blown into the furnace in a jet, forming a fine spray, which bursts into a cloud of flame as soon as it enters.

Wood, too, is often used for fuel where it is cheap, and waste products are sometimes utilised. In ironworks, for example, the gases from the blast-furnaces which at one time were discharged into the air, forming those flames which used to make such a magnificent spectacle at night in the iron-producing districts, are now often led away and burnt under the boilers. Another instance that occurs to me is in the sugar plantations in the West Indies, where the sugar-cane, after being crushed, is used for fuel. It has very little heating power, but it costs nothing, and so special furnaces have been devised in order to burn it. I mention these as illustrations of what is one of the great objects of modern engineering—to make use of waste products.

The chief dangers with regard to steam-boilers are the possibility of explosion through too great pressure and through the water getting too low.

The safety valve is intended to guard against the former. It is a valve on the top of the boiler, which is loaded either by a heavy weight or else by a lighter weight at the end of a lever, so that, when the steam reaches a certain pressure, it lifts the valve and some of it escapes. Thus the pressure cannot rise beyond that point. The other danger is guarded against by a valve, operated by a float inside the boiler. When the float descends below a certain level, it opens the valve and allows the steam to blow a whistle. Another safeguard against the same danger is a plug of soft metal in the top of the flue. This will not melt so long as it is in contact with the water, but, as soon as the water falls below it and leaves it dry, it melts and lets the steam into the flue, thereby putting the fire out.

By discharging the steam from an engine into a vacuum instead of into the air a considerable addition is made to its power, for, to the force of the steam pushing on one side of the piston, we add the force of the vacuum pulling on the other side. The apparatus by which this vacuum is formed is called a condenser.

The commonest form of condenser is like a small tubular boiler. The steam, on entering the shell, comes into contact with pipes which are kept cool by cold water circulating through them. The condensed steam (that is to say water), and any air which may get in with the steam, are withdrawn by a pump known as the air-pump. The water is thus recovered, and can then be pumped back into the boiler and used over again. Because of this fact, these "surface condensers" as they are termed, since the steam is condensed by contact with a cold *surface*, are invariably used on ships. The cooling water is pumped through the tubes by another pump called the circulating pump.

The huge wooden towers which are often to be seen at electric generating-stations are for the purpose of cooling this circulating water after it has become heated in the condenser. It is pumped up to the top and allowed to fall in fine spray like rain, being cooled through contact with the air as it falls.

At some generating-stations rows of revolving jets, like lawn-sprinklers, can be seen. These are for the same purpose, and neither of these cooling devices will ever be found where there is a plentiful supply of water.

Another form of condenser is the evaporative. In this the steam is led through pipes which are placed on the roof of the engine-house, or in some other exposed place. On to these pipes water is allowed to trickle, and the heat of the steam inside the pipes causes it to evaporate quickly. Now evaporation is always accompanied by a fall in temperature, so that the evaporation of this water makes the pipes very cold and condenses the steam within. This is very curious, and on the face of it a strange anomaly, as the steam by its own heat produces the cold which condenses it. It reminds one of how the sun is made hotter by the heat which it loses.

One of the most striking features of modern engineering is the central power-station. Not only are there the great stations for generating electricity for public use, but there is a central power-station in most large works. Until the advent of electricity into practical engineering a large factory would be driven by a large number of separate steam-engines, each with its own boilers; but now there is always one large power-house, where all the power for the whole works is generated and from which it is distributed by electricity. Thus there is scope for organisation and labour-saving devices which did not occur years ago.

The generating-station of the London Underground

Railways at Chelsea, one of the largest in the world, shows what can be done in this respect. The boilers are placed in two rows on two floors. The coal is unloaded from barges by means of electric cranes at one end of the station. These cranes drop it into the hopper of an elevator, which carries it up to the top of the building and delivers it to a conveyer, which takes it along just under the apex of the roof and drops it into the coal-bunkers, which are right at the very top of the building.

From the bunkers it falls down shoots into the mechanical stokers, which feed it into the furnaces. The ashes fall out of the grates at the back of the boilers, and then down shoots to the ground floor, where a conveyer receives them and takes them out of the building. It seems as if it would be impossible to carry organisation and method further than this, as the whole boiler-house is almost automatic.

CHAPTER III

SOURCES OF POWER (*continued*)

THE GAS-ENGINE

ONE of the most remarkable features of engineering in recent years has been the rapid development of the gas-engine.

It is but a short time since it was regarded as only suitable for very small powers, in places where there was not room for a steam-engine with its necessary accompaniments—a boiler and a store of coal. To-day, however, it is driving many large factories, and, indeed, it shows signs of being a very serious rival of its elder brother the steam-engine.

For they both belong to the same family, the heat engines. Heat is the real source of power in both cases.

In the steam-engine, as we have just seen, the heat of the fuel is generated in a furnace under a boiler, in which it is used to expand water into steam. The pressure resulting from that expansion is then used to push a piston, and in that way the energy of heat is converted into energy of motion. In the gas-engine, however, the fuel is burnt actually in the cylinder of the engine, and the heat produced expands certain gases, causing a pressure which moves the piston. So, once again, we see heat converted into motion. Gas-engines, from the fact that the fuel is burnt in the engine itself, are known also as "internal-combustion" engines.

It will be interesting at this point to see just what happens when gas explodes. All kinds of matter, whether solids, liquids, or gases, are built up of tiny particles called molecules. Each molecule, in turn, is composed of two or more smaller particles called atoms. There are about eighty different kinds of atoms, and the molecules of some substances are formed of one kind only. Such substances are called elements. Iron (and all the other metals), carbon, oxygen, hydrogen, and nitrogen, for example, are all elements, but the great bulk of the things which we see around us are compounds, their different properties depending upon the different *combinations* of atoms of which their molecules are built up. A familiar example of a compound is water, the molecules of which are formed of two atoms of hydrogen and one of oxygen, combined together.

Now some atoms have an affinity for each other and will, if given favourable conditions, enter into certain combinations, and in many such cases heat is given off when the combination occurs. Thus, when we apply heat to a lump of coal in the presence of oxygen, the carbon atoms and the oxygen atoms set about combining together, every atom of carbon being joined by two atoms of oxygen and so forming the gas known as carbon dioxide, or carbonic-acid gas. In just the same way, if hydrogen is heated in the presence of oxygen they will combine, forming water as mentioned just now. This action of two elements combining together, and generating heat as they do so, is what we usually speak of as burning, or combustion ; and it is clear, from what has just been said, that for anything to burn it must be in the presence of some other substance with which it can combine, and that by some means, such as the application of a little heat, the proper conditions can be set up which are conducive to the joining together of their atoms.

Carbon cannot burn without oxygen, nor can hydrogen or any of the other gases which go to make up "coal-gas." Many people make the mistake, for instance, of thinking that a gas-holder might explode in a thunderstorm ; but so long as it contains coal-gas and no oxygen, as ought always to be the case, there is no danger whatever. An electric spark might be introduced into a gas-holder with perfect safety so long as there is no oxygen present. I do not say that gas-holders never have exploded, but, when such a thing does occur, it must be due to some abnormal state of affairs altogether.

When a solid like a lump of coal burns it does so on its surface. It cannot do otherwise, for it is only on the surface that the carbon and oxygen can come sufficiently near together. It must, then, burn slowly. The burning of a gas, on the other hand, is very different, for it and the oxygen can be thoroughly mixed together, so that every atom of the inflammable gas has atoms of oxygen near it with which it can combine. Thus, a large volume of gas can be entirely burnt in an instant, and heat is then generated instantaneously, to be followed by an almost equally sudden expansion, and it is that sudden expansion which we call an explosion.

But, some readers may say, If the gas is burnt up, what is there to expand? True, the gas has been burnt ; but it is not correct to say that it has been burnt *up*, for it has only been turned into another gas, and when air is used to supply the oxygen, there is the nitrogen to be considered as well. Now nitrogen, which forms about four-fifths of the air, is an unsociable gas which is very reluctant to enter into any combination, and so it remains a passive spectator of the burning process ; yet it is there, and aids in the explosion by suffering expansion by the heat. This can perhaps be made clearer by a concrete instance.

Suppose that we have a mixture of air (that is to say, oxygen and nitrogen) and a gas called carbon-monoxide, of which we shall hear more later on in this chapter, and that we apply a light to them. The heat of the match, taper, electric spark, or whatever it may be that we use, will set up the conditions under which the carbon-monoxide and oxygen can combine, and then these two will join together into a new gas, carbon-dioxide.

Thus at one moment we have a volume of *cold* gas consisting of oxygen, carbon-monoxide, and nitrogen, while a moment later we have, instead, carbon-dioxide and nitrogen in a *highly heated state*, and therefore greatly increased in volume. That sudden increase in volume is the explosion.

We see, then, that a gas explosion is simply an instance of burning, exactly the same as the burning of a coal-fire, the difference being accounted for by the fact that while a solid can only burn gradually,[1] a gas can burn suddenly.

We see, too, that since the two gases, whatever they may be, combine in certain definite proportions—as, for example, two atoms of hydrogen with one atom of oxygen, or two of oxygen with one of carbon, and so on—if we want to get a very complete combustion of the gases in our mixture, we must have them present in exactly the right proportions. If we do not, there will be some of one or the other left over, after the explosion, uncombined, since there was not sufficient of the other for it to combine with.

In a gas-engine, then, we have a cylinder, closed at one end and open at the other, and in the closed end

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[1] This does not apply when the solid is in the form of very small particles. If reduced to a fine powder, so that it can be thoroughly mixed with air, coal will explode just like a gas. Many colliery accidents have been caused in this way.

we place a quantity of explosive mixture, that is to say, inflammable gas and air in the right proportions. Just as the piston is at its nearest to the closed end we ignite this mixture, and the explosion which follows drives the piston violently forward. Thus, we see, the action of the gas-engine is quite different from that of the steam-engine, for, instead of a steady pushing effect, we have a series of sudden explosions. Moreover, it is necessary that three strokes should take place before an explosion can occur, so that we only get one power stroke in every four, the other three being preparatory strokes, during which the engine is getting ready for the power stroke.

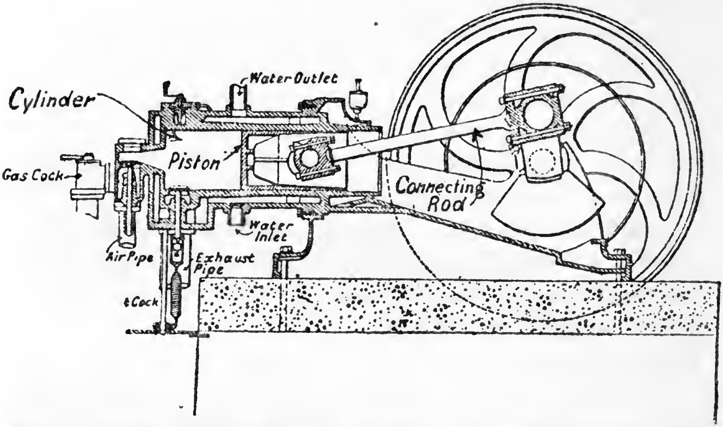

FIG. 5.—Section of "National" Gas-Engine. The "water inlet" and "outlet" are for passing cold water through a space round the cylinder, to keep it cool.

Notice that there is no piston-rod, but that the connecting-rod is connected directly to the piston.

What power is it, then, which performs these three preparatory strokes? Nothing but the momentum of the fly-wheel.

Let us imagine that we are watching a gas-engine at work, and that an explosion is just taking place.

The piston is driven forward, imparting momentum to the fly-wheel. That momentum then forces it back, and in so doing pushes out of the cylinder the burnt gas left in as the result of the explosion. Next it goes forward again, this time sucking in a fresh supply of gas and air, which the next backward stroke compresses into the space at the back of the cylinder. Then a fresh explosion occurs, and the whole series or cycle of operations is gone through over again.

The reason for compressing the charge of gas and air is that a much stronger explosion results than if it were not compressed. In fact the gas-engine was invented as long ago as 1850, but it was not until the discovery of this fact in 1876 that the gas-engine became of practical utility.

The cycle of four strokes, as described above, is called the "Otto" cycle, after the French engineer who invented it, and it is the mode of working adopted in nearly all large gas-engines.

The piston of a gas-engine is longer than that of a steam-engine, so that it needs no piston-rod and cross-head to guide it. It is really a hollow cylinder with one end open, and the connecting-rod enters it at that end, and is connected to a pin inside the piston itself.

The connecting-rod, crank, and fly-wheel are practically the same as those of the steam-engine. The valves which let in the mixture and let out the spent gases are shaped something like a mushroom, and so are called "mushroom valves." The illustration (Fig. 6) will explain what they are like and how they work better than a great many words. Each valve is kept closed by a spring, but it has a stalk or spindle, and when it needs to be opened this spindle is pushed up by a revolving disc like an eccentric, only it has no strap, called a cam. There is generally one cam for the inlet valve and one for the exhaust valve, and they are fixed on what is called the cam shaft. This is a small shaft turned round by the engine itself by means of gearing, so arranged that it revolves once for every two revolutions of the crank. It is therefore often called the "half-speed" shaft, and the need for the arrangement is clear when we remember that if it went at the same speed as the crank it would open the exhaust valve not only during the exhaust stroke but also during the compression stroke, and so let out the fresh gas during the compression stroke, just when it most needs to be kept in.

Sometimes the inlet valve has no cam, but the suction of the engine itself is relied upon to open it at the right time.

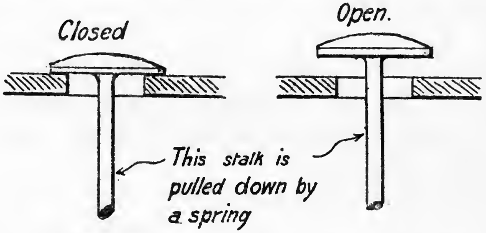

FIG. 6.—The Mushroom Valve, as used in Gas-Engines. The Valve is opened either by a cam pushing the stalk upwards, or by the suction of the engine.

The speed of a gas-engine is regulated by a governor like that used on a steam-engine. If the engine goes too fast, the governor either causes it to miss an explosion or two, or else reduces the supply of gas, and so makes the explosions weaker, until it has resumed its proper speed.

The explosion is caused in one or two ways. In some cases an electric spark is made to pass between the ends of two wires which project inside the cylinder, while in other cases there is fitted to the end of the cylinder a small tube, which is kept red hot either by the hot exhaust gases from the engine or by a gas jet outside the cylinder, and things are so adjusted that just at the end of the compression stroke the gas finds its way into the hot part of this tube and is exploded by the heat. The former method has the merit of being more easily regulated, so that the explosion shall occur at exactly the right moment, while the second is considered more reliable. When electricity is used it is obtained from a tiny dynamo called a magneto driven by the engine, or else from a storage battery.

It would seem from what has been described above that the action of a gas-engine must be jerky and spasmodic, and such is no doubt actually the case. By having the flywheel sufficiently heavy, however, and working the engine at a fairly high speed, the variations become so slight that for practical purposes the engine may be regarded as quite steady and regular in its motion.

One of the defects of the gas-engine is that it will not readily start itself. It cannot possibly do so, as the three preparatory strokes have to be performed before the power stroke is possible. In the case of small engines this can easily be overcome by turning the engine round a few times by hand. Another way still is to have a hand pump, by which the explosive mixture can be compressed into the cylinder and the compression stroke of the engine thus imitated. Another way still is to let the engine, when it is working, pump up a store of compressed air in a reservoir. Then, when the engine needs to be started, some of this compressed air is allowed to enter the cylinder and push the piston. A few strokes having been made like this, sufficient impetus will have been acquired for it to perform its three preparatory strokes, and so start working in the normal way.

The reversal of a gas-engine, too, is not so easy as that of a steam-engine. It is an easy matter to alter the action of the cams so as to cause the engine to work in the opposite direction, but it generally has to be stopped and restarted, all the difficulties described above being consequently encountered. With a steam-engine, on the other hand, both the starting and reversing can be accomplished by the simple movement of a handle.

Ordinary coal-gas, such as is used for lighting, was, until a few years ago, invariably used to drive gas-engines, but now there is a cheaper gas, known as "producer gas," which answers the purpose almost as well and is very much cheaper. Moreover, it can be generated in a simple little contrivance, called a "suction producer," with very little trouble and with perfect safety. It is this cheap gas which has brought about such a remarkable increase in the use of gas-engines during the last few years.

Producer gas is made from coal or coke, and it consists mainly of a gas called carbon-monoxide, and hydrogen. It is different from coal gas in that the latter is distilled from coal by merely heating it, while the former is made by actually burning the coal.

Coal and coke are both impure forms of carbon, and when heated sufficiently the carbon will combine with oxygen from the air, forming carbon dioxide, otherwise carbonic-acid gas. This is what occurs in an ordinary coal fire. This gas, as we already know, consists of molecules each made up of one atom of carbon and two atoms of oxygen. It will not admit any more oxygen into the arrangement, and so it will not burn.

If, however, it is brought into contact with some more carbon in a highly heated state, the three atoms just referred to are joined by another atom of carbon, so that there are then two of each kind. Instead of taking the additional atom in and forming a quadruple partnership, however, the four atoms pair off and form

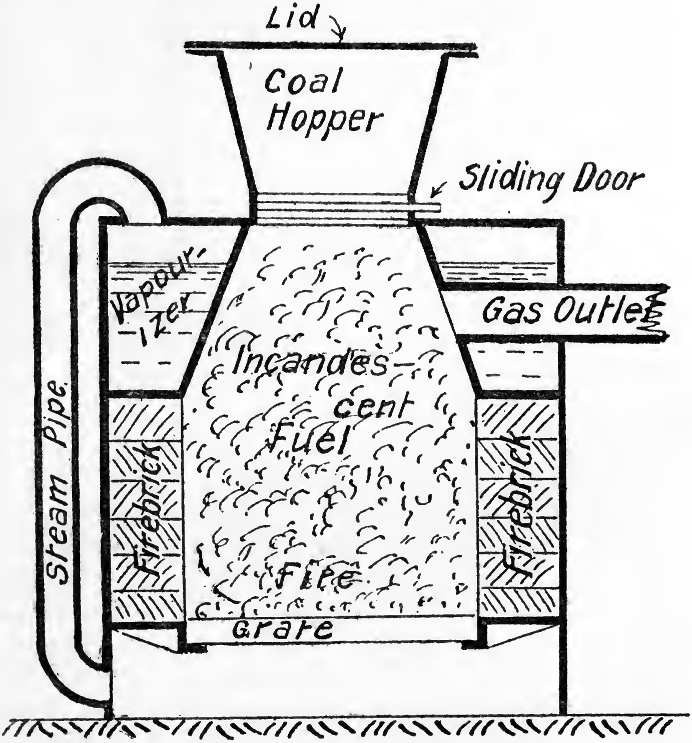

FIG. 7.—Diagram showing the construction of a Suction Gas Producer. To charge the producer, the Hopper is filled with coal and the lid closed. Then the Sliding Door is opened, and the coal falls in. So the coal is put in without letting any air in.

themselves into *two* molecules, each made up of one atom of carbon and one of oxygen. Those molecules constitute carbon-monoxide.

Now when carbon and oxygen combine into carbon dioxide, heat is liberated (hence the heat of a coal fire), but when that is converted back, as just described, into carbon-monoxide, heat is consumed. We have to provide a supply of heat from some source in order to force the atoms to make the change. If, however, we bring some more oxygen into contact with the carbon-monoxide, and give it just a little heat, we shall get carbon-dioxide once more, and when that change occurs *the heat just referred to is liberated again.* Or we may put it that carbon-monoxide, if mixed with air, will burn. Those beautiful blue flames which can be seen hovering over a *deep* fire, such as those often made by night-watchmen in an old bucket, are the burning carbon-monoxide.

Now let us examine the plant in which these changes are carried out quietly and automatically. There is an iron cylinder, lined with firebrick and set up on end. At the bottom of this there is a grate on which a fire is made, and then the whole thing is filled right up to the top with coal. Under the grate there is an inlet for air, and at the top (which, by the way, is entirely covered in) there is an outlet connected to a pipe which leads ultimately to the engine. At every suction stroke of the engine some air is drawn in at the bottom and passes up through the fire. The coal at the bottom of the producer is thus kept burning, and the air as it enters is soon transformed into carbon-dioxide. Since all the oxygen in the air is thus used up soon after it enters the furnace, the coal only burns just at the bottom. That which is higher up cannot burn for lack of oxygen, so it becomes a very hot, but not burning, mass of carbon. Now the carbon-dioxide formed in the fire at the bottom has to pass up through this mass of hot carbon, and in so doing it is changed into carbon-monoxide. Thus, although it is only the product of a coal fire, it is not the incombustible gas, carbon-dioxide, which passes out to the engine, but the burnable monoxide.

In order to save some of the waste heat which escapes from the furnace there is placed in some suitable position a vapouriser, a vessel containing water which will be heated by the escaping heat. A certain amount of the water is thus turned into steam, which is carried down by a pipe to the bottom of the producer and introduced under the grate. It is then sucked up through the fire. Now steam, we already know, consists of oxygen and hydrogen in combination, and when it is passed through a heated mass like this, it is split up into these two elements. The oxygen immediately combines with some of the carbon, forming more monoxide, while the hydrogen passes on to the engine, and so enriches the mixture.

There are certain other products which arise from the coal, but these two are the principal ones. After leaving the producer the gas goes through a "scrubber," as it is called. This, again, consists of a vertical iron cylinder, filled with coke, through which the gas has to find its way. As it passes upwards it meets water, which is sprayed on to the top of the coke and trickles down through it. This cleans the gas, cools it, and also removes dust which might get into and clog the cylinder of the engine.

At present only coke or anthracite coal can be used in these producers, as ordinary coal contains tarry products which cannot be removed in a small plant, and which, if they were not removed, would form soot in the cylinder of the engine.

The economy of these suction producer plants is so great that, even in a very small plant, power can be produced at the rate of ten horse-power for an hour for a penny. The gas is, however, not quite so powerful as coal gas, so that an engine working on producer gas has to be slightly larger to give the same power.

The waste gas which comes from the blast furnaces at an ironworks is largely carbon-monoxide, and it is very frequently used to drive gas-engines.

Gas-engines have not yet been used to any extent for marine purposes except in the case of small boats driven by small gas-engines using vapourised oil as the gas, some of which will be described later, and some tugs on the Rhine which have gas-engines and suction producers.

It will soon come, however—of that there can be no doubt, and at the moment of writing this there is being designed a small cargo "steamer" driven by a gas-engine and suction producer.

The great difficulty is with the speed and the reversing, as mentioned in the last chapter in connection with steam-turbines, and in the case referred to the same method of overcoming it is being tried. The engine (which has six cylinders by the way) is to run at an invariable speed of 500 revolutions per minute, and it will drive a dynamo which will supply current to an electric motor, which will turn the propeller at a speed of only 80 revolutions per minute. The speed of the propeller will be varied electrically, and it will be reversed by the same means, so that the speed and direction of the engine will remain constant under all circumstances—just the conditions under which a gas-engine works best and most economically.

On small boats and for light jobs, oil-engines are often used. These are mostly exactly the same as gas-engines, except that there is an additional part called a "vapouriser," in which the oil is heated and so turned into vapour. Very often this is simply an extension of the back part of the cylinder, which is, at starting, heated by a lamp outside. When once it is hot enough and the engine is going, the lamp is no longer needed, however, for the heat of the explosions is sufficient to keep the vapouriser hot. At each "charging" stroke a little oil is sucked in by the action of the engine. This falls into the hot vapouriser, and is turned immediately into vapour, which is compressed and exploded exactly as the gas is in a gas-engine.

There is one kind of oil-engine, however, which must be mentioned specially, as it does not work quite like an ordinary gas-engine; indeed it may be said that it has no "explosion" stroke. It is called the "Diesel" engine, after its inventor.

During the charging stroke the engine draws in pure air—not air and oil. By the next stroke this air is compressed to about 500 lbs. per square inch pressure, and that compression raises it to a temperature of about 1000°, which is sufficiently hot to ignite the oil. When, therefore, at the commencement of the "power" stroke, a jet of oil is forced into the cylinder by a pump, it begins at once to burn, and continues to do so steadily so long as the jet lasts. Instead of an explosion, therefore, we have, in this engine, a steady burning, and by varying the duration of the jet, the speed of the engine can be regulated to a nicety. Such an engine, it is clear, needs no vapouriser, and none of the devices for igniting the gas which so often give trouble in other engines.

The petrol motor is also a type of gas-engine, but it is of such importance, and appears in so many different forms, that it cannot be dealt with adequately at the end of an already lengthy chapter. It will, therefore, be referred to later on.

It would be impossible to conclude this chapter without reference to the most modern of all forms of gas-engine—the internal-combustion pump. It may be described as a gas-engine in which the piston, connecting-rod, and fly-wheel are all composed of *water.*

To understand this remarkable machine it will be necessary to turn to the diagram (Fig. 8). There are two tanks, a lower one containing the water to be pumped and a higher one into which the water is delivered by the pump.

Let us look at it as we did at the gas-engine, assuming that an explosion is taking place. The water in the cylinder is just commencing to be driven downwards, and, since the mushroom valves at *M* prevent it from going to the suction tank, it is bound to go to the delivery tank. The explosion, of course, does not force it very far, but the column of water in the pipe still continues to move a little further, because of its momentum, after the force of the explosion has spent itself, and during that time it sucks in fresh water from the suction tank, and also some air through a valve at the top. Then, since the delivery tank is higher than

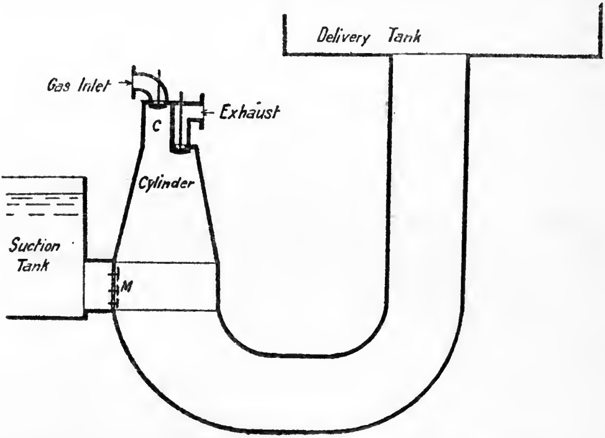

FIG. 8.—Sectional diagram showing how the "Humphry" Internal Combustion Pump works.

the cylinder, the water begins to gravitate back, and in so doing it pushes out the spent gas through the exhaust valve, closes the valve itself, and finally entraps some air in the space *C* which it compresses. This air, acting like a spring, first gives way before the moving water and then rebounds, as it were, and drives the water downwards once more. Again the momentum of the moving water causes it to "suck," and this time it draws gas in through the inlet valve, returning a moment later to compress it, after which another explosion takes place.

So the same cycle is gone through over and over again, and it will be seen that it is really exactly the same as the "Otto" cycle in an ordinary gas-engine, the oscillation, or surging to and fro of the water in the pipe, doing the work of the fly-wheel.

This is the most efficient internal-combustion motor in existence, since it uses a greater percentage of the force of the explosion than any other form of engine can do. Its working parts, too, are few and small, so there is little to wear, little to lubricate, and little to get out of order, as the water itself forms the main working parts. For this reason it may be found economical to use it for supplying water to a water-turbine, and so driving machinery; or it may revolutionise the methods of propelling ships, for it has long been known that a jet of water issuing from the stern of a ship is much more effective than a screw-propeller, only until now a suitable pump has not been forthcoming to form the jets. It may be that here is the solution of the difficulty.

CHAPTER IV

SOURCES OF POWER (*continued*)

RUNNING WATER

MY task in describing the most modern methods of securing and turning to account the power which is to be obtained from running water will be rendered much simpler if I give a description of a great installation in the United States; one of the finest examples of a water-power plant that the world possesses.

There may not be quite the same glamour about it that there is surrounding the famous installation at Niagara Falls, but in one sense it is far more interesting, for while there is only one Niagara in half a world there are rivers in many countries which might be harnessed and set to work as is being done with the Susquehanna at McCall Ferry, in Pennsylvania.

This spot is a little over twenty miles from the mouth of the river, forty miles from Baltimore, and sixty-five from Philadelphia.

Here a huge dam has been thrown across the river 2500 feet long and from 40 to 80 feet high, making it one of the largest in the world, and by its means some of the water is forced to pass through water-turbines, which, when the work is complete, will be capable of producing 120,000 horse-power, to be conveyed electrically to the neighbouring towns. It will be evident that the construction of such a dam, right across a rapid river, was no light task. The first thing to be done was to build temporary dams, called "cofferdams," to keep the water back and leave a part of the river-bed dry. Huge timber "cribs" or boxes were made and filled with rock, so that they would sink in the river ; these were placed in the water, about ten feet apart. The bed of the river is of rock, which naturally is a great advantage when a dam is to be built, since it forms a thoroughly sound foundation, and the cribs were shaped to fit exactly the shape of this rocky floor. The shape was ascertained by anchoring a boat over the spot and taking careful soundings. When the cribs had been accurately sunk in position, strong horizontal timbers twelve inches square were placed in between them, and these were covered with vertical planks. Finally bundles of brushwood, weighted with stones to make them sink, were thrown into the water and covered with clay and sand so as to form a solid embankment. The structure was then quite water-tight, and by its means practically the whole of the water of the river was diverted into one half of the river-bed, having the other half dry.

In the dry space thus formed a bridge was built, to facilitate the conveyance of the concrete and other materials from the bank to the site. It is usual on a job like this for the temporary bridge to be a light trestle structure, supported on piles, but in this case it was thought that, owing to the heavy floods to which the river is subject, a bridge of that description would probably be carried away. A substantial concrete arch viaduct was therefore made, first of all from one bank to an island in the middle of the river and later from the island to the further bank. This bridge, although it is only temporary—a mere tool or appliance used in the construction of the dam—is 59 feet wide, itself a work of no mean order. It carries several lines of railway track, of standard gauge, besides special tracks for huge travelling cranes.

It was built just on the down-stream side of where the dam itself was to be, so that cranes upon it could easily reach over and drop huge tubs full of concrete right into the required place. Except for a small portion of it, which will form, ultimately, a part of the foundations of the power-house, it will all be blown up with dynamite when the permanent work is complete.

Next a long level platform of concrete was laid, on the solid rock, to form the foundation of the dam, and upon it the dam itself was raised.

This too, was made entirely of concrete, a material which is coming into use more and more every day, in engineering works. It is formed by mixing stones and sand with Portland cement in suitable proportions.

In this case, as such an enormous quantity of it was required, special methods of mixing were devised. The material arrived on the spot by railway, in trucks called "dumping cars," since the bottoms can be let down and the whole contents "dumped" in a few seconds. The line was made to pass over huge storage bins, some for rock, some for sand, and some for cement, so that the material could be dropped out of the cars straight into its proper bin. Under these bins there was a tunnel in which ran measuring cars. Each of these would stop, first of all, under the cement bin; a door would be opened, and the right quantity of cement shot into it; then in like manner it passed under the sand and stone bins, receiving from them the correct proportions of sand and rock, after which it passed, but a short distance, to the concrete-mixing machine, into which it discharged the whole of its contents.

A concrete-mixer is a simple machine in which all these materials are well and thoroughly mixed together, with the proper quantity of water. There were eight of them used on this job, and each had two of the measuring cars in attendance upon it, one discharging while the other was loading, so that the work went on continuously.

The storage bins were capable of holding 14,000 cubic yards of material, and the mixers turned out the finished concrete at the rate of 2300 cubic yards per day. It is difficult to realise the magnitude of cubic measure; a yard in length does not seem much, but a cubic yard contains an astonishing quantity of material, so that the real meaning of the above quantities will be better understood if they are stated in this way: a store of over 20,000 tons of material was kept, to draw from, and this was turned into concrete at the rate of, roughly, 4000 tons per day. There we get a much better idea of the vastness of the undertaking.

The concrete, after passing through the mixer, was discharged into buckets containing one yard each, resting upon railway trucks, and these, in trains of about five trucks, were hauled out along the temporary bridge by steam locomotives.

On arrival at the spot where the actual building of the dam was in progress, each bucket was picked up by a peculiar kind of crane, called a "pelican crane," from its fancied resemblance to that curious bird. These cranes consist of a strong framework, from which there extend upwards, on one side, long inclined arms, over 100 feet long, so that the crane can stand on the bridge and reach right over where the dam is being built. The bucket is picked up off the truck, at a point near the bottom of the inclined arm, and is then carried outward until it has reached the right spot, when the bottom of the bucket is let fall, and the concrete drops into its place.

Concrete is, of course, different from such materials as brick or stone, in that it needs to have a mould or form, to hold it in the desired shape until it has set, and in concrete work the construction of these moulds often costs more than the concrete itself, so that it is always important to reduce this cost as much as possible. In this undertaking steel frames were designed specially, as shown in the accompanying drawing (Fig. 9), which supported a casing of timber forming a huge box, the shape of the dam, which was filled with concrete. The dam was thus built, in sections 40 feet long, and as soon as one section had set the framing could be separated into a few parts, lifted up by a crane, and taken away to be used in the same way for another section.

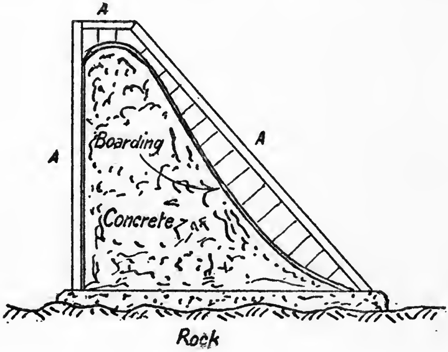

FIG. 9.—Diagram showing how the Concrete Dam was formed. Steel beams as at *A*, *A*, *A* formed frames, at intervals, from which short steel props supported boarding, which formed a complete box. The concrete was filled into this box, and when set, the frames and boarding were removed.

The dam is nearly 60 feet high, and 70 feet wide at the bottom.

The drawing just referred to also shows us the shape of the dam. The vertical side is the upstream face, against which the force of the water will press, while the curve is on the downstream side, so as to form a kind of prop against the pressure of the water.

It is unlike many dams, which have a flat top with a roadway upon it, for the river is subject to violent floods, and it is necessary that the flood waters should have plenty of space in which to fall over the dam, as otherwise serious damage might be done. As a matter of fact, in times of flood there will be a depth of 18 feet of water *on the top* of the dam, so that regarded merely as a waterfall it will be an imposing spectacle.

A good illustration of the difficulties which engineers have to face, and which are probably quite unsuspected by the general public, is furnished by this dam. Whoever would expect that a concrete structure of these dimensions, always in contact with water, would be liable to damage, if not to destruction, from the expansion and contraction due to changes in temperature? Yet such is the case, and if no provision were made and scope allowed for the play of this irresistible force, the solid concrete would soon be rent by cracks and fissures.

As mentioned just now, the dam was built in sections of 40 feet, and between these sections layers of tar paper have been put. This forms a soft elastic joint, giving play to the forces of expansion and contraction, and so enabling them to expend themselves harmlessly.

All the machinery employed was worked by pneumatic pressure. Two large air-compressors were used, driven by steam, and the air from them was conveyed by pipes to the machines. The concrete-mixers and the pelican cranes, besides a host of smaller tools, were all operated by compressed air motors.

And now, the question may be asked, What is the use of this great dam? What purpose does it serve? It is simply to produce a difference in level in the water. The force with which water issues from the ordinary domestic water tap is due to a difference in level—the difference, namely, between the level of the tap and that of the cistern up near the roof of the house. For this reason the water will come out of a tap on the ground floor much faster than it will out of a tap in, say, a bathroom one or two floors higher up. At these upper floors, the difference in level, or "head" of water, to use the technical term, will be much less, and so the pressure will be less in proportion. Speaking roughly, every two feet of head, or difference in level, will produce one pound per square inch of pressure.

The ordinary fall in a river, even it be a rapid one, is gradual, so that in order to be able to take advantage of the force of the stream a dam must be constructed; this raises the level of the water on the upstream side, and then, if it be allowed to pass through a pipe or channel from the higher to the lower level, it will rush through with a force due to the difference in level. Suitable machines can then be placed in this pipe or channel, and the water as it rushes through will work them.

Of course, care needs to be exercised in choosing a site for a dam, because raising the level of the water will cause the river to rise higher up its banks for several miles back, and if the banks should be fairly flat the water would simply overflow. The banks, for some distance above the dam, therefore, need to be steep enough to hold the river even at its higher level.

The "weirs" on a river are natural dams, and the force due to the difference in level can be seen by the energetic way in which the water squirts through the interstices in the lock gates, when the river is a navigable one. A huge dam, such as the one we are now considering, is in fact merely a repetition on a very large scale of the mill-dam which is to be seen on most of the rivers of England, where the old-fashioned water-wheels are in use. The "mill-pond" is the widened part of the river due to the raising of the water level by the dam; the "mill-stream" is simply the conduit which leads the water from the higher level to the wheel, over which it falls, into the water at the level of the lower side of the dam.

Instead of a water-wheel, however, in modern plants a "water turbine" is used; and instead of taking the water round a mill-stream, which in some of the old mills is of considerable length, the turbines are placed near to or actually in the dam itself, so that the water simply rushes through tunnels or pipes from the higher to the lower side, turning the turbines as it goes.

In this case there are ten turbines, placed in pits formed in the thickness of the dam itself, at one end. Each turbine consists of two wheels fixed to a vertical shaft, which comes up to the top of the pit, and is there connected to an alternating-current dynamo. These are different from ordinary dynamos inasmuch as they lie upon their sides and rotate upon a vertical axis instead of on a horizontal axis, as is usually the case. They can thus be connected directly to the shafts of the turbines, whereas ordinary upright dynamos would need to have gearing in order to change the direction of the shafts.

The arrangement can be easily seen from the drawing (Fig. 10), which is a section through the dam just where one of the turbines occurs. The water enters a chamber on the right, through submerged arches, in order that ice or anything else floating on the surface may be kept out of the machinery. There it encounters an iron grating or screen, a further precaution against solid matter entering and jamming in the turbines; after that it passes down the intake pipe, part goes through each of the wheels, and then through the draft tubes into the "tail race," as the channel is termed into which the water is discharged on the lower side. The flow of water through the turbine can be regulated by an adjustable door at the mouth of the intake pipe. All these pipes, and the turbine pits as well, are simply openings in the solid block of concrete.

The turbine wheels themselves are cast iron wheels, in which are arranged a number of buckets or vanes which the rushing water pushes round on much the same principle as a windmill is pushed round by the wind rushing past its sails. The arrangement of vanes is, however, more complicated than the sails of a windmill, because the water does not pass straight through; it first enters from all around, passing towards the centre, and then flows downwards. There are, therefore, two sets of vanes, one of which is acted upon by the inward movement of the water and the other by its subsequent downward movement. Turbines which work by the inward movement only are called "radial-

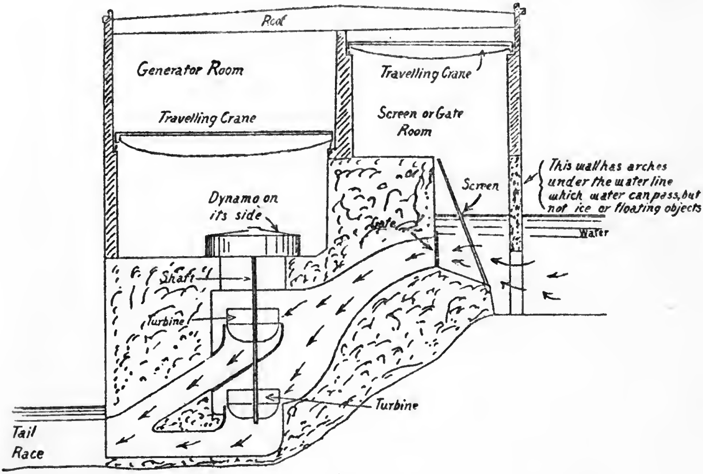

FIG. 10.—Section (simplified) showing how the Turbines are placed in the solid mass of concrete.

flow" turbines, since the water flows in the direction of the radii, in other words towards the centre. Others, which are worked by the downward movement only, are called "parallel-flow" turbines, since the flow of water is parallel with the axis; while those which use both, as just described, are called "mixed-flow" turbines.

The dynamos are, of course, enclosed in a building known as the power-house, which is situated upon the top of the dam. It contains an overhead crane capable of lifting the heaviest part of the turbines or dynamos, for convenience in placing them in position, or in case they need to be taken to pieces at any time. Each pair of turbine wheels, by the way, with the shaft and the rotating part of the dynamo, together weigh about 150 tons.

Mention was made just now of the danger of floating ice getting into the machinery. Ice is, in fact, one of the great troubles with a plant like this, and the whole scheme has been devised so that, as far as possible, all ice shall naturally float to the other end of the dam, away from the power-house. There are fenders, too, formed of floating logs, and also the submerged arches noticed just now. Still, ice might, under certain circumstances, evade all these obstacles, so "chutes" are provided at certain points, openings in the dam through which water rushes, and over which lumps of ice would be carried without their doing harm by passing through the machinery.

Altogether, this wonderful undertaking may be regarded as the most up-to-date example of this particular type of installation, and probably it will remain so for many years to come.

It only represents, however, one kind of water-power plant; that in which a low fall is used. In some favoured localities a mountain lake or stream can be tapped at a high level, and the water brought down in pipes at a great pressure.

There is an installation of this description in Switzerland, where the water is drawn from a lake over 3000 feet above the power-station. Consequently the water has a pressure at the latter point of 1300 lbs. per square inch, and it is quite evident that a small jet at that pressure will have as much force in it as a large volume of water at McCall's Ferry. The motor generally used under these conditions is therefore quite different from the one just described. It is known as the "Pelton wheel," and consists of a large wheel, fixed on a horizontal shaft, and having a large number of metal cups attached to its circumference. The water issues in the form of a jet from a nozzle, and strikes against the inside of the cups, thereby driving the wheel round; a very simple machine in its general ideas, but a very efficient one under these conditions. Its speed is regulated by deflecting the nozzle upwards so that part of the jet misses the cups altogether.

Before leaving the subject, reference may be made to a source of water-power which is not much used, although it seems possible that, some day, a satisfactory method may be found of turning it to account—the rise and fall of the tide.

One of the first patents recorded at the British Patent Office, and dated in the reign of James I., granted a monopoly for the establishment of floating mills in harbours and estuaries, and there seems little doubt that the idea was to use the force of the tide to work them. There are such mills in some parts of Europe to-day; they may be described as like paddle ships, only, instead of machinery in the ships turning the paddles, the paddles turn the machinery. The vessel is anchored in a tidal creek or river, and the water, flowing past, turns the wheels. Unfortunately, however, the velocity of the tidal current is not sufficient to develop much power by this means.

Many people have meditated upon the possibility of anchoring an old ship at some convenient spot, and in some way making its rise and fall on the tide do useful work, but when analysed the amount of power so obtained would, even if it could be done conveniently, be ridiculously little. For suppose it were a vessel with a buoyancy of 1000 tons, and that it was anchored at a spot when the rise and fall was say 30 feet; the amount of work done in twelve hours would be 1000 tons lifted 30 feet, or 67,200,000 foot pounds—seemingly a huge figure. It only represents, however, what a five-horse-power gas-engine, with suction producer, would do easily *for about a shilling.* This is an illustration of how a promising-looking idea often fades away to nothing when critically examined.

The best scheme of all—one, in fact, which is actually in operation in a few places—is this. Across the mouth of a tidal creek a dam is built. In it are a pair of lock gates which open inwards so as to form a large "non-return" valve; they will open and let the water in freely, but close as soon as it attempts to return. Thus the creek behind the dam forms a large lake or reservoir which is filled every tide, and when the tide turns the water can be allowed to run out again over a water-wheel.

As far as the writer is able to ascertain, this plan has not been tried with a modern turbine, but only with an old-fashioned, inefficient water-wheel. It is just possible that under very favourable natural conditions—that is, a large creek with a very narrow opening and a very great tidal movement—it might be a success, and there seems no reason why the water should not be made to work the turbine as it flows in as well as coming out of the reservoir.

The real difficulty would appear to lie where, perhaps, the non-technical reader would least suspect it. The water passing in will carry a certain amount of mud and sand with it, which it will deposit in the reservoir, and the cost of removing this periodically will probably be sufficient to make the plan an expensive one.

CHAPTER V

HOW POWER IS CARRIED

WHEN in an earlier chapter I enumerated the sources of power as wind, water, and heat, it may have surprised some readers to see no mention of electricity. We are so accustomed to speak of trains, trams, and machinery as being "driven by electricity" that we often forget that it is not a source of power, but simply a means of conveying power from one place to another.

This, perhaps, needs a slight qualification.

When generated by means of chemical batteries, such as we use to work telegraphs and electric bells, electricity may be ranked among the "prime movers," but the quantity that can be produced in that way is so small and so limited in its uses that the statement just made is for practical purposes quite accurate.

We need only think of the fact that no one has ever seen a dynamo giving out current by itself, to realise this. It needs some other force, one of the three already enumerated, to drive it, and then it produces the current of electricity which may be used in such marvellous ways to drive machinery perhaps many miles away.

It is as a means of transmitting power, therefore, that electricity is of so much service to the engineer. It has in this way worked changes which are little short of miraculous.

There is no better instance of this than the modern electric tramcar. It possesses possibilities of usefulness so much in advance of the old horse-drawn car as to make it really a new invention, and its existence is entirely due to the convenient way in which electricity can convey the power generated by large engines at the generating station to the cars upon the road.

The "tube" railways, too, which are such a boon to Londoners, are unthinkable apart from the use of electricity to drive the trains. Moreover, in some parts of the world there are vast stores of power, in the shape of waterfalls, running to waste because they are too far from the centres of population, where the energy is required. Here electricity steps in, and forms a means by which this force can be conveyed many miles to some place where it will be useful. An instance of this was described in the last chapter.

In modern factories, too, it is the practice to make use of electricity for turning the machines. Where there used to be many leather belts and long lines of revolving shafts there are now motors, sometimes one for each machine, and sometimes one for each small group of machines. In the old days it was no uncommon thing for 30 per cent of the power of the engine to be taken up in simply turning round the shafting, without working a single machine. How serious a loss this was hardly needs pointing out. Supposing, too, that there was some small job which had to be finished after the ordinary working hours, the whole of that shafting had to be kept in revolution for the sake, perhaps, of one small machine.

The electric motor has altered all this, for among other very valuable qualities it has this one: it resolutely refuses to take in more current than it needs to do the work in hand. If it has a light job to do it takes little current, and as the load upon it increases it takes just enough extra current to enable it to do its work and no more. This, too, is an inherent virtue in the machine, and is not the result of any regulating device.

Thus, if only one machine is at work in a factory, the engine and dynamo are only called upon to supply the tiny quantity of current needed for that one machine, and no more.

Electricity is one of nature's mysteries. We have not the faintest idea what it is. We are able to form an idea as to how a current of electricity is formed ; it seems to be a commotion among the electrons, the tiny particles, of which, science tells us, all matter is built up. We may go so far as to say that these electrons are electricity, but that does not help us much, since we cannot say what the electrons are. They are almost infinitely minute. Their size is for smallness as much beyond our powers of comprehension as the distance of the stars is for magnitude. Still there is direct evidence of their existence, and there seems no reason to doubt that it is a movement among these, communicated from one atom to another along a long line, which accounts for what we are accustomed to call a current of electricity.

That is enough, however, as regards pure theory.[1] The engineer is most concerned with the practical application of scientific phenomena to the service of mankind. He only troubles about the theories in so far as they help him to understand and make better use of the phenomena. So, since, without knowing what it is, we are able to turn electricity to many useful purposes, we will leave the theories and come to the practical applications.

Of all the wonderful things that have been observed in connection with electricity there is one which for practical purposes is of more importance than any

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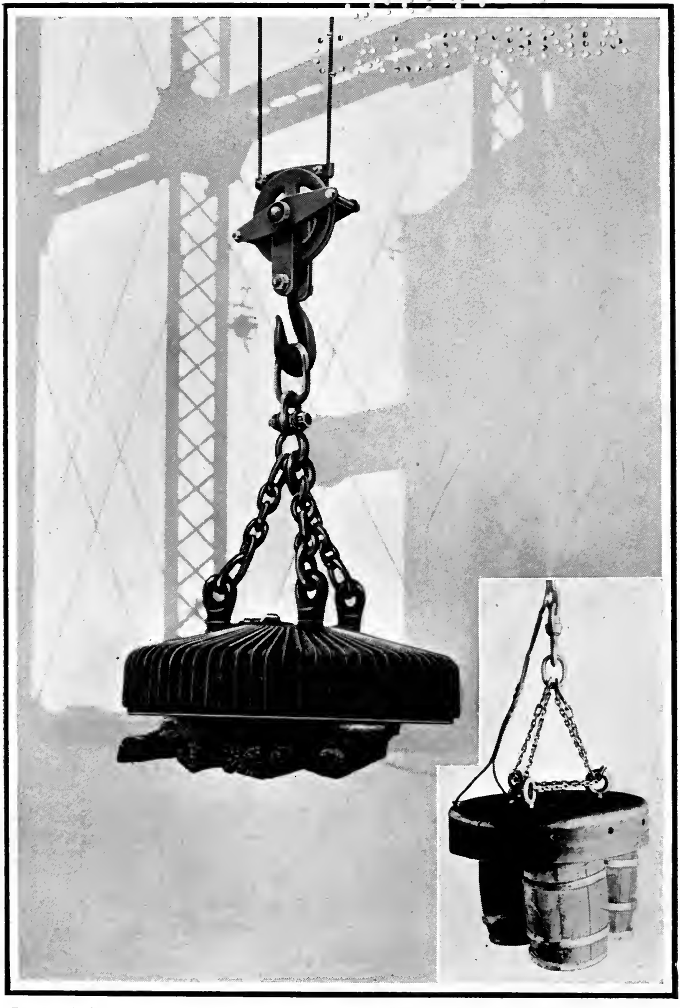
[1] Readers who would like to know more about this are referred to *Scientific Ideas of To-day*.



By permission of *Messrs. Wellman, Seaver, & Head, Ltd.*

AN ELECTRO-MAGNET ATTACHED TO A CRANE FOR LIFTING PIG-IRON

The moment the current is stopped the pigs will drop off. The smaller picture represents a similar magnet lifting wooden kegs full of iron nails.

other. It is this. When electricity is flowing through a wire or any other conductor it exercises a mysterious influence all around. If the current is strong enough it will move a piece of iron or it will cause agitation in the needle of a mariner's compass. It does not need to touch these things, but can exercise this force or influence at a considerable distance. This strange influence, as inexplicable as electricity itself, we call magnetism.

Nor have we yet exhausted the wonders of this phenomenon, for just as a current in a wire turns the wire into a magnet so the movement of a magnet in the neighbourhood of a wire will cause a current to flow along it, or, as it is usually expressed, will "induce" a current in it.

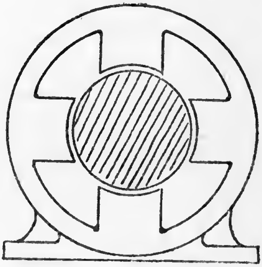


FIG. 11.—The essential parts of a Dynamo. The shaded part revolves. The other part remains still.

In these two facts, then—that electricity can produce magnetism and that magnetism can produce electricity — we have the secret of the dynamo. It is, in the principles of its construction, a remarkably simple machine. There is a part which remains still, called the field magnet, an iron frame-like structure wound over and over in certain parts with wire enclosed in an insulating covering. Through this wire a current of electricity passes, and so the whole structure is made into a powerful magnet. Then inside this frame there turns another part called the armature. This is also of iron, and upon it too are wound layers of insulated wire.

When the armature is turned rapidly round by an engine or some other suitable power, the movement of the wires on the armature in the neighbourhood of the field magnets causes currents to be induced in them. These currents flow to a part called the commutator, which is fixed upon the same shaft as the armature and which turns with it. Two or more small arms, or brushes as they are called, are placed with their ends in contact with the commutator, and these collect the current, which can then be led away along wires to any place where it is needed.

But there are two kinds of dynamos. The one just described generates "direct" or "continuous" current while the other generates "alternating" current, and before it is possible to make clear the difference between the two it will be necessary to explain these terms.

Instead of electricity passing along a wire just imagine for a moment water flowing along a pipe. It is easy to conceive a constant stream of water being pumped along the pipe by an engine and used to drive a water motor at the further end. That would be a continuous current. But suppose that instead of a constant stream the engine pushed the water in the pipe to and fro—a few inches one way and then a few inches back in the opposite direction—the force would still be communicated to the further end of the pipe, and a suitably designed motor could be driven by it, but it would be a totally different sort of current from the constant stream of water always in the same direction.

That illustrates for us, in a rough approximate sort of way, the difference between the direct current and the alternating current of electricity.

The direction in which the induced current flows along a wire depends upon the direction in which the wire moves in relation to the magnets. If the direction of movement be reversed the direction of the current will be reversed also.

Now any point upon a revolving body (except, of course, its centre) is continually passing first one way and then the other, up and then down, or to the right and then to the left, just whichever way you look at it, one way one half the revolution and the other way the other half. This applies of necessity to the wires on the armature as it revolves, and thus the currents induced in them are alternately first in one direction and then in the other—that is to say, they are alternating currents. In the direct-current dynamo as just described this is corrected by the action of the commutator, which consists of a number of segments insulated from one another, which make contact with the brushes in succession. A brush is only in contact with a segment during the time that current is being generated in one direction. The moment the direction in any of the wires begins to change, the segment to which those particular wires are connected passes under the other brush.

An alternating-current dynamo, however, has no commutator, but instead simply two insulated metal rings, against which the brushes slide continually, so that the alternations of the current are unchanged. There is another difference between the two machines, and that is that in the alternator it is generally the field magnets which go round and the armature which stands still. There is no principle involved in this, however ; it is simply a matter of convenience.

The difference between the two kinds of dynamo can therefore be put briefly in this way. In an alternator the natural alternations of the current are not changed, but in the direct-current machine there is a commutator which turns them into a continuous stream.

This naturally brings the question, What are the advantages of the two types? We will come to that in a moment.

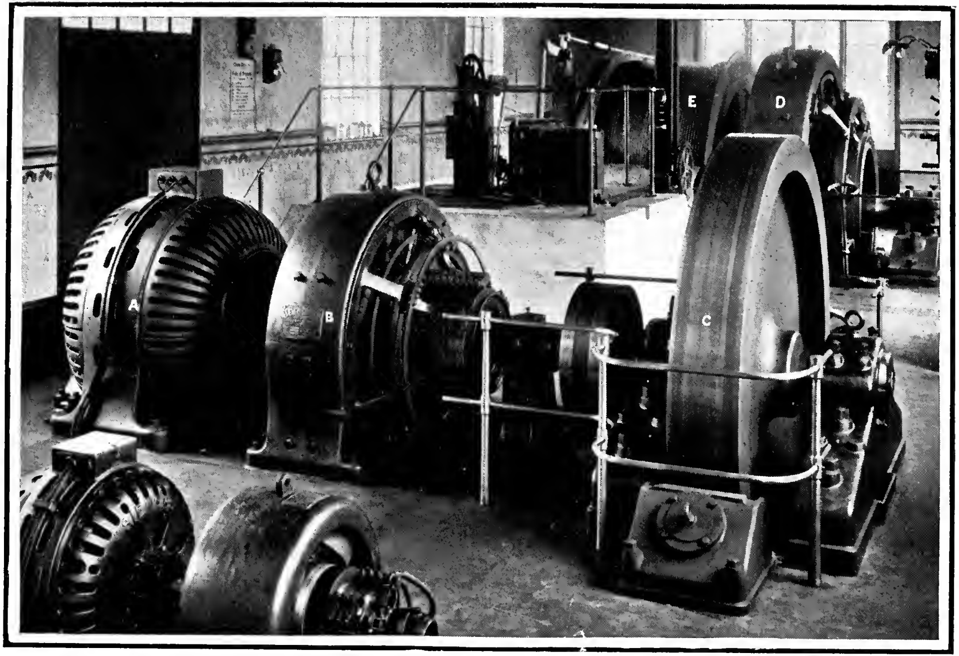
We measure a supply of water in two ways. We say there is a flow of so many gallons per hour and a pressure of so many pounds per square inch. In just the same way a current of electricity can be described as having a strength of so many "amperes," which is the equivalent of gallons per hour, and a pressure of so many "volts," which is analogous to pounds per square inch. It is not necessary to go into the exact value of these units of electrical measurement, but it will be interesting, perhaps, to state that the current given off by the familiar dry cell such as is often used for electric bells is at a pressure of a little over one volt.

There is another electrical measurement which we often use in conjunction with these two, and that is the "ohm." It is used to measure the resistance which a wire offers to the passage of a current along it. A copper wire 1000 yds. long and $\frac{1}{16}$ in. in diameter has a resistance of about eight ohms.

An ampere is the strength of the current which a force of one volt will cause to flow along a wire having a resistance of one ohm. Thus, it will be seen, these three measures are all related to one another.

If we were transmitting power by water through a pipe we could use a lot of water at a low pressure or a very little water at a high pressure. So long as the machine which it worked at the further end were made to suit, it would not matter which of these we did, except for one consideration: the pipes would have to be in proportion to the quantity. By using the small quantity at a high pressure we could do with much smaller pipes, and the saving in cost if the line of pipes were a long one would be considerable. If they had to be made of an expensive substance like copper, the difference would be very great indeed.

But the "pipes" used for transmitting power by electricity are solid wires made of this costly metal, and so if the distance be considerable the current is always



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Electricity at the Coal-Mine

This shows how electricity is used for winding up the loads of coal from the bottom. The current from the power-station goes to the induction motor A, which drives the dynamo B and the heavy flywheel C. The current generated by B drives the motor D, which turns the drum E, and so hauls in or lets out the rope. If D were driven direct from the supply it would require a great deal of current when actually lifting the loaded cage, and *none while standing still;* thus the current would be taken in "gasps." By the arrangement shown a small current flowing continuously does just as well. When D is still and is taking no current from B, the induction motor A has little to do, so it expends its energy in driving the flywheel C up to a high speed. Then, as soon as D starts and takes current from B, a heavy load is thrown upon A, slowing its speed down slightly, whereupon the momentum of the flywheel C comes to its assistance. Thus we see the remarkable case of a comparatively small motor (A) driving (D), a more powerful machine than itself.

generated and transmitted at a very high voltage, in order that the quantity, and consequently the size of the wires, may be kept down to the minimum.

Now at a high voltage a commutator is a nuisance. As a segment recedes from under a brush the electricity leaps across the space from one to the other, causing great heat and doing damage to both. The same difficulty does not occur with the slip rings on an alternator, since the brushes never leave them, and in most cases it is only the moderately powerful "exciting" current for the field magnets which passes through them, and so for generating high voltages the alternator is invariably the machine used.

A concrete illustration of this will make it quite easy to understand. In the case of the London Underground Railways the current is generated at Chelsea at a pressure of 11,000 volts, and of course it is alternating current. From there it passes to the sub-stations placed at intervals along the system, where it first of all goes to the transformers. These are simply huge induction coils. Most of us have played with induction coils at some time or other. They are often called shocking coils, because they are used to give people electric shocks. They consist of two coils of wire, one inside the other, and if a current of low voltage is sent through one of them, a current of higher voltage (but of proportionately reduced quantity) will come out of the other. They are usually worked by a single chemical cell, the current from which we are ordinarily unable to feel, but which in its intensified form we feel sometimes more than we like.

The difference between the current which goes in and that which comes out is due to the difference in the number of turns of wire in the two coils, and it will work equally well the opposite way—that is to say, we can arange such a coil so that, if fed with a small current of high voltage, it will give out another current at a much lower voltage but immensely increased in volume.

That, then, is what takes place in the transformers in the sub-stations. Current at 11,000 volts is fed into them, and a much greater current at 500 volts comes out. Now 500 volts is a suitable pressure for working the motors on the trains, but the current is still alternating, whereas the motors used need direct current, so it passes from the transformers to machines called converters. These are practically a direct-current dynamo and an alternator combined into one machine, and the current which goes in alternating comes out continuous. The converter automatically sorts out the little puffs of current which constitute the alternating current, puts them all the same way about, and delivers them all in one continuous stream.

From the converters the electricity passes to the conductor rails, which take it to the motors on the trains.

As we are concerned, in this chapter, with the transmission of power by electricity, and shall be dealing with traction in a future one, we will not pursue the course of the current any further. We have seen, however, how it was generated at a high voltage so that it could be conveyed by small cables, and how it was transformed into a lower voltage for use, and finally converted into continuous current as required by the motors. And now we shall see where the continuous-current dynamo scores over the alternator.

The arrangement which we have just been looking at shows how cost was saved in the copper conductors, but from that saving must be deducted the cost of the sub-stations and the transformers and converters. We can easily see, then, that if the current has not to be conveyed very far it is cheapest to generate direct current to start with at about the voltage that we need, and so save the use of converters and transformers altogether.

Speaking generally, then, we may say that alternating-current dynamos are used when a high voltage is needed for transmission to a long distance and direct-current dynamos for generating low voltage currents for use near at hand.

Readers may sometimes be puzzled by hearing alternating current spoken of as "single-phase," "two-phase," or "three-phase," terms which may conveniently be explained at this point.

In some alternators, the conductors on the armature, in which the current is induced, are all arranged together, so that the current flows, first one way and then the other, in them all simultaneously. That is a "single-phase" machine, and produces "single-phase" current.

In others these conductors are grouped in two sets, so arranged that the current induced in one set is flowing at its maximum strength just as that in the other set is changing its direction and is consequently not flowing at all. Such are called "two-phase" machines, and produce "two-phase" current, as it is called—in reality, two separate currents, each flowing in a separate pair of wires.

A "three-phase" machine, in like manner, has three sets of conductors, and produces three separate currents, the alternations in which succeed each other at equal intervals. These three separate currents are spoken of collectively as "three-phase" current, and it must be noted that they do not require six separate wires as might be expected, but only three, for the relative times of the alternations are such that at any moment the current in two of them is equal in volume to that in the third, and opposite in direction, so that each wire in turn acts as the "return" wire to the other two.

Now we can take a look at the motors which turn the electricity back into mechanical power when it gets to the end of its journey.

The direct-current motor is a beautiful machine. It is small, quiet, easy to control, starts itself readily, is easily reversible, and is efficient into the bargain. We have seen how on the underground railways the expense was incurred of turning the current from alternating into direct. That was simply in order to secure the advantages of the direct-current motor. Were it not for this, direct current would probably go out of use altogether, except for such work as electroplating, for which alternating current is no use at all.

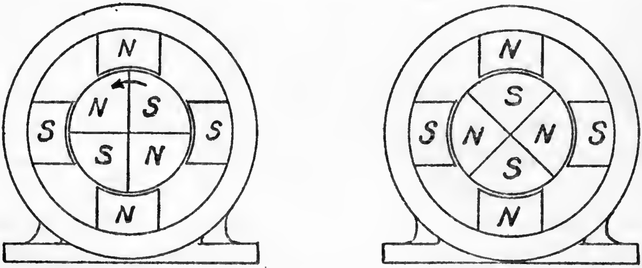
This valuable machine is exactly the same in construction as a direct-current dynamo; in fact one machine can be used for both purposes. The reason for this can be easily explained. Every magnet has two ends, and there is a mysterious difference between them. If a magnet be suspended so that it can swing round freely, one end will turn to the north and the other to the south. These two ends are therefore called the north and south poles of the magnet. Now if two magnets are placed near together with their like poles (that is to say, the two north or the two south) touching, they will repel each other, but if a north and a south be brought together they will attract each other. We may put it briefly; unlike poles attract, like poles repel.

Now just as the direction of movement of the wire in relation to the magnet determines the direction of the induced current, so the direction of the current determines the polarity of the magnet. If you had an electro magnet and found that one particular end was a north pole you might know for a certainty that if you reversed the direction of the current it would become a south pole.

These two facts, taken together, explain why the armature of a dynamo will turn round if current be fed into it and so become converted into a motor. When the current commences to flow the armature becomes a magnet, and its poles are attracted or repelled, as the case may be, by the field magnet, the result being that it is forced round.

This is one of those matters in which a diagram will explain easily what mere words would never be able to make clear at all.

Fig. 12 is a diagram showing the two essential parts of a motor. The field magnet, when made in that form, has four poles, two of which will be north and two south. We will assume that they are as marked, N. meaning north and S. south.



FIGS. 12 and 13.—Diagrams showing the working of a Direct-current Motor.

The armature, too, although it is round, is so wound with wire and so fed with current that it also is a magnet with four poles, and we will assume that it is in the position shown. Then we can easily see that, as soon as the current begins to flow, the armature will be forced round in the direction of the arrow.

But we are then confronted with this difficulty. As soon as the armature reaches the position shown in Fig. 13 it will stop, as the unlike pairs of poles are then as near together as they can be, and any further movement will tend to separate them, which of course the magnetic force will try to resist. Fortunately, however, we can, by altering the course of the current in the armature, cause its poles to shift backwards until the state of things shown in our first diagram is restored, and this the commutator does for us automatically. Just at the moment, then, when the poles come together, the poles of the armature move back electrically (for it must be clearly understood that the armature does not move back, it is only the magnetism which takes up a fresh position on the armature), and so the magnetic force generated by the electricity supplied to the machine causes it to rotate continuously.

In a direct-current motor, current is supplied to the field magnets so as to energise them, as well as to the armature. In the motors used for alternating current the electricity is supplied only to the field magnets, and since it is alternating it has the effect of inducing the necessary current in the rotating part. These motors are therefore called "induction motors." They are not so convenient as direct-current motors, since except with three-phase current they do not reverse themselves, the speed cannot be regulated, and they are not so reliable. Still it is so convenient to have motors that will work with alternating current that they are used very largely. There is another kind of alternating-current motor that is used on railway trains, but that will be referred to in the chapter on electric traction.

Another great advantage of the transmission of power by electricity is that it enables many things to be done by power which would be impossible without it. It has been suggested that it may even result in the revival of home industries. It would be in many cases impossible for a home worker, such as a weaver, for instance, to have a steam-engine or even a gas-engine in his house to drive his machine, but an electric motor driven off the public mains would take up very little room, need no attention, and be always ready to start.

It must not be thought, however, that in factories electricity has entirely done away with the use of shafting, pulleys, and belts. On the other hand, the use of roller bearings has given the latter a new lease of life. It used to be the invariable practice for the shaft simply to slide round in a bearing—that is, a broad ring of metal encircling the shaft, in which it was free to turn easily. Needless to say this caused heavy losses through friction, but with a ring of rollers instead of the solid bearing this loss is very largely removed, and it is claimed in some cases that machinery in a large workshop can be more cheaply driven by shafting with roller bearings than it can by electric motors.

CHAPTER VI

THE ENGINEER'S MATERIALS

IRON AND STEEL

In the course of his work the engineer brings into use a great variety of materials, but there is one—iron—which stands far above all others in importance. Indeed it would be no exaggeration to say that without it engineering as we know it to-day could not exist.

The use of iron marked one of the stages in man's development, so that one period of the world's history is known as the "iron age." This was no doubt due to the fact that iron in a natural state is practically unknown. The ores in which it is contained are to all appearance simply lumps of stone bearing not the slightest resemblance to the metal, and so it would of necessity be only when man had gained a certain amount of knowledge that he would discover the metallic treasures hidden in the rocks around him.

The ores of iron are mostly either oxides or carbonates—that is to say, iron in combination with oxygen and carbon. Not mere mixtures, be it observed, but chemical combinations, which means to outward appearance different substances altogether. A simple illustration of such a combination is common rust, which is oxide of iron—iron in combination with oxygen—and but for the fact that we have been in the habit of seeing it form on iron, and so have come to associate the two in our minds, we should never dream that there was any connection whatever between the dull red dust and the bright, tenacious metal.

Iron ores are very plentiful in many parts of the world, and needless to say the quality varies considerably, so that different combinations can be used to produce different classes of iron.

When the ore comes from the mine it is first of all roasted in a furnace to drive off the moisture, after which it is taken to the blast-furnace. This is a huge vertical cylinder, often 90 or 100 feet high, built up of firebrick, strengthened with iron. The fire is made at the bottom, and the ore, together with fresh supplies of fuel to keep up the fire, is thrown on at the top. Around the lower part are a number of holes through which air is blown, and under the influence of the air-blast, intense heat is developed. The effect of the heat upon the ore is to loosen the connection between the iron and oxygen, or iron and carbon, as the case may be, and so allow the iron to get free. At the extreme bottom of the furnace there is a hole which is normally closed by a plug, and when sufficient molten iron has accumulated in the furnace this plug is removed and the metal allowed to run out.

At the same time that the ore and coal (or coke) are thrown in, quantities of limestone are put in too. This combines with certain earthy impurities in the ore, and forms a thick liquid called slag, which floats on the top of the iron, and is allowed at intervals to run out through another hole higher up in the furnace. It is this slag, after it has cooled and solidified, which constituted those enormous mounds which were at one time such a conspicuous feature in the iron-producing districts, and are so now, indeed, in many places. There used to be no way of getting rid of it, and so in the course of years veritable mountains of it accumulated, but now it has been found to be very good material for making roads and also for concrete, and the mounds are disappearing.

The heat of a blast-furnace is something over 2000° Fahrenheit, and what with the roar of the blast, the rattle of the hoist which takes up the ore and fuel, and the noise of the other machinery near, to stand by a blast-furnace is a most awe-inspiring experience.

A blast-furnace at night-time used to be a glorious spectacle, great flames leaping up skywards as if from an active volcano, lighting up the country for miles round; but those flames were really good gases burning to waste, and so they are not to be seen now. Instead, the mouth of the furnace is closed, and the gases are led away through huge pipes to heat boilers or drive gas-engines.

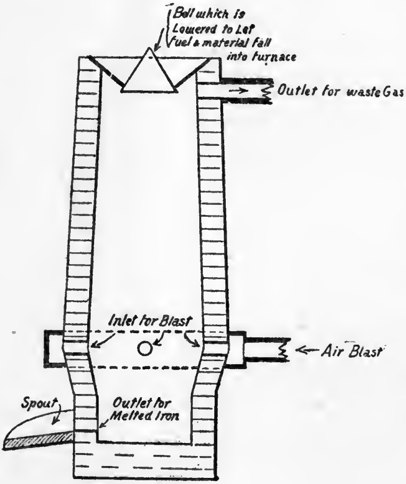


FIG. 14.—Section through centre of Blast-furnace.

But the thought will probably occur to some readers, How, if the furnace is closed at the top, can the ore and coal be thrown in? The explanation is that the top of the furnace is shaped like a basin with a hole in the bottom, and the hole is stopped up with a cone or bell-shaped stopper as seen in Fig. 14. The ore, coal, and limestone are thrown into this basin, and when the proper quantity has been deposited there the plug is lowered for a moment, and it all falls into the furnace.

It takes several days to get a blast-furnace going,

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BLAST FURNACE FOR SMELTING IRON

The striped structure near the middle is the furnace itself. The inclined framework to its left is the hoist up which the fuel, ore, and limestone are carried. Some of the large pipes are for carrying the air blast to the furnace, and others for taking away the waste gases. The stack of vertical pipes in the foreground is an arrangement for extracting the dust from the waste gases.

and so it follows that they work continuously day and night, year in and year out, for long periods.

When the furnace is tapped the iron runs along a spout, and then falls on to a bed of sand in which channels have been formed. It is allowed to run until these are full, and then a fireclay plug is again inserted in the hole and the metal left to cool.

When it has cooled it is broken up into pieces of about a hundredweight each, and is then known as "pig" iron, the pieces being called "pigs."

This is by no means pure iron, but contains from 3 to 5 per cent. of carbon besides other impurities, which make it hard and to a certain extent brittle. It cannot be forged or welded, and it is quite unsuitable for taking a severe tensile or pulling stress, but it is able to resist great pressure, and it has the advantage that it can be readily melted and cast into a great variety of forms. There are a great number of articles made of this "cast iron" (as it is called, since it is *cast* in a mould), not only in engineering works but all around us. The familiar black iron saucepan, for instance, which is to be found in every home, is made of cast iron. Most domestic fire grates, garden rollers, the frame of the typewriter on which these words are being written, and thousands of other things, are made in the same way and of the same stuff, while the engineer finds it one of the most useful of all his materials, simply because it can be so easily cast into almost any desired shape.

The making of castings is not usually done at the same works where the pig iron is made, but the iron-founder buys the pig iron from the blast-furnace owner and casts it in his own works.

Here there is a smaller edition of the blast-furnace, called a "cupola," in which the pig iron is melted up ready to be poured into the moulds. The moulds are made of sand, in iron boxes, and the making of them is a very interesting operation. Imagine a box, without bottom or lid, and divided horizontally into two halves, one of which has pegs which fit into holes in the other, so that the two can always be fitted together very accurately; then you will have a good idea of a "moulding-box." A wood pattern is made the shape of the casting required, and is half buried in sand in the bottom half. The sand is, of course, rammed very hard; the top surface is dusted over with very dry, dusty sand, and then the top half is put on to it and filled with sand too. After that has been rammed hard the top half is lifted off, the dry sand preventing the sand in the top half from sticking to that in the bottom half, so making them part easily. Then the pattern is taken out and the top half put on again. A hole is left in the sand which forms the top half of the mould, and through that the iron is poured, filling the cavity left by the pattern and so producing a perfect replica of it in iron.

When there are hollows in the casting, such for example as the inside of a pipe, a core of wet sand is made and baked in an oven until it is hard, almost like brick, and that is laid in the mould so as to form the hollow.

The old-fashioned way of ramming the sand was for a man to do it with a long iron rammer, and in many cases that is the only practicable way still, but many things can be moulded by machinery, and where that is feasible it is much cheaper. Some of these machines are simply presses. The pattern is cut in half and each half fixed on a board; the moulding-box is put over it, filled with sand, and heaped up. The movement of a handle then causes a block to descend upon the heaped-up sand and give it one or two vigorous squeezes, thereby making it hard and solid. The machine is often worked by compressed air. Another form of moulding machine, however, is rather more interesting, since it utilises a principle which we are familiar with in very different circumstances. Probably every one has at some time or other seen a grocer fill a bag with sugar, and has noticed that he invariably consolidates the sugar by giving the bag one or two smart bumps on the counter. In the type of moulding machine known as "jarrers" this idea is used. The pattern is fixed on a board as in the other case, and the board is fixed on to a table. Then the box is put on too, and filled with sand. On the movement of a small handle the table is raised an inch or so, with the pattern, moulding-box, and sand on it, and then simply *dropped.* This is repeated very rapidly for a few seconds, at the end of which time the sand is hard and solid.

The methods I have described apply, of course, only to very simple castings. Some complicated ones need to have moulding-boxes made in a large number of parts and the use of a number of cores of different shapes.

By heating cast iron for a considerable time and then allowing it to cool very slowly it can be made less brittle, and then it is called "malleable cast iron." That can, however, only be done with small castings, and it greatly increases the cost, to say nothing of taking several weeks to do.

By reducing the amount of carbon in the iron to say $\frac{1}{5}$ to $\frac{1}{2}$ per cent. it can be made flexible and elastic and capable of being forged and welded. It is then known as "wrought iron," and it is made by a process called "puddling." Pig iron is melted in a small furnace, much smaller than a blast-furnace, and of a different form altogether. It may best be described as a large covered cauldron containing liquid iron. The "puddler" has a long iron rake which he inserts through a hole and stirs the iron about. As he does this he, of course, exposes it to the air, and so the carbon burns out of it and it becomes a thick pasty mass. This the puddler manipulates with his rake into lumps, which he then rakes out of the furnace. The lumps are then heated again, but not to melting-point this time, and are placed in a pile under a powerful hammer and beaten into a block, which is subsequently rolled into plates, bars, sheets, or whatever it may be required for.

This wrought iron is "stringy" in its nature, so that while it can be bent without fracture in one direction it will be liable to break if bent the other way. For this reason and also on account of its inferior strength, it has largely been superseded by steel, which has no "grain." Wrought iron is still used, however, sometimes, in preference to steel, because it rusts less quickly. Steel is intermediate between cast iron and wrought iron, inasmuch as it contains about 1 to 1½ per cent of carbon. Thus we see that the differences in the various kinds of iron (for steel is simply a kind of iron) are due mainly to the differing proportions of carbon which they contain. Pure iron is for practical purposes useless.

Steel puzzles people very much, for knives are made of it, for instance, and fine edge tools and delicate instruments, yet rails and girders and other rough, heavy things are said to be made of it too. Can it be that they are all made of the same material? The answer is that although they are all steel the steels are of very different quality. For instance soft steel ("mild steel," as it is called) costs only about £4 or £5 a ton, while high-class steel such as tools are made of may cost as much as £100 a ton. The difference depends on the composition, mainly on the precise amount of carbon which they contain. Then there are other kinds of steel used for special purposes, such as the "nickel-chrome" steel used for making guns. These are all nearly the same, only with slight variations in their constituents, which often result in vast differences in the properties of the metal.

It is indeed one of the great beauties of steel that it can, by slight variations in its composition, be made to possess such a great variety of qualities suitable for different purposes.

One way of making mild steel is called the Bessemer process, after Sir Henry Bessemer, who invented it. The iron, as it comes from the blast-furnace, is placed in a vessel called a converter, and a blast of air is blown through it. The air actually bubbles up through the liquid metal, so that oxygen (which is, of course, one of the constituents of the air) is brought into contact with every particle of iron, with the result that the carbon in the iron combines with it, just as the carbon in coal combines with the oxygen in the air and forms a coal fire. The consequence is that, after the air has been blown through the metal for a while, the converter contains a mass of practically pure iron. A certain quantity of a special iron ore called "spiegeleisen," which contains a known quantity of carbon, is then thrown in, and the result is a mass of steel containing just the desired amount of carbon.

The converter is a curiously shaped vessel with holes in the bottom for the air blast to come up through. It is supported on two pivots, one on each side, so that it can be tilted into a horizontal position for the iron to be poured in; in that position the iron does not reach the air-holes. When it has been filled, the blast is turned on and the converter swung round into an upright position, so that the air blows up through the metal. When the process is complete the converter is turned down again before the blast is turned off. But for this arrangement, of course, the liquid metal would run through the holes in the bottom, and the whole process would be impossible. It is interesting to know that Sir Henry Bessemer, whose name is now famous throughout the world in connection with the manufacture of steel, was not, when he made this invention, a steel maker. He was an engineer, it is true, but his business was the manufacture of bronze powder, and he only experimented in the manufacture of steel as an amateur.

The other great method of making mild steel is known as the Siemens-Martin process, again after its inventors. The furnace in which this is carried out might be described as a shallow oblong bath, the heat being supplied by gas similar to the producer gas described in a previous chapter in connection with gas-engines.

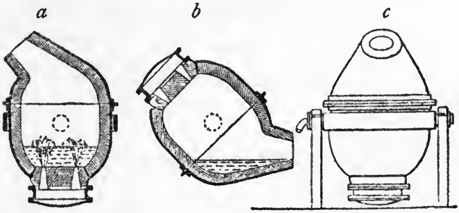


FIG. 15.—Bessemer Converter. *a*, Vertical position ; see how the air is blowing up through the steel. *b*, Horizontal position for charging and emptying. *c*, Front view, showing how the converter swings on pivots.

At each end of the furnace there are two huge brick flues, through one of which comes the gas and through the other air. On entering the furnace the gas and air mingle and burst into flame, the roof of the furnace being so made as to deflect the flames down on to the surface of the iron, while the waste gases which are produced by the combustion (the smoke, as it were, only there is little or none of that dirt which we associate with smoke) escape through the two flues at the opposite end. Now that brings us to a very interesting thing. Those waste gases are very hot, and it would be a great pity to lose all their heat; yet how can it be recovered? The means adopted are ridiculously simple.

The two flues at each end are each connected with two large chambers, filled with loosely stacked bricks, so that the hot gases, as they pass out, have to go around and between these bricks, and in so doing impart to them intense heat. After that has been going on for a while the course of the gases is reversed, and the gas and air come in at the opposite end, while the waste gases go out where, a moment before, the new gas and air were coming in. Thus the fresh gas and air, passing through the heated bricks, pick up and carry back into the furnace a great deal of the heat which was taken out a short time before by the waste gas. So the process goes on, first one way and then the other; the stacks of bricks are first heated by the waste gas, and then in turn they heat the gas and air coming into the furnace. Furnaces so arranged are called "regenerative" furnaces.

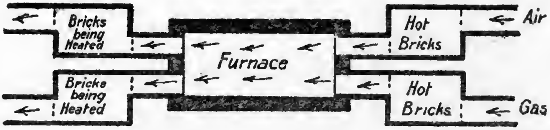


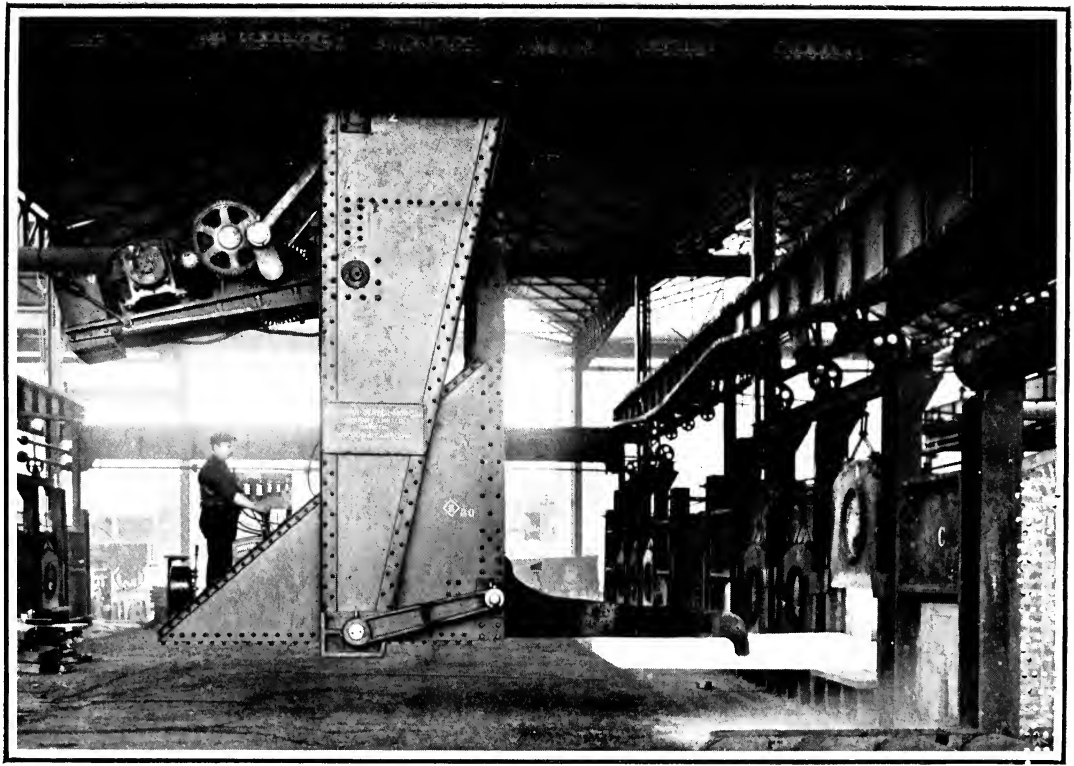
FIG. 16.—Diagram showing how the waste gases in a Regenerative Furnace are made to give up some of their heat, which later is carried back into the furnace.

Thus the iron is boiled, as it were, until much of the carbon has been burnt out of it, and by the addition of certain special ores the right mixture has been obtained.

The men who attend the furnaces have to wear dark-blue spectacles, as the glare of the boiling metal is so great that with the naked eye absolutely nothing can be seen. Viewed through dark glasses, however, it is a magnificent sight—a lake of fire, bubbling and surging, and when the lumps of ore are thrown in, the splashes which arise are more glorious than the finest display of fireworks.

When the steel is ready, it is run out of the furnaces into ladles and cast, in iron moulds, into ingots—great rectangular blocks weighing, perhaps, as much as 10 tons each.

The next stage is the rolling of these ingots into rails, girders, plates, bars, or whatever form may be required. This is done in a rolling mill. It is in principle just like the ordinary domestic mangle. The ingot, having been reheated to a white heat in an underground furnace known as a "soaking pit" (since the ingot must be thoroughly *soaked* through with heat), is lifted by a huge pair of pincers attached to a powerful crane and laid on the "live rollers." These are a large number of rollers laid near together and parallel to each other, just above the level of the floor, all rotating in the same direction and at the same speed. As soon as the ingot rests on these they carry it forward to the rolling mill, where it passes between the rollers. These are different from the rollers of the mangle, to which I compared them just now, in that they have grooves in them shaped according to the work that is required of them. The first pair of rollers have *large* grooves, so that they can take in a whole ingot and reduce its girth a little, while increasing its length. Then it passes on over other live rollers, until it reaches another rolling mill, through which it passes again and again, backwards and forwards, each time getting smaller and smaller in section, until at last it is a rail or girder or angle iron, or whatever it is intended to become.



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A MECHANICAL HAND AND ARM

A Charging Machine at a Steelworks. It has just picked up a 5-ton slab of steel, and is in the act or placing it in a furnace to be re-heated. The machine can travel to and fro, to right and left, up and down, and also rotate upon its axis.

Plates are made, too, in just the same way, the only difference being in the shape of the rollers.

Specially designed steam-engines have to be employed to drive these rolling mills, owing to the exceptional circumstances under which they work. Consider it for a moment. Merely to spin the rolls round requires scarcely any power at all, but the moment they grip the end of the approaching ingot enormous force—many thousands of horse-power—is required to be exerted all at once. In some modern mills, electric motors are used for this purpose, each of which is provided with an enormous fly-wheel, which the motor, when it is working light, drives up to a great speed. Then as soon as the entrance of the ingot into the rolls causes the motor to slow down somewhat, the great force stored up in the momentum of the fly-wheel comes into play and assists the motor. Thus, when working light, the motor is able to store up a supply of energy which comes to its assistance when it is hard pressed.[1]

Electricity, in fact, plays a great part in modern steelworks.

The furnaces are often fed with material by a huge electrically-driven "charging machine." This travels on rails, either overhead or else on the ground, and possesses a marvellous mechanical arm, the action of which is remarkably like that of the human arm. The machine can move up and down in front of a long row of furnaces, and if one of them needs some more iron putting in, it will run perhaps to the other end of the shed, pick up a box containing several tons of material, bring it back, and put it through the door of the particular furnace that needs it. Then, having turned the box over to tip out its contents, it will withdraw it and take the empty box back. All the

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[1] Page 80 shows this principle applied to hauling coals up out of a coal pit.

different motions are worked by electric motors, and the whole thing is controlled by one man, who stands on a little platform on the machine itself.

Then, in some works, there are machines of a similar description which, instead of a hand for taking hold of the boxes of material, are armed with claws by which they can pick up a hot ingot and hand it about as easily as a hostess can hand a cup of tea to a guest (see page 98).[1]

The steel of which tools are made is produced by quite a different process. Instead of being made from the crude iron as it comes from the blast-furnace, the finest and purest wrought iron is melted up with other ingredients in a crucible. In the case of mild steel, it is a refining process: the impure iron is put in the furnace and the impurities are got rid of until the desired mixture is left, while in the other it is simply mixing, the purest of materials being melted up together. Moreover, while mild steel is turned out by the hundred tons, crucible steel is made in lots of a few hundredweight. Thus the expensive materials and small quantity, together, account for the large difference in cost.

Both mild steel and crucible steel can be cast in moulds just as cast iron is, and there has been a great development in the use of mild steel castings in recent years, as they are stronger and less brittle than iron castings, and also (an important point for electrical machinery) they possess better magnetic qualities as well.

But, of course, the many varieties of iron and steel do not exhaust the list of materials used by the engineer. Some of the more important of the others will be described in the next chapter.

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[1] The methods by which electricity is used to melt iron and steel are referred to in Chapter XXII.

CHAPTER VII

MORE MATERIALS

BESIDES iron and steel there are two other materials largely used by the engineer of to-day. These are Portland cement and copper.

The former, as we shall see later, has of recent years entered into a remarkable partnership with steel, giving us the wonderful new building material, "ferro-concrete," while in railway construction, harbour works, and all great public undertakings it is invaluable.

Despite its name, it has nothing to do with the place called Portland, except that the place has given its name to a kind of building stone which is found there, and Portland cement, if mixed with water and allowed to set, looks like this Portland stone.

It is a mixture of chalk and clay, or as the chemist would say, silica, which is derived from the chalk and alumina, the material of which clay is made. The chalk is obtained from a quarry, and the clay either from beds or pits or from the mud of certain rivers.

There are two processes by which it is manufactured, known as the "wet" and the "dry" respectively. In the older, the "wet," the clay is used in a wet state, as it comes from the river bed whence it has been dredged up. It generally comes to the works in barges, and it is sent first to the "wash mill," a machine in which it and chalk from a quarry near by, in the proportions of about one to three, are thoroughly mixed up and stirred together, with water. This is a very important part of the process, as the quality of the cement depends upon the two materials being very intimately mixed together.

The wash mill having stirred it up very thoroughly, until it looks very like milk, the "slurry," as it is now called, passes to a rotary kiln, a very interesting piece of machinery. It is a large iron tube formed of plates riveted together as we see the plates riveted together in a boiler. It may be as long as 50 yards and 7 or 8 feet in diameter, and at intervals along it there are strong iron rings entirely encircling it, which are supported on rollers so that the whole structure can turn round and round bodily. It is of great weight, for besides the steel shell there is a lining of firebrick, and inside that the material that is being treated. It is an impressive sight, therefore, to see this great heavy drum slowly turning over and over, and of course it needs a powerful engine to drive it.

One end is slightly higher than the other, and at the upper end the slurry is fed in through spouts. At the other end there is blown in a jet of air and coal dust. Now coal dust, as was noticed in an earlier chapter, if fine and mixed with air, will burn like gas, and so as the slurry trickles down from the upper end it meets the hot gases and eventually the hot flames of a very efficient coal fire coming from the other end. It is thus first of all dried, and all the water driven out of it (it would, of course, stick to the bottom of the furnace in a lump but for the continual movement), then as it travels along, getting nearer and nearer to the hottest part of the furnace, it is well burnt, and falls out at the lower end in the form known as "clinker." The milky-looking liquid has by that time been turned into a hard, stony solid.

Of course the clinker as it falls from the "rotary" is very hot, and according to modern practice that heat must not be lost if it can possibly be captured and turned to some further use. Under the kiln, therefore, there is another tube, a sort of miniature of the larger tube above, and into this the hot clinker falls. The lower tube or "cooler," as it is called, slopes the opposite way to the kiln, and so the clinker starts to travel back to the place whence it started, meeting a draught of cold air as it goes. This air cools it quickly, but, what is more important, it heats the air, and it is the same air which is injected with the coal dust into the kiln ; so, becoming heated in this way, the air carries back into the furnace a great deal of the heat which the clinker has brought out with it.

This form of kiln is a remarkable contrast to those which used to be in vogue. With them the slurry was, after mixing, allowed to dry in tanks until it was about the consistency of butter. It was then dug out in lumps and stacked in a brick chamber along with alternate layers of coke. The whole mass was then ignited, and when the coke had all burnt the kiln was opened and the clinker taken out. This meant alternate firing and cooling, not a continuous process like the rotary, and a great deal of heat was lost.

After leaving the rotary kiln the clinker passes to the grinding mills.

That is the wet process. In the dry, the clay is obtained in as dry a state as possible, and after being subjected to a little heat to make it quite dry it is ground up with the right quantity of chalk, often in what is called a ball mill—that is, a revolving drum with heavy steel balls in it, which roll and tumble about as the mill is rotated, and so pound up the material with which it is partly filled. This powder is then mixed with a little slurry, and formed into bricks about the same size as the ordinary building bricks. These are fired in a vertical kiln, a tall tower heated by gas at the bottom, the bricks being fed in at the top and withdrawn a few at a time at the bottom, so that here again the process is continuous.

The final grinding of the clinker into the fine, impalpable powder which is the finished cement is a very important matter. The reason why cement after being wetted turns into a hard, solid mass is because of the process of crystallisation which is set up among the particles when they come into contact with water. They crystallise into such a shape that the whole mass of crystals interlock with one another, and it is that interlocking which holds them together and makes a myriad particles into a solid block. We see, then, that the strength is due to the mixture of the cement and water, and it is quite clear that the finer the particles into which the cement is divided the more thorough will the mixture be and the stronger the resulting block. It used to be ground with millstones just as flour was ground in the old windmills, but now machines called "tube-mills" are generally used for the purpose. These grind it much finer than the old stones.

The difference between ball-mills and tube-mills it may be interesting to explain. The former is a large drum, perhaps 10 feet long and 6 feet diameter, partially filled with steel balls, revolving about thirty times a minute. The latter is also a drum, and is also partially filled with steel balls, but it is longer and narrower, say 24 feet long and 4 feet diameter, and it rotates about half as fast again. Thus the material, passing from end to end, is longer subject to the pounding of the balls, and the latter, because of the higher speed, are more energetic in their action, resulting in a very fine powder being produced.

Cement is now being made, too, from the slag which comes from the blast-furnaces in ironworks.

The molten slag runs on to rapidly revolving rollers, and at the same time water is sprayed on to it. Thus it is cooled and solidifies in granulated form. It is then left for some days to cool thoroughly.

After that it is broken up into small pieces and ground in a "ball-mill," the grinding being completed in a "tube-mill."

We come now to our third great material, copper.

At one time the chief use of this metal was to cover the bottoms of ships, but, with the advent of the iron ship, that use died out. About the same time, however, there arose a fresh demand for copper for electrical purposes, and that demand is so great that although the production has increased very greatly it is barely able to supply the requirements of the great electrical industry.

Copper, like iron, is found in the form of ore, in combination with other substances, including, however, unlike iron, some impurities which are more valuable than itself. The refiner of iron gets nothing more valuable than blast-furnace slag, which was for years an absolute drug in the market (people would not even take it away unless they were paid to do so), but the refiner of copper gets gold and silver.

The first thing that is done to the ore is to heat it to a moderate temperature—"calcine" it, is the technical term. That is to drive off the sulphur. The ore is in the calcining furnace for from twenty-four to thirty-six hours, during which time it has to be stirred about or agitated in some way so that the process may go on uniformly throughout the whole mass of ore.

Then it goes to a furnace to be smelted. This is very like what is done with iron, which, as we have seen, is first roasted at a comparatively low temperature and then taken to the blast-furnace; and the similarity does not end there, for the furnaces used for smelting copper are most of them either like the blast-furnace that is used for iron, or else like the Siemens steel furnace. The product from these furnaces is, however, not a nearly pure metal like pig iron but a substance called "matte," which only contains from 45 to 50 per cent. of copper, so that another process has to be gone through.

Again we find a remarkable similarity with the manufacture of iron, for the plant which is used very largely for this is the Bessemer Converter. The strangeness of the situation increases, too, when we find that while the steelmaker uses the Bessemer Converter to burn carbon out of iron, the copper smelter uses it to burn iron out of copper. A converter is of course always lined with a kind of mortar, made of sand, in order to protect the iron shell from destruction by the heat. In the steelworks this lining, however, plays a further part in the process, for certain ingredients are mixed with it which enter into the chemical changes by which the steel is formed, and the same is the case at the copperworks. There the silica in the lining having an affinity for iron, the two combine and form slag, leaving the copper with only about 1 per cent. of impurities.

This 1 per cent., however, is partly gold and silver, which are worth some expense to recover, while the remainder of the 1 per cent. consists of other metals—such as arsenic, antimony, bismuth, tellurium, and silurium, which spoil the copper as a conductor of electricity. While, therefore, the gold and silver are worth recovering for their own sake, the others are worth extracting for the sake of the copper, and the method most largely adopted is electrical. It is indeed very curious that whereas the dynamo is the cause of the large demand for this very pure copper, it is also the dynamo which enables it to be produced, for only by its means can those large currents be generated which are necessary for the process.

The process is precisely similar to that by which our spoons and forks (or rather the spoons and forks of some of us) are electro-plated. The scientific name for the process is "electrolysis," and briefly it is this.

If a piece of metal be suspended in a suitable liquid and connected to the positive pole of a battery or dynamo (the end, that is, from which the current appears to flow), and some other object—it matters not what, so long as it is a conductor of electricity—be hung in the same liquid and connected to the negative pole of the battery or dynamo and the current then turned on, very minute particles of the metal plate will be dissolved off, will pass through the liquid, and become deposited on the second object whatever it may be. In electro-plating the current thus conveys particles from a plate of silver and deposits them upon the object of a baser metal which it is desired to cover, and so a fine layer of silver is spread over the object.

The plate of metal to which the current passes from the dynamo is called the "anode," and the other the "cathode."

In making "electrolytic" copper the anodes are slabs of the 99 per cent. pure copper referred to just now, and the cathodes are plates of copper. The current causes the anode to be dissolved and the particles to be deposited on the cathode ; and fortunately it can be arranged so that it is only the particles of copper which are thus deposited, while all the other matters settle to the bottom of the tank in the form of "slime." The pure copper, when a good quantity of it has been deposited, is torn off the cathode, while the slime is drawn off at intervals and the precious metals extracted from it.

CHAPTER VIII

THE ENGINEER'S TOOLS

Now that we have seen the materials which the engineer uses, it will be interesting to look at some of the tools with which he fashions them.

The ordinary man uses the word "tool" to indicate such things as hammers, files, chisels, and planes, but those the engineer distinguishes by the name of "hand" tools, using the latter word in a much wider sense to cover many very elaborate and wonderful machines, which he calls "machine" tools.

The most useful of all is the lathe, a machine in which a piece of metal can be turned round while a suitable cutting-tool is held against it so as to take a shaving off it as it turns. Whoever it was that thought first of the idea of shaping things by turning them round in this way must have been a genius, and he certainly conferred a great boon upon his fellow-creatures ; for by this simple means operations are made quite easy which, without it, would be difficult and in some cases impossible. Give an expert workman even a very simple lathe, and it will be difficult to find a job which he cannot do with it.

Of recent years, however, the lathe has undergone great developments. These have been mainly in the direction of making it work automatically, so as to need the minimum of supervision. Automatic lathes are made which can take in a bar of metal and turn it into pins of any desired shape, cutting each off when done and throwing it out, immediately starting on a fresh one and so working on continuously.

Another important tool is the planing-machine, which takes shavings off iron or steel as easily as a carpenter planes soft wood. It consists of a heavy iron table, which travels to and fro with the piece to be planed bolted down upon it. Across it is a sort of bridge to which the tool is fixed, and after each journey of the table this tool is moved automatically a short distance. Thus, starting at one edge, it makes a series of parallel cuts, gradually working its way across until the whole surface of many square feet, it may be, has been planed quite level.

Most of us have seen large circular saws at work cutting wood, but the fact that such saws can be used to cut iron and steel may come as a surprise. Suppose we have a steel girder, such as are used for making the framework of large buildings, and we wish to cut a foot off its length, our best way to do it will be with a circular saw. The saw used for iron is very similar to that used for wood, only it is generally smaller and it works at a much slower speed. That is because of the heat. A saw which has cut through a piece even of a soft substance like wood, is quite hot when it has done its work, and when it is used for biting through hard iron or steel it naturally gets much hotter still, so that, if it worked as fast as a timber saw does, it would quickly get so hot as to become softened and useless. Even at its slow speed it has to be cooled and lubricated with a continual stream of soapy water.

There is one very remarkable form of saw, called a "high-speed" saw, in which this heating effect is turned to useful account. One very extraordinary feature about this machine is that the part which cuts is often softer than the thing which is cut, and yet after long use it shows scarcely any signs of wear.

The revolving disc is not of hard but of soft steel, and instead of having sharp teeth it is simply roughened on its edge. Yet it revolves very fast, so fast, indeed, that its circumference travels as quickly as the fastest express train. It is this high speed which does the cutting and nothing else, for as soon as the edge of the disc touches the girder, or whatever has to be cut, enormous heat is produced by the friction ; so the girder becomes softened and the disc easily rubs its way through. So easy is this rubbing action that, as I mentioned just now, the disc itself shows scarcely any wear. But how is it, it will probably be asked, that the disc is not softened too? It is because in the case of the girder the friction takes place all at one spot, and so it is softened there, while, in the case of the disc, a part which is at one moment in contact with the girder is the next moment flying through the air and *so losing its heat,* and before the revolution of the disc has brought that particular part back to the girder again it will be quite cold, so that the heat in the disc itself is dissipated as quickly as it is developed. These machines cut with surprising speed, for a girder 12 inches deep can be cut right through in less than a minute.

But of tools used for cutting, perhaps the most remarkable of all is the oxygen blow-pipe. This is a little tool something the shape of a pistol, which a workman can easily hold in one hand. It is connected by a flexible tube to a cylinder of compressed oxygen, and by another tube to a supply of coal-gas. Thus a jet of oxygen and a jet of coal-gas issue from the nozzle at the end of the blow-pipe, and, mingling there, produce a fine point of flame burning with intense heat. If this be directed upon the edge of a thick bar or plate of steel it will in a few seconds melt a tiny groove in it, and, if the pipe be moved along, that groove can be developed into a cut and in that way very thick pieces of steel can be severed quite easily. The harder the steel, too, the more easily is it cut, for hard steel contains more carbon than soft, and that has a tendency to burn with oxygen, actually increasing the heat of the flame. A bar of iron a foot long can be cut right down the centre in fifty seconds. It is said that scientific burglars have been known to use these blow-pipes to open safes with; but a very strange thing about them is that, while they will cut hard steel of any thickness almost like butter, they are completely baffled by a thin sheet of copper. The reason of this is that copper is such a good conductor of heat that the heat of the flame is conducted quickly away, and so the part in contact with the flame never becomes hot enough to melt.

There is another purpose for which the oxygen blow-pipe is used, and strangely enough, it is the exact opposite of what I have just been describing—namely, for joining pieces of metal together. Wrought iron, and also some qualities of steel, can be heated until they reach a soft plastic state, and if two pieces in that state are placed together and hammered, they become united. That process is called "welding." Now there are many instances in which it is impracticable to do this owing to the shape of the pieces, and in such cases they can often be welded by a jet of oxygen and acetylene, in a suitable blow-pipe.

The process, to watch, is very like the soldering of two pieces of tin by a tinsmith. The workman holds the blow-pipe in his hand much as the tinman holds his "iron," and with it he heats the two edges to be joined until they are almost melting. Then he places the end of a piece of iron wire in the flame, and, just as if it were solder, melts it into the joint. Thus he works along until the whole joint is finished, when a very sound and strong job is the result. Other metals besides iron and steel can be joined in this way.

It may be interesting in this connection just to turn aside for a moment and see how the oxygen is made for use in these tools. As is well known, it is one of the constituent parts of the air, forming in fact about 20 per cent. of the bulk of the atmosphere, the remaining 80 per cent. being mainly nitrogen.

Now just as steam has a liquid form for which we have a separate name, water, so air has a liquid form, only since it has no name of its own we are forced to call it "liquid air." It is not easy to induce air, under the conditions which exist around us, to enter into the liquid state, but great pressure and cold will do it. Air is therefore compressed by an air-compressor, or pump, and is forced to pass through a coil of pipe. At the bottom of this coil it escapes and passes upwards around the outside of the pipe.

When a gas is compressed it always becomes hotter. The force expended in compressing it is converted into heat, and as soon as it is allowed to expand again it loses exactly the same amount of heat that it gained when it was compressed. If, therefore, you take any heat out of it while it is under pressure it will be *that much* colder when it is expanded than it was before it was compressed. That is to say, if you compressed air at 50 degrees until it had reached 100 degrees, and then cooled it by 30 degrees down to 70, when you expanded it again it would be only 20 degrees—the original 50, that is, less the 30 which you extracted.

So, when you compress the air in the liquid-air machine it gains heat, some of which it loses on its way through the coil, and when it escapes at the bottom it is therefore somewhat cooler than it was to start with. That in turn passing upward cools the coil still more, so that the next lot of air which escapes is colder still; and so the process goes on, the air getting colder and colder, until at last it reaches *minus* 170° C.[1] (which is the "boiling point" of liquid air), and after that it comes out liquid.

As soon as it is allowed to rise above that temperature it boils, passing back into vapour once more, and the remarkable thing about it is that the nitrogen passes off into gas first, leaving the oxygen behind. The last gas which arises from the liquid then is pure oxygen, and this forms an easy means of separating it from the nitrogen. After being collected in this manner it is compressed into strong steel cylinders for ease in conveying it about.

The subject of air under pressure naturally leads us to think of those tools which are operated by compressed air. When it is necessary to drill a hole in iron the best way to do it is to put the piece of iron under a drilling machine, and in a very short time the hole will be through. In this machine there is a vertical spindle, driven round by power, to the bottom end of which the drill is fixed. The work has to be held or fixed upon a table under the drill, and by turning a handle the latter can be brought down on to it. But suppose that the work is so large, or is so fixed that it cannot be taken to a drilling machine. What is to be done then? One thing is to drill it by hand, but that is a slow and costly operation. In many cases, however, a little pneumatic drilling machine, which can be carried in the hand, will do it easily and quickly.

These little machines are just like tiny steam-engines fixed in a small iron case and driven by compressed air instead of steam. They are so small that they can be easily handled by one man, and when he wants to drill a hole he simply fixes up the little machine (which is

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[1] That is, nearly twice as much colder than freezing point, as freezing point is colder than boiling point.

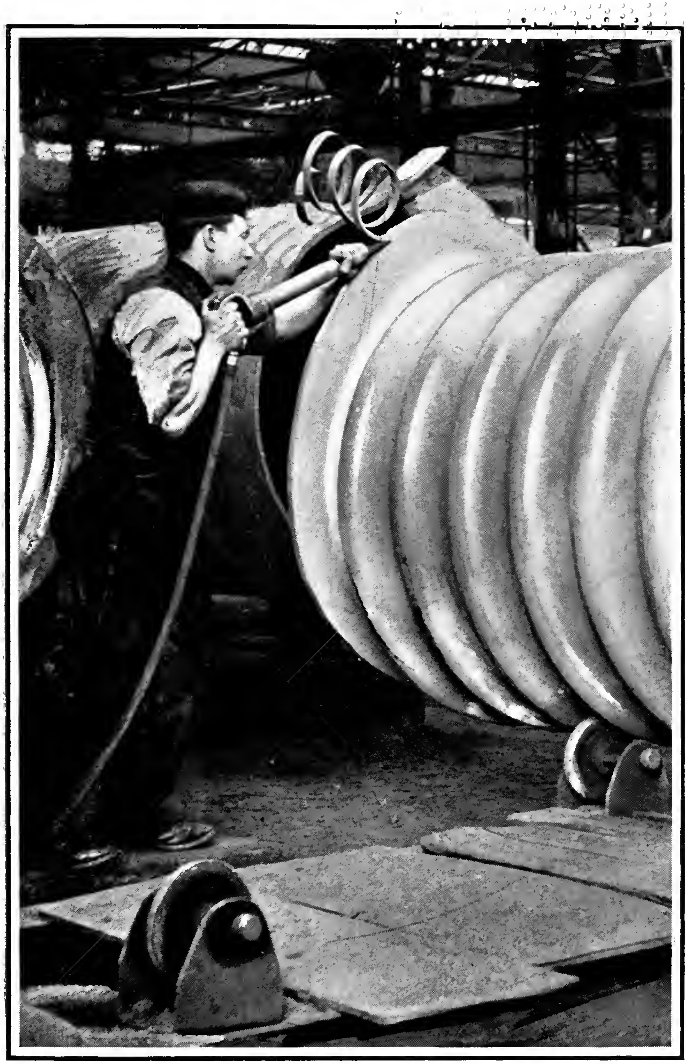
quite an easy thing to do) and then turns on the air, when the drill is driven round and the hole soon made. Indeed, unless the hole is a large one he does not need to fix his machine at all, but simply holds it in his hands.

It often happens, too, that a piece of iron has to be trimmed or shaped in some way under such circumstances that it can only be done by chipping it with a chisel. A man can do this by hand, using a chisel in one hand and striking it with a hammer held in the other, but that again is a slow and consequently a costly way of doing it, and here a compressed-air hammer solves the difficulty.

These are called "pistol" hammers, because they are like a pistol in appearance. What corresponds with the barrel of the pistol is really a cylinder in which a little block of steel slides up and down like a piston, while at the muzzle end there is a holder into which the chisel fits. The operator holds the hammer by the handle, puts the point of the chisel against the work, and then presses a little trigger which is just under his thumb. Instantly the little block of steel commences to fly up and down inside its cylinder, and every time, of course, it gives the chisel a sharp knock (see Plate opposite). A hammer like this will give hundreds or even thousands of blows in a minute, whereas the most industrious workman cannot do more than, say, one per second when working with an ordinary hand-hammer.

In many branches of engineering, rivets play an important part. A boiler, for instance, is entirely built up of steel plates riveted together, and the same applies to iron and steel bridges and ships. When rivets are put in by hand this is how it is done.

Three men and a boy work together in a squad. Two of the men are skilled riveters, and the third is a semi-skilled man who is called the "holder-up," while the boy looks after the little forge in which the rivets are



By permission of the *Consolidated Pneumatic Tool Co., Ltd.*

A PNEUMATIC HAMMER AND CHISEL

Here we see a man using a Pneumatic Hammer and Chisel. He is cutting a piece of metal off the end of a steel boiler flue. Observe the size of the "shaving."

heated. When the men are ready to put a rivet in they call to the boy, who picks up a white-hot rivet out of the fire with a pair of tongs and throws it to the "holder-up." The latter picks it up with another pair of tongs and inserts it in the hole. He takes great care to push it right in, and then he holds a heavy hammer against it while the other riveters hammer on the point of it with lighter hammers, taking alternate blows. When they have knocked down the point of the rivet into the semblance of a head, one of them throws down his hammer and snatches up another tool called a snap. This is like a hammer with a cup-shaped depression in its face. He holds this depression over the partly formed head while his mate flogs it as hard as he can with his hammer, and so the nicely rounded heads such as we see on railway bridges are formed.

Now in a ship, boiler, or bridge yard, where there is a great deal of riveting, much of it is done by what the workmen call an "iron man." Just squeeze a pellet of bread or putty between the thumb and first finger, and you will see exactly the way in which an "iron man" squeezes up a rivet. It is just like an enormous thumb and finger, large enough to span over a wide plate and rivet up the joint on the further edge. It is worked by hydraulic pressure, and is often portable, being carried by a crane specially used for that purpose. A rivet is simply put in the hole, the machine brought into the right position, a tap turned to let in the water, and in an instant the rivet is squeezed up and a stronger job made than the most skilled of hand-riveters could make in four times the time. The thumb and finger each have a suitably shaped tool, so that the heads shall be nicely formed.

The "iron man," however, is a ponderous machine whose sphere of operation is consequently limited, and he can only work to advantage where there are long straight rows of rivets which can be done one after the other in quick succession. So for odd rivets and rivets in awkward positions a pneumatic pistol-hammer, as described just now, is often used, a cup-shaped tool being substituted for the chisel.

Some mention must be made of that powerful tool the steam-hammer. This has a cylinder like that of a steam-engine supported in a strong iron frame. In the large sizes this frame is virtually a strong iron bridge, with the cylinder in the middle, supported on massive iron columns at each end. The piston-rod, which is much thicker in proportion than that of a steam-engine, carries at its bottom end a heavy block of iron, which forms the head of the hammer ; immediately under this, resting on the ground, is another block which forms the anvil. A small lever at one side works a valve which controls the entrance of steam to the cylinder. When this handle is in one position the steam enters beneath the piston and lifts it up, taking with it the piston-rod and head. In the middle position of the handle the head is held stationary, and, in the third, the steam enters above the piston and causes it to come down with a powerful blow.

By skilful manipulation of the handle the force of the blow can be regulated to such a nicety that the huge block of iron forming the hammer-head can be made to tap gently, without breaking it, on the shell of an egg placed on the anvil.

As mentioned in the chapter on gas-engines, there are now many works which have no steam-power available to work a steam-hammer. In such cases a pneumatic hammer is often used constructed on the same principles as a steam-hammer, but worked with compressed air instead of steam. There is an air compressor combined with the machine, which is worked by the same power which drives the rest of the machinery in the works.

For many purposes, powerful hydraulic presses are now used. For example, the steel tubes of which heavy naval guns are made are forged out of hollow ingots by means of presses. The steel is made hot, and is then pressed into the desired form. In other words, a series of squeezes are substituted for the blows of a hammer. Thick steel plates, too, can be pressed into most fantastic shapes by these tools, so doing quickly and neatly work which would be very expensive, if not impossible, by any other method. A simple example of this is the "trough" flooring often used to form the floor of a railway bridge. A plate of steel is heated, put under a press, and quickly converted into a deep trough, and a number of these troughs, placed side by side, constitute a floor strong enough to carry a railway train.

Another instance of the use of presses is in railway vehicles. It has been found that the best way of fixing the wheels on to the axles is to make the axle a "tight-fit" in the hole in the centre of the wheel, and then force it in by means of a hydraulic press, with a pressure of perhaps 50 or 60 tons.

The principle of these presses is very simple. There is a cylinder with a piston inside it, only instead of the latter being a disc, like the piston of a steam-engine, it is usually a solid block, and is then known as a "ram." The water is forced in by a pump at a pressure of, say, 500 lbs. per square inch, with the consequence that the "ram" is pushed out of the cylinder with a force of 500 lbs. for every square inch of its area. Hydraulic "power" is not, really, a power at all, but simply a means of concentrating power. The cylinder of the pump is small. Suppose it is only 1 square inch in area; the engine which works it keeps on pressing the ram of the pump down with a force of 500 lbs.; that pushes the water into the cylinder of the press, which may have an area of 100 square inches, with the result that it will be pushed with a force of 50,000 lbs. It takes a great deal more water, of course, to fill the press cylinder than it does to fill the pump cylinder, and the latter has to make many strokes to every one of the former, so that what is gained in force is lost in speed. There is no real gain of power, therefore, in a hydraulic press, it simply transforms a quickly moving weak force into a slowly moving powerful one.

This chapter might be continued to an almost indefinite length, so great is the variety of appliances which the engineer uses; but there is one machine which must be mentioned, before concluding, on account of its wide usefulness. In almost every works, and particularly in shipyards and bridge-yards, it is necessary to be able to cut bars and plates quickly and cheaply and also to make holes in them, and for this purpose the punching and shearing machine is most valuable. In its combined form it has two jaws, one for punching and one for shearing; it is worked by a simple mechanical movement, and is usually driven by a belt. The punching action is exactly like that of a railway-ticket clipper. There is a steel die with a hole in it, and exactly over this hole there is a punch. A steel plate, perhaps an inch thick, is placed upon the die, and the punch comes down upon it, going right through the plate, and pushing a small circular piece through the die, from the bottom of which it falls, leaving a circular hole in the plate.

The shearing movement is a combination of the action of the human jaws and a pair of scissors. One jaw is fixed while the other moves up and down, much like the jaws of an animal; but, instead of meeting as the teeth do, one jaw slides past the other like the blades of a pair of scissors. Thus they can bite a piece off a plate of iron or steel as easily as a pair of scissors cuts a piece of thin card.

CHAPTER IX

BRIDGES

PROBABLY one of the earliest structures which man learnt to make for himself was a bridge.

Its origin is far back in prehistoric times, but it seems probable that the idea arose in some such way as this. Just imagine a tribe in the Stone Age, the sort of people whose chipped-flint tools are found now in the beds of river gravel, showing that they lived by the banks of the rivers. They would most certainly want at times to get across their river, and would be forced to ford or swim it. One night there is a storm, and the next morning a tree is found blown down across the stream, with its top on one bank and its roots on the other. Even then, in all probability, they do not realise at once all that it means to them ; but during the day the boys of the tribe start playing on it, strip off some of the branches, and try who can climb across it in the shortest time, until it dawns upon the primitive intelligence of their elders that, there, is a new and convenient way of getting across the water.

Soon other tribes will hear of it, and before long will find ways of making trees fall across in suitable positions, and so the building of bridges becomes a regular thing.

Whether this fanciful peep into the remote past is true or not, there can be no doubt that from very early times bridges have been very important structures, and to-day they are more so than ever.

Modern bridges may be divided into four kinds, arch bridges, girder bridges, suspension bridges, and cantilever bridges.

Arch bridges are generally built of stone, brick, or concrete, but sometimes steel and iron are employed.

Some of the stone-arch bridges are remarkable for their beauty. Waterloo Bridge over the Thames in London, for instance, is so beautiful that a great Italian architect said that it was worth travelling from Rome to London simply to see it. Bridges of the other types, however, are more remarkable for their strength than anything else.

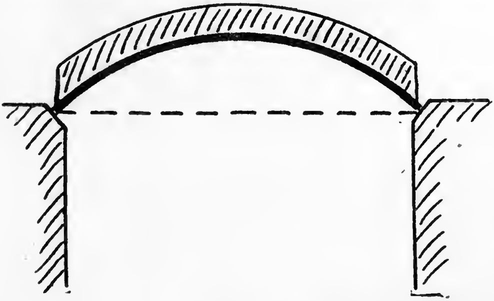
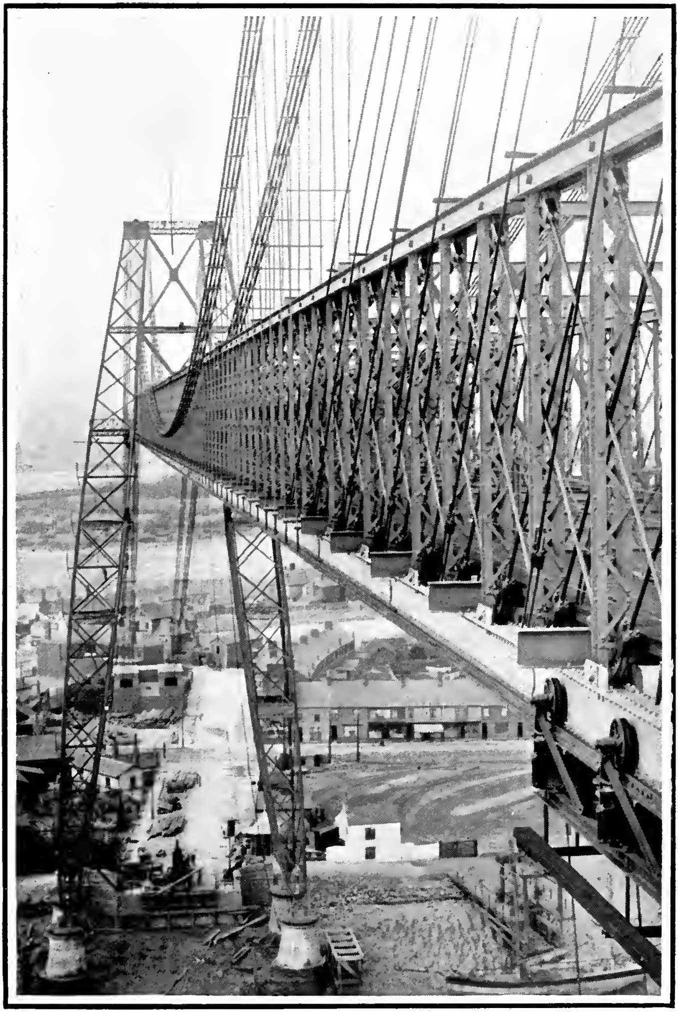


FIG. 17.—Diagram showing the source of strength in an arch.

The arch owes its strength to the fact that the shortest distance between two points is a straight line. In the diagram, Fig. 17, for example, the shortest distance between the two abutments is the dotted line. If, then, we make a curved structure like the curved line and place a uniform load upon it, one of three things must happen. Either the material of which the arch is made must be compressed until its length has been reduced to that of the dotted line; the abutments must be pushed apart; or the load will remain supported upon the arch. It only remains, therefore, to make the arch sufficiently strong to resist



By permission of *Messrs. Alfred Thorne & Sons*

THE "TRANSPORTER" BRIDGE AT NEWPORT (SOUTH WALES)

The great girder is supported at each end upon a huge trestle, one of which can be seen. On the right we get a glimpse of the trolley which travels on the bottom flanges of the girder, from which is suspended the car below.

the compression and the abutments sufficiently rigid. The abutments we see, then, are subjected to a push or thrust sideways as well as a downward pressure, and that is the distinctive feature of the arch.

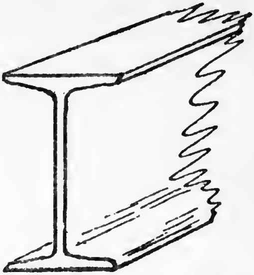


FIG. 18.—The simplest type of steel beams or girders. These are just a solid piece of steel, rolled as described in Chapter VI. They are much used in the framework of buildings. They are generally called rolled steel joists.

Most bridges are simply two girders (which is another name for beams), with a floor between. We see such girders carrying railways across our roads, or roads across railways, or spanning rivers and valleys. Some of them are very complicated structures, but in principle they are just the same as the familiar beam of wood which we see in a house, supported at its ends on two brick walls to carry a roof or floor. They are generally built up of iron or steel plates and bars riveted together; a material known as ferro-concrete is now coming into use for such purposes, but that will be referred to in a later chapter.

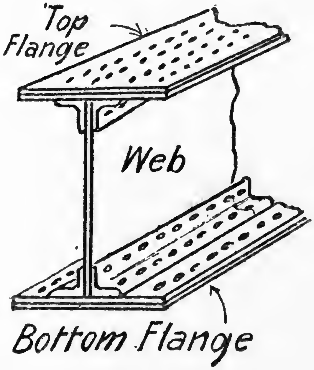


FIG. 19.—This is a "Plate Girder." A vertical plate forms the "web," and each flange consists of one or more plates. The flanges are connected to the web with "angle irons," and all are riveted together.

Suspension bridges are on quite a different principle. They are supported by tall towers, from the top of which depend strong steel cables, or chains built up of plates of steel, and from these cables or chains the bridge itself is suspended.

Of cantilever bridges perhaps the best-known example is the famous structure across the Firth of Forth in Scotland. It may be likened to several men standing in a row and extending their arms out towards one another. Each outstretched arm is a cantilever. Another way to describe a cantilever is to say that while a beam is supported at each end, and has its load in between, a cantilever is supported at one end only. Every bracket fixed to a wall, a common object in most houses, is a cantilever.

The cantilever principle plays a very important part in the construction of theatres and public halls nowadays. In old halls the galleries are supported upon columns which often seriously interfere with the view of the audience; but, in modern buildings of that description, the galleries seem to be supporting themselves and everyone has a clear view. The secret of the structure is that, hidden beneath the floor, there are powerful steel cantilevers firmly fixed in the walls, so that they are capable of supporting the whole weight of the gallery and its occupants without the assistance of columns at all. How it is arranged can be seen in Fig. 21.

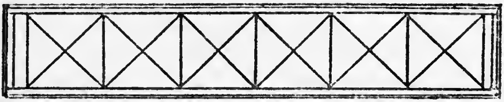


FIG. 20.—This is a "Lattice Girder." The flanges are built up of plates and angles, as in a plate girder, but instead of the solid-plate web, there is a system of struts and ties.

The designing of a bridge used to be a matter of judgment only. The designer made the parts as strong as they seemed to him to need to be, and his judgment was verified afterwards by each part being tested with heavy weights before it was erected. Now, however, the underlying principles are so well understood that the requisite strength of each part can be calculated out with great accuracy upon paper. In complex structures this is by no means an easy thing to do, and a competent bridge draughtsman needs to be a pretty good mathematician. Many of the necessary calculations have, however, been boiled down into short convenient formulæ easy to remember and to work out. Just one simple instance of this may be of interest. A girder is generally, if viewed as though cut through the centre, the shape of a capital letter I, and the horizontal parts at the top and bottom are called the "flanges," while the vertical part is known as the "web." Now the action of the load is to compress the top flange inwards towards the centre, and to pull the bottom one outwards from the centre, the web connecting the two together and preventing them from moving in relation to each other. An important problem, therefore, is to find out what the push or pull will amount to in order that the flanges may be made sufficiently strong. This is told

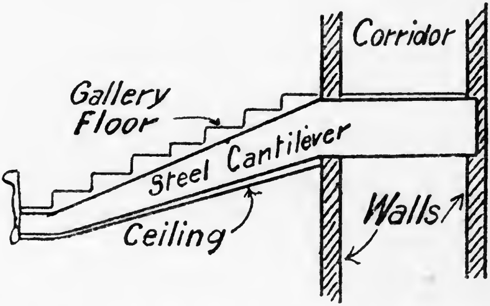


FIG. 21.—This shows how the galleries in modern public buildings are supported from the walls by means of cantilevers.

by a formula which is usually written down like this—

$$\frac{W \quad L}{8 \quad D}$$

which means that if we multiply the weight (W) which will come on the girder by the length of the girder (L), and then divide the result by eight times its depth (D), we shall get what we want—namely, the pull in the bottom flange and the push in the top.

Another way in which the labour of elaborate calculations is saved is by diagrams. A calculation which would need great mathematical skill, and take considerable time to work out by figures, can often be done easily and in a few minutes by means of a diagram.

The load which a bridge is designed to carry is the utmost that it would be possible (not merely probable) by any combination of circumstances to get upon it. For example, if it be a railway bridge, it is assumed to be covered with as many of the heaviest locomotives as can be crowded together, or, if it is a foot-bridge, it is assumed to be covered with a dense mass of people. Then, when the maximum possible load has been allowed for, the bridge is made about five times as strong as would carry it, or, to use the technical phrase, a "factor of safety of 5" is used.

When a bridge is designed its main features are decided upon by the chief-engineer, and then (in England) he sets a large staff of skilled draughtsmen to work out the details under his supervision. Many sheets of drawings are thus produced, giving even the minutest details. After that, the "quantities" are reckoned out—that is to say, the exact weight of steel of each description, the number of cubic yards of excavation and concrete in the foundations, the quantity of brick-work, stone-work, wood-work, and so on, often forming a schedule many pages in length. Then a specification is drawn up stating exactly what qualities the various materials must be, the tests which they are to stand, and the conditions under which the work must be carried out. Finally, these three, the drawings, the schedule of quantities, and the specification, are sent to the contractors to make up their tenders upon, and when a tender is accepted they become the basis of the contract.

In America the details are left to the contractor to design for himself, so that he may make them to suit his plant, subject of course to the engineer's approval.

Certainly not the least important part of a bridge is the foundations, and they are frequently the most difficult part to construct, especially when, as is often the case, they are in deep water. An example of this kind of work recently occurred during the building of the new part of Blackfriars Bridge over the Thames in London.

The difficulty, of course, is to get the water out of the way, and to keep it so until the foundations can be constructed. This is often done by sinking a "caisson," as it is called, a large iron box, inside which the work can be carried on and which will itself ultimately form part of the foundations.

In the case referred to, a strong stage was first made by driving timber piles into the bed of the river, leaving a large open space in the middle of it for the caisson to be lowered down.

The caisson was built up of steel plates connected by rivets, and was put together on this staging so that, when it was ready, it could be let down the space on to the bed of the river. About half-way down a caisson there is a steel floor, and above that is placed a quantity of concrete in order to make it heavy enough to sink in the water.

When all is ready, the caisson is lowered by means of hydraulic jacks on to the river-bed, and its lower edge being sharp, it cuts its way into the soft mud. In the floor of the caisson there is a hole, and a steel pipe is connected to it, coming up through the concrete to well above water-level. At the top of this pipe or shaft there is an air-lock, an arrangement of doors which enable men and buckets of dirt to be passed through without allowing any air to escape. When, therefore, the caisson has settled down as far as it will go of its own weight, these doors are kept closed, and air is pumped into the shaft so as to keep the water out of the caisson while men go down and shovel away the dirt out of the inside. As this goes on the caisson

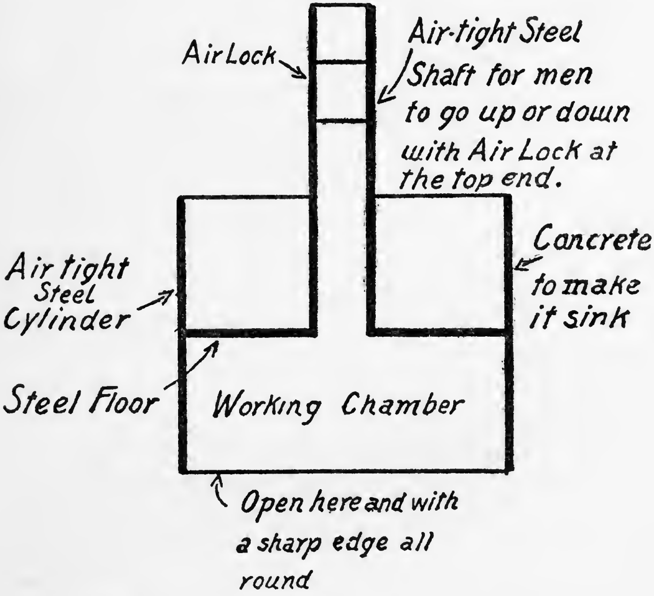


FIG. 22.—Diagram showing construction of a Caisson, for building foundations in deep water.

gradually settles down farther and farther, until it reaches a hard stratum, capable of furnishing a good foundation. Then the whole of the bottom chamber is filled with concrete, and the shaft as well, so that it becomes a huge block of concrete encased in steel. The piers of the bridge, of stone or whatever they may be, are then built up on the caisson, and finally the piles are drawn out.

It is clear that the main feature of this operation is the compressed air, which keeps the water from entering the open end of the caisson while the men are at work there; it is a most convenient and effective way of doing the work, but sometimes it can be done just as well without the compressed air. Only recently a bridge was erected in the Straits Settlements which well illustrates this method.

In this case the bridge is supported upon iron cylindrical pillars fixed in the bed of the river. The cylinders are about eight feet in diameter, and are made in short sections which can be bolted together so as to form any length required. The lower sections are made of steel, but the part which is above the lowest tide-level is made of cast iron, because iron or steel which is alternately wet and dry is very subject to rust, much more so than when it is always wet, and cast iron resists rusting much better than steel does.

First of all a light temporary bridge was made of steel piles driven into the bed of the river. The first intention was to use screw-piles such as are often used to support seaside piers. These are long iron or steel columns, with a large screw-thread on one end, and they are put down into the bed of the river and then screwed round, and so driven into the ground just as a carpenter drives a screw into a piece of wood. In this case, however, it was found that the mud was so soft that the screw simply stirred up a large muddy "puddle" and made no progress at all, or it might be expressed by saying that the thread of the screw would not bite in the soft mud.

The screw-threads were done away with, therefore, and a sharp point put on instead, after which they could be driven by a pile-engine just as timber-piles are usually driven. This is such a common occurrence that most of my readers have probably seen it in operation, but as there may be some who have not, I ought perhaps to give just a brief description. A pile-driver, or pile-engine as it is sometimes called, consists of a vertical wooden frame in which slides a heavy block of iron, called a monkey. At the top of the "monkey" there is a clip to which a rope is attached so that it can be wound up by means of a winch to the top of the frame, and no doubt it is this climbing action which has earned it the name of "monkey." As soon as it reaches the top the catch is released either by the pulling of a string, or in some other convenient way, and then the monkey falls. The machine is so placed that the monkey falls upon the head of the pile and drives it in with an action exactly analogous to that of a hammer and nail. When there are a good number of piles to be driven, a steam-winch is generally used, but where there are only a few it is done by hand.

After a temporary bridge had been constructed of piles driven in this manner, sections of iron cylinders which were to form the pillars of the permanent bridge were taken out upon it to the spot where they were to be sunk, and several were put together and lowered on to the river bed. The edge, which was sharp, at once cut its way into the mud to a distance of several feet, and the whole thing was heavily weighted until it had gone as far down as it would. Then a pump was set to work to empty the water out of the inside; for, observe, it had no floor such as a caisson has, being

By kind permission of J. J. Webster, Esq., M.Inst.C.E. *Westminster*

A 70-Ton Bridge taking a River Trip

This photograph shows a bridge, weighing 70 tons, being carried down the River Mersey by a floating crane. The crane, which belongs to the Mersey Harbour Board, could have taken, comfortably, another 30 tons, as it is designed to lift 100 tons.

simply a large pipe, and when it was emptied of water by a pump it was found that the clay, into which it had penetrated some distance, made a sufficiently good watertight joint against the metal pipe to permit men to go down and clear out the mud and clay which was inside. As that operation went on the huge cylinder sank lower and lower, until it reached the solid rock under the clay. In this way the cylinders were sunk to a depth of about eighty feet.

When the rock had been reached, the inside of the cylinder was filled with concrete, and a fine strong foundation upon the solid rock was the result.

Reverting for a moment to the question of driving piles, there is a method which is used sometimes which is interesting on account of the fact that it would not appear on the face of it to be at all likely to be effective. It can only be used when the pile has to be fixed in sand.

We have been taught to regard a man who lays his foundations upon sand as an example of folly, and no doubt such was the case in the state of the building art at the time when the saying upon which this is founded was first uttered. With modern methods, however, sand can, if treated properly, be made to furnish a very good foundation, for if dry or uniformly wet it is very solid and firm—very different from wet clay, for instance, which if wet will allow anything standing upon it to slide.

It is possible, therefore, to fix a pile very firmly in sand, and it can be done in this simple way. Inside the pile a small pipe is fitted, through which water is pumped, the water issuing as a strong jet at the bottom. As the pile is lowered this jet blows its way through the sand, stirring it up so that the pile can be let down quite quickly. Then, when it has gone far enough, the small pipe is withdrawn, and the sand settles back all round the pile, so that in a very short time it is quite solid again, and the pile is quite firm.

Another way of building foundations in water is by what is called a "cofferdam." This consists of a number of piles driven in near together with boarding between, the interstices being afterwards stopped up with clay or some other impervious material. That constitutes a waterproof wall from behind which the water can be pumped out, and then the work can proceed. This plan is often used where the water is not very deep, or where it is tidal and the part where the work has to be done is dry at low tide.

The embankment wall in front of the new County Hall in London is built under the protection of a "cofferdam" constructed in this way.

Perhaps the most important bridge built in recent years is the Blackwells Island Bridge, across the East River in New York. The length of the largest span is second only to that of the Forth Bridge, and in other respects this bridge is unapproached. It is estimated that it will carry 200,000,000 tramcar passengers every year, besides many millions of pedestrians and carts.

It is over 1200 yards long, and is a two-deck arrangement, the lower one carrying a wide carriage way and four car tracks, while the upper deck carries four elevated railroad tracks and two wide promenades for foot passengers. The steelwork alone weighs over 50,000 tons, and it cost about $20,000,000 or £5,000,000. Altogether it is clearly one of the greatest structures that man has ever created.

It is of the cantilever type, the great advantage of which is that it can be erected easily. It often happens with bridges that they are easy to make but extremely difficult to put up. Suppose, for example, that this had been a girder bridge; the largest girder would have had to be over 1100 feet long, and it would have been necessary to build a temporary stage or bridge, on which to put this huge girder together, or else to put it together elsewhere and then hoist it up into position. Now engineers can do many wonderful things, but either of those methods is almost beyond their powers, especially on a busy tidal river. A girder bridge is out of the question, therefore, and the suspension principle is not suitable for such a very heavy structure. Against this put the ease with which the cantilever structure can be built up. Each pair of cantilevers actually meet in the middle of the span, but they do not depend for their stability upon that fact, since they derive their strength entirely from their ends. It is quite safe, therefore, to start at the ends and build outwards, piece by piece, the part already completed forming a stage upon which the next piece can be brought out and put in place.

In most bridges of this kind there is a small girder supported between the two adjacent ends of the cantilevers, which forms an adjustable filling-in piece, but in this case each pair of cantilevers actually join up into one, and so the preliminary measurements had to be very exact, otherwise they would not have met properly. As a matter of fact all the steelwork was made at a bridgeworks many miles away and brought to the site all ready to be put together, yet so exact were the measurements that when the two arms met in the middle of the channel the steelwork came almost exactly right, and scarcely a thing had to be altered.

It is easy to see that this depended entirely upon the distance across the water being measured accurately to within a small fraction of an inch. Consider for a moment what that means. To measure with such accuracy as that across a waterway over a thousand feet wide! How can it be done? A steel wire might be stretched across and then measured afterwards, but that would sag in the middle; it would stretch, too, with its own weight, and there would be considerable variation in it with the changes in temperature. That, then, would not be sufficiently true for the purpose. Let us see how it was done.

The method adopted is what is called "triangulation," and it is additionally interesting in that it is the method by which all surveying is done and by which accurate maps are produced. It is on the same principle, too, that the distances of the heavenly bodies are found.

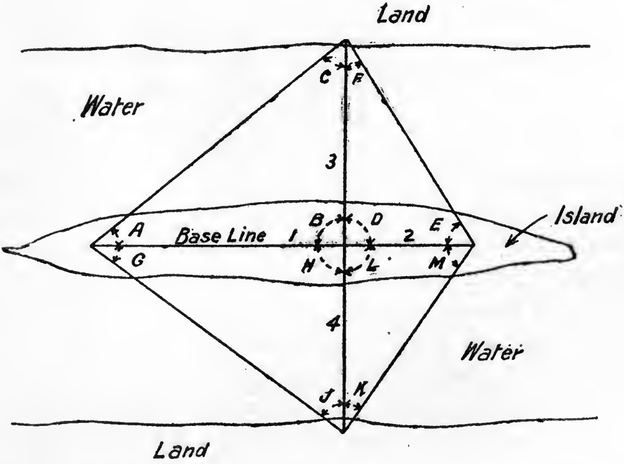
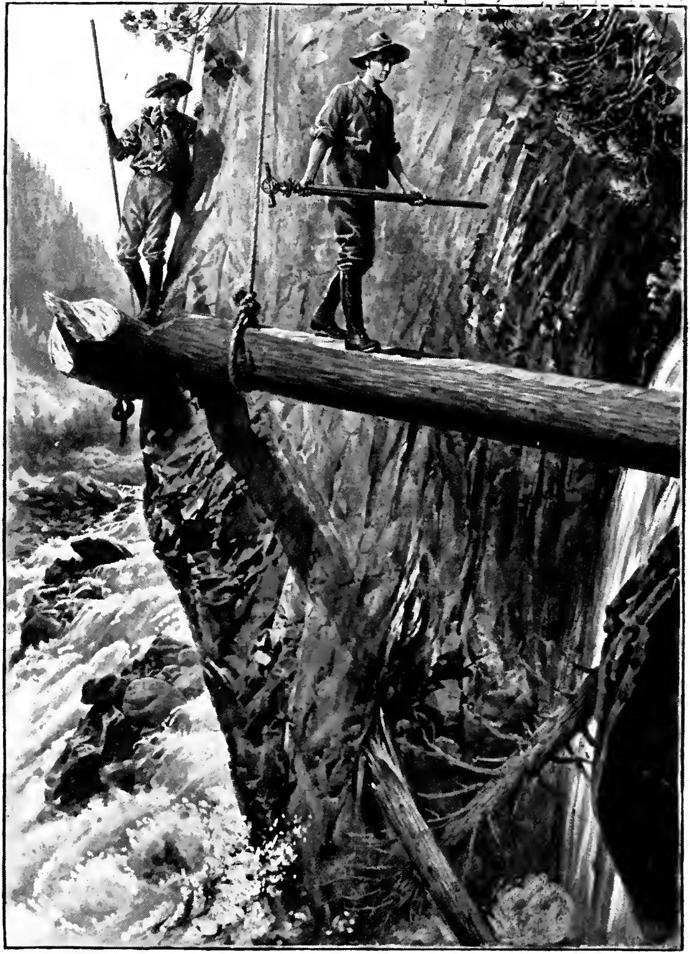


FIG. 23.—Taking an exact measurement across water.

The two parts of the base line 1 and 2 are first measured with scrupulous care. Then the angles A and B are observed with a theodolite, and, as a check, the angle C too. From that the length of the line 3 can be calculated. This is again checked by observing the angles D, E, and F.

Line 4 can be measured in an exactly similar way, by means of angles G, H, and J, and K, L, and M.

It is based upon the fact that if we know the length of one side of a triangle, and the number of degrees and



SURVEYING UNDER DIFFICULTIES

This striking picture represents men surveying for a new railway. The line will have to run on a ledge cut in the face of the cliff, and the surveyors are here shown examining the rocks and measuring the heights and levels so as to determine the best course for the cutting.

parts of a degree in the angle at each end of that line, we can calculate the length of the other two sides.

As the illustration shows, the two middle supports are on an island between the two channels, and on this island a line was measured to form the base of the triangle. This line was 1671.03 feet long, and it was measured with a steel tape 200 feet long. This was first of all checked by the Government Standards Department, and found to be correct at a certain temperature and when subjected to a pull of 12½ lbs. It was then laid down, supported on pegs at every 25 feet, and carefully pulled to exactly the weight of 12½ lbs., which was sufficient to pull it quite straight. Each time it was used the temperature was taken, and the measurement which it showed was carefully corrected accordingly. If the temperature was above that at which it was tested something was added, or if it was lower something was deducted, so as to obtain the utmost accuracy. Three times the line was measured like this, and the results only showed a variation of about one-fortieth of an inch.

Each end of the line was marked by a small hole drilled in a brass plate fixed upon a granite pillar.

Then the angles were measured with a theodolite. This is a telescope mounted on a strong tripod stand. It can be pointed in any direction, and there are scales and graduated circles attached to it, by means of which its exact direction can be determined. It is first set up and sighted upon an object; then it is swung round and sighted on a second one, and the amount that it has to be moved (which can easily be read off the graduated scale) shows the angle formed by straight lines drawn from it to the two objects.

A theodolite, therefore, was set up at one end of the line and sighted upon a rod set up at the other end, and then upon another rod set up on the opposite bank, and so the angles at the end of the base line were determined, and from that the distance of the rod on the opposite bank could be calculated.

As a matter of fact, to ensure accuracy the base line was divided into two, and two triangles were constructed on each side of it, as shown in the diagram (Fig. 23). Thus eight angles were measured on the island, and then the theodolite was taken to the mainland and two angles measured on each bank, making twelve in all, and they were all measured a hundred times over, and the mean of the measurements taken, so as to eliminate errors. It will be seen that each pair of triangles has one side in common, so that they check each other, and that the two triangles of each pair are reckoned from two different parts of the base line, so that they too are checked one against the other.

I have gone at some length into this description since it is a remarkable feat of measuring, and shows the extreme care which has to be taken in work of this kind. Most of us think, if we measure a thing a few feet long accurately within about a sixteenth of an inch, that we have been very particular. What, then, are we to think of a length of over a thousand feet measured to within a fiftieth of an inch?

The actual making of the steelwork of a bridge is not a very interesting operation. The parts are first of all set out or drawn full size on a large wooden floor, and a model or template is made, in thin wood, of each piece of iron or steel. Then the plates or bars are cut to the same size and shape as the wood templates, and the holes are either drilled or punched in. The pieces are then assembled together and connected temporarily with a few bolts, after which rivets are put in and the work is then finished.

When a bridge is over a waterway along which tall ships have to pass, it generally has to be made to open in some way. The Tower Bridge over the Thames in London is a well-known example of this. Its main span consists of two hinged cantilevers, called "bascules," which can be raised into a nearly vertical position when a ship needs to pass through.

Of "swing" bridges, one part of which is made to swing open like a gate, there are innumerable examples, but a very remarkable one near Manchester deserves special mention. When the first canal in England was constructed (now known as the Bridgewater Canal) it had to be carried across the river Irwell, and at that time its promoters were thought by the public to be mad even to entertain the idea of carrying a canal on a bridge over a river. They did it successfully, however, and when the Irwell at that point was converted into the Manchester Ship Canal, the engineers went "one better" still, for they pulled the old bridge down, and now the Bridgewater Canal crosses the Ship Canal on a *swing* bridge. There are gates, of course, at each end of the bridge, and also at the ends of the canal itself, and when a ship wants to pass, these gates are closed and the bridge, with the water in it, is swung round.

There is a small but rather curious opening bridge, over one of the docks in London. It carries a road over one of the basins, and as there is not room for it to swing it is arranged so that, to open, it rises up off its supports and *slides off up the road.* The first time I saw it I happened to be approaching just as it was opening, and I was no little astonished to see a bridge apparently coming along the road to meet me.

Opening bridges are in many cases worked by hydraulic power, but in the more recent ones, electric motors are generally used.

There is also a new type of bridge for use across navigable rivers, known as "transporter bridges," of which, as far as I know, there are only three or four examples yet in existence. Over each bank there is a tall steel tower, supporting the ends of a large girder at a level sufficiently high for the tallest mast of a ship to pass under it. On the girder there runs a carriage or trolley, from which there is suspended a large platform. The carriage can be pulled to and fro by means of electric motors. The passengers and vehicles get on the platform when it is close to the bank, and are then carried across to the other side. It is really like a ferry-boat suspended from a bridge overhead instead of supported on the water below.

CHAPTER X

IRON AND STEEL SHIPS

MERCHANT steamships may be divided into three classes—those which are built primarily for passengers, those which are mainly cargo steamers but which carry passengers as well, and those which only carry cargo, and have no passenger accommodation at all.

These last, though often spoken of contemptuously as "ocean tramps," are really of the utmost importance, for they carry the great staple commodities on which so much depends—the grain and the coal, the oil and the timber. They are, therefore, well worthy of our consideration.

A trip round any busy seaport will show the reader, if he has not noticed it already, that there are many different types of the ordinary cargo steamer. The feature which displays the differences most noticeably is the arrangement of the structures upon the deck, and it may reasonably be asked why there are these varieties, and how it is that a common type has not come to be agreed upon.

The answer to that question is that the differences are not merely arbitrary, but are due to a variety of influences, and it will be interesting to look briefly at these, as the reader will then be able, the next time he sees a cargo steamer, to understand something of the ideas underlying its design.

The early steamers had "flush" decks, which means that the deck ran from end to end without any structures of considerable size upon it; a light bridge was provided, supported upon slender uprights, for "look-out" purposes, and that was about all. On the face of it, this seems a very simple and admirable arrangement. It had many disadvantages, however, as we shall see.

In the first place, it permitted a wave to come on board at the bow and sweep right along the deck, often doing great damage. This was mitigated somewhat by building the ships with "shear," that is, with a slope upwards fore and aft, so as to make the ends taller than the middle. That, however, was not sufficient, so ships were built with an upper deck, so that the bow should be high enough to cut through the waves instead of allowing the water to come on board. Owing, however, to the method by which the tonnage of a ship is reckoned, as will be explained later, that had the effect of adding largely to the tonnage *on which dues have to be paid* without materially increasing the carrying capacity of the ship.

The difficulty was therefore got over in this way. The bow was raised and covered in, forming what is known as a "top-gallant forecastle," which not only had the effect of keeping the water off the deck, but provided better accommodation for the crew as well. That did not provide, however, against a wave overtaking the ship in the rear and coming on board just where the steering wheel was, so a hood or cover over the wheel became usual, called the "poop." Nor did either of these sufficiently protect that very important point, the engine-room. For it needs but a moment's thought to see that there must be openings in the deck over the engines and boilers, and if a volume of water should get down these, it might extinguish the fires and leave the ship helpless, absolutely at the mercy of the waves. The light navigating bridge was therefore developed into a substantial structure the whole width of the ship, surrounding and protecting the engine- and boiler-room openings, and incidentally providing accommodation for the officers.

Ships of this type answered very well indeed, for if a wave of exceptional size should manage to get over the forecastle, the water fell into the "well" or space between the forecastle and the bridge-house, and then simply ran overboard, so that the after part of the ship was kept dry.

Then troubles arose with the loading. The engines, of course, need to be in the centre, for they represent considerable weight, which, if not balanced, will cause one end of the ship to float too high in the water. Thus the hold of the ship is divided by the engine-room into two approximately equal parts, but out of the after-hold must be taken the space occupied by the tunnel through which the propeller shaft runs, from the engine to the screw. Thus the capacity of the after-hold becomes less than the forward one, and if both be filled with a homogeneous cargo such as grain, (and, as we shall see presently, such a cargo must always entirely fill the hold), the forward part of the ship would float low in the water. The trouble could not be rectified by placing the engines further forward, for then the ship would not float properly when light.

Shipbuilders overcame this trouble, however, by raising the whole of the "quarter-deck"—the part of the deck, that is, which lies behind the after end of the "bridge-house"—and by that means they made the after hold deeper than the other. Thus the commonest type of all, the "raised quarter-deck, well-decker," came into existence, a type of which many examples are to be seen on the sea.

At this point it will be convenient to explain the meaning of the word "tonnage" as applied to merchant vessels. Originally it meant the number of "tuns" of wine which a ship could carry. Nowadays it is arrived at by means of a complicated system of measurements, which may be briefly explained thus. The number of cubic feet in all the enclosed space in the hull and deck structures is first ascertained. That, divided by 100, gives the gross tonnage. The net tonnage is reckoned by deducting from the gross tonnage the space occupied by engines and boilers, coal, water ballast, the accommodation for the officers and crew, and other spaces entirely necessitated by the working of the ship and of no use for stowing cargo. "Displacement tonnage" is the weight of the water displaced when the ship is loaded, which is exactly equal to the weight of the ship and cargo. This last system is that employed for all naval vessels, so that when we are told that the *Dreadnought's* tonnage is 17,900 we know that the hull, guns, armour, and all the normal requisites of the ship actually weigh 17,900 tons. On the other hand the gross tonnage of the "Orient" liner *Otranto* is 12,124, yet it displaces 15,250 tons.

The rules for determining gross and net tonnage are somewhat arbitrary, and the two tonnages do not by any means always bear the same relation to each other or to the "displacement." The gross tonnage is generally considerably less than the "displacement."

Now it is on the *net* tonnage that the "dues" are paid, and so we can now see clearly the dilemma, referred to just now, which faces the designer of a ship. For considerations of seaworthiness it is desirable to have the deck well above the water line, in order that it may be too high for heavy seas to come on board. That, however, will increase the enclosed space, and consequently the net tonnage, and unless the cargo be very light, to fill these spaces would be to overload the ship. Consequently on most voyages they would have to be empty, and, naturally, the owner objects to pay dues on empty spaces which cannot earn any "freight."

This has led in quite recent years to the invention of what are called "turret-ships,"[1] in which the high deck is provided, without unduly increasing the tonnage. In this type the vertical sides come up to some distance above the load line; then they curve in horizontally, and form a narrow deck called the "harbour deck," on each side of the ship. From this they curve upwards to the turret deck. This deck, and the two short sides leading up to it, thus form a long, level platform with parallel sides, running the whole length of the ship, and this platform is known as "the turret." (A part of a turret-ship can be seen facing page 182.)

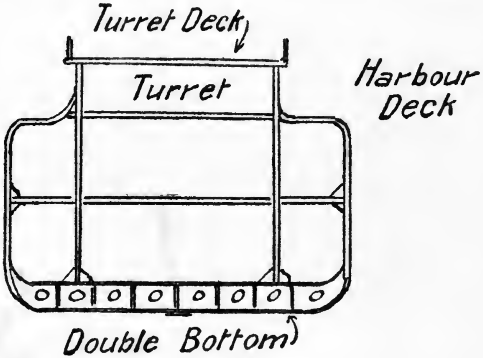


FIG. 24.—Cross section of a Turret-ship.

In addition to the advantage of the high deck without useless space, this arrangement makes a very strong form of structure, and so ships of this type can be made comparatively light. It has a special advantage,

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[1] These must not be confused with an old type of naval vessels called by the same name.

too, when the cargo consists of material like coal or grain.

Many ships have been lost through a cargo of that description shifting to one side during a gale, a danger which can be provided against by entirely filling the hold. But a difficulty arises through the tendency of the cargo to shake together; so that, even if the hold be filled to start with, it may not remain full; so "trunks" or deep shafts are constructed, leading from above the deck down into the hold, and these, being filled right up, hold a reserve which tends to fall down into the hold and keep it full. Of course, the stuff in the trunks is then liable to shift, but they do not contain sufficient for that to be of any serious consequence.

Now the turret of a turret-ship answers the purpose of a "trunk" admirably, and the curved form of the hold, too, causes the cargo to settle down very readily.

The "harbour deck" can be utilised for loading long things such as timber, rails, or iron girders.

Many ships of this type have been built, notably some very fine vessels for the "Clan" line.

In some trades, there is only cargo to be carried in one direction, vessels having to return in ballast, and for this purpose the double bottom which all modern steamers possess, and which will be described presently, is flooded with water to form the ballast. For a rough ocean voyage, however, that is not enough, as it does not sink the vessel sufficiently to keep the screw always immersed. As the stern of the vessel passes through a trough between two waves, the propeller may for a moment be out of the water altogether, and then the engine, having little or nothing to resist it, begins to "race"; it spins the screw round very fast, with the result that a moment later, when it strikes the water again, the shock may be sufficient to break something, perhaps the propeller shaft itself.

More ballast space must, therefore, be provided for ships engaged in these trades, and it must not be too low down, or the ship will roll badly from side to side. In some the sides are made double, like the bottoms, and filled with water. In others the boat is made something like a turret-ship, only the sides are carried straight up, and the space above what would in a turret-ship be the "harbour deck" forms tanks for water ballast. These are called "cantilever-framed" steamers.

The majority of these cargo steamers—in fact, all those intended to carry bulk cargoes—have only one deck, but there are many which have two or more, so that they can more conveniently take a miscellaneous cargo of cases and packages.

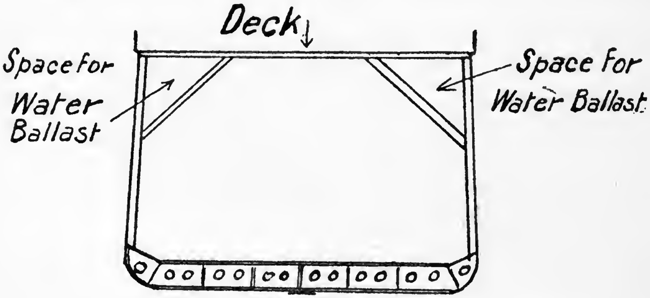


FIG. 25.—Cross section of Cantilever-framed Steamer.

To the landsman, the word "deck" usually means the main covering of the ship, which runs from end to end about on a level with the bulwarks. Technically, however, the word "deck" is applied to any *floor* in a vessel.

There are many ships afloat known by the name of "tank steamers," specially built for carrying oil in bulk. Originally these were simply ordinary ships with tanks placed inside them, but they are now built so that the vessel itself forms a series of tanks. There is usually a division called a "bulkhead," right down the middle of the ship, and transverse bulkheads at frequent intervals, and these with the sides of the ship constitute "oil-tight" reservoirs in which the oil can be carried. There are always two decks, the lower of which forms the top of the tanks, while between the two are trunks for the purpose of ensuring that the tanks shall always be quite full, an arrangement similar to that described for steamers carrying grain. Suitable pipes are provided by which the oil can be pumped out, and in this way a ship carrying 1700 tons of oil can be discharged in about six hours. Air pumps, too, are in many cases provided to suck out the explosive vapour which is left in the tanks when they are emptied of oil, and which, being heavier than air, does not disperse itself.

Special care has to be taken to prevent any leakage of oil into the boiler-room. For this reason there are generally two bulkheads between the oil and the boilers, the space between which is either filled with water or provided with a pump to remove quickly any oil that may leak into it.

For the same reason, the engines and boilers are often placed right aft, since then the oil can only leak towards the engine and boiler space from one side, and not from two sides, as must be the case if the engines are in the middle. When light, such a steamer, of course, floats with its stern low in the water, or "trims by the stern," to use the nautical phrase, but that is quite as it should be, for it ensures that the propeller shall be sufficiently immersed, and the bow being high is of no consequence.

Some of these steamers are very large; there is at least one with a displacement of 21,000 tons—more than that of the *Dreadnought.*

In vessels which carry passengers as well as cargo the conditions are somewhat different from those which apply to cargo vessels. They are, generally speaking, larger, and the difficulties with regard to the high deck do not apply, for the space which would be wasted on a purely cargo boat can be used for the passenger accommodation. They are therefore built with a larger "freeboard," by which is meant the distance from the water-line to the gunwale. There are generally several decks forming part of the actual hull of the ship, and several more which are really the floors of a building of lighter construction than the hull, and not, strictly speaking, a part of the ship, but simply erected upon it.

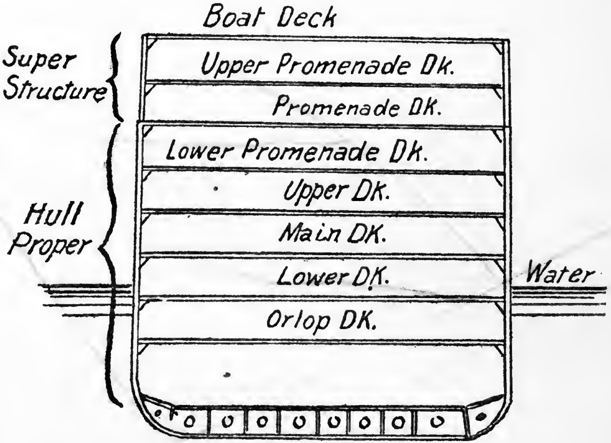


FIG. 26.—Section of modern liner, showing the decks.

As an example of a large passenger and cargo steamer, a section is given in Fig. 26 of the latest transatlantic liner, the *George Washington*. This boat has not been designed to break speed records, but simply to give passengers a comfortable and reasonably quick voyage, and also to carry a fair amount of cargo.

It will be seen that there are eight decks, the lowest six of which are actually a part of the ship, while the two top ones are part of the superstructure.

The "lower deck" is just level with the water-line, so that it and all those above it are available for accommodating the passengers and crew, while the one underneath and the space below it are available for cargo, stores, and machinery.

Passenger steamers are invariably divided up into water-tight compartments. At frequent intervals there are complete transverse bulkheads or water-tight dividing walls, with water-tight doors in them. These doors are, in some cases, arranged so that they can be closed *from the bridge* either by hydraulic power or electricity. In some ships a more safe arrangement still obtains, there being no opening at all in the bulkheads, so that, to get from one compartment to another, a man has to go up to one of the upper decks, above the water-line. A ship fitted like this has little to fear from a collision, for one or two compartments may be filled with water without any risk of her sinking.

The fitting and furnishing of high-class passenger steamers is of the most elaborate description, but as so much has been written about that in the daily press and magazines, and as, moreover, it is more in the province of the architect than the engineer, it is not necessary to go into details here.

CHAPTER XI

THE BUILDING OF SHIPS

THE last chapter deals mainly with the general features of various types of merchant vessels. We now come to the method by which ships are designed and built.

It must be understood that a ship floats as the result of the balancing of two opposing forces. Gravity tends to pull the ship downwards, but that is resisted by an upward force due to the displacement of a certain quantity of water by the ship. When a vessel is launched, it sinks until it has displaced or pushed aside a volume of water exactly equal in weight to its own weight. Then the two forces exactly balance and it neither sinks nor rises. As it is loaded it sinks farther, displacing a further weight of water equal to the weight of the cargo. If a vessel be loaded until its weight exceeds the weight of water which it is able to displace it sinks; that is what so often happens when water rushes in after a collision.

But it is not sufficient for a ship merely to float. It must maintain an upright position. This is ensured by giving it such a shape that the centre of gravity and the centre of buoyancy will naturally place themselves in a vertical line.

The meaning of the "centre of gravity" is pretty generally understood, but the other term may need a little explanation. It means the centre of gravity of the water which the ship displaces. Thus, one is the point about which all the *downward* forces balance, while the other is the point about which the upward forces balance.

In Fig. 27 we see the "midship" section of a ship in its upright position, and it will be seen that the two "centres" are exactly in a line vertically. In Fig. 28 the same ship is shown when leaning over to one side. Now it is easy to see that the shape of the displaced water (shown shaded in both figures) is different in these circumstances from what it is when the ship is upright, and this difference in shape shifts the centre of buoyancy to the right. It is easy to see, too, that the upward force of buoyancy and downward force of gravity, acting together, will then tend to "right" the ship.

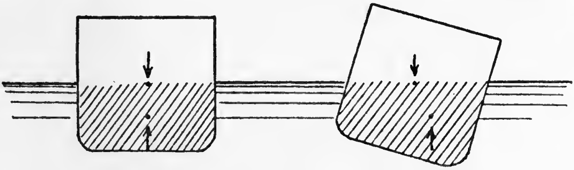


FIG. 27. FIG. 28.

Midship section of a ship showing why it floats upright. Normally the centre of gravity and the centre of buoyancy are in the same vertical line. If the ship inclines to one side, the centre of buoyancy moves to that side too and tends to push it back to the upright position.

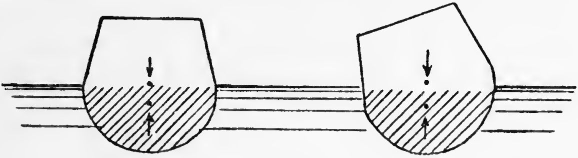


FIG. 29. FIG. 30.

A ship of this shape would be unstable, for the centre of buoyancy would remain under the centre of gravity (or rather would move slightly in the opposite direction to the inclination of the ship), and so there would be no tendency to "right" itself.

By way of contrast Figs. 29 and 30 show a form of vessel which will tend, not to keep upright, but to turn over.

We may say, then, that the stability of a ship depends upon its shape.

One thing the designer has to do, then, is to give his vessel such a size and form that it will sink to the required depth under the required load, and that it will float in an upright position. In this, however, as in many other matters, he has to use a nice discrimination; for, if he makes his centre of gravity too low, the ship will be very safe from the risk of capsizing but it will roll terribly. Judgment, experience, and wide knowledge are all necessary, therefore, for the designing of a ship.

Most of us at some time or other, probably on a summer evening, have watched a ship riding at anchor on a smooth sea, like the Ancient Mariner's craft—

> "As idle as a painted ship
> Upon a painted ocean,"

and it has seemed the perfect embodiment of peace and rest. Yet there were forces within and around that ship endeavouring to distort it and rend it asunder. The only reason why they were not apparent was because the ship was strong enough to resist them. And the reason why it was strong enough? The designer had analysed and calculated those forces and provided against them.

Suppose we were to make a model boat of some flexible substance, such as indiarubber, and fill it with alternate pieces of lead and cork.

It would float something like the sketch (Fig. 31), bent and distorted by the varying degrees of buoyancy of its different parts, and the different weights of the lead and cork. If, however, our model were made of stiff material like iron, it would retain its shape as in Fig. 32.

In precisely the same way some parts of a ship are more buoyant than others, and some are more heavily loaded than others, and the heaviest loads do not always come where the greatest buoyancy is, so that if a ship were not made stiff enough it would be distorted like the indiarubber model. By very laborious methods, all these stresses have to be calculated out and the ship made stiff enough to resist them. The pressure of the water, too, is always trying to push the sides of the vessel together, and the ends inwards towards the middle.

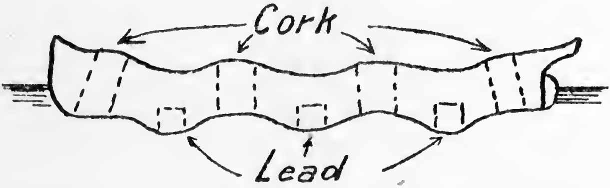


FIG. 31.—This is how a ship would be distorted by the various loads within it, were it not rigid enough.

All these forces are at work constantly, even in still water. What must the condition be, then, in a storm? The worst stresses of all that a ship has to withstand are those caused by crossing large waves at a distance apart equal to its own length. It is then (see Fig. 33) lifted by the water at both ends, and almost unsupported in the middle, while at other times (see Fig. 34), it is lifted in the middle but not at the ends. Under these conditions its position much resembles that of a bridge.

FIG. 32.—This is how the same boat floats when it is rigid. The comparison of these two show us how a ship is being strained by powerful forces even when lying at anchor in still water.

Indeed, there is much in common between a bridge and a ship, and it may almost be said that the modern steel ship is the lineal descendant of a certain railway bridge. It came about in this way. Failure though it was, the famous *Great Eastern* has undoubtedly had a great influence on the design of modern steel ships, and it was the embodiment of very original ideas. These its designer, the famous engineer, I. K. Brunel, drew very largely from the famous tubular bridge which his friend Robert Stephenson constructed over the Menai Straits in Wales.

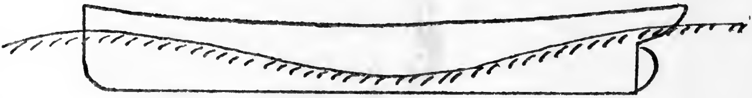


FIG. 33.—This shows how two waves lift a ship at the ends.

In a previous chapter on bridges the ordinary "plate girder" has been described, consisting of a vertical "web" connecting two horizontal "flanges." Sometimes such a girder is made with two webs instead of one, a little distance apart, and it then is called a "box girder." Its principle is exactly the same as the single-web girder, the difference being simply one of construction.

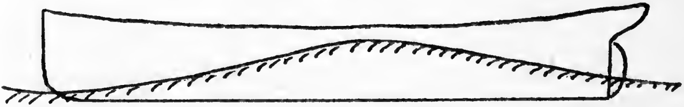


FIG. 34.—This shows how a wave lifts a ship in the middle.

Now a modern steel ship owes its ability to resist the worst of the forces which assail it to the fact that it is a box-girder. The bottom is the lower flange, the decks are the upper flange, while the sides are the webs.

In designing a ship, then, the designer first of all settles the size—the length, breadth, depth, and draught.

Then he settles the "midship section," and from it develops the general form of the vessel, shaping it so as to have the necessary stability, to slip through the water easily, to have the necessary buoyancy, to be easily steerable, and numerous other conditions, many of which only an instinct born of experience and study can teach him. Then the details of the design have to be worked out, due regard being had to the various forces which we have already noticed as being exercised upon the ship by its load and the water, with other minor forces too numerous to mention here. As one who has had some experience in the comparatively simple art of bridge design, the writer does not hesitate to describe the designing of a large ship—to meet all the various demands of speed, comfort, safety, strength, and carrying capacity—as the most difficult feat in the whole realm of engineering practice.

When the design has been completely worked out on paper, and probably embodied in a model as well, it is sent to the mould loft. This is a capacious building sometimes half as long as the proposed ship, and its wooden floor constitutes a huge drawing-board. On this the details of the ship are "set out" in chalk *full size.* Then upon another large but portable drawing-board the exact shape of each successive pair of ribs is drawn. To ensure permanency the lines are cut into the wood with a sharp tool, and then the portable board is taken to the workshops where the drawings are reproduced in steel.

A ship is built from the keel upwards. First of all piles of timbers are placed in a row on slightly sloping ground near the water's edge. These piles of timbers are known as the "keel blocks." Upon them is built up a huge plate girder, in a large ship as much as five feet in depth. The bottom flange of this girder forms, strictly speaking, the keel, and the girder itself fulfils a function precisely analogous to that of the backbone of an animal.

To the central girder are riveted, on each side, other girders which form the ribs. These are nearly as deep as the central girder at one end, but they taper off, and at the same time curve upwards, according to the shape of the bottom of the vessel. A reference to Fig. 35 will make this quite clear.

At intervals between these ribs, and at right angles to them, other girders are fitted, so that the whole form an enormously strong framework, which is then covered with a "skin" of steel plates both above and below. Thus the hollow "double-bottom" of the ship is formed. This form of structure, which is one of those features derived indirectly from the Menai Bridge, is not only of the greatest possible strength, but it provides a space between the two skins which can be filled with water for ballasting the ship; moreover, should the vessel run aground and perforate the outer skin, the inner one will prevent her from sinking.

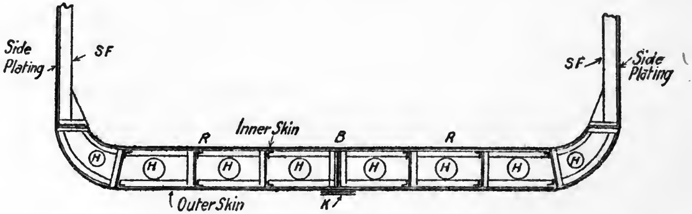


FIG. 35.—Section showing the double bottom of a modern ship. B is the central girder or backbone, the bottom flange of which (K) forms the keel. The ribs (R) are fixed in pairs, one each side of the backbone, and between them the longitudinals (L) are fitted. Both upper and under sides are covered with plating, and at the ends the side frames (S F) are erected; they are plated on the outside only. The holes (H) in the ribs are put in for the sake of lightness.

Then, all around the edge of this double bottom strong vertical girders are erected, which form the "side-frames," and horizontal girders fitted between these make up a structure similar to that of the bottom, except that on the sides there is an outer "skin" only.

All the connections are made with rivets which are put in, as far as possible, with the "iron man" described in an earlier chapter, since the enormous pressure exerted by the "pinching" action of this machine ensures that the rivet shall entirely fill the hole and make a very tight joint. Where an iron man cannot get at them, the rivets are closed by hand or with a pneumatic "pistol" riveter, also described in the chapter on tools.

The joints in the plates are made water-tight by caulking. This process consists in hammering the edge of the uppermost plate with a tool like a blunt chisel, thereby swelling it out and causing it to press tightly against the other plate, and closing up any gap there may be between the two.

The side frames are connected across the ship by beams which support the deck, and these again are covered with steel plates, completing the structure, and forming, as was remarked just now, a huge box girder.

The transverse strength is still further increased, as well as the safety of the ship made more secure, by the cross partitions or bulkheads which are placed right across the ship at intervals.

The stem and the stern of a large ship are each formed of a huge steel casting.

It will be noticed in the above description that, except for the "central girder" or backbone, all the main members of the structure are transverse with short longitudinal members fitted between them. That is usual in merchant ships, but in the Navy the opposite plan is the practice. In war-vessels, the

CHAPTER XII

CURIOUS SHIPS

SHIPS are always interesting, but there are some which are especially so because of their unusual form or strange purpose. In this chapter I am going to describe some of these special craft.

The great navies do not consist entirely, as we might think, of fighting ships. Just as the old knights of the Middle Ages used to be accompanied on their campaigns by armourers who could repair any damage to their masters' weapons, so the fleets of the modern navies are sometimes accompanied on their voyages by repair-ships—floating factories—on which quite large repairs can be effected at sea.

The most recent of these in the British Navy is the *Cyclops*, and it is so wonderfully fitted up that it is well worth description.

To look at, it is much like an ordinary, fair-sized cargo steamer; indeed it was being built as such, and was half-finished when purchased by the British Admiralty and adapted to its present purpose.

It has on board an iron-foundry in which iron castings up to a ton in weight can be made, also brass castings; a smithy with an equipment of tools and appliances which many a works ashore would envy. There are huge stores of iron and steel of all sorts, shapes, and sizes, with timber to supply the capacious carpenter's shop.

There are "machine shops" fitted with lathes and other machine-tools, and a boiler-shop capable of turning out quite large work.

Indeed it may be regarded as a well-equipped and up-to-date engineering works, on four floors. Four electric lifts carry goods and passengers from one floor or deck to another. The power is generated in a "central station" and conveyed electrically to various parts of the ship, where seventeen electric motors drive machines or groups of machines. Several of the larger "shops" are lit by large "arc" lamps, just as large workshops ashore often are.

There is a distilling apparatus for making pure water, an ice-machine, a bakery with a motor-driven dough-mixer, and of course wireless telegraphy.

The ship itself is propelled by twin-screws, and can steam at fourteen knots per hour.

Complete assortments of portable tools are carried, so that the *Cyclops* men can sally forth to execute repairs *in situ* upon the other ships, while there are powerful winches, derricks, and cranes upon the deck, by which heavy pieces can be lifted from other vessels for treatment on board.

We are all familiar with the methods by which coal is unloaded from ships. Sometimes it is shovelled into baskets, which are pulled up by hand and then tipped over the side—a very primitive method. A more modern way is to have large steel buckets which are filled by men in the hold, and which are then drawn up by a steam-crane. Still more refined is the use of a "grab," a huge "hand" which is let down on to the coal by a crane, and which, on being pulled, grasps a "handful" which it holds until released by some suitable means, when it opens and lets the coal fall.

The best of these methods, however, is thrown into the shade by a "self-discharging" collier which has recently been built. It can carry 3100 tons of coal, and can discharge all of it in about eight hours, at a cost of about one-tenth that of any other method.

At the bottom of the ship is what might be called a "false bottom," forming a clear space underneath the cargo the whole length of the ship. In this space there are "belt conveyers." Doors can be opened to allow the coal to fall upon these conveyers, and it is carried by them to one end of the ship, where they deliver it to other conveyers which take it up to the level of the deck. Here there are other conveyers, each enclosed in a large pipe which can be swivelled round and raised or lowered at will.

To unload the vessel, these pipes are placed in position, with their ends over the barge, railway truck, or whatever it may be that the coal has to be discharged into, the conveyers are set going, and some of the doors opened. Quite automatically, then, the coal commences to travel to the after-end of the ship, then up to the deck and through the pipes, from the end of which it falls, like water from the spout of a tea-kettle.

The "false" floor slopes towards the conveyers, so that quite 75 per cent. of the cargo discharges itself, the remainder having to be assisted by a little hand labour.

An automatic weigher is fitted, which silently records the quantity of coal which passes.

There are some very interesting boats used for dredging, a very important operation in connection with all seaports.

A fine example of this kind of craft has recently been built for use at Venice. It is a twin-screw steamer, capable of going a sea-voyage under its own steam, and it can dredge in two ways.

One is by means of buckets or scoops fixed to a chain. In the centre of the vessel there is a large opening, down which a "ladder," as it is called, can be lowered. This is a powerful steel girder, one end of which is pivoted on the ship, while the other can be lowered down on to the bed of the channel to be dredged, and at each end of it there is a roller. Around these two rollers there is an endless chain, built up of steel links and pins, something after the manner of a cycle-chain, and to this chain the buckets are fixed. In operation, the free end of the ladder is let down and the upper of the two rollers is turned round by the engine. This causes the chain to move; the buckets are carried down the under side of the ladder and scrape along the bottom, each scooping up its load of mud and returning, filled, along the upper side of the ladder. On reaching the upper roller, each bucket, perforce, turns over, and in so doing throws its contents into a hopper on the vessel or through shoots into barges lying alongside. This particular vessel can reach down to a depth of 66 feet, and scoop up over 500 tons of mud per hour.

Its second mode of action is by suction. Under some conditions it is possible to suck the mud up better than to dig it up. For this purpose a large pipe is let down, and a powerful pump on board sucks water up it, bringing the mud with it.

It is often easier to dredge the mud up out of a channel than it is to get rid of it, for it must be conveyed to some place where it will not be likely to be carried back into the channel. The common way is to deposit it in barges for conveyance to some suitable spot, and that method is provided for here; but there are two other ways as well. This dredger has a hopper which is capable of holding 1000 tons, so that it can, if desirable, be its own barge, and when its hopper is full it can steam away and dump the contents out at sea. The hopper has a bottom formed of doors which can be let down, dropping the whole of the contents into the water in a moment.

The last way of disposing of the mud is the most interesting of all. Think of a huge pipe, with flexible joints, 2000 feet long, floating on the surface of the water, a veritable "sea-serpent." Through such a pipe the dredger can pump its sludge, discharging it into the water 2000 feet away.

In the harbour at Bombay there is a quantity of low-lying land, some of which (about a square mile) is now being reclaimed, in order to provide a site for railway sidings. This is being done by depositing material upon it, obtained from the bottom of the harbour itself, and two special dredgers have been built for the purpose.

They work by suction, as the Venetian dredger does, but there is in this case a rotary cutter—a sort of gigantic auger—fixed at the mouth of the suction-pipe. This cuts up the material, some of which is heavy clay, and renders it capable of being drawn through the pipe. So powerful is the suction that lumps of stone of 400 lbs. weight have been sucked up.

Having dug up and raised the clay, the dredger then drives it along a line of pipes, 4500 feet long, the end of which is on the land to be raised. One of these dredgers has delivered as much as 2700 cubic yards an hour, and together they are able to do in an hour as much work as 5000 carts and an army of men could do in a day by old methods.

Perhaps a word of explanation is not out of place here with regard to the pumps employed. It is easy to see that an ordinary pump could not be used for suction-dredging, because the lumps of earth would prevent the valves closing properly ; so this method would be practically impossible but for the existence of the centrifugal pump, which has no valves.

Every one must have observed that when a liquid in a round vessel—tea in a teacup, for example—is stirred so that is rotates, it shows a desire to escape outwards, away from the centre. Being restrained from getting away by the strength of the vessel, it heaps itself up round the edge, the faster it is stirred, the higher being the heap ; and if an outlet were provided it would rush out with considerable energy, due entirely to the centrifugal force caused by the rotating movement. If, then, we construct a strong, circular, closed vessel, with a wheel inside it having vanes or paddles so that it can impart a spinning motion to water, with an inlet near the centre and an outlet at the circumference, we shall have a powerful pump. For we need only fill it with water and drive the wheel round to cause the water to fly out of the outlet, and at the same time other water will be sucked in through the inlet to take its place. That, then, is the principle of the centrifugal pump, without which suction dredgers would be impossible.

A new cable-repairing ship has recently been launched at Newcastle-on-Tyne, which affords an excellent example of this interesting kind of vessel. Her name is *Telconia*, and she belongs to one of the great submarine cable-repairing companies.

Her capacity is 1000 tons, and she is driven by twin screws with triple-expansion engines. Externally she is not unlike an ordinary merchant vessel, except that at the bow, just where the figure-head used to be in old vessels, and at the stern, just over the rudder, there are two large sheaves or pulley-wheels over which the cable can be hauled in or let out. Inside, however, she is arranged quite differently from the ordinary ship, for all the quarters for the crew are at the after-end, and the whole front part of the ship is given up to the special machinery and appliances which are needed for its special work. First and foremost, there are two picking-up machines, steam winches of a somewhat special form. Then there are stores of grapnels, ropes, buoys, and other special tools and apparatus, all arranged so that they can be got out for use quickly, if required. An electrician's room, too, with many special forms of instruments, is an indispensable part of the outfit. Finally, there are huge bunks for storing cable.

The principal functions of a ship of this description is to go to a damaged cable, pick it up, repair it, and then lay it down again. The electricians at the shore end are able to tell how far off the fault is, and as the course of a cable is always carefully recorded as it is laid, the position of the fault on the ocean bed can be determined very nearly. The ship then proceeds to the spot and starts to fish for the cable. She lowers her grapnel about a mile to one side of the supposed position of the cable, and then very slowly—a mile an hour or even slower—she steams or drifts across it.

There are several kinds of grapnel used, according to the nature of the sea-bottom, but the most usual is called the "centipede," from its resemblance to the active little insects of that name. It consists of a central shank, with little hooks, like the flukes of small anchors, projecting from it. Sooner or later—sometimes remarkably soon—this picks up the cable, which is then drawn up on board.

First it is cut and tested electrically to see in which half the fault lies and how far away it is; the good end is then tied to a buoy and dropped overboard, while the ship pulls in the other end, slowly steaming along as it does so. Periodically the cable is cut and tested to see if the fault has been reached, and as soon as it has a new piece is spliced on. Then the ship returns, paying out the new cable as it goes, until it reaches the buoy. The "good" end is by that means recovered, spliced to the new piece, the whole cable dropped back into the sea, and the work is finished.

What must surely be a unique vessel has just been built at Stockholm, for it deliberately, and of set purpose, capsizes itself.

The city of Stockholm is built upon rock, which has frequently to be blasted away for any such works as road extensions or harbour improvements, and the only way of disposing of it is to take it out and drop it in the sea. That is the purpose of this boat.

It is really a barge with a perfectly flat deck, but with a low bulwark on three sides. On this deck the stone is heaped, and the barge is then towed out to sea.

Now on the side which has no bulwark, there is a cylindrical steel tank, supported fifteen feet or so above the deck, on tall columns, while on the opposite side, under the deck, there is another similar cylinder with a third smaller cylinder beside it. Ordinarily the high cylinder is empty, the low cylinder is full of water, and the small one full of compressed air, things being so arranged that the tank full of water just balances the elevated tank when the latter is empty, so that under those conditions the vessel is quite stable.

On arrival at the spot where the rock has to be tipped, the tug withdraws to a distance, taking with it one end of a rope, attached to a valve on the barge. When all is ready this rope is pulled, and by that means a valve is opened, which allows the compressed air to force the water in the lower tank up into the higher one, thereby upsetting the balance of things altogether, tipping the barge over, and shooting the rock into the water. A second pull on the rope permits the water to run back into the lower tank, when it rights itself.

This chapter can be fittingly concluded with a reference to a wonderful little lightship recently constructed by the "Corporation of Trinity House," that curious survival from old days, which is responsible for the very modern up-to-date system of lighthouses and lightships around the coast of England. It has all the attributes of an ordinary lightship—a powerful occulting light placed at a high elevation—yet it can be left to itself without attention for three months at a time.

In shape it is like a lifeboat, and in the centre there rises a four-legged structure which carries the light. This is 26 feet above the water, and gives a flash of 5100 candle-power—strong enough to be seen 10 miles away.

In the hold are four steel cylinders containing compressed gas, enough to keep the light burning day and night for 100 days. The light itself is an argand burner, but experiments are being made, and probably an incandescent burner and mantle will be used eventually.

A lightship of course, like a lighthouse, does not show a steady light, but a series of flashes with dark intervals between, and by the frequency and duration of these flashes, mariners can identify the different lightships. One way of producing these flashes is by a shutter which opens and closes, but that is wasteful, for the light is burning part of its time in obscurity. The better way, and the one now generally adopted, is to surround the light with a lantern containing a series of lenses and prisms which collect all the light and concentrate it into beams. The lantern revolves round and round, and of course carries the beams of light with it; it becomes like the hub of a great wheel, the spokes of which are made of light. The distant observer can only see the light when one of the beams falls directly upon his eye, and thus as the lantern turns round he sees a series of flashes.

But what turns the lantern round? In this case it is ingeniously arranged for the gas to do it itself. The gas, on its way from the cylinder which contains it to the burner, passes through a little motor, like a tiny three-cylinder steam-engine, and the lantern is so delicately balanced and fitted with ball-bearings that this little engine can turn it quite regularly.

Under the lantern there hangs a large bell, which is struck by a hammer every time the boat moves with the force of the waves, and so a signal is made which can be heard in foggy weather.

CHAPTER XIII

HOW BIG GUNS ARE MADE

It is sad to think that so much refined skill and valuable labour is expended upon devising machines whose ultimate object is killing people. Yet such is the romance attaching to warfare that even the most peaceful man finds a great fascination in hearing about them.

It is a remarkable fact that in the Crimean War, so recent as to be well remembered by many people still living, the guns used by the British, at that time undoubtedly the leading engineering nation, were only made of cast iron, and were of very primitive construction. Since then, however, the chemist has succeeded in making explosives of much greater power than were known in Crimean days, and the engineer and metallurgist have responded by producing guns of the most perfect structure conceivable (with our present knowledge) in which to utilise the new explosives.

The large guns at present used in the great navies of the world are known as 12-inch; that being the diameter of the bore. Guns of 13½-inch bore are under discussion, but many authorities consider that seeing the 12-inch are able to reach as great a range as is of any practical use, the greater quickness with which they can be handled and fired, as compared with the 13½-inch, more than compensates for the heavier projectile thrown by the latter. We shall probably find, however, that 13½-inch guns will be in use before long.

Just a word of explanation is necessary, at this point, in regard to explosives. In an earlier chapter we considered the way in which gas explodes through sudden expansion caused by heat. The explosion of a solid or liquid is not quite the same.

We know that there are solids and liquids formed of a combination of elements which, if separated, at once assume a gaseous and therefore more bulky form. Water, for example, if split up into its constituents, becomes oxygen and hydrogen, both gases ; and while there is still exactly the same amount of matter in both, the gases occupy much more space than the liquid did. If, then, by some means, we could separate water into its constituent gases *suddenly*, we should cause an explosion.

In the case of water there is no known means of doing this, for oxygen and hydrogen readily combine, and are then very loath to part, but there are gases which enter, very reluctantly, into combinations of solid or liquid form, and separate again on the slightest provocation, so that a very little thing, such as slight heat or a sharp blow, will cause these liquids or solids to turn into gas with inconceivable suddenness and with almost irresistible force. That, briefly, is the explanation of the explosion which takes place in a gun.

The gun itself is simply an enormous tube, in its modern forms invariably open at both ends. One end, however, called the "breech," can be securely closed by a door or stopper called the "breech-block." To fire it, the "breech" is opened, the shell put in, and then the cartridge containing the explosive. The breech-block is then replaced and securely fastened ; an electric spark or a blow from a hammer fixed to the breech-block explodes the charge, and its sudden expansion into gas drives the shell along the tube and out at the muzzle end with great force.

How Big Guns are Made

Modern guns are of great length. The 12-inch gun of 1864 was only about 15 feet long; the 12-inch gun of the present day is over 50 feet long; it would overtop the roof of a three-storey house, if reared up against it. This is because the explosive pushes the shell so long as it is in the gun, but ceases to do so the moment it has left the muzzle, so that the advantage of a long gun over a short one is exactly the same as that which a long-armed man has over a man with short arms when throwing a cricket-ball. The gun is made sufficiently long to give the explosive time to impart the utmost possible velocity to the projectile.

But the modern gun is not a simple tube. The British practice is to make it of three layers of solid steel and a layer of wire. First a steel tube is made, the full length of the gun, and with a bore of 12-inch diameter. It is of a special quality of steel, produced by the addition of nickel and chromium, and hence called "nickel-chrome gun-steel." It is formed, moreover, in a special way.

When an ingot of steel is cast, as described in an earlier chapter, certain impurities have a tendency to collect together into one place, and by so doing they form a weak spot in the ingot. Fortunately, however, they always gather in that part which sets last, which, in the case of a solid ingot, must be the centre. This fact is ascertained in a very interesting way. If an experimental ingot be made and then cut in two, and its cut surfaces polished, the steel will look just the same all through; but if a piece of ordinary photographic bromide paper, moistened in sulphuric acid, be laid upon the polished surface, the chemical nature of the impurities enables them to imprint themselves upon it, so that a picture is produced from which the exact position of the weak place can be seen.

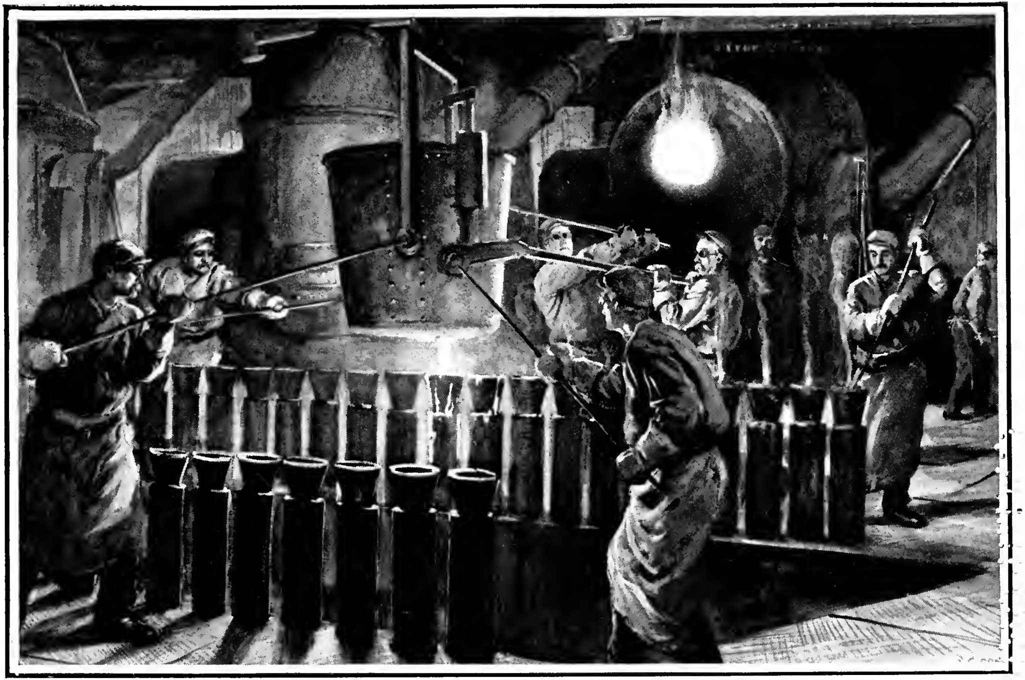
A solid octagonal ingot is therefore cast, to start with, and its centre is then cut right out; in that way removing what is known to be always the weak place in the ingot. Then this hollow ingot is forged under a powerful hydraulic press until it is approximately the right length and diameter, after which it is placed in a lathe, turned on the outside, and bored on the inside.

Over the first tube another is made to fit tightly, and then over that the wire is wound. This is more correctly steel tape, about $\frac{1}{4}$ inch wide and $\frac{1}{16}$ inch thick, and it is of enormous strength. We can realise this from the fact that three heavy cart-horses could be lifted by a single strand of it, small though it is. It is wound on just like cotton on a reel, except that there are only twelve layers at the muzzle end, increasing to eighty layers at the breech end. Altogether about 130 miles of wire are wound on a 12-inch gun.

Finally, another tube or jacket of steel forms the outermost layer of all.

The breech-block is a most marvellous piece of mechanism. There are different varieties of it made by different makers, but they are mostly like a huge screw stopper, fitting into and entirely closing the end of the gun. The screw thread is not continuous, however, for if it were, it would take too long to screw in, but there are rows of projections like short threads on the block and corresponding rows on the inside of the gun, so that the block can be pushed in, and then a partial turn causes the two sets of threads to engage with one another and the block is made quite fast. For it is easy to see that it has to withstand the full force of the explosion, and so must be very firmly fixed.

If the charge should be fired by accident before the breech was closed, the consequences would be too awful to contemplate, but such an occurrence is pre-



CASTING SHELLS AT WOOLWICH ARSENAL

In this drawing we see the casting of a steel shell. In the background towards the right is a Bessemer Converter in the position for pouring out the metal. The molten steel from it has just been transferred to the huge ladle which the men are manipulating. The rows of vertical objects are moulds, and the liquid steel is being poured from the ladle into them. Just beyond the ladle there is another converter (not in use) in its vertical position.

vented by the firing mechanism being so arranged that it cannot possibly be operated except when the breech-block is securely fixed in its place.

For convenience in opening and closing, the block works on hinges like a door, and there is an automatic arrangement whereby the empty cartridge-case is withdrawn and the gun cleaned by an air blast, whenever the breech is opened.

When operated by hydraulic power, the breech of a 12-inch gun can be opened in a little under 4 seconds and closed and *properly* secured in a little over 4 seconds. By hand it takes half as long again.

The 12-inch projectile weighs 850 lbs., and is driven by a charge of 350 lbs. of cordite; it leaves the muzzle at the rate of 3000 feet per second, and at a range of about 14 miles will pierce through wrought iron 17½ inches thick.

The gun itself weighs about 70 tons.

Large guns are usually mounted upon the ship in "barbettes." Barbette is a very old fortification term, and means the platform on which the men and guns stood, behind the ramparts of a fort, so that the guns could be fired over the ramparts. On a ship it means the space inside the protection of a rampart of armour plate, in which guns can be mounted. Inside this space there stands a turret, a circular rotating fort, with sides and roof of armour plate, in which the guns are actually placed, so that they are entirely enclosed except for the gaps out of which the muzzles project. Its upper part is above the edge of the barbette armour, so that the guns fire over it.

The turret is a two-storey arrangement, on the upper floor of which are the guns, usually a pair, although the question of placing three guns in one turret is now being considered. Each gun rests upon a cradle, which is free to move upon a strong steel slide. When it is fired, and the recoil causes it to slide backwards, its motion is checked by a hydraulic ram, or a spring which not only acts as a buffer, but, as soon as the recoil has spent its force, returns the gun automatically to the position for firing. The slide is fixed upon pivots so that it is capable of a see-saw movement, and it can be raised or lowered so as to elevate or depress the gun according to the distance of the object aimed at.

The laying of the gun—that is, its movement in a horizontal plane—is done by turning the whole turret.

From the centre of the lower storey of the turret, called the working chamber, there is a steel shaft, which reaches right down to the magazine in the lower part of the ship, and in it there are hoists, up which the ammunition is sent to the working chamber. It is received by the men there, and sent by them up other hoists to the guns, as required. The working chamber is entirely shielded by the thick armour of the barbette, so that the ammunition is comparatively safe there, and it only goes up to the guns as required, and is loaded into the gun instantly.

These hoists are so arranged that, whatever position the gun may be in, a shell coming up will stop, automatically, *exactly* opposite the breech, and a mechanical rammer can then push it straight into the gun. Thus the gun can be loaded while it is actually being moved to alter the elevation. It is these devices which explain the otherwise incredible fact that these huge guns with their 850-lb. projectiles can be loaded and fired at the rate of four rounds a minute.

With a range of something like fourteen miles it is necessary that the "sights" should be telescopes. Open sights on the principle of those on a rifle would be quite useless for such a distance.

All the movements of the guns and turret, the hoists and the rammer, are made by power, generally hydraulic, but sometimes electric, or a combination of both. They can be controlled by the simplest possible movements of a handle.

The elevation of the gun depends, of course, upon the distance of the object aimed at. The farther away it is, the greater the elevation. This distance or range is found by instruments in the "range-finding" station, and from there it is communicated to the men in the turrets by simple indicators. Knowing the range, the gunner sets his telescopic sight accordingly, and then sights his telescope exactly upon the object.

We can now pass on to an example of the floating platforms, called battleships, on which such guns as these are placed.

CHAPTER XIV

WAR VESSELS

THE DEADLY BATTLESHIP

PAGE 182 shows us a very remarkable ship, one of the most powerful battleships on the waters, the *Minas Geraes*, belonging to the Republic of Brazil.

It is of the *Dreadnought* type, and has been designed and built by the well-known firm of Sir W. G. Armstrong, Whitworth & Co., Ltd., of Newcastle-on-Tyne.

I will attempt to draw a pen-picture of this great vessel.

Imagine a great flat deck, in round figures 500 feet long and 80 feet wide. None of those raised structures with which we are so familiar upon the deck of a merchant ship are to be seen, except in the centre, where there is a comparatively small "deck-house," surrounding the two huge funnels and the single tripod mast. Fore and aft the deck is quite clear, except for small things such as bollards, in order that there may be nothing to interfere with the fire of the guns.

In front of the "deck-house" there are two turrets, each containing two 12-inch guns; behind it are two more, while one stands on either side of it.

On its roof, forward, there is a "conning" tower, a small building of armour plate, from the security of which the officers can "con," or watch, what is going on around, while just above it is a platform forming the bridge from which the ship is navigated, and a similar smaller tower stands upon the after end.

Springing from near the foot of the mast on each side, and supported from it, is a light but strong arm, from the end of which a boat is suspended so that it can be quickly dropped into the water, while high up on the mast itself is a small protected platform, from which the firing can be controlled and its effect more easily seen than it can be from the deck. On the mast, too, are yards for signalling and to carry the wireless telegraph apparatus, while dotted about and peeping through holes in the side of the ship are many smaller guns.

In order to appreciate the "points" of a battleship, it is necessary first of all to understand the conditions which control the design of such a vessel.

Primarily, she is a floating fortress, a platform upon which powerful guns can be mounted. In ships of the *Dreadnought* type there are either ten or twelve 12-inch guns ; in this particular one there are twelve, and it is clear that, other things being equal, the more there are the better. But every pair, with the turret in which they are mounted and the necessary machinery for working them, weighs 500 tons, and the "barbette armour" with which they are protected weighs another 100 tons, making 600 tons in all. Thus twelve guns will represent a load of 3600 tons for the ship to carry.

Then it must be capable of developing a high speed, for it is quite evident that the ship or squadron which can move the fastest will be able to choose the conditions under which to fight, and fight only in circumstances favourable to itself. This necessitates engines and boilers of ample power, and consequently of great weight. Sufficient coal must be carried, too, to enable the ship to travel a distance from its base without the risk of being "becalmed" through lack of fuel.

Finally the ship must be protected with armour to resist the enemy's guns, and when we remember that that is sometimes 12 inches thick it is easy to see that it, too, represents an enormous load upon the ship.

It is clear, then, that a vessel of this type must be a series of compromises. She must have as many guns as possible, and must be as thickly armoured as can be, but neither of these must be so heavy as to impair the speed. In the same way, the weight allowed for offensive purposes (in the guns) must not be unduly increased at the expense of the weight of defensive armour or *vice versâ*. All these and various other considerations have to be taken into account and balanced one against another, and it is apparent what endless scope they afford for differences of opinion and for keen discussion.

There are also certain considerations peculiar to different nations. For instance, the patriotic Briton may be grieved to hear that whereas the *Minas Geraes* carries twelve heavy guns, Great Britain does not possess a ship with more than ten 12-inch guns. One does not, of course, know exactly what was in the minds of the respective designers, but the difference may be due to the fact that Britain, being the premier naval power, would, in the event of being involved in a naval war, almost certainly be the attacking party. The scene of operations would probably be somewhere near the enemy's coast-line, and so British ships need to be designed to have a greater range of action than those of other nations. Moreover, as will be seen presently, the *Minas Geraes*, while she has the maximum number of guns, has to pay for the fact by having comparatively thin armour, an arrangement which may perhaps be justified by the probable conditions of a naval war in South America.

The modern battleship has a "primary armament," as it is termed, of heavy guns, all the same size, for use

By permission of the Brazilian Naval Commission

THE "MINAS GERAES"

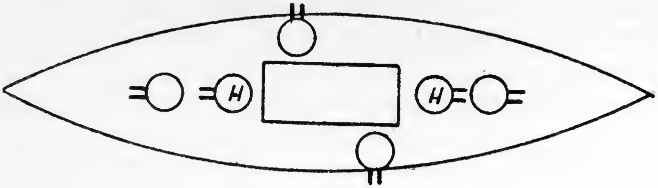
A battleship of the "Dreadnought" type, built at Newcastle for the Brazilian Government. It is the first ship that ever fired *ten* of the largest guns simultaneously.

against ships of its own class, and a "secondary armament" of lighter weapons, for repelling an attack by torpedo craft.

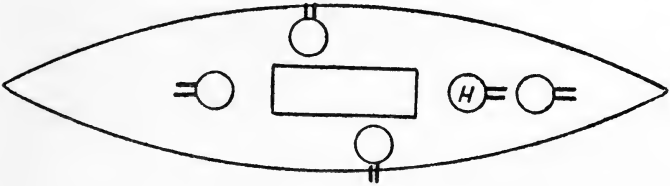
The arrangement of the heavy guns is a very important matter, for they must be so placed that as many as possible can be fired simultaneously in the same direction. The diagram (Fig. 37) shows how they are arranged on the *Minas Geraes*, each of the circles representing a barbette in which a turret revolves. Four of these are, it will be seen, upon the centre line of the ship, two forward and two aft. Of the two in front, the hindmost is on a higher level, so that its guns can fire over the top of the other; they can also be rotated so that the guns can be fired to either side. The two turrets at the rear of the ship are arranged in a precisely similar way.

Then there is the turret on either side, whose normal position is with the guns pointing out over the side of the ship, but which can be rotated so that they can be fired fore and aft. Thus we see that eight guns can be fired simultaneously forward, and eight guns aft, but ten can be fired to either side. This ship was the first to fire ten 12-inch guns on the broadside.

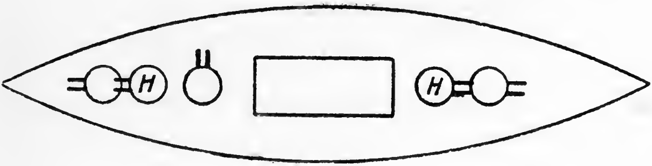
It will be noticed that two guns (those in one of the side turrets) will always be out of action, unless the ship be attacked on both sides at once, a state of affairs which good seamanship would avoid, so that the effective armament may be said to be only ten guns. The ideal arrangement would be to keep the deck of the ship quite clear, so that the side turrets could be turned right round and all guns fired to either side. This is rendered difficult because of the presence of the funnels, mast, and other necessary structures on the deck, but it has been managed on some of the British ships now under construction and also on some of the



12 Guns.—
8 can fire forward.
8 ,, ,, aft.
10 ,, ,, on either broadside.



10 Guns.—
8 can fire forward.
6 ,, ,, aft.
8 ,, ,, on either broadside.



10 Guns.—
4 can fire forward.
4 ,, ,, aft.
10 ,, ,, on either broadside.

FIG. 37.—Various arrangements of the heavy guns on a *Dreadnought* battleship.

Each circle represents a turret, with two guns.

Those marked H are on a higher level than the others.

In some of the latest ships the structures on the deck are so arranged, that the midship guns can be fired to *either* side.

United States battleships, which will be able to fire all their ten guns on either broadside.

This result is achieved by lengthening the ship somewhat, and placing all five turrets on the centre line, the second and fourth being higher than the others, as shown in the diagram (Fig. 37). Under this arrangement four guns can be fired fore or aft, but the whole ten on either broadside.

The guns on the *Minas Geraes* are operated by hydraulic power in all their movements except the turning of the turrets, which is done by electricity, and in every case emergency gear, either hydraulic or hand power, is provided so that should one set of apparatus be thrown out of order, another can be used.

The magazines are kept cool by a draught of cold air produced by a refrigerating machine capable of cooling 300,000 cubic feet of air per hour.

The secondary armament consists of twenty-two 4·7 inch guns and six 3-pounders, that is, guns which fire a projectile weighing 3 lbs. Fourteen of the former are placed in casemates—that is to say, they fire through holes in the armoured sides of the ship—while the other eight are located in suitable positions on the deck-house, each behind its own armour shield.

The 3-pounders are placed, some on the deck-house and some on the roofs of the turrets which contain the 12-inch guns.

The sides of the ship, from the top to 5 feet below the water line, are covered with armour plate. In the centre, where the engines and magazines are, this is 9 inches thick, but over the less vulnerable parts it is only 6 inches and in some places 4 inches.

There are two triple-expansion engines, which develop about 25,000 horse-power, and are capable of driving the ship at a speed of 21 knots. The huge size of each of these will be realised from the dimensions of the cylinders. The high-pressure is 39 inches diameter; from that the steam passes to the intermediate-pressure cylinder, 63 inches diameter, and from that it divides and goes to *two* low-pressure cylinders, each 73 inches in diameter. The stroke of the piston is in each case 3 feet 6 inches. The steam is generated in eighteen water-tube boilers.

Although this recently-built ship is fitted with reciprocating engines, it is quite exceptional now for large warships not to have turbines, either of the Parsons or Curtis type.

CRUISERS

The battleships of a fleet may be likened to the infantry in an army. They bear the heaviest part of the fighting; comparatively slow in movement, they are capable of dealing and receiving the hardest blows.

The cruisers are more like the mounted infantry, for they are faster but less heavily armed, and not so securely protected. The largest type of cruisers afloat are almost as great a tonnage as the largest battleships, but they have only eight 12-inch guns against the battleship's ten or twelve, and their thickest armour is only 8 inches thick as compared with 10, 11, or 12 inches. On the other hand, they could beat a first-class battleship in a race by at least 4 knots an hour.

Indeed, there are building for the British Navy two large cruisers which will be larger than any battleship yet proposed, for their tonnage will be about 26,000, with turbines of over 70,000 horse-power, and a speed of 28 knots; whereas the largest battleship building is only 22,500 tons, with a speed of 21 knots.

But cruisers are not all of this large type. There are, indeed, a great variety of them, down to quite small vessels, each particular type having its special purpose in warfare. Of course, as the size of the ship diminishes, the size of the guns is reduced too.

THE FASTEST SHIPS AFLOAT

Another very interesting class of naval vessel is the "destroyer." Its name arose in this way. The invention of the torpedo was followed by the construction of torpedo-boats, small vessels armed with tubes for launching torpedoes, whose method of warfare is to creep up to a larger vessel under cover of night or by some subterfuge and endeavour to cripple it with one well-directed torpedo.

Now a new weapon or mode of attack always calls forth an answer, and the answer in this case was the torpedo-boat destroyer, a vessel a little larger than the torpedo-boat, with a few light guns powerful enough to sink the smaller craft, and of enormous speed. Its primary duty is, therefore, to chase the torpedo-boats and drive them off the sea, but its great speed makes it a very useful vessel for scouting and similar purposes as well. It is also provided with tubes, so that it can launch torpedoes itself on occasion.

A destroyer usually has two or four huge funnels and a single mast, and is generally one of the ugliest of vessels. It has nothing in the nature of armour, but, on the contrary, is built of the thinnest plates possible. At first the designers appear to have gone a little too far in this direction, for one of the early British destroyers was completely lost in the North Sea, and there seems to be little doubt that she simply broke in two owing to the extreme lightness of her structure, and went to the bottom like a lump of iron.

This extreme lightness is in order that the maximum of engine-power can be got on board. The latest type of destroyer is of 1000 tons only, yet her engines, which are Parsons turbines, can develop 15,500 horse-power, that is, 15½ horse-power to the ton, whereas in the largest cruisers the engine-power is less than 3 horse-power to the ton. Practically every other consideration is sacrificed for speed, with the result that a rate of over 40 miles an hour is attained by some of these vessels (see opposite).[1]

SUBMARINE BOATS

But perhaps the most fascinating of all boats to the general reader is the submarine. There is a romance and mystery about it which makes it very attractive.

The purpose of a submarine boat is to attack a larger vessel by means of torpedoes, without the latter being aware of its presence. For example, two hostile ships approach each other. Concealed behind one of them is a submarine, and as soon as it gets within a suitable distance it dives below the surface, proceeds to the other vessel, and quite unsuspected, probably, launches its deadly torpedo. Though itself invisible, its officers can see what is going on around by means of a small tube which projects above the surface, and by a series of reflectors and lenses shows them a picture of the surrounding objects, and so enables them to stalk their prey. This tube is called the "periscope."

Needless to say, a submarine has no deck in the ordinary sense of the term; in fact, her form is

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[1] In this connection it may be interesting to state that a knot, or nautical mile, in which the speed of ships is usually given, is one minute of longitude measured along the equator; in other words, $\frac{1}{21600}$th of the earth's circumference. Ten knots are equal to about 11½ statute miles, so that 15 per cent. added to the number of knots gives approximately the equivalent in ordinary miles.

By permission of *Messrs. J. I. Thornycroft & Co., Ltd.*

THE FASTEST SHIP IN THE WORLD

The British Torpedo-boat Destroyer *Tartar*, which can travel at a speed of over forty-three miles an hour.

approximately that of a fish, but there is a nearly flat part with a light handrail where the crew can get a little, very little, exercise when the boat is on the surface. At one point on the submarine's "back" there is a small "conning" tower, and it is through it that the crew pass in and out. When it is necessary to descend below the surface the "hatch" at the top of the tower is of course closed. There is also another "hatch" on the back of the boat, through which the torpedoes are taken on board.

The engines are of the "internal-combustion" kind, and are generally driven by paraffin or some other similar oil, and there are usually two propellers. The engines can, however, only be used when the ship is on the surface, for they would use up the air and soon suffocate the crew if worked under water. Electric motors are therefore provided to turn the screws, and the engines, when the ship is on the surface, can be made to charge electric accumulators, which supply the current to drive the motors when she is submerged.

The boat is caused to sink in the water by very simple means. There are tanks on board which are normally filled with air. When it is desired to sink, water from the sea is pumped into these, the air becoming compressed into a much smaller space, and the weight of this water causes the boat to descend. To rise, all that is necessary is to open a valve and allow the compressed air to force the water out again. The air then fills the tanks as before, and the boat ascends to the surface.

To keep the boat level when under water, there are horizontal rudders and fins on the sides, and in some cases tanks containing water ballast at both ends, and a pipe connecting the two. If one end of the boat floats a little higher than the other, a pump transfers a little water to the higher end from the lower, and so the vessel can be perfectly balanced, and kept on an even keel. The action of the pump can be controlled by a pendulum, and so the balancing be made quite automatic. To prevent the men being suffocated during a long submersion, a supply of compressed air or oxygen is carried, and also chemicals to remove the carbonic acid gas produced by breathing.

The working of a submarine is a very risky business, and there have been many catastrophes connected with them. It is easy to see that some accident, such as a collision, may happen which will let water into the boat, and so prevent it from rising to the surface, and one does not need great imaginative powers to be able to picture the terrible plight of the crew, practically buried alive—quite safe, perhaps, for the moment, but knowing that in a short time they must all be suffocated. It will be interesting, then, to see the provisions made for the men's escape in such a case. Many devices have been invented and tried, but we shall only have space for one, which has been adopted in the British Navy.

If the hole in the submarine caused by the collision is anywhere except in the top, the water cannot entirely fill it, for a certain amount of air will be entrapped in the upper part of the vessel, and in that air-filled space the men can live. To provide against the case of a hole right in the top, where, owing to its very nature, it is extremely likely to be hit, two vertical partitions are fixed to the roof and extend some little way downwards, as shown in the diagram (Fig. 38), and these form pockets in which air will be entrapped under almost any conceivable conditions. This air-space, however, will not save the men; it will only provide them with a place of refuge in which to make their preparations for escape.

In each of the air-pockets, special helmet-jackets are provided—one for each man (see page 192). Each consists of a helmet, large enough to go over a man's head, and leave him room to move it freely inside, connected to a jacket of strong waterproof material, with sleeves, and a waist-belt. In the front of the helmet is a window out of which the man can see, and in a pocket of the jacket is a small can containing certain chemicals. The dampness of the man's breath causes one of the chemicals to give off oxygen, while the other, at the same time, absorbs carbonic acid. Thus the air in the helmet is continuously re-oxygenated and purified, and so the man can go on breathing it over and over again. The apparatus, moreover, only weighs 16 lbs., so that the air imprisoned in it is enough to make it act as a lifebuoy, and enable the wearer to float easily.

As soon as the men have their jackets on they are comparatively safe, for they cannot be drowned. They can then, without haste or confusion, open the lid in the top of the "conning tower," or the "torpedo hatch," and climbing through it one at a time float gently up to the surface.

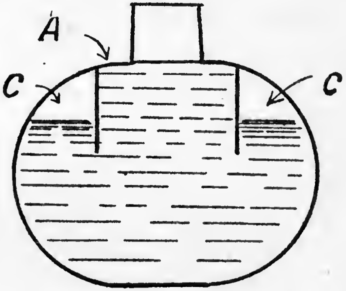

FIG. 38.—Section of a submarine, showing the air-tight pockets for entrapping the air and giving the men a chance to escape if the boat be "holed" at the top. Suppose the hole is at A, the whole boat will fill, except the two compartments C C, where the men can find a temporary refuge in which to prepare for their escape.

But the wonders of this ingenious contrivance have not yet been all told. In one part the jacket is double, and forms a sort of bag, which on arriving at the surface the man can inflate by blowing into it. Thus he forms a lifebelt around him, and he can then open the window in his helmet and breathe the fresh air again. This is necessary unless he be rescued quickly, for the chemicals cannot go on purifying the atmosphere indefinitely. The helmet will, however, keep a man alive for nearly an hour.

One great advantage of these helmet-jackets is that the men can practise in them, and then, in the event of an accident, they have only to do something which they have often done before, and are quite used to. In the Naval Dockyard at Portsmouth (England) a large tank has been constructed, with a structure at the bottom which represents a sunken submarine. Men being trained for work on these boats are lowered down by a sort of lift to the bottom. There they array themselves in the apparatus, get out of the lift cage, enter the "submarine," and find their way to the conning tower, up which they climb, finally opening the hatch at the top and floating up to the surface. Thus the conditions of a submarine sunk at the bottom of the sea are almost exactly reproduced, and the men become quite familiar with what they are to do in an emergency.

In conclusion it may be interesting to state that what is believed to be the largest submarine boat afloat, the British "D 1," is of 800 tons displacement; it can travel 16 knots an hour on the surface or 10 knots an hour submerged.

In concluding this chapter, a few words on torpedoes may be of interest, for it is not only torpedo-boats which are armed with them, since practically all war-vessels, including the largest, have torpedo tubes.

A torpedo is really a small automatic submarine boat. It is shaped something like a cigar, and has a small screw-propeller driven by a compressed air motor, the air being stored in a chamber inside the torpedo itself, and it has automatic rudders, which cause it to maintain a predetermined depth below the

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A LIFE-SAVING HELMET AND JACKET

This apparatus enables men to escape in safety from a sunken submarine. The man has risen to the surface, inflated his jacket so that he cannot sink, and opened the window of his helmet so that he can breathe fresh air.

surface. In the front part is a quantity of high explosive which is fired by a mechanical device the moment the nose of the torpedo strikes anything.

The accounts of the Russo-Japanese war raised considerable doubts as to the efficiency of torpedoes, and several Governments have been trying experiments for themselves. One of the most important of these was carried out by Italy. An old, out-of-date battleship was used, and it is interesting to know that she is one of those which made some sensation, years ago, through carrying 105-ton guns. A torpedo was fixed to her side so as to reproduce as nearly as possible the conditions which would arise if a ship were struck in precisely the right spot, and then it was fired by electricity. Instantly the ship began to heel over, and quickly sank. At the bottom she still remains, but divers who have been down report that a hole of fifty square metres in area was torn in her side by the explosion, a fairly conclusive proof of the efficacy of the torpedo if properly directed.

CHAPTER XV

SUBMARINE DIVING

It is quite a natural transition to pass from the submarine boat to the submarine man.

The diver's work is becoming daily of increasing importance. Every warship, for example, now carries men trained as divers, who can go down to clear a propeller if it should get entangled with a rope, or to scrape the ship if it should have become foul during a long cruise. Such great undertakings as the large Breakwater at Dover Harbour are carried out largely by divers, while without them many a valuable wreck would be entirely lost which with their aid can be recovered.

The ordinary diver's dress consists, first of all, of a strong metal helmet. This completely envelops his head, but it has three glass windows through which he can see. It is fixed to a metal corselet or breastplate which covers his shoulders and breast. This in turn is attached to a water-tight suit completely covering the man's body ; except his hands, which project through elastic cuffs which make a water-tight joint round his wrists.

Air is forced by a pump down a flexible tube, and enters at the back of the helmet, afterwards escaping through a little valve so constructed that, while it will let air out, it will not permit water to get in. Thus the man is provided with a supply of fresh air ; moreover, the air prevents him from being crushed by the pressure of the water. The pressure which exists under water is due to the weight of water lying above, and consequently it increases as you descend. Approximately every 2 feet in depth produces a pressure of 1 lb. per square inch, so that at a depth of 70 feet, for example, the water presses upon a diver with a force of about 35 lbs. on every square inch of his body. This acting upon his chest —for, of course, his suit is quite flexible — would prevent him from breathing ; it would be equivalent to lying on one's back with a 35-lb. weight on every square inch of one's chest.

The water, however, presses upon the little valve mentioned just now, and prevents it opening to let out any air until the pressure of the air inside the suit is equal to the pressure outside, and therefore the air keeps the dress distended and prevents the water squeezing the man.

On the face of it, it seems as if this would simply be changing one evil for another, and that the air pressure would have the same effect as the water. It is not so, however, for whereas the water pressure is outside the man's body only, the air pressure is inside his lungs as well. The outward pressure due to the air in his lungs balances the inward pressure of the air around him, and so they neutralise each other and he is able to breathe freely.

The quantity of air contained in his dress makes the diver buoyant, and he needs to be weighted so that he can descend and stand firmly on the bottom. He has 40 lbs. of lead slung across his chest and 40 lbs. more on his back, while his boots have lead soles weighing 16 lbs. each. Even then, however, if he is careless, and lets his dress become too much inflated with air, he soars up to the surface like a balloon.

The diver is usually connected with the surface by a rope called the "life-line" as well as by the air-pipe, and embedded in this rope there are often telephone wires connected to an instrument inside the helmet so that the diver can talk freely with his mates above.

There is usually another rope, called the "shot-rope," which is tied to a heavy weight sunk at the bottom, and forms a kind of hand-rail by which he lowers himself down and pulls himself up. Still another line is attached to the bottom end of this, called the "distance-line," the purpose of which is to prevent him losing his way when moving about below. He keeps the "distance-line" in his hand wherever he may go, and when he wants to ascend he simply follows the line, which, of course, leads him back to the "shot-rope."

Let us now watch a diver dress himself preparatory to going down. He first of all arrays himself in plenty of thick woollen garments. Then, with the assistance of an attendant, he gets into the diving dress, pushing his hands through the elastic cuffs, which grip tightly round his wrists. His boots are put on for him, and then the corselet or breastplate. This latter has a loose ring all round its edge, fixed on by screws. The edge of the dress is placed under this, and, when the screws have been tightened up, it is firmly gripped and the joint made quite water-tight. Finally the helmet is screwed down on to the corselet, and the man is ready to descend.

The greatest depth at which a diver has actually done work is 210 feet. Within about this limit descent is easy and safe, so long as proper precautions are taken. The greatest danger arises from a too-quick descent or ascent.

Air, of course, is very elastic and easily compressed. For example, at a pressure of 15 lbs. to the inch it has only half the volume that it has when it is free, so that when a diver has descended to 30 feet he needs to have twice the quantity of air in his suit, to keep it properly distended, than he does when he is at the surface. It takes time, however, for the air-pump to supply this extra air, and so if he descends too quickly he will get "nipped" by the pressure of the water. If he is climbing down and feels the pressure increasing, he has only to stop a little while and wait for more air ; but, if he should by any chance fall, he will not be able to save himself from a squeeze which may injure him seriously. Since, however, he can be suspended in the water by the life-line and air-pipe, a serious fall can only occur if his attendants are grossly careless.

It seems strange at first sight, but a much greater danger attends a rapid ascent than a rapid descent.

The effervescence of soda-water is a phenomenon familiar to every one. It is due to the fact that liquids are capable of dissolving gases to a certain extent, and the greater the pressure the greater is the quantity of gas which they can dissolve. Now soda-water is water under pressure in a bottle, and in it is dissolved a quantity of carbonic-acid gas. As soon as the cork is taken out, the pressure falls and the water is then unable to hold as much gas as it did before, and so the gas comes bubbling up to the surface.

The human blood can absorb gases just like any other liquid, and when a diver is at work the extra pressure of the air which he breathes causes the blood to dissolve an abnormal quantity of air, which, if the pressure be suddenly removed, will bubble out of it much as the gas does out of soda-water. This would result in air bubbles being formed in the tissues of the body, possibly in the heart itself, causing serious illness and perhaps death. A diver must, therefore, come up slowly, so as to decompress himself gradually, and allow the dissolved air to escape from his blood by degrees. Strange though it may seem, a man who has come up from a great depth too quickly—as, for instance, if he be "blown-up" through too much air getting into his dress—must, although perhaps insensible, be *sent down again instantly*, and then drawn up gradually. Or sometimes a "recompression chamber" is kept in readiness—a steel cylinder in which the man can be placed, fastened up, and the air around him compressed, to be afterwards gradually let out.

The idea that compressed air is liable to burst in the drum of the ear is an erroneous one. There is a little tube connecting the inside of the ear with the nose, so that the pressure is the same on both sides of the "drum," and consequently there is no tendency to burst it in. There is the possibility, it is true, that the tube may be stopped up through some temporary cause, such as a cold, but the action of swallowing will probably clear it, and if not, the ears will hurt the diver before he has gone far down, and he will return to the surface.

There are jobs, however, in which the necessity of a tube for the supply of air makes the use of a diving dress, such as that just described, quite impracticable. In a flooded mine, for example, where the diver may have to clamber about over obstructions and through tortuous passages, it would be impossible for him to drag a long length of pipe after him. For such cases, a self-contained apparatus may be used, in which the man takes his atmosphere with him, something like the submarine escape apparatus, described in the last chapter.

It is generally stronger, however, and enables the man to live without fresh air for a longer period—as much as two hours. For this purpose a small steel cylinder is slung on his back, into which is compressed

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INSIDE A DIVING-BELL

This unique photograph was taken in a diving-bell sixty feet below the surface of the water.

about one hundred cubic feet of air with an extra proportion of oxygen in it. He also carries a metal chamber containing caustic soda, which absorbs the carbonic acid produced by breathing. By this means the air in the helmet can be breathed several times over, and at the same time gradually replaced by fresh air from the cylinder.

Any of these forms of diving dress can be used in rescue operations at fires or after colliery explosions; for, equipped with them, men can walk about unharmed in the foulest atmosphere.

Another method of diving is by means of a diving-bell. This is a large steel box, open, as a bell is, at the bottom, but otherwise completely air-tight. The men get inside it, and the whole thing is then lowered on to the bed of the sea or river. Of course, the air enclosed in the bell prevents the water from entering, and they can then work on the sea-floor, just as in the case of the caisson described in the chapter on bridges. Indeed, a caisson is simply a special type of diving-bell.

Of course, air is pumped down into the bell through a pipe, continually, and it afterwards escapes through the open end of the bell and bubbles up through the water. Thus the sight of air coming up from below, where diving operations are going on, which usually seems alarming to the uninitiated onlooker, is really a sign that all is right and that the men below are being given a plentiful supply of fresh air.

These "diving-bells" are often used in the building of breakwaters with concrete blocks. The bell is lowered by a crane on to the floor of the sea just where a block is to be laid, and the men inside it can then easily level the ground and make it ready to receive the block. Then the bell is drawn up and the block lowered into its place, being adjusted by "helmet" divers.

Sometimes a diving-bell has a shaft and air-lock fitted to it, like a caisson, and it is then called a "caisson bell." Men and material may then pass up and down without the necessity of raising the bell every time. Which kind of bell is used depends upon the particular nature and circumstances of the job.

In some cases a decompression chamber is fitted in the upper part of the bell, and when it is time to return to the surface, the men get into this and seal themselves up. The bell may then be drawn up as quickly as the crane can lift it, without risk to the workmen, who let the air in the chamber escape gradually until the pressure has all gone, when they emerge from their temporary prison.

The British Admiralty have, at Gibraltar, a special diving-bell plant, for laying moorings. It consists of a steam-barge, with a large hole in the centre, and in this hole there hangs a diving bell, suspended by wire ropes. When it is desired to fix a mooring on the bed of the sea, this barge is anchored over the spot and the bell is lowered. When the work is finished, the bell is drawn up again, and the barge moves away.

An interesting, because unusual, example of divers' work occurred not long ago at Winchester Cathedral.

It is evident that the builders of this structure, which was erected in the eleventh and thirteenth centuries, encountered water when they had dug down to a depth of about 10 feet, so they were unable to carry the foundations lower than that. They therefore dug trenches of that depth, placed a layer of timbers at the bottom, covered them with chalk, and then proceeded to build the walls. These foundations lasted for centuries, but eventually subsidences began to occur which endangered the safety of the whole building.

On investigation, it was found that below the water-level there was a bed of clay 6 feet thick, then a peat bog 8 feet 6 inches thick, and then a bed of gravel, and it became apparent that if the foundations could be "underpinned"—that is, fresh masonry placed underneath, until they reached right down to the gravel—the venerable building could be saved. At first sight this would seem a very easy thing to do—just dig away the earth from the foundations, a small portion at a time, and pump out the water while the men go down and do the necessary work; then, one little piece being finished in this manner, fill in the excavation and repeat the process with another small piece.

There is this difficulty, however. The action of pumping would suck some of the sandy and other lighter material from under the foundations, and so bring the building down.

The only hope of saving the cathedral, then, lay in the employment of a diver.

First of all the earth was dug away from the side of the wall to a width of about 5 or 6 feet, and to the depth of the old foundations, at which point water was reached. Then the diver took the work in hand, digging downwards, and also horizontally under the wall, until he had removed all the clay and peat. Then bags of cement concrete were let down to him, and these he laid side by side until the whole area of the excavation had been covered. With a sharp knife he then slit the bags open and spread the concrete, after which it was left to set.

With the layer of solid concrete at the bottom it was safe to pump the water out, so that the rest of the work could be done in the dry in the ordinary way.

Thus, in short lengths, a few feet at a time, the whole of the walls were carried down on to the firm stratum of gravel, and the structure is now safe.

When we remember that all this work has to be done by the diver in pitch darkness and entirely by "feel," it is impossible to withhold our admiration of the men who perform such tasks.

It frequently happens that submarine rocks have to be removed, in the interests of the shipping to which they constitute a great danger, and here again the diver is essential.

The diver, of course, inspects the rock and decides where the hole or holes should be in which the explosive is to be placed. Then the holes are bored.

Sometimes he does this himself, with a pneumatic drill (see chapter on tools) supplied with compressed air from the boat above. At other times it is done with a diamond drill, worked by a steam-engine on a barge anchored over the spot.

A diamond drill consists of a hollow steel bar, or tube, in one end of which are fixed a number of diamonds. These, being the hardest substance known, can cut through anything; and so, when the bar is turned rapidly round by the steam-engine above, it quickly cuts a large circular hole in the rock.

When the hole is ready, the diver clears it of any dirt or small pieces of rock, and right at the very bottom of it he places the explosive, generally dynamite. This is in the form of cartridges, and after it has been put in and carefully pushed down, the hole is sealed up with clay, or something of that sort, which forms what is known as the "tamping." Through the tamping two insulated wires are led up into the boat. Every one having then withdrawn to a safe distance, the explosive is fired by electricity and the rock is blown to pieces.

There is another way of breaking up a sunken rock without the aid of an explosive. A large bar of steel is used, weighing perhaps 10 tons, with a point of very hard steel, like that of an armour-piercing shell. This is suspended from a boat anchored over the rock, and is alternately pulled up and dropped, care being taken that it shall always fall upon exactly the same spot. Its action is therefore exactly like that of the sharp-pointed hammer with which coal is broken in the domestic coal-cellar.

CHAPTER XVI

WATER-SUPPLY

No work of the engineer touches the welfare of the public more closely than the provision of water for domestic use.

There is no naturally pure water. The rain becomes contaminated, even as it falls, by impurities acquired from the air ; and no sooner has it touched the ground than it commences to pick up still more.

These impurities are of two kinds. First there are substances dissolved in the water, just as sugar is dissolved in tea, and in that case the particles of the substance and the particles of water are so intimately mixed that it is not easy to separate them—no form of filtration will do it. Fortunately, however, these impurities are not of serious moment, producing merely what is known as "hardness," so they are for the most part left in the water as it reaches us through the "main."

The other impurities are matters held "in suspension" by the water—that is, floating in it. Muddy water is an example of this, the dirty colour being due to tiny solid particles "suspended" in the water. The heavier of these particles will, if the water be kept still for a time, settle to the bottom, but the lighter ones will remain suspended for a long while and so have to be filtered out.

Some of these particles are so exceedingly small that they are quite invisible to the naked eye, even when present in large numbers, and water may appear perfectly clear and bright, yet be quite unfit to drink. This applies to the deadliest impurities of all, the microbes, of which there may be myriads in apparently clean water, some of them, perhaps, capable of producing serious disease.

It is these matters "in suspension," then, and particularly the microbes, against which the water-engineer has to wage incessant war.

When we reflect upon this matter and think of the vast volume of water which has to be provided to supply the needs of a large town, and the enormous difficulty of freeing it from these insidious little foes, it is surprising that we do not have to pay for it by the pint instead of having an unlimited supply of it for a water-rate of a few pounds or even shillings per year.

After the rain has fallen upon the earth, a certain amount of it soaks in and penetrates to a great depth, until it reaches a waterproof stratum, in a hollow of which it lies, as in a great subterranean reservoir. This water, in slowly percolating through the earth, undergoes a natural process of filtration, and so if we sink a deep well, and tap the underground reservoir, we shall obtain a supply of really excellent water—not by any means pure, observe, but free from all dangerous impurities. The sides of our well must be waterproof, however, in order to make it quite certain that we draw it all from the bottom, and do not get, mixed with it, any other water which has escaped the filtering process. For that which is found near the surface, and in shallow wells, is of very doubtful quality.

Deep wells, however, will not provide sufficient water for a large town, so that in most cases recourse must be had to river water. The great bulk of the supply of London, for example, comes from the Thames and the Lea, and when we contemplate the many sources of possible contamination to which the water of such rivers is liable, it seems truly remarkable that it can ever be rendered fit for drinking at all. Fortunately, however, it can be done by methods which are very simple, and, as is proved by the excellent health enjoyed by those who live in some of the largest towns, perfectly reliable.

The reason for this very satisfactory state of things, as we shall see presently, is that impure water contains within itself the very material which is required to purify it.

The foundation of the present systems of treating water was laid in 1829 by Mr. James Simpson, the engineer at that time of the Chelsea Water Company (London). He took raw water—dirty water we might really call it, only "raw" sounds less offensive—from the Thames and placed it in tanks called "decanting basins," where it remained at rest for a period; exactly how long he gave it is not known, but the present day practice is about twenty-four hours. During this time the heavier particles of suspended matter fall to the bottom, and the clarified water is then drawn off through a floating pipe, so that it is always taken from near the surface. Periodically, of course, the decanting basins are cleared of the sediment which collects at the bottom.

Sometimes the process is assisted by the addition of chemicals, generally alum, which combines with certain substances in the water, and then falls to the bottom, carrying with it a good deal of the suspended matter.

From the decanting basins he led the water to sand filters, and it is a very remarkable fact that although bacteriology—the science which relates to microbes—was unknown in Mr.Simpson's day,he appears to have hit upon the most perfect means of intercepting them. In other words, although he could not at that time have been aware of the real nature of these deadly "impurities," he nevertheless invented a form of filter which is still up-to-date, and is used now in all parts of the world.

It consists of a large tank, in the floor of which channels are formed; upon this floor is laid a layer of coarse gravel, then a layer of fine gravel, then coarse sand, and finally about 3 feet of fine sand. It is this fine sand, or rather the top half-inch of it, which really forms the filter. The water flows in at the top, and very slowly percolates downwards through the sand and gravel, finally passing away through the channels. At first the filtration is very imperfect, and the water is allowed to run to waste; but it gradually improves until, after about twenty-four hours, the filter becomes what is known as "ripe," and the water which comes from it is then fit for drinking.

Microscopical examination shows that by that time the grains of sand forming the top surface have become coated with a substance to which the name of "zooglea jelly" has been given. It is evidently formed out of something contained in the water, and it constitutes the real filtering material. It effectively keeps back not only microbes but other impurities, and, so long as the layer of jelly-coated sand is not disturbed, the filter can be relied upon to pass only water fit for drinking by human beings.

After a time, of course, dirt collects upon the surface of the filter, and then a thin layer of sand, with the dirt, has to be removed, but after a day or so the filter "ripens" again and works as well as before. If the preliminary clarification of the water is good, a filter will work without cleaning for a year or more.

In the case of large towns there are usually large storage reservoirs. The use of these enables the water to be taken from the river only when it is comparatively clean. After heavy rains, when the river is muddy, no water is taken. The prolonged storage also enables a great part of the suspended matter to settle, just as it does in the decanting basins. The latter are still used, however, in many small towns where the cost of a large storage reservoir would be too heavy.

It might seem, from what has been said, that the methods of purifying water have not undergone any development since Mr. Simpson's time, and, so far as the sand filter is concerned, that is practically the case. A French engineer, named Puech, is responsible, however, for an improved method of clarifying the water, which is being largely adopted now in place of the decanting basins. It is much more effective than they, and so enables the "Simpson" filters to go for a longer time without needing to be cleaned.

His system consists of a series of filters through which the "raw" water is passed. First there is one entirely of coarse gravel, then one of finer gravel, and another and another, and finally one of coarse sand, making generally five in all. Their action is quite different from the Simpson filter, for the dirt is deposited on the gravel or sand right through the whole layer and not simply on the surface; indeed every particle of gravel appears to take its share in the process, the water leaving some of its impurities on every one that it touches, just as we know all dirty water does on any solid substance it may happen to come in contact with. The action is so thorough, however, that it leaves nothing for the Simpson filter to do except to deal with the microbes.

Of course, such filters soon get very dirty, and M. Puech has invented a very ingenious method of cleaning them. In the bottom of each filter there is a series of pipes through which air can be blown. This, bubbling up through the gravel and water, produces an effect very similar to the action of water when boiling (only, of course, the water is cold), and causes the dirt to be carried upwards to the surface. At the same time a current of water is caused to flow along the surface and carry the dirt away. Thus a filter can be cleaned in a very short time.

Filtered water is kept in covered reservoirs. These are generally made of brickwork or concrete, with a roof of the same material consisting of small arches supported on piers, the whole structure much resembling the vaults under a cathedral. The sides are made watertight with a layer of cement, and the roof with a layer of asphalt, to prevent the possible contamination of the water by any soaking through.

Reservoirs for storing unfiltered water are generally open, and to all appearance are simply a piece of ground enclosed by a mound of earth something like a railway embankment. Many people have wondered how ever it comes about that such a structure can hold water, and if it were only what it appears to be there is no doubt that the water would soak into the earth or through the bank, as quickly as it was pumped in. The mystery is solved, however, when we know that such a reservoir is only built upon a spot where there is a continuous stratum of clay or other waterproof material close to the surface, and concealed in the embankment there is a vertical wall, also of clay, carried right down into the waterproof stratum below. Thus it is a complete tank of impervious material.

THE GREAT COOLGARDIE WATER SCHEME

So far we have been dealing mainly with the methods by which water is cleaned and purified. We will now turn to an example of the way in which water is conveyed from one place to another.

In the year 1892 gold was discovered in a remote part of Western Australia, near the present town of Coolgardie. The region was dry and desolate, scarcely any water could be obtained, and what little there was was salt. In those early days water was a luxury, costing half-a-crown a gallon, and even then, as it was very impure, caused much sickness.

As the goldfield developed, it became evident that something must be done, and so the Colonial Government decided upon a great scheme.

Among the Darling range of mountains, near the coast, there is a river known as the Helena River, of very pure water, which flowed through a narrow valley. At one point in this valley two gigantic arms jut out from the mountains on either side, forming a narrow gate through which the river passed. Such a spot was an almost ideal one for the construction of a dam, and accordingly a large concrete dam was built across this narrow opening. The general methods of building such a structure have been referred to in an earlier chapter, so it will be enough to state here that the dam is 760 feet long, and about 100 feet high at the deepest part, the foundations being carried down nearly 100 feet below the bed of the river. At the base it is in some parts 120 feet thick, tapering upwards to a width of 15 feet at the top.

The effect of a dam like this is to hold back the water, and form a large lake or reservoir, from which water can be taken as required, while the surplus falls over the crest and flows on just as it did before the dam was there. From this reservoir the water is conveyed through more than 300 miles of pipes to the goldfield.

The general lie of the country rises from the coast inwards, and the service reservoir, which actually supplies the town of Coolgardie, is 1200 feet higher than the reservoir formed by the dam ; consequently the water will not flow of its own accord, but has to be pumped. Eight pumping stations, therefore, had to be placed along the route, each equipped with the most up-to-date pumping machinery, and it is interesting to find that after searching the world for the best machinery, the engineers eventually gave the order to an Anglo-American combination, half the engines being made in England and half in the United States.

These engines are worthy of a little description. There are twenty of them in all, and they are of the kind known to engineers as "horizontal duplex triple-expansion direct-acting Worthington steam pumping engines." Each one is practically two separate engines (hence the term "duplex"), each of which consists of three steam-cylinders, and one water-cylinder, or pump. The steam passes through all three cylinders in succession, thereby making full use of the expansion, as explained in an earlier chapter, and is then condensed by being brought into contact with the cold surface of the water-main. Some idea of the size of these engines will be gathered from the fact that the largest cylinder of each three is nearly 4 feet in diameter, and the stroke of the piston is 3 feet.

They have no fly-wheels, as the to-and-fro motion of the piston is exactly that required to work the pump, and consequently rotating parts are quite unnecessary. The piston-rod communicates the movement of the piston direct to the plunger of the pump, which explains the meaning of the term "direct-acting." The name Worthington refers to a well-known American engineer who invented this type of machine, and whose firm actually made one-half of these engines.

The water-cylinder, or pump, is not constructed in quite the same way as the cylinder of a steam-engine, but in principle it is very similar. The plunger is analogous to the piston, and as it moves one way it sucks water into one end of the cylinder; as it returns it forces that water out, and sucks a fresh lot in at the other end; thus, whenever the plunger is moving, water is being drawn in at one end of the cylinder and ejected at the other, and the stream of water produced is nearly constant. There is a short time, however, just as the direction is being reversed, when the plunger is still, and so the two halves of the engine work alternately, one being at the centre of its stroke just as the other is starting. The flow of water is thus very steady —but it is made more so still by the use of large vessels containing air which are connected to the delivery pipe; the air acts like a spring cushion or buffer, and so helps to keep the pressure in the pipes quite steady.

The valves through which the water enters and leaves the cylinder are interesting. They are, like all pump valves, what are known as "non-return" valves, which is to say that they will permit the water to flow one way but not to go back the other. The mushroom valves on a gas-engine are non-return valves, but those used on these engines are more simple still. If we picture to ourselves a hollow with a hole in the bottom, and a metal ball lying in the hollow, we shall get a good idea of what they are like. Water entering through the hole will raise the ball and pass through easily, but the moment it tries to get back the ball will cover the hole and effectually seal it up. The water is drawn in through a valve of this description situated in the bottom of the cylinder, and is forced out through a similar one placed at the top.

The power of each engine is stated as 300 horse-power, but that gives us little idea of their great size and strength, for an engine engaged in moving a heavy and inelastic substance like water has to work very slowly, and of course the slower an engine moves the larger it has to be to do a given amount of work. A 300 horse-power *high-speed* engine would look a mere pigmy if placed beside these large machines.

In speaking of a pumping plant it is customary to refer to its "duty," by which is meant the amount of work it is capable of doing for every pound of coal burnt, and it is very interesting, as giving us an idea of the vast amount of energy stored up in coal. During tests these engines did work equal to lifting nearly 1,000,000 lbs. one foot high for every pound of coal burnt—a truly wonderful feat.

We are all familiar with the large cast-iron pipes generally used for water mains; but in this case pipes of an unusual type were employed. They are made by an Australian firm, and are well known out there. Two large steel plates are rolled out into the form of a semicircle; the edges, too, are "upset" in a special machine, that is, they are swelled out so that the plate becomes just a little thicker along its edge than it is elsewhere. Then two of these plates are placed together, with two special steel "locking bars," as they are called, between them. These bars have a groove on each side, into which the edges of the plates fit, and when all are together a hydraulic press "pinches" the sides of the grooves together, so that they firmly grip the "upset" edges of the plates. The pipes used on this undertaking were 30 inches in diameter and 28 feet long. Most of them were made of plates $\frac{1}{4}$ inch thick, but some few, which had to stand a specially heavy pressure, were a shade thicker. About 60,000 of them were used, weighing about 75,000 tons.

The great reservoir on the Helena River, when full, contains 4,600,000,000 gallons of water, and the plant is designed to convey it over the 330 miles to the gold-fields at the rate of 5,500,000 gallons per day.

WATER SOFTENING

We can now leave the public water-works altogether and consider a very important process of purification frequently carried on by the consumer himself.

Those of us who live in the country can, and generally do, provide ourselves with a supply of soft water, by collecting the rain which falls upon the roofs of our houses ; a privilege which is denied the dweller in a large town, because the dirt which settles upon his roof renders such water quite unfit for use. Probably every one, however, has experienced the luxury of a wash in soft water, and while he may not know the precise reason, he is fully aware that there is an important difference between it and the hard water from the "main." In many industries—such, for example, as laundries and dye-works—soft water is almost a necessity, while everywhere where steam boilers are in use it is a great advantage, for hard water leaves a slaty deposit inside the boiler, which, if not removed at great expense, causes a great waste of heat, and sometimes even serious accidents.

The hardness of water is due to certain substances, principally forms of lime and magnesia, which it dissolves out of the earth, and which, as mentioned already, are not removed by the processes used at the water-works.

When we wash our hands in soft water we find that we get them clean much quicker and with less soap than when we use hard water. This is because the dirt upon our hands is stuck on with grease, and to get it off we must dissolve that grease, just as we must dissolve the gum in order to get a stamp off an envelope, and grease will not dissolve in water ; soap, however, contains soda, which becomes mixed with the water, and then it is able to dissolve the grease. But if there is a certain form of lime in the water, the soda prefers to combine with it instead, and as hard water contains this form of lime, there is no soda available for washing until the lime has taken up all the soda that it can combine with; in other words, a certain amount of time and a considerable quantity of soap have to be expended, before the cleaning of our hands begins at all.

We can get these impurities out of the water by distilling it—that is, evaporating it into steam and then condensing it back into water, but that is too expensive a process for commercial purposes. Some of them can be removed by boiling the water, being thrown out of solution and settling on the bottom and sides of the vessel, and ultimately forming a stony deposit, such as is often found in domestic tea-kettles.

They can all be removed cheaply, however, by means of chemicals. Certain substances are capable of being dissolved in water, while others are not, and in some cases we can turn a soluble substance into an insoluble one. If to a quantity of water with some substance dissolved in it we add some other substance, which will combine with the first, and together with it form an insoluble one, it will then be precipitated, that is, will separate itself from the water, and either fall to the bottom of the vessel or submit to be filtered out. This is the principle upon which water is softened by chemical action.

There are several systems for softening water on the market, some of them entirely depending upon the use of chemicals, and some which employ heat as well. A whole book could be written about them, but a description of one of the best known will be sufficient.

Imagine a tall cylindrical tank, formed of steel plates riveted together, with a small separate tank (called the intermediate tank) at the top. From the bottom of the intermediate tank a pipe depends, inside the large tank, with an open end near the bottom of the latter.

On the top of all is a curiously-shaped tank called the receiver, which is fixed so that it can rock from side to side like a see-saw, and which has a division inside it, dividing it into two compartments, while just over it is the end of a pipe from which the hard water runs. The water falls into one compartment until it is full, and then the receiver overbalances, tips over, and empties that compartment into the intermediate tank below, and at the same time brings the other compartment under the pipe. So it goes on oscillating from side to side, a definite quantity of water being tipped into the intermediate tank at each oscillation.

Close to the receiver is another tank containing the chemicals, and every time the receiver tips over, it opens a valve and lets a certain amount of the liquid chemicals flow out of the chemical tank into the intermediate tank. By this ingenious but perfectly simple contrivance, just the right proportion of chemicals is added to the water, quite automatically.

From the intermediate tank the water, mixed with the proper quantity of chemicals, flows down the vertical pipe to the bottom of the large tank. Up this it slowly rises, the impurities, now rendered insoluble, falling to the bottom. At the top of the large tank is a mass of "wood wool"—fine wood shavings—through which the water passes, and then the process is complete. This wood wool acts as a filter, and intercepts any of the impurities which have not already been precipitated, so that only pure, soft water passes out. A valve at the bottom of the large tank enables the accumulated deposit of impurities to be drawn off periodically.

CHAPTER XVII

ELECTRIC TRACTION

One of the most remarkable changes that has ever come over public habits has been brought about by the introduction of electric traction.

Millions of people who would rather walk or stay at home than travel in a horse tram now go regularly by electric car; railways of a type impossible without electricity now thrive on passengers who used to patronise omnibuses and cabs, while some of the older railways have doubled and trebled their traffic by giving up the steam locomotive. Traction may therefore be said to be one of the most important of the purposes to which electricity has been applied.

It will be simpler if we see, first, how electric power is used on tramway cars, turning our attention to the electric railways later.

The electric equipment of a tramcar may be summarised as the motors, which drive the car, the controllers and switches which govern the supply of current, the brakes, and the conductors which bring the current to the car.

The motors are invariably of the direct-current variety described in an earlier chapter; but while they are exactly the same in principle as the stationary motors, so often to be seen driving machinery, they are very different in construction. The conditions under which they work are such that they must be of the very highest class, both as to material and workmanship. The jolting of the car subjects them to mechanical shock such as no stationary motor ever has to withstand, while the sudden starting and stopping, and the continually varying current, causes both mechanical and electrical stresses, which would soon destroy an ill-made machine.

They have, too, to be both water and dirt-proof, for, being fixed under the car, they get covered with dust in dry weather and mud in wet. The steel or iron ring which constitutes the field magnets in an ordinary motor is therefore developed, in the case of a tramway motor, into a case which completely encloses the armature and through the ends of which the shaft projects.

A motor of a suitable size for fixing underneath a tramcar would not be able to develop sufficient power if its speed were so slow as to permit its being directly connected to the wheels, so there is usually a pinion or small tooth-wheel on the motor shaft which works into a larger tooth-wheel on the axle of the car, which of course increases the turning power, but reduces the speed.

There are sometimes two and sometimes four motors on a car, yet they are all completely controlled by the movement of that one small handle which the driver moves from his position in the front of the car. That handle forms a part of a very complex arrangement called the "controller," which is enclosed in the sheet-iron box behind which the driver stands.

If we are filling the domestic bath and the water is coming in too quickly we turn the handle of the tap. That has the effect of partly closing the orifice through which the water passes, in that way *resisting* the flow somewhat, and causing the water to pass more slowly. In the same way the flow of electricity can be regulated by placing a variable resistance in its path. At some convenient place upon the car, very often under the seat, there are coils of wire which form "resistances," and these are connected by a number of wires to the controller.

In the controller there is a vertical shaft or drum which is rotated by the handle, and to which are fixed a number of copper segments. Close to these, but not under normal conditions touching them, are a number of metal fingers which are connected electrically in various ways—some to the source of supply, some to the resistance coils, some to different parts of the motors, and to the brake magnets where a magnetic brake is used. The arrangement of these segments and fingers, and the way they are connected up, is most complicated, but when once it has been made, the operation of the controller is simplicity itself. With the handle in its central position the segment fingers are all separated and no current can pass, but as soon as it is turned slightly in one direction a segment makes contact with certain fingers, forming a path through which current can flow to the motors—a path, however, which offers great resistance, so that that position of the handle is like a tap partially turned on. As the handle is turned further, other segments and fingers come into contact, with the result that easier paths are provided for the current, until, in its extreme position, it is like a fully open tap and the whole force of the current may pass, without check, to the motors.

If the handle is turned in the opposite direction, the current is kept shut off from the motors, and the magnetic brake is applied with varying degrees of force; the means by which it is brought about being exactly the same, certain segments making or unmaking contact, as the drum is rotated.

To one side of the first drum (the controlling drum, as it is termed), and parallel with it, there is a second one, called the reversing drum. It is constructed in much the same way as the other, and when it is turned round it reverses the course of the current through the field magnets of the motors and so reverses their direction.

The reason why the current must be "turned on" to the motors gradually needs, perhaps, a little explanation. As stated in an earlier chapter, the electric motor is self-regulating as far as the current which it consumes is concerned. That is because whenever the armature is being turned round an electric force is generated in it—in other words, it acts as a dynamo even while it is working as a motor—and the force which it generates opposes the incoming current. It does not, it must be understood, generate current, only force, but that force would produce a flow of current were it not overcome by the greater force of the incoming current, just as the current of a sluggish river is overpowered and pushed back by the greater force of the rising tide. The quantity of current which is able, then, to pass through a motor is that due to the number of volts by which the force of the incoming current exceeds the force generated in the motor itself. Now the latter is in proportion to the speed, so it is easy to see that when the armature is (as it is at starting) nearly still, there is practically none of the opposing force, so the full force of the supply is available to drive current through the machine. This, if resistance were not introduced artificially, would mean that at starting an excessively heavy current would pass, heating the wires and burning the insulating material—"burning out the armature," to use the technical term. On the other hand, when the motor is working at a good speed, it is generating a powerful force within itself, so that the whole force of the supply may safely be used—indeed is needed in order to force sufficient current through the machine to keep the speed up, if it is doing hard work.

What has just been described applies to all motors, not simply to those used for traction purposes, and it clearly explains that valuable quality of the electric motor referred to previously, in virtue of which it takes only just as much current as will enable it to do its work. For we can easily see that if the "load" on the machine, or the amount of work that it is set to do, be increased, it will slow down slightly; the "opposing" force which it generates will thereby be reduced, and the quantity of current taken will increase, enabling it to exert more power to cope with the increased work. On the other hand, if the load be reduced, the speed increases, generating a greater "opposing" force, and so automatically reducing the quantity of current taken.

In addition to the controller there are, at some convenient place upon the car, "fuses"—pieces of wire which melt and disconnect the circuit if the amount of current coming into the car exceeds what has been decided upon as the safe limit. There is also, as a further precaution, an automatic switch called a "cut-out," generally placed under the canopy just above the driver's head, which opens and cuts off the current if it should exceed the pre-determined limit. It is simply a switch which is pulled open by a spring, but which, when closed, is held so by a catch. There is a small electro-magnet near, consisting of a few turns of thick wire through which the whole current entering the car passes, and of course the strength of that magnet varies with the amount of current flowing in the coil. As soon as the current reaches a certain volume, the magnet becomes strong enough to release the catch, whereupon the switch, under the influence of the spring, flies open, and cuts off the current.

Regular travellers by electric car must all, at some time, have been startled by a loud "click," accompanied by a flash of light, coming from somewhere over the driver's platform. That is the "cut-out" operating. It will be found to occur generally when the car is starting under a heavy load, perhaps uphill. The driver moves his handle a little too fast, "turning on" the current more quickly than the motor gets up its speed, so that too heavy a current passes. As the writer once had occasion to explain to a nervous fellow-passenger, it is, though startling because of its suddenness, nothing to be alarmed about, but rather the contrary, for it shows that this important safety appliance is in order and doing its work.

The arrangements for applying the brakes on a tram-car vary greatly according to the local circumstances. In some cases a hand brake is relied upon, but that makes great demands upon the driver's physical strength, and also, to a greater extent than one would think, upon his judgment ; for the moment when the brakes are doing the most work is just *before* the wheels begin to skid on the rails, so that to get the best result the driver must put them on hard, but must stop just short of the point at which the wheels will cease to revolve—a matter of no little difficulty.

On most systems, therefore, there is some kind of electrically operated brakes in use. The simplest of these methods is to use the motors themselves.

As was remarked just now, a motor, even when working as a motor, behaves as a dynamo as well. In the same way, a dynamo also acts, simultaneously, as a motor.

Many people suppose that the force required to drive a dynamo, is simply that necessary to overcome the friction in the revolving part, as is, in fact, the case with most other machines. This is only true of a dynamo, however, so long as no current is taken from it. As soon as the two wires leading from the dynamo are connected so that current can pass, greater power is required to drive the machine. That is because of the "motor-like" action within the dynamo. The current which is being generated, as it flows through the coils, sets up exactly those magnetic forces which we saw in an earlier chapter cause the armature of a motor to turn round, and these magnetic forces tend to turn the armature in the *opposite* direction to the force of the engine or whatever it may be that is driving the dynamo. Indeed, by far the greater part of the power employed to work a dynamo is expended in overcoming these magnetic forces, so that, roughly speaking, we may say that the power required to drive a dynamo is in proportion to the quantity of current which we take from it. From that we shall be able to see how the motors can be utilised in "braking" a tramcar.

Suppose the car is running down a hill. No current is being supplied to the motors, but they are being driven by the car, and so are acting for the time being as dynamos. So long as the wires leading from them are disconnected, the driving of the motors does not absorb much of the momentum of the car, but if they be connected through some of the resistance coils, and so a little current taken from them, they commence to act as a brake. If the resistance be gradually cut out this braking effect will increase, until, if all the resistance be taken out of the circuit and a heavy current allowed to flow from the motors, the effect of a very powerful brake is obtained. These different connections are of course made and varied by the simple movement of the controller handle.

In some cases an arrangement is adopted known as "regenerative control." In this, the current generated by the motors on a car running downhill is paid back to the supply, so that cars running down are actually helping to drive other cars which are climbing uphill on other parts of the system.

One of the great electrical manufacturing companies recently published an illustration of what they humorously described as the "First example of a Regenerative System." It consisted of a small tramway line with one car, worked by a horse. After pulling the car uphill, the horse got *on the car*, which was allowed to run down by itself, under the influence of gravity alone. By consuming a certain amount of fodder while on the downward journey the horse generated sufficient energy to pull the car up again. It does not appear to be a very perfect illustration of the regenerative principle, but it is a sufficiently curious example of tramway working to merit a passing reference.

A more usual arrangement is to use the current generated by the motors to work magnetic track brakes. An electro-magnet is suspended by a spring just above the rail, so that normally it hangs quite clear. As soon, however, as it is energised by the current it is pulled down and grips the rail. The friction between the magnet and the rail causes the former to be pulled back relatively to the car, an action which is made to pull a lever, and so apply a brake to the wheels just as it is applied when hand-power is used. There is thus a threefold action; first, the check on the motors, through current being taken from them; then the dragging of the magnets on the rails; and finally, the pressure of the brake-blocks upon the wheels. It will be observed that as the wheels slow down the power of this brake diminishes, so that, unlike the hand-brake, it is impossible to apply it too hard.

Now we come to the means by which the power is conveyed from the generating station or sub-station to the cars.

The commonest method of all is what is known as the trolley system.

In this there is overhead a bare copper wire, called the "trolley wire," supported either by long iron brackets, or by wires spanning the street. This is fed with current, at intervals of about half a mile, from underground cables. The cast-iron boxes, or cupboards, to be seen at the side of the road along a tramway route, are at the places where the trolley wire is thus fed with current. They contain switches by which the current can be cut off from the overhead wires if necessary.

In some places there are other wires stretched immediately over the trolley wires. These are called "guard wires," and their purpose is to prevent anything, such as telegraph wires, from falling upon the trolley wires.

There are generally automatic devices which cut off the current instantly in the event of a trolley wire breaking, so that passengers in the street below stand no chance of receiving a shock.

The current is conveyed from the trolley wire to the car by the trolley arm, a long, flexible arm of iron, which is fixed to the roof of the car, and carries, at its upper end, a little grooved roller, called the "trolley wheel," which runs along as the car moves, in contact with the trolley wire.

The wire which actually carries the current from the trolley wheel to the car is well insulated, and is inside the trolley arm, so that there is little fear of passengers on the top of a car, even if they be touching the trolley arm, getting "electrified"; but, as a precaution, the arm itself is connected by a good conductor to the wheels of the car, so that if, by a remote chance, current should escape from the wire to the arm, it would choose the easiest path to the earth, through the wheels, and not injure any one.

Another system, which has been adopted very largely—indeed, almost exclusively—in London, is the conduit system. It is more costly than the trolley system to lay down, but it has the great advantage, in busy parts, that it needs no posts to cause an obstruction to the traffic, and no overhead wires, which, at junctions particularly, are somewhat unsightly.

It consists of a small tunnel, formed mainly of concrete, under the ground, between each pair of rails. In the crown of the tunnel, or conduit, as it is called, there is a slot about three-quarters of an inch wide, and within the conduit itself two steel "conductor" rails.

A contrivance called a "plough" is fixed under the car. It has a narrow shank, thin enough to slide easily in the slot, and at its lower end are two little cast-iron blocks, called "shoes," which slide along in contact with the conductor rails. The current comes along one of these rails, passes into one shoe, and up through a copper strip buried in the shank, to the car. Thence it returns *via* another copper strip and shoe to the other rail.

Another system is known as the "surface-contact" system, because the car carries a shoe which makes contact with objects let into the surface of the road. There are several varieties of this system, the idea of which is to secure the advantages of the conduit system as described just now, at a less cost.

The chief difficulty lies in devising a suitable automatic switch which shall make each "stud," as it is generally called (the iron block in the surface of the road), "alive" with current when a car is passing over it, but "dead" as soon as the car has passed. In most cases this is worked by the action of a powerful magnet on the car.

It cannot be said that any of the varieties of the surface-contact system have "caught on," up to the present, although examples are working satisfactorily in several places. This is probably due to the fact that, considering the wear and tear to the studs from heavy vehicles passing over them, and the apparent liability to damage through damp, people cannot bring themselves to trust in the efficiency and reliability of the little subterranean switch, while the consequences of people stepping upon a stud accidentally left "alive" assume more serious proportions in the public mind than is perhaps justified.

Except in the case of the conduit system, the current, after it has been through the motors, is led to the wheels, and from them passes to the rails. In order to induce it to flow along the rails direct back to the generating stations and not to flow into the earth, and at the same time to make the track perfectly even, the lengths of rail are generally welded together. Being buried in the ground keeps the temperature of the rails so even that there is no appreciable expansion and contraction, so that in some cases the rails, after being welded, are absolutely continuous for miles. This is the more surprising because railway rails, which are only a few inches above the surface, expand and contract to such an extent that a space is left at every joint, and the bolts which connect them are in oval holes, in order that these forces may have freedom to expend themselves, and even then, in very hot weather, they have been known to become bent through the expansion.

The most usual way of doing this welding is by means of a compound called "thermit." This consists of a powder—a mixture of powdered aluminium and iron oxide. If a quantity of this mixture be placed in a crucible and ignited at one spot, a process of combustion is started which, in a few seconds, spreads throughout the whole mass.

What happens is this. The aluminium and the oxygen in the iron oxide combine, and form what is known as "slag," the iron out of the oxide being left, and great heat being liberated in the process. Thus, after the combustion has taken place, the crucible contains very hot molten iron with a layer of slag floating upon it. The iron is not quite pure, but contains a small percentage of carbon, so that it is about like "mild steel," while the heat produced by the process is so great (about 5,400° Fahrenheit) that it is very fluid.

In applying this to the welding of tramway rails, the two lengths to be joined are placed end to end, with a small space, about half an inch, between them. Then the joint is enclosed in a mould made of sand, formed in two moulding-boxes, as described in an earlier chapter, the mould completely enveloping the ends of the two rails, and forming a cavity into which the liquid steel can be poured.

Then through a hole in the mould left for the purpose, a gas "torch" is introduced, by which the ends of the rails are made red hot.

Meanwhile, over a hole in the top of the mould a crucible has been fixed, with an iron plug in the bottom. A quantity of thermit is then put into this and ignited. After about thirty seconds the combustion is complete, and then the plug is knocked out with an iron bar and the metal runs into the mould, completely filling the space between the two rails, absolutely uniting with them, and forming a perfectly homogeneous joint. The mould is so shaped that, in addition to filling the space between the rails, the metal also forms a broad, thick rib all round the joint, just as nature does round the joint in a once-broken bone, making the joint very strong.

The same method of welding can, of course, be used

Photo. Fred. Marsh, F.R.P.S. *Clifton*

WELDING THE JOINTS IN TRAMWAY-RAILS

This interesting photograph was taken at night, and represents the welding of a joint in tramway-rails by the "Thermit" process.

for jointing other things than tram-rails. Such things as propeller shafts on board ships, and large pieces of machinery which have got cracked or broken, are frequently mended very successfully by this method.

We can now leave tramways, and turn our attention to electricity as applied to the hauling of railway trains.

At the commencement, the practice with regard to electric railways was almost identical with that adopted in regard to tramways. Direct-current motors were used, and were supplied with current at about 500 volts (the usual voltage on tramways), the only difference being that the conductor, instead of being a wire suspended overhead, was a third rail, supported upon earthenware insulators, between the rails on which the wheels run.

In many cases, only one "conductor rail" was laid, the electricity, after it had passed through the motors, being led to the wheels, thence finding its way back along the rails or through the earth, as in the case of tramways. On some systems, however, there are two insulated rails, one to convey the current to the motors and the other to take it back again. On the "District" Railway of London and most of the London tubes there are two insulated rails, while on the City and South London Railway (the prototype of all the tubes) there is only one, and the writer has often heard observant passengers remark upon this fact, and speculate as to the reason for the extra rail. It may, therefore, be worth a short explanation.

A general idea seems to be that it is intended to preserve the electricity and use it over again, as if electricity were a thing of value which it is wasteful to lose. This is a complete misunderstanding of the very nature of electrical energy. It used to be the custom to talk about the "electric fluid," and although we do not now believe that electricity is a fluid, it certainly behaves in many ways as if it were, and it is therefore often convenient to talk about it and think of it as if it were. We shall not be far wrong, therefore, if we think of the whole earth as being pervaded, through and through, with an invisible fluid, limitless in quantity, and therefore of no more intrinsic value than the atmosphere or the water of the ocean, but which we can force along suitable conductors just as we can pump air or water through a pipe.

Just before people began to realise the possibilities of electricity as a motive-power, there were established, in several of the large manufacturing towns, systems of pipes by which compressed air was supplied from a central compressing station to any manufacturers who cared to use it as the motive-power to drive their works.

Now so long as the air was free, it was of no intrinsic value, but as soon as it had been compressed by the action of the pumps it became of value, and the manufacturers were prepared to pay for it. When, however, it had passed through a compressed-air motor, and exhausted its force by working the machinery, it became of no value again.

In other words, it was the force which had been imparted to the air which was of value, and not the air itself; and in precisely the same way, it is the force which the dynamo imparts to electricity which is of value, and not the electricity itself. For we may think of a dynamo as a pump which pumps electricity along a conductor just as an air-compressor pumps air along a pipe. Therefore, when electricity has exhausted its force in working a motor, it has ceased to have any value, and as far as the question of economy is concerned may be discharged to the earth at once.

Suppose, then, we lead it to the track rails; some of it will flow along to the point where the other end of the dynamo is connected to the track rail, but since it is uninsulated, some of it will escape into the earth, and there form currents and eddies just like what we see if we empty a bucketful of water into a pond. These currents and eddies will cause currents to flow along gas and water pipes, or any other good conductors which may be buried in the ground, thereby setting up a process called "electrolysis," and ultimately damaging them. It is to avoid this that the second insulated rail is used.

This brings us to another little misunderstanding which it will perhaps be well to clear up. When the earth forms part of an electric circuit, one end of the dynamo or battery is connected to the conductor and one to the earth. The current then flows along the conductor to the machine or instrument which it has to work, after which it is led to the earth, and we speak of it as returning through the earth to the battery or dynamo. Now in some cases, such as telegraphs, the point where the current enters the earth may be hundreds of miles from the point where the dynamo or battery is "earthed"; how, then, can the electricity find its way back, all that distance, to the right place? The answer is that it does not.

What happens can be illustrated by the compressed-air installation referred to just now. The compressor drew air from the atmosphere and drove it along pipes, at the end of which it was discharged to the atmosphere once more. There was a complete air circuit, yet the same air did not travel round over and over again. Air was simply taken from the great reservoir, the atmosphere, at one place and put back at another. It would be impossible to detect it, but theoretically there must have been a movement of the atmosphere from the point where the air was being discharged into it, towards the place where the compressor was sucking air out of it. That exactly illustrates what happens when a dynamo or battery draws electricity from the earth at one point, which is discharged back to the earth at a distance—a slight general movement of the electricity in the earth from the one point to the other.

As has been stated above, the early electric railways were constructed and worked precisely on the same lines as electric tramways, but in recent years the electrical equipment of railways has developed along lines of its own.

We saw in the chapter on the "Transmission of Power," that for reasons of economy, when great power has to be transmitted over a long distance by electricity, the current has to be at a high voltage, and also of the alternating variety. On the tramways and early railways this current is transformed, and converted in sub-stations into low voltage direct current for use on the cars and trains.

Now these sub-stations are costly to build and to maintain, so the idea gradually developed that it would be a good thing if they could be dispensed with altogether. For tramways it is obviously impossible, for high-tension currents flowing along bare conductors in the public streets are clearly not permissible. On a railway, however, which is private, and where no one goes on the line except officials, the conditions are quite different; there, a high-voltage current, provided it were carried upon a carefully insulated conductor, well up overhead out of reach, might safely be permitted.

That only removes half the difficulty, however, for the motors generally used with alternating current—"induction motors," as they are called—are not, generally speaking, suitable for traction purposes. They do not start well, and it is not possible to regulate their speed so nicely as can be done with a direct-current motor. It has been found, however, that so long as the current does not alternate too rapidly, it can be used to drive a machine in all essential respects similar to a direct-current motor. The alternating current generally used for electric lighting or for working induction motors alternates as many as a hundred or two hundred times per second, but for this purpose it must not exceed about twenty-five or thirty times per second. The rapidity of alternation is called the "periodicity" of the current, and the motors just described are generally spoken of as "single-phase" railway motors, since they require "single-phase" current to work them.

Most of the recent electric railways are therefore on the "single-phase" system, with these "single-phase" motors.

The current is carried by an overhead wire suspended from light girders which cross the line at frequent intervals. It is not, however, attached directly to the girders, but is suspended by means of wires from two other wires which are attached to the girders. There are two advantages in this. First, a wire stretched between two points, no matter how light it may be, always "sags" somewhat, and if the "conductor wire" were like that the collector on the train would not slide smoothly along it at the high speed which railway trains attain. The two upper wires, of course, sag in the middle, but the conductor wire is suspended from them at frequent intervals by short wires of varying lengths, so that the conductor wire always hangs practically straight and level. The second advantage is that the two wires can be insulated from the girder, and the short wires, too, can be insulated from them and from the conductor wire, so that for current to escape from the conductor wire it would have to jump over two or even three separate insulators, a very important advantage in view of its high voltage.

Instead of a trolley arm a "bow collector" is generally used. This consists of a light iron framework, the top of which is slightly "bowed," and which rubs against the wire as the train passes along. It can be lowered flat on the roof of the car when not in use. The raising and lowering is generally done by compressed air.

After passing from the conductor wire to the car through the collector, the current goes to a transformer on the car itself, which transforms it down to a safe voltage for use in the motors. It then passes to the motors and from them to the rails, through which it returns to the power station.

The speed is regulated by means of a controller, much the same as on a tramcar.

The brakes on an electric train are usually worked by compressed air, derived from a pump operated by a small independent motor.

CHAPTER XVIII

THE IRON HORSE

THE first form of mechanical power that was used for hauling vehicles along a way formed of rails was a steam-engine, and to-day the steam locomotive remains the principal agent for that purpose. It is true that electric traction has come into use on some lines and has proved a great success, but it is quite wrong to assume, as some people do, that the steam locomotive will soon be a thing of the past.

On the contrary, it is still being developed ; some of the finest brains are still occupied in improving it, and many large works are exclusively employed in its manufacture. The truth of the matter is that steam traction and electric traction both have their place in the railways of to-day. The steam locomotive, owing to the limitations imposed by its size and movability, is less efficient than the stationary engine in an electric generating station ; in other words, it needs to consume more coal in order to generate the same power. Therefore it pays, under certain conditions, to generate the power in a stationary engine instead of on a locomotive, and convey it to the train by electricity. The question is, then, whether in any particular case the saving in coal will be sufficient to compensate for the cost of the electrical apparatus and for the percentage of power which is lost in transmission from one place to the other. It is easy to see that on a short, busy line the saving will be at the maximum and the cost of electrification at the minimum, while on a long line with few trains there would be little saving in using electricity, and the maximum of expense. Thus, speaking generally, we may say that for short, busy lines electric traction is best, but for long lines steam traction.

In all essential particulars every steam locomotive is just the same as an ordinary stationary engine, but in details there is an immense variety of types. The variations are due to many causes, such as the character of the traffic to be worked, the nature of the line—whether flat or hilly—and the particular fancies of its designers. It will be interesting to notice the main points of difference and the reasons for them.

The first great distinction is into the two classes, goods engines and passenger engines.

The former are built for tractive power rather than for speed, and the driving wheels—those which are turned by the power of the steam and so propel the train along—are comparatively small in diameter, so that the power developed by the mechanism of the engine may not be partially wasted through having to work through large wheels. It is really like the difference between the high-gear and the low-gear on a bicycle. Many cyclists use a three-speed gear, and for ascending a hill or for riding against a strong wind they use the lowest gear, because though it takes them along more slowly, they can climb hills with it which would be impossible on a high-gear. So the small wheels of a goods engine, though they prevent it from attaining great speed, enable it to pull very heavy loads—loads which would be beyond the power of the large-wheeled passenger engine.

For the same reason goods engines have as many as three, four, or even five pairs of wheels, all the same size, and coupled together with cranks and connecting rods, so that the steam turns not merely one pair, but several. This gives the engine a sufficiently good grip of the rails to haul heavy trains. Engines with three, four, and five pairs of wheels coupled together are called "six-coupled," "eight-coupled," and "ten-coupled" respectively.

On the other hand, the passenger engine has large driving wheels and fewer of them, for its loads are not so heavy and it must attain high speeds. It used to be fashionable for fast passenger engines to have but a single pair of driving wheels of very large diameter, as much as eight feet. Such engines were called "single wheel" engines, a type which has gone out of use lately in favour of "four-coupled" engines, those in which two pairs of rather smaller wheels are coupled together.

We can therefore distinguish the purpose for which an engine is intended by the size and number of its driving wheels. Indeed, a little observation will show that the number of wheels determines in a general way the whole design of the engine. This may seem strange, but the number of wheels is really such an important feature that all the other details are more or less dependent upon it.

In addition to the large wheels, there are on most engines smaller wheels, either in front or behind, or both. These are not directly attached to the engine itself, but to a small truck under the engine. This little truck is so fixed to the engine that it has a certain amount of "play": while still supporting the engine it can move slightly in relation to it. This gives the engine an amount of flexibility which enables it to pass easily and safely round curves which would be impossible if all the wheels were rigidly held in a straight line. But for this arrangement either all engines would have to be of a limited length or else the curves would have to be made much less sharp than they are at present. A truck with four wheels is generally called a "bogey"; one with two wheels a "two-wheel truck." If the truck is in front of the driving wheels it is described as "front" or "leading," and if behind them as "trailing."

An instance of how the arrangement of the wheels shows the type is the very popular form of express passenger engines at the present time, known by the name of "Atlantic," which may be distinguished in this way. They have a four-wheel leading bogey, then four driving wheels (two pairs) coupled together, and then a two-wheel trailing truck.[1]

Engines are again divided into two other classes (the dividing line cutting right across the division already referred to), namely, tender engines and tank engines. The purpose of the tender is to carry a supply of coal and water for the journey, and if an engine only goes short trips, with frequent opportunities for replenishing its stock, the tender can be dispensed with altogether, for enough can be taken on the engine itself. In that case tanks are fitted to the engine for holding the water, and so such come to be known as tank engines.

The mechanism by which the steam drives the wheels

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[1] A FEW OF THE PRINCIPAL TYPES OF LOCOMOTIVES

American.—Four-wheel front truck and four coupled driving wheels.

Atlantic.—Four-wheel front truck and four coupled driving wheels, two-wheel trailing truck. (For fast passenger service.)

Decapod.—Two-wheel front truck and ten coupled driving wheels. (For heavy goods service.)

Mogul.—Two-wheel front truck and six coupled driving wheels, of which middle pair are connected to cross-head. (For fast goods trains.)

Consolidated.—Two-wheel front truck and eight coupled driving wheels but no trailing truck. (For heavy goods service.)

Pacific.—Four-wheel front truck and six coupled driving wheels, two-wheel trailing truck. (For heavy fast passenger service.)

is exactly the same in principle in a locomotive as it is in a stationary engine. There are generally two cylinders, each with its piston and piston-rod, cross-head, connecting-rod, and crank, just as described in Chapter II. The two cranks are placed at right angles to each other, so that while one piston is at the end of its stroke, just reversing its direction and therefore doing no work, the other piston is at the middle of the stroke, and therefore pushing its hardest. If the cranks were put opposite to each other, as would seem to be the natural arrangement, there would be a "dead point," as it is called. This term means the point at which the connecting-rod and crank form an exactly straight line, so that the push of the piston has no tendency to turn the crank either way. If a single-cylinder engine, or a two-cylinder one with cranks set opposite, should by chance stop on the "dead point" it cannot start itself, but needs to be moved by some other force until the dead point is passed. In large stationary engines, which stop at comparatively long intervals, this is of no moment, and the difficulty is met by having notches cast in the fly-wheel, wherein the point of a crowbar can be inserted and the engine turned a little way by hand, or in some cases a very small engine called a "barring" engine is provided to start the large one.

Either of these expedients would be very inconvenient on a locomotive, however, so the cranks are always set at right angles to each other.

The cranks are placed on the axle of one of the pairs of large wheels, the other pairs being coupled to this pair by additional cranks and connecting-rods. These latter are always at the side of the engine (never between the wheels), and so have come to be known as "side-rods."

In some cases the cylinders are placed outside the wheels of the engine, and in others inside, between the two rows of wheels. Engines are therefore often referred to as "outside-cylinder" and "inside-cylinder" respectively.

By far the greater number of locomotives are "simple," the steam from the boiler going direct to both cylinders, but there are examples of "compound" locomotives, in which the steam goes through two cylinders in succession. The London and North-Western Railway (England) used to build "three-cylinder compounds." There were two small "outside" cylinders, one on each side, which formed the "high-pressure" cylinders, and the steam passed from them to one large "low-pressure" cylinder placed in the centre, between the other two. In other cases the cylinder on one side is the "high-pressure" and that on the other side the "low-pressure."

One English railway has some engines with four cylinders, two "inside" and two "outside," but they are not compound. They are, in fact, merely two ordinary two-cylinder "simple" engines rolled into one, and were designed to work a very heavy service of passenger trains which generally needed two ordinary engines. Very large and heavy locomotives, however, while they are excellent from the point of view of the mechanical engineer or locomotive superintendent, since they reduce the cost of hauling the trains, rouse strong objections from his colleague the civil engineer, for they severely try the "road" and increase the cost of maintaining it. That is what limits the size of the steam locomotive.

The valves which let the steam into and out of the cylinders are in many cases worked by eccentrics, as described in Chapter II., but there are also a number of special "valve gears" used, in which, by an arrangement of levers, the motion of the cranks themselves is made to work the valves.

The boiler of a locomotive is of what is called the "tubular" or "fire-tube" type. It consists of a cylindrical shell of steel plates which holds the water, with about 200 or more tubes, about 2 inches diameter, of iron, copper, or brass, running from end to end. At the back there is a large chamber called the "fire-box," with iron "fire-bars" at the bottom, forming a grate upon which the fire is made. The heat from the fire passes through the tubes into another chamber at the other end, called the "smoke-box," at the top of which is the chimney.

In the smoke-box there is an arrangement of the utmost importance, called the "blast-pipe," the invention of which, indeed, by George Stephenson, made it possible to raise, in this comparatively small boiler, enough steam for the engine; for it should be understood that a locomotive boiler is much smaller, in proportion to the quantity of steam which it is called upon to supply, than a stationary boiler. That is why, instead of one or two large flues, there are a large number of small tubes, so as to provide the utmost possible area through which the heat can pass into the water. But this carries with it the disadvantage that the hot gases will not travel so readily through the small tubes; and, moreover, the locomotive boiler has not the advantage of a tall chimney to create a draught, as the stationary boiler has. Therefore, unless some artificial draught can be provided, the fire will not burn vigorously enough.

This was one of Stephenson's great difficulties in the early days, until he hit upon the happy idea of the "blast-pipe." It is a nozzle placed at the bottom of the smoke-box, pointing upwards to the chimney; through it comes the steam from the cylinders, shooting upwards in a powerful jet and inducing a strong draught through the tubes. This blast is, of course, only in operation while the engine is running; but for use in getting up steam, or while standing at a station, there is an arrangement whereby a jet of steam straight from the boiler can be directed up the chimney, so as to perform the same function that the blast does when the engine is moving. This steam-jet can be turned on and off at will by the driver.

The "steam dome," which forms such a prominent feature in most engines, is for drying the steam. When the latter arises from the surface of the water, a good deal of liquid water (as distinct from the vapour-steam) is carried with it, and if it went direct to the cylinders this water would go too, partially filling them. The steam is therefore taken from the boiler through a pipe whose open end is near the top of the dome, and the steam, by the time it has risen from the surface of the water to the mouth of this pipe, has dropped most of the water it contained and so reaches the cylinders in a dry state. In some engines, which have no dome, the same result is achieved by having a long horizontal pipe inside the boiler, close to the top. The steam has to enter this pipe through holes in the top of it, an arrangement which serves the same purpose as the dome.

The pipe containing the steam is then taken through the smoke-box, where the heat is very great, by which means it is still further dried.

The consequence of getting any considerable quantity of water in a steam-engine cylinder is very serious. Water is as incompressible as a lump of iron, and, if there were more of it than would fill the space which is normally left between the extreme position of the piston and the cover at the end of the cylinder, the piston would be stopped in its movement exactly as if the cylinder had been made too short. The whole of the mechanism of the engine would be brought to a sudden stop, unless something broke. In all probability the cylinder-cover would be "blown" off as if by an explosion. When an engine starts, the cylinders are cold and the steam condenses copiously, so a small cock is provided at each end to let it out. These are called "drain-cocks," and can be opened and closed by a system of rods operated by the driver. He always opens them when starting, allowing water (and steam, too) to escape, with the violent hissing noise so familiar to us all. Then, when the cylinders have become hot and the steam ceases to condense, he closes them.

So far we have considered the means by which the engine is propelled along, but it is almost equally important that it should be able to stop. On passenger trains there are generally three independent brakes—a steam-brake on the engine, a hand-brake on the tender, and a "continuous" brake of some kind on every vehicle in the train.

The "hand" brake is like that on a horse-carriage, except that it is applied by a screw instead of a lever; in the steam-brake the blocks are pressed against the wheels by steam pushing a piston in a cylinder; while the "continuous" brakes are worked by air. Of these last there are two systems in use—the "vacuum" and the "Westinghouse."

In the "vacuum" there is a cylinder, placed in a vertical position under each vehicle, with a piston inside it and a piston-rod coming out through the bottom end. Connected with this there is an iron pipe, with a short flexible pipe at each end. When a man couples two vehicles together, he also couples the flexible pipes, so that there is a complete pipe running continuously from one end of the train to the other. This is known as the "train-pipe."

On the engine is a little appliance called an "ejector." In this a jet of steam blows through a nozzle in such a way that it sucks the air from the train-pipe, thus creating a vacuum in all the brake-cylinders throughout the train. Moreover, by keeping the ejector partially at work, the vacuum is maintained in spite of the inevitable small leakage of air.

In the brake-cylinder there is a small "non-return" valve, which permits the air to be sucked from both sides of the piston equally; there is nothing then to keep the piston up, so it falls to the bottom of the cylinder by its own weight, and the brake is then off. As soon as the train needs to stop, however, the driver, by the movement of a handle, stops the ejector and admits air to the "train-pipe." This enters the lower part of the cylinder, but is prevented by the "non-return" valve from entering the upper part. There is therefore the full pressure of the atmosphere under the piston, and a vacuum above it, so that the piston is pushed upward, a movement which is communicated by the piston-rod to a system of cranks and levers which press the blocks against the wheels.

The guard also can, in an emergency, admit air to the train-pipe and so put on the brake, and in the event of a coupling breaking, so that the train comes in two, the flexible connection becomes broken, air rushes in, and the brake is applied to both parts of the train automatically. Hence this system is styled the "automatic vacuum brake," and vehicles fitted with it can often be distinguished by the initials "A. V. B." marked on them.

Of course, the same inrush of air takes place when a vehicle is uncoupled from its train, so that just at the moment when, probably, it has to be pushed by hand or pulled by a horse, it becomes immovable. This is provided for by a loop of wire placed in a convenient position on either side of the vehicle. It is only necessary for a man to pull one of these, when it opens a valve and lets air in to both sides of the piston, the result being just the same as it is when there is a vacuum both sides; the piston descends by its own weight, and releases the brake. As soon as it is coupled to an engine again, the ejector withdraws the air from both sides of the piston, and it is then ready to go "on" again as soon as it is needed.

With this brake a train of twelve carriages, going at 60 miles an hour, can be stopped in 400 yards in 25 seconds.

The "Westinghouse Automatic" brake, which works by compressed air, is a little more complicated than the "vacuum." Again there is a cylinder and piston under each vehicle, the movement of the piston being arranged to apply the brake-blocks to the wheels. In addition to that, however, there is a reservoir for compressed air, and a very ingenious contrivance known as the "triple-valve." Pipes with flexible connections form a complete "train-pipe," running the whole length of the train.

On the engine there is a little steam-pump which compresses air into a large reservoir underneath the engine, to a pressure of about ninety pounds per square inch, and, when the driver moves a handle, this compressed air passes through the train-pipe to the triple-valves.

Let us suppose that the brake has just been applied. The cylinders are all full of compressed air, which is forcing the pistons forward and holding the blocks tightly against the wheels. When the driver wishes to release the brakes, he moves the handle and permits compressed air to pass along the train-pipe to the triple-valves. These are so arranged that under these circumstances they supply air to the reservoirs, but let the air out from the cylinders, so that the pistons are free to move backwards and release the brakes. Thus the one action of sending a supply of air along the train-pipe releases the brakes and replenishes the store of air ready for the next application.

This state of things continues until the train needs to stop again. Another movement of the same handle then shuts off the supply of air to the train-pipe, and lets out the air which the pipe already contains. At first sight it seems strange that a compressed-air brake can be applied by liberating the compressed air, but the explanation lies in the triple-valve. As soon as the supply is shut off, and the pressure in the train-pipe allowed to fall below that in the reservoirs, this remarkable little valve disconnects the reservoirs from the train-pipe, but connects the reservoirs to the cylinders. Thus the pistons are pushed forward and the brake applied.

The guard, too, has a handle by which he can let out the air from the train-pipe, and so stop the train even in spite of the driver. The same thing happens automatically if the train should be severed.

The whole secret of the thing resides in the triple-valve—a beautiful piece of mechanism, but unfortunately too complicated for a detailed explanation here.

Readers may be tempted to inquire which is the better of these two systems, but that is a question to which no answer can be given. Some railways prefer one and some the other.

Goods trains, with few exceptions, have no continuous brakes. The slow speed at which they travel renders them unnecessary. They depend upon the brake on the engine and tender, and also the hand-brakes applied by the guards in the two vans.

When speaking, earlier in this chapter, of the purpose of a "tender," reference was made to the supply of water. On a long "non-stop" run the largest tender is unable to carry sufficient, so some device is necessary by which water can be taken "on board" without stopping the train. This is done by means of a trough and scoop. Some spot is chosen where there is a stretch of perfectly level line, and there a narrow trough is placed between the rails, perhaps nearly a mile long. Under the tender there is a hinged scoop which can be let down when required. On reaching the trough the driver lets down this scoop, with its mouth in the direction in which the train is moving. The motion of the train, without pumping or other aid, then causes the water to rush up from the trough into the tender, until the latter is full. Then the scoop is drawn up again.

The very latest form of locomotive is worked by a steam-turbine. This is an experiment which is being made by a great British firm of locomotive builders.

The whole structure is supported on two four-wheel bogies, one pair of wheels, in each, forming the driving-wheels. The boiler is of the usual locomotive type, and the coal and water are carried in tanks and bunkers on either side of it. From the boiler the steam goes to the turbine, which works at the enormous speed of 3000 revolutions per minute, and drives a dynamo which supplies current to four motors. Two of these have their armatures mounted on each of the axles of the driving-wheels. The turbine thus works at a constant high speed, the conditions which suit it best, and the speed of the driving-wheels is regulated electrically.

A novel feature in a locomotive is that the steam is condensed, thereby adding to the power of the turbine, and also saving the water, which is pumped back into the boiler. The water carried in the tanks is, therefore, only used for condensing the steam. A small pump delivers it from the tanks to the condenser. Then a second pump sends it along to a "cooler," which is placed in the front of the engine in order to get the full benefit of the blast of cold air caused by the motion of the train, and from the cooler it goes back to the tanks. Since the steam is condensed there can, of course, be no steam-blast to urge the fire, so a small fan is employed which forces air from the neighbourhood of the cooler (where it has become somewhat heated) into the fire-box. Thus something of a regenerative system is established, waste heat from the condensed steam being carried back to the fire.

Although intended for main-line express-passenger work, this engine, it will be noticed, is without the large driving-wheels usual in engines for that kind of service, and it may be interesting to notice the reason for this difference. In an ordinary "reciprocating" engine two strokes of the piston make one revolution of the crank; therefore, in a locomotive, two strokes of the piston represent a distance travelled equal to the circumference of the driving-wheels. An increase in speed may therefore be secured in two ways—one by increasing the number of strokes per minute, and the other by increasing the size of the wheels. Now there is a practical limit to the speed of the piston. If it be too great it subjects the whole mechanism to excessive wear and tear, and there is also a difficulty in getting the exhaust-steam out of the cylinder quickly enough. Therefore engines for fast traffic are made with large wheels, so as to keep the speed of the piston within proper limits. This difficulty, however, does not apply to electric motors, which work well at high speeds, so that in the case of the turbine-locomotive the driving-wheels may be made comparatively small, their small circumference being compensated by the rapidity with which they turn round.

CHAPTER XIX

HOW RAILWAYS ARE WORKED

In this chapter, and the next one also, I am compelled to draw my descriptions mainly, though not entirely, from what is done in Great Britain. The reason for this is that, owing to the special conditions which obtain in that country, the management and signalling arrangements have to be of the most elaborate character. For one thing it is a small country, so that it has no great trunk lines—as the term is understood in the United States, for instance—but, on the other hand, it has certain very densely populated districts. Thus the lines are short, but crowded with trains, necessitating an elaborate care to prevent accidents which is absolutely unnecessary elsewhere.

There was a good story going about a little while ago. Two men were talking in the train, and one of them made the assertion that it is never safe to trust a man farther than you can see him. The reply was brief, but crushing: "Can you see the man who is driving this train?"

I mention this story because it brings out a fact which we seldom fully realise. When we calmly take our seats in a railway carriage, and without a thought of danger allow ourselves to be whirled along at sixty or seventy miles an hour, we are putting unlimited confidence in a large number of men who are individually quite unknown to us. Nor is our confidence misplaced, for a railway train is one of the safest places on the face of the earth.

Let us see, therefore, who these men are to whom we entrust our lives, and how they do their work.

We naturally think first of the engine-driver. What a task his is! He is expected to know every inch of as much as 400 miles of line. He must be familiar with the position of every signal, know where every gradient is (even in the dark), how steep it is, where the curves are at which he must reduce speed, and how fast he may go through stations and junctions. He must know all these things, too, with such certainty that he will not hesitate to drive a train through the dark at a high speed if necessary. Then when we think how his sight may be impeded by rain, or other atmospheric conditions, his work appears more difficult still. It has often seemed almost incredible to me that any man can have sufficient "nerve" to drive a fast express at night. Yet we know that hundreds do it every day, and with perfect safety.

Then, on the top of all this, he must keep his eye on his watch and on his Working Time-table. At the end of his journey he has to write out a journal for the inspection of his superiors, and, if he has been late anywhere, he must state the reason. The guard keeps a similar journal, and records are kept too in all the signal-cabins, so that any failure to keep proper time can be inquired into, and if it is found to be due to the driver's fault he gets into trouble.

The Working Time-table is a private book issued to the company's servants only, and, on an important line, it is a most wonderful volume. It generally runs into hundreds of pages; on the Great Western Railway, the largest line in England, it is three or four inches thick. In addition to the information given in the public time-tables, it contains the times when trains pass different places, not simply where they stop; and also it shows goods-trains, empty trains, light engines (that is to say, engines without a train, going to or coming from their work), and a lot of other details which the public do not need to know.

There is also an "appendix" to the Working Time-table which gives us all the standing instructions by which the working of the line is regulated—such as the rules for block-working, to which I shall refer presently.

Then, in addition to the Working Time-table, there are notices of special traffic which are issued weekly. If, for instance, the engineer's department needs to have possession of the line at some point one night or on Sunday, to make some repairs, the fact has to be published in the weekly notice with all the necessary instructions to all who may be concerned. If a Sunday-school or a club have a special excursion train, full particulars have to go in the weekly notice.

A driver has copies of all these sent him, and he has to pick out and remember anything which may concern him.

He has, too, to rely largely upon himself. His colleague, the signalman, has many ingenious devices to keep him from making an error, but not so the driver. For example, it is possible that he may approach a sharp curve at too high a speed, as a driver did at Salisbury some years ago, causing a bad accident, and there is nothing whatever but his own knowledge of the road to prevent him doing so. It is true that he has the assistance of the fireman; but he has his fire to see to, and, as on a hundred-mile trip he will have to shovel perhaps as much as three tons of coal, it is evident that he cannot be on the look-out all the time. Thus the driver's responsibility is very great.

He begins his career as a cleaner in the engine-sheds, where he learns all about the engines. Then he becomes a fireman, and then a driver of goods trains, afterwards passing to slow-passenger and then to express-passenger trains. Finally, he usually goes back a step, for an elderly man does not as a rule feel equal to the strain of express driving; so, after passing the prime of life, he generally settles down to the less exacting and more regular work of driving a slow branch or suburban train.

But, however good drivers may be, they cannot save a train from disaster if the road on which it runs is not perfect, and this brings us to another lot of men of whom we hardly ever think at all. I mean the men who look after the permanent way—that is to say, the actual rails on which the train runs, with the chairs and sleepers by which they are supported. It is called "permanent" because when a railway is being made the contractors put down a temporary way for their own use, and, when the embankments, cuttings, tunnels, and so on are finished, this temporary way is pulled up and replaced by a "permanent way."

The line is divided up into lengths of, generally, about two miles, and a gang of men called platelayers are appointed to look after each length. They go up and down all day long tightening up bolts, driving in spikes, occasionally putting in a new sleeper, or in some such way keeping the line up to a high state of perfection. The chief man in the gang is called the ganger, and one of his duties is to walk over his length twice every week-day and once on Sunday. Thus the line is inspected thirteen times a week, and the value of this inspection is illustrated by the following incident.

I remember once passing through a tunnel near London, at one end of which I noticed a gathering of high officials. A few hours later I learnt that the ganger of the length had that morning noticed something wrong with the brick lining of the tunnel. It was found to be unsafe, and had to be closed immediately. My train was the last that went through until it had been reconstructed. The vigilance of that man had possibly averted a terrible disaster.

The name platelayer is a survival from the old times, when the rails were flat plates of iron, supported at intervals on blocks of stone. They were then made of cast iron, and later of wrought iron, but now rails are always made of steel. The latter is cheaper, and, as it is stronger, a steel rail can be allowed to wear down much more than an iron one before it is renewed. The sleepers are generally of timber, well creosoted to keep them from rotting.

The platelayers also work the fog-signals in foggy weather. They are all attached for this purpose to certain signal-boxes, and, as soon as a fog comes on, each man repairs to the cabin, gets his fog-signals, and goes to his post. It is all carefully arranged, so that, in the event of a fog coming on suddenly, no time is lost.

Now we come to the signalman. A signalman's duties are very important and onerous, particularly at large stations and junctions, and in the past there have been many serious accidents through signalmen's mistakes. Every accident, however, set ingenious minds to work to devise systems and appliances by which such accidents should be made impossible in the future. A modern signalman therefore has a carefully devised system to work to, and many clever appliances to keep him from making a mistake, but still a great deal depends upon the man who has to work them.

At first there were no signals at all on the early railways ; but after a time a station-master, on the Stockton and Darlington line (England), hit upon the idea of putting a lighted candle in his window when he wanted a train to stop, and out of that simple invention the signalling methods of to-day have grown up. By easy stages there was evolved the post, with an arm for signalling by day and a lamp for use at night, such as we are all familiar with now. This was as early as 1842, but although the post and arm were then practically the same as they are now, the method of working them was very different. Each signal was worked by a lever at the bottom of the post and each set of points by a lever near them. Several years later, however, a signalman had a brilliant inspiration. He thought of working a signal from a distance by pulling a wire. This seems ridiculously simple to us; but it was then a really important invention, and it made possible the great system of "interlocking" to which, more than to anything else, we owe our safety to-day.

Under this plan all the signals are worked by wires from a central position, and the points are worked by rods from the same place. This central position is always enclosed for the protection of the appliances, and of the man working them, and thus we get the modern signal-cabin. In this cabin there are a row of levers, one for each signal or set of points, and these levers are made to interlock with each other so that they can only be pulled in proper combinations.

This system, though it originated more than fifty years ago, is in use to-day to a greater extent than ever on all the railways in England, and also in America. I will therefore give a simple illustration of it.

Here we have three plans of a small junction, and I show a set of points and a signal forming three different combinations. The first two are quite safe, and therefore it is possible for the signalman to make them. The third, however, is dangerous, because it would permit a train to go from A towards B, and another from C towards D at the same time, and they might collide at the crossing. The lever which works the points, and that which works the signal, are therefore interlocked so as to render such a combination impossible. As soon as the points are set to send a train along the branch, the signal is locked at danger. On the other hand, as soon as the signal has been lowered, the points are locked in the straight ahead position.

Writers of fiction, and still more poets, would often be the better off for a little knowledge of the working of railways. I well remember having heard a recitation relating to a signalman who went to sleep on duty. I forget the whole story, but these words I remember very clearly:—

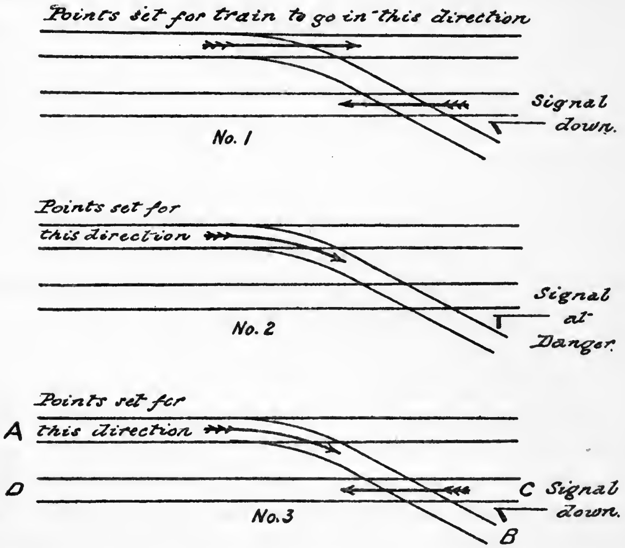

FIG. 39.—Diagrams illustrating the principle of interlocking. One signal and one set of points shown. Nos. 1 and 2 are safe combinations, and can be made. No. 3 is dangerous, and *cannot* be made. Arrows indicate trains.

> "When the roar of the 'limited' woke me,
> And I'd got the line to clear."

These words can only mean that while he was asleep an express train had approached at full speed, and there was something on the line which he had got to get out of the way before it reached him. Now such a state of things is quite impossible—in England, at any rate. The worst that would happen if a signalman went to sleep would be that a train, if it came along, would have to wait, no matter how important a train it might be, at the cabin in the rear until somebody or something woke him up.

This is ensured by a system called the "block system." It is enforced by Act of Parliament, and is embodied in a code of regulations of which every official on a railway has a copy, and with which they all have to be familiar.

Its main principle is this. The line is divided up into sections which are separated from each other by a signal-cabin and a set of signals, and *only one train is allowed in a section at a time.* At each cabin there are two signals for each line. The one at the side from which the train approaches is called the home signal, and the other, which is a little way on the further side, is called the starting signal. The cabins are in telegraphic communication with each other, and before a signalman may allow a train to pass the home signal, he must inquire of the man in the next cabin whether the line is clear, and the latter must not reply in the affirmative unless the previous train has passed safely and everything is clear. He obviously could not give this reply if he were asleep, so that to bring about the conditions mentioned in the poem, the train would have had to run past both the home and starting signals at the previous cabin while they stood at danger, not to mention the distant signal, an indicator which is placed 1000 yards farther back still to warn the driver when the home signal is against him.

But some of my readers may be tempted to ask, What is the good of the starting-signal, and why is it so called? In the first place it is an additional safeguard, as just explained, because while a driver might pass one, it is inconceivable that he would pass two signals at danger ; and, in the second place, it is useful in this way. Very often a cabin is at a station, the platform being between the two signals, and it would be a useless waste of time to keep a stopping train standing just beyond the end of the platform simply because there was a train in the section ahead, perhaps a mile away. Under these conditions therefore a signalman may, *after the train has nearly stopped*, lower his home signal and allow it to draw slowly up to the starting signal, but there it must stop until the section ahead is clear.

It is, in fact, an invariable rule that things shall be so devised that any failure, either of a man or an apparatus, shall result in stopping the traffic rather than incurring the slightest risk. We have just seen how the sudden illness or the falling asleep of a signalman would only stop the traffic, and in just the same way the signals are so constructed that if anything breaks they at once go to danger, and all the electrical appliances which are used give a danger indication in the event of the current failing.

Probably every one has heard, while waiting at a station, sounds as of the striking of a small gong proceeding from the signal-cabin. Those sounds are the audible signs given by the special electric telegraph instruments by which the block system is worked.

Let us in imagination go into the signal-cabin and for the moment assume the duties of signalman. For distinction we will call our cabin B, the next one in the direction of the capital (which we call the "up" direction) shall be A, and the next in the opposite direction C. We will also assume that it is on an ordinary double line.

In front of us there will be a row of levers, and above them, on a shelf, four instruments something like clocks. These are the block-telegraph instruments, and, in the centre of the dial on each, there will be a little pointer like the needle of a toy-compass. All the needles will be upright, and will point to the words "Line blocked"[1] printed on the dials. We shall notice, too, that to one side of each dial there are the words "Line clear," and opposite to them "Train on line."

At the base of every alternate instrument there is a handle which hangs down vertically, and to every pair of telegraph instruments there is a separate instrument (known as a bell instrument, since a bell is its chief feature), with a gong on the top and a handle below. Our gong can be rung by the man in the next cabin while the handle enables us to ring a similar gong in his cabin.

Suddenly there is a sound on the bell instrument marked "A and B," four strokes in rapid succession. Our colleague at A is asking us, "Is line clear for express-passenger train?" We then look at the block telegraph instrument marked "A and B down line" (for if a train is coming from A, which is on the up side of us, it must be a down train), and there we see that the needle is pointing to "Line blocked," at which position it was placed when the last down train passed us. This confirms our recollection that the previous train has safely proceeded on its way, and, after satisfying ourselves that all is clear about our own cabin, we turn the vertical handle of our instrument to the right and secure it there with a little pin. Immediately our needle points to "Line clear," and the corresponding needle in A cabin does the same. From this the man at A knows that he may let the train come forward, and he then lowers his signals.

Presently there are two rings on the bell, which means "Train entering section," and we then unpin

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[1] Here we see the origin of the term "block system."

our handle and turn it to the left, making both our needle and A's point to "Train on line." Finally, when the train passes us, we give A three rings, with a pause between the second and third, which means "Train passing out of section," and then we unpin our handle again, and let it hang down vertically. Both needles then go to "Line blocked," and there they stop as an indication that, if nothing happens in the meantime, we may give "Line clear" to A for another train, as soon as one comes along.

In the meantime we have of course rung up C on the "B and C" bell instrument, with four beats, to which he would reply just as we did to A.

The bell signals, I ought to explain, are always repeated by way of answer, and to make sure that they are properly understood, but I did not mention these replies in the foregoing description for the sake of simplicity.

The instruments just described are not exactly the same on all lines. In some, for instance, there is only one for each direction instead of two, and it has two needles; but they are all on the same principle, and, if a reader should ever see one of a different type, he will have no difficulty in understanding it from what I have just said.

The great bulk of the traffic in this country is worked under this system, but it is clear that it does not render a mistake on the part of the signalman absolutely impossible. For instance, nothing but his own care and attention to the proper routine prevents a man from giving the "Line clear" signal, when in fact the train has not yet passed, or from pulling off his signals before he gets "Line clear" from the other cabin, so some lines use a further development whereby a mistake is made almost an impossibility. This is called the "lock and block system."

The instruments are in this case somewhat different, and they are made to interlock with certain signal-levers, and also are connected electrically to an apparatus called a treadle, which the train works as it passes over it.

When the lever of the starting signal has been put to danger, it becomes locked, and cannot be pulled again until the man in the next cabin sends a "Line clear" message which automatically unlocks the lever.

The man in the other box, too, when he has once sent a "Line clear" message finds his instrument locked, so that he cannot send the same message again until the train has arrived and passed over the treadle.

Thus, a signalman cannot possibly make either of the mistakes referred to just now. In fact, at places where there are no points where shunting may have to be done, the signalman becomes merely an automaton.

I expect readers will wonder why such an apparently perfect system as this is not adopted universally. One reason is that the men are so well trained, and work the ordinary block system so methodically, that it is in practice as safe as the "lock and block" system. The second is that it is allowable at certain places, and under certain conditions, to modify the block system slightly. At these particular cabins, if a man gets the message "Is line clear?" while a train is standing between his home and starting signals, he must not reply "Line clear," but he may give a bell signal, meaning "Section clear, but station blocked." The other man must then *stop the approaching train dead,* and tell the driver verbally that he may proceed cautiously as far as the next home signal. He must confirm this by showing him a green flag or a green light, and then the train may pass. This arrangement, which is called the "permissive block," is impossible with "lock and block" instruments, yet without it some of the great north and south lines, for instance, could not cope with their enormous goods and mineral traffic.

The rules for block working have something to say, too, about the safety of trains at junctions. I used to travel to London every day by the London and South-Western Railway, and at Vauxhall an instance of this often occurred. Just beyond the London end of the platform the two up local lines converge and become one, so that they form a junction, and very often an up local train would stop in the station for several minutes for no apparent reason. Presently another train would come in on the other up local line, and, as soon as it had stopped, the first train would start. That was because of a rule that two trains must not approach a junction at the same time. Suppose the first train had started, and a few seconds later the second had come in, and through a miscalculation, or through slippery rails, it had gone a few yards too far, it would have run into the first one with perhaps serious consequences. This rule is, with some special exceptions, in force at all junctions, and I mention it for this reason. I have often seen a train stopped under these conditions, and instantly there have been heads out of every window trying to see what was the matter. It may occur the very next time you go by train, and it will then be of interest perhaps to see for yourself why you have been stopped.

So much for the methods of working double lines of railway ; but in many parts of England, and still more abroad, there are single lines where the trains go either way over the same metals. If it is a short branch, it is sometimes worked with only one engine. No other engine is ever allowed on the line. Then, of course, no signalling or system of working is necessary.

In many cases the line is, however, of considerable length, and sometimes important trains pass over it.

It is then divided up into sections, and at the end of each section there is a loop, or passing place, just like what we often see on tramways. The ordinary block system will prevent one train from overtaking another, but what is to prevent two trains from starting from opposite ends of a section at the same time and colliding in the middle? At one time the ordinary telegraphic communication was thought to be sufficient; but the frailty of human nature came in, and, through a misunderstanding between two signalmen, a terrible collision occurred on a single line near Norwich.

This led to the adoption of the staff system. For each section there was a staff, a sort of short walking-stick with the name of the section on it, and no driver was allowed to enter a section unless he had the proper staff in his possession. This was quite safe, but it had drawbacks. Suppose there were three trains all waiting to go the same way, and none ready to come back? What then? The first train might go with the staff, but the other two would be locked up for some time. This difficulty was got over by having a box of tickets at each end which the staff would unlock—it had a piece like a key on one end for the purpose. A signalman could then *show* the driver the staff but not give it him, handing him instead one of these tickets giving him permission to proceed. So the first and second trains could go with tickets and the third take the staff.

But what often happened was this. A fourth train turned up unexpectedly after the third had gone, and still no train happened to be coming the other way to bring the staff back. The fourth train then had to wait until some one either walked or came on horseback with the staff. This, of course, took up valuable time, so ultimately the tablet system was invented to get over the trouble.

In this there is an electrical apparatus at each end of the section, containing a number of tablets. When a train is ready to start from one end the signalman takes out one of these tablets and hands it to the driver, who takes it as his permission to proceed just as in the case of a staff. But the action of taking the one tablet out locks up the instruments at *both* ends, so that it is impossible for either signalman to obtain another one. As soon as the tablet is put in at the other end, however, it unlocks both, so that if there is a second train to go in the same direction a second tablet can be taken out, and so trains could keep on going in the same direction until all the tablets had been used, a most unlikely thing to happen, as there are a lot of them. All the same, however, as only one tablet can be out at a time there is no risk of a collision.

Some lines use what is called the electric-staff system ; but it is practically the same as the tablet system, except that the tokens, instead of being tablets, are the shape of the old staff.

On some important single lines there are devices by the side of the line to enable the tablets to be exchanged without the train having to stop, and in some cases it is arranged to have a master-tablet for through trains, the taking out of which locks up all the instruments all along the line. This would, of course, only be used for important trains.

CHAPTER XX

RAILWAY-SIGNALLING MACHINERY

In the year 1908, in the British Isles, 1250 million people travelled by train, besides season-ticketholders, yet there was not a single fatal accident to a passenger.

This fact is sufficient to justify me in saying that, as far as safety is concerned, the art of railway signalling has almost reached perfection. Signal engineers are therefore devoting a good deal of their energies now to improvements in other directions—such as reducing the labour employed, or increasing the capacity of the line by making it possible to get more trains through in a given time.

With these ends in view "power" systems are being installed—systems in which the muscles of a man's arm are replaced by electricity, compressed air, or some other form of power. In most cases, although a man's muscles can be dispensed with, his brains are still required, so that he still controls the signals and points by means of handles in the signal-cabin although the power does the hard work for him.

On lengths of line, however, where there are no sidings or cross-overs, but where the traffic is all straightforward, it is possible to do without signalmen altogether and make the trains themselves control the signals so that they work automatically.

Parts of the Metropolitan District Railway (London), and most of the London "tubes" are instances of this automatic signalling, and on the former some of my readers have probably witnessed the passing of the signalman and the actual demolition of the cabins. Between South Kensington and Mansion House, for instance, there is not now a single cabin except at St. James's Park, where there is one which is opened if, in an emergency, they need to use the cross-over road there.

The line is divided up into short sections, averaging about 900 feet in length, and there is a signal at the commencement of each section. The working is exactly like a man entering a room and locking the door behind him, the door remaining locked until he has passed out of, and locked, another door at the further end of the apartment.

The signal stands normally at safety, but, as soon as a train passes it, it goes to danger and remains so until the train has passed out of that section into the one beyond. This would not be regarded as sufficient on a line where there are fast trains. On such, as was explained in the last chapter, there are always two signals protecting a train, but it is quite safe for a line like the District.

The system on which these lines are worked is called the "Westinghouse Electro-pneumatic," the signals being worked by compressed air controlled by electricity. The electricity is in turn controlled by the train itself, by means of what are called "track circuits," that is to say, electrical circuits of which the track—the actual rails on which the trains run—forms a part.

One of the rails is made electrically continuous throughout. The steel plates which connect the lengths of rail together (usually called "fish plates"), being unfortunately bad electrical connections, are supplemented by flexible copper "bonds" which carry the current from one piece of rail to the next. The other rail is also fitted with these bonds, but instead of being electrically continuous throughout, it is divided up, by special insulating joints, into lengths which correspond with the sections. Each of these lengths of rail is connected to an electric cable.

Current from a dynamo is led to the continuous rail, and from there it goes to the signal and holds it at safety. From the signal it returns to the divided rail, and then goes through the cable back to the dynamo.

As soon as a train enters a section it "short-circuits" this current, provides it, that is, with a short and easy path through its wheels and axles, so that the electricity can get from the continuous rail to the other and back to the dynamo without going to the signal at all. It therefore deserts the signal altogether, and permits it to go to danger which it is made to do by its own weight.

To be quite accurate, it is not the same current that flows through the rail which works the signal, although the result is the same as if it were. The former goes to an instrument called a "relay," which is a switch closed by an electro-magnet, but opened by a spring or weight. When this current, which is a weak one, passes through the coil of the magnet, it closes the switch and allows the stronger current to flow which works the signal; but as soon as the weak current ceases, the magnet loses its power, the switch springs open, and so the stronger current ceases also.

It will be evident that this is a very safe system, as any failure of the air-pressure, or of the electricity, only causes the signal to go to danger. In fact, the action by which the train puts the signal at danger is really an artificial failure of the current.

These track circuits are very useful, too, in connection with ordinary hand-power signalling as well as with automatic and power systems. For instance, if a train be shunted from one line on to another, to allow something to pass, it is possible for a signalman to forget that it is there and let another train run into it. To prevent him doing so, it is a rule that under those circumstances the guard shall go to the signal-cabin and stay there, as a reminder, until the train has been shunted back on to its own road again. If, however, it were standing on a track circuit, it could be made to lock the signals at danger and so protect itself.

But that is by the way. To return to the District Railway: the pneumatic motors by which the signal-arms are actually lowered are small cylinders with a piston inside, like the cylinders of a steam-engine. The air comes along a pipe from a compressor, and enters the cylinder through a valve. This valve is worked by an electric current from the relay, and it is so made that, as long as the current is flowing, the compressed air is admitted and the arm held down. As soon as it ceases the valve moves, shuts off the air from the pipe, and lets out the air in the cylinder. Then the arm, which is weighted at the back end, flies to danger of its own accord. Thus, as I said just now, any failure of either air or electricity puts the signal to danger.

On the ground, close to each signal, there is a device by which the brake is put on if a train runs past it at danger. A small iron arm is raised when the signal is up, but lowered when it is down, being operated by a pneumatic motor just as the signals are. When this arm is up it strikes against a projecting lever on a passing train, and, by moving it, puts the brake on.

At the stations where there are junctions, the automatic system is impossible. There must be a human brain to supervise the operations ; so at such places as Mansion House, South Kensington, and Earl's Court there are signal-cabins. In each of these there is what looks like a large dwarf book-case, with a row of handles along the top. These are the handles of switches by which the signalman can send an electric current, or stop it, as may be necessary. Thus he operates the signals just as the relay does on the automatic sections.

The working of the points is a little different, because they need to be forced sometimes in one direction and sometimes in another. The motors are, therefore, double-acting—the air pushes the piston one way when the electricity is flowing, and the other way when it stops.

In each of the cabins there is an illuminated diagram. A plan of all the lines in the station, and some distance on each side of it, is drawn upon glass. Behind the glass are electric lamps arranged to work in connection with the relays. Normally the whole is illuminated, but, as soon as a train enters a section, that section (on the plan) becomes dark. The signalman can thus see at a glance the position of the approaching and receding trains.

Inside the "bookcase," as I have called it, is an arrangement whereby the handles above are all interlocked just as the ordinary levers are interlocked in a hand-worked system.

In America, where automatic signalling originated, and where it is much more largely used than it is anywhere else, one of the principal reasons for its adoption was that the lines often traverse wild, uncivilised districts, where no signalman could be induced to live.

The chief advantage of an automatic system in England is economy. To take the "District" as an example, in order to increase the number of trains it was necessary to reduce the length (and increase the number) of the sections. This under the old system would have meant building a large number of new cabins and employing more signalmen ; but, with automatic signals, to divide a section into two only means an extra signal and a set of relays.

On the North-Eastern Railway of England, and in several places in the United States, there is an interesting system in use called the "Hall Electric-gas System." The train controls the signals automatically by electric track-circuits something similar to the District method, but, instead of compressed air, compressed carbonic-acid gas is used to supply the motive power. This saves the cost of the piping, because the compressed gas can be stored in a cylinder at the foot of each signal post. The gas is compressed to 900 lbs. per square inch, *at which pressure it is liquid*, and it is liberated through a valve which lets the pressure down gradually to 40 lbs. per square inch before it enters the cylinder of the motor. If it were admitted direct from the storage-cylinder to the motor, the sudden expansion would cause it to freeze.

Incidentally, this illustrates the interesting scientific fact that matter may take three different forms. Carbonic acid is under ordinary conditions a gas ; indeed, we manufacture it in our lungs and exhale it every time we breathe. If we compress it, however, as we have just seen, it becomes liquid, and if we subject that liquid to a certain degree of cold, it freezes and becomes solid.

There is enough gas in one cylinder for 12,500 operations, and two cylinders are placed at each post, so that if one runs out the other can be connected up immediately. Periodically the empty ones are all taken away and full ones put in their place.

The London and South-Western Railway (England) have adopted at several places along their line the "low-pressure pneumatic" system. In this everything is done by compressed air, the motors for the signals and points being worked by a pressure of 15 lbs. per square inch, and the valves by a pressure of 7 lbs. This is "low" in comparison with the Westinghouse system, which uses air at 65 to 70 lbs. pressure.

A great number of pipes are needed—four for each set of points, and three for each signal—to convey the air from the cabin to the motors. The points and signals are worked by the movement of small handles in the signal-cabins, which when pulled admit air to the pipes, and these handles are interlocked. All the signals go to danger automatically when a train passes, and on some parts of the line they work entirely automatically—the train controls them by track-circuits, as in the Westinghouse system.

On the London and North-Western Railway at Crewe and Euston (England), and on the North-Eastern Railway at York (England), there is an all-electric system called the "Crewe" system. It was devised by Mr. Webb, for many years the chief mechanical engineer on the London and North-Western Railway. Switches in the cabin permit currents of electricity to pass to the signals or points, as the case may be. The points are worked by electric motors placed on the line close to them, and the signals by electro-magnets.

Another all-electric system (the Siemens) has been tried on the Midland Railway and the Great Western Railway, and is now being installed on a large scale at Snow Hill, Birmingham (England). This system is largely used on the continent of Europe.

Signal engineers have a curious way of calling hand-power systems "mechanical" as opposed to "power" systems. It is strange, seeing that there is far more mechanism in the latter than in the former. The "half-and-half" system in use at St. Enoch's Station, Glasgow (Scotland), and at Victoria Station, London

(London, Brighton, and South-Coast Railway), is therefore called "electro-mechanical."

In this there are the usual large levers for working the points, and the signalman pulls them over by hand. Above them, on the edge of the shelf on which the block-telegraph instruments stand, there is a row of small handles, and through these the signals are worked by electricity. There is a small electro-motor on each signal-post, by which the arm is pulled down. It remains down as long as the current is flowing, but flies to danger as soon as it stops. Of course the handles and levers are all interlocked.

There are also hydraulic systems, but they are not much used in cold countries owing to the liability of the water to freeze.

Probably a good many readers will at this point be inclined to remark, "I see the advantage of an automatic system, but what is the advantage of a power system which is not automatic?"

In the first place, the men are relieved of much hard work. Then it is easy to arrange in a power system that every movement of a signal or point shall be repeated back to the signal cabin by a return current, so that when a lever or handle has been moved, the next one cannot be pulled until the "return" has come which indicates that the points or signal have properly responded to the movement. This is very safe, but it is not so great an advantage as it at first appears to be, since even in a mechanical system there is something of the sort, for an experienced signalman can tell a good deal by the "feel" of his lever when he pulls it.

Then the cabins can be very much smaller with a power system, as the small levers or handles take up much less room than the large levers used in mechanical systems. Points and signals can be operated, too, at a much greater distance from the cabin, so that fewer cabins are needed. A striking instance of this is at Staines (England), on the London and South-Western Railway, where two "power" cabins now do the work that used to require five.

It is hardly necessary to refer in detail to the mechanical signalling which is in operation in the majority of cabins. The long row of levers is familiar to every one. Each of these is connected to a signal or set of points, to the former by a wire and to the latter by a rod, the interlocking apparatus being under the floor.

I will therefore pass on to the second part of the chapter, which I think is sufficiently important to have a sub-heading. I propose to call it

HOW TO READ SIGNALS

In this I will try to describe briefly the "visible" part of the signalling machinery—the part by which the driver gets his instructions—and I venture to think that this will interest many of my readers, as it relieves the tedium of a wait at a station, and adds much to the interest of a journey if one can understand something of the signals.

As I explained in the last chapter, there is at every station, for each line, a home signal and a starting signal—the former at the side from which the train approaches, and the latter at the other side, the platform being between them. Then about 1000 yards back there is a distant signal. This is distinguished by having a V-shaped piece cut out of the end of the arm, and its purpose is to indicate to a driver how the home signal stands. If it is at danger, therefore, a train does not stop, but slackens speed, so as to be able to stop if necessary at the home signal.

Sometimes a tall signal has a second arm, slightly smaller than the other one, and comparatively near the ground. This is a repeater, which goes up and down with the upper arm, and is used at places where something,

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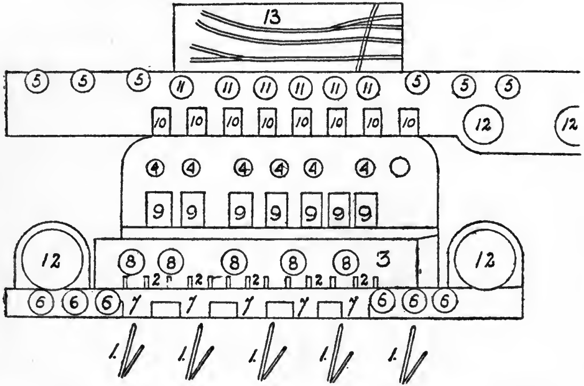
THE INTERIOR OF A SIGNAL CABIN

Showing hand-power levers for working points, electric levers for working signals, "lock and block" instruments, indicators, etc. (see key).

Railway-Signalling Machinery



1. Hand-power levers for working the points. 2. Electric levers for working the signals.
3. A combined instrument, constituting the "Lock and Block" instruments for five different lines in one direction, and six in the other.
4. Tiny model signals which indicate, when "up," that the section *ahead* is "blocked," and when "down" that it is "clear."
5. The bell instruments by which the adjacent cabins communicate with this one.
6. The "Pushes" by which the man in this cabin can ring the bells in the adjacent ones.
7. Plungers, the pushing of either of which unlocks the starting-signal at the next cabin in the rear, and permits a train to enter the section.
8. Indicators which record that such permission has been given.
9. Indicators which show when the next cabin in *advance* has unlocked the starting-signal at this cabin for a train to pass.
10. Indicators which show whether certain safety devices on the line are being operated by a train.
11. Small model signals which show whether certain remote signals are working properly.
12. Train describers, by which the signalmen tell each other the kind of train that is approaching.
13. Plan showing the positions of all the points, signals, &c., controlled from the cabin.

such as a bridge, obscures the driver's view of the upper arm when the train is in certain positions. The very small arms sometimes seen close to the ground are "fogging" arms, and are for the information of the men who put the fog-signals down on the line in foggy weather.

The signals which control shunting operations are generally near the ground, and very often take the shape of discs, which do not go up and down, but turn round a quarter of a circle. These are called ground discs.

At large stations there is often a small arm to be seen, just under the ordinary signal arm. This is known as a "calling-on" arm, or "draw-ahead" signal, and its purpose is to give permission to a driver to go on although the large signal is at danger. This seems a dangerous and improper proceeding, but it is both necessary and safe under conditions like these. In many large stations the platforms are long enough for two trains, the first of which can be signalled in, in the ordinary way, after which the large signal must be kept at danger in order to protect it. Another train may then approach which has passengers wishing to change into the first, so that it must be admitted into the station at once. It is therefore stopped dead by the ordinary signal, and then the small arm is lowered, by which the driver knows that he is to draw gently up to the other train.

If the station is a terminus, there is generally another small arm under the "calling-on" arm. It is usually distinguished by being of some peculiar shape, and it is used to let in the engine which is going to fetch the train out again.

Signals may often be met with where the arm has a large ring fixed on it. These relate to goods or "slow" lines, and are so marked to enable them to be easily distinguished from the others. For the same reason shunting-signals (when placed on a post) sometimes have a letter S fixed on the end of the arm. A cross on the end of an arm indicates that it is out of use.

As far as possible signals are placed close to the lines to which they refer, but when there are several lines in the same direction this is not always possible. Sometimes they are then placed on a bridge, each signal over its own line, but very often they are put one above another on the same post. The top one then refers to the line on the extreme left; the next one to the left but one; and so on if there are more than two. This is not allowed, however, to interfere with the almost invariable rule that a signal for the main line must be the highest of all, so that if the main line is not on the left, the main line signal has a post to itself higher than the other ones.

As regards the lights for showing signals at night, the usual rule is red for danger, and green for safety; but sometimes, on signals of minor importance, the danger-light is now purple, so as to avoid the confusion that might result from having too many red lights. The danger-lights on shunting-signals are sometimes white, which may seem surprising, but it is now an invariable rule that a white light is a danger signal, since if it were not so a street lamp or a light in a window might be mistaken for a safety signal, or a well-directed stone from a small boy might, by knocking out the red glass, make a signal stand permanently at safety. A "calling-on" signal shows a green light for safety, but nothing at all when at danger.

On some lines now a distant-signal is distinguished by a special lamp which shows a strip of light the shape of the stripe on the arm of a lance-corporal, in addition to the ordinary "Bull's Eye."

The small light shown at the back of a signal lamp is to enable the signalman to see that the light is burning properly, and that the arm goes properly to danger. It is unnecessary when he can see the front of the signal. These lights are white when at danger, but obscured when at safety.

CHAPTER XXI

THE MANUFACTURE OF GAS

In spite of the many advantages of Electric Light, gas manufacture is still an important and thriving industry. This is, no doubt, largely owing to the introduction of the incandescent mantle, and the ever-increasing use of gas for heating purposes. In Great Britain alone about 14,000,000 tons of coal are used annually for making gas.

The general principles of the manufacture of coal-gas are well known. Suitable coal is heated to about 2000° Fahr. in fire-clay retorts for a period of six to twelve hours, and as the result gas is given off, which subsequently undergoes certain purifying processes, while coke is left in the retorts. So far the matter is familiar and commonplace, but when we see how it is done on an enormous scale it becomes very interesting.

First of all let us visit the Retort House of a large works. It is a huge plain building of two storeys, about 50 feet wide, and of a length which varies according to the size of the works. Down the centre runs a rectangular brick structure, with a flat top, nearly as high as the roof of the house. This is the furnace which contains the retorts.

The latter are thick strong pipes of fire-clay, either oval, round, or else resembling a capital letter D in shape. They are about 18 feet long, and run right through the furnace from side to side, being closed at each end with an iron lid.

They are placed in groups of from six to ten, each of the groups being termed a "bench" of retorts, and a large house will contain as many as twenty or thirty benches, or 200 to 300 retorts. Just behind the iron lid there is an outlet, from which a pipe called the "ascension pipe" runs vertically upwards, like the pipes of an enormous organ.

The retorts are not generally heated by the direct heat of a fire but by producer gas. As explained in the chapter on Gas-Engines, if air be drawn through a *deep* coke fire, *closed at the top*, the process of burning only takes place at the bottom of the fire, the fuel above it being simply heated to incandescence; the consequence of which is that the carbonic-acid gas, the incombustible gas which results from burning, is converted, in passing upwards, into carbonic-oxide or carbon-monoxide, a gas which burns with great heat.

Beneath the retorts, therefore, a Gas Producer is placed—simply a large deep furnace, the gas from which is led up brick passages to combustion-chambers formed in the brickwork amongst the retorts. At the same time fresh air, called in the gas-works "secondary air," is drawn into the combustion-chambers, and as soon as the gas and air mingle they burst into flame. The flames then pass through passages amongst and around the retorts, finally escaping to the chimney stack. The secondary air on its way to the combustion-chamber passes through passages formed in the brickwork around the retorts, so that it intercepts and carries back some of the heat which would otherwise escape into the atmosphere. The "secondary" air is so called to distinguish it from the "primary" air, which is that drawn in at the bottom of the producer. There is usually one producer for several benches of retorts.[1]

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[1] It will be noticed that the heating of gas-retorts by producer gas is very similar to the method of heating a Siemens Steel Furnace, described in an earlier chapter.

I have stated already that the Retort House is about 50 feet wide, while the retorts themselves are under 20 feet long, so that between the furnace and the wall on either side there is a wide passage way. Here, on the first floor, there are rails on which run two large machines, one a "charging machine" and the other a "coke-discharging" machine.

In the top of the charging machine is a hopper containing coal, and in the front of it a spout which just fits nicely into the mouth of the retort. The machine places itself in front of the retort to be filled, and pushes the spout just into its mouth; then a ram starts to move backward and forward, at each forward stroke pushing a quantity of coal into the retort, until it is half full. At the same time, a similar machine at the other side of the house has been doing the same thing through the opposite end of the retort, so that between them they fill it quite full. Then they withdraw their spouts, the doors are closed, and the coal is left to bake.

The coke discharger may be either a "pusher" or a drawing machine. Both are somewhat similar at first sight to the "charger."

A pusher has a long arm consisting of tubes sliding one in another like a telescope, and on the end of it is a rammer, the shape of, and almost filling the retort. When all the gas has been obtained from the coal the doors are opened at both ends, the machine inserts its rammer and pushes the whole of the coke right out through the opposite end.

A "drawing machine," on the other hand, has an arm like a rake, which it inserts into the retort, and with which it draws the coke out. These machines work by hydraulic power, and the speed with which they do their work is truly remarkable.

Two charging machines working together can fill a retort with 9 cwt. of coal every 45 seconds, that interval, of course, including the time taken in moving from one retort to the next. The coke-discharger can work even more quickly.

There are similar machines worked by electric, pneumatic, and (for small works) by hand power.

The gas, as it is given off by the coal, escapes up the "ascension pipes." These bend over and dip down into a large pipe called the "hydraulic main," which runs along the top of the furnace. This pipe is half full of water, or rather "liquor," as it is called, the nature of which we shall see presently, and the outlets from the ascension pipes dip down into this liquid. This forms a "liquor seal"—gas coming from the retorts can bubble up through it, but no gas can get back, as it might otherwise do, when the retort lids are opened.

From the hydraulic main the gas passes to the "foul main," which leads it to the condenser.

Now, any one who has tried the little experiment beloved of boys of making gas in a "churchwarden" pipe, will have noticed that it is smoky in appearance. That is because of the steam and tarry vapour which must be got rid of before the gas can be sent out through the mains. This clearing process takes place to a certain extent in the hydraulic main and foul main, but it commences in earnest in the condenser.

In old works, this simply consists of a zig-zag pipe fixed to the outer wall of the Retort House, and cooled by contact with the air. Through this the gas slowly passes, being cooled as it goes, a good deal of the vapour being condensed into liquid tar, which runs down and is drawn off through a valve at the bottom. In a modern works, however, the gas passes through pipes which are kept cool by water circulating round them, just like a surface-condenser in a steam-engine plant.

Thence it goes to the "washer," where it is forced through little metal tunnels with holes in the bottom, partly immersed in water. Out of these holes it has to find its way, the tiny globules of tar which form the vapour being broken and liquefied as it does so; and as the holes are under water, it must needs at the same time bubble up through it, giving up to the water some of the ammonia which it contains. Here the last vestige of tar is removed.

The gas still contains impurities, however, the principal ones being ammonia and sulphuretted hydrogen, which must somehow be got rid of. The first, fortunately, has a great liking for water, so the gas is made to travel up a high tower called a "scrubber," passing among layers of wet boards set on edge, and meeting a spray of water falling from the top. In many works, too, it goes through a rotary washer, in which revolving steel brushes throw a spray of water through which the gas has to pass.

Finally, in the "purifiers," it percolates through layers of iron oxide, which absorb the sulphuretted hydrogen, and it is then ready to go to the gas-holder.

Of course, the gas will not pass through all these different appliances of its own accord, since they all offer some slight resistance to its passage. At one point in the series, therefore, such as between the condenser and the washer, there is a pump called the Exhauster, driven by a steam-engine, which acts like the heart of the system, and keeps up a regular circulation.

Most works, both large and small, use horizontal retorts as described above; but, in some, inclined or vertical retorts are used. These are more easily charged, of course, because the coal will fall into them, and does not need to be pushed in. In the same way, the coke will fall out. In some of them the process of gas-making is made continuous instead of intermittent, the coal being fed in in small quantities at the top, at frequent intervals, and the coke being taken out in the same way at the bottom. The relative advantages of the different types of retort is a subject of much discussion among gas engineers.

The introduction of the vertical retort has, however, had a more important effect indirectly, than it has had up to the present, directly, for it has revolutionised the methods of working in many works equipped with horizontal retorts.

It is desirable to get the gas out of the retort as quickly as possible after it has been given off, for if it remains in contact with the hot coke it becomes impoverished. For this reason it used to be the custom to fill the retort only about two-thirds full; a layer of coal, that is, was spread on the bottom so as to leave a clear passage above for the gas to reach the ascension pipe. To accomplish this, the coal was fed in with a long scoop, which was pushed right in, and then turned over, so as to have the coal evenly spread upon the floor of the retort, a plan which is still in use in small works. It is quite evident, however, that it would not work in a vertical retort, for the weight of the coal would cause it to fill the retort entirely, and leave no passage for the gas; and the fact that vertical retorts gave a satisfactory result opened the eyes of the engineers to the fact that, at any rate in large works where they use charging machines, they might as well fill their horizontal retorts right up, thereby effecting an enormous saving in labour.

Under the old system, the men worked in three shifts of eight hours each. During a shift, they discharged and charged each retort once. An 18-foot retort under those circumstances was filled with about 6 cwt. of coal, which it gasified in eight hours. Under the new system, 9 cwt. of coal is put in and left for twelve hours. The men can do the work of charging and discharging in the same time as before, after which the retorts are left practically to themselves for four hours. Thus two shifts per day of eight hours, with four-hour intervals between, can make as much gas as three shifts, working continuously, used to do under the old system.

So much for coal-gas. Now we can turn our attention to "carburetted water-gas," which is often used to enrich it; that is to say, increase its light-giving power, and sometimes, even, instead of it.

The two gases are really very similar in composition. They are both only "gases" in the commercial sense of the term, being mixtures of several gases as known to the chemist. These constituent gases are much the same in both cases, the difference between the two mixtures lying mainly in the proportions.

Speaking roughly, the principal constituents of coal-gas are hydrogen (about 50 per cent.), methane, a *combination* (not a mixture, mind) of carbon and hydrogen (over 30 per cent.) and nearly 10 per cent. of carbon-monoxide. These three gases make up about nine-tenths of the whole. The precise composition varies in different towns.

The same three gases make up four-fifths of carburetted water-gas, but instead of the carbon-monoxide being under one-tenth of the whole, it forms nearly one quarter, resulting in more perfect combustion, so that this gas gives a more brilliant flame than does coal-gas, and by adding it to the latter a greater illuminating power is produced.

The plant for making carburetted water-gas is quite different from that for making coal-gas. The part where the gas is actually made, which corresponds, in fact, to the bench of retorts, consists of three cylindrical steel vessels, lined with fire-bricks. The first of these is called the generator, the next the carburettor, and the third the superheater.

The generator is really a furnace, with a grate at the bottom. It is filled with coke and ignited, and the fire is then urged by means of a blast of air from a fan. Except for a door, through which the coke is fed in, the top of the generator is closed, so the hot gases from the fire have to pass through a short pipe into the carburettor. This is filled with loosely-stacked bricks, like the regenerating chambers in a Siemens Steel Furnace, and these become heated by the hot gases. The latter then pass on to the superheater, which is also filled with bricks, after heating which they escape up a chimney. After this preliminary process—which is spoken of as "the blow"—has been going on for a little while, there is in the generator a mass of incandescent coke and in the carburettor and superheater masses of hot bricks. Then all is ready for the "run," or actual gas-making part of the proceedings.

The blast is shut off, and a jet of steam from a boiler introduced instead. Now we saw when discussing the subject of gas-engines that steam in passing through incandescent carbon becomes split up and forms hydrogen and carbon-monoxide. Consequently there issues from the generator into the carburettor a volume of these two gases. Entering the carburettor they encounter a fine spray of oil, the gas and oil spray passing down together through the hot bricks, the oil being thereby vapourised and mixed with the gas. Then to ensure that these processes shall be complete, the stream flows on through the further mass of hot bricks in the superheater, after which the gas may be regarded as made.

After leaving the superheater the gas goes through an "oil-heater," where some of its heat is utilised to heat the oil for use in the carburettor; then it passes *via* a washer, scrubber, and condenser to the holder.

When the "run" has been continued for a little time the generator, carburettor, and superheater begin to get too cold, so the steam is then shut off and the heat got up again by another "blow." So the process goes on, run and blow alternately.

In addition to the advantages which the gas itself possesses, the plant has valuable qualities of its own.

Suppose a spell of foggy weather should set in, the demands on the gas-works are very heavy. The spare retorts are unable to respond to this, for it takes at least three days to get the heat up, and even then the stresses due to expansion and contraction are so severe as to be liable to damage the retorts and their settings. It is much better, therefore, to get up the heat more gently, and take a fortnight over it.

The consequence of this is that sufficient gas must be kept stored in the gas-holders, to provide against an unexpected demand.

On the other hand, the water-gas plant can be going full swing in three hours from the lighting of the fires. Moreover, it sometimes happens that the quality of the coal-gas produced in a works falls off for some reason—such, for example, as a cargo of bad coal—but when carburetted water-gas is used for enriching it this can be rectified by simply increasing the quantity of oil used.

The oil, by the way, is what is known as "crude" petroleum, a somewhat misleading term, since it is the residuum left after the lighter oil used for burning in lamps has been distilled. It is therefore a waste product, and consequently cheap.

Reference was made just now to the "liquor" in the hydraulic mains. By this term is meant water with ammonia dissolved in it, a very plentiful commodity about a gas-works, for it is not only found in the hydraulic main but comes from the washers and scrubbers in large quantities. In large works, and many small ones too, there is a special plant for recovering the ammonia, which then becomes a valuable by-product.

Coal-tar, the other principal by-product of the gas-works (of course leaving out coke) is chemically one of the most wonderful substances known; from it are manufactured such various things as dyes, benzol, a spirit used for driving motor-cars, a substitute for sugar, and photographic chemicals. The gas-engineer usually prefers to get rid of it not by selling it but by turning it as far as possible into gas, but there is a very modern form of gas manufacture in which the gas itself is a by-product, and the large quantity of tar produced is an important feature of the process.

The process referred to is the manufacture of a fuel called coalite.

As we have seen, when coal has been subjected to a heat of about 2000° Fahr. in a retort, certain things in it are dispersed and coke is left. This, we all know from our own experience, is a smokeless fuel, and in that superior to ordinary coal, but it has the disadvantage that it will not ignite readily, and does not burn with quite such a cheerful blaze. Consequently it is not popular for domestic use. If, however, instead of 2000° the coal is only heated to 800°, the coke which is produced is somewhat different. While it is smokeless, like ordinary "high-temperature" coke, it ignites readily, and burns more like coal. This "low-temperature" coke has been named "coalite," and it is claimed for it that it is going to provide us with a suitable fuel for use in our houses—easy to light, cheerful to look at, giving more heat than a coal-fire, and at the same time abolishing the smoke nuisance. The prospect of clear skies and no fog, even in our great cities, is a very alluring one, and it is hoped that this new fuel will soon achieve all the success that is claimed for it.

From an engineering point of view, however, the chief interest lies in the method of production and also in the valuable by-products.

Instead of the usual type of retort, special vertical retorts made of iron, are used. Imagine an oblong cast-iron box, with twelve holes in the bottom, each of the holes being the outlet from a vertical pipe fixed under the box. There you have a good idea of the "coalite" retort. The pipes are about 9 feet long, 4½ inches in diameter at the top, and slightly larger at the bottom. The lower end is closed by a door, so that when coal is tipped into the box (which we may really call the "mouthpiece" of the retort) it falls down into the pipes and fills them ; while to discharge them it is only necessary to open the door at the bottom. They are, of course, set in brickwork, and heated by producer gas.

Now the remarkable thing is that the difference in the temperature applied to the coal brings about a result differing not only in quantity (as might be expected) but in kind. It would seem reasonable to suppose that the lower temperature would produce "underdone," and therefore heavier, coke, because less changed from its original state as coal, less gas, and less tar.

As a matter of fact, a ton of coal treated by the low-temperature process gives roughly the same weight of coalite, less gas, less ammonia, but more than twice as much tar as it does by the high-temperature process ; tar, moreover, which differs so much from ordinary gas-tar, that it may be regarded almost as a different substance. Treated chemically, this tar yields motor-spirit, fuel oil, disinfectants, an excellent insulating material for electric cables, besides other things. It is this valuable tar that makes the process commercially possible.

There is one feature about a gas-works which always attracts attention, on account of its huge size. I mean the gas-holder.

It is often spoken of as a gasometer, a term which is somewhat misleading, for it suggests a measuring appliance. It is quite true that the height of a gas-holder tells the quantity of gas in it, but it is not used for that purpose. It is simply a huge flexible chamber, capable of expanding or contracting as the gas comes in or goes out.

First of all, a great tank is built, generally underground, and frequently constructed of concrete. Sometimes, however, it is made of iron plates, and then it can be placed above ground. This tank is filled with water, and its purpose is to enable the holder to slide up and down freely, yet without the gas being able to escape.

The holder itself consists of a cylindrical steel vessel, closed at the top, but open at the bottom. It is placed in the tank, and when empty, sinks right down into the water. The gas enters through a vertical pipe which comes up through the floor of the tank and has an open end just above the water-level. The pressure of the gas is not very great, but it is sufficient, when spread over the large area of the roof of the holder, to be able to lift it up, and so as the gas enters it makes room for itself by raising the holder bodily. Since the latter's lower edge dips into the water, however, the gas is prevented from escaping, whatever the position of the holder may be.

An outlet is provided for the gas by means of a second vertical pipe, and when the gas is going out faster than it comes in, the holder, of course, descends accordingly.

Where the holder consists of a single cylinder, it is known as a "one-lift" gas-holder, but in most modern holders there are two, three, or even four cylinders, working one inside another, telescope-fashion. The thought occurs at once—what keeps the gas from escaping at the joints between the cylinders? This is provided against by a very ingenious contrivance.

Take, for example, the case of a "three-lift" holder. The topmost section is inside the others, and it has all around its bottom edge, on the outside, a deep gutter, capable of holding water. On the top edge of the next section, *but inside,* there is a similar gutter in an inverted position, so that the inverted gutter on the one can hook into, as it were, the gutter on the other. Now it is the upward pressure of the gas upon the roof which lifts the holder, and as it is only the inside one which possesses a roof, it follows that that must be the first one to rise. Before its lower edge gets clear of the water in the tank, its gutter, filled with water, hooks under the inverted edge of the next section, making a gas-tight joint with it. The second section in turn does just the same with the third, which never entirely leaves the tank. Thus, no matter how they may rise and fall, there is always a perfect, water-sealed joint at each point.

CHAPTER XXII

ELECTRIC LIGHTING AND HEATING

QUITE primitive tribes have discovered that, by twirling a stick between his hands while its point touches another piece of wood, a man can kindle a fire.

The reason of this phenomenon is that there is friction between the stick and the other piece of wood, and, when spinning the stick round, the man expends energy in order to overcome the friction. It is one of Nature's great laws that no energy can be lost, so the energy of the man cannot be lost; it is simply converted from energy of motion into heat, which is manifested at the point where the friction takes place.

Now it is a very remarkable thing, but the principle upon which we generate light and heat by electricity is exactly the same as that which underlies the savage's "fire-stick" just described. An engine drives a dynamo, thereby forcing electricity along a wire; we put in its path some obstacle, such as a narrow gap across which it has to leap, or a fine wire through which it has to pass, by that means producing something analogous to mechanical friction, and the result is that the mechanical energy of the engine is converted into heat at the point where the obstacle is. Indeed, it is interesting to start one step farther back still, and remember that the engine is driven by heat. We start with heat energy, which is changed by the engine into mechanical energy, only to be converted immediately by the dynamo into electrical energy, which is then turned back by the lamp or heating appliance into heat once more. Thus we have a perfect endless series, the original heat, after several changes, being restored to what it was to commence with.

The simplest, and at the same time the most familiar of the appliances used for turning electricity into heat, is the incandescent electric lamp, or glow-lamp as it is often called. The current is led to the lamp by a comparatively thick wire, which offers little resistance, but in the interior of the lamp itself it has to pass through a very fine "filament," which offers very great resistance to its passage. Consequently the energy of the electricity is absorbed in forcing its way through the filament, and it emerges from the other side of the lamp with scarcely any force left, the energy having been converted into heat in the filament, which consequently glows with a bright light.

This heat would, if proper precautions were not taken, cause the fine filament to be burnt up almost immediately ; it is therefore enclosed in an air-tight glass bulb from which practically all air has been withdrawn, and since nothing can burn without the presence of oxygen, the absence of oxygen in the bulb preserves the delicate filament and permits it to be heated without being destroyed.

The pumping out of the air from the bulb of an electric lamp is a very important matter, and no ordinary mechanical air-pump is able to do it well enough ; air escapes through the valves, or past the piston, and so a sufficiently good vacuum is not produced. A beautifully simple little appliance is therefore used, called a mercury air-pump. It has no valves ; the cylinder consists of a glass tube, and drops of mercury sliding down inside it form a succession of pistons. The drops of mercury make such perfect contact with the sides of the tube that no air can possibly get past.

Originally the filaments were made of carbon. This was produced by mixing a paste of some suitable substances, composed mainly of carbon, forcing it through a small hole so as to form a fine thread, and then heating it gently by an electric current until all the substances other than carbon had been burnt out and a thread of practically pure carbon left. These "carbon filament" lamps are now being largely superseded by the more modern "metal filament" lamps, in which the filament is made of one of several rare metals, such as tungsten and tantalum. These give as much light as the older lamps, and consume less than half as much current. At first there was great difficulty in forming fine threads or wires of these metals, and the difficulty had to be got over by a process known as sintering. The metal is reduced to a powder and mixed with a temporary cement into a paste, so that it can be forced through a small hole, and so formed into a fine thread, much as the carbon filament is made. It is then heated by an electric current, which burns away the cement and welds the particles of metal together, so that the final result is a fine wire of pure metal. Quite recently, however, a method has been discovered of drawing these metals into wire directly, avoiding the somewhat roundabout process just described.

The other method of producing heat by electricity is exemplified in the familiar "arc-lamp." In this there are two "pencils" of carbon, a material which is found deposited on the walls of the retorts in gasworks. As the word pencil indicates, these pieces of carbon are frequently similar in shape to a sharpened lead-pencil, and they are placed in the lamp with their points touching. On current being passed through, from one to the other, a certain amount of heat is generated at the point where they meet, owing to the fact that they do not make a perfect contact, and the electricity experiences a little difficulty in flowing past that point. Thus the tips of the carbons become hot, and a little cloud of vaporous carbon is formed. At the same moment a mechanism which forms part of the lamp, and which is worked by a magnet energised by the current itself, draws the two carbons apart a little distance. Although they cease to touch, the carbon vapour forms a sufficiently good conductor to enable the current to go on flowing across the space, but nevertheless the resistance is sufficient to cause very intense heat to be generated. This raises the points of the carbons to a white heat and so produces the light. The carbons suffer a gradual consumption at the points, and so the distance between them becomes increased. That increases the resistance, however, and consequently reduces the quantity of current which passes through the magnet. In this way the strength of the magnet is reduced, and the carbons then come nearer together again, until they are the correct distance apart. Thus the lamp automatically adjusts itself, as the carbons are burnt away.

There are some special forms of arc-lamp in which the carbons are impregnated with special materials in order to produce a redder and warmer light than the familiar blue light of the ordinary arc-lamp. These are known as "flame arcs." In others the same result is sought to be achieved by enclosing the arc in a glass globe containing certain gases, which glow and give a warmer colour to the light.

For purely heating purposes, very similar methods are employed. For domestic use there are many appliances such as radiators, water-heaters, cooking stoves, foot-warmers, even warm bandages and heated carpets, constructed upon the same principle as the glow-lamp. There are coils of wire, of platinum, or of some alloy which will stand being heated in contact with air (for it is obvious that, when required to *give out* its heat, the wire must not be enclosed in a vacuum), and these coils are heated by means of a current of electricity. These appliances have the great advantage in a house that they consume no air, and in most of them there are a number of separate coils, so that, by sending the current through fewer or more of them, the heat can be nicely regulated.

Small furnaces for chemical experiments, or for dentists' work, coffee-roasters, and many other heating appliances besides those for domestic use, are made in this way. The system is only suitable, however, where moderate temperatures are required. For high temperatures the principle of the arc-lamp is generally followed, though not invariably.

The heat produced in that little space between the two carbon pencils, known as the "arc," is almost inconceivable. It is estimated that in a lamp the positive pencil—that is, the one to which the current is led—exceeds 6000° F. All metals, even platinum, will quickly melt if exposed to it, and thus the "electric arc" enables us to construct the most powerful furnaces known. This seems at first sight strange; for, since the heat given by electricity is only a reproduction of the heat of a coal fire, it appears as if the former could not by any possible means exceed the latter. The explanation is that electricity provides us with a method by which we can concentrate the heat of a large body of coal in a very small space.

Iron is now being smelted in electric blast furnaces,[1] and electric furnaces for making steel have been in operation for some years. Two such are shown in Figs. 40, 41, and 42. Many manufacturing processes

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[1] It appears probable that the electric furnace will provide a means of making steel *direct* from iron ore.

which not long ago were impracticable, through lack of a means of producing a sufficiently intense heat, are now carried on by electric furnaces. Most of these are on the principle of the "arc," the substance to be melted being placed in or near the gap across which electricity is passing. These furnaces are of special value in some places where there is little fuel to be had, but plenty of water-power. Current for the furnace can then be generated by the water-power, and the lack of fuel is of no moment. It is interesting to note that even then heat is the original source of the power, for it is the sun's heat which makes the rain which gives the water-power.

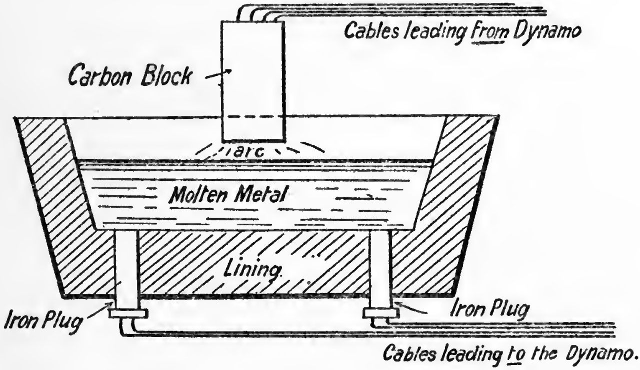
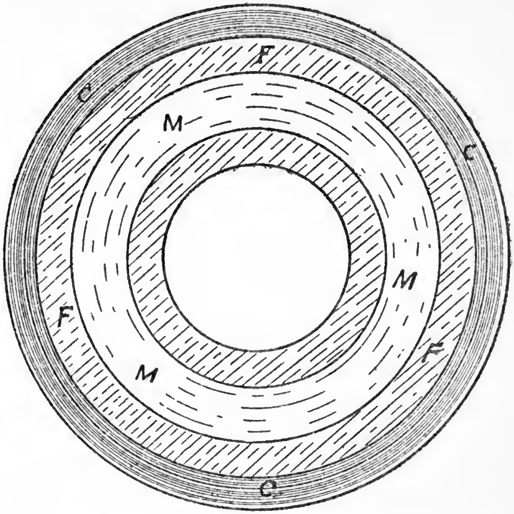


FIG. 40.—The "Girod" Electric Steel Furnace ("arc type). The furnace consists of a steel vessel lined with a heat-resisting lining. Over the centre there are suspended one or more blocks of carbon, while in the floor of the furnace are a number of iron plugs. At first the carbon blocks are lowered into contact with the metal in the furnace, and the current, being switched on, flows from them through the metal to the iron plugs. Then the carbon block is raised, and a powerful arc is formed between it and the surface of the metal.

In the welding of metals the electric arc can accomplish wonders. Suppose two bars of iron need to be welded together. One plan is to put them on insulators, with their ends touching, and to send a current through from one bar to the other. Owing to their making

FIG. 41.



As seen from above.

FIG. 42.

As seen through centre.

Another kind of Electric Steel Furnace (induction type). F. F. F.—the furnace proper, formed like a circular trough. M. M. M.—the molten metal in the trough. C. C. C.—a coil of wire round the furnace. In this kind of furnace the heat is produced by current flowing through the metal itself, just as it is in an incandescent lamp by current flowing through the filament. The current is not led to the iron from a dynamo, but is actually *generated in it* by induction. The furnace takes the form of a circular trough, outside which is a coil of wire. Thus it is practically a huge induction coil, and powerful alternating currents in the outer coil induce currents in the ring of molten metal lying in the trough.

an imperfect contact, heat is generated at the point where they touch. Thus they are soon brought up to welding heat, and, on being pressed together, become united. Very large bars can be welded in this way, and bars of awkward shapes which it would be impossible to weld in the ordinary way by heating in a fire.

Whenever great heat needs to be applied locally to some part of a piece of metal, whether for welding or any other purpose, the arc forms a very convenient means of doing it. The usual method is to lead the current to the metal to be treated. The workman is provided with a carbon-rod fixed in an insulating handle, to which is attached a shield to protect his hand from the heat. The carbon rod is connected to the return wire, so that as soon as it is placed upon the metal, current commences to pass, after which the rod is withdrawn a little distance and the conditions which obtain in an arc-lamp are set up almost exactly. In the case of the lamp, as we have seen, the positive carbon is raised to a very intense heat, and as, in the arrangement just described, the metal itself occupies the place of the positive carbon in the lamp, it follows that it, too, will likewise be raised to an intense heat. Thus, if an iron or steel casting, for example, be found to contain a fault, the metal may by this means be remelted at that particular point and the fault practically removed.

It will probably be assumed that to produce this great heat needs current at very high pressure, and that therefore it is dangerous work. On the contrary, while a very large volume of current is used, running often into thousands of amperes, the pressure is quite moderate, not more than forty or fifty volts, quite insufficient under ordinary circumstances to cause a man any serious injury.

The subject of lighting and heating being largely a domestic matter, naturally leads us to think of the public mains by which the current is brought along the streets to our own doors. These are invariably of copper, generally encased in an insulating covering of indiarubber and tape, placed in pipes buried under the pavements. The pipes are first laid like any other pipes, and then the cable is drawn through by main force. At frequent intervals there are cast-iron boxes, called "junction boxes," where the branch-wires join on to the main cables.

There are instances in which, instead of insulated cables, bare copper strips are used, stretched upon insulators in pipes. This idea, however, does not find general favour.

In distributing current from a generating station by means of a network of cables and wires, the electrical engineer is faced with many difficulties. The chief of these is to keep the pressure from varying at different points in the system under varying conditions.

Copper is a good conductor, but it is not perfect. It offers *some* resistance, and consequently takes out from the current some of its energy, which it converts, according to the principle we have just been discussing, into heat. The effect of this is that, at the farther end of a long cable the pressure will be considerably less than that generated by the dynamo. If the current is only taken for use from the far end of the cable that does not matter, for it can be generated at a higher voltage in the dynamo, so that by the time it reaches the other end it is just correct. But supposing there are lamps connected to the cable at frequent intervals all along its length ; if a number of these are switched on, near the dynamo, the pressure at the farther end will be reduced more than it is when only those at the other end are alight. So, according to the varying number of lamps alight over the system, the relative pressure at the different points will be constantly changing. This accounts for the varying degrees of brightness in the lights, which we have all noticed at times.

This difficulty cannot be entirely overcome. It can be mitigated, however, by using cables of ample size, so that there may be a free flow of current, as it were, even when the demand is greatest, and by care and watchfulness at the generating station.

At every public generating station there are storage-batteries or accumulators. These are charged by the dynamos when the demand for current outside is not heavy, and they form a reserve which can be drawn upon in case of need. If, for example, a sudden darkness causes a lot of lamps to be switched on at once the demand for current may be so great that the dynamo cannot keep the pressure up. Then the switchboard attendant can switch in some of the cells of the storage battery to assist the dynamo. Moreover, if an accident should cause a momentary stoppage of the machinery, the storage battery can keep the lights going for a short time by itself.

The cost of the copper in the distributing cables is a very serious item in an electric-light installation, and has led to the invention of a very interesting arrangement known as "the three-wire system," in which two thick wires and a thin one are made to do the work of four thick wires.

To understand this we must refer to the two diagrams, Figs. 43 and 44. The two large circles represent dynamos, the small circles lamps, and the horizontal lines wires. We will assume that the current supplied to consumers is at 110 volts, and consequently the lamps in use are constructed for that voltage.

In the former diagram each dynamo has its own two wires through which it supplies current to a lamp. The lamp needs, say, one ampere, so that each dynamo has to generate one ampere at 110 volts, and each of the four wires needs to be large enough to carry one ampere.

Now turn to the second diagram. There the two

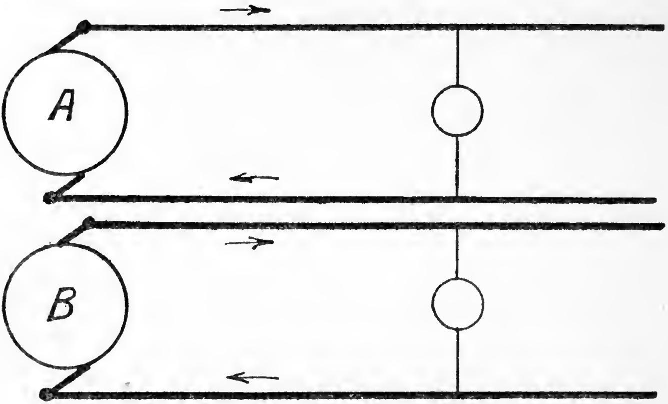


FIG. 43.

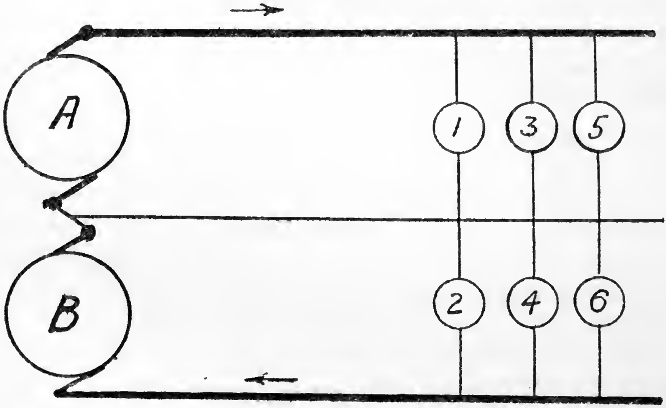


FIG. 44.

Diagrams showing how three wires are made to do the work of four.

dynamos are joined together "in series," that is, one behind the other, and when two dynamos are joined together in that manner they together generate the same quantity of current that either of them would do by itself, but at *twice* the pressure. Therefore these two will generate current at 220 volts instead of 110. In a similar way if two lamps, each of which needs 110 volts, be coupled together "in series" so that the same current passes through both, they will only use the same quantity of current that either would do by itself, but it will need to be at twice the voltage.

Suppose then we rearrange our lamps as at 1 and 2 (Fig. 44), the current will pass along the top wire through lamp 1, then through lamp 2, and back along the bottom wire. The two lamps will therefore be "in series," and will require current at 220 volts, exactly what the two dynamos "in series" are prepared to supply ; and they will only need one ampere for the two, whereas in the former figure, with the two dynamos working separately, they needed one ampere each.

Thus, in the first arrangement we need four wires, each capable of carrying one ampere, while in the second we light our lamps just the same, but only need two wires, capable of carrying one ampere each—a clear gain of the cost of two wires.

Of course, I have assumed, for simplicity's sake, a case in which two dynamos are employed to light two lamps only, a state of affairs which would not exist in practice, but which serves the purpose of illustration, for the principle which applies to two lamps applies equally well to two thousand, or any other number.

We have not yet, however, seen the purpose of the third (middle) wire. In order to see this, we must imagine some more lamps, joined up as at 3, 4, 5, and 6. If these are all switched on at once the condition of things is exactly the same as it is for 1 and 2 only, for current will pass along the top wire; one ampere will go through the lamps 3 and 4, and another through 5 and 6, exactly as the one ampere went through 1 and then through 2. Thus, so long as the two sets of lamps—those connected between the upper and middle wires, and those between the middle and lower—are taking an equal quantity of current, everything is exactly the same as in the simple example of the two lamps.

But suppose we switch one lamp out, say No. 4. The one ampere which passes through No. 3 will then be blocked, and will return through the middle wire to the dynamos. But the middle wire is not connected to the two dynamos "in series," but to the joint between them; therefore the current which goes through 3 and returns by the middle wire, will be generated by dynamo A only, and will be only 110 volts, the correct pressure for a single lamp. On the other hand if, instead of 4, one of the upper set be switched out, say 5, the current for No. 6 will be generated by dynamo B, and will flow along the middle wire and back by the lowest one. Thus, the duty of the middle wire is to carry to or from the dynamo (as the case may be), the difference in current, the amount by which the current consumed by one set of lamps exceeds that consumed by the other set, and as the lamps are always arranged so that this difference cannot be very much, the middle wire may be quite small.

Thus, we see, the work of four large wires can be done by two wires of the same size, and one very thin one, representing a considerable saving in a large installation.

In conclusion, reference may be made to a machine which may be noticed in many generating stations, and which is somewhat mystifying to a visitor. It is called a motor generator, and looks like two dynamos, or even three, placed side by side on the same base, apparently working each other.

Its purpose is this. There may be an outlying district supplied from that station, and, because of the resistance of the long cable, the current needs to be sent out at a higher voltage than that sent to the nearer districts. It is not worth while to have a special engine and dynamo to supply this one cable, so current from the other dynamos is taken and made to drive a motor, which turns a small dynamo so wound with wire that it generates the voltage required. Where the three-wire system is in use, the motor has to drive *two* small dynamos, and that accounts for there sometimes being three machines together.

CHAPTER XXIII

MEASURING TO A HAIR'S BREADTH

THERE is in existence a letter written by James Watt, in which he mentions, as a reason for gratification, that at his works at Birmingham they had just bored a steam-engine cylinder so accurately that it was not more than three-eighths of an inch out of a true circle. That gives us a measure of the degree of accuracy attained at that period, and it seems quite amusing at the present day, when it is quite an ordinary thing to work to one-thousandth of an inch.

The difference is due mainly to the vast improvements in the construction of the lathes and other machine-tools with which the work is done. This improvement also makes possible a degree of standardisation which is very important, but which was out of the question in the old days. Take, for example, a machine such as a steam-pump, of which there are many sent to the most out-of-the-way parts of the earth. It used to be the plan to "fit" each one up in the workshop, each piece being made to fit the parts with which it was connected. The cylinder would be bored, for instance, and then the piston turned to fit it, the latter being tried in the former to see that it was all right, and the same with the other parts. The workman made the parts to fit each other as he went on, and very beautiful work was done in this way, but there was one great drawback. Suppose one small but important part broke; the machine might be at a mine in remote Siberia, or the East Indies, but wherever it might be, the whole thing would probably have to go back to the makers to have that one part replaced.

Where a single machine is built, for some special purpose, the same old process necessarily obtains to a great extent; but, where the machine is made in numbers, it is nowadays almost always standardised. Each part is made "to gauge," and has a distinguishing number or code-word, so that a part to replace one broken can be ordered by telegraph and despatched immediately. This system also tends to reduce the cost of production, for special labour-saving devices can often be invented for producing the same thing over and over again; and, moreover, the men get more expert and quick when employed constantly on producing the same little part than they can possibly do if they have to make all the parts in turn. There is, of course, a disadvantage to be set against this. A workman, who sees a complete machine growing under his hand, naturally feels a greater interest in his work, and takes a greater pride in it, than one who simply turns out one particular part by the thousand.

Under these modern conditions, the putting together of the complete machine, which used to be called "fitting," is now more appropriately called "assembling," for the different parts come into the "erecting shop" all exactly alike and ready to put together, and very little fitting is required.

Now it is obvious that this system is only made possible by the use of very accurate measuring appliances. A workman used to have a steel rule and a pair of callipers, and that was about all; if he had to turn a rod 2 inches in diameter, he would set his callipers at 2 inches by his rule, and then proceed to turn the bar in the lathe, gradually reducing its size, and trying it frequently with his callipers until he found that they would *just* pass over it. In a modern lathe, however, intended for standardised work, he sets the tool which does the cutting in a certain way, and then, by turning a wheel, brings its edge up to the bar to be turned, and when it has advanced far enough a stop prevents it from going any farther. Thus the machine can be said to do the measuring itself; there is no need to use callipers, and, so long as the adjustment of the machine is not altered, it will go on turning bars exactly 2 inches in diameter.

Many machine-tools have "micrometers" attached to them, whereby their adjustments can be controlled with great accuracy. This instrument, as its name implies, is intended for measuring very minute distances. It consists of a very carefully made screw, turning in a suitable nut. Suppose that it has twenty-five threads to an inch; then if you turn it round twenty-five times, its point will advance or recede an inch; or if you turn it once, the movement will be one twenty-fifth of an inch. And suppose, further, that it is fitted with a large disc-like head, on the edge of which are marks dividing it into equal parts, say, for example, forty parts. We can then easily turn it exactly one-fortieth of a revolution, and it is quite clear that that will move the point of the screw one-thousandth of an inch. The micrometer takes many forms, but that is the principle of them all.

The accuracy of standard work is always tested by "gauges," usually called "limit gauges," the term limit implying that they reach the limit of accuracy. In the case referred to just now, of rods 2 inches in diameter, the gauge would consist of a little block of steel with a hole exactly 2 inches in diameter in it, and the rods would be tried by inserting them in that hole, which they should exactly fill. On the other hand, suppose we were dealing with small cylinders which had to be bored out to 3 inches diameter; then the gauge would be a steel plug, of exactly the right size, which would be inserted in them.

But it may be asked: Why, if the tools are so accurate, are these gauges necessary? The reason is that there may be faults even in the most perfect machine; the adjustment may be a little out, or some part a little worn; an instance of those difficulties, referred to in the opening chapter, which crop up in practical working, and which the pure theorist is apt to overlook.

Another form of tool, which is really a measuring device, is known as a "jig." These are made in innumerable forms, each one being specially devised for a particular job, but the idea underlying them can be made clear by a single example which came under my notice recently.

All readers will be familiar with what is called the "gear case" of a lawn-mower. It is the iron cover which encloses the tooth-wheels on one side of the machine. It is to start with a plain iron casting, just as it comes from the iron-foundry, and therefore it possesses certain irregularities common to all castings; yet it has to be fitted accurately to the side of the machine, for which purpose it must have holes which exactly coincide with corresponding holes in the other part, and it also has certain holes for supporting the ends of the axles on which the tooth-wheels turn, and these, too, must occupy the exactly proper positions relative to the other holes. The way it would be done, if a single machine were being made, would be to fix the position of one hole and then measure those of the others from it. The place for each hole would first be rubbed over with chalk, and the hole itself scratched on the white background, and finally the exact centre of the hole would be marked by hammering a little sharp-pointed punch into it and so making a little dent in the iron. Then the casting would be taken to the drilling machine and the holes drilled as nearly in the correct position as possible, the whole being a very laborious and therefore costly proceeding.

In the works referred to, they have a specially made iron box, into which the casting is placed and clipped in position with screws. Then a lid is placed on the box and fastened down. Now every hole that has to be drilled in the casting is represented by a hole in the box or lid, so that all that has to be done is to take the box to the drilling machine, and let the drill pass through each of these holes into the casting beneath. Thus all measuring and marking is saved, and the holes are all drilled in exactly the right places. The saving in time is obvious, the result is more accurate, and a less skilled man can do the work; moreover, since the same box and lid can be used again and again, each of the covers is bound to be, as far as its holes are concerned, exactly like the others. The box and lid form a "jig."

One of the most marvellous measuring appliances in the world has recently been invented and made for the Standards Department of the British Government. It is called a "comparator," since its duty is to compare yard measures with the "standard yard" and determine the difference, if any.

The imperial standard yard, which is the legal basis for all measures of length within the British Empire, is a bar of metal 1 inch square and 38 inches long, the metal being an alloy of copper, tin, and zinc. One inch from each end there is a circular recess, half-an-inch in diameter and half-an-inch deep, in the centre of the bottom of which is fixed a little gold plug. On the plug are engraved five fine lines—three vertical and two horizontal; and the distance from the centre one of the vertical lines at one end to the corresponding line at the other end, at the temperature of 62° F., is one yard. This is within one two-hundredth of an inch of the standard yard of Henry VII., still preserved at the Standards Office.

The whole apparatus is most complicated; but, put briefly, this is how it works. There is a sliding table, on which the standard yard is placed. Over each end of this there is a microscope, so mounted that it can be moved by a very fine screw adjustment until the line on the standard bar comes exactly between two threads of spider's web stretched across the lens. When both microscopes are thus adjusted, the standard is taken away, and the bar which is to be compared with it is put in its place. The table upon which it rests is then moved by a screw until the mark at one end of the bar is exactly under the microscope at that end. Then the other end mark is examined through the other microscope, and, if it comes between the spider lines, it is correct; but, if not, then the microscope is moved until it does so. The distance, then, that the microscope has to be moved is clearly the difference between the standard and the bar being checked.

A machine on these lines, in which the travel of the microscope is measured by a micrometer, is in no sense new; but in this case, instead of the turns of the micrometer screw, a wonderful natural scale, formed by the decomposition of a beam of light, is used. The divisions in this marvellous scale are about $\frac{1}{40000}$ (one forty-thousandth) of an inch apart—I put the fraction in words lest readers should think the printer had added a nought in error.

A beam of light, usually from glowing hydrogen, is first passed through a prism, in order to disperse some of the rays and bring into use just those selected for the purpose. The beam of this selected light is then allowed to fall upon and be reflected by two pieces of glass. The explanation of what happens belongs to a work on light, and it must suffice to say here that the result of this reflection is to produce, in the field of view of a small telescope fixed near by, a brightly illuminated background crossed by vertical dark lines.

Now, one of the pieces of glass by which the light is reflected is fixed to the microscope, and, as it moves, these dark lines pass like a panorama across the field of view of the telescope. There are two spider lines across the lens of the telescope, and with their aid it is quite easy to count the number of lines that pass; and it follows from the laws of light, and the way the instrument is arranged, that half the number seen to pass the centre of the telescope, multiplied by the wave-length of the light used, will give the movement of the microscope. By this means the minute fraction of an inch mentioned just now can be measured easily, and, as the distance apart of these dark lines depends absolutely upon the "wave-length" of the light, the wave-length of light becomes a standard of length which may be of great value in years to come.

There is a man, only one man in the world apparently, who can rule fine clean straight lines, with a sharp diamond, a forty-thousandth of an inch apart—the mark on the British Standard Bar, although fine to the naked eye, covers forty-five of these lines—and it is thought that by using a measure ruled with these fine lines, in conjunction with this machine, the length of the yard and the metre can be measured and expressed in terms of the wave-length of light; so that if, for any unsuspected reason, there should be any slow shrinking or expansion taking place in the standard bars in London, New York, and the other capitals, this may furnish, as time goes on, a means of discovering it.

The part of the comparator where the dark lines are formed is called an "interferometer," and the lines themselves "interference lines," since they are caused by the waves of light interfering with each other.

From the above rather theoretical piece of apparatus (for one cannot avoid the reflection that, for most purposes, the fact that a measure may be a few forty-thousandths of an inch out is of no practical moment whatever) we can turn to one of great practical utility, a sounding-machine by which, as it goes along, a ship may "feel" the bottom of the sea and so avoid dangerous shallows. A form of this apparatus commonly used, known as "Wigzell's," after its inventor, takes advantage of the fact that the pressure of the water of the sea depends upon the depth. At the surface it is nothing, but as one descends it becomes greater and greater owing to the weight of the mass of water lying above. This machine, then, is a little cylinder with a piston in it, the latter being held back by a silver spring. When it is lowered into the water, the pressure forces the piston in against the pull of the spring, and the distance it moves depends entirely on the amount of the pressure, and therefore on the depth. The full extent that the piston moves is recorded by a little sliding indicator which it pushes along, but leaves behind when it returns to its normal state, as it is drawn to the surface. From this the depth is read, and the indicator can then be pushed back to "zero," when the instrument is at once ready for use again.

A somewhat similar device, invented by the famous Lord Kelvin, consists of a tube of glass, coated inside with a chemical which changes colour if brought into contact with sea-water. This is lowered into the sea, and the air in the tube becomes compressed, according to the pressure of water. The distance that the water penetrates up the tube, therefore, represents the depth, and this is recorded by the discolouration of the chemical with which it is coated.

Speaking of appliances used on board ship brings to mind a rather curious little appliance for automatically weighing the cargo on a ship. In the centre of the vessel there is a vertical pipe, or shaft, open to the water at the bottom end. In this there is a float which is connected with an apparatus, something like an ordinary weighing-machine, on the deck. Of course the water rises in the shaft as the vessel sinks down under its load of cargo, and the float striving to rise, too, indicates the weight on board. It seems at first sight as if this would do just as well hung over the side of the boat; but then it would be interfered with by waves, currents, and the movement of the vessel, whereas in this small central shaft the water is quite still, except for the up and down motion due to loading and unloading.

The name of this appliance is "porhydrometer," and it is mainly useful on barges and such small craft. It is so delicate that, on a 200-ton ship, a man stepping on or off will make a difference.

The measuring of water is, of course, an important matter, especially in places where it is scarce and expensive. At waterworks there is usually a meter known by the name of "venturi," which records automatically on a strip of paper the rate at which the water is flowing out. The principle on which it works is curious and interesting. In the main pipe there is placed a narrow neck, and it follows that the water has to flow more quickly through this neck than it does in the main pipe. Now, observation of such a common thing as the water issuing from an ordinary garden-hose will show us that water in rapid motion behaves differently from water which is still or moving slowly. The water in the hose-pipe is under pressure, and is trying not only to pass along the pipe, but to burst it;

in other words, it is exerting forces in *all directions.* The water which issues from the nozzle, on the other hand, has force in one direction only—namely, the direction in which the nozzle is pointed, and that is how it comes about that we can direct the jet where we want it to go. The "all-direction" force in the pipe is due to the pressure, and the "one-direction" force in the jet is due to the velocity at which the water is travelling. When water is still and under pressure the force in all directions is quite uniform; but, as soon as it moves, the force due to velocity begins to grow (in one direction) and the forces due to pressure correspondingly diminish.

Thus, when the water rushes at increased speed through the neck in the pipe, the pressure at that point becomes reduced because of the increased speed. Indeed, the reduction in pressure bears a definite proportion to the speed. Therefore, if a pressure-gauge be connected to the large part of the main, and another to the neck, they will show different pressures, and the difference will indicate the rate at which the water is flowing through the neck.

This meter, then, consists simply of a suitable gauge for measuring this difference, and recording it by a movable pen upon a moving strip of paper.

That tells the flow in gallons per hour, but there are meters of another kind which register the actual number of gallons which pass. These are mostly constructed like little steam-engines, with a cylinder, or cylinders, and pistons. The water drives them as it passes through, and the number of revolutions, of course, tell the quantity which has passed. A clockwork mechanism counts the revolutions and records the quantity on a dial.

Electricity is generally measured by the magnetic force which it generates. Every conductor becomes a magnet while current is passing through it, and the strength is in proportion to the volume of the current. The magnetism is distributed along the whole length of the conductor, and at any one point it is consequently very small; but by winding the conductor round into a coil, insulating it of course so as to prevent the current taking a short cut from one turn to another instead of travelling the whole length of the conductor, we can concentrate a good deal of it within a limited area. We can concentrate it still further by putting an iron core in the middle of the coil, when practically the whole of it will be manifested in the core, and that is how an electro-magnet is built up. Within certain limits, however, the fact remains that whether it be a single straight wire or an electro-magnet the magnetic power will be in proportion to the quantity of current passing. If, then, we take an electro-magnet and place near to it a piece of iron, or another magnet which is able to move except that it is held back by a spring, the amount by which it is pulled and the spring stretched will tell us the quantity of current flowing. That is the principle of the ammeter, the instrument which shows the number of amperes.

Now we know, from an earlier chapter, that the quantity of current which flows against any given resistance depends upon the pressure. Consequently, if we couple together an instrument like an ammeter with a coil of fine wire offering a high resistance, and let current pass through both in succession, the instrument will tell us the quantity which passes, and if we know the amount of resistance we shall be able to tell the pressure.

This can be made clearer by an example. Suppose we want to find the pressure of the current flowing in a wire. We tap that wire at some convenient point by connecting another branch-wire to it, and we lead the current from the branch to an ammeter, and thence through a resistance-coil back to the return (or negative) wire, or to the earth if there is not one. Suppose, too, that we make the resistance-coil of such a size that the total resistance in the branch circuit shall be 200 ohms. Then we look at the ammeter and see that one ampere is passing. Now one volt pressure acting against one ohm resistance, causes a current of one ampere; therefore, to produce one ampere against 200 ohms must need 200 volts, from which we see that the pressure in the main wire must in this instance be 200 volts. As a matter of fact, the instrument would in practice be so marked as to show us the number of volts straight away. A voltmeter, therefore, is the same as an ammeter, except that the dial is marked differently and it is not connected up in the main circuit, but in a branch (or shunt, to use the technical term) in series with a resistance.

An ohmmeter is the converse of a voltmeter. A current of known pressure is generated by a battery or small dynamo, and the quantity which flows through any circuit, under the influence of that pressure, shows the resistance of the circuit.

There is another common unit of measurement used for electricity, the "watt," which represents the actual amount of work that the current is capable of doing. It is found by multiplying together the current strength in amperes and the pressure in volts. For instance, 50 amperes at 200 volts is 10,000 watts, or, as it is often expressed, 10 kilowatts. This term is often used to express the size of dynamos. To say a 200-volt dynamo, would convey no idea of the size of the machine, nor would it be any more definite to call it a 50-ampere dynamo. Call it 10 kilowatt, however, and you give its size at once—its coils may be wound with wire in such a way as to produce 100 amperes at 100 volts, or 20 at 500, but it will be the same size of machine, will require the same power to drive it, and will do, theoretically at any rate, the same amount of work either in lighting, heating, or driving. The name "Watt" is given by way of a tribute to the memory of the father of the modern steam-engine.

A thousand watts (or a kilowatt) for one hour constitute the Board of Trade unit by which electric current is bought and sold. It is measured by electricity meters, which are really small and very feeble electro-motors, just powerful enough to turn a clockwork counting mechanism, and arranged so that the speed shall vary with the current.

This chapter could be prolonged almost indefinitely, but I must mention some very interesting devices for measuring heat in places where an ordinary thermometer would be useless.

Take the case of the upper part of a blast-furnace. No ordinary thermometer could survive the heat there, nor could any one get near enough to read it, but it so happens that the electrical conductivity of a wire varies with the temperature. If, then, a wire, through which electricity is passing, be introduced into the furnace, the reduction in the current will indicate the increase in resistance which in turn tells the heat.

If two wires of different metals be joined together into a loop, and the heat at one of the joints be raised above that at the other joint, a current of electricity will be generated in the loop. The amount of that current will vary, too, in proportion to the difference in heat between the two joints, forming another means by which the heat at some inaccessible spot can be measured and read off at a safe distance. Of course these methods are both useless in such a place as the furnace itself, since the heat would destroy the wire, but they are often very useful.

The heat of a powerful furnace is sometimes ascertained by the simple but effective method of placing in it a series of bars made of different alloys, and noting which of them melt and which resist the heat.

The last measuring appliance which I propose to refer to is that for ascertaining the power of a steam-engine. It is called a steam-engine indicator, and consists of a small cylinder with a piston inside it held down by a spring. The lower end of this small cylinder is connected by a pipe with one end of the engine cylinder, and the pressure of steam in the latter lifts the small piston against the force of the spring. The extent to which the small piston is moved by the steam indicates, of course, the pressure of steam in the engine cylinder, and by an arrangement of levers this movement is made to draw a diagram on a moving piece of paper. In other words, the engine is made to write down its own character.

From this diagram it is easy to calculate the pressure per square inch which the steam exerts against the piston in the engine cylinder.

Now the power of a steam-engine is usually stated to be so many "indicated horse-power," and a horse-power is the power required to lift 33,000 lbs. one foot high (or the equivalent) in a minute. Thus, suppose we had an engine the area of whose piston was 100 square inches, and the indicator showed the pressure to be 60 lbs. per square inch, the steam would obviously push the piston with a force of 6000 lbs. Suppose, further, that the piston moves a foot at each stroke and makes 200 strokes per minute, it will then move 200 feet in every minute.

Therefore, we can see that this engine will do work equal to lifting 6000 lbs. 200 feet in a minute. This would be spoken of as 1,200,000 *foot-pounds*, and, since 33,000 foot-pounds make one horse-power, the power of our engine would be 36½ horse-power.

Gas-engines, and occasionally steam-engines, are described as being of so many *brake* horse-power (often written B.H.P.), in which case a brake is applied to the fly-wheel and the actual amount of work which the engine is capable of doing is calculated by that means.

CHAPTER XXIV

LIFTING AND CONVEYING MACHINERY

POLITICAL economists tell us that all labour, other than mental, consists in moving matter from one place to another. If this is so, it is evident what an important part in the economy of the world must be played by those appliances whose chief purpose is the lifting and conveying of goods and materials. Nothing, too, serves to illustrate more clearly the recent progress of engineering than the rapid development of this class of machinery.

It will be interesting to start with an appliance the usefulness of which is specially appreciated by the general public—the passenger-lift. Not long ago there were but few of these and they were nearly all hydraulic, but to-day they are everywhere and most of them are electric. This is not unnatural, for electricity is to be had in most places from a public supply, while hydraulic power generally necessitates a steam-pump and a large hydraulic accumulator. The compact little electric motor, too, is much more easily found room for than the long hydraulic cylinder. Electricity, moreover, makes safeguards possible which were unknown in the older lifts. A modern "push-button" lift, for example, may be left entirely unattended, and a child may play in it with safety. For the car will resolutely refuse to move until all the gates are shut, and no gate will allow itself to be opened unless there is the car just level with it. If you are on a floor where the car is not, you push a button, and in a few moments the car comes to your floor and stops for you. Then you open the gate and enter. After closing the gate behind you, you push one of a row of buttons in the car, one for each floor, and the car then goes up or down as the case may be, to the floor whose button you pushed. If you and another man push buttons simultaneously, the lift does not hesitate, but serves the one who, according to a prescribed "table of precedence," has the first claim. A scheme such as this, while by no means difficult to arrange with electricity, would be almost impossible with any other power.

The precise method by which these automatic lifts are controlled is too intricate to describe in detail, but the general principles can be briefly illustrated. The motor is started and stopped by a controller, a piece of mechanism with which we are already familiar, only instead of being operated by hand, like the controller of a tramcar, for example, the lift-controller is worked by a series of magnets which are energised by the currents which pass through the "push-buttons."

The current from each button passes through a switch on each of the gates, which is only making contact when the gate is properly closed. If any one of the gates is open, therefore, all the buttons are thrown out of operation, for no current can pass from them, and the car cannot be moved. At the same time there is a lock on each gate which is only released by the car standing opposite to it.

The actual lifting and lowering mechanism of an electric lift is fairly simple. The motor turns a screw, the threads of which engage in the teeth of a tooth-wheel. This combination of a screw and a tooth-wheel constitutes what is known as "worm-gearing," the screw being the "worm," a name probably derived from the wriggling appearance which it presents when it is revolving. The wheel, in turn, drives a small barrel, around which wire-rope is wound. One end of this rope passes over a wheel and supports the car, while the other end passes over another wheel and supports the balance-weight. When the barrel, then, is turned (in one direction) it winds up the car, and it is assisted by the balance-weight pulling at the other end of the rope. Consequently, it only has to lift the amount by which the car and its load exceeds the balance-weight. When turned the other way it lifts the weight and lowers the car.

As a matter of fact the motor often has to exert its power in order to bring the car *down*. It would appear to be the correct thing to make the weight just balance the car, so that all the motor would have to do would be to lift the load in the car. The practice, however, is to make the weight balance the car and half the maximum load as well. This is a very clever device, the advantage of which can best be made clear by an example. Suppose a car weighs half a ton and the maximum load is 6 cwts., and let us take the case of a full load going up and the car coming down again empty.

If the weight balances the car, the motor has to lift 6 cwts. on the up journey, and on the down journey it has to lift nothing.

Now see the difference if half the load is balanced as well. The motor then has to lift only 3 cwts. on the upward trip, but it has to lift 3 cwts. of balance-weight as the empty car descends. The same total amount of power, then, is expended, and it may well be asked: Where does the advantage come in?

In the first case the motor may be, and often is,

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A "TITAN" CRANE

It is being used in the construction of a breakwater. It is in the act of handling one of the huge concrete blocks of which such structures are built.

called upon to lift 6 cwts., but in the second case it can never be called upon to lift more than 3 cwts. Consequently, a motor of approximately *half the size* will do. The net result of this ingenious arrangement is, then, that at a cost of 3 cwts. of balance weight (a mere nothing) a considerable saving can be effected in the cost of the motor and gearing, and the whole concern is materially cheapened.

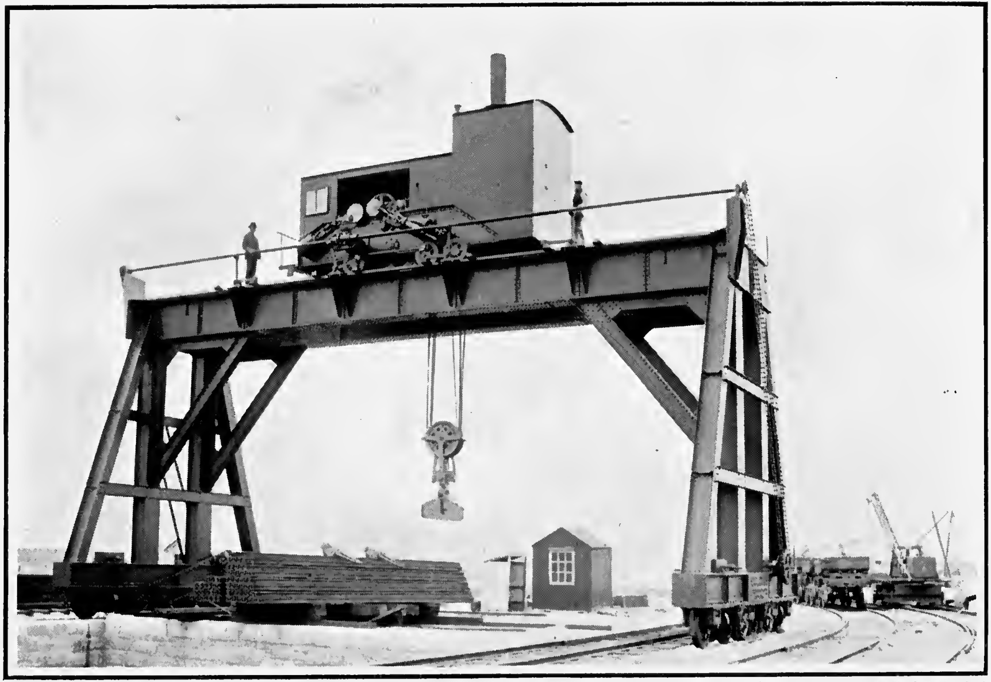
Nervous passengers may be comforted to hear that there are ample safeguards against accidents in all passenger lifts. The car, it will be noticed, slides between two guides, and there is a powerful spring clip which grips these. It is only the pull on the ropes which keeps this clip open, so that if they should break, the car would not fall to the bottom, but would be instantly held stationary by this clip.

Of cranes there is an almost endless variety, many of them designed and constructed for some special purpose. An interesting example of these is the "Titan" crane, largely used for setting the concrete blocks used in the construction of breakwaters. One of them is shown, facing page 320, actually lowering a block into position.

Modern breakwaters are almost always built of these concrete blocks. They are made of shingle and Portland cement cast in a wooden mould, and are brought to the site either in barges or on trucks. They are very large, weighing perhaps 50 tons each, and are built up into the wall just like huge bricks, so that we may look upon these "Titan" cranes as gigantic mechanical bricklayers. Now cranes capable of handling such heavy weights as 50 tons need a firm support to stand upon, and the great advantage of this type is that it can stand upon that part of the wall which is already finished. First there is a very strong carriage, which runs upon railway wheels, so that it can be moved forward as the work proceeds. This carriage supports a great horizontal beam, one end of which stretches out a long way, while the other end overhangs but little. On the long end there are rails, upon which runs a small but very strong truck, from which depends the rope which lifts the blocks. At the other end is a heavy weight, frequently a mass of concrete, to balance, partially, the weight of the block, and for the same reason the engine, boiler, and machinery are placed there also. The great beam, with its balance weight, machinery, and its load too, can swing right round as if it were pivoted upon the top of the carriage.

Its method of working is this. First it lowers a diving-bell on to the sea floor, the workmen inside the bell levelling the ground and making ready for the block. Then the bell is drawn up and the massive arm swings round to pick up the block. It stops over where the block is, either in a truck on the breakwater behind it or in a barge alongside; the truck on the beam is run out or drawn back (of course all the movements are done by the steam-engine) until it, too, is over the block, and then the rope is let out and hooked on. Quickly the 50-ton mass of concrete rises in the air, the arm swings round, the truck travels to the correct position, and down goes the block into the water, just in the right place, to be finally adjusted by divers working below.

It is obvious, however, that only one of these cranes can work at a time on one breakwater, so where it is very large two parallel "gantries" are built—long, narrow stages, one on each side of where the breakwater is to be. They are constructed of piles and beams, and along the top of each is a line of rails, supporting several cranes of another kind, known as



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A "GOLIATH" CRANE

The steam-engine on the top can lift a load, traverse from side to side, and also move the whole structure to and fro upon the rails.

"Goliaths." These consist each of a pair of girders, placed parallel to each other, and supported at their ends upon legs which have wheels capable of running on the rails. The girders therefore span across the site of the breakwater, one end resting by means of its "legs" on each of the "gantries." On the girders there is a truck supporting the winch which raises and lowers the blocks. The winch on its truck can travel to and fro along the girders, and the whole structure can travel along the gantries, so that the winch can be brought over any desired spot. These cranes can be driven by steam-power or electricity, whichever is most convenient, and several of them can work simultaneously at different positions along the same gantry.

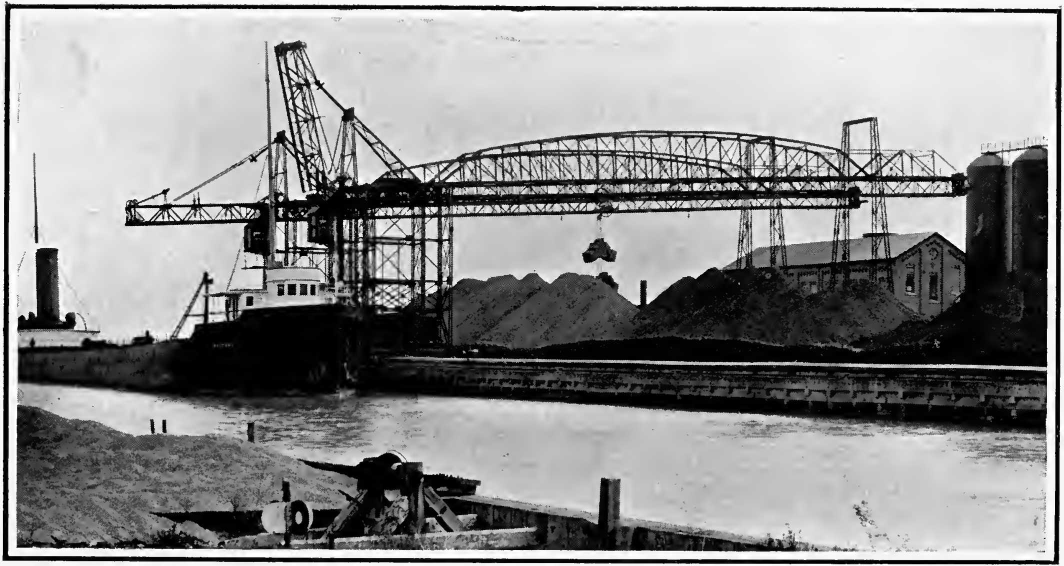
A similar crane, but without the legs, its girders resting directly upon wheels which run on the gantries, can be seen in most factories where heavy objects have to be moved frequently, and in most engine-houses for handling the heavy parts of the engines during erection or when under repair. These cranes are called "overhead travellers." They are being largely used, too, in shipyards, the two gantries being placed one on each side of the ship under construction, so that the cranes can quickly haul up plates, ribs, or other parts, and place them in position. They can also be used for holding the hydraulic riveting machines. Several overhead travellers can work on the same pair of gantries.

A very useful form of lifting appliance is the "transporter," which is very largely used for loading and unloading ships with such cargoes as coal and ore. It consists of a long steel beam, supported upon tall trestles. On this beam there runs a small trolley, which is hauled backwards and forwards by machinery at one end. From this trolley hangs a rope, to which can be attached a bucket or a "grab." One end of the beam is often made to overhang the water, so that the trolley can run right out over the ship and lower the grab or bucket right down into the hold. Then when it is filled it is hauled up, and the trolley runs back with its load towards the other end of the beam. These work very quickly, and all the movements are easily controlled by one man, who is stationed in a small cabin placed at a suitable spot, where he can observe easily what is going on.

Sometimes a rope is used instead of a beam, and the apparatus is then called a "Blondin." One of these was much talked about some years ago in connection with the erection of the bridge over the Zambesi near the Victoria Falls. A great part of the material used was carried from one side of the river to the other by this means.

This brings us to what is perhaps the most wonderful conveying appliance in existence, of course excepting the railway—the aerial ropeway. Districts which can scarcely be traversed by any living creature, and which are so mountainous and rugged as to be quite impracticable for an ordinary railway, are crossed quite easily by these "railways in the air."

Essentially a ropeway consists of a long wire rope, with its two ends spliced together so as to form an endless loop, which is stretched round two large wheels or drums and supported at intervals on smaller wheels. The large wheels may be several miles apart, and, one of them being turned round, the rope is made to travel at a rate of about four or five miles per hour. Buckets are hung upon this moving rope at intervals—not attached to it, observe, but simply hung on, by means of an ingenious clip. This clip keeps them from slipping off or sliding along even when, as is often the case, the rope rises at a very steep angle, yet it lets go



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TWO TRANSPORTERS

One of them is idle; the other is unloading iron ore from the ship and placing it upon the store-heaps. The "grab," the huge hand which picks up the ore, has just opened and let its contents fall upon the heap. It is seen hanging from the middle of the Transporter.

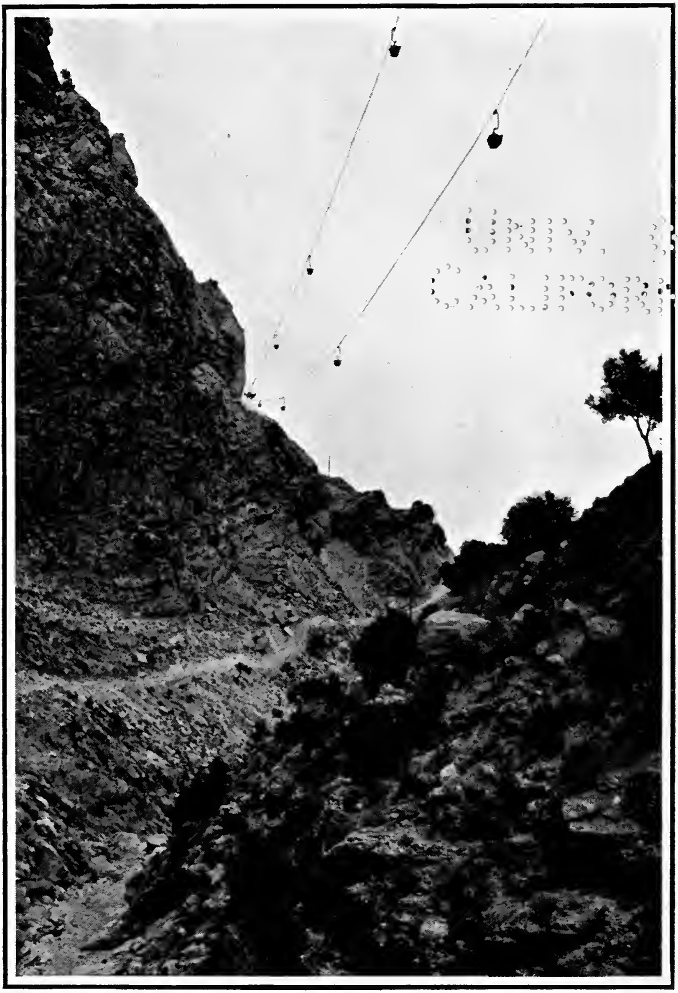
the rope instantly, when the bucket reaches the end of the journey.

Each of the large wheels is mounted in a substantial framework, known as a "terminal frame," and one of them is adjustable, so that the rope can be pulled to the requisite degree of "tautness." The frame also supports a "shunt rail," a sort of siding on to which each bucket as it arrives is shunted, to be loaded or unloaded, as the case may be. The "hanger" by which each bucket is suspended not only carries the little clip already referred to, but also two small grooved rollers. The shunt rail is in the form of a loop, one end of which forms a junction with the incoming part of the rope and the other with the outgoing part, and the rope is so guided by wheels that just as it passes the first junction it dips down and leaves the bucket supported, by means of the rollers, on the shunt rail. The bucket is loaded or unloaded, and then pushed along by hand to the other junction, where it runs on to the outgoing rope and is carried back to the other end. Thus the buckets come in in regular succession, and, as regularly, are sent back.

Between the two terminals the rope is supported by wheels fixed on tall trestles of steel or timber. The wheels have grooves in them in which the rope runs, deep enough to keep it from slipping off, but not so deep as to interfere with the clips which grasp the upper side of the rope.

Although buckets have been referred to above, other receptacles can be used instead if the material to be conveyed necessitates it, such as cradles, for example, for carrying timber. Ropeways, moreover, do not always require to be driven. Sometimes when the loading end is higher than the unloading end, the loaded buckets descending on one side pull up the empty ones the other side. Nay more, when the difference in level is great enough, the ropeway may actually have energy to spare which can be used to drive other machinery.

Some of these lines are as much as 10 miles long.



By permission of *Ropeways, Ltd.*

AN AERIAL ROPEWAY

It is shown crossing a wild rocky valley where other means of transport is well-nigh impossible.

CHAPTER XXV

PROTECTION FROM FIRE

In the original scheme of this book I did not put down this subject, but one afternoon, while engaged upon one of the earlier chapters, I chanced to look out of the window and perceived an unusual glare in the sky. Soon great masses of flame became visible, and it was evident that a serious fire was in progress not far away.

It turned out to be a very large block of shops filled with drapery, furniture, and other inflammable matter, and situated amid rows of houses, and actually adjoining some. When I reached the scene of the fire, the whole block of buildings was blazing from top to bottom. The heat could be felt a hundred yards away, and there seemed to be no hope whatever of saving the adjoining houses.

Yet within an hour the fire was practically out and the houses uninjured.

This struck me as being such a remarkable triumph for the engineer, in the extinguishing appliances, that I decided to include this chapter. If, however, the building had been built on modern "fire-resisting" principles, the fire would probably never have reached serious proportions at all.

In large buildings, the framework is almost always mainly of iron or steel. Where space is scarce and of fabulous value, as it is in some populous cities, the buildings cannot be extended horizontally, so they have to expand upwards. The number of floors must be increased. Now, every extra floor means more weight to be supported, and if brick walls were the only supports available a very tall building would be impracticable, for the walls would need to be so thick that there would be scarcely any useful space left at the ground level. The high building, therefore, called into being the steel frame, in which each floor is formed of a network of steel girders supported on vertical steel columns, the brick walls having little to do except to keep the weather out.

Now, strange as it may appear, a heavy beam of wood resists fire better than a steel girder. The surface of the wood beam becomes burnt, leaving a layer of charred wood which protects the rest of the beam. Thus while it is weakened somewhat, it still retains, in all probability, sufficient strength to do its work. Steel, on the other hand, if unprotected, while it does not burn, becomes so softened by the intense heat of a great fire, that it bends like lead. After the fire referred to just now there were to be seen heavy steel beams bent into the most fantastic shapes, showing how they had been softened by the heat.

A steel-framed building is not therefore necessarily fireproof; to make it so the steelwork must be protected in some way.

The use of iron "joists" for forming the floors came in before the time of steel frames, and it was soon followed by the use of concrete to fill in between them. The concrete, however, did not always require to be as deep as the joists, and so the under side of the latter was left at the mercy of a fire on the floor below. To get over this difficulty several patent systems were invented, most of which used firebrick tiles, which spanned the space between the joists, and not only supported the concrete of the floor until it had set, but also covered entirely the under side of the joists, forming in some cases a clear space underneath them, so that the fire should be effectively prevented from touching the iron. The concrete, by the way, which is used for fireproof floors is often made of "coke breeze," as it is called—fine coke—which, strange to say, on being mixed with cement ceases to be a good fuel and becomes an excellent fire-resisting material, while its weight is considerably less than other kinds of concrete.

After that, it soon became the custom to encase the iron uprights as well in some fireproof material—frequently concrete—resulting in the complete fire-resisting buildings of the present day.

Meanwhile, from other causes, another kind of building material had come to the front, which, in addition to its other qualities, is perfectly fire-resisting. It is known as "ferro-concrete" or "reinforced concrete," and is steel and concrete in intimate combination. It may seem strange to call this new, for concrete was known to the ancients, and iron has been used in buildings for years. They had been used together, too, as in the concrete floors described above, but they had never been used *in combination*, so that under those conditions they formed what may quite correctly be called the newest building material.

As explained in the chapter on bridges, the strength of a beam consists in the power of its upper part to resist compression and its lower part to resist tension. Now concrete is excellent for the former purpose and steel for the latter, so that a beam made of concrete, with steel bars embedded in its lower part, to resist the tensile stresses, is very strong. When loaded it exhibits a remarkable degree of elasticity, bending slightly, but returning to its original form when the load is removed —a condition of things which is absolutely necessary in any lasting structure. It appears to be subject to no form of decay, for the cement has the power of completely preserving the steel from rust; indeed if the bars be rusty when put in, the cement combines chemically with the rust and entirely removes it: very different from the action of paint, for if paint be put on rusty iron the rusting process still goes on under the paint, and is all the more serious because it is unseen.

Ferro-concrete is also, as has been said, perfectly fire-resisting, and as it is built up continuously a building constructed of it becomes what is called "monolithic," one single piece of ferro-concrete, without a joint, from top to bottom.

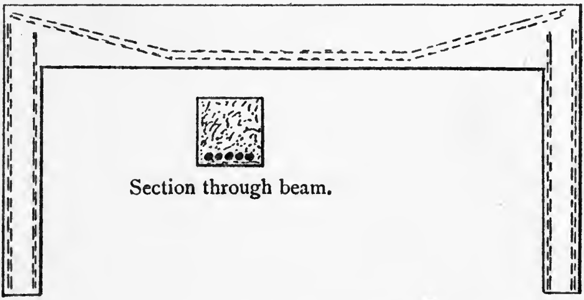


FIG. 45.—Reinforced concrete beam, supported on two reinforced concrete columns; the dotted lines show the "reinforcement" of steel rods.

Wooden moulds have to be constructed in which to form the various parts. When it is a beam, the steel bars are laid in the bottom of the mould and the concrete filled in around and above them. The uprights are made in just the same way, except that the bars are placed at the corners. Each part is thus moulded in position, and when the concrete has set the timber is taken away. There are several special forms of bars used for this purpose, the idea being to give them such a shape that the concrete will grip them securely; but it seems as if smooth round steel bars answer as well as anything, the cement having a power of adhesion to smooth steel which is positively astounding.

Thus we see that a modern "fire-proof" (or, to use a more accurate term, "fire-resisting") building has all its floors, main walls, and supports formed in such a way that not only will they not burn, but they will not be seriously weakened by heat. The interior fittings may be of wood, and the rooms may be filled with inflammable material, but should they catch fire the building itself will stand secure, and most probably the fire can be confined to the room in which it starts.

When the fire is thus hemmed in by walls and floors of fire-resisting material, there is still need of fire-extinguishing appliances to put it out. A device of this nature which is often installed in factories and warehouses is called a "sprinkler." It consists of a nozzle fixed in the centre of the ceiling, if the room is a small one, or several distributed about in the case of a large room, connected by pipes either to a tank high up upon the roof, or in which water is stored under pressure. Normally each nozzle is closed by a specially devised plug, which is held in place by a piece of lead or some similar metal. As soon, then, as a fire breaks out in the room, it melts the lead, the plugs are released, and each nozzle sends forth a spray of water, drenching the whole contents of the room, and quickly extinguishing the fire.

Many buildings, too, are fitted with fire-alarms which automatically call the fire-brigade. There are different varieties of these, but one will illustrate the principle on which most of them work. Imagine an ordinary mercury thermometer, but with two wires penetrating the glass tube. One of these is low down, so as to be always in contact with the mercury, while the other is higher up, at say 100°. Thus they are normally disconnected, but as soon as the temperature of the room rises to the prearranged limit, the column of mercury reaches the higher wire and connects the two electrically. This completes a circuit, and so permits current from a battery to flow, ringing a bell or other alarm.

But the best-known and most interesting of all fire-appliances is the fire-engine. He must be a very phlegmatic person who does not feel a thrill when he hears the shouting of the firemen, and sees the engine gallop past. Indeed, some people appear to be so moved by the sight, that they cannot help running after the engine, though they cannot possibly keep up with it, and the fire may be miles away.

The galloping horses, however, are gradually being superseded by self-propelled engines, either steam or petrol, and the hoarse cries of the men are giving place to a loud-mouthed bell.

The horsed fire-engine is still used, though, to a very large extent, and deserves a description. It is a beautiful piece of engineering, combining great power in a very small compass. There is a tiny boiler, which is heated by a coke fire. Behind it is a beautiful little two-cylinder vertical engine working two pumps. Both engine and pumps are small, but they work at a high speed, and so get through a large amount of work. The two large brass vessels which form such a conspicuous feature on a fire-engine are air-vessels, whose duty is to act as spring buffers, and equalise the flow of water, as explained in an earlier chapter.

The engine stands in the station with the fire all laid ready for lighting. The harness is all attached, and the horse-collars are suspended from the ceiling by cords. These collars are in halves, hinged together at the top and open at the bottom, so that they hang like an inverted letter V, and do not need to be put over the horses' heads, but simply drop on to their necks, and all that has to be done is to close the two lower ends and fasten them together under the horse's chin, as it were. Each horse stands in a stall on its own side of and within a few feet of the engine; thus a few seconds suffice to lead out the horses, drop the collars on to them, fasten the latter, and then all is ready. The rushing through the air fans the fire, and in a few minutes steam is up.

The steam *motor* fire-engine is very like the horsed engine, except that its engine (using the word in its proper sense) is normally connected to the wheels, but by a simple arrangement can be quickly disconnected on arrival at the fire, and connected to the pumps. Thus the same mechanism which pumps the water propels the vehicle to the scene of operations.

It is clear that an engine of this type must always have steam up ready to start. The fire is not lit, however, only laid, but the water is kept hot at the station either by a large gas burner or a special stove.

The very latest type of all is the petrol fire-engine. This is really a very strongly made motor-car, able to withstand plenty of rough travelling without likelihood of breaking down, with a pump mounted upon it. On reaching the fire the motor is disconnected from the wheels and connected to the pump in a few seconds—more quickly, in fact, than the hose can be got out and coupled up.

Some fire-engines carry what are called chemical cylinders, by which a jet of water can be thrown instantly the fire is reached, without having to wait for the hose to be connected to the water-mains. The cylinder itself is full of water, and to start the jet a chemical is mixed with it. This, combining with another chemical already in the water, causes carbonic acid gas to be given off. The evolution of the gas creates a pressure in the cylinder enough to force the jet to a considerable height. Such a jet is a better fire-extinguisher, too, than ordinary water, for it contains carbonic acid gas dissolved in it, and this gas, as is well known, itself has a damping effect on fire.

The hand fire-extinguishers which are often hung up in public buildings for use in an emergency are constructed on this principle. They contain water and a glass vessel holding the chemicals. The latter has to be broken by a blow, and then the apparatus is ready to work.

CHAPTER XXVI

THE CONQUEST OF THE AIR

SINCE ancient times man has desired to emulate the birds and insects by flying in the air, yet only within the last few years has the feat been accomplished. The final battles in the struggle between man and the air have been decided, too, with astonishing suddenness, so that quite young people can remember the time when "to fly" was the proverbial equivalent for the impossible; yet now almost every day sees fresh records being made in this astonishing sport, and before long, no doubt, it will pass from the stage of a sport for the adventurous, and become one of the recognised features of our daily life.

The means, too, by which success has been achieved, is quite opposed to the well-worn theory that if a man wants to do a thing he must imitate Nature, for the flying-machine has in many of its features no counterpart among the birds and insects. It is true that there is a certain resemblance between a monoplane and a bird, when it is soaring with outstretched wings, but there is certainly no natural biplane nor is there any revolving propeller in Nature, or indeed any rotary motion at all, except in certain very low forms of insect life.

Thus we are face to face with a very curious problem. If man's ways of flying are the best, how is it that Nature has not adopted them? or on the other hand, if Nature's ways are the best, why does not man copy them? This is a very interesting subject for reflection, and the answer seems to lie along one of two lines, or perhaps along both.

Nature's appliances are for all-round use, and, looked at from that standpoint, they are unrivalled. As a machine for running, walking, jumping, crawling, and swimming, there is nothing to compare with the legs of a lion, for instance. They will take their owner over rough places as well as smooth, up steep hills, and also along level ground, up trees and precipices if need be. For all-round purposes it would be almost impossible to improve upon them, yet for travelling along a smooth and level road the inferior strength of a man *on a bicycle* can rival the speed of the fastest animal, and beat most of them for endurance over a long distance. This, too, is only one example of many which might be brought forward, which seem to indicate that for certain special purposes the mind of man is capable of devising appliances different from, and sometimes better than, those which grow naturally.

The second answer to the question why we do not always imitate Nature is this. We cannot. Take the case of a bird's wing. It is a piece of mechanism which puts to shame the very best that the engineer can produce. Many attempts have been made to produce a machine with wings which flap like a bird. Some very ingenious and clever devices have been made, but the friction of the various parts has in every case been such as to make them absolutely worthless for practical purposes. Compared with the beautiful mechanism of the bird's wing, they are crude, clumsy, and inefficient in the extreme.

It seems reasonable to say, therefore, that we have departed from Nature's models because on the one hand we cannot copy her ways successfully, and on the other, within certain limitations, we are able to produce things of our own which answer the purpose as well or even better. The aeroplane will never be able to glide about in all weathers with the skill and certainty of the seagull, but for a plain, straightforward fly it may soon be able to rival the best of the feathered world.

The idea of imitating the bird, indeed, may have been the means of delaying the day of ultimate success, by diverting men's minds into wrong channels, since the boy's kite, a simple appliance which man has been making for centuries, is the real model from which the flying-machine has grown.

For it needs to be made quite clear that there is no mysterious secret which had to be solved before men could fly. A kite is an aeroplane, and an aeroplane, in the conventional sense of the word, is nothing more than a self-propelled kite.

Every boy knows that there are two ways in which a kite can be got to rise in the air. One is to hold it by the string, while the wind blows under its inclined surface, and driving as it were a huge wedge under it, lifts it up. The second method is used if there is not sufficient wind to lift the kite. The same result can then be achieved by running swiftly along, and pulling the kite by means of the string against the still air. The principle is precisely the same in both cases, namely, a relative movement of air and kite against each other.

Now supposing that, instead of pulling the kite along against the air by a string, we could furnish it with a motor and a screw-propeller, by which it could drive itself along, the result would obviously be just the same. *There we have the idea underlying the flying-machines of to-day.*

The theory of the action of these machines can be explained thus. When we walk upstairs we place first one foot and then the other upon successive stairs, and press downwards. As we press a foot downwards upon a stair, the latter reacts, that is, exerts an *upward* pressure, passive it is true, but very real nevertheless, and we may say that it is that reaction of the stairs which enables us to ascend. We can see this from an experience which most of us have gone through at some time or other. Who has not, perhaps in the dark or in a fit of abstraction, reached the top of a flight of stairs, and then in mistake taken another upward step. The foot, meeting with no reaction from a stair, has fallen swiftly, and caused a stumble, startling if not serious. In that false step we made just the same action, and exerted just the same force, as we did in the true steps which preceded it, but we did not raise ourselves any higher. In other words, it is the reaction which raises us.

FIG. 46.—End views of different kinds of "Planes." If either of these be moved swiftly in the direction of the arrows it will tend to rise.

Now let us apply that principle to the kite or aeroplane. We take a flat or approximately flat surface and move it quickly through the air, holding it in such a position meanwhile, that it tends to throw the air downwards. The air possesses that curious property (inertia) common to all matter, whereby when it is still it likes to remain still, and when it is in motion it resists any stoppage or change in that motion. Therefore, when the movement of the plane tends to throw the air downwards, the air resists it; in other words, it reacts upwards, just as the stair reacts against the pressure of the foot.

We see the same thing when a man throws a cricket-ball. The ball (and his arm as well), owing to their inertia, resist the sudden forward movement which constitutes the throw, and therefore react backwards. For this reason he instinctively places one foot farther back than the other, when throwing, in order to form a sort of prop to resist this reaction. It is possible, by a stretch of imagination, to think of a man raising himself in the air by quickly throwing downwards a succession of cricket-balls.

The difficulty in realising this reaction of the air arises from the fact that we are apt to regard air as being infinitely soft and "giving." Yet we know that when the wind blows we feel its force, and if we put our heads out of a railway carriage window we feel the resistance which even still air is able to offer to the passage of a body through it. These facts both show that air, soft and yielding though it may be, still has some of the properties which we are apt to associate with solids, though in a slight degree only. Indeed, we may put it that air has a certain amount of "solidity," due, however, not to the adhesion of its particles, as in a true solid, but to the inertia of each separate particle.

Of course it is not the solidity of a staircase. If we stop for a moment in our ascent of a flight of stairs we only need to suspend our muscular efforts, but if we wish to remain at a certain height in a flying-machine it will not do to place our planes so that they cease to throw the air downwards, for the bank of air upon which we are supported is too soft, and we should sink in. Therefore, even to stay at a uniform level, we need to have our planes so set as to deflect the air downwards sufficiently to compensate for the "giving way" of the air beneath us.

This brief explanation of the principles and theory of flight in a machine heavier than air naturally brings us to the details of the machines themselves.

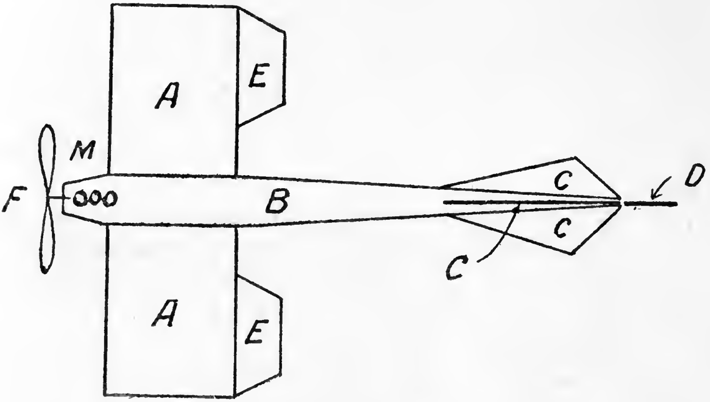
In this connection it is worthy of remark that, short though the time is since the flying-machine has been a real success, it has been sufficiently long for certain definite types to have come into existence. I recently attended an international exhibition of flying-machines, having attended the similar one just a year before, and nothing was more striking than the obvious fact that in the course of that year there had been no change at all worth mentioning in the main features of the machines. Of course details of a minor nature had been improved materially, but the main features were identically the same.

Nearly all machines fall into the two classes of monoplanes and biplanes. As the words indicate, the former has one plane or surface, while the latter has two of them.

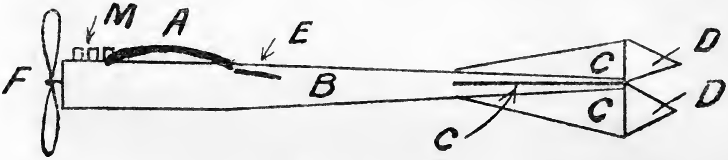
The monoplane, as has been said, is in its main outlines like a bird with its wings outstretched. There is nothing in the nature of a flapping action, however, the lifting power being obtained simply by the curve or inclination of the plane (or pair of wings, whichever we like to call it) as the machine is driven forward. The driving force is a petrol motor similar in many cases to those used for propelling motor-cars, except that the weight is "skinned down," that is, every part is reduced to the lightest possible form that the makers dare to adopt, so as to get the maximum of horse-power with the minimum of weight. The extent to which this has been carried will be understood from the fact that one type of aeroplane motor gives 100 horse-power and weighs only 220 lbs., so that the weight is less than 2¼ lbs. per horse-power. The power of a good strong horse from only that small weight of machinery is very striking.

The wings are generally made of a framework of either wood or light metal tubes, braced together with struts of like material and stays of fine steel wire. Then this framework is covered with a special fabric something the nature of "mackintosh."

The backbone of the monoplane, or part which corresponds to the body of a bird, is also made of a



As seen from above.



As seen from one side.

FIG. 47.—Diagrams showing the parts of a Monoplane. *A*. Main planes. *B*. Body or backbone. *C*. Fins. *D*. Rudders. *E*. Balancing planes. *F*. Propeller. *M*. Motor.

light framework, usually covered in with fabric in order to give some protection to the rider, who finds his seat within this framework near where the two halves of the main plane (or the two wings, if we like to call them so) are connected to it. The motor is also placed near the same position, while the propeller is in some cases at the front and in some cases behind.

At the rear end of the backbone or body there is a smaller plane or pair of wings, the purpose of which is to control the " tilt " or angle of the main planes, or it may be described as a sort of horizontal rudder by which the machine can be steered upwards and downwards. There is also at the end of the body, or in the tail as we might term it, a vertical rudder like that of a ship, by which the machine can be steered to either side. All these are controlled by means of wires from the rider's seat.

A biplane is something like two monoplanes placed one on the top of the other. Just now the aeroplane was referred to as an elaboration of the kite, and just as the ordinary flat kite is a monoplane, so the box kite is a biplane.

Just imagine two flat surfaces consisting of waterproof fabric stretched upon a frame about 6 or 7 feet from back to front and perhaps 40 feet from end to end, one forming a kind of floor with another one like a low roof over it, supported upon light wooden or tubular uprights, with diagonal ties of fine wire to keep the whole affair from collapsing sideways, and there you will have a good representation of the main planes of a biplane.

The rider sits on a seat at the centre of the lower plane with the motor just behind him. Stretching backwards behind the motor there is usually a long framework which carries at its end small planes, to prevent the machine from tipping over forwards or backwards, and a rudder for steering to either side. In some cases the rear planes are movable, so as to form horizontal rudders as described in the monoplane, but in some makes they are fixed, while there is a horizontal rudder, or elevating plane as it is termed, at the end of a short light framing in front of the main planes.

Some of these machines have two propellers side by side and some have only one. In the former case they are driven by means of chains as the rear wheel of a bicycle is driven, but in the latter the propeller is generally connected directly to the shaft of the engine.

The propellers are mostly made of wood, and generally they have only two blades.

These machines are to a certain extent self-balancing, but nearly all flying-machines, whether biplanes or monoplanes, are balanced by the action of the rider himself in one of two ways. One is to pull the planes out of shape a little by means of wires led to the driver's seat. Thus if he feels himself tilting over to the right, for example, he manipulates these wires so that the right-hand end is twisted upwards and the left-hand downwards. The right-hand end then tries to steer its way upwards and the left-hand end the opposite way, and so the balance is restored. The wires are worked by a single handle, the movement of which in one direction raises the right-hand end of the machine and the other the left.

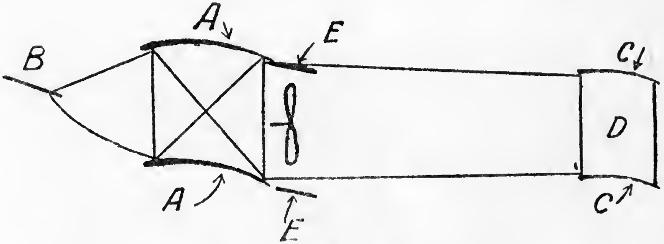


FIG. 48.—Side view of a Biplane. *A*. Main planes. *B*. Elevating planes. *C*. Rear planes. *D*. Rudder. *E*. Balancing planes.

The second method is by means of small planes hinged to the back edges of the larger planes. These are called balancing planes, and are in fact horizontal rudders by means of which one side of the machine can be steered upwards while the other is steered downwards. The man, after a little practice, becomes so used to working his balancing planes, that he balances his machine as instinctively as a bicyclist does, without any thought or conscious effort. By this means a much greater degree of stability can be assured than seems possible by any method of automatic balancing, for so long as he keeps his presence of mind he can recover his balance even after he has been tilted to a considerable angle by a sudden gust of wind. It is easy to see that this is a matter of the greatest importance to the utility of the flying-machine, for if it is only going to be a fair-weather craft, and incapable of taking care of itself in moderately bad weather, its sphere of usefulness is seriously curtailed. There seems every reason to believe, however, that the difficulty of bad weather is quickly being overcome, and that just as the bicycle, which used to be a fair-weather machine, to be left at home when the roads were bad or greasy, has now become useful and reliable under all circumstances, so the aeroplane will soon be able to venture out under almost any conditions.

There are a few machines made of the "triplane" variety, in which another plane is placed above the others, but up to the present these have not been largely used.

There is a general idea that it is very dangerous to venture high up in one of these machines, but that is not necessarily the case. Indeed, other circumstances being the same, a man is almost safer the higher he goes. This strange circumstance is due to the fact that one of the most fruitful sources of failure at present is the motor. Even motor-cars are sometimes to be seen stopped, through the failure of the motor, by the roadside, and when we remember the lightness of the aeroplane motors, it is not to be wondered at, if they should be even more liable to break down than their stouter brothers of the road. Now if the engine of an aeroplane stops, there is little or no danger so long as there is a suitable open spot within reach upon which to land,[1] and if the machine is high up in the air, it can travel for quite a long distance without the engine's assistance, though of course it is gradually descending all the time. Thus when high up the rider has a very fair chance of looking round him and finding a suitable landing-place, whereas, if near the ground he has no such opportunity, but must come to earth at once, even if he has to alight among a neighbour's chimney-pots. Moreover, at high altitudes the movements of the air are free from the gusts and eddies caused by contact with obstructions such as trees, buildings, and hills.

On the other hand, there is little safety in being near the ground, for a fall of say 20 feet is quite likely to be fatal, and one from 1000 feet can be no worse than that.

The most serious danger to the aeronaut is the failure of the actual machine itself. If some part gives way and throws the machine out of balance, say the collapse of one end of the main plane, nothing whatever can save a terrible disaster. This danger can only be provided against by the most careful attention to every detail of the construction of the machine.

Though not, strictly speaking, connected with the conquest of the air, a short reference may perhaps be made here to those curious water craft known as "hydroplanes," since they proceed upon the surface of the water on precisely the same principle as the

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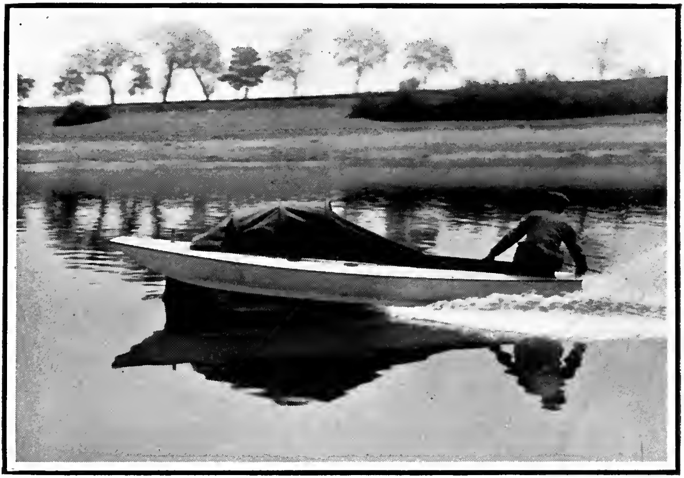
[1] I have actually seen M. Paulhan, the hero of the first long-distance cross-country flight in England, stop his engine when some 600 feet up and come to the ground as gently as a seagull alights upon the water.

aeroplane may be said to glide upon the surface of a bank of air. When still or travelling slowly, they float in the water just as an ordinary boat does, but, as soon as they are driven to a certain speed, they rise upon the surface of the water and skim over it with remarkable swiftness. This they are able to do because of the peculiar shape of the hull, the bottom of which forms a flat plane capable of acting upon the water just as the planes of a flying machine act upon air. One of these curious craft is shown in the upper illustration facing this page, while underneath it is a similar boat, invented by Sir John Thornycroft, the famous builder of fast warships, which combines the skimming powers of the hydroplane with more seaworthy properties than such craft usually possess.

The hydroplane skimming across the surface of the water, as a flat stone can be made to do if skilfully thrown, affords another illustration, which may appeal specially to some readers, of the principle underlying both hydroplanes and aeroplanes. The difference, too, between the stone heavier than water yet supported upon its surface because of its shape and speed, and a log of wood which is supported in the water because of its being lighter than water, illustrates the difference between the two kinds of aerial craft.

Those which we have been considering are heavier than air, and owe their ability to stay supported upon it to their shape and movement. We will now take a look at those which are lighter than air, and float because of their lightness.

Of course, the ordinary spherical balloon has been known for many years. It consists of a gas bag or envelope of some light but gas-proof material, to which is suspended a car capable of holding a few people. In order to provide a means of attaching the car to the flimsy material of which the balloon is made, the



A "HYDROPLANE"

This craft glides upon the surface of water as an aeroplane glides upon air.

By permission of *Messrs. J. I. Thornycroft & Co., Ltd.*

A "SKIMMER"

Invented by Sir John Thornycroft, which at low speeds floats just like an ordinary boat, but which when driven at about twenty knots rises up on to the surface and skims along like a hydroplane, its speed then increasing to twenty-seven knots (over thirty miles) an hour.

envelope is generally enclosed in a large bag of network, to which the car is actually suspended.

The buoyancy of the balloon is due to its being filled with a gas lighter than air, until it is so distended that it takes up more space than does an equal weight of air. Then it floats for precisely the same reason that a ship floats in water. The ascent and descent of a balloon is arranged by very simple means. Around the car there are tied bags of sand, and if the aeronaut wishes to go higher, he simply lets fall some of the sand from these bags. That lightens the balloon, and it ascends. The descent is controlled by means of a valve in the top of the balloon by which gas can be permitted to escape, and so the balloon be allowed to become slightly deflated. This valve is worked by a cord from the car, and when the balloon is wanted to descend the discharge of a little gas will cause it to do so.

Thus, as long as there is ballast left in the car and sufficient gas in the envelope, the ascent and descent can be controlled.

For suddenly deflating the balloon in the act of alighting upon the earth there is a "ripping panel," a patch lightly sewn on the envelope, which a vigorous pull upon a rope will tear right out, and so let all the gas escape almost instantaneously. But for this, there is a danger of the wind catching the balloon while still partially inflated and dragging it along the ground, but with it the moment the car touches earth the rope can be pulled, and instantly the whole thing collapses.

The gas most commonly used for balloons is coal gas, the weight of which is such that 1000 cubic feet will lift 40 lbs. More effective is hydrogen, which will lift about twice as much, but it is too expensive except for special purposes.

Hydrogen for use in balloons can be obtained by decomposing steam somewhat in the manner described in an earlier chapter. If a jet of steam be blown through a tube containing white-hot pieces of iron, the steam is split up into oxygen and hydrogen, the former of which combines with the iron at once and leaves the hydrogen free.

An ordinary spherical balloon cannot be propelled or steered, for it simply drifts with the wind. It has been put that such a balloon is in a perpetual calm, for, however fast it is moving, the surrounding air is moving in precisely the same direction, and at precisely the same speed. A ship can take advantage of the force of the wind because it is supported in the water—in other words, it is the *difference* in motion between the sea and the air which enables a sailing-ship to propel and steer itself—but the balloon, being entirely immersed in air, can only drift with the air, unless it has some powerful mechanical force to assist it. The force generally used is a petrol motor, driving a propeller ; and in order that it may cleave its way through the air with the least possible resistance, steerable balloons are made of elongated shape with pointed or rounded ends.

There are two types of these airships, known as rigid and non-rigid respectively. The former are kept in shape by means of a rigid framework, while the latter owe their form to the gas bag being fully distended with gas.

Most unlikely-looking materials are sometimes used for these balloons, some of them being made of metal, and not always of the lightest metal available—aluminium—but even of iron. Structures of such weight are necessarily of enormous size or they could not possess sufficient buoyancy. For example, one has recently taken the air which is 120 metres long, and holds 13,000 cubic metres of gas—close on half a million cubic feet.

This particular airship has four petrol motors, aggregating 250 horse-power.

Wonderful structures these are, but there seems to be reason to doubt whether they will ever be able to overcome the one inherent obstacle to success, namely, their huge size and the consequently great resistance which they offer to the air. It is inconceivable that they will ever be able to proceed against a strong wind; and when at anchor, fastened to the ground, a very moderate gust is sufficient to wreck them.

Attempts have been made to combine the two types of flying machine, a notable example of which is a huge steerable balloon of the rigid type, nearly 200 feet long and 33 feet in diameter, which for its car has a monoplane which can be detached if and when desired. This balloon is interesting, too, in that it is stiffened by an ingenious arrangement of rubber tubes, which are made rigid by being filled with compressed air.

In concluding this chapter, I must give a brief reference to a remarkable motor which has been devised specially for aerial craft, and which is very largely used. It is called the "Gnome" engine, and has already been referred to because of its remarkable lightness.

The cylinders are arranged like the spokes of a wheel around a central hub, which forms the crank chamber. Unlike all other engines in which the cylinders are still while the crank is turned, the crank in this case remains still and the cylinders revolve themselves round it. Thus the engine forms its own fly-wheel, and moreover the cooling of the cylinders, an important thing in all internal-combustion engines, is accomplished automatically by their swift and continual motion through the air.

CHAPTER XXVII

A MISCELLANEOUS CHAPTER

THERE are a number of interesting examples of the engineer's skill which do not naturally fall under any of the headings of the preceding chapters, and so I propose to gather a few of the most striking of them here.

The motor-car branch of engineering has not been referred to at length, because there is quite a large range of popular books on the subject, and many people are familiar with it who are quite outside the engineering profession. There are, however, one or two special features which deserve a reference. One of these is the Renard train.

This consists of a train of vehicles hauled by a motor wagon much as a locomotive hauls a railway train, only it is for use on ordinary roads. In the ordinary way, if a trailer be attached to some form of road locomotive, it can be steered quite satisfactorily, but if many were so attached there would be trouble in going round corners, for each one would take a different curve from the one in front, until they would be colliding with the building at the corner. A certain officer in the French army, however, saw the utility, for military purposes particularly, of being able to haul a long train of wagons in this way, so he devised a means of getting over this difficulty. The locomotive not only propels itself, but propels every vehicle on the train as well. It does not simply pull it along but drives it by turning its wheels, or holds it back when necessary by restraining the rotation of the wheels. The whole train is coupled together by special couplings so that it is as if there were a continuous shaft running the whole length, the turning of which turns all the wheels, yet it is flexible between the vehicles, so that the train can easily go round corners. And not only does the "engine" do that. There is a special steering coupling as well, which causes each vehicle to steer the one behind it in exactly the same course which it takes itself. Thus, wherever the "engine" goes the trailing wagons follow exactly ; if it quickens its pace they do the same, or if it slows down they slow down too. Such a train can consequently go almost anywhere, through narrow, crooked streets or over rough ground. It can turn the sharpest corners, and each succeeding vehicle will follow the preceding one just as if they were running on rails ; indeed it can curl itself up into a spiral just as easily as it can go along a straight road ; and it can go backwards just as easily as forwards.

Another very interesting motor vehicle is the motor sleigh made for Captain Scott's Antarctic expedition. This has four wheels, two on each side, just like a motor-car, except that instead of being ordinary road wheels they are tooth wheels, and round the pair on each side there is an endless chain something like that on a bicycle, only larger. Moreover, it has large teeth on its under side, so that it can grip the snow. The weight of the sleigh rests upon these chains, so that when the motor turns the wheels and moves the chain round and round, the chain gripping the snow by means of its teeth, no matter how smooth it may be, propels the sleigh along. It does not travel fast, being designed for two to three miles per hour, but it is capable of pulling several ordinary sleighs behind it.

To go to another department altogether, many readers will probably be interested to know something about freezing machinery. This is a most important branch of engineering, since without it many parts of the world would find a large part of their food-supply cut off. The method by which extreme cold can be produced mechanically was explained in an earlier chapter in connection with the production of oxygen for engineering purposes. The same principle is employed in a refrigerating machine on board ship or in a cold storage.

Some compressible gas, such as carbonic acid, is first compressed by a pump. Then it is passed through pipes with water circulating outside them, like a surface condenser. This has the effect of cooling the compressed gas, so that when it reaches the refrigerator proper, in which it is allowed to *expand*, it falls to a very low temperature. The cold thus produced is carried into the chamber which is to be cooled either by blowing air through the refrigerator into the chamber or else by a non-freezable liquid circulating through the refrigerator and then around pipes in the chamber, just as heat is often conveyed from a boiler into a public building, only in this case, of course, it is cold which is conveyed, and not heat.

Some remarkable machines are to be found in connection with printing. The large rotary printing machines which turn out newspapers by the mile are too complicated in their details to be described minutely here, but it will be sufficient to say that there is a large cylinder which rotates about a horizontal axis. On this is fixed the type, or rather a plate which has been cast off the type so that it forms a perfect replica of it. This is bent round and securely attached to the cylinder, and then the latter rotates at a high speed, the paper (which is like a huge ribbon on a reel) running under it. As soon as the impression has been made on one side, the paper passes another cylinder which prints the other side, and then a knife cuts the paper the correct size and in the right place. Finally it folds the paper, and, in some cases where there is more than one sheet, gums the inside one. Thus the machine takes in a roll of paper and turns out newspapers printed, cut, folded, gummed, and counted.

The marvels of the rotary printing machine are, however, quite put in the shade by some of the type-setting machines, the action of which is almost human. The one used for newspapers is called the "linotype," and, as its name implies, it makes a line of type at a time—one solid type, that is, for each line, and not separate type for each letter. This has the drawback for other than newspaper work that, if a word has to be altered, it is not easy to do it ; but in another and perhaps more wonderful machine still, the "monotype," a separate type is made for each letter, and so alterations can be made as easily as with hand-set type.

This marvellous machine, which is often used for books, consists of two parts, the key-board and the caster.

The former is very like the keyboard of a typewriter, except that it has a very large number of keys. The operator sits at his machine and writes out his matter just as a typist would, the result being, however, simply to punch a lot of little holes in a long strip of paper.

Now every one must have noticed that there is a very important difference between typewriting and printing. In the latter case the lines are all exactly the right length, but in the former they vary. In hand-setting the compositor adjusts each line—or justifies, as he calls it—by putting in thicker or thinner spaces between the words so as to make them fill out the line precisely. But how, one is tempted to ask, can that possibly be done by machine ; for, as in the case of the typewriter, when you depress the space-key to make a space, you do not know how the line is going to turn out as regards length.

In the monotype this difficulty is got over, as we shall see, in a very simple and effective way. When the end of the line is near, and the operator finds that he cannot get another word in, he presses a key and instantly a little indicator shows him what size of space he will need to have between the words to make the line exactly the right length. Then he presses suitable keys, which record that size by means of holes in the paper. Now that paper, as we shall see presently, goes at a later stage to the caster, which makes the type in accordance with the holes in it, and it is important to note that it starts at the end of the line and sets it up backwards. When, in punching the strip by means of the keyboard, the operator comes to the end of a word, he presses a "space" key just as a typist does. This makes holes indicating, as we might put it, "a space is to come here," but it does not show the width of that space. When he gets to the end of the line, as we have seen, he presses a special key and that makes holes indicating "the spaces in this line need to be of such and such a thickness."

Thus when the caster begins a line, since it works backwards, the first indication it finds on the strip is the instructions as to how thick the spaces need to be, and after that, whenever it comes across the instructions to make a space, it makes it that thickness. By this means every line is just the right length.

The caster is quite separate from the keyboard, in fact, they are usually in separate apartments, for the former makes considerable noise while the latter is best worked under quiet conditions. It is a most complicated piece of mechanism, but its mode of working may be described briefly. The paper strip passes over a plate with a row of holes in it, and under an indiarubber pad with a hollow in its surface, into which compressed air is pumped. Thus as soon as a hole in the paper comes over one of the holes, the air can pass into the hole, but otherwise the holes are kept closed by the paper. The compressed air passing through different combinations of holes causes different movements in a little frame which is filled with brass dies, each one having cut into its surface the impression of a letter or character of some sort, or else a plain block to form a space.

Underneath this frame there is a plate with a little square hole in it of variable width, and as soon as the holes in the paper uncover the holes meaning a certain letter, the frame moves so as to bring that particular die over the hole and at the same time the hole opens or closes up, as the case may be, so as to produce a type exactly the right width for that letter. At the same moment a little pump sends up a jet of liquid type-metal into the hole, completely filling it. This sets instantly, and then a knife comes along and cuts off the bottom of the type so as to make it exactly the right height, and then the machine pushes out the finished type on to a little table set to receive it. As soon as one line is finished the machine itself pushes it upwards and so leaves room for the next line to take its place.

Thus any one watching this machine at work sees a constant stream of newly made type coming out in quick succession, one line succeeding another with surprising rapidity.

CHAPTER XXVIII

ENGINEERING OF TO-MORROW

It is a notoriously dangerous thing to prophesy, but one cannot help observing certain tendencies which have characterised the progress of the recent past, and it is quite reasonable to suppose that they will continue to mould the progress of the near future. From them, therefore, some suggestion as to future developments can be obtained.

It will be mere suggestion, however, for there can be no doubt that progress will be increasingly rapid, and exactly where it will lead us to is impossible to tell. New discoveries in science will probably open up new opportunities for the engineer, just as modern discoveries in electricity have done. But of one thing we may be quite certain ; for many years to come the energies of the engineer will be directed largely to the utilisation of waste materials and waste forces.

The amount of force that is being wasted now is little realised outside the engineering profession. For example, coal contains a certain measurable amount of energy which we often desire to convert, for convenience of transmission, into electrical energy. We have the most elaborate machinery for doing this, machinery on which we pride ourselves, and which we consider typifies the progress of the present day, yet how much of the coal's energy do we lose in the process ? In an *up-to-date* generating station not much more than ten per cent. of the energy of the coal consumed passes out in the form of electrical energy. Nine-tenths of it are lost.

Let us consider what that means. Coal is a commodity of which there is but a limited supply. The supply may, it is true, be enough for another century, but there must be an end to it ultimately. In Great Britain alone, for example, the production of coal runs into well over 250 million tons per annum, a rate which obviously cannot be kept up for an unlimited period ; and there are other countries which are equally prodigal.

Now, under modern conditions, industry largely, indeed almost entirely, depends upon coal. Where the coal is there will the industries gather. This statement is entirely and absolutely true except for those few places where there is an abundance of water-power ; but, as such places are comparatively rare, we may almost disregard them when taking a general survey of the situation.

We are therefore confronted with three alternatives. First, vast supplies of coal may be found elsewhere, in new countries, which will be able to meet the needs of the world for many centuries, but that will inevitably mean that the industries will move to those places where the coal is to be found; for it is easier and cheaper to take, once for all, the factory to the coal than it is to keep on, year after year, continually bringing the coal to the factory. If this is to be the ultimate solution of the problem, then it must mean a terrible dislocation of the existing arrangements and a serious loss to existing interests.

Let us imagine for a moment what would happen if the coal in South Wales were to give out, while more abundant supplies still, and equally good, were found, say, at some convenient spot on the coast of Africa. The great iron, steel, and tinplate mills in South Wales would of necessity have to be moved to the neighbourhood of other coalfields. The shops which supply the needs of the workers in these mills would find their trade gone; businesses which had been built up by a lifetime of care and industry would quickly cease to exist. The owners of property would suffer equally, and the effect of this general decline, even of one district only, would react in other places and cause widespread misery.

The workers themselves could probably follow the work to its new location, but even that would mean the breaking up of many families, and be the source of much personal suffering.

Yet if the imagined failure of the supply in South Wales were made up by a new supply from new sources, the world as a whole would be just as well off as before. We can see, therefore, that the discovery of new coalfields to replace the old, while it may keep the world going industrially, will be accompanied with serious consequences to whole communities which we ought to endeavour to stave off as long as possible.

The second alternative is the discovery of some new source of power which can be obtained anywhere, so that it can be used by existing factories without necessitating their removal to new districts. Now there is practically only one source of all energy, the heat of the sun. As has been pointed out already, wind-power is the result of the sun's action, and so is water-power, while the energy of coal is entirely due to the action of the sun's heat in times gone by.

The sun itself, astronomers tell us, will in time grow cold, having exhausted its vast stores of energy, but that will not be, they reckon, for millions of years, so for the moment we may regard the sun as the one permanent element in the situation. Is there not then the possibility that we may find some more effective way of catching and turning to account the energy which is streaming to us from the sun. A friend of mine has a theory, a pure theory at present, which may contain the germ of some such solution of the problem. He says the earth and the sun remind him of a dynamo. This machine, as we know, consists of two parts—an armature which rotates, and a field-magnet which provides a kind of bath of magnetism within the influence of which the rotation takes place, and it is the movement of the armature within the influence of the field-magnets which causes the current to be generated. Now, says this theory, the earth is revolving within the influence of something analogous to magnetism proceeding from the sun; if we could find the correct way to construct on the earth something analogous to the electrical conductors upon the dynamo armature we might be able to generate force, either electrical or something similar. Such a scheme would, no doubt, theoretically at any rate, slow down the rate of rotation of the earth and so lengthen the day, but it is probable that the total amount of energy required by the whole of mankind is so small in comparison with the vast momentum of the earth that that would never be appreciable. Of course this scheme is only a piece of pure imagination, but it is sufficiently original and ingenious to merit a reference.

Another, and perhaps more likely source of power, is the rays which are no doubt being emitted from our sun other than those which give light and heat. There is every reason to believe that the waves in the ether which convey light and heat from the sun to the earth are accompanied by other waves of different lengths from those which we perceive with our senses, and there may be possibilities in some of these which we have not up till now realised. This, however, is not a subject for the engineer but for the physicist to investigate; but should the latter discover that there is any real source of power in the sun's rays which we have not tapped to the full already, the engineer will not be slow in finding the means to turn it to practical advantage.

The third "solution" to our difficulty is not really a solution at all, but simply a means of putting off the evil day. I mean some more efficient ways of utilising the sources of energy as they exist at present. For example, suppose we could discover some form of "coal battery" by which the energy of coal could be converted direct into electricity with only a small loss. It is a curious fact that, while we can convert electricity into heat with a very small loss indeed, the contrary process is accompanied by the enormous loss referred to in the beginning of this chapter.

It is quite safe to say, therefore, that one of the great efforts of engineers for many years to come is likely to be in the direction of devising more efficient ways of using the stores of energy which exist in our coal deposits.

Several ways of doing this have been referred to already, such as the use of the waste gases from the blast-furnaces in ironworks for heating and also for driving by means of suitable gas-engines. All forms of furnace are now made, if possible, to work on some sort of regenerative principle so as to utilise heat which would otherwise be wasted, while the steam-turbine has provided in a remarkable way for the use of waste steam. In an ordinary steam-engine the full force of the steam cannot be made use of. The expansive force within the steam can only be utilised by passing it through a series of cylinders, and there are certain practical difficulties in the way of having a sufficiently numerous series of cylinders to extract it all. A steam-turbine, however, can be arranged so that practically every ounce of force in the steam is transferred to the rotor of the turbine, so that it comes out at the "exhaust" end like the steam from a lightly boiling kettle.

Indeed, the turbine will go even farther, and, if this exhaust steam be led through a turbine to a condenser, the *waste* steam from an ordinary engine can be made to do an astonishing amount of work. In many cases a factory is lighted throughout by electricity generated in this way, by an exhaust turbine using the steam which for many years previously was allowed to run to waste.

The steam-engine, whether reciprocating or turbine, however, suffers from one great difficulty. A certain amount of the heat employed becomes locked up in the steam and cannot be recovered and put to use, but, on the other hand, often requires an expensive plant to get rid of it. Who has not noticed, at some large generating station, huge erections of wood of such size that they are perhaps the most prominent feature in an outside view of the station. Those are cooling-towers, and their purpose is to dissipate into the atmosphere heat which would be valuable if it could, instead, be captured and taken back to the boiler. Heat is consumed in converting the water into steam, and, in order to get as much force as possible out of the steam, it must be converted back into water before it is liberated. This is done, as we saw in a previous chapter, by condensing it through causing it to come into contact with cold water, the heat in the steam being transferred to the water which thus carries it away, and it is that water which has to be cooled at considerable expense. Even in those cases where there is no cooling-tower there is something equivalent, either nozzles by which the water is thrown into the air in fine spray, or else, where there is a stream handy, the cold water is drawn from the stream and the hot put back. In any case the result is the same, good heat is being wasted.

Similar considerations apply to the internal-combustion engine in its many forms. Heat which ought to be put to good use has to be got rid of simply because up till now we have not found a satisfactory way of making use of it. Along these lines, therefore, we may expect to see great developments in the future.

Another field for ingenuity and research is the electric accumulator. Just think how the problem of installing electric trams would be simplified, did we but possess a light and efficient accumulator. There would then be no need for the unsightly overhead wires, or the costly surface contact or conduit systems. Many minds have been engaged upon this problem for years, including that of Mr. Edison, but so far without any conspicuous success.

New, simpler, and cheaper processes and machines for all purposes are always required, and of these we shall without doubt see many examples in the years to come. There is a great need for trained scientific men to tackle these industrial problems. It is not enough nowadays to go blindly on in the hope that a new process or invention will be discovered by accident. The modern inventor who is going to make a real success must find out something that is needed, and then set himself patiently and laboriously by careful investigation to search for it. We shall probably hear less in the future of the man who, by a lucky chance, invents a tin-opener or a pencil-point protector, and makes his fortune immediately, and more of the skilled and patient investigator who, by years of industry, makes an invention which assists some important industry.

The social reformer (and we are all social reformers to a degree) will more and more need the engineer's aid; for every writer who has attempted to picture an ideal state of society has found himself confronted with the question: "Who is to do the dirty work?" and his only possible answer is "Machinery." The engineer is then called in to devise wonderful contrivances which relieve men and women from the menial "degrading" duties of life.

The automatic charwoman, the automatic scavenger, the automatic coal-heaver, are dreams which our imaginative writers have dreamed over and over again, and something of the sort is not far off. We already have machines which sweep our rooms, and peel the potatoes in the kitchen, while quite recently there has been put upon the market a little machine humorously called the "Electric Mary Ann," which performs many of the duties of the general servant—such as cleaning the knives, and blacking the boots—with efficiency and despatch.

In fact, there is no class of men who will have a greater influence on the social and economic progress of the world than the engineers.

In the introduction I quoted a remark of John Ruskin's, which seemed to belittle the engineer's work. Let me conclude with another quotation from the same writer, in which he indicates quite the contrary. He is discussing the true principles of "economy" or "house management" as applied to national affairs, and he thus enumerates the great works which are needed for the nation's happiness and wellbeing:

"The sea roars against your harbourless cliffs—you have to build the breakwater, and dig the port of refuge; the unclean pestilence ravins in your streets—you have to bring the full stream from the hills, and to send the free winds through the thoroughfare; the famine blanches your lips and eats away your flesh—you have to dig the moor and dry the marsh, to bid the morass give forth instead of engulphing, and to wring the honey and oil out of the rock. These things, and thousands such, we have to do, and shall have to do constantly, on this great farm of ours."

Every one of these things is the work of the engineer.

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