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ING BENEATH THE SURFACE
OF THE WATER

BY

T. W. CORBIN

AUTHOR OF "ENGINEERING OF TO-DAY," "MECHANICAL INVENTIONS
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NOTE

THE author desires to express his thanks to the individuals and firms who have so kindly lent photographs for the purpose of illustrating this book. Their names are inscribed under the illustrations themselves.

He would also like to acknowledge gratefully the assistance which he has received from Mr. Blake, of Messrs. Heinke and Co. Ltd., Diving Engineers, of London, and from Mr. Charles Bright, M.I.E.E., F.R.S. (the son of Sir Charles Bright, the engineer of the first Atlantic Cable), who have been good enough to afford valuable information on those branches of the subject in which they are specialists.

Finally, he would like to mention with gratitude the *Diving Manual* of Mr. R. H. Davis, the Managing Director of the well-known firm of Submarine Engineers, Messrs. Siebe, Gorman & Co. Ltd., from which much interesting information has been obtained.

where they sank, with valuable treasure inside them. This same modern diver can go down, creep to the treasure-room, recover the treasure, and bring it to the surface once more.

The submarine torpedo boat, by a long process of gradual development, has now been brought to such perfection that it is hardly an exaggeration to state that it is as safe when voyaging under water as an ordinary boat is on the surface. The sea claimed many victims before it was thus finally beaten. Beaten it is, though, for the occasional losses which, alas, will still occur, are by comparison only like the losses which even a defeated foe can often inflict upon a victorious enemy.

Nor is the fight without its heroes. Alexander Lambert, the diver, whose gallant feat at the Severn Tunnel I shall describe presently, rivalled, for sheer desperate bravery, the finest deeds ever performed upon the battlefield. With no excitement to give him courage, no comrades to cheer him on, absolutely alone and in darkness, with pitfalls on either hand, and with obstacles before him over which he could only crawl, he groped his way along the water-logged tunnel. He did it, moreover, in a new kind of diving dress to which he was not accustomed. Never was a braver deed done, yet it is safe to say that many divers have been as brave, and, if the need should arise again to-day, there are many men ready to emulate the noble deed of Alexander Lambert.

But enough of this moralising about the achievements of the civil engineer and the prowess of the diver; the real romance of it all lies in the story of the men, their tools and their work. Just how the work is done, just what the tools are like, with here and there a little picture of the men themselves: those are the things you want to hear, and to them we will now proceed.

CHAPTER II

AIR, NATURAL AND ARTIFICIAL

OF chief importance in submarine work is the question of air. What a bother it is that we must have air, and have it continually. Some of the native pearl divers, who dive naked, can remain without air for two minutes at a time; but little work can be done in two minutes. For most purposes a diver must remain down much longer than that, and so he must be provided, somehow or other, with a supply of air.

Since, then, it is so important, we had better devote a little time to the consideration of air itself; for we shall then be much better able to understand the later chapters.

Air is a mixture of several gases. When pure, roughly 80 per cent. of it is nitrogen and 20 per cent. oxygen. There are small quantities, also, of carbonic acid (even pure air contains a trace of this), argon, helium, krypton, neon, and xenon. Some people might be horrified if told that they were breathing a gas called xenon, but it is a fact, nevertheless. They need not be alarmed, however, even were it as harmful as its name sounds, for there is very little of it, only one part in 170,000,000. The others are a little more plentiful, up to argon, of which there is about 1 per cent., but even that is so little that for our present purpose we may dismiss them all from our minds and think no more about them, contenting ourselves with the fact that for practical purposes pure air consists of nitrogen and oxygen, in the proportion of 79 of the one to 21 of the other.

And that reminds us of a fact about air which is well worth remembering. Whatever its constituents may be, they are always thoroughly mixed, so that the proportions are always the same. This is surprising when we bear in mind that some are heavier than others, and the reason is believed to be that all gases consist of molecules a considerable distance apart, all skipping about rapidly somewhat like a swarm of gnats on a summer evening, so that they automatically mix themselves together and keep themselves mixed.

Nitrogen, although it does no harm to us, is of no direct use. It simply serves to dilute the oxygen. The old saying that you "cannot have too much of a good thing" does not apply to oxygen, for it is certainly a good thing, yet we might have too much of it.

When we inhale, our lungs lay hold of the oxygen but leave the nitrogen. The latter is exhaled the next moment, but the oxygen is passed on to the blood and by it carried through the arteries to all parts of the body. There it combines with carbon, of which our tissues are built up, and forms the well-known combination carbonic acid gas. Thus the blood fetches oxygen from the lungs, distributes it about the body, and brings back carbonic acid.

The same thing occurs when anything burns. A fire would go out if it were deprived of a good supply of oxygen. The oxygen combines with the carbon in the coal, wood, oil, or whatever it be; oxygen goes to the fire, but carbonic acid gas comes away from it. When the combination of the oxygen and the carbon takes place quickly we call it combustion, but when it occurs slowly we call it oxidation. Both are the same except for the speed at which the process is going on.

So, we may say, there is a slow fire continually burning in our bodies. Now if we were to flood a furnace or even an ordinary domestic fire grate with pure oxygen, the fire would burn with extraordinary energy, and would consume not only the fuel but the grate itself as well. It would be so fierce as to be uncontrollable—so long, that is, as it was supplied with too much oxygen. In much the same way, if we were to breathe too much oxygen, this natural burning process, which is continually going on within us, would be forced to such a degree as to be very harmful to us.

True, in certain illnesses it is beneficial to give the patient a little pure oxygen to breathe, but that is only for a moment and to help him round a "tight corner," as it were; it would be disastrous if it were continued for long.

And thus we see the purpose of the nitrogen in the air; it prevents our getting the oxygen too strong.

So much for pure air. Impure air has a deficiency of oxygen, and in its place some carbonic acid. We do not need to displace all the oxygen, and substitute carbonic acid, in order to make air unfit to breathe. Even as little as 10 per cent. of the latter gas is enough to render a person breathing it unconscious, while as soon as it rises to 3 per cent. it begins to cause discomfort. Even a small percentage of it, then, must be got rid of from any chamber in which a living man is. Moreover, if the man is doing work, he has all the more need of pure air, and impure air is all the more injurious. Therefore, since we do not send a diver down for the fun of the thing but to do certain work—sometimes very hard work—it is specially needful that the chamber in which he is, be it submarine boat, diving bell, or diver's helmet, must be pure.

Our air is naturally purified in two ways. The wind provides us in our cities and towns with a supply of pure air from the vast open spaces of the earth. Great gatherings of people like London and New York, with their millions of breathing men and women and their many fires all giving forth the noxious carbonic acid, receive by the winds volumes of pure air from the great uninhabited spaces of the broad Atlantic. By the winds the air is distributed over the face of the earth, and good is sent to take the place of bad. But that is only a local purification. If a wind from the ocean comes and blows away the impure air of London, leaving in its place great volumes of pure air, it simply means that the two kinds of air have changed places: the bad air is still in existence, and, if there were no other process of purification going on, the air all over the globe would in time become bad.

Fortunately that other method is provided by the trees and plants. They work the reverse way. Whereas animals consume oxygen and produce carbonic acid, they consume carbonic acid and produce oxygen. In order that vegetables of all sorts may live, they need this (to us) harmful gas. They take it, split it up into its two component parts, use the carbon and liberate the oxygen into the air. There is thus a continual cycle going on—a sort of perpetual motion. We get carbon into our bodies by eating it; when we have done with it we burn it up by bringing it into contact with oxygen by means of the blood. Thereby we turn both into carbonic acid.

That floats away in the air until a vegetable gets hold of it and turns it back again, the oxygen being made fit for breathing once more and the carbon being built up into the tissues of the vegetable, possibly to provide us with food. Thus, once more, both oxygen and carbon come back to us. It is even possible to conceive circumstances in which the same oxygen and the same carbon might in this manner be used over and over again in the body of the same animal.

That is somewhat beside our subject, however, and I only introduced it here because the natural purifying process leads up to the artificial purifying processes which are often employed in connection with diving.

In diving matters we use the same two methods. The ordinary helmet diver is kept supplied with a stream of pure air. Just as the wind drives away the smoke and the impure air from our great towns, replacing it with sweet fresh pure air, so the constant stream of pure air pumped down to the diver drives away the impurities caused by his own breathing and leaves pure air in its place.

That is how we do with the ordinary helmet diver and with the men who work in diving bells, but in the case of a man in a submarine boat and in certain special kinds of helmets, we have to adopt nature's second method. We have to provide a means whereby the impurities shall be taken right away, removed out of existence, and not simply removed to another place; and at the same time fresh supplies of oxygen must be produced from somewhere.

As is usually the case, man's artificial methods are poor and clumsy compared with the perfect ways of nature, and here we have an instance of this. The vegetables purify the air perfectly, for they take away the carbonic acid by removing the carbon from it and giving us back the pure oxygen. Thus at one and the same operation they take away what is harmful and give us what is good. We men do it by two separate operations. We have to provide one means for supplying the diver with a quantity of oxygen sufficient for his needs, and another for ridding him of the carbonic acid.

Fortunately there are several chemical substances which have a great fondness for carbonic acid, and which will readily absorb it from the air. You can see an instance of this in ordinary lime water—water, that is, in which lime has been dissolved. Lime is a compound of calcium and oxygen called by chemists CaO. It is soluble in water, and when a little of it is put in water it disappears from view just as sugar does when dissolved in tea or coffee, leaving the liquid quite clear. If, however, we add carbonic acid gas to lime it becomes not calcium and oxygen simply, but calcium, carbon, and oxygen. The CaO (one part of calcium and one part of oxygen) and the carbonic acid (one part of carbon and two parts of oxygen) become $CaCO_3$ (one part of calcium, one of carbon, and three of oxygen), a substance which we know as chalk.

Now chalk is *not* soluble in water. Therefore when the carbonic acid joins the lime it changes the latter from a substance which is dissolved in the water, and therefore invisible, into a visible powder floating in the water. Hence, if we expose a quantity of lime water in a vessel in a room where the air is impure, we shall after a little while see the plain clear water become cloudy and white.[1] The lime will have become partly

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[1] This is a good way of testing whether the air in a room is pure.

changed into chalk and (this is the important point) a certain amount of carbonic acid must at the same time have been taken from the air. In other words, the air will be a little purer because of the lime water.

Caustic soda is another substance which has a great affinity for carbonic acid—indeed, that is the substance generally used for the purpose. A comparatively small quantity of it will keep the air in its neighbourhood free from carbonic acid for quite a long time. Some of the substances used with diving apparatus are of secret composition, but there is reason to believe that caustic soda or some kindred substance plays a very important part in them.

Unlike the natural action of the vegetables, you will notice, these chemicals take the carbonic acid as a whole, oxygen and all. They do not separate the carbon and oxygen. There are, it is true, chemicals which give off oxygen readily, and in some cases these are used in diving, but in most cases the oxygen is carried compressed, in steel bottles, and liberated as needed.

All gases are easily compressible. The air which we breathe is compressed. We live at the bottom of a mighty ocean of air many miles deep, and since we are at the bottom of it we are where the pressure is greatest. The whole weight of the upper air is supported by the air in which we live, and consequently it is compressed to a pressure of about 14·7 lbs. per square inch.

On a mountain 15,000 feet high the pressure is only 7½. That is because there is a less thickness of air above at that height than there is at the sea level, and consequently the air there has a less weight to support and is less compressed.

If you were to go up such a mountain with an india-rubber bag of air, containing say one gallon, the bag would stretch as you ascended until at the top you would have not 1 gallon but 2 gallons of air. It would be thinner air, however, less compressed. So, just as the pressure at the sea level squeezes the air into a smaller compass than the lighter pressure at the top of a mountain, so we can, by exerting pressure, get a great amount of air into the compass of a small bottle. The oxygen which is used to supply magic lanterns and cinematograph machines is contained in steel bottles or cylinders, into which it is compressed until the pressure reaches what is known as 120 atmospheres. That means 120 times the pressure of the atmosphere at sea level, or nearly 1800 lbs. on every square inch.

If a cylinder is large enough to hold one cubic foot when it is open to the atmosphere, it contains one foot more for every 14·7 lbs. of pressure which is added. Such a cylinder, therefore, when the gas had reached the pressure of 120 atmospheres, would contain 120 cubic feet. So you see, under this high pressure a great quantity of oxygen can be carried in a very small cylinder.

Thus a diver may be in a small chamber of some kind, cut off from all communication with the surface, yet if he be provided with a cylinder of oxygen and some caustic soda he will be safe from suffocation for some considerable time, for the soda will remove the carbonic acid and the cylinder will provide a supply of oxygen, and so the atmosphere in which he lives will be continually purified so that he can go on breathing it over and over again. How long he will be safe will depend upon how much oxygen and caustic soda he has.

While, theoretically, pure oxygen would seem to be the best for this purpose, experience shows that a mixture of pure oxygen and air is best for the diver, and it is generally such a mixture which is carried.

The cylinders which have to withstand this enormous pressure need to be very carefully made. For should one burst it would go off like a bomb. It was my misfortune a little while ago, to be at one of the dockyards when just such an accident occurred. A cylinder intended to hold compressed air was being tested when it burst, fragments flew all over the workshop where it was, killing two men and injuring several more. That was probably because, in the Navy, they cut things finer and take risks which would never be allowed in civil life. Their cylinders are probably thinner (in order to save weight) than those in general use. However that may be, there is no reason to fear any danger from the latter. My readers may sit and enjoy a cinematograph show in perfect comfort although there may be cylinders near containing oxygen at a pressure of over three-quarters of a ton on every square inch. There is enough force in them to blow up the whole building if they should burst. But they will not burst, for reasons which I will now explain.

Each cylinder is made out of a seamless tube. Ordinary tubes have a seam in them formed by welding. A strip of steel is made hot, and then drawn through a hole so shaped that it curls the strip up into a tube and presses the two edges together so that, being hot, they become welded.

And that welded joint is a possible source of weakness, for the two edges may not have become perfectly joined into one piece.

A seamless tube, however, is made quite differently. At first sight it seems impossible that a tube can be made in any other way than by curling or rolling up a strip and joining its two edges. Yet it can be done quite successfully in this manner. A block of steel of the highest quality forms the material. It is, to start with, quite solid, but the first operation is to drill a hole in the middle. There you have a tube, very thick and very short, it is true, but a tube nevertheless, and it is without seam or join of any kind. Then it is made very hot, and while in the hot and soft state it is drawn out by wonderful machinery until it is changed from a short but thick tube into a long but comparatively thin one. And it is still, you will notice, seamless. Thus a tube is formed without any seam or weak spot, but of equal strength all through.

But there is the danger that it may be misshapen—too thick on one side and too thin on the other. Therefore each tube which is to be used for an oxygen cylinder is carefully measured to see that there is the full thickness of metal in every part.

Then one end is heated and squeezed in so as to form a neck like the neck of a bottle. This adds to the strength at that point by making the metal thicker there than elsewhere. After that the other end is heated and closed over to form the bottom. Then there is formed something of the nature of a seam, but to compensate for that the metal is very thick indeed at that point, so that ample strength is assured.

And when all is done the cylinders are tested. Water is pumped into them to a pressure of 1½ tons per square inch—double, that is, what they have to bear in use. What terrible danger, one is apt to think, there must be to the men who do the testing. That is not so, however, for water is used, and not a gas of any kind.

Take the case of a cylinder, such as was mentioned just now, capable of holding one cubic foot. That would only reach the test pressure when 240 feet of air had been forced into it. That air would be like a coiled up spring, and if it had the chance would spring outwards with resistless force. If a small crack or leak should appear, it would begin to rush out, but a small crack would not let out enough to lower the pressure to any great extent. Therefore the air would continue to force its way through, making the crack larger and larger until within a fraction of a second it tore the cylinder to fragments, which would be hurled far and wide like pieces of a lyddite shell.

Now let us compare what would happen were water used for the test instead. Water is practically incompressible. One cubic foot could be got into the cylinder, and little more. The pump, when set to work, would not have completed a single stroke before the pressure gauge would spring up to the pressure desired. The cylinder, strong though it is, would itself expand a little under the stress, but the water would not give way at all. Thus, if a crack were to occur the first few drops which leaked out would be enough to relieve the pressure inside, and nothing more would happen.

But there is a danger that this very act of testing may weaken the cylinder, and so what is intended as a safeguard be the reverse. Suppose you wanted a piece of string to support a weight of 10 lbs., and so you tested it by tying 20 lbs. on to it. It might be that the latter weight was just about as much as it could carry without breaking, and if that were the case the string would be so stretched that it would be much weakened. The application of the test load of 20 lbs. might, in fact, render it incapable of supporting the 10 lbs. for any length of time. That illustrates what might happen to one of these cylinders as the result of testing. But such a thing is provided against.

The cylinder under test is placed in a closed vessel of water. As the pressure is applied to the cylinder it expands, as I have just said. Now to the water vessel there is attached a tall glass tube like a huge barometer tube, and as the cylinder expands inside the enclosed vessel it forces some of the water up this tube. Presently the pressure in the cylinder is released, and the cylinder shrinks back again. If it resumes its original form exactly, the water in the tube will sink back to its normal level again, but if the cylinder has been permanently stretched the water in the tube will remain higher than it was to commence with. Now steel is to a certain extent elastic, which means that it can be stretched and when released will spring back to its original size. But there is a limit to its elasticity; if stretched beyond that point it does not resume its former size. It is then said to have been stretched beyond its "limit of elasticity." When that occurs it has been damaged, but so long as it is stretched only within the limit of elasticity you may go on stretching it and releasing it again for a very long time without doing it any harm.

The action of the water in the glass tube shows, therefore, whether in being tested this elastic limit was reached or not. If the water falls back to the original level the limit has not been reached and the cylinder has not been in any way damaged, but if the water fails to fall to the full extent there is evidently a "permanent set" in the cylinder, and it is rejected.

But all metals are apt to become "weary" under the action of repeated stresses, and the alternate filling the cylinder with gas and then letting it out again will in time cause it to become weakened. This weariness can, however, be removed by heating, and so at regular intervals the cylinders are carefully annealed and then tested afresh.

Thus cylinders of compressed oxygen or any other gas are quite safe in spite of the terrific pressures which they contain, and may be safely carried about by divers or any one else.

A further interesting point is how gases can be compressed to this high degree. It is done by an air-compressor: we might call it an air-pump, only by one of those curious customs which arise sometimes, for no apparent reason, the latter name is generally used for pumps which draw air out, but not for those which force air in. If we want to create a vacuum, we use an air-pump: to fill a cylinder we use an air-compressor.

A compressor is very like any other pump. There is a cylinder much after the fashion of that of a steam engine, with a piston inside it. As the piston recedes from one end, it sucks in air through a valve which opens to admit it; then as it returns, it forces the air out through another valve which opens to let it pass. These two actions occur alternately at each end of the cylinder. Often there are two cylinders in a compressor, the first one taking the air from the atmosphere and compressing it to half the desired amount, then passing it on to the other, which completes the work. Such a machine is a "two-stage" compressor, since it does its work not all at once, but in two stages. The reason for this is the trouble caused by heat. If you, my reader, do some hard work it makes you hot, and the same thing happens with machinery. Power has to be used up to compress the air, and that power is converted into heat at the point where the work is done, namely in the cylinder. The air becomes hot and the cylinder becomes hot, and so the latter has to be covered with a "jacket" of cold water. There is an outer cylinder surrounding the cylinder proper, and between the two the water circulates. Even then it is difficult to keep the cylinder sufficiently cool if all the work be done in one of them, but by dividing the work up so that one half is done in each, the heat produced is divided up too, and the problem of cooling is solved.

This turning of power into heat where heat is not wanted is the plague of the engineer's life, for it occurs in all sorts of places, and upsets some of the most promising schemes. Yet we ought to be very thankful for it, since it is the continual compression of the gases which form the sun which keeps up the solar heat and enables us to live at all.

The compressors which I have described are operated by some form of power such as an engine or electric motor, but the pumps[1] which are employed in diving operations are generally worked by hand. This is because the greatest depth to which a diver ever goes is about 200 feet, and at that depth, as we shall see presently, he needs a pressure of about 100 lbs., no more. This is much smaller than the 1800 lbs. or so which we sometimes need in the cylinders of compressed air or oxygen, and so less powerful means are sufficient to work the pumps. Moreover, they must of necessity be light and portable

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[1] These particular pumps are an exception to the custom just mentioned.

so that they can be taken about to the spot where the diver may be employed.

They are generally encased in a strong wooden box, so that they are always "packed up" ready to go to their work. Then the lid of the box is lifted, two little doors

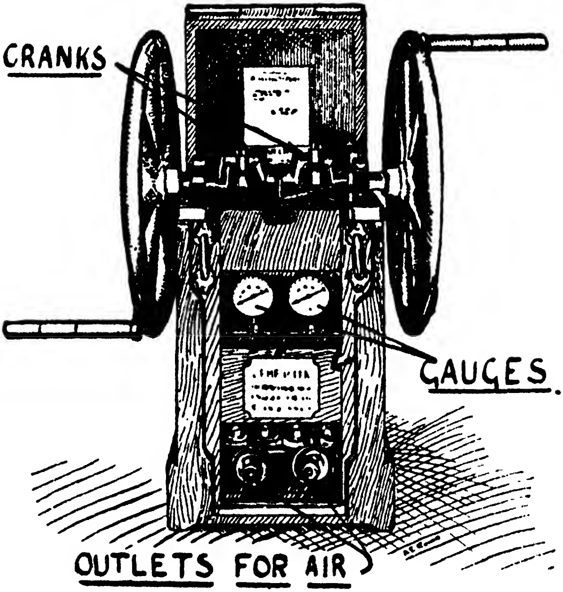


FIG. 1.—This is the kind of Pump which supplies the Diver with Air while he is at his work.

removed from the front, and all is ready. One of these pumps is sketched in the accompanying illustration. The two heavy iron wheels, to which are affixed the handles which the men turn, are to insure the regular and steady working of the pumps. Turning them rotates two cranks, which move the two pistons up and down in two cylinders inside the case. The particular one drawn is intended for either one or two divers, and so it has, as you will observe, two outlets for the air. Inside the box there is a handle which, in one position, causes both cylinders to discharge air through one of these, while in its other position the cylinders act quite separately, each supplying one diver. Higher up in the front of the box are the two pressure gauges which show the pressure of the air as it passes from the pumps down to the divers below. By observing these gauges the attendants can tell how far down under water the divers are.

So now we know what the air is made of, how it becomes impure, and how it can be purified. We have seen how it can be compressed into a small space and carried about in bottles. We understand, too, how a worker under water deprived of his natural atmosphere can make an artificial one of his own, so that cut off from all communication with the surface he can still live and do his work.

Now we will pass on to the modern diver's dress.

CHAPTER III

THE DIVER AND HIS DRESS

THERE are two kinds of dress which a diver may wear. In one he is supplied with air by means of a tube; in the other he is quite independent of any connection with the surface. As the former is the more usual, we will talk about that first.

Imagine a large garment of the "combination" type, consisting of socks, trousers, and shirt, all in one, with no opening in it at all except a wide one at the neck, and made of strong material through which neither water nor air can pass. That is about what the diver's dress is like. Its manufacture is very interesting to watch.

First of all, there is a layer of specially made cotton fabric called twill, which has been tanned like leather, to enable it the better to resist the wet. This is covered with several coats of that thin rubber solution the very mention of which makes us think of "punctures" and all the horrors of burst bicycle tyres. Then upon this is laid a thin sheet of pure india-rubber, and the art consists in bringing the two into contact just when the solution has reached the exact degree of dryness appropriate to the operation. When this is done the two things, cotton and rubber, become almost as one. The combined material is stored in long rolls, from which the parts of the garment are cut as required. Each part as it is cut has another layer of cotton solutioned on to it, making a kind of sandwich of cotton with rubber between. The pieces having been sewn together, the joints are pressed, coated with more solution, then covered with a narrow strip of "proof," as the sheet rubber is termed, and finally a wider strip of proof and cotton. So carefully is this done, that on no account is a brush allowed to be used for fear that a loose bristle should get into one of these joints; even a hair from the operator's head would cause a leak.

Then when the garment has thus been formed, certain parts have extra thicknesses solutioned on to them to protect them from wear.

There is no opening down the front, like an ordinary shirt; the man has to get in feet first through what in some parts of England would be called the "neck-hole," which consequently has to be unusually large. The edge of this hole is strengthened by a strong strip of very high-class rubber, forming what one would like to call a ring, only it is not round. This is fastened on to the dress with layers of fabric strongly solutioned, like a collar many sizes too large. Moreover, it has holes in it at intervals, for it is this "collar" which enables the dress to be connected to the metal corselet, which in its turn carries the helmet, and the holes are for the bolts which couple the dress and corselet together.

There are cuffs, too, formed of the same thick strong rubber used for the "collar," with an arrangement by which they can be clipped tightly round the wrist so as to form a water-tight joint there.

The "corselet" is a heavy plate of brass, curved to fit the shoulders, with one part coming down on to the man's chest and a similar part falling a little way down his back, while in the centre there is a hole through which his head projects. The rubber collar just fits over the edge of the corselet, and small bolts pass from the corselet, through the holes in the collar and then through holes in a number of brass strips, which are made for the purpose and which form a kind of rim all round the edge of the corselet, the collar being securely clipped between the corselet and the strips.

The helmet is a round ball-shaped object, made of beaten copper coated with tin, which screws on to the hole in the corselet. In front of it there is a little glass window glazed with polished plate glass three-quarters of an inch thick. At each side there is another little round window, so that the diver has a very fair view both to the front and to either side.

The helmet is not so heavy as it seems, for it is made of thin metal, and owes its strength to its shape and the care with which it is made rather than to its thickness. A seamless tube of copper is beaten with a wooden mallet into approximately the shape required; then a thicker piece of copper is brazed into it to form the crown; while a strong brass ring is brazed to the bottom to form the screw which connects it to the corselet. Other brass rings are brazed to the sides and front to form the windows, the front one of which, by the way, can be unscrewed.

At the back is the air inlet valve, to which is connected the rubber tube through which the air is supplied. It would be rather uncomfortable for the poor diver to have the air continually blowing in almost on the back of his neck; so ducts are provided inside the helmet, which carry it round to the front and blow it in in flat jets across the three windows. This has the effect of shielding him from a direct draught, of supplying the air near where he wants it—namely, at his mouth—at the same time keeping the windows free from mistiness through the condensation of his moist breath on the glass.

In the latest kind of helmet there is another duct, which runs round just under the front window, and which takes away the foul air, leading it to the outlet valve at the side of the helmet.

The inlet valve is of the kind known to engineers as a non-return valve. It is, in effect, a little trapdoor which the incoming air can push open and pass, but which, if the air-pipe were to burst, would immediately slam to and prevent the air returning the way it came in. Thus in the event of such a catastrophe the man would be left with a helmet full of air, enough probably to enable him to reach the surface, whereas without it the air would all escape instantly and he would stand a good chance of being drowned.

The outlet valve is also like a little round door, but it is kept closed by a spring, the pressure of which the diver himself can regulate as he needs. If he slackens this spring to its fullest extent, he will lose the air just as fast as it comes in *when at the surface.* As he descends, however, into the water, the water presses upon him more and more because it is itself pressed upon by the weight of water lying above. Therefore he needs to have his dress blown out balloon fashion. The pressure of air in his dress must, in fact, just balance the pressure of water outside. It comes to him from the pumps fairly regularly, so that by adjusting the spring of the outlet valve he can restrain the exit of the air and thereby adjust the pressure of that contained in his dress.

In this way, too, he can regulate his buoyancy. When his dress is just blown out enough to enable him to work in comfort, he is just heavy enough to sink in the water. Thus he goes down, but if he wishes to ascend he has only to tighten up his outlet valve a little, the dress becomes more distended, his buoyancy increases, and up he floats. The valve is so made, too, that when the spring is screwed up as tightly as it is possible to do, it is just weaker than the dress. The air pressure therefore cannot possibly become so great as to burst the dress.

This question of the air pressure is so important to a clear understanding of things connected with diving that I must just refer to it again. The dress is quite flexible, so that if the air pressure could not be increased as the diver descended he would be nipped by the pressure of water and the life simply crushed out of him. Something of the sort may happen if a diver suddenly fall into deep water, or should he descend a ladder or rope faster than the pumps can supply him with the extra air required to produce the necessary increased pressure. On the other hand, too much air will distend the dress and blow him up to the surface suddenly, an almost equal danger for reasons which we shall come to in a later chapter. This last danger is provided against to a great extent in the construction of modern dresses, they being made so that they will not hold too much air, while the former should be impossible if the diver's attendants at the surface look after their duties properly, but I mention them here to show the supreme importance of air pressure in all matters of helmet diving.

To resume our description, there is sometimes a second outlet valve fixed in the front of the corselet. The purpose of this is to enable the diver to work if need be on his back, the other valve being useless in that position.

Nor must we forget his boots, of leather, very strongly made, with brass caps over the toes, and with soles of wood, on to which is nailed a layer of sheet lead to ballast him, as it were, and insure his keeping "right-end-up." A more recent development in the boot line is for the sole and the cap covering the toes to be made of thick solid brass, this being an improvement on the wood and lead. On his hands he may wear rubber gloves with, if the water be very cold, thick woollen gloves under them.

The boots weigh 16 lbs. each. On his chest there is hung a lead weight of 20 lbs, while on his back is a heavier weight still of 25 lbs. With these on, he will just sink nicely and in an upright position when his dress is properly blown out. On the surface, of course, he has a tendency to fall backwards because of the extra weight behind. It is necessary, however, since his helmet is somewhat heavier in front because of the windows and their brass fittings.

Sometimes a telephone is fitted inside the helmet. The instrument is made quite flat, so that it does not incommode the diver. It is just near his ear, so that he can easily hear all that is said to him, while he on his part has only to speak to be heard on the surface. He need not turn his head to speak into the telephone, and he can "ring up" the surface by simply pressing a little button with his chin. The wires are carried up inside the "life-line" as it is called, the rope attached to the helmet by which his mates above can regulate his ascent and descent, and by which in the absence of a telephone he signals to them. Or sometimes it is incorporated in the air-pipe.

Instead of a telephone there is sometimes a species of speaking-tube, which has the advantage that it needs no delicate electrical apparatus. An ordinary speaking-tube would not do, since the air would escape up it. It has therefore to be provided with a bell-shaped mouth (a very flat bell, it is true, because of the limited room) covered with a membrane of thin metal stiffened by springs so as to be able to resist the heavy air pressure. As the man speaks he causes this diaphragm to vibrate, that causes the air the other side of it to vibrate too, which vibrations are carried by the air in the tube to the attendant above. This, of course, necessitates a second tube—one, that is, in addition to the air supply pipe.

It may be interesting to describe the operation of dressing the diver for a descent. He has on, we will assume, warm woollen underclothing suitable for the place where he is working and the work he has to do. He then gets into the "combination" dress, the corselet is put on him and properly secured to the collar. His boots are put on his feet, his cuffs adjusted, and his gloves put on if he wears them. Last of all the helmet is screwed on the corselet, and fastened so that it cannot come unscrewed. The front window is, however, left open so that he may breathe fresh air as long as possible. This ought really to be closed before he steps on the ladder to go down, for if he fell into the water with it open he would be drowned. The men, however, usually prefer to run that risk, and have it closed at the very last moment.

An attendant stands with the air-pipe in one hand and the life-line in the other, paying them out as the diver gropes his way down, while two more men turn the handles of the pump, and a fourth listens with the telephone to his ear. Thus the diver descends to his work, and there we will leave him for the present.

The self-contained diving dress is in many ways very similar to the one which I have just been describing, but it is different in some details. The most important of these is the absence of the air-pipe and, instead, the presence of apparatus for purifying the air within the dress and helmet. In this case the diver carries on his back, after the manner of a soldier's knapsack, a case containing caustic soda and two small cylinders holding a mixture of oxygen and air. A tube leads from the helmet to the caustic soda and another to the cylinders, so that the carbonic acid produced by the diver breathing in his helmet is drawn off through the one by the action of the soda, while through the other he receives supplies of fresh air and oxygen to replace what he has used up and also to increase the pressure in his dress as he descends.

The apparently trivial fact that he has *two* cylinders of air is really a most important one. Suppose that he be employed in exploring a flooded tunnel or mine (the chief use for these self-contained dresses), he might go a long way in, and then find that he could not get back again before his oxygen had given out. This wonderfully simple yet effective arrangement provides against that, however, for he uses one cylinder at a time, and when he finds that that is exhausted he turns on the other. And that serves to indicate to him that the time has come for him to be returning. It is fairly safe to assume that he will be able to get out as quickly as he got in, and so this timely warning that half his oxygen supply is gone guards against the danger.

In the ordinary dress men can do useful work at as great a depth as 200 feet; in the self-contained dress a diver cannot descend more than about 50 feet. One charge of oxygen and air and caustic soda will last for about two hours, whereas in an ordinary dress, at 50 feet, a man might stay down three hours or even longer.

Thus, on the whole, the ordinary dress is the better of the two, since it has a greater range of usefulness; but when the place to be entered is such that a long length of tube trailing behind him would hamper the diver's movements very much, then the self-contained dress is evidently the better. So each has its uses; and which should be employed for a certain job depends upon the circumstances of the case.

CHAPTER IV

THE SENSATIONS OF DIVING

A QUESTION which occurs to one is, What does it feel like to be in compressed air? So far as a moderate pressure is concerned—that which corresponds to being about 30 feet down in the water—I can speak from my own experience. The first thing you feel is a curious sensation in the ears. A slight feeling of discomfort grows, as the pressure increases, into a sharp pain, which is relieved, however, when you go through the action of swallowing. This is due to the fact that the ear consists of a passage across which is stretched a little diaphragm, a kind of miniature drum-head. This passage is open to the air so that vibrations conveyed by the atmosphere can reach the drum and cause it to vibrate. In order that it may vibrate freely, and so respond even to the feeble vibrations which cause a faint sound, the air pressure needs to be the same on both sides of the drum, and to attain this result nature has constructed a little tube from the inner side of the drum to the nose. Thus the air passes freely down the ordinary ear passage to one side of the drum and through the nose, and this "Eustachian tube," as it is called, to the other side, causing the pressure to be the same at both sides. But often the Eustachian tube is more or less blocked up, especially so if the owner of the ear be suffering from a cold in his head.

Now it is easy to see that the slightest block in this tube will be felt if the pressure of the atmosphere be increased, for the new pressure will be communicated at once to one side of the drum through the outer ear passage, while the pressure on the other side will remain what it was before. Thus the drum will be slightly stretched, bulged in, until the block in the tube either gives way and lets the air through or is in some way removed. In the ordinary course of things the stoppage is caused merely by a thick liquid which collects in the tube, and the action of swallowing tends to move this, thereby permitting the air to pass and equalise the pressures. It is the slight bulging in of the ear-drum which causes the pain, and thus it is relieved by the action of swallowing. Many men who work under compressed air carry some acid drops in their pockets, which they suck when the air pressure is changing, as that induces a natural tendency to swallow.

If a man, by reason of a cold or from any other cause, has his Eustachian tubes really clogged, he will have to refrain from diving until he is right again; it would be impossible for him to go into compressed air without serious consequences.

Apart from this little trouble with the ears, one does not feel much in going down, to the depth I have mentioned at any rate, and I am told that with a little practice it is no more trying to go down to greater depths.

Even this ear trouble, too, vanishes as soon as the pressure ceases to change. A diver might feel it as he descended and as he rose to the surface again, but it would not affect him while he remained at the same level.

In the same way a man working in a diving bell feels it only as he descends and ascends, or, if it be one of the kind of bells which remains permanently down, and to which the men pass through a shaft, he will only feel it as he passes through the air-lock where the pressure changes.

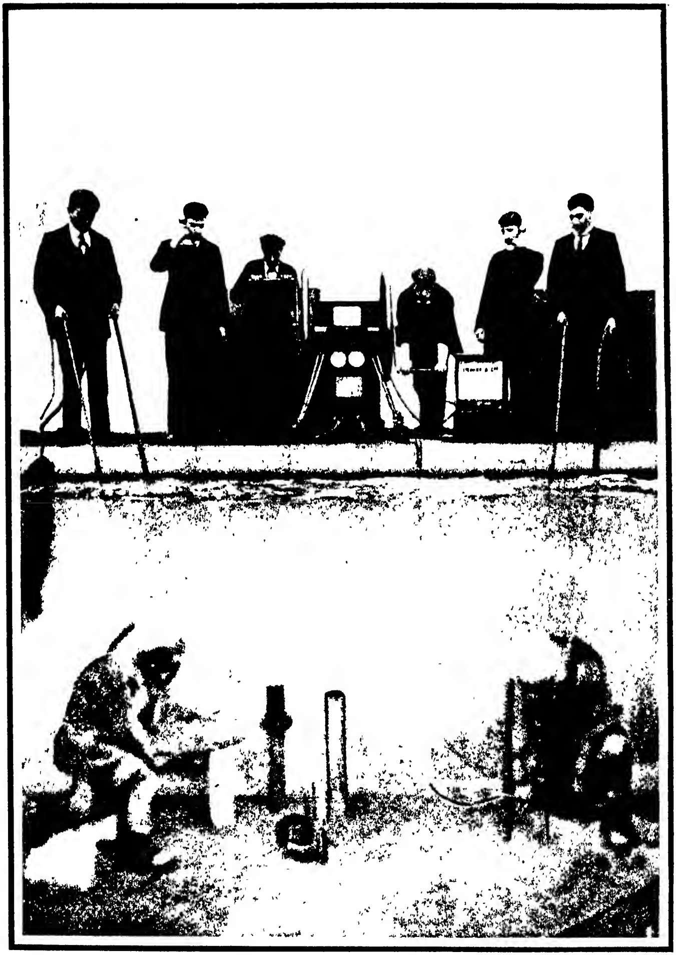
It is a standing joke when a visitor enters a diving bell to invite him to whistle. In compressed air he cannot make a sound. Even his speaking voice is changed in tone until it becomes a sound worthy of a Punch and Judy show.

But the most curious sensation connected with diving (and it does not apply, of course, to work in a diving bell) is the sense of lightness. The diver with his helmet on, and his dress distended by the air inside it, displaces an amount of water equal in weight to that of himself and his apparatus. Indeed, as I have already mentioned, he can by adjusting the outlet valve vary his buoyancy so that he can just sink or just float. To walk about in the water he needs to be on the heavy side so that he may get a foothold, but even then he can jump immense heights. Indeed, were he to walk with the usual walking action he would proceed by a series of leaps and bounds. This lightness is useful at times, for if a diver is working on the construction of a breakwater, we will say for example, and he wishes to get from the ground level on to a piece of partly completed wall, he can spring on to it with the utmost ease.

What the diver can see while below depends upon circumstances. It is evident that in clear water he will see more than in muddy water. He has lamps, of course, to help him. An electric light is often used enclosed in a strong case with thick glass windows to resist the pressure, or even an oil lamp in a case supplied with air through a pipe much as the diver himself is supplied. But even with these aids the water obscures his vision. Under average conditions we may say that his state is very much like that of a man in a thick London fog. He can just see dimly; he has to grope his way about, and often needs to call in the sense of touch to help that of sight.

The worst sensation of all that a diver is likely to experience is in the case of a too rapid ascent. He may descend as quickly as the pumps can keep him supplied with the necessary air. Indeed the quicker he descends the better, for at great depths the total time which he can stay under water is very limited. Coming up, however, great care is needed.

This is because of a curious action which goes on in the blood. If a liquid and a gas are brought into contact, the former absorbs some of the latter. Some liquids will absorb gas more quickly than others, but the quantity which each particular liquid will absorb depends upon the pressure. The higher the pressure the more gas will it take up. And if the pressure be removed, the gas will come bubbling out again. Soda-water consists of plain water with carbonic acid absorbed or dissolved in it. The water and gas are brought together under pressure, and the absorption due to that pressure occurs. The liquid so produced is placed, still under pressure, in bottles each one securely stoppered so that the pressure is maintained until it is opened. Then, as we all know, the gas begins to bubble out, causing the fizzing which is the distinctive characteristic of soda-water and its kindred beverages. All the gas does not thus escape. That quantity which corresponds to the ordinary atmospheric



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DIVERS AT WORK

This picture gives a good idea of Divers at work, and shows how they are looked after by their attendants above.

pressure remains, but all that which was in the liquid because of the exceptionally high pressure comes out.

Now the human blood is a liquid, similar in many ways to other liquids. It is rather more sluggish than water—about twice as much so in fact—so that it does not absorb gases so easily. Still it does absorb them, especially at high pressures. When, therefore, a diver goes down, and the pressure of air within his dress is increased so as to keep him from being crushed by the water, some of the air (principally nitrogen) is absorbed by the blood. It does not absorb all it can immediately, and so the process goes on practically all the time he is subject to the pressure. And as soon as the pressure is released, the air begins to bubble out again. If this takes place gradually no harm is done, but if it were to occur without restraint, bubbles would collect in one side of the heart, amid the muscles of the joints, and in the spine, thereby causing illness and probably death.

In shallow water, up to six fathoms, a diver can go down as he likes, stop as long as he likes, and come up how he likes. But below that he has to be careful. He must not stay down too long, and the longer he stays the more thoroughly saturated with air does his blood become and the more cautiously must he ascend.

The British Admiralty have gone very carefully into this matter, and a committee of experts have, under their direction, drawn up a table for the guidance of divers. According to this, if a diver is working 200 feet deep (about the extreme limit), he should not remain under water for more than twelve minutes at a time, reckoned from the time he leaves the surface until he *begins* to ascend. He must, however, make six halts on his way up so that his ascent should take, in all, just over half an hour. If for some *very* special reason he remains at this depth for an hour, he must make eight pauses on his way up, the shortest of them being for fifteen minutes, and his ascent will take altogether nearly *four hours*.

It rests with the diver's attendants to see that these times are observed, for he cannot of course look at his watch when he is under water and indeed he has very little idea of time at all. Consequently, when he descends he very largely trusts his life in the hands of his comrades above.

If by accident a diver is brought to the surface too quickly, even though he may be in a state of collapse, he must be sent down again at once. It seems cruel to send an unconscious man down into the water again, but that is the only thing to do, unless a "decompression chamber" is at hand. This is a strong steel cylinder in which the man can be shut up and the air inside compressed. Either he or his mates can let the pressure down by easy stages, and so the conditions of a gradual rise to the surface are reproduced.

So far we have been thinking of the ordinary helmet diver, whose air supply is sent him continually through a pipe from above. His sensations must be every different from those of the man in the self-contained dress whose air is provided by chemicals or from steel cylinders which he carries with him. How lonely he must feel, out of touch with his fellow-men. The ordinary diver hears the strokes of the pump which is forcing air down to him. He feels unconsciously all the time he hears that, that his mates above are working for him. It produces a feeling of companionship which is lost to the self-contained man. I shall be telling in a later chapter the great historic incident of the Severn Tunnel, the incident which established the self-contained dress as a recognised form of diving appliance. The tunnel was flooded, and a diver went in a self-contained dress to turn off a valve. Cut off from all communication with his fellow-creatures, he groped his way along the half-finished tunnel, a journey not free from danger even had there been no water there. Thus he penetrated a distance of over 1000 feet. Who shall describe the sensations of that man? Probably neither he nor any one else can adequately do so.

Thus we are forced to confess that the ordinary sensations of the diver are—well, ordinary. If he has not to work in some exceptional depth, and if everything goes right, as it generally does, thanks to the excellent appliances and the well-trained men who are available nowadays, the work is not particularly adventurous or exciting. If anything unpleasant occurs at all, it is likely to be during the ascent.

At rare intervals, of course, divers are called upon to perform heroic feats like the one just referred to, but not often.

I cannot do better than conclude this chapter with a reference to one of the greatest writers in the English language. Robert Louis Stevenson was the son of an engineer, and in his early days commenced training as an engineer himself. Fortunately for us he gave it up, and took to writing those delightful books instead, but before he did that he once descended in a diving dress, a most interesting description of which he gives in his "Random Memories."

CHAPTER V

THE EVOLUTION OF THE DIVER'S DRESS

IT was a great temptation to start this book with the earliest facts known about divers and their dresses, and gradually lead up to the things of to-day. On the whole, however, it seemed that a more understandable way would be to explain first the apparatus and methods at present in use, and then let the early history follow.

Even Homer, who wrote about eleven centuries before Christ, had something to say about diving. True, he did not say much—he only mentioned that a man was thrown out of a chariot with an action like that of a diver, but that is enough to show us that diving was known even in those far-off times. Probably (one might almost say certainly) that was naked diving, such as we do ourselves at the swimming baths; but quite early in history men tried to invent apparatus by which they could stop under water for a good long time—longer than they could possibly remain without air. It has been thought that that kindliest of beasts, the huge but gentle elephant, among the many services which he has rendered mankind, first taught us to think of diving apparatus. For the great quadruped is himself an expert performer under water. He goes down right below the surface for quite long periods, keeping himself alive meanwhile by breathing through his trunk, the tip of which he holds just above the surface. There are old prints in existence which show Alexander the Great, who died in 324 B.C., seated at the bottom of the sea, inside a glass barrel, let down by chains from a ship above. These prints, though old, were, of course, made long after Alexander's day, and are based probably upon nothing more than a legend, but, as with most legends, there is a certain basis of truth, for he undoubtedly employed divers largely in his naval wars. With their aid he cut his enemies' ships adrift by severing their cables under water, and sawed down the submerged stakes which they had driven into the bed of the sea and upon which they hoped his boats would impale themselves. We are also told by old historians that the enemies retorted in kind, so that, as early as that, diving of a very effective sort was well known.

FIG. 2.—The reputed Inventor of the Diving Apparatus.

Whether they then had any apparatus to assist them we do not know, but Aristotle, who was Alexander's tutor, when a youth, tells in his writings of an apparatus "like the trunk of an elephant" which enabled men under water to obtain supplies of air.

EVOLUTION OF DIVER'S DRESS

The great Roman, Mark Antony, the colleague of Julius Cæsar, seems to have known something of diving, for when he was in Egypt he desired to show off his skill as an angler before the Egyptian queen, Cleopatra, and so arranged for a diver to put a fine fish upon his hook under water. The lady was too clever for him, however, for she too sent down a diver to put a fish on his hook—*a salted one.*

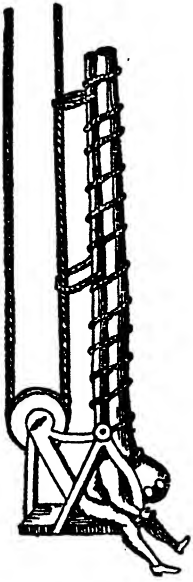

FIG. 3.—An early Form of Diving Apparatus.

And so amid the ancient writings there are frequent references to diving feats, generally in warfare, where the favourite tricks seem to have been cutting ships adrift, taking away under-water defences, and even boring holes in the bottoms of hostile vessels; and in some instances references are made to men keeping themselves alive by means of a tube, one end of which was held in the mouth while the other floated on the surface.

In the British Museum there is an old book which contains a picture of a diving dress; the man appears to be clothed in a tight-fitting garment and a helmet, from the top of which a leather pipe runs up to the surface, where it is buoyed by being tied to a bladder. This book was published in 1532.

Then a little later an Italian named Lorini invented a most curious contrivance. A little seat was formed on the end of a long pole on which a man might sit, while to the pole was lashed a long leather tube. At the

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DIVERS AND THEIR DRESS

Captain Gardiner, a famous Salvage expert, and one of his divers, nearly ready for a descent.

bottom of the tube there was a kind of globular bag with a slit in the side of the tube near it, which enabled a man to put his head through into the bag. (Fig. 3.)

Clothed in a close-fitting suit of goat-skin, the man sat on the seat with his head in the bag at the bottom of the tube, and so he was lowered into the water. His arms were free so that he could work, and the bag had holes in it covered with glass out of which he could see. The tube, being stiffened with hoops of iron, was able to keep distended even in a considerable depth of water, and so the man at the bottom of it was able to breathe. Rather "stuffy" it must have felt, but no doubt it served his purpose in a way.

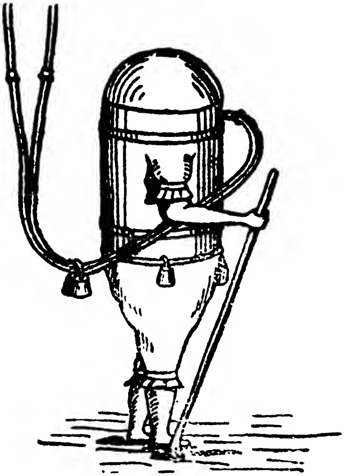


FIG. 4.—An early Form of Diving Apparatus.

About another century nearer our time, a man of Devonshire, Lethbridge by name, tried his hand at the same thing. He says that he sealed himself up in a barrel, and stayed there for half an hour without any air from outside. Then he constructed a pond in his orchard, and tried the same thing again, but under water this time. To his surprise he was then able to stop in for even longer. Encouraged by these successes, he had a large elongated barrel made of wood, which was lowered down into the water in a horizontal position by a rope, while he lay full length in it. There were two holes in the underside through which he thrust his arms, and a glass window through which he could see. He states that he frequently went down in shallow water, and stayed there without any fresh air for thirty-four minutes. He even went down as deep as twelve fathoms, but that, he confesses, was "difficult." He appears to have had a try at salving some treasure from a sunken ship in Plymouth Sound, but without success.

Again we skip a century or more, and then we find a man walking about below the water encased in a thin cylinder of sheet metal. This entirely covered him down to his hips, with a hole on either side for his arms to go through. Underneath he wore a suit of leather, to which the bottom edge of the cylinder was fastened. He inhaled air through a mouthpiece something like the mouthpiece of a speaking-tube, which was connected by a pipe to the surface, while he exhaled through his nose into the interior of the cylinder, and the foul air escaped up a second tube. Thus he acted as his own air-pump. Weights were attached to him to make him sink, and when he wanted to rise he shed one of them, rising, therefore, on just the same principle that a balloon does, when it throws away some of its ballast. (Fig. 4.)

There was no air pressure in this apparatus, you will observe, and the diver so equipped could not go far down, or he would have been crushed by the water. To overcome this, the inventor, a German named Kleingert, of Breslau, added an air reservoir, which the man took down with him. This was a strong metal box with a cylinder at one end like that of a pump. There was a piston in this cylinder, free to move in and out, and, as the concern sank in the water and the pressure increased, the piston was forced in and the air inside thereby compressed to the same pressure as the water outside. From the air contained in this box the diver drew his supply through a tube, and so the pressure in his dress became the same as in the box, and that being the same as the pressure of the water, the diver got exactly what he gets in the up-to-date apparatus—just sufficient pressure of air to balance the pressure of water.

The date of this ingenious invention was 1798, just about the time when Watt was creating the modern steam engine, and within a few years after that the first really modern apparatus, a metal helmet combined with a waterproof suit and supplied with air by a pump, made its appearance. An old helmet of beaten copper with two tiny windows, one for each eye, a connection at the top for the air-pipe and a tap to regulate the escape of the air, was shown me quite recently. It has been in existence since about the time of which I have been speaking. (Fig. 5.)

FIG. 5.—A Diving Helmet of 100 years ago.

In 1819 a man named Augustus Siebe, who will always be remembered in connection with diving dresses, brought out a complete dress in all essentials like those in use now, except that the jacket was separate from the lower part of the dress, and so the air escaped at the lower edge of the jacket. This meant that, if a diver fell, the air escaped and he might be drowned, so, later on, this "open" dress, as it was termed, gave place to one of the "closed" type, where the dress is entirely air and water-tight, so that, no matter what position he may be in, the diver runs no risk of losing his air. And that brings us to the modern apparatus already described.

But before concluding the chapter, we must skip back some two hundred years and take a look at what may be regarded as the precursor of the modern *self-contained* dress. A man named Borrellus, in a book written in Rome in 1682, tells of a diving apparatus which he had invented. A very large helmet, *two feet* in diameter, shaped to fit the man's neck and shoulders, covered his head, so that he had a fair amount of air to start with. He carried with him a primitive kind of air-pump, a cylinder and

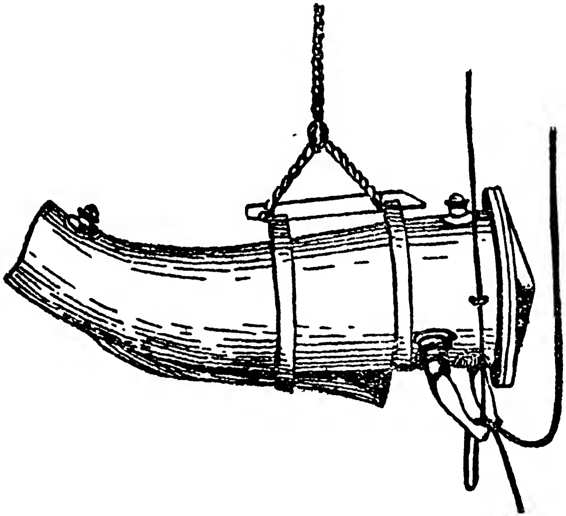


FIG. 6.—An early Form of Diving Apparatus.

piston with the piston at the top. By pressing this piston down when he needed it, he could transfer the air in the cylinder into his helmet so as to increase his pressure and also to increase his weight by the water which flowed in at the other end of the cylinder. Thus, by the same action, he caused himself to descend and also gave himself the extra pressure needed. But the most curious part about the thing is the device for "purifying" the air. A tube, about three feet long, left the helmet at about where the man's mouth would be, curled downwards, and then returned to near the same point, while in the loop thus formed there was an enlargement forming a kind of sac or bag.

The idea was that this purified the air. The diver put his mouth to one end of the tube to inhale and to the other to exhale, and the inventor contended that by thus passing through a tube, *kept cool by the water*, the air was rendered fit to breathe again, while the moisture of the man's breath would condense in the cool tube and collect in the sac. This last part of his claim is no doubt sound, but "I hae ma doots," as our Scotch friends might say, about the other. If one really must breathe vitiated air, it is possibly nicer to have it cool, but cooling is not, to any extent at any rate, the same as purifying. Thus it seems doubtful if this ingenious contrivance was of much use, but it is interesting, since it appears to have been the first attempt to purify the air and so bring about the self-contained diving dress.

CHAPTER VI

DIVING BELLS

THERE is a well-known swimming expert who will sing you a song under water; which seemingly marvellous feat he performs in a most simple way. He takes with him to the centre of the bath an ordinary iron bucket: he then inverts it over his head so that it covers him down to below his mouth. Then, bending his knees, he sinks down until the water entirely covers him and his bucket as well. The air inside the bucket keeps the water from entering it, and at the same time enables him to go on breathing for a little while: not for long, it is true, but long enough to sing a verse of a song, the sound of which passes up through the water.

Now that bucket, so used, is a diving bell. If only it had a pipe through which fresh air could be pumped down, a man so equipped could remain under water for a long time. If it were larger he could remain longer, even without the air-pipe, for the air there originally would last out longer. The main fault about the bucket, regarded as a diving bell, is that it contains so little air to commence with.

Of course if the man went down to any great depth the bucket would be of no use, for the air inside it would be compressed as the water pressure rose. By the time he had descended a little over 30 feet it would become compressed to half its original volume, so that probably the water level would by then have risen above his nose. This entry of the water would happen, indeed, in any bell, no matter what its size might be; and so, even large bells, although they may contain enough air for the man or men inside to breathe for a long time, need to be supplied with air from outside so that more may be forced into the bell as it descends, to keep out the water altogether.

The name diving "bell" is used because the early examples were most of them bell-shaped. Now, however, they are more often the shape of square or oblong boxes, or else round cylinders like magnified coffee tins, since these forms are more suitable for the actual work which they have to do than the old bell-shape.

It is said that the old English monk, Roger Bacon, was the first to suggest the diving bell. He was a very remarkable man for his time (1250), so much so that his neighbours took him for a wizard, but really he was an extremely clever scientist, and it is quite likely that this tradition may be correct, although there are no documents in existence to prove it.

A book printed in the year 1664, however, describes how two Greeks gave an exhibition before the Spanish king, Charles V., the father of King Philip of Armada fame, in the year 1538. These two entered a large "kettle," which was lowered into the water, mouth downwards; the kettle being suspended by ropes and weighted with lead to make it sink. We are told, too, that they took a lighted candle with them, and brought it up again still burning. This exhibition took place at Toledo in Spain, before the king and a crowd of people. Cannot we just imagine the wonder of that simple crowd when they saw the men come up alive, and with the candle still alight too!

About the same time a man named Sturmius invented a diving bell, into which he contrived to introduce fresh air by a curious means. His method was to take it down in glass bottles and liberate it by breaking them.

It is strange that two separate men of the not very common name of Bacon should be associated with the early history of this wonderful idea; but it is so, for the great Francis Bacon, in his famous book *Novum Organum*, tells how men working on wrecks could have a reservoir of air in which to breathe. This took the form of a hollow vessel of metal which was let down to the bottom of the sea with its open mouth downwards. It stood upon three legs about the height of a man. The men, who must have dived naked, were able to do a little work, run to this vessel, put their heads inside, have a good breathe, and then go back to work again. Thus it saved them the time which they would otherwise have had to expend in going up to the surface for air, and when we remember that two minutes is a long time for men, even with long training, to remain without air, we can see what a great saving this contrivance must have effected, by providing them with a breathing place close at hand.

The first really practical diving bell was the invention of the great astronomer Halley, whose comet pays us periodical visits still. The bell was made of wood, in shape very like the bucket which we were speaking of just now. It was 3 feet in diameter at the top, 5 feet at the bottom, and 8 feet high. Ropes suspended it from above, while heavy weights fastened to its lower edge caused it to hang in the vertical position and to sink as the rope was paid out. The original part about it was the curious way in which fresh air was supplied. Halley had his air, as many people have their drink, in barrels. There were two of these, lined with lead to make them sink and each attached to a rope. At the bottom of each was a hole, while to the top was connected a leather pipe, with a weight at the end. The barrels were let down empty—of water, that is, and consequently full of air. This did not escape through the hole at the bottom for the simple reason that it *was* at the bottom; nor did it escape through the pipe, because the weight on the end

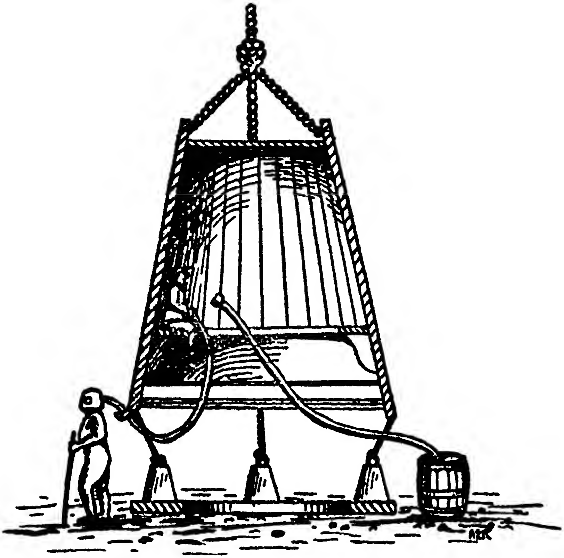


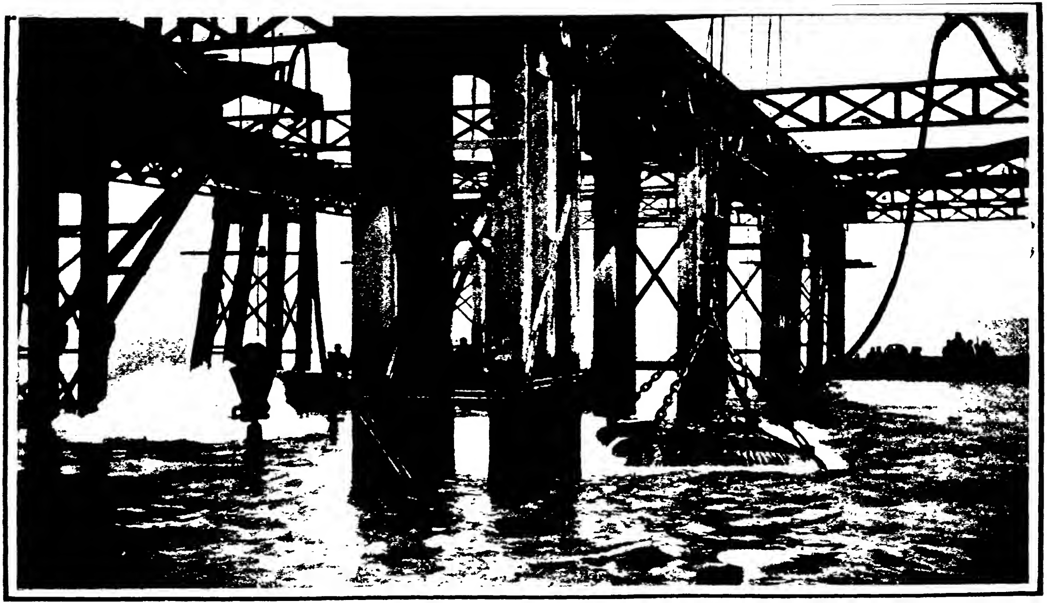
FIG. 7.—Suggested section of Diving Bell invented by Dr. Halley (of Comet fame), to which the air was taken down in barrels.

caused it to fall down to an even lower level than the bottom. So the sinking barrel carried all its air down with it. But when it had arrived, and the weighted end of the pipe was lifted up inside the bell, then the air naturally rushed up into the bell, while the water rushed in through the hole in the bottom to take its place in the barrel. The two barrels were let down alternately, and so well did the arrangement work that the future Astronomer Royal was able, with four others, to remain in a depth of from nine to ten fathoms for an hour and a half without inconvenience of any sort.

This idea was copied, and more or less improved, by others, until in 1788 the great engineer Smeaton, who designed one of the famous Eddystone lighthouses, invented a diving bell to which air was driven by a pump. This he improved a few years later into a bell very like what is used to-day. He made it for some work which he had to do in the construction of Ramsgate Harbour. It was a square chest of cast iron, 4½ feet high, 4½ feet long, and 3 feet wide, so that there was room in it for two men to work; at least Smeaton says so in his description of the work at Ramsgate, but it would seem uncomfortably close quarters for two men. The air was pumped down to them through a tube by a "forcing air-pump," as he terms it, in a boat above.

The simplest way to tell of the modern bell will be to describe it at work on a breakwater, such as those at Dover, which are constructed of enormous blocks of concrete weighing 50 tons or so each, laid by divers.

The first thing needed in such work is some quick and easy way of handling these great weights. One way is to drive in rows of piles along each side of the proposed breakwater, so that it is ultimately built in a sort of



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DIVING BELL IN USE

A bell just being lowered into the water. The work here shown is the construction of the Harbour Extension at Folkestone.

avenue of piles. On the tops of each row of piles a kind of long strong platform is formed, constituting what is known as a gantry, on which runs a travelling crane.

There are lots of cranes which travel, but they are not all what are known to engineers as "travelling cranes," for the term has come by long custom to be applied almost exclusively to an arrangement such as I am about to describe.

A strong girder passes from one gantry to the other, across the breakwater that is to be. Its ends are fitted with wheels so that it can run on rails on the gantries, lengthwise of the breakwater. It also has rails of its own, on which a small carriage or truck can travel from end to end of itself, or *across* the breakwater, and this carriage bears the crane proper—the mechanism, that is, which actually lifts the load. Sometimes a steam engine is fitted on the carriage, but more often, in these days, electric motors. Such is a "travelling crane" or "overhead traveller."

To build the breakwater the traveller is run along the gantry to the shore end where a block is lying in readiness. The craneman, seated up above, on the girder, manipulates his motor, and a powerful hook descends on the end of a chain or wire rope. This is fastened to the block, and the order given to lift. The craneman then sets his motors going, the block rises, and at the same time away goes the whole concern down the gantry with the fifty-ton block swinging beneath it.

Arrived over the spot where the block is to be set, the craneman stops the crane from travelling farther. Maybe the position is just right, or he may have to run his carriage a little way to one side or the other. Then ne slowly lowers the block until it finds its resting-place on the bed of the sea.

Now that is all very well as far as it goes, but it would not do simply to drop the blocks on the sea-floor without any preparation. So before lowering a block the crane first lowers a diving bell. This is a strong box, built of steel plates riveted together. Those used at Dover were 17 feet long, 10 feet wide, and 6½ feet deep, and, with the heavy cast iron ballast weights which were fixed to the lower edge to make them sink, they weighed 35 tons each. A contrast in size to the little thing used by Smeaton!

Strong chains are fixed to them whereby the crane can lay hold of them, glass lenses let into the roof or sides admit a certain amount of light, and small platforms are fitted inside on which the men can sit or stand as they go up or down.

A structure of this description, with workmen inside, is lowered on to the place where a block is to go, and the men clear and level the ground, making all ready for the block. While doing this they are, you see, within a strong chamber like a room, in some cases quite a large room, well supplied with air through a pipe or pipes, and brilliantly lit with electric light, the current for which comes down through flexible insulated cables. Under such conditions working under water is as safe, and almost as comfortable, as in many a workshop on the surface. The worst of it is that it is apt to be rather "sloppy" under foot.

All having been made ready, the bell is pulled up and the block lowered down by the crane in its place, being guided and adjusted by helmet divers.

On many jobs, I should explain, gantries are not constructed, but a different kind of crane is used which does not need them. "Titan" is the name which has been given to it, or, since it is so often used for this work, it is frequently termed a "block-setting crane." It consists of a short and very strong steel tower fitted with wheels for travelling. On the top of this tower there is pivoted a long and very powerful arm, along which runs a carriage like that of the traveller. The tower runs on rails on that part of the breakwater which is already finished, while the arm is long enough to reach out beyond the end of the completed work and so lay the blocks there. Whichever crane is used, however, the procedure is the same. The diving bell is first lowered, and then the block.

"But," I think I can hear someone say, "it is all very well to talk about the men's safety, but suppose the air-pipe got cut, would not the men be drowned? It seems a thing which might easily happen." That is provided against in the same way that it is with the helmet diver, by having the air pass in through a "non-return" valve. The pipe might then be cut, but the air already in the bell would not escape, and in all probability that would easily last until the bell could be drawn to the surface. It must be remembered, too, that there is generally a telephone from the bell to the air-compressor, so that the men in charge of the compressor know just how their comrades below are faring, and the air supply can be adjusted to suit them. Then, again, there is telephonic communication between the bell and the craneman, so that, the moment those in the bell wish to ascend, instant effect can be given to their wishes.

And now we can turn to another form of diving bell known as a caisson—a French word originally, but pronounced in technical English either "cayerson" or "cassoon,"—you may take your choice.

Suppose that you want to build the foundations for a bridge in the middle of a river. The caisson is probably the means you would adopt. First of all, piles are driven in around the spot where the foundations are to be, so as to form a strong staging on which to work. On this

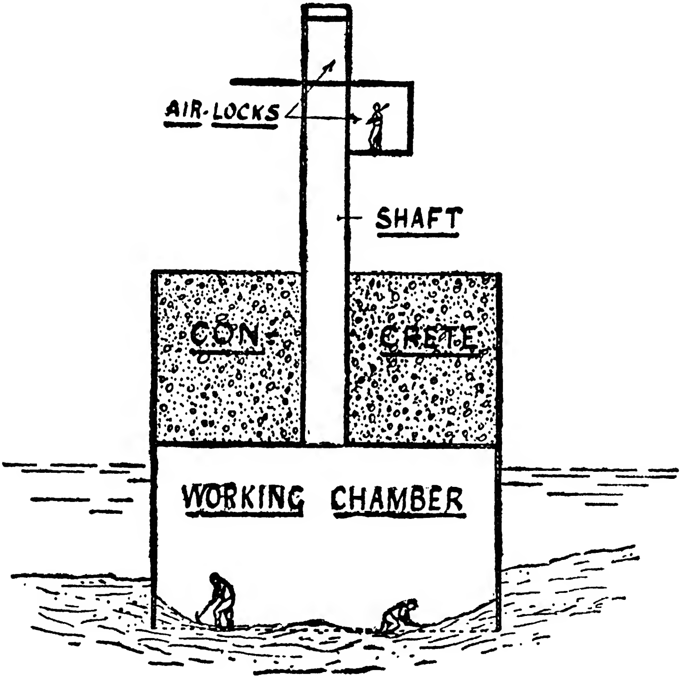


Fig. 8.—A Caisson such as is used for Constructing the Foundations of Bridges.

will be built up a strong steel cylinder open at the bottom, and with the bottom edge made as sharp as possible. About half way up the cylinder will be a strong steel floor with a hole in the centre, and from that hole there will arise a vertical steel pipe or shaft, probably about 3 feet or so in diameter.

That will be the "caisson." When it is all ready, it will be lowered down on to the bed of the river exactly where the foundation is to be. The upper story, as we might call it, from the floor to the upper edge of the cylinder, will probably be filled with concrete to make it heavy, for it has got to bite its way, by means of its sharp edge, into the ground. Then on the top of the vertical pipe is fixed an "air-lock."

This consists of an air-tight chamber, with air-tight doors. You open the door and enter the chamber; then, having closed that door behind you, you open a tap which gradually lets air into the chamber until it reaches the same pressure as that in the shaft; then you open the other door, and step through it into the shaft. Thus the air-lock enables anyone to enter or leave the lower part of the caisson *via* the shaft, without letting any but a very small quantity of air escape.

The air-lock having been fixed, air can be pumped into the shaft, driving out the water in the lower part or "working chamber," after which all is ready for work. The workmen, passing through the air-lock, enter the working chamber, and commence to dig away the earth inside. As they do this the sides of the excavation fall in, and the caisson sinks lower and lower into the earth until it reaches a good solid stratum on which it is safe to build the foundation of the bridge. The earth which is dug out is hoisted up through the air-lock, sometimes the same one through which the men pass, but more often through another specially made for it.

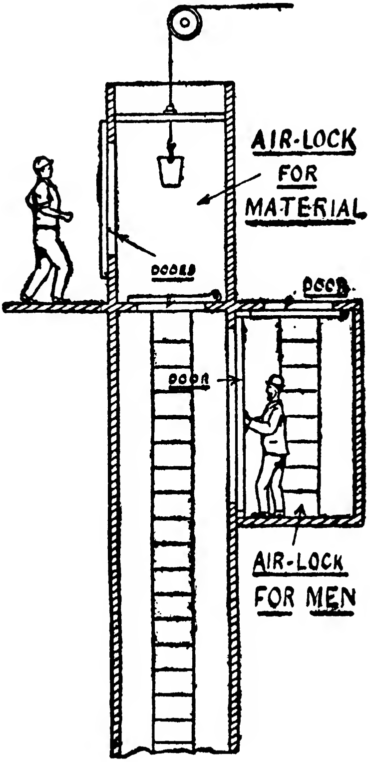


Fig. 9.—The top of a Shaft above a Caisson showing the two Air-locks, one for Men and the other for Material.

When it has gone low enough, the caisson is generally filled in with concrete, so that the caisson itself forms a kind of steel sheath around the lower part of the structure. It is very like a diving bell, you will observe, except that it is permanent, forming ultimately a part of the work in hand, and not simply lowered for a time and then drawn up again.

Then there is another kind of bell which is a sort of mixture of these two, and it has a mixed name to denote the fact, for it is called a "caisson bell." This is like an ordinary diving bell, but with a shaft springing from its roof fitted with an air-lock at its upper end. It has the advantage that it can be left down until the work is finished, even if the men have to come up. They can easily get out through the air-lock, and fresh men can go down the same way to relieve them. A bell of this description is often fitted to a special barge so that it can be conveniently taken to any place, lowered down, work done, and then raised again. The British Admiralty have one at Gibraltar, for example, for laying moorings. The working chamber measures 14 feet long, 10 feet wide, and 7 feet high, while the shaft is 3 feet in diameter and 37 feet high, and the whole weighs about 40 tons. There is a square opening in the centre of the barge, in which the bell hangs, suspended by steel wire ropes from a four-legged structure which stands over the hole. When the bell is drawn up, the shaft stands up in the air like a huge chimney in the middle of the barge, completely dwarfing the real chimney belonging to the steam engine which works the machinery on board.

When bells are used for deep diving they sometimes have a decompression chamber incorporated in them. A part of the bell is partitioned off as it were, and closed by an air-tight door. When it is time to ascend, therefore, the men shut themselves up inside this, and the bell can be drawn up as quickly as the crane can lift it, the men decompressing themselves after they have reached the surface. But for this the bell would have to be raised slowly and by degrees, as explained in an earlier chapter.

CHAPTER VII

THE PRINCIPLES OF THE SUBMARINE BOAT

THE precise details of the modern submarine torpedo boat are well-guarded secrets. The men who build them, and who work them, are all sworn to secrecy, and it would be treachery to his country for one of them to reveal what he knows about them. If, however, we think out the principles which must control the design and the operation of one of these boats, it is not difficult, with the aid of the scraps of information which are available and a little knowledge of the submarines of the past, to form a very good idea as to what even the most modern ones must be like.

The submarine, as almost everyone knows, is a boat which can travel beneath the surface of the sea. There are two main kinds of them—submarines proper and submersibles. The former are intended to work entirely under the surface; they are therefore small, suitable for short sallies from a port, or for being carried on the deck of a large ship and launched when near the enemy. They never voyage any distance on the surface.

Submersibles, on the other hand, are comparatively large, and are capable of making quite long voyages, on the surface, just like any other ship. Most of the modern submarines are submersibles.

The submarine proper has no engines. Her propeller is worked entirely by an electric motor, which draws its current from accumulators. These, as my readers are probably aware, are secondary batteries—batteries which need to be charged. First, current from a dynamo is driven through them; then when that has been done for a time, the two ends are connected together and current flows out of them. This current gradually becomes weaker, however, so that after a while the batteries have to be charged again.

The submersible has an oil or petrol engine as well. When on the surface, she uses this, and by its means can in some cases go fairly fast and for long distances. When she is ready to dive, the engine is stopped and an electric motor is set to work instead. The engine and the motor can be made to turn the same shaft by means of clutches. These are couplings which can be connected and disconnected at will. There is one, for example, in every motor car, between the engine and the mechanism which turns the wheels. By working it the driver can at any moment disconnect his engine from the rest of the machinery of the car, and so let his car go "free-wheeling," as a bicyclist would term it. A moment later he can "throw the clutch in" again, and then the engine and

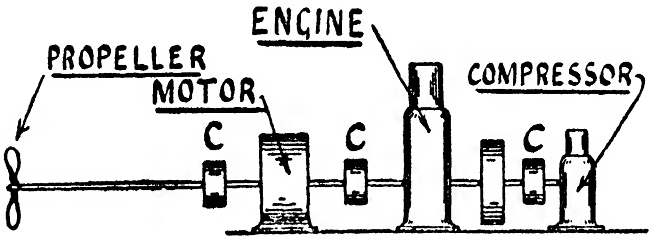


FIG. 10.—The Machinery of a Submarine. By means of Clutches (C) they can be worked in various Combinations.

the rest of the mechanism will be working together once more. He can do either, connect or disconnect, by the simple movement of a pedal.

In just the same way the submersible's engine and motor are each connected to the propeller shaft by means of a clutch. It is quite easy, then, when the time comes to dive, to stop the engine, disconnect it entirely by throwing out the clutch, and by the same means bring the motor into action. Thus the engine is readily available for surface work and the motor for under-water work. The engine is the better of the two, and is always used when possible, but since it consumes air, which is valuable in a boat when submerged, while the motor needs no air at all, the latter is always employed when below the surface.

It could be easily arranged, and probably is so arranged in all cases, for the engine while running to charge the accumulators. An electric motor is exactly the same as a dynamo which generates current. In fact, the same machine can be used for the two purposes. If you put current into it, it will give out power; if you put power into it—in other words, if you drive it—it will give out current. By making the engine drive the motor, then, the latter can be made to generate the current which, after being stored in the accumulators, will, later on, drive it. A boat which could not charge its own accumulators in this way would need to have them charged at intervals by current from another ship. In like manner the engine can be made to work an air-compressor, and so fill the cylinders of compressed air which are needed under water.

So much for the driving of the boat; now we come to the most important of all matters in the submarine, the diving and the regulation of its movements under water. The ordinary ship steers to right and left only, but the submarine steers upwards and downwards too. It seeks to dive down a little way, then pursue its course on a level, parallel with the surface, until it is time to come up again, and then it needs to be able to rise to the surface quickly.

To this end it has rudders working in both directions; one or more to steer to right and left, and others to steer up and down. It has tanks, too, which can be filled with water so as to increase its weight and enable it to sink. There are several ways in which these can be filled and emptied at will. Water can be pumped in from the sea into closed tanks already full of air. That would compress the air, and so when it was desired to empty the tanks again it would probably be sufficient to open the cocks connecting with the sea, when the compressed air would push the water out again. Or the air might be allowed simply to escape, letting the water flow in to take its place. In that case the water would need to be pushed out again, either by a pump or by admitting to the tank compressed air from cylinders arranged for the purpose. Whatever method is adopted, the purpose and result are the same—to make the boat heavier and so make it sink.

A thing floats in the water because it is able to displace a quantity of water which is heavier than itself. When, for example, you throw a piece of wood into a pond it pushes aside some of the water and sinks into it. But when it has pushed aside or displaced a quantity of water whose weight is equal to its own, it does not sink in any farther but remains floating partially submerged. The depth to which it buries itself in the water depends upon the proportion between the weight of the thing itself and an equal volume of water. The lighter the thing is, the more of it will remain above the surface.

Thus, by taking water on board any ship, and thereby displacing some of the air which was there before, the vessel can be made to sink deeper into the water. Many ships do this habitually. If one has little cargo, so that she would float high out of the water, it is often arranged to take in "water ballast" to make her sink deeper.

Now you may have noticed from your own experience that a thing either floats on the surface of the water or else sinks to the bottom. You never see anything floating at, say, a foot below the surface. Nothing floats *in* the water as a balloon does in the air; it either floats *on* the water or not at all. That is because of the fact already referred to, that water is practically incompressible. A cubit foot of water weighs just the same at the bottom of the sea as it does at a foot deep. Consequently a thing which will not float at the surface will not float anywhere.

There is a very interesting little experiment which anyone can try illustrating this. Get a deep vessel of glass and fill it half full with salt water. Be sure that the water contains all the salt which it is capable of holding, a state of things which will be indicated by the fact that salt remains at the bottom undissolved. Then very gently pour fresh water on the top of the salt water, taking care not to disturb the latter. Finally place an egg on the surface and see what happens. It will sink in the fresh water, but will stop falling as soon as it reaches the salt water. It will in fact float on the surface of the salt water.

Now that is because an egg is just heavier than its own volume of fresh water, but lighter than its own volume of salt water. If the water of the sea got heavier as one descended, a submarine, by adjusting its weight, could sink to any desired level and there float; but since it is just about the same all the way down, with not even as much difference as there is between fresh water and salt water, some other method of regulating the depth has to be found.

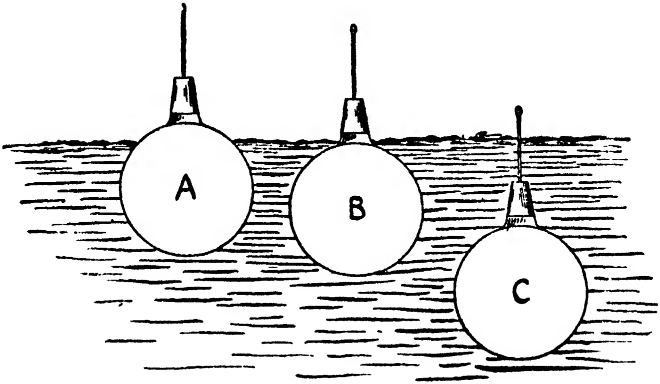


FIG. 11.—Various Positions of a Submarine. A, on the Surface. B, In "Diving Trim." C, Submerged.

So now we understand the conditions under which a submarine boat has to float and dive. Let us now see how these conditions can be used in submarine navigation.

The normal position of the vessel is with a considerable portion of her out of the water. To get into "diving trim" water is admitted into the ballast tanks, so that she sinks until only the conning tower, the short stumpy tower erected on her back, is out of the water. At the same time water is introduced into what are known as "trimming tanks," one at each end, to insure that she shall maintain an even keel. If she sinks a little too low at the bow, some of the water in her fore trimming tank is pumped or blown out into that in the after part of the ship, and *vice versa*. By these means she is all but submerged yet kept floating quite level. Last of all, there may be a small tank right in the centre into which water can be introduced without altering the trim of the boat and by which the final adjustment of the buoyancy can be made.

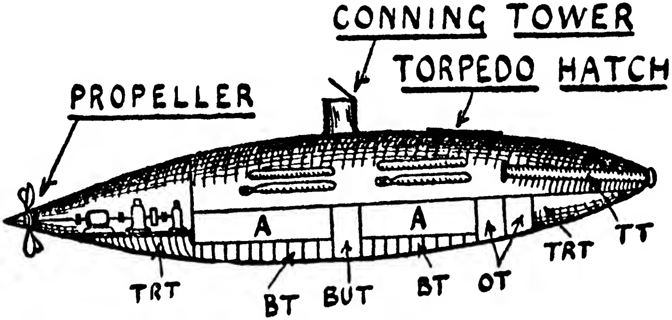


FIG. 12.—How a Submarine may be arranged internally. TT, Torpedo Tube. TRT, Trimming Tombs. BT, Ballast Tanks. BUT, Buoyancy Tanks. OT, Oil Tanks.

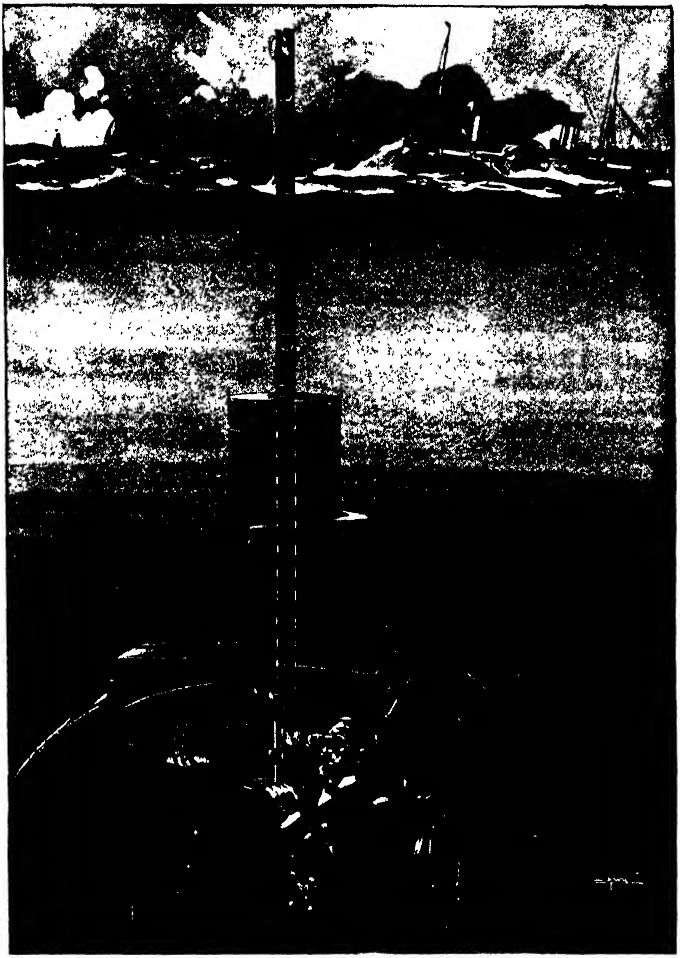
Under these circumstances the boat weighs but a few hundred pounds less than the water which it can displace. Just a little more water in her, and she would sink like a stone, and sink to the bottom too. That little extra water must not therefore be admitted. This is where the use of the horizontal rudders comes in. They are powerful enough to steer her downwards in spite of this slight reserve of buoyancy. Of course she has to be in motion for her rudders to have any effect, and so she can only keep under water so long as she is moving. If for any reason, purposely or accidentally, her propeller stops, up she comes to the surface of her own accord.

If she needs to come up quickly, she can steer herself upwards, just as in diving she steers herself downwards. Or she can blow some of the water out of her tanks, while finally in some cases there are weights hung on the outside of the boat which can, in an emergency, be dropped, so that, relieved of them, she fairly springs to the surface.

While moving under water, too, the rudders are constantly at work keeping her at the same level, just as on the surface the ordinary rudder is always at work keeping a ship on a straight course. A spirit level or a pendulum will play much the same part in this as a compass does ordinarily, for it will show the man who is steering whether his ship is pointing upwards, downwards, or level.

This difficulty of keeping the ship level has been one of the chief obstacles in the development of the submarine. So long as the boat is fairly deep and short there is no trouble, and this was the shape adopted in many of the earlier ones. It is not a convenient shape, however, for other reasons, and so the difficulty has had to be overcome by a laborious development of the rudders and balancing devices until just the right shape, size, position, and arrangement were found.

The periscope, which forms the eye of the submerged vessel, is a kind of combination of a telescope and a camera obscura. A long tube projects upwards from the boat: to the top end of it there is fixed a mirror, or else



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.

a glass prism, which has just the same effect. This reflects down the tube a picture of what is in front of it. Lenses suitably arranged enable an observer in the boat to see this picture, and so to see what is going on on the surface. The picture which he sees, however, is on a very small scale, and the details are very tiny; or else, if he has lenses which magnify, he may see larger details, but the range of view becomes correspondingly smaller. In any case the tiny mirror or prism only "sees" a small piece of the view at a time, and has to be turned round to look in different directions. Anyone who has had experience of looking through a telescope will realise how difficult it must be to control the movements of a submarine by what one can see through the periscope, for the telescopist has the full use of his eyes as well as his instrument, and he takes with them an extensive view all around, picking out for examination with the telescope anything which is specially interesting. If he had to search the whole horizon with the telescope alone, it would be a difficult thing to do. The submarine is therefore, when submerged, if not exactly blind, like a very near-sighted man, and it has to grope its way about with extreme difficulty.

And now a word as to the air supply. If the boat be of fair size, the air which it contains will last for a good time. There is a case on record in which a submarine with seven officers and men on board remained under water for fifteen hours without needing to have recourse to the flasks of compressed air with which they were provided. Many of the older submarines therefore made no preparation at all for any air supply, but depended entirely on what the boat itself contained when it went under. Nowadays, however, there is generally a reserve of air carried which can be liberated if desired in the boat, thus partially renewing the atmosphere which it contains.

So there we have the main ideas which must be found exemplified in any submarine, and armed with this information we shall find little difficulty in wrestling with the descriptions given in the following chapters.

CHAPTER VIII

THE EARLY HISTORY OF THE SUBMARINE

CONTRARY to the general idea, which is that the submarine is a very modern invention, it has in fact a quite respectable history behind it.

We have heard already of Alexander and his glass barrel, but we cannot go so far back as that and find real submarine boats. The first reference to them as actually existing, in old writings, is from the pen of a Right Reverend Bishop of Upsala in Sweden, who, before the time of our Queen Elizabeth, saw leathern boats in which he says certain pirates used to move about under water in the exercise of their nefarious calling.

One of the old sea-dogs of the Armada period had ideas on the subject of a very practical kind. William Bourne was his name, and, although he did not apparently ever put his scheme into actual use, he has left us a description of it. He conceived of a boat parts of which should be made of leather, shaped like concertinas and controlled by screws so that they could be made to bulge in or out. By bulging them in he thought to make the displacement of the vessel less without altering its weight, and so to make it sink to the bottom of the sea, while to rise again he intended to do the reverse, and bulge the leather parts out. The air supply he proposed to get through a hollow mast projecting above the surface.

The practical idea of under-water navigation can therefore be traced back to the time when history is common to both the great English-speaking peoples, and readers on both sides of the Atlantic will be able to join in honouring this far-off ancestor who took so early a part in the evolution of this wonderful invention.

The first man of eminence to venture his life in a submarine was King James the First, who, though a very cautious man (as might be expected since he came from the north of the Tweed), was so taken with an invention of Cornelius van Drebbel, a clever Dutch inventor, that he made a voyage (at least, so tradition says) in a boat which he had made. This was on the Thames. No details or plans of the vessel have come down to us, but it is claimed that it could travel under water from Westminster to Greenwich, and it appears to have been propelled by twelve rowers. It is also said that this clever Dutchman had found out, what was not thoroughly understood then, that it was one particular part of the air which men needed for breathing, and further, that he knew of a "chemical liquor" which was able to give off this vital constituent of the air, oxygen, as we call it now. Whether or not he really knew of such a liquid is doubtful, for it is not known now, and so if he did know of it the knowledge has died since. The fact that his boat was a success proves nothing, for, as has been remarked already, if it be of fair size men can live in a submarine for quite a long time on the air which it contains, without purification.

As is often the case with inventors, many of those who helped to evolve the submarine were much hampered for lack of funds. One of these, Day by name, hit upon an original method of "raising the wind," the ultimate results of which were, however, tragic. He was a wheel-wright living in Suffolk, and he started with experiments on keeping alive under water in a closed vessel. In this he made some very successful trials, sinking himself in one of the Norfolk Broads, where he stayed in 30 feet of water for twenty-four hours. His vessel was an ordinary small ship, of the kind used on the broads, covered in so that it could be sunk without filling.

But at this point the financial difficulties cropped up, and his thoughts turned to a local gentleman of wealth named Blake, who was noted for a fondness for making bets or wagers. Day therefore wrote to Blake, and suggested that he should make a bet with some one that a man would sink himself in the sea to a depth of 100 feet, remain there for twelve hours, and then rise again none the worse. Of course Day was to be the man to perform this feat and win the bet for Blake, who was to pay the intrepid diver £100 for every £1000 which he made out of it.

This curious arrangement was finally concluded, and the experiment took place near Plymouth. A ship was fitted with what we might call a waterproof cabin, and loaded with ballast till it sank. Part of the ballast consisted of two heavy detachable weights controlled from the cabin, the intention being that Day should release these when the time came for him to return to the surface, and that the ship, relieved of their weight, would forthwith float up.

Thus Day descended, but he never rose again. In fact, no sign of him or his boat has been seen from that day (nearly 150 years ago) to this. Probably he had not allowed sufficiently for the pressure of water at that great depth, and his craft was crushed immediately, after which it was carried out to sea by some under-current. The whole resources of Plymouth Dockyard were put at Blake's disposal to try and find the unfortunate craft, but without avail.

The title "Father of the Submarine" has been conferred on an American named Bushnell, who began work on the subject in 1771. His vessel was of curious shape, being like two turtle shells placed together, wherefore it is often referred to as Bushnell's "Turtle"; or we might describe it as something like an ordinary boat made very short and very deep, deeper in fact than its length. It was propelled along by a contrivance which from the description seems as if it must have been a screw, although the invention of the screw is generally put down as occurring at a little later date. He calls it "an oar formed upon the principle of the screw," and goes on to describe how when it was turned one way it would send the boat ahead, and when the other astern. If it was not like the modern screw propeller, it is difficult to see what it could have been like.

Anyway, Bushnell had one to drive or pull the boat along (it was fixed at the bow of the boat), and another on the top in a vertical position, which had the effect of driving it downwards or lifting it up, at will. There was a rudder at the stern; ballast at the bottom caused it to float upright; and there was a valve which could be operated by the feet of the solitary man who formed the crew, the effect of which was to admit water until it was ready to sink. Then the vertical screw did the rest.

There were force pumps, too, by which the "crew" could force this water out again, and a pedal arrangement whereby he could turn the propellers with his feet. No arrangement was made for purifying the air, but it was found that a man could remain below in her for half an hour.

The earlier attempts at constructing a submarine were some of them made for the sake of inventing, purely and simply. The feelings animating their makers were akin to those which impel men to seek the South Pole and other inaccessible places. Others had a definite idea that they might be used in warfare, but none of them seem to have conceived a reasonable and intelligible way of going to work. Vague ideas were mentioned in the old records about blowing up hostile vessels, boring holes in them, and so on, but nothing very practicable.

Bushnell, however, combined with his submarine a very definite scheme of operation against an enemy—a scheme which he tried against the English in the War of Independence, that melancholy struggle, which, though it fills with pride the heart of every good American, can only be recalled by Britons with a sense of bitterness—not the bitterness of defeat, but the bitterness which follows from knowing that their country was in the wrong. It is sad to think that the first practical submarine was thus used between two nations of the same blood, engaged in an unjust war, but we may now comfort ourselves with the certainty that neither submarine nor any other weapon will ever be used between them again.

That is by the way, however; let us get on with Bushnell's scheme. To the top of his vessel there was fitted what we might call a gigantic screw-driver with a screw loosely fixed to its upper end. In action, the submarine was to dive under the vessel attacked, and screw this loose screw into the bottom of it. Of course in those days ships were of wood, and so this was not so impossible as it seems. Attached to the screw was a cord, at the other end of which was a box containing a quantity of explosive, with clockwork to let it off after a certain time.

This box was carried attached to the stern of the submarine just above the rudder; it was lighter than water so that it would float; and the man inside the submarine was able to detach it when he wanted to. Thus, you see, he first drove in the screw; then, having set going the clockwork (probably by pulling a string) he liberated the box, which floated up to the surface, near to the ship because it was attached to it by the screw and cord. Then the submarine withdrew to a safe distance, and in due time the explosive went off. Or rather that was what it ought to have done, but as a matter of fact, although it was tried again and again, something always went a little wrong and no damage was done.

This ingenious man eventually retired into obscurity, perhaps unwilling to be associated with such unsportsmanlike methods of warfare. Although the idea of the submarine was so old it was long before it proved its effectiveness against a foe, but during the Great war it claimed many victims, albeit these victims were for the most part helpless women and children passengers on unarmed ships, not to speak of the crews of merchant vessels, claimed by the German *Untersee boote.* One is almost tempted to think that the people of that time had got the right idea, for it certainly is contrary to our notions of what is "sportsmanlike" to sneak up to an enemy and blow him up, without his having a chance to hit back.

But although Bushnell may have been ashamed to be connected with the submarine, others were not, for in 1800 the famous American engineer, Robert Fulton, who did so much for the steamship, invented a boat which he called the *Nautilus*. It was in shape like an elongated egg. It had a mast which could be raised when wanted, but which normally lay flat on the top; it also had a propeller worked by hand. So it could sail when on the surface, and use its propeller when under water.

Its mode of attack was similar to that of Bushnell's Turtle, except that the explosion was to be caused by pulling a string instead of by clockwork.

This vessel was offered to the French, who were then at war with the English, and it was tried in the Seine at Paris and also off Brest, where Fulton tried to blow up two English vessels which were cruising off the port. The attempt was not a success, however; something went wrong as usual, and Fulton returned to Brest in chagrin.

Unable to get the French to take up his idea, he crossed to England, but with no better success, and so eventually he returned home to America. Here he invented a submarine capable of carrying a hundred men propelled by a form of paddle (which worked so silently that the boat was called the *Mute*) and armed with under-water guns. Fulton died, however, before anything much was done with this remarkable craft. It is said, however, that in 1812 he nearly succeeded in boring a hole through the British ship *Ramillies* then lying off New London.

It is not generally known that an attempt was made to rescue Napoleon from St. Helena in a submarine. It was an Englishman, too, who was employed to perform the feat. He was, it is said, an ex-officer in the British Navy, who had assisted at some of Fulton's experiments, and so had gained some valuable knowledge of the subject. Then he seems to have left the Navy, and set up as a smuggler. He was a man of great resource and coolness in the face of danger—just the man in fact for a desperate enterprise. An offer of £40,000 the day his boat was ready tempted him to take on the task, and he set to work to build an under-water craft 100 feet long, fitted up with all the (at that time) latest features of the submarine and with two folding masts. It is thought that the intention was to sail the boat as near as possible to the island which held the famous prisoner, and then dive to avoid the ships keeping guard, rising to the surface close in-shore. Unfortunately for the scheme, however, the ex-Emperor died before the boat was finished.

CHAPTER IX

LATER HISTORY OF THE SUBMARINE

FROM the times referred to in the last chapter down to the present the experiments with submarines were almost continuous. Someone or other was always trying his hand at it, and to tell of all these attempts would be wearisome, so we will pick out those of interest.

It is a strange fact that although the submarine was almost from the first looked upon as an engine of warfare, its invention is almost entirely due to civilians. Now that the Navies of the world have taken it up, it is different of course, but nearly all the early experimenters were not naval men—in fact they were most of them not even sailors. In 1851 an American *shoemaker*, L. D. Phillips, constructed a boat, armed with a cannon capable of being fired under water. If all the claims made for this little ship were true, it must have been a remarkably successful one. It was tried on Lake Michigan, and it is said that the inventor and his wife and family spent a whole day in it exploring the bottom of the lake—rather a curious form of picnic. On another occasion, too, it discharged its gun at an old hulk, and succeeded in hitting it. Except for that, the only harm it ever did was to its inventor, who descended in it in Lake Erie, and never returned. It is believed that, as had occurred so often before, he went down too low, and the pressure of water crushed his boat in. This boat is remarkable as showing a stage in the gradual development of the long thin shape which characterises the modern submarine. One would have expected that the long graceful lines so common among fishes would have caused inventors to make submarines of that shape from the earliest attempts, but difficulties of construction and in keeping a long boat level under water probably account for the fact that the contrary was the case, and it is interesting to notice how the examples became more and more like the present shape as time went on.

Although now the Germans are among the great engineering nations, they did very little for the early stages of the submarine. That was probably because their warfare was at that time exclusively on land. In 1850, however, they were engaged in war with Denmark, and while the latter country was not a foremost naval power, the Germans had then no fleet at all worth speaking of. The Danes were able therefore to attack the German seaports and coast towns almost with impunity. While this was going on, an ingenious German soldier, Bauer, conceived the idea of a submarine, which, he thought, would cause the Danes such uneasiness that they would at any rate keep at a respectful distance from the coast, and not take quite the liberties which they had been doing.

The project was enthusiastically supported by his comrades, who subscribed, themselves, nearly the whole cost of building the vessel.

Its appearance certainly justified its inventor's foresight, for it so scared the Danish ships that thereafter they kept much farther out to sea than before. He was soon in trouble, however, for he made the same old mistake, and dived too deeply. Fortunately, the boat withstood the pressure so that it was not actually crushed. But it leaked badly, and let in so much water that it would not rise again.

And then occurred what must have been a dramatic scene. Bauer and his two companions were imprisoned at the bottom of the sea, with apparently no hope of escape from a lingering death. Bauer, however, saw a chance. It entailed letting more water into the already partially flooded vessel. This his comrades thought was madness, and would not agree to. Being two to one, they could have enforced their view, but Bauer argued the matter with them and eventually succeeded in convincing them that he was right. We can picture the fierce contest of the three, the one anxious to try what he saw to be the right plan, the two others resisting what to them seemed to mean instant death by drowning —all three of them conscious that if anything were to be done, it must be at once.

During the time this was going on, moreover, their friends above, by well meant but mistaken efforts were like to have precipitated matters. They had located the sunken craft, and were trying to fish it up with grapnels, and in doing so they kept banging on the glass windows with which the upper part of the boat was fitted; had it not been for good fortune they would have broken them in, letting the air out and destroying even the faint chance of escape which existed.

But the glass stood the test, and Bauer was able to persuade the other men. They let in more water until the air inside had become compressed to the same pressure as that of the water outside. That enabled them to open a door in the boat, get out quickly and swim up to the surface. Thus all three escaped safely, but the boat was lost, at any rate for a time. It was raised many years later, and is now in the Naval Museum at Berlin.

Unable to induce the German Government to help him, Bauer brought his ideas to England, where he secured the interest of the Prince Consort, Queen Victoria's husband. After a certain amount of talk and some trials, the project was, however, abandoned by the English Government, and Bauer tried the Russians, who were then engaged in the Crimean war, against England and France. For them he built a boat called the *Diable Marin*, or marine devil.

Like most of them about this time, it was worked by a screw propeller driven by the feet of the crew, but it was unique in its mode of fighting. A large "mine" was attached to the outside and there were two long india-rubber sleeves, as we might call them, affixed to two holes in the shell of the boat close by the mine. The ends of the sleeves terminated in india-rubber gloves, so that no water could enter through the holes; yet, on the other hand, a man inside could put his arms up the sleeves and into the gloves, so that in effect he had his arms outside the submarine. Thus he was able to detach the mine and fix it to the bottom of the vessel being attacked. He saw what he was doing through a little window.

There is an amusing story told about this boat. One foggy night a sentry on the fortifications of the great Russian arsenal, Cronstadt, spied something floating on the water very near him, then he noticed a man standing upon it, who on being challenged gave the correct countersign. Now, a man who came floating into the harbour at that time of night, on a mysterious-looking craft, might have been an Englishman from the fleet which was outside blockading the port, but when he gave the correct countersign there seemed to be no other explanation possible to the simple-minded sentry than that he really was a devil, marine or otherwise. So he threw down his arms and fled in terror. The little craft thus proceeded up the harbour, sentry after sentry fleeing from the apparition.

After this Bauer continued to work for the Russians, and performed many successful experiments. One of these was on the occasion of the coronation of the Tsar Alexander the Second, when Bauer took a band on board his boat and performed the Russian National Anthem under water.

After a while, however, the Russians seem to have got tired of him, and to have tried several ways of getting rid of him. One was to send him to dive under a certain vessel without telling him that she was lying in such shallow water that he could not possibly get under. Some official or other, it seems, thought the bothersome boat would be better out of the way stuck in the mud. On another occasion it was suggested to him that he would be the better able to think out his ideas in the peaceful solitudes of Siberia. These gentle hints that he should betake himself elsewhere had their desired effect. He left Russia in disgust, and after several unsuccessful attempts to get other governments to assist him, this remarkably clever but unfortunate man gave up.

About the same time a famous English shipbuilder, Mr. Scott-Russell, who built that marvellous ship the *Great Eastern*, constructed a curious submarine vessel for use against the Russians at Sebastopol, which was then being besieged. She was propelled by rowers in diving dress seated on platforms outside the boat. She actually went round to Portsmouth, and there dived successfully under a merchant ship, but she was not finally completed when the war ended, and ultimately she was broken up.

In the American Civil War, both sides tried the use of submarines, and during that period the first power-driven boat of the kind was built. It had a steam engine for use on the surface and electric motors for use when submerged.

The Southerners had several boats to which they gave the name of "David," from the idea that they would do to the great vessels of the Northern States what the stripling David did to Goliath of Gath.

In 1863 the Federals (the Northern States) were blockading the Confederate (Southern States) port of Charleston. After some preliminary experiments the Confederates built the first *David*, a boat shaped like a cigar, about 50 feet long, propelled by a screw driven by a steam engine. It does not appear to have been a real submarine, although it was called so, but was intended to fight in the position known as "awash," that is to say, with the uppermost part of her just above water.

She was armed with a weapon known as a spar torpedo, a long spar or pole with a torpedo attached to its end. With this she had an encounter with the Federal ironclad *New Ironsides*, which was partially successful.

The ironclad was one of the blockading squadron, and one dark night the little *David* stole out with the purpose of sinking her if possible. In the awash position there was but a very small portion of the *David* to be seen, and at first the *Ironsides'* men took it for a plank floating in the water. Then someone hailed it in case it were a boat, getting for answer a volley of musketry from the tiny craft, which killed one of the officers of the ironclad. Then with its spar torpedo the little vessel charged its mighty opponent, and there followed a terrific explosion which lifted a huge body of water in the air, to fall a moment later on both ships. The officers and crew of the "submarine," thinking they would be swamped, dived overboard, most of them being picked up by hostile vessels and becoming prisoners of war, but one of them, seeing that their craft had not sunk, swam back to her, and, assisted by another who had clung to her since he could not swim, managed to navigate her home again.

And what of the ironclad? She presumably was sunk by the torpedo? Not a bit of it. She was absolutely unharmed. So the attack had succeeded, inasmuch as the enemy had been reached and the blow delivered, but it had failed in so far as it had not inflicted any damage to the ship, and the greater part of its crew had been taken prisoners.

This partial success encouraged the Confederates to build a real submarine to work under water, and after making and losing several through capture or accident, they at last became possessed of a submarine which we will call *David the Tenth*, as its real number seems doubtful, a vessel which is unique among submarines in that she really did sink an enemy's ship. She did so, however, when navigating on the surface in the "awash" position, and so she was at the time acting more as a surface torpedo boat than as a submarine.

She first of all, however, drowned no less than thirty-five men of her own crews. Once she was floating "awash," with her hatches off when the wash of a passing steamer swamped her. Fished up and put to rights, the same thing happened again in a squall. A third time she foundered from an unknown cause. Fourthly, she fell foul of the cable of a large ship, and again went to the bottom. Each time most, if not all, of her crew were drowned, and it speaks volumes for the courage of the Confederate hosts that they were able to find crews to man such an unfortunate boat. It seems, however, as if some, at least, of the accidents were due to the nervousness of the crew, who would not consent to the hatches being closed, thereby laying themselves open to the chance of being swamped.

However that may be, at her fifth and last sinking she did really do something to justify her existence. Off Charleston there lay a fine new ship belonging to the Federals, the *Housatonic*, and against her this "David of the unknown number" went out. The blockading fleet had been warned as to what might happen, but they thought that the submarine attack would be almost sure to be against those ships which were lying closest to the shore. The officer of the submarine had thought of this, and so he steered his vessel through the blockading lines, and assailed one of those ships which lay farthest away. The attack was therefore almost a complete surprise.

In the darkness of the night those on the large ship saw "something like a plank floating in the water"; then they realised what it was, but it was too late to ward off the blow, for the little vessel was so close that the big ship's guns could not be pointed at her. Seeking therefore, at leisure, for the most vulnerable part, the submarine used her spar torpedo; the inevitable explosion followed, and this time the great ship began to fill, heeled over, and sank.

Unfortunately for the crew of the aggressor, they had, owing to that same nervousness for which the boat's previous history is ample excuse, insisted on the hatches being kept open, with the result that the commotion caused by the explosion swamped them, and so attacker and attacked went down together.

There is a very pathetic story connected with another boat built in America, but this time in the southern continent, at Valparaiso. Her inventor was a German named Flach, who was living there. She was a cylindrical vessel with conical ends, worked only by hand power, but she carried compressed oxygen for purifying the air, so that she might remain a considerable time under water, and she was well provided with detachable safety weights so that she ought to have risen quickly when required. She had a small gun on deck for use above water, while a kind of short gun was built into her bows. This latter was covered with a cap which could be removed the moment before firing.

After several surface trips in Valparaiso Bay, Herr Flach decided to take a dive in her. Crowds of people assembled to see the performance. The inventor took his son and six other people on board with him, the boat was set in motion, the horizontal rudders turned to make her dive, and she slowly sank out of sight. Time passed and she did not reappear. Hour after hour went by, and at last darkness fell, but still no sign of the submarine. At last a boat from a British warship which was lying in the bay noticed a stream of bubbles coming up from a spot near where the dive took place, and with that quickness for which British tars are famous they soon located the unfortunate craft, imbedded nose downwards in the mud.

In spite of the deep water, ropes were got round her to pull her out, but they turned out to be too weak, and just as further attempts were being made, which would possibly have been successful, orders arrived by telegram for the warship to leave, orders which could only be obeyed, and so the poor fellows had to be left to their fate. There can be little doubt that when once pointed downwards the weight of the gun in the bows carried the boat quickly to the bottom in spite of the rudders, and so she found a home in the soft mud where she lies till now.

It is sad to think of the poor fellows dying perhaps a lingering death below, but our sympathies must go out, too, to the gallant sailors compelled to desist in the midst of their merciful work and to go off whilst there was the possibility of saving fellow-creatures. No doubt with their habits of rigid discipline, they went away promptly and readily, but there was many a sad heart on board that ship as she left Valparaiso because of the thought of the lives they might have saved.

This sad accident occurred in the year 1866, nine years before Mr. Holland commenced the experiments which have led to the modern submarines of Great Britain and the United States, and which will be described in the next chapter.

Meanwhile we must return to the Old World, where, in 1876, we find an English clergyman interesting himself in the subject—the Rev. George William Garrett. He built a tiny submarine in which he performed in one of the docks at Liverpool with considerable success, so much so that he then proceeded to build a larger one 50 feet long. It was driven by a steam engine with an abnormally large boiler. Steam was raised in this at very high pressure, and when about to dive the fires and the chimney were sealed up, the engines being worked by the steam stored in this large boiler. It is said that in this way the boat could travel a dozen miles under water. She went down off the Welsh coast, and never came up again.

The reverend gentleman, however, evidently did not go down with his boat, for we hear of him again a few years later acting in conjunction with the famous Swedish gun-maker, Nordenfeldt. The latter seems to have been taken with Garrett's way of using bottled-up steam, and together they contrived a submarine which was purchased by the Greek Government. Then they built another of improved design, which they sold to the Turks.

Next they constructed a very large one for Russia. She was built at Barrow-in-Furness, came round to the Solent (near Portsmouth), where she underwent some trials, after which she departed for St. Petersburg, but unfortunately she was wrecked on the way.

These Nordenfeldt boats seem to have been very successful, except for one thing—they were very unsteady under water, moving not in a straight line, but as if on a switchback, a fault which was somewhat trying to the crew. They were the first boats to be armed with the Whitehead torpedo,[1] and the effect when this was discharged from the tube at the bow was decidedly alarming, for the sudden lightening of the ship at that end when the torpedo left her caused her nose to shoot upwards.

The Nordenfeldt boats rose and sank by means of vertical propellers, as the old Bushnell's "Turtle" did, and

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[1] See Chapter xii.

not by means of horizontal rudders as most of the submarines have done and as practically all do nowadays.

Another very successful submarine was designed and built by a Mr. J. F. Waddington, a Liverpool shipbuilder. At each end of his boat there was a vertical tube passing right through it, and in each of these there was a pair of screws driven by an electric motor. The operation of the screws caused water to be sucked in at one end of each tube and ejected at the other. If the water thus passed up one of the tubes it depressed that end of the boat, if downwards it tended to raise it. So by working these propellers together or separately the craft could be raised or lowered in the water and also kept level. In addition to this, it also had an automatic arrangement for keeping it level. There was a pair of horizontal rudders ahead and another astern, both being worked by motors controlled by a pendulum. When the pendulum hung in the boat vertically the motor stopped; if it hung in such a way as to indicate that the bow pointed upwards, they started to work and turned the rudders so as to correct this inclination: as soon as the boat became horizontal they stopped again. In the same way, if the stern rose up the motors worked the opposite way, and corrected that too.

About the same time a Russian named Drzewiecki was trying what he could do. He made three or more boats, the most peculiar feature of which was that they were armed with torpedoes attached to the outside of the boat which could be released while passing under a hostile ship, and, being furnished with *suckers,* would attach themselves to its hull.

Another curious boat was invented by an American, Professor Tuck, of San Francisco, and ironically named by him the "Peacemaker." The commander of the boat was outside it, arrayed in diving dress, so that he was free to manipulate the torpedoes with which it was armed. Later on, however, this was altered, and he was placed under a kind of glass dome. This boat had the further peculiarity that she was worked by a fireless steam engine, the necessary heat being raised by a chemical action in which caustic soda played an important part.

Finally we may mention perhaps the most curious of all submarines, a sort of under-water bicycle, which was invented by an American, Alvary-Templo by name. Its body was like a huge cigar 16 feet long and 2 feet in diameter. Right through the centre there was a hole in which the "crew" sat, dressed in a diving dress, with his arms and head above the boat and his legs dangling down below it. With his feet, he turned pedals which worked the screw, and the rudder was controlled by a pair of handle-bars just like a bicycle. The diver's helmet was connected by tubes to air reservoirs in the body of the machine. It does not seem to have caught on either as a weapon of war or as a sport.

CHAPTER X

SEMI-SUBMARINE BOATS AND WORKING BOATS

ANOTHER class of submarine boat has been aptly termed the Semi-submarine. The submarine proper and the submersible both use the water for protection, for when immersed they run little risk from any ordinary weapons even if they could be seen, while as a matter of fact they are practically invisible. The semi-submarine, on the other hand, has her vulnerable part under water, and therefore protected by it, while a less important part, one which cannot be easily damaged by an enemy's fire, and does not matter much if it is, is above and therefore visible. This above-water part is kept as small and inconspicuous as possible, but all the same it can be seen as an ordinary submarine cannot.

We may therefore say that submarines proper and submersibles are protected by the water both from being seen and from being hit, while the semi-submarine is only protected by it from the enemy's guns.

One of the first of these, known as Nasmyth's Floating Mortar, was the invention of the famous engineer, James Nasmyth, whose name is well known as the inventor of the steam hammer. This curious craft was quite large, being about 80 feet long and 30 feet wide. Its shape was unlike that of any other craft, being something like a lemon which has been sat upon, and floating "flatways" in the water; it was built of timber 10 *feet* thick.

In the water only the rounded upper part was above the surface, and that, being so thick, was invulnerable to the projectiles of that day (1853). It had a steam engine to drive it, by means of a single screw propeller, and a kind of cannon was fixed to the bow (under water), which would go off automatically if struck violently against the side of another ship. In a hollow in its upper side was formed a chamber for the look-out man, whose head was covered with a small dome with windows. This dome and the funnel were the only things projecting on the upper surface. The idea was that other ships would be practically impotent to inflict any damage upon this queer vessel, while it, by "ramming" them with its cannon-shod nose, would be a formidable antagonist.

The cannon, as it has been called for lack of a better name, was very short and very strong. It was formed by a large heavy brass casting which was fixed to the nose of the boat, with a shallow cylindrical hole in it, into which was fitted a projectile with a charge of powder behind it. On ramming the other vessel, the powder would be exploded and the projectile driven into its side, while the strength of the casting itself would protect the attacking vessel from damage. All that it would feel, indeed, would be the recoil, which would be an advantage rather than otherwise in that it would tend to cause her to draw back clear of the sinking vessel.

Needless to say this curiosity was never in action. Indeed it was never actually built.

In the American Civil War the Confederates had a boat which was called the *Manassas*. Cigar-shaped and floating very low in the water, the only thing which was visible was the rounded back (covered with iron bars for protection) and the funnel and the muzzle of a small gun.

Her real weapon, however, was under water, for she was intended to act as a ram and to sink hostile ships by running her sharply pointed bow against their sides. She was, in fact, a huge projectile weighing nearly 400 tons, which fought by hurling herself bodily against the foe. In order that she herself should not be crumpled up by the terrific impact, the front 20 feet of her length was solid and was covered with iron plates.

On the other side, the Federals invented the *Keo-Kuk*, a vessel of somewhat similar shape, with only the funnel and two round cylindrical turrets projecting from her back. When in fighting trim only those were visible above water; everything else was below. Each turret contained a powerful gun, and the nose of the boat was strengthened so that she too could ram, just as the *Manassas* could.

She did not turn out a great success, for, in order to avoid collision with another ship, she got too near the famous Fort Sumpter at Charleston and was fairly riddled with shot. So badly damaged was she that, the weather becoming rough, she sank the same night.

Another Federal boat was the *Spuyten Duivel*, which appears to have been shaped more like an ordinary torpedo boat, only that her deck was rounded instead of being flat. Her appearance must have been most curious, for she had one funnel in the middle and one right back in the stern, while she also had three bare masts (for what purpose it is not clear) and a conning tower, the top edge of which curved outwards like an inverted bell. Ordinarily her hull projected three feet out of the water, but when going to fight she had tanks which when filled sank her down until only a foot remained visible. Her weapon was a spar torpedo—a torpedo, that is, on the end of a long spar—which latter could be projected when required from a hole in the bow. Fortunately for all concerned, the war ended before she could be used.

About the year 1880 Messrs. Berkeley & Hotchkiss, the latter of whom is famed for his Hotchkiss machine guns, invented a most curious and original craft. The main body of it was like a genuine cigar-shaped submarine, but in addition there were two long cylindrical floats, one on either side. These were divided up into a lot of small compartments which were filled with cork, so that they might be hit and perforated many times by hostile shots without losing buoyancy to any great extent. The boat itself was too heavy to float, but was suspended by the floats to which it was attached by a series of jointed levers. Normally they were drawn in close when they held her above water, and also formed a kind of shield on either side of her, but for fighting the levers were operated and the floats were pushed outwards and upwards, so that the main part sank in the water and only the floats remained above. She was propelled by steam, and had a single torpedo tube.

About the same time the Frenchman, M. Legane, produced another vessel of somewhat the same sort. Her shape was quite different, for she was more like an ordinary ship. The space between her main and upper decks, however, was filled up solid with timber, so that the only part which an enemy could see and hit was nothing more than a block of wood, while the essential parts of the craft and the crew were safely tucked away below the surface. Holes or shafts were cut through the timber for the funnel and to give entrance to the space below. The weapon used was a spar torpedo.

In 1881 there was built at Chatham Dockyard, for the

British Navy a ship called the *Polyphemus*. Her body was really cigar-shaped, but on the top of it was built a superstructure like that of an ordinary small war vessel, so that afloat she looked like a small gunboat. Her bow was made strong so that she could act as a ram, and she had a number of torpedo tubes. The idea of the peculiar form of construction was that the upper part of her, while convenient, was not essential, and could all be shot away without really injuring the vessel, the essential part of which was safely protected by the water. Her one exploit of note was when during the naval manœuvres she was ordered to break through a mighty boom of timbers and steel wire cable across the mouth of Bantry Bay. This she charged full tilt, and broke through as if it had been a piece of cotton.

Finally we may describe a type of boat of which the United States Navy has several. They are the invention of Mr. Clarence C. Burger, and may be described as two boats in one. The upper one is shaped much like an ordinary boat with a very deep keel, somewhat after the manner of racing yachts, to the bottom of which is attached the cigar-shaped submarine part. The upper boat, as we might call it, is divided up into an immense number of small water-tight compartments, which are packed full of some very light solid substance. So this upper part can be battered about to almost any extent without destroying its buoyancy, while the lower boat will be safely suspended from it in the water below.

Now we come to a number of interesting boats of the submarine variety which differ from their warlike fellows, in that their purpose is to do useful work and not simply to fight. In a way, therefore, they are self-propelled diving bells, but their features are very different from the bells described in a previous chapter.

The first of any importance was the invention of a French scientist, Dr. Payerne. Having seen the operations which were in progress about the year 1840 for the recovery of the famous *Royal George* at Spithead, he became interested in the subject of work under water, and was struck with what seemed to him the primitive nature of the appliances used. And, like a sensible man, he not only noticed the faults of the existing apparatus, but tried to find out something better. After several preliminary experiments, he produced a really serviceable boat, which rendered valuable services at the construction of the breakwater at Cherbourg.

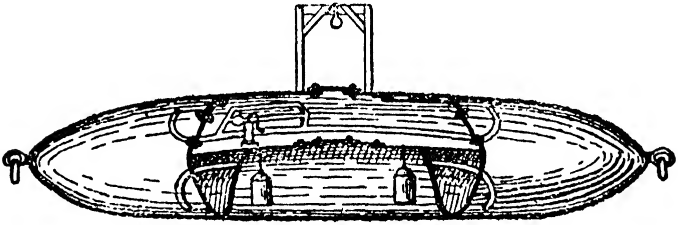


FIG. 13.—Dr. Payerne's Diving Boat.

It was about 43 feet long and 10 feet deep, and it weighed about 62 tons. Shaped like a sausage, it was divided up inside into five chambers, as will be seen from the illustration. The dividing walls were water-tight and air-tight, and the whole structure was strongly built of iron plates riveted together.

Entering through the door at the top, which could be securely closed before descending, the crew reached the upper chamber, in which was a hand-pump for various purposes and the apparatus needed for controlling the vessel.

Thence they could pass through another door, which could also be closed and made air-tight when required, into the "working chamber." At either end there was an air chamber, while around the working chamber was formed a fifth chamber known as the ballast chamber. An ingenious system of pipes connected the various chambers and the pump, the purposes of which we shall see in a moment. In the working chamber, the bottom of which was open to the sea, there hung two heavy iron weights (weighing about 4 tons) which could be lowered on to the floor of the sea if necessary. Lastly, over the door at the top of the upper chamber there was an iron framework to which could be fixed pulley blocks for lifting heavy things from the inside of the boat.

The method of working was something like this. Air was first pumped into the air chambers; the crew entered, and closed the upper door behind them. Water was then admitted to the ballast chamber, which already contained, by the way, about 36 tons of iron ballast. Water could also be pumped into the air chambers if needed. By these means the boat was made heavy enough to sink to the bottom. As it sank, the water would enter the working chamber as the air there became compressed, but it was easily driven out again by the admission of more air from the air chambers. One member of the crew of nine men remained in the upper chamber to look after the pump and air-supply arrangements, while the other eight passed through the lower door into the working chamber, where they could do work on the sea floor just as could be done in an ordinary diving bell.

To ascend, it was only necessary to pump some water out of the ballast chambers. Or the weights could be lowered so that they lay on the ground, when of course the boat would rise as the suspending chains were paid out. These weights also formed a species of anchor for the boat.

For air supply the men in this craft were quite independent of the surface for a long time. Every hour fresh air from the air chambers was admitted to the upper and working chambers. The carbonic acid, too, was got rid of by blowing the air with a kind of bellows through lime water.

The only means of moving this craft when submerged was by the men inside "punting" it along with poles, but a few years later Dr. Payerne, in conjunction with M. Lamival, brought out another idea for a similar boat, but propelled mechanically by a screw propeller worked by a steam engine.

A very strange submarine worker was built by an Italian, M. Piatti del Pozzo, about 1897. It was an extremely strong steel ball, the walls of which were nearly 3 inches thick, so that it could be lowered to great depths without being crushed. Unlike the Payerne boat, there was no connection with the water when submerged, but instead the work was to be done by a strange claw-shaped appliance and a species of telescopic crane fixed to the outside but operated from within. The idea was, it will be seen, to be able to work under greater pressure (and therefore at greater depths) than men could possibly endure in a boat communicating with the water. The air inside would, of course, be normal, all the pressure being resisted by the strength of the boat itself. This strange craft had three screw propellers driven by electricity, but these were only needed as an adjunct, for the boat was suspended from a ship above. She would therefore only be able to navigate herself within a small range.

In a previous chapter we noticed the inventions of a Church of England clergyman. Another clergyman, the Abbé Raoul, of Milan Cathedral, has distinguished himself in the same way, and, it must be admitted, in a way more suitable for a preacher of goodwill amongst men, for this craft was intended to help the sponge divers on the North African Coast and save them from some of the risks of their hazardous calling.

This boat was called (or we may be right in saying *is* called, for it was said to be still in use not long ago) the *Bou-Korn*, and in shape she appears to be like a lemon with one of the points cut off. She is 16 feet long, and is built of metal sheathed with wood to protect her from collision. Three screws propel her, one of which, situated at the pointed stern, drives her along, while the other two (one on each side) push her sideways, and so enable her to turn in even her short length. She gets the sponges by means of a kind of grapnel operated from inside. A remarkably safe, useful, and handy little boat she seems to be, from all accounts, of which her reverend inventor has reason to be proud.

Years ago, in the United States, a boy of ten, Simon Lake by name, was reading that wonderful story of Jules Verne, *Twenty Thousand Leagues under the Sea*, and out of that simple incident has come one of the most successful submarines of all. His first attempt, made while he was still quite a boy, was little more than a wooden box on wheels 14 feet long, 4½ feet wide, and 5 high, strongly built, and painted with coal tar. One of her three wheels was turned by a crank inside, and it was intended to sink on to the sea floor and then roam about like a self-propelled bathing machine. Having found the wreck, or whatever was being sought for, a diver was to leave the boat in diving dress and do the work which was needed. Since Lake's later boats have been called Argonaut No. 1 and No. 2, this little craft has since come to be known as Argonaut Junior.

Argonaut No. 1 was launched in 1897 at Baltimore. She was 36 feet long, cigar-shaped, and strongly built of steel. She had a gas engine and propeller, dynamo, searchlight, and pumps for air and water. Her chief feature, like that of the younger brother, was an air-lock through which divers could emerge while down below. With a crew of five men, she made a voyage of 2000 miles sometimes submerged and sometimes on the surface, in the latter condition weathering a severe storm which wrecked many other ships. She explored the bed of the Atlantic Ocean, besides that of rivers and bays, finding several wrecks and having numerous adventures, not of a serious character. Parts of the ocean floor are, her inventor says, quite flat and hard, like a good macadamized road, and along these places his ship, supported on her three broad-tyred wheels and driven by her propeller, travelled quite easily.

To demonstrate the uses of his vessel, he wanted to search for the cables communicating with the submarine mines which defend Hampton Roads; the authorities would not grant permission, but a cable which was laid specially was found quickly and without difficulty, thus demonstrating how such a vessel could search out, find, and cut the cables for firing such mines and so render them harmless.

Later Mr. Lake reconstructed this boat, making her longer than before, and adding to her upper side a superstructure not unlike the hull of an ordinary boat. This gave her greater stability under water, and with her increased size enabled her to carry eight men and to cruise for 3000 miles.

Though originally intended for pacific work, the Lake boats have developed into warlike craft, of which we shall hear more in the next chapter.

CHAPTER XI

SUBMARINES OF TO-DAY

British

THERE are still some "queer fish" to tell about, but we are now reaching the practical, useful, reliable submarine of to-day. The British Navy has the largest fleet of submarines in the world, and they are believed to be modelled more or less upon the boats which were purchased in the year 1901 from the American inventor, Mr. John P. Holland.

The first of the long series of boats which he built was a tiny affair, manned by one man, and even he had to remain sitting all the time he was in her, for there was not room for him to stand. He worked the propeller with his feet, not a very easy thing to do since he had to wear diving dress. Five little torpedoes were carried, which he could launch and explode at a distance by electricity. As he sat, his head projected up inside a kind of dome on the top of the vessel, with glass sides through which he could see.

The second Holland boat was shorter and fatter, and still a small affair, but it was driven by a small engine.

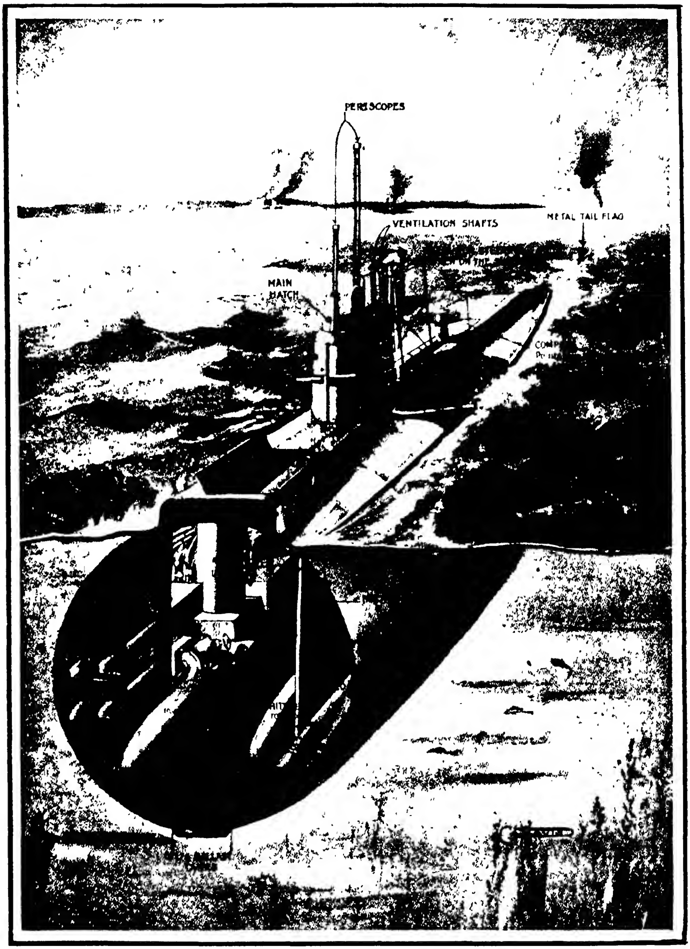
Next, in 1881, appeared Holland No. 3, about 30 feet long and driven by a 15 horse-power oil engine. The next one, Holland No. 4, was small, and its history was brief, for it met with an accident and sank. Holland No.

5 came to grief on some rocks, so even this man, perhaps the most successful of all the inventors of submarines, had his catastrophes.

Holland No. 6 was only thought about, never built, but when in 1895 the United States Government invited inventors to enter into a competition by submitting plans for submarine boats for the United States Navy, Holland's seventh boat appeared and carried off the prize. A large vessel compared with the others, it was 85 feet long with a displacement of 100 tons. It had three torpedo tubes (tubes out of which torpedoes can be launched) and two small turrets with guns in them for fighting on the surface. She was never finished, for before that stage had been reached Holland had thought of improvements, and although the United States Government had bought her he induced them to agree to take Holland No. 8 instead.

This boat was a little smaller than No. 7, only 75 tons, and was shaped like a porpoise. She had three weapons: first, a tube for launching aerial torpedoes; then an under-water tube for Whitehead torpedoes (which are described in a later chapter); and finally, an under-water gun. The first two were placed pointing ahead and the last astern, the purpose of which arrangement was this. Suppose the submarine to be approaching a ship; when near enough she lets off her aerial torpedo, then she dives, and fires her under-water torpedo: if those do not take effect she goes on under the vessel attacked, letting fly with her gun just after passing her. A very clever arrangement, but evidently not altogether satisfactory since it was much altered afterwards.

Indeed, this boat was so much changed that she became a practically new boat, known as Holland the 9th



THE DETAILS OF A SUBMARINE

This picture has been drawn to give an idea of the details and internal arrangements of a submarine.

by the time the United States Government took her over.

She is still in existence, and may be looked upon as the parent of the submarines of the United States, Great Britain, and, to a certain extent at least, Germany. The French have worked along lines of their own which will be described presently.

Holland the 9th was built in 1896. In 1901 another Holland boat was built for the United States of America, called the *Adder*, but also spoken of as Holland the 10th. A company had been formed by Holland to construct these little vessels, called the Holland Torpedo Boat Co., and when the British Admiralty, about the year 1901, came to be interested in submarines, they chose to buy some from this company for the purpose of trying experiments. They had been for many years very sceptical as to the fighting value of submarines, and regarded them somewhat as cheap weapons which might be of some use to impecunious and weak nations, but which were of no value to the greatest of all naval powers. They purchased these Holland boats ostensibly with the idea of finding out the best way to guard against submarine attacks, and after careful inquiries came to the conclusion that the boats of the Holland Company were the best to be had.

They did not purchase the actual boats, but only the designs, which were carried out at the great shipbuilding yard of Messrs. Vickers, Limited, at Barrow-in-Furness. They built five of these in all, and it is believed that they are identical with the *Adder* and her sisters on the other side of the Atlantic. We are now in the region of official secrets, but it is fairly safe to say that the following description represents the early boats of both Navies.

They have a displacement of 120 tons—meaning that that is the actual weight of them when they have sufficient water ballast on board to enable them to sink. They are 63 feet 4 inches long, and 11 feet 9 inches wide. In shape they somewhat resemble a rather fat cigar, with a shallow superstructure on the top which forms a small deck. One screw propeller serves to drive them through the water, driven by a 190 horse-power gasoline motor when on the surface and an electric motor when below.

The speed on the surface is 8 knots; below it is 5 knots. The armament of aerial guns, &c., mentioned in connection with Holland the 8th, is abandoned, and a single torpedo tube at the nose of the boat is the only weapon.

Possessed of these five Holland boats, the Admiralty seem to have become enamoured of the submarine, for they soon set to work to build more and to introduce improvements of their own. The "A" class followed the Hollands, all of them being designated by the letter A and a number, thus:—A1, A2, A3, &c.

They are no fatter, but much longer than the Hollands, so that they are more like long thin cigars. Most of them are 200 tons displacement, with a speed of 12 knots on the surface and 7 or 9 knots submerged. They all have conning towers and periscopes, which the Hollands had not.

These were followed by the "B" class, similar but larger (314 tons), with the deck on their backs raised somewhat higher, so that they are more comfortable boats to navigate on the surface, on which they are capable of travelling 2000 miles on their own account, while even submerged they can go 150 miles.

The "C" is an improved form of the "B," about the same size. There is a gap in the numbers in this class, No. 11 being at the bottom of the North Sea, as will be told in a later chapter.

The "D" class are nearly 600 tons, with 1200 horse-power oil engines and 550 horse-power electric motors, which drive twin screws. On the surface their speed is 16 knots and under it 10 knots. They are capable of a voyage of 4000 miles.

The "D" class was followed by the "E" class, and in 1913 by the "F" and other classes now forming the most homogeneous and powerful flotilla in the world. The "E" class originally carried four torpedo tubes, but the more recently built vessels carry still more. The super-submarine or ocean-going vessel is vastly superior in strength, size and horse-power to the earlier types.

FRENCH

France was the first nation to take up the submarine seriously, and she now possesses a very large fleet of these boats only slightly smaller than the British. The French have, however, worked very largely along their own lines, so that it is easy to describe theirs quite separately from those of any other nation.

In 1885 a certain M. Goubet invented a tiny little submarine of only a ton displacement. In shape it was like a lemon, slightly elongated and then squashed rather flat, about 16 feet long, 6 feet deep, and 3 feet wide. The crew of two men sat back to back in the middle, their heads projecting up into a little dome with windows in the sides through which they could see.

It was armed with a little torpedo, attached to the outside of it and fitted with spikes. The idea was to let this loose underneath an enemy's ship so that it would float up, and by virtue of the spikes become attached to it.

Three years later there appeared the *Gymnote*, designed by M. Gustave Zédé, the boat which is to the French submarines what Holland the 9th was to the British and American. She was the first to appear in the official list of ships of any Navy.

The idea was originally due to M. Dupuy de Lome, a celebrated French naval engineer, but he died before his plans were completed. They were, however, finished by M. Zédé and adopted by the authorities.

This boat was cigar-shaped, about 60 feet long and about 6 feet wide and deep, her displacement being about 30 tons. A 55 horse-power electric motor drove her propellers, and she had a telescopic conning tower and a periscope. Her weapons were two Whitehead torpedoes.

A few years later M. Zédé was entrusted with the building of another improved boat, embodying the fruits of the knowledge which had been gained with the *Gymnote*. Like M. de Lome, however, he died before his task was accomplished, and so his country, with that happy knack of doing graceful actions which is characteristic of them, altered the name of the boat from *La Sirène*, which they had intended to call her, and christened her the *Gustave Zédé* instead. She was finished under the direction of M. Romazzotti, and a very famous boat she became.

She was 160 feet long, 270 tons, and was shaped, as her predecessor was, like a very elongated cigar. Electric motors of 360 horse-power propelled her along. On the surface she seems to have behaved well, but under water she was difficult to steer and to keep level, so that she was altered a good deal from time to time, and eventually became the heroine of a very clever feat which in those days brought her much renown.

A French fleet was lying at Ajaccio, on the coast of Corsica, and the *Zédé*, then at Marseilles, was ordered to make a mimic attack upon them.

She slipped away from Marseilles without anyone being aware of the fact. Next day, as the fleet were about to leave Ajaccio, one of the ships, the *Charles Martel*, felt a curious shock. At the same time a strange white furrow was noticed on the water, and a few moments later the *Gustave Zédé* came to the surface a hundred yards off. She had arrived unknown to anyone, and had completely taken them unawares. Her commander then rather spoilt his triumph by trying to be too clever, for he dived again, and tried to run across the path of another ship, which had to alter her course to avoid running the submarine down. Thus, at the moment of success she was ruled by the umpires to have been put out of action, for, of course, in actual warfare the other ship would have been only too glad to run her down, and would not have changed her course.

At this point comes along M. Goubet again, with a larger boat this time. Much shorter than the *Gustave Zédé*, she was a little larger in other directions, so that she was more of the lemon shape. She steered herself by means of her propeller, which was mounted at the end of a kind of joint like that in a man's wrist which can be turned in any direction. If then, for example, she wanted to steer upwards, she would turn her propeller slightly upwards, so that it not only drove her along but pushed her stern slightly downwards, and her nose upwards. To turn to the right, she would in like manner move her propeller round slightly in that direction, and so on. This arrangement must need a somewhat complicated mass of mechanism, but it is a most effective way of steering.

But the most remarkable thing about this boat was an automatic apparatus for keeping her at any particular depth. Its details are not known, however, and it does not seem to have been a great success. For some reason the French Government did not take on this craft, although they made many trials with her which were deemed very successful. Her inventor managed to sell two boats like her to the Brazilian Government,and he formed a company in England called the British Submarine Boat Co., but they do not seem to have done any business.

In 1899, another boat, called the *Morse*, was launched. She was very like the *Gustave Zédé*, but embodied a number of improvements. Next, as the result of an open competition for designs, the *Narval* was built, a boat very like an ordinary torpedo boat in shape, with a flat deck. She had a steam engine for running on the surface, the furnaces for which were fed with oil fuel, and an electric motor for below water. Then the Government went in for a number of boats of a new type called the Farfardet type, driven by electric motors only. They were an improved form of the *Gustave Zédé*.

Then occurred what is known as the Fashoda Incident, when the British General, Kitchener (now Lord Kitchener), completing the conquest of the Soudan, found a small French force under Major Marchand ensconced in the remote African town of Fashoda, a place which they had reached by a long and arduous journey across the continent.

At the present time the two nations are the best ot friends but then they were very suspicious of each other, and a very little thing might have set going a disastrous war. Fashoda is a very remote and unimportant place, not worth the life of a single soldier, but when nations feel that their "honour" is involved they will sometimes fight without stopping to think how trivial is the matter really at stake. So both these great nations allowed themselves to get very excited about Fashoda, which few people had heard of before and most have forgotten since; and in France this took the very practical form of a public subscription to build two submarines to be presented to the Navy with the special view, of course, of frightening those "perfidious" people across the "Manche," as they call the English Channel. The two boats were built, but they have never been used against us, nor is it likely that any of France's submarines will ever be so employed, at any rate not for many generations when the memory of the Entente shall have become but ancient history. May that day never come!

These two were of the same type as the *Gustave Zédé*, as are others which have been built since. There have also been a number of boats constructed like the *Narval*, while others have been built, too, on quite new lines, of which not much is known.

Thus, it will be seen that while the British and American submarines started with the J. P. Holland boats, and have kept (particularly the British) to improvements on that type, the French started with the *Gymnote*, had nothing to do with the Hollands, and have gone on developing a number of new types since. Thus their large submarine fleet is more varied than any other, a doubtful advantage in case of war, since the crews have to be trained specially for each type of boat, and are not so easily interchangeable as they would be in a more uniform fleet, and a fleet of similar vessels is for many reasons handier in warfare than a mixed one. The old *Gustave Zédé* has long gone to the scrap heap and a new type of powerful vessels has arisen.

In concluding this reference to the French boats, one is tempted to mention a ship which is not a submarine in any sense, but is used in connection with submarines. It has been built by the famous Creusot Company in France, who are builders of submarines, for the purpose of taking submarines to the place where they have to deliver them when they have built them. It consists of a large ship with a kind of tunnel from bow to stern under water. Into this tunnel the submarine crawls, as it were, and is then shut in by means of collapsible doors until it reaches its destination, after which it comés out again in the same way. Truly, she must be a queer craft.

AMERICAN

As we have seen already, the British and United States fleets of submarines, like their owners, start from a common origin, and the early boats of the two nations were just alike. They have each developed, however, along their own lines, and we have already followed that development in the case of the British boats. It is characteristic of the British Navy at the present time, that they have comparatively few types of ships. The aim is to have a few standard types, the members of which of course vary as successive vessels are improved in detail; but speaking generally, all the ships of each type are alike. The intention of this is to make the whole fleet as far as possible uniform, for the reason mentioned a moment ago. And the principle has been applied to submarines no less than to other classes of ship. The A's and the B's, the C's and the D's, are all improvements one over another, but in their main features they are believed to be very similar.

The United States Navy, however, have a greater variety of submarines, including some of the semi-submarines of the "Burger" type, and some submarines of the "Lake" type described in previous chapters.

Other Nations

The Russians, who have had a fondness for the submarine from Crimean times (as is indicated by their patronage, up to a point, of the unfortunate Bauer), were the first to take up the Lake boats. They purchased one called the *Protector*—the immediate successor of *Argonaut* the second—which they rechristened the *Ossetyr*. Like the *Argonaut*, it could not only swim, but run on wheels on the bottom. She was about 70 feet long and 11 feet wide, displacing about 170 tons. She had gasoline engines with twin screws for surface propulsion, and electric motors for under water, while she carried enough air, compressed in tanks, to enable her to stay under for 60 hours. In order to dive, when she intended to go just under the surface, she took in water until nearly sinking, as most submarines do, and then steered downwards with her rudders; but if she intended to do a tour on the bottom, she then, of course, let in enough water to sink.

The horizontal rudders were of the type sometimes called hydroplanes. They are fitted in the middle of the boat, on each side, and so have the effect of carrying the vessel under in a horizontal position, and not nose downwards as rudders at the rear do. Three torpedo tubes constituted her armament, one being at the stern and two in the bow, one on either side.

The Russians now have other boats of this type; also some similar to the Hollands, and others built for them by Krupp were taken over by the German Government.

The Germans were somewhat slow in taking up submarines, and like the British and Americans, they started with some Hollands by way of experiment. From these they have developed a type of their own, of which little is known.

Japan has a number of submarines which are believed to be very similar to the British. It is a curious fact that although both countries had a number of submarines on their active list during the Russo-Japanese war, neither of them seems to have made any use of them.

Nearly all the other nations have some ships of this kind, but it would be wearisome to enumerate them all here. Readers who wish to know about them should refer to the *Navy League Annual*, or to some other reference book on Naval affairs.

All the descriptions given above may, of course, be out of date sooner or later so far as they relate to existing vessels, but the stage seems to have been reached when there will not be much in the way of novelty of design; increase in size is the most likely thing to occur, and so the descriptions will possibly be fairly true and accurate for a long while to come.

CHAPTER XII

SUBMARINE WEAPONS

A CASE of explosives which can be made to "go off" at some desired moment is the common form of weapon for use under the water. If it is still, it is called a Mine, but if it moves it is a Torpedo.

Torpedoes are supposed to take their origin from the old fireships, like those with which our ancestors drove into helpless confusion the great fleet of Spain. These were small ships filled with anything that came handy which would burn easily and fiercely. And they were set adrift in such a position that wind, tide, or current would carry them among the enemy's ships, and at a suitable moment they would burst into flame. The enemy's ships in the old wooden sailing-ship days would be easily set on fire, and under certain circumstances would be quite unable to escape.

The time of the fire breaking out on a fireship could easily be arranged by having a train of some slow-burning material, which could be lit at one end before the ship was set off. It would then burn slowly along its length until at last it reached the huge bonfire within the ship and set it alight. Then in a few moments it would be burning furiously, the whole vessel becoming a mass of fire, with flames pouring out of the port-holes, and pieces of burning matter floating aloft in the air.

Then woe betide any wooden ship it might come near.

I have never seen a fireship, but I have seen a burning building set fire to another one across a wide street, so one can easily imagine how terror-stricken a fleet would be when the fireships came drifting among them.

No doubt they were often disguised so that the opposing ships thought them just ordinary craft until they were too close to escape. At times, too, there would be devoted sailors concealed within them directing them, men who took their lives in their hands, even as soldiers and sailors are prepared to do to-day, knowing that the very remote chance that they might be able to slip overboard and swim to safety was the only thing which stood between them and certain death.

In the case of the blockade of a harbour at the mouth of a river, it was easy for the fireships to be used, for the ebbing tide would carry them just where they were wanted; but in a case like that of the Spanish Armada, it is evident that fireships could only be used under certain favourable conditions, for the same current, whether of wind or water, which would carry them would also carry their prey away from them, the moment the latter slipped their anchors.

Of course the direction of the wind or current might be such that it would carry the attacked ashore unless they held fast to their moorings, but that could not have been the case always.

The secret of their success against the Armada was probably more moral than anything else. A few years before, an Italian named Gianibelli had invented "explosion-ships" for use at the siege of Antwerp. A bridge had been thrown across the Scheldt to prevent supplies being taken to the beleaguered city, and the defenders very much wanted to destroy this. Gianibelli therefore got two ships, loaded them with a great quantity of gunpowder, with large stones and other heavy objects all round it and over it, and fitted clockwork so that the powder would explode after a certain period. These ships were allowed to drift down upon the bridge and in due course went off, the result being the most disastrous explosion ever known by the men of that time. The bridge was demolished, along with the neighbouring forts; the ground was shaken for miles, and large heavy stones were hurled a distance of a mile.

Now Gianibelli was, in 1588, employed by the English, and the Spaniards knew it. So when they perceived the fireships coming upon them, it is said that a cry of "the Fire Antwerp" went up, and the great clumsy galleons tried to get under way in a hurry. With their great sails some would blanket the others or keep the wind off them so that they could not move. The former would then stand a good chance of running into the latter, panic and confusion would reign among the large vessels, just as there have been panics in public halls when the terrible cry of "Fire" has been heard.

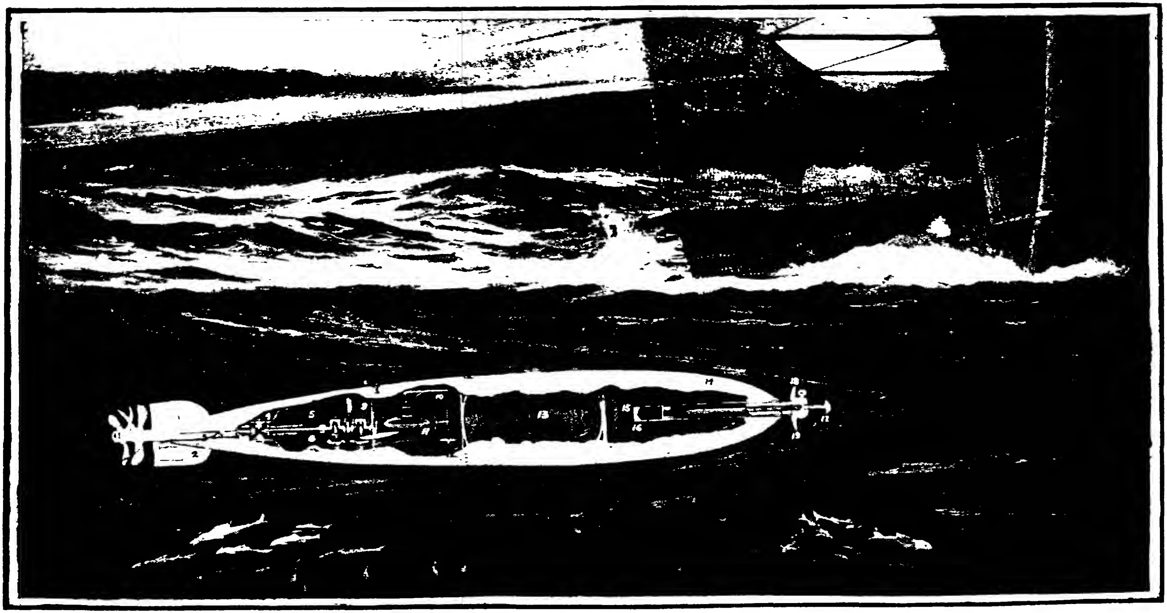
A while ago there were three steamers creeping through the foggy night up the Thames. Presently one of them went aground on one of the mud banks with which the Thames estuary abounds; a moment later the second one had run into her; then the third crashed into both of them. Thus there was seen the rare sight of a triple collision, and the "Port of London Authority" had the task of raising three wrecks at once. That somewhat illustrates what probably took place among the Spanish galleons, when, befogged by fright, they tried to escape from the little English fireships.

It is true that during the Russo-Japanese war the damage inflicted by the torpedo was slight, but during the Great war its potency for evil was shown on many occasions in the North Sea, the Baltic, the Adriatic, the Dardanelles and elsewhere. The moral effect also is great; the knowledge that the waters are infested with lurking submarines waiting an opportunity to discharge their weapon, the constant alertness, the sudden appearance of a lengthening white streak, and the consciousness that only by the utmost skill in manœuvring can disaster be avoided, cannot fail to tell upon the nerves of the strongest.

I remember seeing nearly thirty years ago a "panorama," a series of illuminated pictures which was to those "remote" times what the cinematograph is to to-day. It was during the Russo-Turkish war, and one of the pictures showed the blowing up of a Turkish ironclad on the Danube by a Russian torpedo. According to the man who painted the picture, the ironclad was completely demolished, but from what I have learnt since he must have been drawing somewhat upon his imagination.

He interpreted, however, the idea which is still very common even among sailors; and so the possibility of attack by torpedoes is believed to get on the nerves of the officers and men of a fleet even if the actual damage which a torpedo might do is not what was supposed. And being thus kept in a state of anxiety they lose some of their efficiency as fighters. So the torpedo probably does more harm by frightening people than by blowing them up.

Of course, torpedoes are always being improved, and so there is always the possibility that what was true in the past may not be true in the future. Admiralties do not advertise what they are doing, and so no one can tell what the future has in store in these matters. The fault



A Torpedo Attacking a Ship

This interesting picture shows how a torpedo after it has been fired from a torpedo-boat or other craft makes for the enemy's ship The latter endeavours to make this dangerous engine inoperative by the protection of the torpedo-net, made of steel wire and held out by steel booms. The figures marked on the sketch of the torpedo refer—reading them in their numerical order—to the propelling twin screws, vertical rudder, bevel-gear, shaft-buoyancy chamber, starting-gear, starting-pin, engine chamber, balance chamber,

with the torpedo so far has been that it did not carry a sufficiently powerful charge of explosive, and consequently the damage done was not enough. Mines, on the other hand, having much greater charges of "powder," in the Russo-Japanese war instantly destroyed great battleships so that they sank at once. Many of us will remember reading of how the *Petropavlovsk*, with the famous Russian Admiral Makharoff on board, sank in a few moments, with nearly all her officers and crew, destroyed by a Japanese mine.

Although the terribly destructive effect of mines and torpedoes has been proved again and again during the Great war, efforts are still being made to increase the size of the torpedo. But a larger weapon would require more powerful mechanism to drive it; this again would require more space, and a stronger and heavier shell to enclose it.

The Italian Government some years ago tried an experiment which seems to indicate, however, that the torpedo, even the 18 inch, is a very deadly weapon *when it hits in exactly the right spot.* An old useless battleship was used for the trial, and a torpedo was fixed close to her side in exactly the position which it would occupy if it had been fired at her from a distance with perfect aim, a condition of things which would be very likely *not* to happen in actual warfare. The torpedo was fired by electricity from a safe distance and the explosion which followed tore such a hole in the battleship that she sank at once. Still at the bottom of the sea she remains, but divers who have been down report that there is a hole in her of 50 square metres in extent. If that result could always be attained, there would not be much improvement needed in the torpedo.

The first modern form of torpedo seems to have been the kind known as a "spar torpedo"—a case of explosive fixed at the end of a long wooden spar, with which one ship could charge another much as the knights of old used to charge with their lances. It is easy to arrange a trigger-like device which will act as soon as the torpedo touches anything, so that it explodes the moment after it strikes the hostile vessel. Some of the early submarines described in previous chapters were armed with a spar torpedo fixed right at the bow, so that all they had to do was to run their noses full tilt against an enemy.

It has been thought that a spar torpedo would be a useful weapon against a submarine. The British Admiralty tried an experiment on these lines not long ago. A barrel was floated in the water so as to represent the conning tower of a submarine just visible above the surface, while one of those ocean sprinters, a torpedo boat destroyer, was armed with a spar torpedo to attack it. The idea was that the destroyer had discovered the submarine on the surface, and with its mighty engine-power had rushed upon it and reached it before it had time to dive below. The torpedo exploded near the barrel, and blew it to fragments. It was judged by those on board that no submarine could have survived such a blow, while the destroyer was going so fast that before the explosion had had time to cause much commotion upon the surface of the water she was safely past the spot.

It is believed that to destroy a submarine it is not necessary to explode the torpedo close to her. When she is submerged there is already the pressure of the water trying to crush her, and a powerful explosion causing a sudden increase in this pressure might very well be more than she could bear. Water is remarkably rigid, and so would transmit the "blow" of the explosion much as the blow of a hammer is transmitted from one end of a chisel to the other. A torpedo somewhat of the "spar" type, inserted in the water as near the submarine as possible and exploded by electricity from the attacking ship, may therefore turn out to be a good way of fighting against these tricky little vessels.

On the other hand, the French once sank one of their earlier and out-of-date submarines with some sheep on board, and exploded a torpedo some distance away; but when the craft was hauled up again the sheep seemed none the worse. But the explosion may in that case have been too feeble or too far away.

The best mode of attacking submarines has been a matter of much anxiety to naval authorities the world over. The British, it will be remembered, scoffed at the submarine, and only bought a few to find out the best way of fighting them.

One result of this is that the British now have the largest and most up-to-date submarine fleet in existence, but the other results are secrets; what opinion they hold as to how submarines should be attacked can only be guessed at.

One thing is pretty certain, and that is that submarines will not be used to fight submarines. It has been remarked that such a contest would be like a fight between two gangs of deaf men in a large field on a pitch-dark night. Some might spend all their time groping about vainly trying to find some one to "go for," while others, colliding by accident against another human being, would be in utter ignorance as to whether he was friend or foe. The end of the scramble would probably be that little damage was done to either side and that little might very likely be inflicted in mistake by friend upon friend.

No, it is larger vessels which will have to find and attack the submarine, and the first part of the task, to find it, is the most difficult. One suggestion, emanating from France, is that large warships should carry balloons which they could send up, keeping them captive at the end of a long rope; or flying machines which could start from and alight upon the ships' decks.

The advantage of this is not at all easy to see at first, but it is really quite simple. If you want to look down into the depths of the sea, river or lake, you will find that it is necessary to look straight down, perpendicularly to the surface, or nearly so. That is because of the refraction or bending of the rays of light which takes place at the surface of the water. Consequently, if you look down from a height of a few feet only, over the side of a boat, for instance, you can only look upon an area of a few feet, for as soon as you try to look beyond that, you look so obliquely upon the surface that your vision is spoiled. If, however, you were up in a balloon, you could then look down upon a large area of sea, and all the time be looking down nearly vertically. Thus from a balloon it would be more easy to detect a submarine than from the ship itself. There could be a telephone from the balloon to the ship, and so the movements of the submarine could be telephoned down.

Another scheme is for two destroyers to steam along abreast with a huge fishing net stretched between them. They travel at such an enormous speed that if a submarine were really about, the destroyers would thus have a very good chance of catching it. Exactly what would happen to the submarine if it were caught in one of these

FISHING ON A LARGE SCALE

In this picture we see how submarines and other small vessels can be "fished for" and lifted with ropes or chains and carried into shallow water. The wreck is being supported from the two barges, which are being hauled along by the tug.

nets is not clear, but it would probably be a rather unpleasant experience for its crew. For one thing, it might become entangled, and so be pulled to the surface in a helpless condition; or if it were caught by one end, the balance of a submarine when under water is such a delicate matter that it might well be turned right over somersault fashion. On the other hand, there is the possibility that under certain conditions the submarine might cleave its way through the net almost without knowing it.

For it is not easy to calculate correctly what will be the effect of heavy moving masses. It used to be thought with confidence that a strong boom of timbers, chains, and wire ropes across the mouth of a harbour afforded secure protection from attack by night. But not long ago at Portsmouth a ship was told off to try this, and by charging at the boom at full speed it cut through it almost without feeling it; and a strong steel wire rope, stretched across a little higher up for the purpose of catching the attacking ship's funnel, was likewise broken as if it had been a piece of cotton. Such is the incalculable effect of speed. What ought to have happened according to expectations was that the attacking ship should have crumpled up and sunk. The authorities were so doubtful of her fate that her crew were entirely volunteers: they hesitated to order any men to undertake a task supposed to be so hazardous. Yet as the event proved there was little or no danger. And so it might be with a submarine caught in one of these sweeping nets.

Or perhaps some form of mine suspended from a float or buoy at such a depth that it would not be exploded by ships on the surface, but only by contact with a submarine, may answer the purpose. A certain colour is given to this suggestion by the fact that the Admiralty, about the same time that the submarine came to the front, acquired several ships which were originally intended for steam trawlers, but which they fitted up in such a way that they can steam along strewing mines in their track as they go.

The latest British submarines, too, are fitted with several guns which they can use on the surface, a fact which seems to indicate that they are intended to defend themselves against attacks by some kind of surface boats. What can the latter be? They can only be torpedo boats, destroyers or other small ships, for against no other craft would such tiny weapons be of any use.

Looking at it all round, the submarine's worst enemy is probably the destroyer, a type of vessel originally intended to chase and sink surface torpedo boats, hence their full name "torpedo-boat destroyers." They are very frail craft, with enormous engine power and consequently very high speed. They are in fact the fastest vessels afloat. H.M.S. *Tartar*, for example, can do 40 knots, or 46 miles an hour, while the slowest of them can do 30 miles an hour.

Against this the fastest submarines can do no more than 16 knots on the surface and 10 knots submerged. If, therefore, a destroyer caught a submarine on the surface, it could possibly get near enough to pepper it with shells from its quick-firing guns before it could dive below again, while it certainly could not escape by flight.

And now we can turn to the torpedoes, which travel by themselves through the water, the offensive weapons of the modern submarine boat.

About fifty years ago a Mr. Whitehead, an English engineer settled in Austria, was approached by an Austrian gentleman about a new weapon consisting of a small boat driven by a clock-work motor and filled with gunpowder. There was a pistol arrangement which was let off by contact with any other body, and which in turn fired the powder. The idea was of course to launch this little vessel in the hope that it would run against a hostile ship and blow it up.

This invention appears to have been of little value in itself, but it set Mr. Whitehead thinking about the subject, and led him to the invention of the Whitehead Torpedo, which is still the most important thing of its kind.

It is really a small automatic submarine boat. In shape somewhat like a cigar, but with the front end more rounded, it is fitted with two little screw propellers driven by a beautiful little engine like a tiny steam engine, only actuated by compressed air instead of steam. The compressed air is carried in a reservoir which forms part of the torpedo. One of the latest improvements is an arrangement for heating this air during the torpedo's voyage. Exactly how it is done is a secret, but it is no doubt by chemical action. Many chemicals will give out heat, if allowed to mix, a simple example being sulphuric acid and water.

The advantage of the heating is that the range of the torpedo is increased and the speed is better maintained. As soon as the engine starts and begins to use air from the reservoir, the pressure commences to fall. If, then, heat be applied to the remaining air, it tries to expand, but being enclosed, it is unable to do so, and instead its efforts in that direction cause the pressure to be higher than it otherwise would be. Thus as the pressure tends to fall through the air being used, the heat tends to raise it, with the result that it is maintained at a more uniform level, the speed is kept up for a longer time, and the effective range of the weapon is increased.

The modern *Whitehead Torpedo* has a range of 6000 yards, and during a part of that distance it can travel at the rate of about 50 miles an hour.

Projecting from the nose is a little "trigger," which on coming into contact with anything will fire the charge of gun-cotton or other explosive concealed within it. This would be a source of very great danger to the users of torpedoes were it not for a very ingenious safety device. Under ordinary conditions this trigger is held by a screw so that it cannot explode the torpedo because of an accidental blow. At the time when it leaves the ship which fires it, it is therefore quite harmless, but during the first thirty yards or so of its course through the water, the action of the water itself upon a kind of little water-wheel, unscrews and so releases this safety catch, and it is then ready for action. Thus by no chance whatever can one of these explode in the ship, for it must have travelled 30 yards *through the water* before the explosion can occur.

A most important point, of course, about such a weapon, is that it should maintain the correct depth below the surface, for if it be but a few feet too deep down it will probably miss its object altogether. Therefore an automatic control of the depth is essential. This is obtained by taking advantage of the fact already referred to, that the pressure of the water depends upon the depth: at two feet down the pressure is exactly twice that at one foot and half that at four feet, and so on. So a little valve known as the "hydrostatic valve is used, which is itself controlled by the pressure of the water. If the torpedo descends too low, this valve operates the rudder and steers it upwards, or if too high in the water it is steered downwards. Indeed, this arrangement works too well, for it would bring a too deeply submerged torpedo up so quickly that it would jump clean out of the water. Therefore this valve is made to work in conjunction with a pendulum placed so as to swing to one end or the other as the nose is pointed upwards or downwards. When the hydrostatic valve tends to throw the torpedo upwards too quickly, the pendulum swings towards the stern of the torpedo and that is made to check its too rapid rise. Thus the partnership between the hydrostatic valve and the pendulum results in the torpedo assuming and keeping to any predetermined level under water.

The two propellers are not side by side as they are in a twin-screw ship but one behind the other, the spindle of one being hollow, so that that of the other can pass through it. They revolve, too, in opposite directions in order to avoid the tendency to turn the torpedo round, which would occur if they both revolved the same way.

Another interesting feature of the modern "Whitehead" is a gyroscope, a little wheel which revolves at the rate of several thousand revolutions per minute, and the effect of which tends to keep the torpedo on a straight course.

The torpedo is different from the projectile of a gun inasmuch as it does not need to be thrown out with great force. The projectile depends upon its initial speed to carry it to the end of its journey, but the torpedo simply needs to be put in the water pointing in the right direction, and then away it goes by the power of its own little engine. So a torpedo tube is very different from a gun. Sometimes it is submerged: that is to say, it ejects the torpedo from a hole in the ship below water. This, of course, is always the case with submarine boats. Surface boats, however, often have the other kind of tube, fitted on the decks, by which they can launch a torpedo over the side of the ship. Having a clear view of the enemy they are perhaps better able to take aim with these than is possible with those under water. The latter are little more than locks by which the torpedo can be got into the water without letting the water into the ship. A cover on the front end is closed while the torpedo is put in the tube. Then a cover at the back end is closed, after which the front cover can be opened to allow the torpedo to pass out.

The Germans and some smaller nations use the Schwartzkopf Torpedo, which is very similar to the Whitehead, except that it is made of phosphor bronze instead of steel.

To defend themselves against torpedo attack when lying at anchor, large war vessels have steel nets which they can put out and which form a kind of wire fence all round them suspended from spars which project outwards from their sides. These nets are the reply of the large vessel to the torpedo of the small one. The latter has made several attempts at a rejoinder. The Whitehead, for example, has an appliance fitted to its nose for cutting through the wires of the nets, while others have tried more ingenious methods still. One of these, invented by a Russian General, consisted of two fish-shaped torpedoes, one of which towed the other, and when the first one struck a net the second dived down and came up again inside the net. At least that was supposed to happen, but since these torpedoes do not seem to have caught on with any nation, it would appear as if they did not quite come up to expectations.

There have been other torpedoes which are controlled from the shore, of which the *Brennan* is perhaps the best known. This is intended mainly for the protection of harbours, and can be operated and guided from a distance. The essence of the whole thing is two long lengths of piano wire, which can be wound on drums by machinery ashore while the other ends pass out to the torpedo. The pulling of the wires causes the machinery inside the torpedo to work and so turn the propellers. One wire operates the port propeller and the other the starboard propeller, and so by pulling one more energetically than the other, one propeller can be made to work the faster, and the torpedo can be steered and made to follow a hostile ship even if it be on the move. In fact, so long as it is within its range the *Brennan* torpedo can fairly hunt down its prey. These are not now made, probably because the authorities consider that the big guns on the shore forts can keep hostile ships at a greater distance away than that at which the *Brennan* can operate.

Lay, *Nordenfeldt*, and *Sims-Edison* are names of other torpedoes controlled from the shore, the operating and controlling power being electricity which passes along wires which the torpedo trails behind it as it goes. There are generally two wires, along one of which passes the current which drives and along the other the current which operates the steering mechanism.

There is also one which is controlled by electricity, but which derives its driving power from compressed carbonic acid gas, which when under certain pressure assumes a solid form so that a large quantity can be carried in a small space. Under proper conditions as to pressure and temperature, this returns to its gaseous form, resulting in an enormous expansion, so that a little solid carbonic acid furnishes enough gas to drive a little engine for a long time, in addition to which extra pressure can be imparted to the gas by heating it by the action of sulphuric acid and lime.

Last, and perhaps most interesting of all, are the torpedoes which are controlled by "wireless" electricity. The best of these is probably the one invented by two gentlemen by name Orling and Armstrong. This torpedo has a projecting mast which rises above the water, and so serves a double purpose. For one thing, it enables an observer ashore to watch its progress and change its course as it may be necessary, while for another it serves as the wireless "*antenna*," the apparatus, that is, which detects the signals coming from the shore station. And this mast is of a very remarkable construction, inasmuch as an enemy might shoot at it all day long with the best guns and the most accurate aim, yet never damage it. It is in fact nothing more than a jet of water shot upwards by compressed air, which, simple though it is, answers all the requirements in the fullest possible manner. It is said that the inventor thought of this ingenious idea when he was asleep—dreamed it, in fact. It is claimed that this torpedo could be made to dive under the torpedo nets and rise up inside, thereby rendering nets as made at present absolutely no protection whatever.

But, so far, I have only mentioned incidentally those powerful submarine mines by which harbours are defended in times of war.

These are cases made of steel filled with gun-cotton. In some instances they are round like a ball, in others cylindrical in shape. Gun-cotton is employed because it is so safe to handle. It can be used wet, and in that state will not explode of itself, but only when a small charge of dry gun-cotton is exploded close to it, and even that is not easy to fire, and needs to be started by a tiny charge of fulminate of mercury. Thus the main charge of gun-cotton can be handled with perfect safety.

Some mines contain as much as 500 pounds of this stuff, enough to destroy the largest vessel.

Sometimes the mines are buoyant, so that they float in the water moored to an anchor or heavy weight, but themselves only just below the surface. There are two ways of firing them. One is by means of an electrical device in the mine itself so arranged that when it receives a blow from a ship running against it an electric current fires the fulminate of mercury, that in turn the dry gun-cotton and finally the large charge of wet gun-cotton.

The other method is to connect the mine by a length of submarine cable to the shore. Watchers on shore can then fire the mine at will, when they see that a hostile ship is over it. In this case it is made to float lower in the water so that friendly ships may pass over it in safety. Or if the water be not very deep, it may lie upon the bottom and not float at all. This is all the better, for the mine need not then be so large. It need only be just large enough to hold the gun-cotton and moreover the steel case is then usually lined with cement, which makes it more water-tight. The buoyant mines, on the other hand, must contain enough air space to make them float.

Another arrangement is to make the mine itself to float low in the water, or even to lie upon the bottom, while above it and attached to it is a small floating case containing the mechanism for firing it. A ship striking the floating case then causes an electric current to flow down to the mine below, and explodes it.

There is still another modification of these arrangements, in which the mine proper and the floating case are both under normal conditions well below the surface out of harm's way. The smaller case, however, is attached to the mine by means of a special kind of link containing a small charge of explosive which can be exploded from the shore. Thus, when an attack is expected, this little charge is fired, and it breaks the link, releasing the small case, which then floats up to near the surface ready to give the enemy a warm reception should he run against it.

Or the whole mine may in this manner be anchored to the bottom of the sea, and permitted to rise to near the surface when needed. This arrangement is called mooring the mines in a "dormant" condition.

The attackers' reply to these defensive arrangements is known as "countermining." If a mine be exploded very near to another, the other one will in all probability be exploded by the shock. So the attackers drop mines where they think others are moored, and fire them just below the surface in the hope of destroying those which the defenders have laid.

It is easy to see that a chain of mines, moored across the mouth of a harbour at fairly close intervals, would render that harbour almost impregnable, and countermining is but a clumsy means of removing them. The attacker can only guess where the mines are; he himself runs great risks when countermining, for he may easily blow himself up instead, and, when charged with wet gun-cotton, the attacked mine is hard to fire even by another mine close by. So that, as far as mining and countermining is concerned, the chances are very much in favour of the defenders, and there we see a work for which the "Lake" submarines seem very suitable. For they can creep about on the floor of the sea, and cut the cables which fire the mines, or cut them adrift from their moorings altogether.

Under very extreme circumstances during war the sea may be strewn with floating mines, similar to those just described, but not anchored in any way, just floating a little way below the surface. These are so very dangerous, however, not only to the people who lay them but also to neutral ships, and they are so liable to stray away far from the seat of war and there do incalculable damage, that they are not used except in the case of very urgent necessity.

CHAPTER XIII

SUBMARINE DISASTERS AND THEIR REMEDY

WE have seen in the preceding chapters how many of the early experimenters with submarine craft lost their lives in their work. Of recent years there have been some sad catastrophes with even modern and up-to-date boats.

The first we shall notice occurred to the British A1 in 1904. She was engaged in defending Portsmouth against a mimic attack, and in the course of this duty was in the Eastern Channel into Spithead, just near the eastern end of the Isle of Wight. All was going well, but those in charge of the boat failed to notice the approach of the *Berwick Castle*, one of the South African liners. Neither did the liner notice the submarine, for she was below with only the periscope showing above water, and of course that is made as small and inconspicuous as possible. The result was that the large vessel went right over the small one, striking the top of the conning tower, breaking the lid and letting in the water, so that she sank at once.

The *Berwick Castle* noticed a slight shock as if she had struck something. The captain thought it was only a dummy torpedo, but he signalled to the nearest warship and reported the matter. Nothing much was thought of it, however, until the operations were ended, and the A1 did not return to Portsmouth. Then it was seen what had happened.

A search revealed a stream of bubbles rising to the surface indicating where the unfortunate A1 lay, in over 40 feet of water. Strenuous efforts were made to get her up, but the depth and the tide, which runs very strongly at that point, made it very difficult. Eventually she was recovered, and her crew of eleven officers and men were reverently taken to Haslar Cemetery, where now they lie, having "as truly lost their lives for their country as if they had fallen in action with its enemies."[1]

The A1 itself, after being repaired, resumed its place in the fleet, as if nothing had happened.

More recently the A3 was lost under almost identical circumstances. In 1910 our friends the French suffered an almost exactly similar loss. One of the cross-Channel steamers leaving Calais struck a submarine which was endeavouring to dive under her, with the result that she was sunk and her crew drowned.

The British A9 almost suffered a similar fate off Plymouth. She was run into by a steamer which damaged her conning tower, but the officer in command, by promptly dropping her safety weights, succeeded in bringing her to the surface, where, with the conning tower above water, she was safe.

On another occasion a French submersible, the *Bomité*, also escaped by the presence of mind of the commander. During some manœuvres (in 1906) this submarine had made a successful attack upon an ironclad, and then dived in order to do the same if possible to another vessel some distance away. While she was under, however, the ships changed their direction, and so when the submarine came

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[1] The words of Admiral Lord Fisher.

to the surface she found herself close to and in danger of colliding with one of them. The officer in command, with splendid courage and resource, decided that it would be better to dive and chance getting safely under the big ship than be crushed, for a certainty, against her armour-clad side. He just managed to scrape through, for, passing under the other vessel, the submarine was struck, her crew thrown down and her hull damaged so that she leaked badly, but by letting go her safety weights she succeeded in getting to the surface again, where of course she leaked less, and so was got away to dock for repairs.

But accidents to submarines have not always been caused by collision. The A5 was at Queenstown one morning in 1905, alongside a larger vessel from which she was taking in stores of petrol for her engines. This operation was finished, and the A5 was making ready to go to sea when an explosion occurred inside her. Her commander and five men were killed, while the rest of the crew were seriously injured. A little later, while these men were being got out, a second explosion occurred, causing further injuries.

It is believed that vapour of petrol had got free inside the boat, and, mingling with the air, had formed an explosive mixture, which was ignited by a spark at some of the electrical apparatus.

As a precaution against this sort of thing, it was arranged afterwards for the submarines to carry some white mice, for these little animals are very susceptible to this particular gas, and begin to squeak as soon as there is the slightest hint of it in the air.

Very soon after this the A8 was in trouble off Plymouth, and fourteen men lost their lives in her. Accompanied by A7, she had gone out beyond the breakwater for practice, the pair being escorted by a torpedo boat with a number of extra men on board, so that they could take turns in the submarines. Both had dived several times, and the A8 was just in the act of taking another relay of men on board when she was seen to dip, the bow going down in the water. This caused her to ship a lot of water through the conning tower, the "hatch" (or door) on the top of which was of course open. Then, before there was time to close this up, she sank: four of her crew who happened to be on the "deck" were washed off and picked up by boats, but the rest were drowned.

Attempts were made to get her up quickly for the sake of the men imprisoned in her, who, had they been able to close the hatch, might have held out for many hours. Presently, however, an explosion was heard down in the water, and fragments of the unfortunate A8 were blown to the surface, making it certain that all was over with the men.

When later the boat was raised, it was seen that they must have been drowned almost at once, so their death was mercifully quick.

It is rather remarkable how every submarine disaster in the British Navy seems to have its counterpart on the other side of the Channel.

The French "Farfardet" dived before the lid of her conning tower had been properly fastened. Three of her crew, who were in the conning tower, managed to escape, but the rest died a lingering death in her at the bottom of the sea. This is a particularly painful accident, for divers who descended and knocked on the side of the vessel heard the men inside reply, but she could not be raised in time to save them.

Not long after this, our neighbours suffered another catastrophe, for the *Lutin*, after diving several times, came to the surface with her stern very deep in the water as if water had somehow got into that end. After remaining in that position for a couple of minutes, she sank. Assisted by two British war vessels, which rushed to the scene, and a Danish salvage ship, which happened to be near, the *Lutin* was eventually got up, but not in time to save the men.

Of course, since Britain and France between them own nearly half the submarines afloat, it is only natural that they should suffer most accidents, but they have not the monopoly of them. Russia, for example, lost one of theirs in 1904, through being swamped by a passing steamer; the German U3 sank in the harbour of Kiel; but it is not necessary to pursue the sorrowful story. Better is it to turn to a method of life-saving which, had it been in use on the boats mentioned, would in most cases have given the men at least a chance of getting safely to the surface.

It will be seen from the disasters which have been described, that the most usual trouble is the entrance of water into the hull of the boat in such quantities as cannot be counteracted by pumps or in any other possible way. This causes the boat to sink and refuse to rise again. The boat itself can probably be recovered at some convenient season, but the men, if they are to be saved at all, must be rescued at once.

The boat may fill quickly, almost instantaneously, to prevent which safety pockets must be invented, in which air will be trapped under any conceivable circumstances. Then, even if it fills slowly, or only fills partially, there is the danger that the sea water may at an early stage get to the electrical accumulators, and when that happens a poisonous gas called chlorine is given off which will kill the crew as surely as drowning unless they are provided with some instant protection. Thirdly, the entrapping of air and protection against chlorine are of no use unless the men can get out of the boat, for which purpose something of the nature of an "air-lock" described in the chapter on "Diving Bells" is necessary.

For the air inside is about normal pressure while the pressure of water outside depends upon the depth, and may be enormous. This is pressing upon the hatches, and makes it impossible to open either of them. And even if they could be opened, and if the men were to be provided with something of the nature of a diving dress and were to put it on inside, when they reached the water the pressure would crush them just as will occur to a diver if he falls suddenly into deep water.

Early attempts took the form of metal cases fitted to the outside of the boat, into which the men could get, and then, detaching them, float up to safety. These were so cumbersome, however, and so interfered with the usefulness of the boat, that they were soon discarded. They played the part which lifeboats play upon an ordinary ship, but the latter fortunately can be carried without inconvenience.

What is believed to be the solution of the difficulty, although it has yet to prove itself, for no submarine so fitted has yet sunk, consists in certain watertight divisions in the boat itself, and a modified diving dress for each man of the crew.

Depending from the top of the submarine are two partitions, running lengthwise of the boat. They do not reach the floor by a good distance, and so are not in the way, for the men passing from one side to the other can easily stoop under them.

Suppose, now, that a submarine has been "holed" near the bottom. The water will rise in her until it has compressed the air in her to the same pressure as its own. The whole of the upper part will be filled with air.

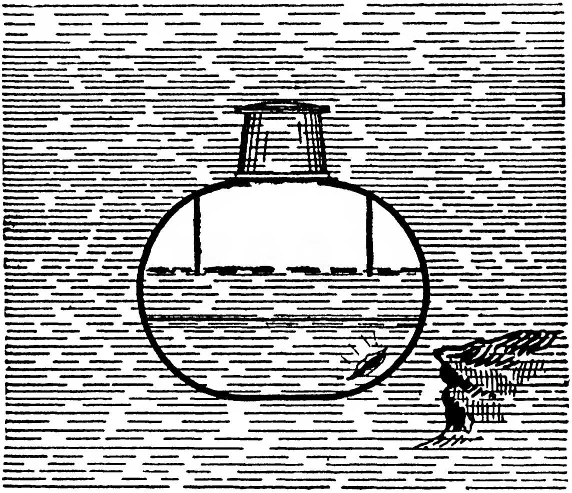

FIG. 14.—This shows how a Submarine perforated low down always entraps a quantity of Air.

Under these conditions the partitions do not help much —they are not needed. But from the very nature of the craft, it is much more likely to be "holed" near the top or, as we have seen, in the conning tower. Now if this happens, or if the lid of the conning tower be accidentally left open, the water will descend, and the air will escape until the whole vessel is filled, except for one or both of the "pockets" formed by these partitions. If the trouble is in the conning tower or between the partitions, both will hold air, while if it is outside either of them, the other one and the space between the partitions will hold air. It is safe to say that air is bound to be entrapped somewhere. Thus even in the case of accidents like those to the A1 and the A8, there would be a refuge in which the men, safe for the moment, could make preparations for escape.

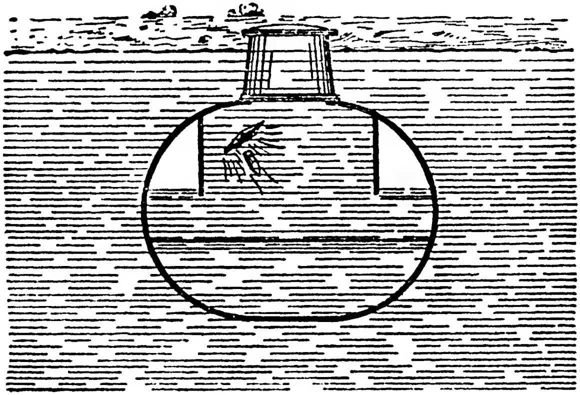

FIG. 15.—Here we see how the Partitions insure that even when perforated high up, a quantity of Air is always retained in a damaged Submarine.

To these, therefore, they repair and find there the helmet jackets which form the other part of the apparatus. These are like a small diver's helmet (large enough, however, for the wearer to move his head about comfortably inside) attached to a water-proof jacket, in a pocket of which there are chemicals which will purify the enclosed air for about an hour. One helmet and jacket complete weigh only 16 lbs., and take up but a little more than one cubic foot, so that it is easy to carry enough for all the members of the crew.

Thus, however sudden the inrush of water, the men have a very good chance of reaching the comparative safety of an air pocket, and once there, since the helmet jacket can be put on unaided in 30 seconds, they can be dressed before the chlorine gets too plentiful.

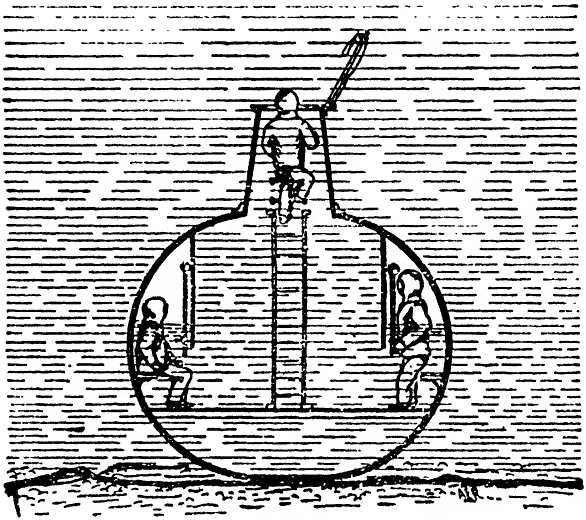

FIG. 16.—Sunken Submarine. This Sketch shows the Air-locks in which the men can put on their life-saving helmets. One man so equipped is seen actually escaping to safety.

But that is only the first stage. If the leak is such that the water flows in freely, the air is soon compressed to the pressure of the water outside, and it is then easy to open the hatch. If, however, the leak is stopped, and

Escaping from a Sunken Submarine

This picture shows how the men in British submarines are given a chance to escape, even though their craft be sunk. One is already floating safely on the surface, another is just rising, while a third is emerging from what would, but for this wonderful dress, be his tomb.

the only difficulty is that the boat will not rise, then water must be admitted by means of the valves until the air has been compressed. Not only is this necessary in order to get the hatches open; it is needed to prevent the men being crushed by the pressure the moment they enter the water. Suppose the depth is such that the water pressure is 20 lbs. to the square inch. The air pressure will be the same, and since the men put on their helmets and jackets in that pressure it will be inside their dresses too. Thus, when they take to the water they will not feel its pressure, for the air inside will resist it just as it does in an ordinary diver's dress. As they rise, and the water pressure falls, the air will expand and some of it will escape under the edge of the jacket, but that will not matter. The boat itself therefore is made to act as an air-lock wherein the air pressure is raised to that of the water outside. All the men have to do, then, is to open either the hatch in the conning tower, or else the one on the back of the boat through which the torpedoes are brought in, whichever is most convenient, and float up to the surface.

The helmet and dress contain enough air to make a man buoyant, and so he goes up automatically. Arrived at the surface, he can open the window in the front of the helmet and breathe the fresh air. But that lets the air escape from the jacket, and so he would sink were he not provided with a life-belt. Part of the dress is double, and into the space between the two layers he can blow air through a little tube, thereby rendering the dress itself buoyant enough to sustain him. Even then, of course, he has to take his chance of being picked up by a boat.

And there is still one other important point to explain. If the depth were sufficient, the air in the pockets might be so compressed that there would be very little space left there for the men to put on their helmets. At only 30 feet, for example, the pockets would be about half full of water. But that is provided against, for there are cylinders of compressed air connected with pipes which communicate with the pockets, and the men, by the simple turning of a tap, can admit this air and so blow the water out again, so that they can fairly rely upon having a whole pocketful of air in which to dress.

The British Admiralty have adopted this plan in all their newer submarines, and, rightly considering that any device of the sort will be of little value in an emergency unless the men are accustomed to its use, they have fitted up a tank at Portsmouth Dockyard, in which the men who are to serve on submarines can practise.

In the bottom of this tank is a structure which represents in all essential features a sunken submarine. The part of it which represents the air pocket is in the form of a lift which can be raised to the surface. Into this a man gets, puts on his helmet, and is lowered to the bottom, where he gets up, gropes his way to the conning tower, opens it, and floats up into daylight once more.

"There is nothing new under the sun." Although he had not the helmet jacket, it is quite clear, as we have already seen, that Bauer, over sixty years ago, used the method of escape just described.

CHAPTER XIV

THE SUBMARINE COMPASS

OUR ancient friend the magnetic compass is of little use inside a submarine; it simply will not work there properly. Placed over the deck of the boat, for use when on the surface, just as in ordinary ships, it is all right, but not inside. Thus the officer controlling the movements of one of these mysterious craft must depend for his direction upon the periscope, with its limited range of vision.

This led to the invention and perfecting of the gyro-compass, which, although it is applicable to any ship, owes its special value to the fact that it will work just as well inside a submarine as anywhere else. I have therefore ventured, for the purposes of this book, to call it the submarine compass.

The old mariner's compass, as all my readers know, consists of a small magnet so suspended that it can swing round freely under the influence of the great magnet on whose surface we live. And the awkward thing about it is that other magnets can influence it too, if they be sufficiently near, while masses of iron in the neighbourhood also have a demoralising effect upon it.

In the old days of wooden ships there was no trouble. Wood has no magnetic properties, and the quantity of iron on a ship, either as fittings or as cargo, was never very large. But now it is quite different. The ship herself is built of iron, that particular form of it which we call steel; there are often hundreds of tons of iron and steel among the cargo of merchant ships; while on warships there are huge steel guns which, with their protecting armour, weigh thousands of tons. And all these have their effect upon the compass.

Moreover, to make the matter worse, every iron ship is not merely a lump of iron—it is a magnet. If a piece of iron be left lying in one position for a long time, it acquires the properties and powers of a magnet. And if, during that time, it be tapped with a hammer, it will acquire these things more easily still. It is believed that the magnetisation of a piece of iron consists in all the tiny particles (the molecules) of which it is composed getting placed in the same direction. Each molecule is naturally a little magnet, but normally they are lying higgledy-piggledy, pointing in all ways and all pulling in different directions. Thus their effect is to neutralise each other, so that a piece of iron in this condition, though it is made entirely of minute magnets, exhibits none of that power which distinguishes a magnet. If, however, you can turn all these millions of little magnets into one direction, so that instead of neutralising each other by pulling all sorts of ways, they are all, or a large proportion of them, pulling together, then the piece of iron becomes a magnet.

The natural magnetism of the earth is able to do this, if it be allowed a sufficient time, so that a bar of iron, left undisturbed in the same position for a few weeks, will gradually become "polarised," as the term is—meaning turned into a magnet. And if, during that time, the iron be hammered, every stroke of the hammer shakes up the molecules, making it the more easy for the earth to pull them into their new positions.

Now, when an iron ship is built, both these conditions prevail. She lies for months in exactly the same position, while all the time men are hard at work hammering away at her, putting in the rivets which hold her together. It is not surprising, then, to find that by the time she is launched she has become quite decidedly magnetic. Of course, the attraction is not very great, because the earth power itself is not very intense. A ship is not likely to pull another one out of its course because of its magnetic power, but it is quite strong enough to affect the direction in which the compass points. Thus, while the earth is trying to hold the compass needle in the one direction always, the ship may be trying to pull it in *any* direction. As the ship changes her course she tries to carry the compass needle round with her, the very thing which we do not want to happen, for the value of the compass is entirely due to the fact that it points (or should do) in the one direction no matter how the ship may be turned.

All these disturbing influences are overcome to a certain extent by "adjusting" the compasses of a ship at frequent intervals. Small magnets and pieces of iron are placed in the case round each compass so as to neutralise all the forces at work except that of the earth itself. But these devices are not entirely satisfactory, and in the case of a submarine boat are barely practicable at all. Compasses are used, as has been said already, on the deck of a submarine as on other ships, but inside it the magnetism of the boat itself and the near presence of so much electrical machinery, consisting mainly of powerful magnets, make satisfactory adjustment impossible.

We can see, then, how valuable must be this new compass which is quite independent of all these outside influences, and which will respond to one influence alone.

We all learn at school about the great French scientist Foucault, who by means of a long pendulum proved the rotation of the earth. We do not hear so much, however, about his experiments with tops or revolving wheels. It is probable that in years to come we shall hear much more of these latter, because the principles which he discovered are being put to practical use in many ways, and will very likely prove of great benefit to us in our daily life, while his experiments as to the rotation of the earth, though very interesting, are of no practical use.

Foucault mounted a spinning top so that it could move in any direction, or, to look at it another way, so that its support could be moved in any direction without moving it. Figure 17 shows the kind of thing I mean. There we see the axle of the wheel is mounted inside a ring, the ring inside a fork, and the fork in a socket. All the joints are made to work as freely as possible, and all the parts are made to balance exactly. Thus you could take hold of the wheel, and the slightest touch would make it move in any direction you like. Not only will it turn round upon its axle, but you can move its axle so that it points in any way desired. Or, on the other hand, you might hold the apparatus by the socket, and move it about freely without necessarily altering the direction of the axle. That is called a Gyrostat, with three degrees of freedom—for (1), it can rotate, (2) it can tilt over sideways, (3) it can swing round in the socket.

Then, setting the wheel in motion, he discovered that it did in fact always remain with its axle in the same direction. Even the continual movement of the earth had no effect upon it. Indeed the stillest ordinary thing which we know is not nearly so stationary as the little revolving wheel. The great mass of the Pyramids, for example, is not so still and permanent in its position as the Gyrostat. If the wheel be revolving fast enough, and the joints be sufficiently free, we might take up the apparatus just illustrated, by the socket, wave it in the air, turn it upside down, do just what we liked with it, and when set down again we should find the axle of the wheel pointing just as it did before.

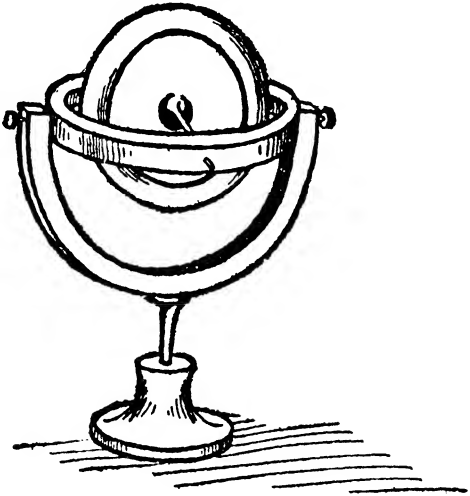

FIG. 17.—A Gyrostat with "three degrees of freedom."

These facts are familiar to a certain extent in connection with the well-known gyro-top, which consists of a wheel rotating inside a ring. The ring can be placed in almost any position, and so long as the speed of rotation is sufficient it will remain just as you put it, defying the force of gravity. That is merely a simple example of this wonderful power which a revolving wheel possesses of maintaining itself always in the same position.

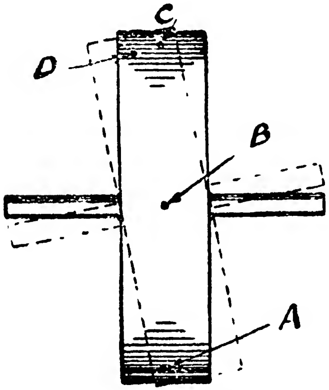

FIG. 18.—Why the wheel always tries to maintain its Axle in the same Direction.

Its explanation is found in the great discovery of Sir Isaac Newton, that if a particle of matter be once in motion it will remain in motion for ever with unvarying speed and in a straight line, unless some outside force interferes with it. At first it seems as if this could not apply to the particles of a revolving wheel, for they do not move in a straight line but in circles, and that is quite true, looked at in one way. If, however, we look at a wheel edgewise—as we see it, that is, in this illustration—then the particles *do* appear to move in straight lines. Take, for instance, the particular particle which lies at the point A. If the wheel be revolved, that particle will soon be at B, and then at C, all of which points are in a straight line. Now suppose that, while the particle is performing that journey from A towards C, we slew the axis round to the position shown by the dotted lines.

The particle will then have to find its way to D instead of to C, to do which it will have to deviate from its straight course, a thing which it strongly objects to do.

All the particles of which the wheel is formed act in the same way, except that those which are farthest from the centre act the most strongly since they move the fastest. Thus they all of them do their utmost to keep in a straight line, and so to maintain the wheel in the same position.

Now suppose we take away the ring, and, instead of it, mount the axle of the wheel directly in the fork. We have taken away one of the "degrees of freedom," so that it now has only two, and under these conditions it will henceforth exhibit an entirely new tendency. You will remember, that with three degrees it ignored the earth's rotation altogether. If fitted with a little motor so that it would go on rotating for a day, a gyro with three degrees of freedom would appear to swing round once in every day. Really it would be the earth which had swung round under the gyro, while the latter remained still. With only two degrees, however, it will place itself with its axle pointing north and south.

This, again, is the result of the fondness of moving matter for a straight line. It is most difficult to explain on paper, but is quite easy to see if you happen to possess a gyro-top such as I referred to just now.

Set it going, and then hold it in your right hand, as shown in Figure 19, between your thumb and finger. You will soon perceive that the slightest turning movement of your wrist, tending to tilt the axle of the gyro, will produce a curious effort on the part of the latter. It will try to twist the ring in your hand. One end of the axle will try to move away from you, and the other end towards you. This movement is called "Precession," and it will continue as long as the axle is being tilted.

Eventually, of course, if you could turn your wrist several revolutions, it would reach a position in which the axle is in line with the wrist. Then the turning of the wrist would cease to tilt the axle, and the precession would cease.

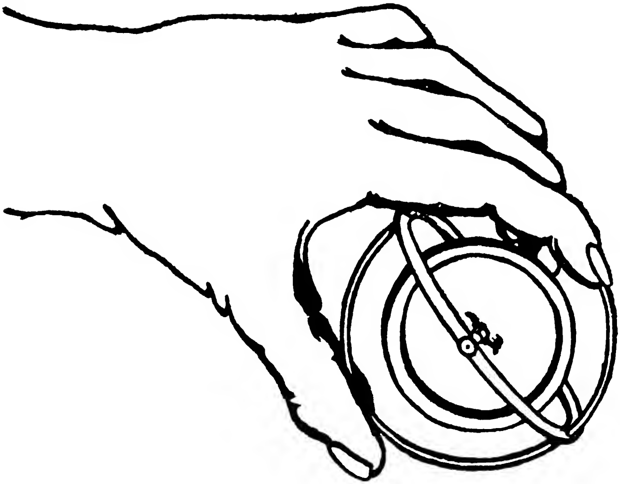

FIG. 19.—This helps us to understand the marvellous "Precession" which causes the new Compass to point North and South.

If, now, while moving the toy thus in your hand, you fix your attention upon one particle of the wheel, and remember that that particle will always endeavour to keep moving in a straight line, you will soon be able to see how and why it produces this curious and surprising effect—precession.

Let us now imagine a gyro, with two degrees of freedom, at some place on the equator. We will place its axle pointing East and West, and set it rotating. As the earth swings round on its axis it will carry the apparatus from West to East, thereby tilting the axle, the East end downwards and the West end upwards.

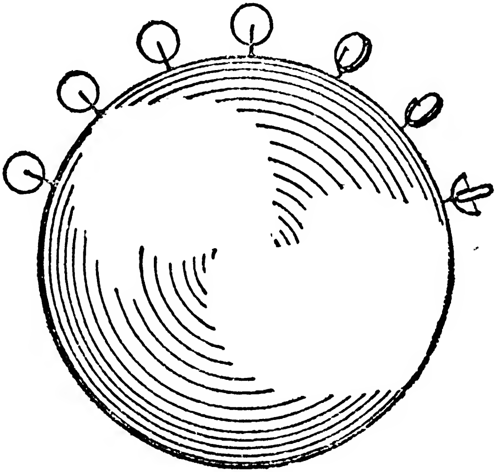

FIG. 20.—This shows how the Motion of the Earth may tilt the axle of a Gyrostat with two degrees of freedom, and how the Precession will then turn it round.

This sketch, wherein, of course, the size of the gyro is enormously exaggerated, will show just what I mean. The effect of this tilting will be to cause precession, and the gyro will gradually swing round until its axle points due North and South. Then the precession will cease, or in that position the axle will no longer be tilted by the motion of the earth.

At least, it ought to cease, but it does not quite; the axle swings round a little too far; then the tilting action begins again, but in the opposite direction, for the end which was tilted downwards is now tilted upwards and *vice versa.* Precession, therefore, commences again, but in the opposite direction, so the gyro swings back, once again overshooting the mark. The simple gyro, therefore, is not good enough for a compass, since it does not point steadily but merely oscillates to and fro in the neighbourhood of a North and South direction. To steady it, and to get rid of this oscillation, has been the whole of the difficulty in devising the gyro-compass, but of that more in a moment.

We have just seen how the apparatus would work at the equator. It will do just the same at any other point on the earth's surface, except at the poles; and since ships cannot get to the poles, the exception does not matter much.

This wonderful new compass, then, is simply that wheel rotating in a fork, slightly elaborated. There is a small but heavy metal wheel, with which is embodied an electric motor which drives it at the unthinkable rate of 20,000 times per minute, or over 330 per second.

This is mounted in a case which forms the "fork," but instead of standing upright in a socket it hangs down in the centre of what we might call a circular "raft" floating in a bowl of mercury. The friction between the "raft" and the liquid mercury is much less than it would be between any two solid substances, and so this gyro is free to precess, if its axle be tilted in the very slightest degree.

Consequently as the earth rotates the gyro precesses until its axis is pointing North and South. Then, since the tilting ceases the precession ceases too, and the axle remains pointing in the North and South direction. Moreover, if anything should by any means divert it from that direction, precession at once comes into operation once more and brings it back again.

The compass card is attached to the upper side of the "raft," so that its movements follow exactly those of the gyro-axle below it. The whole is enclosed in a case very like that of an ordinary compass, with a glass top, through which the card can be seen and read.

It takes twenty minutes to get up the high speed of the wheel, and it will run for several hours after the current has been cut off. The ordinary current from the ship's electric-light wires is employed to drive it, but not directly. The ordinary current drives a motor which turns a small dynamo, thereby generating a different kind of current known as "three-phase alternating." The reason for this is to enable a special kind of motor to be used on the gyro, which will only work with this kind of current. It is known as a "three-phase induction motor," and its useful feature in this case is that it *will* insist upon rotating at a speed which bears a certain relation to the speed of the dynamo which supplies the current. The first motor can be regulated as to speed, and as soon as that has been adjusted correctly it is certain that the gyro motor, and therefore the gyro itself, is being driven at the correct speed too.

The oscillating from side to side mentioned just now, would, if unchecked, cause the compass to be pointing wrongly most of the time. The rotation of the wheel, however, causes a strong blast of air, and by a very simple but ingenious arrangement this has been made to blow against the apparatus, as it swings *away* from the true direction on either side, and so to damp out the oscillations altogether.

The perfecting of this valuable navigating instrument is due to the efforts of a German engineer, Dr. Anschütz, of Kiel.

CHAPTER XV

THE TIDE

IN all submarine work the tide is of importance. Sometimes it is a help, sometimes a hindrance. Sometimes its absence (for there are tideless seas) makes difficult things which would otherwise be easy, while at other times its absence is convenient.

In order to understand the tide and its ways, we need to think of what would happen if the earth were perfectly round and its surface perfectly smooth. The water would then cover the earth, and (except for the bulging towards the equator due to the fact that the earth is spinning round) it would be of equal depth everywhere.

Then let us suppose that the moon suddenly comes into existence. Its attraction will at once begin to heap up the water. For we must remember that the moon attracts—it pulls the earth just as the earth pulls it. We usually think of this the one way only, the great earth holding the little moon by its attractive power, and keeping it always in its course. We picture the moon as tied to the earth by invisible bonds, wheeling round it as something on the rim of a wheel revolves round the hub.

That is wrong, however. The attraction is mutual, it is the result of both attracting each other. And the moon does not really go round the earth, but both revolve in nearly circular orbits round the centre of gravity of the pair. The moon has a large orbit and the earth a small one, but they are both revolving round this common centre of gravity. In the case of the earth the figure which it describes round the earth-moon centre of gravity is very small, for it is so much heavier than the moon that this point is within the surface of the earth.[1] The centre of the earth revolves round it nevertheless, with the result that, in popular language, the earth is constantly "wobbling" because of the action of the moon upon it.

Not only does the moon thus pull the earth out of the even course which it would otherwise pursue, but it actually deforms it as well. The solid crust of the earth bends under the pull of the moon, forming earth-tides, which though only a few inches in amount and very difficult to measure, are measured with considerable accuracy. And if the solid earth is thus bent, how much more is the water likely to be pulled up into heaps, as we know does in fact occur?

If the earth were round and smooth, as we are supposing, these heaps would be perfectly regular, one on the side where the moon is, and one round the other side exactly opposite. At first sight this seems strange, for the natural result of an attraction on one side would appear to be a heap on that side, and a depression on the other. A simple way to understand this apparent contradiction is to think of it thus:—On the nearer side the moon pulls the water away from the earth; on the other side it tends to pull the earth (since it is nearer) away from the water. The nearer a thing is to the

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[1] It is the common centre of gravity of earth and moon which in turn revolves round, not the sun, but the centre of gravity of the whole solar system.

moon the more strongly it is pulled; therefore the nearer water is pulled the most strongly, the earth itself is pulled less strongly, the farther water is pulled least of all. And all the time the attraction of the earth itself is trying to arrange the water at the same depth all over its surface, with the consequence that between the two forces these two heaps of water or tidal waves are formed.

It stands to reason that these heaps will remain almost stationary under the comparatively still moon, while the earth in its daily rotation spins round under them, so that if we imagine ourselves stationed at any one point, we shall be carried past one of them every twelve hours. The earth's motion carries us from west to east, and so, as we are not conscious of the fact that we are moving, it appears to us that the tidal waves pass from east to west.

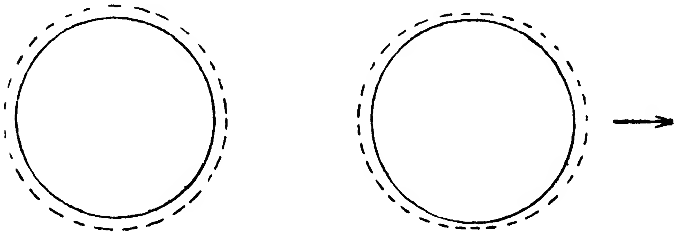

FIG. 21.—The left-hand Figure shows how the Water would lie upon the Earth by Gravity alone. That on the right shows how it is heaped up on two sides by the Moon. The inner Circle is the Earth, the dotted Circle the Surface of the Water, and the Arrow represents the supposed direction of the Moon.

The time of their passing is not precisely twelve hours, however, but a little longer. The moon revolves round the earth in the same direction in which the earth spins, from west to east, and it completes its journey in about twenty-eight days. Therefore, if we are standing at one particular spot, and we pass one of the waves at noon, by the time we get round to noon again that wave will have been carried a little farther away, by the movement which the moon has accomplished in the meantime. Now if the moon moves once round us in twenty-eight days, in one day it will move about a twenty-eighth of a circle, and to catch up the wave which we passed on the previous noon we shall have to go on for $\frac{1}{28}$th of a day longer. A twenty-eighth of a day is about fifty minutes, and so the tides occur about fifty minutes later each succeeding day.

If the tide is high at our observation point at eight o'clock to-night, it will be high again at about 8.25 to-morrow morning, and about 8.50 to-morrow night. The following morning it will be at about 9.15, and so it will go on getting later every day by about fifty minutes.

Nor is that all, for the sun also has a say in the matter; in spite of its great size, exceeding by far that of the moon, its pull is comparatively feeble (less than half), for it is so far away. Still it has its effect, and to see what that effect is we must notice what are the relative movements of them both. At "New Moon" both bodies are on the same side of us: then the moon gradually draws away from its larger companion, and gets farther and farther from him, until in about fourteen days it is "Full Moon," when the sun and moon are on exactly opposite sides of us, after which in another fortnight it gets round to "New" again. Between these are the two points known as the First and Last "Quarter" respectively, when one lies in a direction at right angles to the direction of the other.

When the moon is "new," therefore, both bodies are acting together: that is quite clear. When they are at the "full" they have the same effect, for each of them tends to form two heaps on opposite sides of the earth, and the places where those heaps are formed are the same points on the earth's surface.

At the "quarters," however, they partly neutralise each other, for the moon tends to form heaps at two places and the sun at two other places.

Thus at new moon and full moon, the high tides are very high and the low tides are very low, while at the quarters they are neither so high nor so low. The specially high and low tides are called "spring" tides, the others "neap" tides.

Suppose that to-day is "new moon"; there will be spring tides along our coasts. The highness and lowness of these will gradually diminish until in a week's time, the moon being then in the "first quarter," the neap tides will occur. After that they will gradually change again until in a fortnight's time there will be "full moon" and spring tides once more, to be followed by neap tides a week later still, leading up to the spring tides at the "new moon" in a month's time.

Now all this would happen with perfect regularity if, as we have been supposing, the earth were round and smooth. But it is not so by any means. The surface of our globe is studded with mighty projections, while the water lies in the hollows between and around them. These projections, where they stand above the water, form the continents and islands. And thus the water is hemmed in and the free flow of the tidal waves over the earth is interfered with, causing strange irregularities.

To commence with, some bodies of water are not large enough for tides to form at all. Even the vast Mediterranean is so small that the moon has passed over it and gone on its way before a tide of any size has been formed, and by the time the moon has returned again that little tide has subsided. Therefore in land-locked waters like the Mediterranean and the Baltic, and all the smaller seas, there is no tide to speak of.

The influences of the moon and sun act most easily upon a vast expanse of deep water, and so it is generally supposed that the tidal waves take their rise in the South Pacific Ocean. Part of each wave dashes up into the North Pacific, hurling itself upon the shores of China, Japan and Siberia, while the other part passes Australia to India, Africa, and so into the Atlantic. Thence it surges up northwards to Britain on the one hand and to the eastern shores of America on the other. About twelve hours later another tidal wave, formed in the same place, follows in the footsteps of its fellow, and so they go on, one wave following another in endless succession.

Any one caring to look at a map of the world, and following this brief description of the course of the tides, will see how the movement due to the action of the sun and moon alone is modified by the interference of the land, and will be able to understand why it is that the sun and moon, the most regular and methodical of bodies, cause a phenomenon apparently so fickle and so irregular as the tides.

How great this interference is, is shown by the fact that in the open ocean the speed of the tide may be 700 miles an hour, while it takes five hours to cover the distance from Plymouth to the Straits of Dover, but 300 miles or so.

That is because of the difference between the open ocean and a restricted and comparatively shallow channel. Indeed the whole nature of the tide changes when it nears land. Out in the ocean it is a wave, a mere undulation of the water. The movement of water is up and down, it does not travel along. How a wave can travel along while the water which forms it does not, is well illustrated by means of the domestic table-cloth. Take hold of one corner, and shake it up and down, when waves will run chasing each other across it. Yet the table-cloth will not move across the table, for you hold it in your hand all the time.

When it reaches the neighbourhood of land, however, the action of the water changes. A tidal wave approaches, say, the mouth of the English Channel—it simply means that the moon is drawing up the water into a heap there—and the water rushes down the Channel to help to form the heap. When the moon's action begins to wane at that particular part, the water being released, runs back up the Channel.[1] Thus the action of the tidal waves when they reach the vicinity of land is to form currents. We therefore have tidal *waves* in the open ocean, but tidal *currents* in the channels and rivers.

When the tide, as mentioned just now, surges up the Atlantic and strikes the shores of the British Isles, it divides into two main branches. One goes up the western coast of Ireland, round the north of Scotland

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[1] Thus we see how it comes about that the tide runs past a place like Brighton from west to east, while the moon, which causes it, passes from east to west.

and down the North Sea. The other finds its way along the south coast, up the English Channel, through the Straits of Dover, to about the mouth of the Thames, where it meets the other branch. But the curious thing is, that the northern branch has so much farther to go that it is not its fellow which the southern branch meets—it is the northern branch *of the previous tide*.

Further, in some places local conditions are responsible for local peculiarities. At Tong-King in China there is but one tide every day, instead of two. As in passing Great Britain the tidal wave is split into two, one of which goes up the Channel and the other round the north, so the wave which enters the gulf of Tong-King is split into two by an island, and since one takes a longer route than the other they arrive in the gulf at different times. This is believed to furnish the explanation of this curious single-day tide, for the two waves are thought to interfere with each other in such a way that one of the daily tides becomes obliterated.

Southampton Water furnishes us with an example of four tides per day. The level rises for seven hours, then ebbs for about an hour, rises again for about an hour and a quarter, and then finally ebbs. This is supposed to be due to the presence of the Isle of Wight, which is off the coast just opposite the entrance to Southampton Water. Something similar occurs at Havre in France, and at Poole, Bournemouth, and other places along the south coast of England, also in the Firth of Forth.

At some places the tide rises much higher than at others, which is also due to local conditions, such as the shape of the coast. The Severn has very high tides, because the water comes sweeping right straight into the Bristol Channel, and as it gradually narrows into the river the water is caught as it were in a trap and piled up high. The Bristol Channel, in fact, acts like a huge funnel into which the tide runs.

Thus at Chepstow, near where the Bristol Channel narrows into the river Severn, the tide rises 50 or even 60 feet, while out in the open sea at the entrance to the channel, before its funnel-like shape has had any effect upon the matter, the rise is only about 18 feet.

The Thames, again, might be expected to have a small range of tide, for the tidal current approaches it not in a straight line, as it does the Severn, but at right angles. This, however, is partly neutralised by the fact that, as just explained, the two main branches meet just at the mouth of the Thames, and the consequence of these two currents colliding, so to speak, is that a heap is formed, and so the tide in the Thames, though less than in the Severn, is higher than in some other rivers not far away.

At London, sixty miles up, it is still 18 feet—as high, that is, as at places which face the open ocean.

The writer well remembers in his boyhood wondering what really happened when the tide passed up a river. How do the two streams affect each other? Does the tidal stream flow at the surface, and the river stream underneath, or *vice versa?* Those were the puzzling questions. The answer is that the tide pushes the waters of the river back as it enters, and both flow out mingled together as it ebbs.

The height above sea level which we use for stating the height of mountains probably means the mean or average height of the sea, if indeed any notice is taken of such a minute matter as the variation of the tide when determining the heights of mountains which are necessarily only approximately correct. For stating the levels of different parts of a country, however, a very definite "datum level," as it is called, is fixed upon. In Great Britain, for example, it is the mean or average height of the water at Liverpool. When, therefore, you look at an Ordnance map, as the official maps issued by the Government are called, and see a level given as so many feet above or below "Ordnance datum," it means that distance above or below the mean tide at Liverpool. At least that is what it ought to mean, but it is not quite accurate, for when the mean level was ascertained in 1844 a slight mistake was made. By employing a self-recording tide gauge at St. George's Pier, Liverpool, and taking the average for every day for four years, the real average is found to be eight-tenths of an inch below that. That shows with what scrupulous accuracy such things are attended to, for who would think it mattered whether the datum was wrong to that tiny amount.

For convenience sake, to avoid having to alter innumerable existing maps and charts, the old level has been retained as a basis. It is purely arbitrary therefore, as indeed it must be in any case, for surely the correct sea level around Great Britain must be not the mean level at Liverpool but the mean of all the mean levels of all the places round the coast.

As a matter of fact, the tide has been carefully measured at fifty different places in Great Britain (forty-two in England and eighteen in Scotland), and it has been found that in some places the mean is over a foot below Ordnance datum and at others a foot and a half above it. The average of all fifty is about 6 inches higher than Liverpool.

In the Thames another standard level is often used for charts. It is known as Trinity High-water mark, and is indicated by a stone built into one of the entrances of the London Docks.

In Ireland the basis is a mark on Poolbeg Lighthouse in Dublin Bay, and denotes the low-water mark of spring tides.

On charts and plans relating to docks and marine engineering work these mystic initials are often to be seen, H. W. O. S. T., meaning high water ordinary spring tides, or L. W. O. S. T., the meaning of which will not need to be explained.

The importance of accuracy in these matters will be understood when it is remembered that sometimes a matter of a very few inches will make all the difference between being able and unable to get a ship into or out of a particular dock. A large ship wishes to use a certain dock, and the question arises, can she get in? In many cases there is ample room, but sometimes the vessel is so deep that she can only just get over the sill, as the kind of "doorstep" at the lock-gates is called. Then the exact level of the sill and the exact height of the tide are of the utmost importance.

The appliances by which the rise and fall of the tide are measured are various. The simplest of all is but a lath of wood fixed to a pier or sea-wall. Marks on it enable anyone looking at it to see how high the water is. This has the disadvantage that any roughness of the surface prevents a clear reading being taken. Moreover, it needs to be inspected periodically by someone who must write down the readings.

Therefore self-recording instruments are often used. These generally consist of a vertical pipe the lower end of which is immersed in the water below the level of the lowest tide. The level in the pipe is, of course, always the same as that of the water outside it, but it is free from waves or ripples, so that a float inside the pipe will rise and fall steadily as the tide rises and falls. The float is connected by a string to the recording instrument which consists of a pencil, the point of which rests upon a long strip of paper which is drawn along by clockwork. The string pulls the pencil so that it rises as the tide rises, and falls as the tide falls. Consequently as the paper passes under the pencil the latter draws upon it a wavy line which is a faithful reproduction of the rise and fall of the tide. This can be kept and referred to at any future time. Moreover, it is more likely to be correct than a number of independent readings taken off by an observer, however conscientious and careful he might be.

One of these recorders, at least, has an ingenious addition which makes it so self-acting that it can be left entirely unattended for quite long intervals. The rise and fall of the float, in addition to controlling the pen, winds up the clockwork.

Another type of instrument, one which is very accurate indeed, works on quite a different principle. A pipe is let down into the water so that its mouth is well below the lowest tide, and this pipe is kept full of air, which enters it, in a small but constant stream, from a reservoir where it is under pressure, and escapes from the submerged mouth. Now the pressure of water, it will be remembered, from earlier chapters, is always in proportion to the depth. And so the pressure at which the air escapes from the pipe will be in exact proportion to the depth of the water above the mouth of the pipe. A very delicate form of pressure gauge measures the pressure of air in the pipe and records it upon a strip as before, and that record of the pressure forms also a true record of the tides.

Before concluding this chapter, there is one point which ought to be made clear, for otherwise it may puzzle any reader who observes the tides for himself. Any particular tide is not necessarily caused by the lunar and solar attractions of that particular day. The tides which we experience on our coasts are the consequence of tidal currents caused by the tidal waves in the open ocean, and these currents are the swinging backwards and forwards of great masses of water. Now, you possibly know from experience of pushing a friend in a swing that you cannot get the swing going to its fullest extent with one push: you need to give it a number of pushes, and the highest swing of all is the effect of all these previous pushes. In the same way, when the sun and moon are acting in conjunction, and therefore pulling their hardest, they do not at once produce the greatest swing of the tidal currents. Consequently the highest swings of the currents occur a little *after* the attractive powers of the heavenly bodies have begun to wane.

On the Pacific Coast of the United States, the highest tide occurs half a day after the full or new moon, and the lowest half a day after the "quarters." To use the technical term, the tides there are half a day "old." On the Atlantic side, however, they are nearer two days old. On the west coast of Ireland they are two days, and at London two and a half days old.

Thus, to see the spring tide at London Bridge, one needs to look for it about two and a half days after full or new moon.

CHAPTER XVI

DOCKS, FLOATING AND OTHERWISE

DOCKS have a great fascination for people, especially landsmen. No visitor to Liverpool or Southampton, for instance, would be satisfied without seeing the Docks. Yet the part which is visible to the ordinary sightseer is not that which we are properly concerned with in this book. He thinks most of the long quays, with their straight stone curbs, the tall warehouses, and the cranes which run along in front of them, swinging the packages in and out of the ships; while we are mainly concerned with the parts below the water level—parts which are unseen, but which cost the most to make, and without which the quays, warehouses, and cranes would be useless. It is, however, impossible to separate them entirely in a description, so we must go briefly over the whole subject.

And we cannot take a better starting-point for the consideration of docks than London, where there are excellent examples of all kinds.

The river Thames, while it is not large compared with such rivers as the Mississippi or the St. Lawrence, is of a good useful size, and for sixty miles or so—right up to London Bridge, that is—vessels of considerable tonnage can easily pass. Very naturally, then, the first dock in London was the river itself, along whose banks great wharves were built, alongside which the small ships of years ago could lie quite comfortably. Some of the smaller coasting and continental vessels even now come up to what is known as "The Pool," the part of the river just below London Bridge.

The wharves are formed, for the most part, by driving rows of timber piles into the sloping banks of the river, and filling in the space behind them with earth or else with the lower floors of the many-storied buildings which form the warehouses. Thus what was once gently sloping fields or marshes is now converted into rows of tall buildings behind vertical ramparts of piles. The feet of the piles (where they enter the ground) are generally speaking above water at low tide, and the river-bed is kept fairly level there by means of another row of short piles farther out, so that there is always a nice soft level bed of mud on which barges and small vessels can lie at the lower states of the tide. The craft of all sorts, from quite natty little steamers to Thames "lighters," as the square-looking barges are called, float alongside at high tide, and are moored to the wharves, resting comfortably on the soft level "bed" when the tide recedes.

At some of the wharves a jetty has been built reaching out into deeper water, nearer the middle of the stream, alongside which lie steamers of larger size, and where they can be always afloat. Some of these are of timber or iron piles, and others of that newest of building materials, reinforced concrete.

But a river, even when it is thus prepared for the reception of ships and provided with wharves for storing the goods which they bring or are to take away, is not generally called a dock. It is really a tidal dock, to a certain extent artificial, but mainly natural, but it is the custom to apply the word *dock* more especially to artificial or mainly artificial basins for the reception of shipping. And of these London furnishes some remarkable examples.

As the ships became larger in size and more numerous, the accommodation in the river itself was not enough, so in 1802 the West India Docks were opened. From Flamsteed Hill, whereon stands the famous Greenwich Observatory, there is a most interesting bird's-eye view of these docks and the ships which use them.

The river just at that point makes two sharp curves, forming a shape like that of the letter U. The land is quite flat, too, and so there could not be a better position for a dock. The ground is cut away and dug out so as to form large rectangular basins with vertical sides, so that ships can come right alongside the edge and still be afloat; narrower channels are cut leading from the river to the basins, and from one basin to another, and in these lock gates are placed so that the level of the water can be controlled.

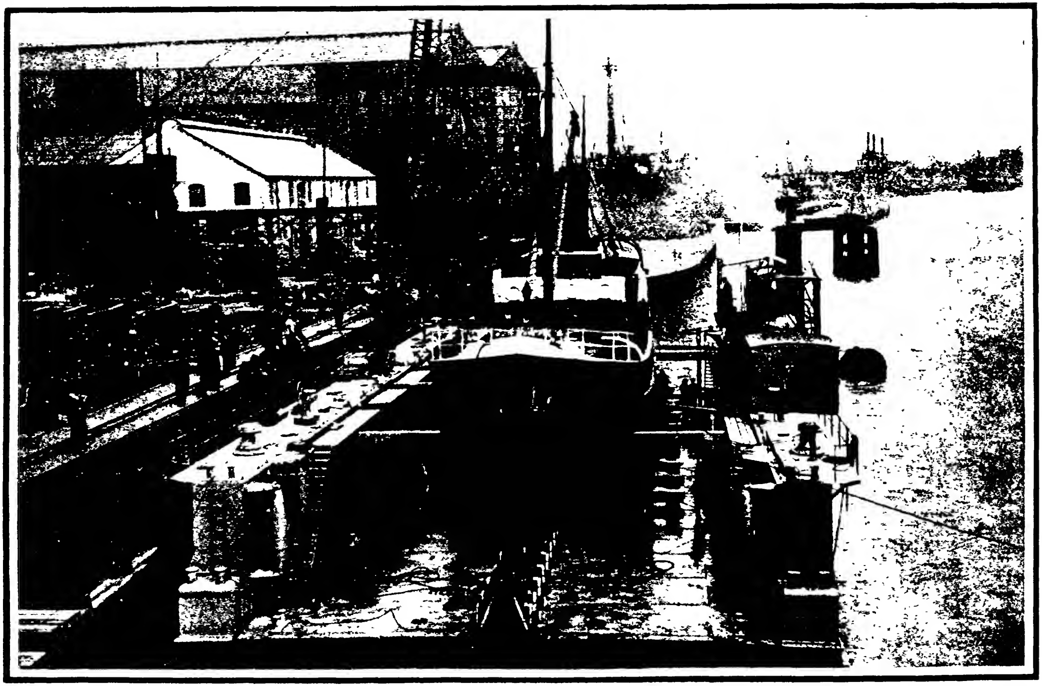
The special advantage of placing a dock in a loop of the river is that two entrances can then be formed, and craft can, if need be, enter at one, pass right through the dock and out at the other, without having to turn.

A few years later a smaller dock, called the London Dock, was built nearer the city of London itself, almost under the shadow of the hoary old Tower. It was for smaller boats, and had the advantage of being within walking distance of the shipowners' offices. Then dock followed dock, as the trade of the port grew—the Surrey Commercial, the East India, the St. Katherine's, the Millwall, the Victoria and Albert, and last of all the great dock down the river at Tilbury, one of the best arranged in the world.

The water part of this dock is shaped like a hand with three fingers. The wrist represents the entrance from the river wherein are the lock gates. The palm of the hand represents the main basin, while the fingers represent long strips of water with quays along each side in which the ships can lie to load and unload.

The railway from London and all parts of the country comes in the opposite way, and it too is in shape somewhat like a hand, the main line being the wrist. This spreads out when it nears the dock into a vast array of sidings, where the trains of trucks can be taken apart and sorted out according to the ships for which they are destined. Then from the sidings the lines separate and run along the sides of the quays. Thus the ships come straight in from the river to their berths alongside the quays, and the trains come in from the opposite direction, and the trucks can be run straight on to the quays close to the ships. Down the centre of each quay there run rows of sheds in which goods can be kept temporarily, as they come from or go to a ship, while, along the edges of the quays run not only lines of railway, but a wider line which carries huge hydraulic cranes capable of lifting heavy weights straight from the ships to the railway trucks or into the sheds, or *vice versa*.

In or near all the "wet" docks are "dry" docks, into which ships go for repairs or painting. Each of these is a huge basin dug out of the ground and lined with brick or stone work. Each one is large enough to hold a ship, and the entrance to it is through a pair of water-tight gates. A ship enters one of these, and the gates are closed: then the water inside is pumped out, so that she



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vertical ones. There are several ways of doing this, all quite simple in principle, but often very difficult to carry out successfully. The first has been mentioned already, namely, the driving of a row of piles at a suitable place, and filling in behind them with earth. The piles are often mere balks of timber shod with a pointed shoe of iron, and fitted at the top with an encircling ring also of iron, to keep them from splitting while being driven in. They are in fact huge timber spikes, and, like ordinary spikes, they are driven in with a hammer. Not with an ordinary hammer, it is true, but with a machine which acts just as a common hammer does.

The most usual form of pile-driver or pile-engine, as it is sometimes called, is a framework of wood of considerable height, in which can slide up and down a heavy iron weight. A rope passing over a pulley at the top of the frame serves to haul this weight up, and when it reaches the top it is released and allowed to fall, whack, on the top of the pile underneath, the frame being so fixed as to guide the weight down on to it exactly. The weight, because of its climbing action, is termed a "monkey." On little jobs, where there are not many piles to be driven, the monkey is pulled up by hand, but where there are a large number a steam engine is employed for the purpose.

Adaptations of the steam hammer have been used for this work too, the advantage of them being that they can give a large number of rapid strokes. When a heavy pile is still it takes a considerable force to set it in motion, because of its inertia,[1] apart altogether

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[1] That property of matter which, when an object is still, tends to keep it still.

from the resistance of the stuff it is being driven into. The pile-engine, with its blow every ten seconds or so (at the quickest), drives it in a step at a time: after each blow it comes to rest, and so this inertia has to be overcome at every stroke. With the rapid strokes of a steam hammer, however, the pile is kept "on the run," as it were, all the time, and after the first few strokes, nearly all the energy is available for overcoming the resistance of the earth.

Sometimes the piles are driven close together: such an arrangement is known as "sheet-piling." At others they are a little distance apart, with horizontal boards fixed to them so as to form a continuous wall.

But piles are not by any means always of wood. Iron and steel piles are used, while for sheet-piling there are some most ingenious forms of steel piles, so shaped that they interlock with one another, and do not simply stand side by side. They are driven in the same way as the others, however.

Then, newest of all, are the ferro-concrete piles. This material is ordinary concrete, made by mixing sand or ballast with Portland cement, but it has steel bars embedded in it. Only a few years ago this form of construction would have been laughed to scorn, for people used to think of concrete as essentially brittle and inelastic, and, moreover, they never dreamed that it was capable of gripping tightly a smooth bar of steel embedded in it. Yet it has been discovered that it is capable of being bent slightly, and afterwards resuming its original form—in other words, it has some elasticity; while if a piece of smooth steel half an inch in diameter be embedded in concrete for a depth of a foot, and you try to pull it out, you will pull the bar asunder before the concrete lets it go. Therefore concrete reinforced by steel bars forms a very powerful combination. It has the advantage, too, for such things as piles, that it is unaffected by wet. Timber rots and steel rusts under the influence of water: especially so when, as in tidal waters, parts are alternately wet and dry. You will notice if you look at old timber and steelwork in such things as seaside piers, that the wastage takes place mainly between the levels of high and low tide.

Ferro-concrete piles are made by pouring liquid concrete into wood moulds, in which the steel bars have been previously laid, and leaving it to set. They need to be kept a good while so that the cement may set very thoroughly, and after that they can be driven with a pile engine just as iron or timber ones can. And when once in they will last for ever. No corrosion takes place at all, and no painting is needed.

Although not often used for the purpose of which we are speaking, it may be interesting to mention here the other kind of piles which are so frequently employed in seaside piers and jetties. They are made of cast iron and are round like columns. At its lower end each has a large thread like an enormous screw. Hence they are called "screw piles," and they are inserted in the ground by screwing them round, not by hammering them in.

But to resume our dock work. When a retaining wall has been formed of piles, it can be filled up behind with earth until a level wharf is formed, against the vertical edge of which ships can come close. It may be that the water there will be deep enough for the purpose without further trouble, but if large ships are to be accommodated, it is generally necessary to deepen the water, for which purpose a dredger can be employed.

This consists of a boat specially built for the purpose, which has a strong arm which it can let down until one end of it reaches the bottom. At both ends of this arm are rollers, over which passes an endless chain, to which are attached buckets or scoops. The upper roller is turned round by a steam engine on the boat, and so the scoops are carried down to the bottom of the water, where they scoop up great handfuls of mud, sand, or whatever it may be, and bring them up again. As they arrive at the top roller and pass over it, they perforce turn over, thereby shooting out their contents into a barge which takes it all away and dumps it at some convenient spot where it will be out of the way.

As the dredger works, it is slowly moved along so that it gradually digs down the ground over the required area to the depth needed. Of course, when the earth is thus to be dug away from the feet of the piles, it is necessary that they should be driven in far enough for their points to be well below the ground when the dredging is finished.

I have already used the term "retaining wall," the meaning of which, I fancy, my readers have quickly seen to be that it retains the earth heaped up at the back of it and prevents it from falling into the water as it would otherwise do. And retaining walls are not always made of piles, whether of timber or something else. They are often of stone, brick, or of concrete. In these cases something has to be done to get rid of the water while they are built. Piles can be driven *into* the water, but stone or other built walls can only be constructed in the dry.[1] So in this case piles play a subsidiary part.

The row of piles is driven a little in advance of where the wall is to be—a little farther away from the land, that is. The temporary wall thus formed is made water-tight in some way such as piling clay against the farther side of it. At each end, too, it turns inwards and runs into the land so as to make a complete enclosure, inside which is the space where the permanent wall is to be built. The temporary wall is, in fact, a dam, and, since it is somewhat in the shape of a box or coffer, it is called a "cofferdam." When completed, the water is pumped out from the inside, and so a dry space made in which the permanent wall can be built in just the ordinary way. When it is finished, the piles are pulled out by main force, like a gigantic dental operation.

The construction of an artificial dock goes on on much the same lines, with the addition of the excavation and the fitting of the gates. The first thing to do is to dig out the earth until a huge basin or dry pond has been formed. Then the retaining walls are built along the edges of the quays, and the two walls and floor of the narrower part which is to form the lock. This can usually be done in the dry without any trouble unless the land where the dock is being built is very wet. Then cofferdams may need to be employed in some form or other, to keep parts dry for a time, or at least powerful pumps may be needed to keep the hole dry as it is being dug and prevent its getting filled with water before the proper time.

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[1] Except in a few cases where they are built of concrete blocks as described in Chapter II.

The lock is precisely the same in principle as the air-lock which we discussed in an earlier chapter. The latter is a chamber separating the high pressure inside the caisson from the low pressure of the atmosphere, and it enables the pressure to be changed gradually as the men go in or out, and also enables them to pass without letting the compressed air escape altogether. In the same way the lock at the entrance to a dock is a space between the high level water in the dock and the low level water of the river outside, and it enables ships to pass in or out easily without affecting the level of the water inside.

It consists of a deep, narrow channel between two walls, with a pair of gates at either end. The length between the gates must be sufficient to take in the longest ship which is likely to use the dock, and it must be wide enough to admit the widest. To let a ship out, the outer gates are closed and the inner ones opened. The water level in the lock is then the same as that in the dock, and the ship floats in easily. The gates are then closed behind her.

Now, formed in the thickness of the wall of the lock are culverts or tunnels, some leading from the lock to the river outside, and others from the lock to the dock inside. All these culverts can be opened or closed at will by means of huge valves.

When the ship, then, is safely locked between the two pairs of gates, certain valves are opened, and the water from the lock begins to run out into the river. Thus the level in the lock slowly falls, and the ship with it, until it reaches the level of the river. Then the outer gates are opened, and she floats out.

To admit a ship the process is reversed, the water-level being raised by letting some run in from the dock to the lock.

It thus appears that the water will gradually escape from the dock altogether, a lockful at a time, until it is empty, but in most cases, at any rate, docks are constructed to hold water at the level of high tide, so that if need be both gates may be opened for a little while at the top of a high tide, and so the level, if it has fallen at all, brought back to the normal.

In order to minimise this loss of water, there are sometimes three pairs of gates forming two locks in one. If a small ship is going through, the middle gates and one of the end pairs are used, but for a long one the two end pairs.

The gates themselves are very like ordinary gates, in general form. They are sometimes, in the case of small ones, made of wood, but large ones are of steel plates riveted together much as ships are constructed. They are, too, a little too large to shut quite flat, and so when closed they form a very flat V-shape with the point towards the way the water is pushing them. Thus the pressure of the water tends to close them and keep them closed tightly. Large ones are generally opened and closed by powerful hydraulic rams.

The lock at the entrance to a dock has, of course, to be constructed under the protection of a cofferdam. This is made approximately of a semicircular form surrounding the place where the lock enters the river, and by its means the work of construction can be finished. Then a breach is made in the cofferdam so that the water runs in gradually and the dock is filled. After that the piles are drawn, and the cofferdam entirely removed.

DOCKS, FLOATING AND OTHERWISE

Dry-docks are made in very much the same way as the others except that they are lined with stone or brick from top to bottom so as to be perfectly watertight. In some cases, too, they have a structure called a "pontoon" to close the entrance instead of a pair of gates. This is like one single gate, not hinged in any way but simply fitting into the entrance to the dock. It is made hollow so that it can be sunk or floated at will. To open the entrance, water is pumped out of the pontoon, wherefore it floats up and is towed to one side. To reclose it the pontoon is floated back again, water admitted, and so it sinks back into its place.

A floating dock is of course different altogether. Imagine a large flat box, oblong in shape and comparatively shallow, floating in the water. Its top is covered so that water cannot get in unless admitted by the proper means, while along each of the two longer edges there is a stout strong wall. The whole is built up of steel plates riveted to each other and to steel framing, just as a ship is. There you have a general idea of a floating dock.

Internally the whole thing is divided up into small compartments, and to any or all of these water can be admitted through valves which can be controlled from the tops of the walls. By powerful pumps, also regulated from the tops of the walls, these compartments can be quickly emptied too. Thus the great vessel, for it is really a vessel, can be made to float on the surface or to sink until merely the tops of the walls are above.

In the walls are workshops, steam engines for working the pumps, quarters for the men, and so on, while on the top are cranes by which heavy articles can be lifted to or from a vessel under repair. Between the two walls, at either end, there is often a light foot-bridge, made to swing open for a ship to enter the dock, but which can be swung to, when it is in, so as to give passage for the workmen from one wall to the other without having to climb down and up again.

Some of these docks are so large that they can lift a vessel weighing 40,000 tons, and the pumps are so powerful that they can raise it in about four hours. For, of course, it is the pumps which really lift the ship, by throwing out of the dock an equivalent weight of water.

The ship, when in the dock, rests on a row of timber blocks placed for the purpose along the centre of the deck. It should be nearly balanced if properly in position, but if the ship should settle down a shade to one side it would not tilt the dock at all because of the compartments which enable a little water to be left in one side so as to balance matters.

There are two main kinds of floating dock—the box dock and the self-docking dock. The former is built up permanently as one structure, and when it needs repairs or cleaning it has to be got ashore somehow, in a dry dock or on what is called a gridiron, a structure on to which a ship may float at high tide and be left high and dry at low.

The other kind, however, can look after themselves, so that, if they are at some place where there are no facilities such as these, they can repair or clean themselves. For this purpose they are made in parts, which can be detached from each other, and any one part can be lifted out of the water by the rest.

One type of self-docking dock is known as the "Rennie," after the inventor. In this the walls are each complete in itself and independent of the bottom, to which they are attached by bolts. The bottom, again, instead of being one single structure, is composed of a number of oblong pontoons placed with their length across the length of the dock. If, then, one of these needs attention, it is simply detached from the rest, the latter is sunk, and the damaged pontoon is floated in and lifted just as if it were a ship.

The latest type is known as the "Bolted Sectional" type, and in it the whole structure is divided up, walls and all, into three sections, each of which forms a complete box dock with bottom and walls. Normally these three are bolted together, and are treated as one, but when needed they can be detached, and any two of them can lift the third.

And this is how they do it. The bottom projects beyond the walls, the projecting part being tapered so that it is not inaptly termed the "toe." So each end section has a toe. If the centre section has to be lifted the two end ones are turned round, each one places its toe under one end of the centre section, and together they lift it out of the water.

If it is an end section that is to be lifted, it is placed with its toe as far as it will go between the walls of the centre section (and the toe being taper will go in easily), while the other end section gets its toe under the other end as before. Thus either end section can be lifted right out of the water, as well as the centre one.

There is still another kind of floating dock known as the "Offshore" type. It has only one wall instead of two. This type is not independent like the others, for it needs to be connected to the shore by means of strong hinged levers, which allow it to rise and fall but always hold it steady and in the right position. These docks are usually made in two halves so as to be self-docking. One half can be detached from its fellow and from the levers and floated on to the other one. Having only one wall, and that on the shoreward side, there is nothing to prevent one half sitting in the lap of the other, as it were, and so being lifted out of the water.

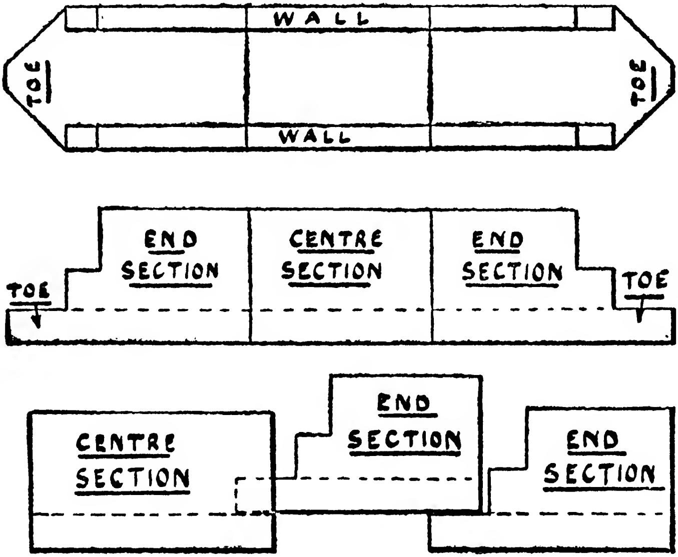

FIG. 22.—How a Floating Dock lifts itself. In the top figure we are looking down upon the complete Dock, in the Second upon the Side. In the third we see an end Section lifted by the other two.

Floating docks often accomplish long voyages, under the guidance, of course, of a tug for they have no means of propelling themselves. Not long ago one went from England, where it was built, to the Pacific Coast of

America, 11,000 miles, having to pass through the dangerous Straits of Magellan on the way. They are well able to take care of themselves, and in some cases, as at Valparaiso in Chili, their permanent resting-place is in an open roadstead.

CHAPTER XVII

UNDER-WATER TUNNELS

THE earliest tunnels were for the purpose not of carrying people under the water but for carrying the water. Leaving out of account certain Roman aqueducts, one of the first, if not the very first, was for the Languedoc Canal to run through, while one of the oldest in England is that which carries the Chesterfield Canal for no less than 3000 yards at a place called Hartshill in Derbyshire.

The advent of railways gave a great impetus to the construction of tunnels, and the Stephensons and other early railway engineers had much to do in the way of finding out the best way to construct them. Of the under-water ones, that under the Thames, which will be described in a moment, is certainly the most important, since it was the forerunner of practically all subsequent borings under rivers.

Tunnels under land, unless they be under very high mountains, are often made in a number of sections simultaneously. A row of deep pits called shafts are dug, and operations are started in both directions from the bottom of each shaft as well as from the two ends. Thus work can go on very rapidly, and the shafts, when the tunnel is finished, serve to ventilate it. Under water, however, intermediate shafts are manifestly impossible except at great cost. A shaft is generally sunk close to the margin of the river on either side, and the main tunnel is constructed from them, while the two approach tunnels, slanting down from the surface to the under-water tunnel itself, are made independently.

In constructing a land tunnel, the method most usual is first of all to cut a small tunnel called a "heading." The sides and roof of this are supported by means of timber props and boards, which are put in as fast as the men dig away the earth. Then this heading is enlarged to the full size, the work being done in the same way by men with picks and shovels digging the earth out, and again the top and sides of the large tunnel are supported by timbers. Then, following up the excavators and timber-men, come the bricklayers, who pull the timbers away a very little at a time, putting in the brickwork instead as they do so. If much timber were taken away the earth would fall in, but by very careful management the brickwork is made to follow closely as the timber is removed, and so the earth does not fall. Thus in time the brick lining reaches from end to end and the tunnel is finished.

That, of course, is assuming that the work has to be done in soft earth. If it be in hard rock, it is worse in one way but better in another. The rock needs to be blasted, or hewn down by some other drastic and difficult method, at much greater cost than the simple digging away of earth, but when done it is safe; no timbering is needed to support it, and in some cases no lining of any kind is needed.

If the tunnel has to be driven in water-bearing strata, special measures have to be taken. It may be possible to drain the water away or to pump it away, or it may need to be dealt with by compressed air, but these matters will come naturally among the under-water tunnels, of which we shall see examples shortly.

The first of these, as I have already said—the patriarch among under-water tunnels—is that under the Thames which now carries the trains of the East London Railway between Wapping and Rotherhithe. It was started in 1825, and finished in 1843, so that it took eighteen years to make.[1] Seven of them are accounted for, however, by the fact that the work was stopped for lack of funds. The unexpected difficulties made the cost so great that the company could not go on. I have seen a little pamphlet issued at the time appealing to the public for voluntary subscriptions to enable the work to be finished. These were not forthcoming, but eventually the Government granted the company a loan which enabled them to complete their task, and now, after about ninety years, it is still sound and strong. Indeed, a high official of the East London Company has informed me that the water percolating through the bricks has formed a hard coating on the inside, petrifying the brickwork as it were, and rendering it even stronger and better than it was when first built. There are something like eleven tunnels under the Thames now, and a twelfth is in progress, but they have all been built with the experience gained at the old Thames Tunnel.

The engineer was the famous Sir Marc Isambard Brunel, a Frenchman by birth but British by adoption. He fled from his native country during the troubles of the great Revolution, and went first to

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[1] The Rotherhithe Tunnel, close by, completed in 1910, only took two years.

the United States, where he acted as an engineer on the construction of the canal leading from Lake Champlain to the Hudson at Albany. After that he passed to England, working for the Admiralty as a maker of pulley blocks used in the rigging of ships, for which purpose he had invented a machine. Before that they had been made by hand, and the new method resulted in a saving to the country of thousands of pounds every year. That this was appreciated is shown by the very handsome little grant of £17,000 which Brunel received for his invention.

This early success led to others in the realm of engineering, so that when he proposed to tackle the knotty problem of boring under the Thames, which had been attempted and abandoned twice before, it was felt that if anyone could do it he was the man. Thus he arrived at the crowning achievement of his career.[1]

So in 1825 the work began, by the sinking of a shaft on the Rotherhithe side of the river. At once the originality of Brunel asserted itself, for he constructed this shaft in quite a novel way. First he laid on the ground a ring of iron the size of the shaft, with a sharp edge to its underside. Then upon this he built what was in reality a large brick tower, 50 feet in diameter 40 feet high, and 3 feet thick. The brickwork was held together by

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[1] He must not be confused with his son Isambard Kingdom Brunel, for many years the engineer of the Great Western Railway, who constructed some famous bridges and also built the pioneer of the modern large ship, the *Great Eastern*, besides being the great advocate of the "broad gauge" railway.

strong iron bolts running through it, so that the whole structure was as solid and rigid as possible.

Then men were sent into the inside to dig out the earth, and as they did so the great weight of the tower caused the sharp edge to cut down into the earth. Thus the tower, as it was to commence with, gradually sank lower and lower into the ground until it was entirely below the surface and became the lining of the shaft. All the trouble and bother of propping up the sides until the shaft had been finished and the brick lining inserted were entirely obviated, and the operation, a great success, has been copied in many ways since.

From the bottom of this shaft the tunnel itself was begun. The river at that point is 1000 feet wide, so the tunnel must needs be a little longer than that, namely 1300 feet. It consists of two separate tunnels side by side, 16 feet high and 13 feet across, separated by a brick wall 4 feet thick through which small arches are cut at intervals. The original idea was for horses and carts to pass through it, as well as foot passengers, and there was to be a spiral roadway at either end by which vehicles could get up and down. These, however, were never built.

Again the bold manner in which Brunel always tackled his tasks is seen. Instead of driving a small heading and enlarging it, as was the only recognised way of making tunnels then, with all its attendant timbering, he devised a structure which he called a "Shield," which enabled him to build the tunnel the full size to start with and entirely did away with timbering.

This shield was of cast iron, 22 feet high and 38 feet wide. It was like a great rectangular frame, with eleven vertical partitions and two horizontal ones. Thus the inside of the frame was divided up into 36 little cells or rooms, each of which was big enough for a man to work in. These men dug away at the earth in front of them, throwing the "spoil," as the stuff dug out is called, from the back of the shield on to a travelling platform which followed close behind it. Thence it was taken away to the shaft and to the surface.

As the earth was dug away in front, the shield was pushed forward by powerful screws, and as it advanced so the brickwork was built close up to it. Thus the roof and sides of the excavation were supported by the shield itself to within a few inches of the "face" at which the men were digging, while the brickwork performed the same function up to within a few inches of the rear of the shield: no fall of either roof or sides could take place, yet the costly and bothersome timbers were rendered quite needless.

To sum up the operation, as the shield advanced there was cut out a great square tunnel 38 feet or a little more in width and about 22 feet in height, which was at once filled in with a mass of brickwork, solid except for the two holes, 16 feet by 13 feet, which form the finished tunnels. Anything more sound and strong it would be hard to imagine, and it is not surprising that it shows signs of lasting for ever.

But even the clever Brunel could not foresee everything. At the place where the tunnel was made the bed of the river is of blue clay, an earth which is quite waterproof and which, had it been continuous, as it was thought to be, would have prevented any entrance of water into the workings beneath it, for there was supposed to be a clear 20 feet or so between the top of the tunnel and the bed of the river. But unfortunately, at some time or other the river had been dredged at one point right on the line of the tunnel. That kind of clay is used nowadays for making cement, but whether that was the reason why it had been dug out no one knows. There it was, whatever the cause—a great hole in the stratum of clay, partly filled in, no doubt by the river itself, with loose porous material which let water through easily.

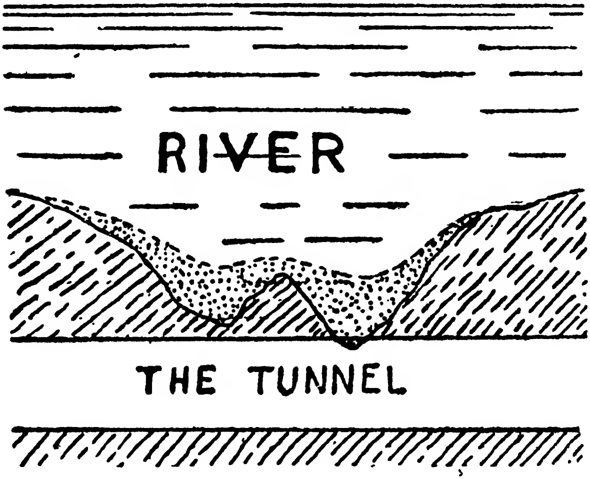

FIG. 23.—The Hole (filled with loose stuff) in the Bed of the Thames, and how the Tunnel cut into it.

As the shield slowly crept across the river-bed, it at last, in the year 1827, struck this hole in the clay and instantly the water made its way in. Not only did the whole of the half-made tunnel become filled with water, but 1000 tons of the loose material in the hole slipped down into it as well.

But Brunel was quite equal to the occasion. Bags of clay were taken out in barges and thrown into the water so as to fill up the hole. Then gravel was thrown in to fill the spaces between the bags, and after that tarpaulins were laid on it and held down with heavy lumps of iron, while finally gravel was spread over the whole lot. Thus the hole in the clay was plugged up and the leak stopped, the water was pumped out, the tunnel cleared, and operations renewed.

Again in 1828 the water broke in, and the same thing had to be gone through once more, but finally in 1843 the work was finished. It was never of much use until the East London Railway took it over; indeed it is very remarkable that just as Brunel the younger produced a ship, the *Great Eastern*, which was of little use in itself, but which taught men for all time how to build large vessels, so his father's great work was a disappointment in itself, but in doing it he taught many lessons which the engineers since his time have been quick to copy. In the accounts which follow of later specimens of under-water tunnels, we shall often see put into use the ideas which Brunel originated.

Another historic work was the construction of the tunnel which now carries the Great Western Railway from Bristol to South Wales under the estuary of the Severn. The river is there 2¼ miles wide, so that, including the sloping "under-land" parts leading down to the under-water part, the total length of the tunnel is over 4 miles.

It was begun in the year 1873, and was constructed on the methods generally employed for land tunnels, namely a small heading afterwards enlarged to the full size, the work being dug out and supported by timbers until the brick lining could be put in. Contrary to what I have said a page or two back, we shall see little of the influence of Brunel in this work; it is, indeed, the great outstanding example of the land method applied to submarine or rather subaqueous tunnelling.

In a tunnel of such great length, with a lining only of brick which is very porous, it was expected that quantities of water would percolate through, and so, from the very commencement, provision was made to drain the centre portion. Naturally such a long boring would follow somewhat the shape of the channel and be lowest in the centre, thence sloping upwards towards each bank, and therefore any water which got into it would tend to run towards the middle.

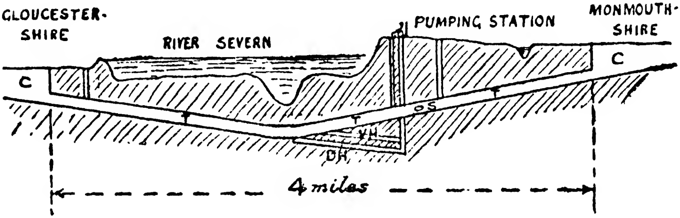

FIG. 24.—Section showing the famous Severn Tunnel. CC, open Cutting at either end. VH, Ventilation Heading. TTT, the Tunnel itself. DH, Drainage Heading. S, The great Spring.

The first operation, therefore, was to sink a shaft on the Welsh shore, or rather on the Monmouthshire shore —for, strictly speaking, Monmouth is not in Wales but in England—which was made very deep, so that a small tunnel from the bottom of it to the centre of the main tunnel would slope upwards and form a permanent drain through which any water finding access to the main tunnel would run away into the shaft, whence it could be pumped to the surface. So, from near the bottom of the 200 feet deep shaft this small tunnel or heading 7 feet square was driven in an upward direction, so as to intercept the line of the main tunnel at the point where it would be lowest, and where therefore water might collect.

Then a second shaft was sunk near the first, for, although the latter was 15 feet diameter, there was not room in it for the hauling up and down of men and material and also for the pumping machinery which was provided to free the workings from the water of the many springs which were encountered in the earth as the work went on. One of them, therefore, was devoted to pumping machinery. A third one was also dug on the opposite Gloucestershire shore, and several others on the line of the tunnel where it sloped down under the land.

All these shafts were dug out after the manner of coal-pits, the sides being supported by timbers until a lining of cast-iron plates bolted together, or of brickwork (they were not all alike), could be put in.

Meanwhile a heading was started from one of the Monmouth shafts along the line of the main tunnel—intended indeed, when enlarged, to form the main tunnel itself. This had been carried to within 130 yards of the Gloucestershire shaft; only that small distance remained to be penetrated, out of 2 miles or more, and up till then no water in sufficient quantity to cause any trouble had been encountered. Well may those in charge have thought that their enterprise was well on the way to a successful completion, when suddenly the whole face of affairs was changed.

In one of the under-land portions, not under the river at all, a great subterranean watercourse was cut into. Down this the water poured, millions of gallons per day, into the shaft, whence it penetrated into the tunnel under the river, and within twenty-four hours had filled up the whole of the workings.

Some years ago I saw this great spring, for it is still flowing, though not into the tunnel, and drank of its beautifully pure clear water, so I know that it does not come, as we might expect, from the tidal river but from the neighbouring hills. About 30 million gallons every day does it pour forth, enough to provide water supply to a large town.

For fourteen months after this disastrous occurrence the work lay at a standstill, while three more shafts were sunk, and more powerful pumping machinery fitted up. These new shafts enabled the water from the spring to be drawn off from the tunnel,[1] pumped up, and thrown into the river, and in that way the tunnel was gradually emptied of water and the work was resumed. All this occurred in 1879 and 1880, and a year later other trouble arose, the river water breaking in this time, much as it did in the case of the Thames. Again the whole work was drowned out, and so it remained until clay bags had been thrown into the river to plug the leak, just as Brunel did. After that it was pumped dry once more, and again the work went on well for a while.

In 1883, however, the great spring got out of control again, and it took four weeks to get the water out.

Finally, however, in 1885, the work was finished, and

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[1] It was during this that Alexander Lambert, the diver, performed the heroic feat referred to in Chapter I.

now the express trains whiz through it safely and smoothly, the waters having been practically conquered. Not without great difficulty, however, for four gigantic steam engines, the finest of their kind at the time they were built, are employed day and night lifting the water from the spring and throwing it into the river, while two others are standing ready to start at a moment's notice should either of the four need a rest for repairs or for any other reason.

An attempt was made to shut out the spring once for all, to bottle it up as it were, and so to save this constant expense, but the water forced its way through the massive wall built to restrain it, and so the battle remains a "draw," neither side coming off entirely victorious.

Three years later a work began which shows us some interesting methods connected with under-water tunnelling—the tunnel under the river Mersey, which carries the gigantic water mains which supply Liverpool with water from the hills of Wales.

The shafts were lined with cast-iron plates which were put in place on Brunel's method. They were built up in the form of towers on the surface, the earth inside being then dug out so that they gradually sank. The work was more difficult, however, than that which Brunel had to contend with, and so his method was improved upon. He had to work in dry strata only, but in this case at Liverpool the ground was wet, full of water like a gigantic sponge. Instead, therefore, of the earth being dug out by hand, it was excavated by what is called a Grab. This is an enormous mechanical hand which is suspended from a crane, and which being let down into the water, closes and grasps a ten-hundredweight or so handful of earth. It can then be hauled up, and at the desired moment the hand can be made to open and drop its burden in any convenient place. This method, I may remark, is often used for under-water digging. Quite recently I saw a grab at work deepening the channel in the river Thames. The crane was mounted in a small steamer, and the grab was let down two or three times every minute, each time bringing up a great handful of mud which it dropped into a barge alongside. A vessel thus fitted up for dredging by means of a grab is called a "Grab Dredger." Grabs are also used for handling coal and other loose materials.

So while the unfinished shaft was full of water, the excavation still went on by means of the grabs until the iron pipe, for it was nothing else, had sunk down flush with the ground. Then concrete was thrown in to seal up the bottom, and, after that had had time to set, the water was pumped out, and the shaft finished off by a properly constructed iron floor.

A kind of door had been fitted in the side of each shaft near the bottom, from which to start the tunnel itself. When the shaft had been completed, then, this door was removed and the tunnelling began. This was done by means of an improved shield, which will be more particularly described in the next chapter, under compressed air. The shafts were sealed over by means of an air-tight deck, and air was pumped under this. Now it is easy to see from what has been said about water pressure in earlier chapters, that at any depth under water or in watery ground the pressure of water will be about one pound per square inch for every two feet in height from the bottom of the tunnel to the surface of the water. That pressure, then, will be tending to force water *into* the tunnel, and if a similar pressure of air be produced in the tunnel tending to force its way *out*, the two will counterbalance each other and the water will not enter. It may not always be possible thus to resist the entire pressure of water by air pressure, for there is a limit to the pressure under which men can work satisfactorily, which may be stated as about 35 lbs., but even then compressing the air is advantageous, for suppose the water pressure were 40 lbs. and the air only 35 lbs., while the water would come in, it would only come slowly and the pumps would be able to deal with it, whereas without the resistance of the air it would come in too fast for work to be done at all.

Thus, if it is not possible to shut out the water altogether by the air pressure, it may be possible to restrain it to a sufficient extent.

Another reason which sometimes limits the use of air pressure is the danger of blowing up the bed of the river. The air, of course, is tending all the time to lift up the river-bed, and, if a thin place were to be encountered, it might burst it upwards just as a bicycle tyre, if pumped too hard, may burst at a weak place. In that case, as many of us know from sad experiences, the tyre loses all its pressure and becomes flabby; and in like manner the air in the tunnel would escape upwards in huge bubbles and in a moment the pressure might be gone and the water free to enter. Thus compressed air, though a great aid in tunnelling whenever water is encountered, has its own dangers, which need to be carefully watched and provided against.

If the leakage of air from the tunnel is only small, it can be overcome by energetic pumping operations, insuring that, however fast it escapes, it is pumped in equally fast. The only trouble, then, is the expense of the extra pumping. In the under-water part of the Baker Street and Waterloo Railway (London) this occurred, and at one point the river Thames seemed to be boiling violently for months, due to the escaping air rising to the surface.

Wherever possible, however, if there is a danger of the air blowing up through the river-bed, the latter is strengthened for the time by a layer of clay being placed on it. And here again the simile of a bicycle tyre helps us to understand, for the layer of clay forms a patch on the bed of the river very much like the layer of india-rubber with which we cover a weak place in a tyre.

One of the most remarkable things about tunnelling is the way the direction is maintained. In the great St. Gothard Tunnel in Switzerland, which is 9 miles long, work was started from both ends at the same time, and the two parts met in the inside of the mountain. It would seem a very likely thing for the two halves to miss each other under these conditions. At all events we might expect them to be a few feet or a few yards out of line, but it is a fact that when they met one was thirteen inches too much to one side and two inches too low. But for those trifling amounts they were exactly right.

The Mont Cenis Tunnel, too, although nearly 8 miles long, was so correctly worked out that the two halves met exactly, as far as any variation to right or left is concerned, but one half was 12 inches lower than the other; while a long tunnel on the Midland

Railway (of England) was out by a single inch in one direction and correct in the other.

It may well be asked how it can be possible for men burrowing thus in the far-off recesses of a mountain or under a river—it may be miles from the mouth—to be thus certain of meeting other men burrowing from the other side. Very careful surveying is responsible for this triumph over the apparently impossible.

The instrument generally used, called a theodolite, consists of a small telescope set upon a strong tripod. Attached to the telescope are graduated circles which enable the direction in which it is pointed to be determined very accurately. The most exquisite workmanship is put into these instruments, and the circles are so finely divided that microscopes are necessary to read the scales. The direction is first determined in the open, and two points are fixed at the mouth of the tunnel, both of them being exactly on the centre line of the tunnel that is to be. If it were to be perfectly straight and level, all that would be necessary would be to keep on fixing further points, as the tunnel grew longer, exactly in line with the first two, but tunnels sometimes curve and vary in level. To determine these variations in direction the theodolite is first set up and sighted upon the two last points, then it is turned to right or to left, upwards or downwards, as the case may be, to the angle necessary to give the new direction, and then some new mark is set up to indicate what that direction is. Every curve in any direction is reduced on the plans to a succession of straight lines, and the angles which they make with one another are carefully indicated. The theodolite has to be set up at each of these corners, sighted back on the line behind, and then turned to the correct angle (read off on the graduated circle) to give the new direction. This is just the bare outline of the process. There are methods of checking and verifying the observations which I have not space to explain here.

Very often the level is more trouble than the direction, particularly so when hills or mountains intervene between the two ends. Elaborate observations with the theodolite, or a similar instrument called a "transit," are then necessary, from one end to the other, right *over* the mountains to determine exactly the respective levels of the two ends of the tunnel.

The direction of the tunnel from either end can be obtained, if no simpler way is possible, by astronomical observations, but often, as in the case of subaqueous borings, the two ends are visible from one another, and then all that is necessary is to fix four points (two on each bank) exactly in line. Thus the exact direction is known at either end, and it only remains to transfer the line from the surface to the bottom of the shafts from which the tunnel starts. This is generally done by hanging two wires down the shaft with a heavy weight on the end of each. The tops of the wires are so placed as to be exactly in line with the points previously fixed upon, and, as they hang vertically, a sight taken across the two wires down at the bottom of the shaft gives the line for the tunnel. It is, of course, necessary that these wires should be quite free from swinging, and so the weight is often made to hang in a tub of water so that the liquid, while leaving the wire quite free to take up a truly vertical position, restrains any slight tendency there may be to swing.

Underground "Tube" Railways, such as those in London, since they follow the line of the public roads above, are often anything but straight. The starting direction is determined at the surface, and then passed down each shaft by means of two wires as just described.

CHAPTER XVIII

THE GREATHEAD SHIELD

THE reading of the previous chapter will have given some idea of the difficulties of tunnelling under water. Not only are there troubles from water which may break in unexpectedly, but certain kinds of ground are almost as bad. Those which are in small pieces and loose, such as gravel and sand, flow almost as easily as water does when pressed down by the weight of the earth above them. Clay, too, although it has the advantage of being waterproof, is apt to bulge in under the pressure from above unless it is strongly supported in some way. Even some of the softer rocks do this. And, moreover, it is not only under the river that water troubles are to be feared, for often the ground of which the banks are formed is loose and full of it. The great spring in the Severn Tunnel, it will be remembered, is not under the river.

Brunel at the Thames Tunnel showed the way to deal with the loose or yielding earth, by the use of a shield, the floors in which formed staging upon which the men could stand to work, while the outer framing formed a temporary support to the surrounding earth until the brickwork, which followed closely behind the slowly advancing shield, could be completed. Brunel also showed how a shaft lining could be made to cut its own way down into the earth, the men having little to do but dig out the débris from the inside.

We see the next step in the little Tower Footway Tunnel under the Thames, which was built about the year 1868. It is closed to the public now since the Tower Bridge was opened, but it is still there, and is used for carrying pipes, electric cables, and such like from one side of the river to the other.

In making this, an improved shield was used, combining the two ideas of Brunel just referred to; for it not only supported the earth around it, but it had a sharp edge with which it cut its way through the earth just as the shaft lining cut its way down.

It also embodied another idea of Brunel's which, so far as I know, he never put into practice, but which he has left on record. I refer to a lining of cast-iron rings bolted together, instead of brickwork. At first sight this seems an unimportant feature, for surely brickwork well built and thick enough is as good as iron plates or rings. The important point is this. A brick lining has to be built behind the shield. No matter how closely it may follow up the shield there must be a small space between the back of the shield and the front of the brickwork, and through that space water or loose material could flow.

But a cast-iron lining can be built up *inside* the shield. Each ring is formed of a number of segments; in a tunnel 10 feet or so in diameter, there would probably be about six segments, and larger ones in proportion. The segments are therefore of a convenient size to handle, and they have a raised edge or flange all round their edges by which they can be bolted to their neighbours.

Each ring is quite narrow, about 18 inches to 2 feet, and so the lining of the tunnel grows two feet or less at a time.

Now the modern shield is made of steel or iron plates riveted together, as the plates of a ship or tank are riveted. In shape it is a *short cylinder*, just a shade larger in diameter than the lining. It may have diaphragms in it, for reasons which we shall come to in a moment, but for several feet from the back it is quite clear inside and free from all obstructions. Thus the end of the lining can go right into the shield, which forms a sort of *cap* entirely enveloping the open end. They are so near the same size that they form a joint very like that between the two tubes of a telescope, the shield being the larger, with the other fitting closely inside it. And this state of things is always maintained,

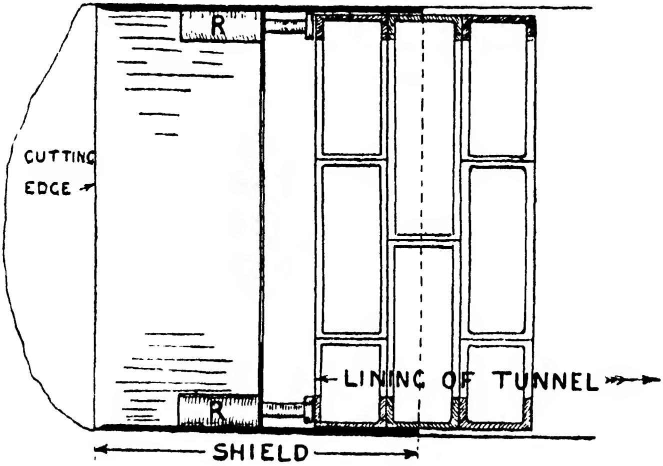
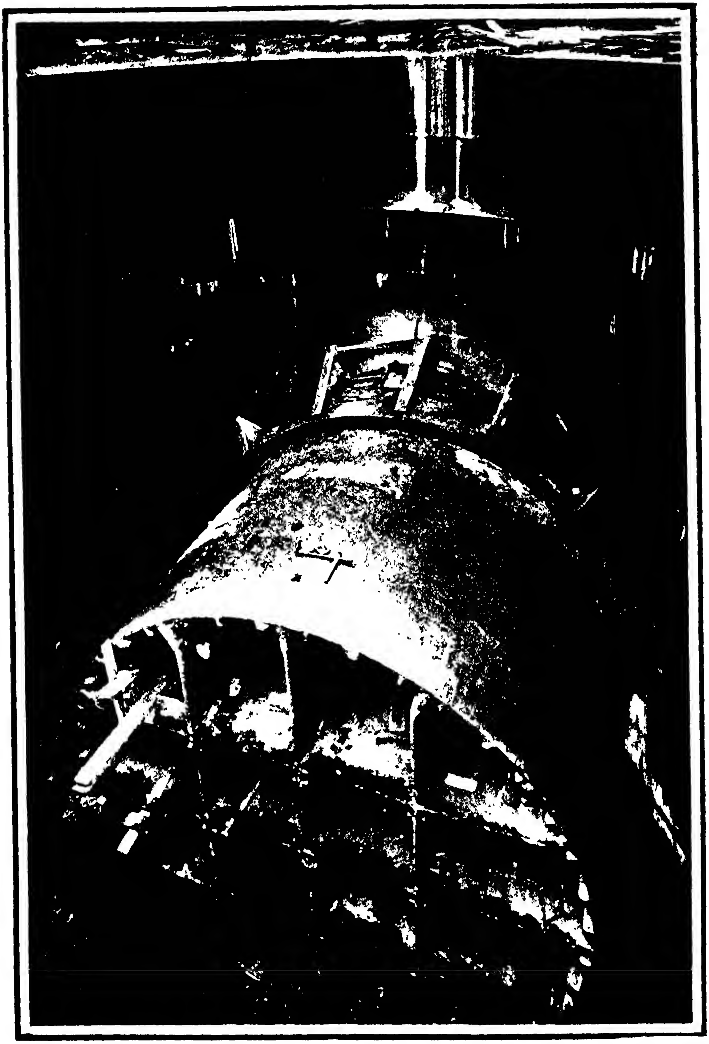


FIG. 25.—A Shield for forming an under-water Tunnel. RR, the Rams which push the Shield along.



By permission of] *[Maurice Fitzmaurice, Esq., M.I.C.E., Engineer-in-chief to the London*

Marvellous Accuracy

This photograph was taken looking down one of the shafts of the Rotherhithe Tunnel. The shield has travelled right across from the other side of the river and is just entering the shaft through the hole left for the purpose. Observe how it has struck the hole exactly right.

for before the shield has advanced far enough to uncover the end of the lining another ring is added. Therefore, right across the river, the whole length of the tunnel, the open end of the lining is always covered entirely by the shield.

This means, of course, that a small space is left all round the lining between it and the earth. For the hole cut out by the shield is the size of its outside diameter, while the diameter of the lining is necessarily a little less than the inside size of the shield. So the space all round is a little greater than the thickness of the metal which forms the shield. This is sometimes filled up by the surrounding material falling into it. If, however, the latter is stiff enough to hold itself up, then the interstice is filled by squirting "grout" (that is, lime or cement mixed with water), into it through holes left for the purpose in the lining.

Thus, with a modern shield in use the loosest material has not the slightest chance of slipping into the tunnel except through the front of the shield itself. Even water could only flow in comparatively slowly, for its only way in would be through that close-fitting joint between the shield and the lining.

When it is only loose material that is feared, the inside of the shield is left more or less open. The shield is then pushed forward and the material dug away, put into small trucks, and sent out of the tunnel. Under some conditions the earth may have to be restrained, by some special device, from flowing too freely in at the front of the shield, but often that is not necessary. Sometimes a little air pressure in the tunnel is a help to keep the "face" from falling too freely. An air-lock is formed at some convenient point in the finished part of the tunnel, and a pressure of perhaps fifteen pounds per square inch is maintained.

If water is feared, however, the shield is covered right across by two diaphragms pierced by doors so as to form air-locks. By this means a higher pressure of air can be kept up in front of the shield than in the tunnel behind it. The advantage of this lies in the fact that men can only work under a high pressure for a short time—the reason for which was explained in an earlier chapter on "Diving"—while men in the lower pressure of the tunnel can work ordinary hours, say eight per day. If the pressure throughout were as high as at the face, all the men would only be able to work short hours.

The shield is propelled along by hydraulic jacks, which are fixed at intervals all round its circumference. These push against the end of the lining which, you will remember, is inside the shield. Their action is just like that of a man seated in a chair pushing his feet against the wall. Since the wall is immovable, if he pushes hard enough he will propel himself backwards, and since the lining of the tunnel is not likely to move, the pushing of the jacks forces the shield farther into the earth.

By the same means it is steered. It is easy to see that if those on the right-hand side push harder than those on the left, the shield will tend to curve round to the left, and *vice versa*. It can be steered upwards and downwards, too, by the same means. There is a little difficulty, however, about this when the ground is soft, for then the shield is liable to steer itself downwards somewhat, because of its own weight. Special means have to be adopted to deal with this.

Although a shield embodying most of these ideas was used at the Tower Subway, the man whose name is associated most closely with its development is that of Mr. J. H. Greathead, the engineer who constructed the first of those low-level underground railways in London which have come to be known as "Tubes."

This work, now called the City and South London Railway, was started in 1886, and finished complete in 1890. It consists of two tunnels close together but quite separate, which at one point pass under the river Thames. Of course, they are much smaller than the old Thames Tunnel, but it is interesting to compare the speed at which they were constructed. The older tunnel took, after allowing for the time that the work was stopped for lack of funds, eleven years, and it was 1300 feet long. The under-water parts of the "Tube" were constructed at the rate of 10 feet per day, which for 1300 feet would come to about four months.

Mr. Greathead had his troubles, however, from water, just as most engineers have in undertakings of this nature. The parts of the tunnels under the Thames were accomplished without trouble of any sort, but at one point the under-land tunnels encountered an ancient watercourse and a bed of wet sand. Here, and only here, on the whole line, it was necessary to close up the tunnel in a convenient place with an air-lock and introduce compressed air.

Such tubes themselves are made completely water-tight, so that once through the wet stratum no further trouble need be feared; there might be any amount of water outside the cast-iron lining, none would get through. This water-tightness is secured in several ways. The joints between the rings are packed with tarred rope, which makes a splendid joint. Those between the segments of each ring are made with strips of thin pine wood, which are clipped between the flanges when they are pulled together by the bolts, while, lastly, the grout, which is squirted in between the lining and the earth, effectually seals up all the joints, besides preserving the iron from rust.

This wonderful little line has been much extended since 1890, when it was first opened, and its trains are thronged with passengers every day. It is not so pleasant or so well fitted up as some of the later Tubes, but they have had the advantage of the experience of this line to guide them.

As far as construction is concerned, the others have used much the same methods. One ingenious improvement has, however, been made in the shield, constituting what is known as Price's Patent Excavating Shield. This, which was employed on the Charing Cross and Hampstead Tube (London), and also in the Rotherhithe Roadway Tunnel under the Thames, is very like the original "Greathead" Shield, but in addition it has on its face a steel frame-work constituting a large wheel nearly as large as the shield itself, and turning round on a centre fixed at the centre of the shield. This wheel carries knives which cut into the earth, and scoops which pick the excavated material up. An electric motor operates it, and so as the shield slowly advances this wheel turns, the knives cut down the earth at the face while the scoops gather it up, and each as it goes round, coming to the point when it turns over, throws its contents into a chute, which delivers it into trucks waiting to receive it at the rear of the shield. The action of this wonderful contrivance reminds me of nothing so much as a carpenter's centre-bit. There one part acts like a knife and cuts into the wood, while another part scoops it up and throws it upwards out of the hole, and in very similar manner the excavating shield cuts and bores its way through the earth.

The quickness, ease, and certainty with which Mr. Greathead ran his two tunnels under the Thames caused the London County Council to call him into consultation when they decided to bore a great tunnel under the river at Blackwall large enough to carry two lines of wheeled traffic as well as two paths for foot-passengers —an under-water main road in fact.

This magnificent work was commenced in 1892. It consists of a single circular tunnel 27 feet in diameter. A floor is formed in this which is wide enough to accommodate two lines of vehicles and two footpaths, while in the semicircular space under the floor there is room for water and gas mains and electric cables. The inside is lined with cast-iron plates covered with glazed brickwork, while the whole tunnel from end to end is lighted brilliantly with electric light.

The total length is 6200 feet, of which 1220 is under water, the rest being the gently sloping approaches up and down which vehicles can drive easily.

Four gigantic shafts were sunk, two on each bank. The lining of these consisted of two wrought-iron cylinders one inside the other, the space between the two being filled with concrete, so that each was an enormous drum 50 feet in diameter, 48 feet high, and several feet thick. They were constructed on the surface, and sunk by removing the earth from inside. The ground, by the way, through which this tunnel was driven was loose and wet—just about as bad for the purpose as it could be

—but tunnels have to be made where they are needed, and not where the ground is good, so the difficulties had to be faced and overcome.

The shield used was very large—27 feet in diameter and 19½ feet long. It had two diaphragms with doors to form air-locks, and also certain divisions which would have formed air-pockets had the water broken in. These would have entrapped sufficient air for the men to breathe until they were able to get through the air-locks. Although thus thoughtfully provided for the men's safety in case of accident, they were never needed.

The earth which the men excavated was sent out to the back of the shield, through chutes which were themselves small air-locks with a door at either end. The men at the front of the shield filled them, shut the inner doors, and then signalled to the men at the back. These undid the outer doors, and out fell the earth with little loss of air.

To the back of the shield there were fixed two erectors, powerful arms actuated by hydraulic power, which picked up the cast-iron segments one at a time, placed them in position, and held them so until they had been bolted up.

The method by which this huge shield was got into position at the bottom of the first shaft was ingenious and interesting. The ends were first blocked up with timber, so that it floated like a ship. This was done in a hole in the ground, or small dock, excavated for the purpose. Then water was admitted into the shaft, and a piece of the side of the latter was removed so that the dock in which the shield lay was in communication with it. The rising water ultimately filled not only the shaft but the dock, and the shield was then floated into the shaft. Pumps quickly lowered the water, and so the shield gradually sank to the bottom, being finally deposited by the water just in the right position.

Since then another tunnel, larger still—one of the largest in fact, if not the actual largest, in the world—has been bored under the Thames, known as the Rotherhithe Tunnel. It is just near Brunel's old tunnel—indeed the approach to the new one actually crosses, at one point, the approach to the old one, and consequently comparisons between the two are almost inevitable.

It was only the under-water part which was completed at the time, in the case of the old tunnel, and, as I have already said, it took ten years or more to construct. The corresponding part of the new tunnel is slightly longer, yet it was finished in nine months. But this must not be taken as any reflection upon the distinguished engineer who was in charge of the older undertaking, for Sir Maurice Fitzmaurice, at that time the chief engineer of the London County Council, who probably knows more about this kind of work than any other living man, has put it on record that, considering the means at his disposal, it "seems almost extraordinary that Brunel's Thames Tunnel should ever have been completed at all."

In a general way the Rotherhithe Tunnel is similar to that at Blackwall except for its greater size. The shield was actually 30 feet in diameter, a size which is only realised when we compare it with some familiar thing. For example, the floors of an ordinary dwelling-house are generally about 10 or 11 feet apart, so that if placed against the side of a three-story house this gigantic shield would be almost as high as the roof. It is not surprising, then, to hear that it weighed 380 tons. It had 40 hydraulic jacks affixed to its edge for pushing it along, and these, when working together, could push with a force of 6000 tons. The work was done under an air pressure of 25 lbs. per square inch, and so large was the plant employed for compressing the air that 1,000,000 feet of air could have been forced into the workings every hour.

The lining of the tunnel is of cast iron, 2 inches thick, to say nothing of the raised edges or flanges of the segments, which add enormously to its strength. Twenty-seven thousand tons of cast-iron segments were used.

An interesting feature of this tunnel is the arches under which vehicles have to pass as they enter the approaches. Large though the tunnel is, it is clear that a cart might be loaded too high to get through it, and it would be a great pity for such to go a long way down the open part of the approach only to find when the tunnel proper was reached that it could not get through, and then have to toil back again up the incline. So arches are provided the exact size of the tunnel, and if a cart be loaded too high the carman finds it out before he has started down the approach at all. Now these arches consist of the "cutting-edge" of the shield. Thus they form not only a loading gauge but an interesting record of the method by which the tunnel was constructed.

In the centre of the river there is only 7 feet of sand between the top of the tunnel and the water. This was clearly a place for a patch of clay such as was mentioned just now. In the case of the Blackwall Tunnel 10 feet of clay were laid down, but here, owing to the near presence of the entrances to two important docks, such was not permissible. Extreme care was therefore necessary to avoid an outburst of the compressed air and an inrush of water, but it was managed quite safely and without mishap of any kind.

The contractors who built the Blackwall Tunnel also constructed part of one under the Hudson River at New York, while several others have been bored under that and the East River on similar methods, but by American engineers; still another is just being started under the Thames.

Indeed, since the successful construction of that little electric railway by Mr. Greathead, the art of tunnelling under water has made such rapid progress, that there is scarcely a place anywhere where engineers would not be prepared to make one.

CHAPTER XIX

SUBMARINE TELEGRAPHY

EVEN in these days of Wireless Messages it is quite needless to remind my readers of the great part which the cable plays in modern life. Despite the genius of Marconi and his associates, the cables are as busy and the cable companies as prosperous as ever.

The early history of the long-distance cable is quite a romantic one—a vast and novel scheme carried out with great skill and courage resulting thrice in colossal failure, but ultimately in triumphant success. There are few incidents which show greater daring than one, the details of which I will relate presently, when the third attempt was made to lay a cable across the Atlantic. It had broken in mid-ocean, and that wonderful but unfortunate ship, the *Great Eastern*, which was laying it, having failed to recover the broken end, had returned to England for more appliances. Hundreds of thousands of pounds worth of cable already lay at the bottom of the ocean dead and useless, yet the people concerned decided that, instead of trying to mend that one, the *Great Eastern* should take on board yet another 2000 miles or so, drop it into what appeared to be the grave of the others, and then, having finished that, return, pick up and complete the one which had just broken. Up till then, every attempt to lay a cable in the Atlantic had failed, and nothing but their confidence in themselves and their advisers assured them that their new venture would succeed any better than the previous ones, yet they took the risk and spent a fortune upon new cable. And the real heroes of this battle royal between man and the sea were Mr. Charles Bright, afterwards Sir Charles Bright, and Mr. William Thomson, afterwards Sir William Thomson, and later still Lord Kelvin.

The first cable to carry electricity under the water was, it is believed, constructed by an officer of the Royal Engineers at Chatham (England). He enclosed a wire in a covering of tarred hemp, and laid it in the bottom of the river Medway, and, considering what a primitive arrangement it was, it seems to have worked very well. The first difficulty was to find a good substance for forming the insulating covering around the wire. It is said that the late Prince Consort advocated running the wire in a "flexible" glass tube; but fortunately there appeared just at the moment when it was wanted the substance called gutta-percha, which fulfilled the purpose so admirably, that it has still no rival. It is the dried sap of certain trees which grow in the Malay Peninsula and the islands which form the Malay Archipelago. The milky sap becomes on exposure to the air almost as hard as wood, but a little heat makes it quite soft and easily workable, while it is a splendid electrical insulator and is subject to no kind of decay. In short, if man had designed something for this special purpose he could hardly have conceived anything better than this purely natural substance.

So, about the year 1850, by which time overland telegraphy had fully established itself, men began to dream of long cables laid upon the bottom of the sea.

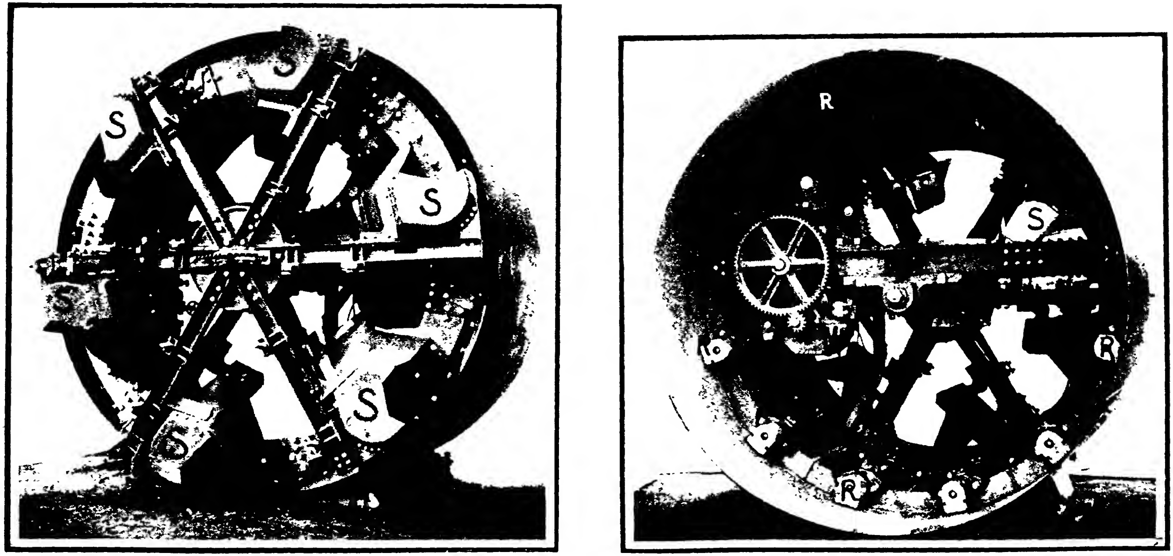
In 1849 short cables were laid and worked successfully. In 1851 Dover and Calais were linked up, shortly afterwards England and Ireland were brought into this rapid communication, to be quickly followed by a cable from England to Holland, over 100 miles long.

But these were all very simple matters compared with the spanning of the broad Atlantic, nearly 2000 miles across, and in parts nearly 3½ miles deep.

However, in 1856, a number of gentlemen formed a company called the Atlantic Telegraph Co. to attempt this stupendous task. They got together the sum of £350,000, the famous writer Thackeray being among the many members of the general public who took shares. Mr. Bright was concerned in the matter from the commencement, being one of those who promoted the company, and he was appointed engineer to the undertaking. The electrician was a Mr. Whitehouse, but what turned out ultimately to be of perhaps more importance than any other appointment, was that a certain young Professor of Glasgow University was among the shareholders, and, it having been arranged that the Scotch shareholders should elect two of the directors, they chose Professor Thomson to be one of them.

The shareholders were mostly in Great Britain, but a good number of Americans were interested in the venture too, and the General Manager of the whole was an American, Mr. Cyrus Field, whose name will always be remembered in connection with submarine cables.

Now it will be interesting to glance at the difficulties which face those who undertake a work like this. It often happens that a thing seems immensely difficult to



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MACHINE FOR DIGGING UNDER-WATER TUNNELS

(Price's Patent Excavating Shield.)

On the left is a *front* view showing the Scoops which traveling round, dig down the earth. On the right is the back view showing the Motor which drives the Scoops, and the Chute down which they throw the spoil.

S = Scoops. M Motor. C Chute. R Rams which push the shield along.

the outsider who knows little about it, but quite easy to the expert. In this case, however, it was quite the opposite, for to the ordinary mortal it seemed that after the problem of overland telegraphy had been so completely solved, it must be quite easy to extend the same principles to under-water cables. To proceed across the sea in a ship, paying out cable as you go, appears to be quite simple, and when that is once done why should it be more difficult to telegraph 2000 miles under the Atlantic than 200 overland? The electric current traverses the smaller distance practically instantaneously, so that the increase of distance would appear to make no appreciable difference. Yet the experts knew better. Not only is the laying of the cable a ticklish and delicate problem, but there are electrical troubles to be faced which do not occur in a land line.

The sea is in parts very deep. Nor is the sea floor level, but has its hills and dales, mountains and valleys, just as has that part of the earth's surface which we can see.

These facts have to be ascertained by sounding the depths at a series of points along the line where the cable is to be laid, and also dredging up samples of the the bottom to see what it is made of. The soundings required by ships for the purposes of navigation are obtained by the simple method of dropping a lead weight on the end of a string into the water and feeling when it touches the bottom, after which the length of string paid out gives the depth. It is surprising how well, when holding the string, one can feel the weight "bump" on the bottom, but that of course only occurs in comparatively shallow water. So long as he is quite sure there is enough depth to float his ship safely, the sailor cares little whether the depth is feet or miles, but the cable engineer, on the other hand, troubles little about a few feet more or less near the surface; what he needs to know is the depth of the ocean even at its deepest points. So the simple methods of the sailor were useless to the cable man, and special sounding appliances had to be devised. Professor Thomson, for this purpose, invented his well-known "Sounding Machine." This consists of a metal tube which is let down into the water in such a manner that it always retains a vertical position. Inside it is a glass tube the upper end of which is closed, but the lower one is open so that as it goes deeper and deeper in the water the air entrapped in it becomes more and more compressed and the water rises higher and higher inside it. The inner surface, being lined with a chemical substance which changes colour when touched by salt water, forms then a permanent record of the height to which the water has risen in the tube, and therefore of the depth to which the instrument has penetrated.

When the Professor was asked what wire he would use to lower this down into such great depths, it is related that he replied with a pun, saying that he would use a "deep C" wire, having in his mind that thin but strong wire which is used for the strings of pianos.

Another method of deep-sea sounding is but an elaboration of the lead weight and string. In this case a number of heavy iron weights are threaded by means of holes in their centres on to an iron rod, being held there by means of a clip which automatically lets go the moment it touches anything. Like the other, it is lowered down into the water, and even at great depths it is possible to feel the moment when the catch is released by contact with the bottom and the weights slide off. The latter are either left at the bottom or are hauled up again by wires attached to them for the purpose. These wires are of course left slack when the appliance is lowered, so that the whole weight shall be borne by the main wire or rope.

Combined with the sounding apparatus is generally an appliance for bringing up a sample of the material of which the sea floor is formed. An inverted cup in which is some soft sticky substance is one means of doing this, shells, gravel, or whatever it may be adhering to it and being so drawn to the surface. Another contrivance is a short tube which on touching the bottom, if it is soft enough, penetrates a little way and when drawn up brings a sample of the material with it, much as the scoop used by the grocer for tasting cheese does.

Low down in the depths of the sea it is very cold, and so these samples of cold mud are very acceptable to the tired cable engineer in tropical climes, for they provide him with a ready means of cooling his liquid refreshment.

The sampling arrangement, too, has a very useful purpose in connection with the sounding apparatus, since it forms a perfectly reliable evidence that the apparatus had really penetrated right down to the solid earth at the bottom of the ocean.

In a letter written to the great German scientist Helmholtz (who was a great friend of his), Professor Thomson speaks of the "Alpine precipices and valleys" under the waters of the Mediterranean, and there is little doubt that the submarine landscape, could we see it, is sometimes as grand and bold in its ruggedness as the Alps or even Himalayas. And across some of these submarine mountain ranges the cable may have to be laid.

It will help us to understand this if we try to picture to ourselves an immense air-ship laying a cable across the Alps, or across the highest mountains we happen to know. Think how the amount of cable sent out will need to vary.

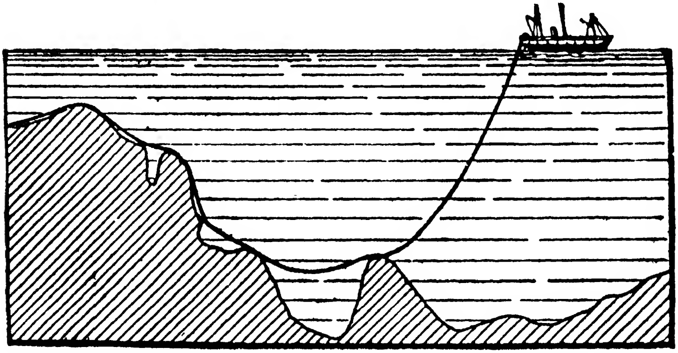


FIG. 26.—How a Cable should not be laid. It should follow the Irregularities of the Bottom.

On a flat plain it will have to be let out about as fast as the ship is travelling, then it may encounter a ridge of great altitude, followed by a deep valley which fairly swallows up the cable. Miles of it may have to be paid out, while the ship makes no progress at all, so that it shall reach the bottom, as otherwise it will be stretched from one ridge to the next, and, strong though it is, it may be unable to stand the strain of its own weight should the span be a long one. While being lowered, too, into these deep valleys in the depths of the ocean, the part which is just leaving the ship has to bear the weight of, it may be, miles of cable—all that, in fact, between itself and that which has found its resting-place on the bottom.

And, moreover, should the ship encounter bad weather during the work, and pitch up and down, as ships do, it will, unless prevented in some way, keep on dropping the cable and then pulling it upwards with a jerk, and the effect of these violent oscillations may easily be to rend the cable in two.

Another difficulty which the original Atlantic Company found in their way was that there was then no ship available large enough to carry the whole cable, so they had to have two, and effect a join out in mid-Atlantic.

But perhaps the greatest difficulties of all were electrical, for, strange as it may seem, the current behaves quite differently in a cable under the water from what it does in a wire overland. The difference is due to what is known as "Electrostatic Capacity." But that is a matter we must return to in a moment.

The two ends of a battery, as is well known, are called the positive and negative poles, and in order that current may flow from the battery the two must be connected to opposite ends of the wire, or whatever it may be that we want to send the current through. In the case of a cable we need to connect one pole of the battery to each end, but fortunately we need not actually have a wire all the way. It answers the purpose if we connect one pole to one end of the cable and the other to the earth; but the farther end of the cable must also be connected to earth. The current then passes from the battery along the cable into the earth at the distant end, and from the earth to the battery again *via* the other pole.

In the case of land lines the connection "to earth" is generally to a metal plate buried in the earth, but in the case of cables "connected to earth" generally means connected to the wire sheathing, which is itself not insulated, and so is more or less in contact with the earth.

Precisely what happens when current flows we do not know for certain, but it seems probable that it is a commotion among the "electrons," the tiny particles of which the whole universe is built up. It has been likened to the action of a row of dominoes set up on end when the first one is knocked over. Most young people have tried that little trick, and have seen the first one knock down the second, the second the third, and so on to the end of the row. Now in that case we see a sort of current pass along, but it is not a current of dominoes—it is a current of commotion or disturbance. And in like manner a current of electricity is not a subtle fluid or anything material flowing along the conductor, but is a disturbance which, started at one end, communicates itself from atom to atom, and so passes right along the whole length even of a long ocean cable. That, at any rate, is the belief generally held.

But however that may be, whether the theory is the right one or not, need not trouble us here, for if it is not a fluid it certainly behaves very like one, and it serves *nearly* all *practical* purposes if we think of the current as a something passing along the conductor much as water passes through a pipe. We can regard the battery as an automatic pump for forcing the current along, and we may assume that it sucks the current in at the negative pole and forces it out at the positive pole. Accordingly, if we connect the positive pole to the cable and the negative to earth, the current will flow along the cable *away* from us: if, on the other hand, we put the negative pole to the cable and the positive to earth, the current will be drawn *towards* us along the cable.

If that be so there is evidently no difference between a "positive current" and a "negative current" except the direction in which the current is moving. The terms positive and negative current seem indeed to be needless, but as a matter of fact they are very convenient terms to use in telegraphy, for sometimes the positive pole is connected to the cable and sometimes the negative, and the handiest mode of expressing these connections is to talk in the one case of "sending a positive current" and in the other of "sending a negative current." "To send a positive current" is but another way of saying "to send a current along the line or cable *away from* the battery"; "to send a negative current" is but another way of saying "to draw or suck a current along the cable *towards* the battery."

But before going further, I should like to add just a word more of explanation about that mystery—the earth return. Current has passed, we will suppose, through a cable, and has entered the earth thousands of miles away. Why should it, and how does it, find its way back to the particular spot where the negative pole of the battery is earthed? It does not. Our fluid analogy provides us with another far simpler explanation of what happens. As I have said, we may regard the battery as a pump the negative end of which is the "inlet" and the positive end the "outlet." If it were a water pump and the cable a pipe, we know that it would first need to suck water from somewhere, and at the distant end something would have to be done to get rid of the water when it arrived. In precisely the same way the electric "pump" sucks current from the earth to supply itself, while that which comes through the cable and has to be got rid of is simply emptied into the earth. Think of the earth as a gigantic reservoir of electricity from which we can pump what we need and into which we can pour away any that we have done with, and the mystery becomes clear. We need no further explanation except to remember that there is a law of nature, by which we must always abide, that whenever we take any current from the earth we must always put back the same amount. We may put it back the other side of the globe, but put it back we must. So long, then, as we obey this law we may take from and give to the earth's store just to suit our own convenience, and that explains how we can use the earth for the "return" of the current. "Return" is but another of those handy phrases which come into use in technical matters. The current does *not* return through the earth; but we speak of it as doing so because the final result is the same as if it did.

In land telegraphy the Morse Code is generally used. This is a code of signals by which any desired letter or figure can be indicated, and it consists of two kinds of signal, short and long, either separately or in combination. For example, a short sign alone means E, a long sign alone T, a short one followed after a pause by a long one A, and so on. It is convenient to write these on paper as short strokes and long strokes, and so they come to be called "dots" and "dashes." The sending apparatus in its simplest form is known as a "Key," and when the operator presses the key he brings the battery for the moment into connection with the "line" or main wire stretching away to the distant station to which he is telegraphing. Thus he sends a current of electricity coursing along the line, and he can make it "short" by holding the key down for just an instant or "long" by holding it down a little longer. The current for a "dash" is about three times as long as that for a "dot." When the key is not pressed the battery is disconnected, no current flows, and so the pauses are formed. Thus the sender sends off the short or long signs at will by the simple motion of his hand, or in many telegraph offices the same results are obtained by the action of a machine controlled by a strip of paper perforated in a certain way to represent dots and dashes.

Now let us transport ourselves in imagination to the other end of the line, and see the signals come in. In almost all cases the line is connected to an appliance called a "Relay." In this there is a little tongue of metal which is drawn to one side whenever a current comes along the line and held there so long as the current continues to flow, but which returns to its normal position as soon as the current ceases. If the tongue therefore flies over to one side and back again *instantly*, it shows that a "dot" has been signalled from the other end, but if it lingers for a moment before returning it shows that a "dash" has been sent.

This little relay is very small and delicate and it would be very troublesome to have to watch its movements in order to read an incoming message, so it is always arranged that it shall be repeated by another electrical apparatus. When it moves over it touches a stop, and for a moment makes a contact whereby current from a local battery is allowed to flow and work a "Sounder" or an "Inker," instruments which give the signs quite clearly either by sound or else in ink on a strip of paper. The incoming current, enfeebled by its long journey, is not strong enough to work these latter instruments itself, but it is able to work the delicate relay, and since that controls the stronger current from the local battery which works them, the result is just the same as if the current from the line were strong enough and went direct to the sounder or inker as the case may be.

We can now understand the slightly more elaborate system used when a telegraph line is of some considerable length. In that case it is found that the signals can be sent more quickly if, instead of short and long signalling currents, with intervals of no current between them, as described just now, the pauses are indicated by current of the opposite kind. A key can be constructed which sends a short positive current for a dot and a long positive current for a dash, with a negative current in between, or *vice versa*. This is called "Double-current" working, as distinct from the "Single-current" working previously referred to.

The relay is in this case a little different, inasmuch as the tongue goes to one side for a marking current and to the other for a spacing current, and not simply to one side for a current and to the other for no current at all.

It will perhaps make it clearer to put it this way, and say that in double-current working there is a current always flowing through the line—the "spacing" current—which is changed to the "marking" current in order to send a signal. The marking current may be either positive or negative, as may be arranged—it matters not which it is, so long as the spacing current is the opposite.

A single-current relay is simply an electro-magnet which is energised whenever current flows, the tongue being just a little piece of iron which is pulled over by the magnet when it is thus energised, but which is drawn back by a light spring when the current stops. In the double-current relay, however, the tongue is itself a magnet, and so it needs no spring, but is pulled to one side by a positive current and to the other by a negative.

Now let us imagine a relay the tongue of which has three positions instead of two. In its normal state, with no current owing, it takes the middle position, but a positive current moves it to one side and a negative to the other. We can then use positive and negative currents instead of dots and dashes. Instead of sending, say, a short signal and a long one with a space between to mean A, we might send two *short* ones, a positive and a negative, and since a short one is but one third as long as a long one, the total time required to send our message will be so much the shorter.

Now, submarine cables are an enormous cost to lay and to maintain, and the cable companies are forced to charge enough for the cablegrams to bring them in a fair profit on their outlay. At the same time their charges must not be too high, or people will be less ready to send cablegrams. Therefore it is above all things necessary to use the very quickest method of getting the messages through, so that the greatest possible number can be sent in a given time, wherefore this code made up of combinations of positive and negative currents is used for such work in preference to the dots and dashes of land telegraphy. The two codes are practically the same, except that one is made up of signals of different *lengths*, while the other is made up of all short signals but of different *kinds*. The kinds of instrument used we shall be better able to discuss a little later.

And now we can sum up the state of things existing when a cable is ready for work. At each end there is a sending key, or something equivalent, and a battery to supply the current, also a receiving instrument in principle, at any rate, like the relay just described. One pole of the battery is connected "to earth." One end of the receiving instrument also is connected to earth in like manner.

The normal condition of things is with both receiving instruments connected to the line. If either end, therefore, has a message to send, all the operator has to do is to disconnect his receiver and connect up his key instead, so that as soon as he depresses it, current from his battery flows along the cable through the receiving instrument at the other end into the earth. And now we can return to the question of Capacity. If two plates of metal (or other good conductor of electricity) are placed near together with an insulating substance between them, they form an "electrostatic condenser," and if the two wires of an electric battery be connected one to each plate, the condenser will become "charged," which means that a quantity of electricity will accumulate on the inner surfaces of the two plates, or, what is much the same thing, the outer surfaces of the insulation, and will be held there by a kind of mutual attraction, so that if the battery be disconnected the "charge," as it is called, will remain. That on one plate will be a "positive" charge, while the other plate will hold a "negative" charge. We may think of the former as having had some electricity forced into it, and the latter as having had some sucked out of it, so that if, by means of a short piece of wire or in any other convenient way, we make an electrical connection between the two plates, in a flash the charges have neutralised each other, as if the surplus on the one had passed to make good the deficiency on the other. That is called "discharging" a condenser. Now the power of *holding* a charge is what I have already referred to by the term "Capacity."

The condenser is the commonest form of electrical apparatus, since it occurs either purposely or accidentally every time current flows anywhere. Every electric light wire, the conductor rails on electric railways, telegraph wires, thunder-clouds—they all form one plate of a condenser. Let us just look at an overhead telegraph line. The wire forms one "plate," the air the insulation, and the earth itself the other "plate." In that case the capacity or power to hold a charge is not much, for it diminishes as the thickness of the insulation increases. The considerable height of the wire above the ground therefore makes the capacity of such a line small. It varies, too, with the nature of the insulation. With air it is less than with gutta-percha. Therefore if we were to take an overhead wire and lower it down to within a few inches of the ground, we should increase its capacity. By insulating it with gutta-percha instead of with air, we should increase it still further.

Now a submarine cable has a core of fine copper wire constituting the conductor which carries the current. Around this is insulation of gutta-percha and outside that a sheath of stout iron wires. There are other layers as well, but these are the most important, and all we need to remember in order to understand the construction. Or we may think of it in another way as a strong steel cable with a core of gutta-percha, through the centre of which runs the fine copper wire. Consequently, we see that a cable has within itself all the parts of an electrostatic condenser. The fine wire forms one "plate," the sheath the other, and the gutta-percha the insulation. The result would be much the same without the sheathing, for the earth and the sea-water would equally well form the second plate.

In addition to the factors which I have already mentioned, there is another thing which helps to determine the capacity of a condenser, and that is the area of the smaller of the two plates. The area, for this purpose, is of course that surface which has a part of the other plate opposite to it. For example, in an overhead line the area of the smaller plate is the *under* surface of the wire, for it is only the under surface which has the other "plate" (the earth) opposite to it. In the cable, however, the one "plate" is *surrounded* by the other, and therefore the effective surface is the whole area of the copper wire. There again we see another reason for the high capacity of the cable as compared with the overhead wire.

Then another thing which we must remember is that this area in either case varies with the length of the wire, and so the capacity of a cable 1000 miles long will be just ten times that of another cable exactly similar except that it is only 100 miles long.

And now we can return to the effect of "Capacity" in a cable. What is needed for effective telegraphy is that the moment current is fed in at one end it shall commence to emerge at the other, and that the moment the supply of current at the sending station stops, it should also cease to flow out at the receiving end. If this could be attained, then the short, sharp, clear-cut currents sent from the one would be equally sharp and clear at the other. Instead of that, however, the first thing the current does is to charge the cable as a condenser. The first current which enters spreads itself all over the surface of the conductor, and until it has done this none flows out at the other end. Then when the current has ceased being sent off from the sending end this "charge" goes on trickling out at the other. Lord Kelvin has said in connection with the old Atlantic cable that a momentary current sent off from one end would take a quarter of a minute to flow out at the other, and even then it was still flowing faintly.

This seems strange to anyone who has seen how suddenly the charge flashes out of an ordinary condenser, but the difference is due to this fact. In the latter case the current can pass in and, because of their convenient shape, can flood, as it were, the whole surface of the plates instantaneously; moreover it can flow out again just as quickly. But in the case of an elongated condenser, like a cable 2000 miles long, the current enters, begins to charge the surface of the wire and the surface of the sheathing, and these two charges, attracting each other in some mysterious manner, cause the normal rate of flow along the wire to be greatly diminished so that the swiftness of the current is nothing like what it is on a land line. So the current flows in slowly as the cable is charged, and flows out slowly when it is discharged, and the time which is thus lost is called the "Retardation" of the cable.

Suppose, then, that a positive current has been sent off short and sharp. Most of it is used up in charging the cable, and a feeble and long-drawn-out current comes slowly from the other end. Then before another positive current can be sent we must wait until that has had time to occur. We can, however, expedite matters by connecting the sending end of the cable to earth for a moment, for the charge will then flow out at the sending end as well as the other, and by applying the negative end of the battery to the cable we can do better still, for the battery will then tend to "suck" the charge out, as it were, and so hasten the complete discharge and the time when we can send another signal.

That is called sending a "Curbing" current, and some modern transmitting apparatus is arranged to send this automatically. It has to be carefully adjusted, however, so that the curbing current shall be just sufficient to complete the discharge of the cable and no more, for if our curbing current were kept on too long it would result in charging up the cable with negative current and sending a negative signal to the other end, which we may not want to do.

To make this a little clearer, suppose that a positive current has been sent, and we want to follow it with another current of the same sign. Before we can send the second one we must get rid of the charge in the cable sufficiently, for if we send it while the charge left in by the first current is still flowing out strongly at the farther end, the second current will simply mingle with the outflowing charge, and the man at the receiving end will see one rather exaggerated positive signal when he ought to see two short ones. The application of a little negative current, however, quickens the discharge of the first positive current; but if it were to be continued too long it would result in the receiving operator getting a negative signal which is not intended for him, and so again he would get a wrong letter.

Although, of course, the instruments and arrangements are somewhat different now from what they were fifty or more years ago, it is a fact that Professor Thomson foresaw these troubles from the capacity of the cable, and introduced the principle of the "curbing" current. He also hit upon another device for the purpose of minimising the effects of Capacity. Given a condenser of a certain capacity, the amount of charge which it will absorb is in proportion to the force of the current which is put into it. If, therefore, a very slight force be used, a very slight charge will be the result, and with a very slight charge the time needed to discharge will be very small. But the force behind the current must of course be sufficient to carry the current to the other end of the cable, and to work the instrument there. So—to work backwards through all the stages—we may say that the more delicate the receiving instrument, the less force will be required to work it; the less the force used, the less will be the charge; and the less the charge, the less will be the time taken to discharge the cable. So the more delicate the receiving instrument the less will be this bother due to "capacity."

And thus the famous Mirror Galvanometer came into being. A minute mirror made of microscope glass had a little piece of magnetised watch spring cemented to its back. This was suspended by means of a single thread of cocoon silk inside a coil of insulated wire. Now a magnet is always affected by a current of electricity flowing in its neighbourhood, and so the faintest currents flowing in the coil had an effect upon the magnetised watch spring, and so upon the mirror. The whole thing was so light, too, and so delicately poised, that very minute currents indeed were not only able to have an effect upon it, but were actually able to move it. The combined magnet and mirror weighed but a fraction of a grain, and so, under the magnetic influence of very faint currents flowing through the coil, the mirror swung one way for a positive current and the other for a negative, with a slight tendency to return to the middle position if left entirely alone. Of course the current from the cable was led through the coil, and so the positive and the negative currents arriving from the distant end were registered by the movements of the mirror.

But the movements were often so small as to be inappreciable, so the instrument was placed in a dark room with a lamp throwing a beam of light upon the mirror. This it reflected on to a screen some feet away, forming thereon a spot of light which moved to and fro a considerable distance with even the slightest movement of the mirror. There are many ways, of course, by which a slight movement can be magnified into a large one, but they involve the use of long levers or other appliances which entail friction and need considerable power to work them. In this case we have a long lever without weight and without friction, capable of repeating on an enlarged scale every motion of the mirror, but requiring no effort upon its part. Consequently the delicacy of this apparatus far exceeded anything which had gone before it, or which has succeeded it, for that matter. The ordinary relay has been spoken of as delicate and light, but it is positively elephantine compared with the Thomson Mirror Galvanometer.

To illustrate this I will mention two experiments which were carried out when the first two successful Atlantic cables were completed—as we shall see later, after several failures, two were completed within a few weeks of one another. These facts are so strange, so fantastic, to all appearances, that I would not dare to mention them were I not able to give the very highest authority for them.

In his life of Lord Kelvin, that other great scientist, of almost the same name, Professor Sylvanus Thompson tells how the electrician Varley tried the first Atlantic cable with a battery made of a brass gun-cap with a single drop of acidulated water and a tiny piece of zinc, and with this minute battery he succeeded in working the mirror galvanometer two thousand miles away.

Another time he asked the operators at the other end to connect up the ends of both cables together, so that he could signal from his own sending instrument to his own receiving instrument, through about 4000 miles of cable. The battery this time was made of a lady's thimble with a few drops of acidulated water and a scrap of zinc, and with that small battery he succeeded in sending signals over even that enormous distance.

Truly the delicacy of the mirror galvanometer is almost incredible.

And now, after this long parenthesis, it is time we got back to our story of the laying of the Atlantic cables, but that we had better do in a fresh chapter.

CHAPTER XX

MORE ABOUT THE SUBMARINE CABLE

IN 1856, then, a company was formed to lay a cable on the bed of the Atlantic Ocean from Valencia in Ireland to Newfoundland, whence the land lines could carry the messages to all parts of the United States and Canada. The cable was made partly in London and partly in Liverpool, and in 1857 was shipped on two naval vessels, the *Agamemnon*, lent by the British Government, and the *Niagara*, lent by the United States Government. The cable weighed about one ton per mile, so that its total weight was about 2000 tons, but it was not the weight so much as the great space taken up by the coils which necessitated the use of two ships.

These two vessels were fitted with tanks for holding the cable, for it was necessary that they be kept wet lest the coils should stick together and the whole cable get entangled as it ran out of the ship. They also had the necessary wheels fitted at the bow and stern for the cable to pass over—the wheel at the stern, of course, for paying out the cable, and that at the bow for use in case any cable should need to be picked up again.

Then a brake is necessary when paying out in order that the cable shall not run out too fast. It is easy to see that when it is being laid in deep water that which has not yet reached the bottom depends, as so much dead weight, on that part which is just leaving the ship, and so, if unchecked, it will pull the cable out of the ship at a terrible rate, and will heap itself upon the floor of the ocean instead of being stretched out in a straight line. Therefore, brake gear had to be improvised and fitted into these ships, and, needless to say, this being the first work on such a large scale, all these contrivances were somewhat primitive, since the necessary experience had yet to be gained.

And so it happened that after the ships had met in Valencia Bay, each bearing half the cable, and the *Agamemnon* had laid about 330 miles of hers, it broke. The man in charge of the brake checked the flow of the cable too suddenly, and not being able to withstand the sudden shock, it parted and the end was lost.

Not having then learned how to pick up the broken ends of cables, there was nothing for it but to return to England. The cable was taken out and stored, while 700 miles more were made ready for another try.

In the meantime Professor Thomson was thinking about the subject, and it was during this interval that he invented the mirror galvanometer mentioned in the last chapter.

In the following year (1858), the ships met again, but this time a different method was decided upon. They departed first of all to the Bay of Biscay for a little practice. Here they practised splicing the two halves of the cable together, laying a few miles of it, pulling it up again, and trying a number of evolutions with the ships which it seemed likely they might have to perform in an emergency.

Then they repaired to a spot in mid-ocean where they finally spliced the two halves together, and, one ship taking each direction, they commenced to lay it on the floor of the sea. Although the summer time had been chosen as likely to provide calm weather, they seem to have been pursued by the most persistent bad fortune in that respect, encountering at least one bad storm, during which some of the cable on the *Agamemnon* shifted and got entangled.

When they had laid six miles the cable broke. Of course, up till then communication had been kept up between the ships through the cable, so the event was soon known to both of them, and they were able to return to their rendezvous, resplice, and start again. After laying another 80 miles the same thing occurred once more, and yet again after 200 miles had been paid out. Indeed, altogether 500 miles of cable were thus lost, and the last time being in foggy weather the ships were unable to find each other, and had to return to Ireland.

After coaling they re-started, and this time both succeeded in bringing their ends safely to land. On August 5, 1858, at 3.55 in the afternoon, a signal was sent from Valencia, and five minutes later, a response came through from Newfoundland. So great was the interest taken in the matter by the public, that this success was the signal for national rejoicings in both the countries thus linked together. But the rejoicings were a little premature, for a fault began to show itself, and, gradually becoming worse, all signals ceased after about three weeks' working.

The fault was probably caused by the entanglement when the coil of cable shifted in the storm. Under modern conditions it could have been located, and the cable picked up at that point for repairs, but in this early stage of the manufacture of submarine cable the quality varied so at different parts of its length, that it was impossible to tell by electrical tests where the fault was. When a "fault" occurs in a cable it is generally due to a breakdown in the insulation at some point whereby the current is allowed at that point to escape to the earth, in other words when the cable "springs a leak" electrically. Now, when flowing along a fine copper wire the current encounters a certain resistance somewhat comparable to the friction which resists the movements of any kind of machinery, but when flowing through the earth there is no resistance at all. The resistance of a modern cable is known by careful tests during manufacture to be uniform at so many ohms per mile, and so, supposing it were 5 ohms for example, and the cable 2000 miles long, the total resistance of the cable would be 10,000 ohms. Now if such a cable went wrong—that is to say, if the currents sent from one end ceased to reach the other—the first thing to be done would be to test the resistance of the cable. And supposing that it were found to have dropped considerably, it would be evident at once that it was leaking to the earth at some point. Then if the resistance were found to be say 950 ohms, it would be clear that the leakage occurred at 190 miles from the point where the test was being made. That distance could then be measured off along the line of cable on the chart which was made when it was laid, and the repair ship could go to that particular point on the ocean, fish it up, and repair it.

In this old cable, however, that was impossible, for the copper used for the conductor wire was not of uniform quality all along its length. Moreover, the insulation was bad, so that at many points along it current was leaking more or less—not sufficiently to make the cable unworkable, but enough to upset the accuracy of such calculations as I have been describing, and to render them useless.

In this particular case the electrician of the company (not Professor Thomson) probably made things worse by applying very powerful currents to the cable in the hope of getting signals through to the other end. These, escaping at the fault into the salt water, probably set up chemical action, which made the fault worse.

In all 732 messages passed through this cable, and a speed of two words a minute was attained, which at that time was thought to be very good.

Nothing daunted by this dramatic failure, after success seemed to be assured, the enthusiasts of the Atlantic Telegraph Company persevered. Some of the directors wanted to give up, sell what they possessed for the best price they could get for it, and so "cut their loss" as the saying now is—in other words have done with the thing, waste no more money on it, but get on with something more profitable. Largely because encouraged by the confidence of Professor Thomson, the majority decided, however, to go on, and raise more capital so as to enable them to have another try.

So in 1865 another expedition started, again from Valencia. There was this difference, however—the cable was all in one ship, for the famous *Great Eastern* had been hired for the work. This ship was too big for her time, although she was only about half the size of the *Olympic*. As a specimen of ship design she was a wonder, since she was the first of the new form of construction which has made the big ships of to-day possible, yet commercially she was an utter failure. Her one success was as a cable-laying ship, for not only was she very large, but she had paddles as well as a screw propeller, and so was very easily handled for a ship of her size—an important matter when a cable is hanging over the stern.

Messages were sent through the whole cable by way of experiment as it lay coiled in the ship with the satisfactory result that nearly five words a minute were sent and received. At this stage the "curb key" previously described was introduced, by which a curbing current is sent after each signalling current, and by its means the speed was raised to six words per minute.

But even with this new venture things went wrong. The cable itself was thicker and stronger than the previous one, and was made with much greater care, yet when about 84 miles out from Valencia a fault was found. There was, of course, a complete installation of instruments in the shore station at Valencia, and a similar set on board the *Great Eastern*, so that messages were continually passing and tests being made. Consequently as soon as the fault got into the water and the current began to escape it was discovered; that part of the cable was then drawn back on board and the fault was mended. A similar incident occurred when the ship was about 150 miles out, and finally, when she was about 1200 miles away, the signals suddenly ceased to arrive at Valencia. Whereas the communication had been continuous from the time she set out until then, after that there was no sign whatever. A week later the *Great Eastern* turned up herself with the news that the cable had broken, and the end had dropped in over 2000 fathoms. They had fished for the end, and had caught it three times, but every time the tackle had broken before they got it to the surface, so they had come home for fresh and stronger tackle.

Then followed the bold stroke which I mentioned in the last chapter. The directors decided, largely on the advice of their experts, Sir Charles Bright and Professor Thomson, that the *Great Eastern* should take out and lay *another* cable, *afterwards* picking up and completing the old one.

So in 1866 off she went again with a brand new cable on board, and the unlaid part of the old one, and this time the success was perfect. Communication with Ireland was never interrupted from the time the *Great Eastern* left; and the other end was safely landed without mishap on the shores of Newfoundland.

Meanwhile in the cable house at Valencia operators sat night and day watching the spot of light thrown by the mirror galvanometer belonging to the old broken cable. For weeks it remained motionless, but at 5.45 on 2nd September 1866 the man on duty was startled to see it move. The *Great Eastern* had got hold of the broken end, had hauled it aboard, and was signalling to him through it. Quickly that cable, too, was completed, and the company, which had been so often disappointed, suddenly found themselves in possession of two good sound cables capable of dealing with any messages the public might like to send and—most important after so many costly failures—to pay for.

Two years later another great cable was laid, also by the *Great Eastern*, and under the care of Sir William Thomson (as he had by then become) from Brest to Saint Pierre. This was longer still, 2580 miles, but it was laid without a single mishap. Indeed, since the problem was once conquered the laying of cables has become quite an everyday matter.

And now it will be interesting to see for a moment how a damaged cable is fished up from the depths of the ocean. I have already explained how the fault is located, and it is but a matter of navigation for a ship to find its way very nearly to the exact spot. Arrived there, a grapnel is lowered until it reaches the bottom, after which the ship slowly steams or drifts at a rate of a mile or so per hour across the line of the cable. Sometimes it is thus hooked at the first attempt, but, if not, a few tries are sure to get it.

The cable is then cut and tested electrically to see in which direction the fault lies, for, of course, the calculations are not so exact that the cable can be picked up for certain at exactly the right place, although the cable ship often gets very near it. The fault is therefore to one side or the other of the place where it is cut—the messages from the ship will go through without difficulty to one shore end of the cable, but not to the other. The "good end" is therefore attached to a buoy, and dropped overboard for the time being, while the ship proceeds to steam along in the direction in which the cable lies, drawing on board the damaged end as she goes. At intervals this is cut and tested to find out whether or not the fault has come on board, and when it has a new piece of cable is spliced on to it. The ship then turns back, paying out new cable until it reaches the buoy, which it picks up. After joining the new piece on to the good end the whole is dropped overboard into the water once more, and the work is finished.

The grapnels used for this purpose are of different kinds, according to the nature of the bottom on which the cable lies, but they are mostly of the kind known as "centipede" grapnels, which consist of a central stalk or shank with a lot of hooks something like the flukes of small anchors projecting all round. The flukes, moreover, are often hinged in a peculiar way, so that if one of them should catch a rock or other immovable object it will spring back and let go, but if it catches the cable it will hold on to it very securely. There are many tales about the curious things which have been brought to the surface with a cable, such as a dead whale enveloped in a coil of the cable, and even a small sailing ship, but most of them have been told before.

The faults are caused in various ways, one very common thing being a kind of submarine worm which finds its way between the wires of the sheathing and eats into the insulation. Sometimes currents will cause the cable to rub on the sharp surface of a rock and so cut itself, but that is more often at the ends, near the shore, and the shore ends of the cables are therefore made thicker and stronger so as to resist such action. The anchors of ships also sometimes foul the cables where the water is shallow, while earthquakes, causing mighty upheavals of the ocean bed, have been known to tear asunder the strongest cables by main force.

Quite a large number of cable repair ships are now always at work, either actually repairing cables or else waiting in readiness to rush off at a moment's notice when and where required.

In general build they are like ordinary merchant ships of average size, and of course they have the large sheaves fitted to the bow and stern for paying out and picking up cable. They have also the necessary tanks for carrying spare cable.

For picking up there are machines something like steam winches, but of a rather special design, while for paying out they are fitted with brakes very different from those in the *Agamemnon*, which allow the cable to slip out quietly and steadily no matter how the weight of cable below may be pulling, and no matter how the waves may be tossing the stern of the ship up and down. There is an appliance, too, which enables those in charge to tell at any time what the pull on the cable is.

Stored in the repair ship, so that they can be got at in a moment if required, are all manner of grapnels, ropes, chains, buoys, repairing material, and so on—in fact, everything that by any chance might be wanted on a repairing job. There is a room, too, full of electrical instruments capable of carrying out any tests or other electrical operations which might, in any emergency, be needed.

It is not often that a cable breaks after it has once been laid, but in the earlier cables there was a chance of the conductor wire breaking. It was then composed of a single copper wire, but now it is almost always of seven finer wires twisted together, the reason being that an excessive strain on the cable might break a single wire but it would be almost impossible for the whole of seven to break in that way. It may be wondered why one cable does not carry several conductors, so that several messages could be passing at once. In some of the short-distance cables there are, in fact, several conductors embedded in the same gutta-percha, and it seems surprising at first to find that this is not so in all cases, for surely it must be much less costly to lay one cable with several conductors in it rather than several separate cables.

The reason is that whenever intermittent currents flow along a wire they will "induce" similar currents in a neighbouring wire if there be one sufficiently near. If an Atlantic cable, for example, had two wires in it, the signals sent along one would produce similar signals in the other. There need be no electrical connection between the two for this to happen, for "induction" will take place regardless of the insulation.

The effect of one wire upon the other depends first upon how near they are together. With a current in the one wire of a given strength, the induced current in the other wire will (like so many things which one comes across in the course of a little scientific study) "vary inversely as the square of the distance." That is to say, if the second wire be half an inch from the first the induced current will be one hundred times as strong as it would be if it were 5 inches away; for 5 inches is ten times half an inch, and a hundred is the square of ten. Therefore two cables, if only 5 inches apart, will exercise little effect upon each other compared with the effect between two conductors in one cable say half an inch apart, while if they be say a yard apart the effect is inappreciable.

Moreover, the current and the distance apart remaining the same, the effect of the inducing current will increase as the length of the two wires increases. Therefore, whereas several conductors can be put into one short cable such as those between England and Ireland, or between England and the Continent of Europe, it would be useless to put more than one in a long ocean cable.

CHAPTER XXI

HOW A SUBMARINE CABLE IS WORKED

THE earliest instrument for receiving the signals sent through a long submarine cable has been described already. Beautiful though that is in its delicacy, it has one great fault, which has led to its almost entire supersession by another, younger, rival. That fault is that the watching of the spot of light as it danced to and fro upon the screen was very trying to the eyes and nerves of the operator. If one movement were missed, the whole sense of a message might be lost, and the consciousness of that fact kept the man continually on the strain, so Sir William Thomson himself set his marvellous brain to work to devise some improved instrument which would itself record the signals which came in, and allow of their being read off afterwards.

The essential feature of any such machine, as you will remember, is that it shall work with the minimum of friction, so that it may be able to respond to the stimulus of the faintest currents.

In the mirror instrument the action is due to the mutual attraction and repulsion of two magnets—one the coil through which the current passes, and the other the tiny piece of magnetised watch spring at the back of the mirror. Now the force which two magnets thus exert upon each other depends upon the combined power of both. If each of them is very weak, the total united force will be weak. And in the older instrument the watch-spring magnet was bound to be weak, for it was so small. The coil was weak, too, but that could not be helped, for it depended upon the current which, as we have seen, had to be kept as weak as possible. To have enlarged and so strengthened the watch spring would have been useless, for the increased weight would have counterbalanced the effect of the increased power. So Sir William, when converting his old galvanometer into his new recorder, turned the apparatus inside out, as it were. He made the coil the movable part, and the magnet which took the place of the watch spring the fixed part. And that permitted him to make the latter very strong. Since it was fixed its weight did not matter, and so it could be made as strong as was desirable.

A current therefore has more power to move the coil in the newer instrument than an equal current had to move the mirror in the old one.

This permits the coil to be harnessed to a little pen of curious construction which writes the messages out in ink. This is a U-shaped piece of glass tube with a finely pointed end. One leg of the U dips into a vessel of ink, from which it draws its supply by a siphon-like action, while it is so suspended that the other leg—the pointed one—can swing to and fro from side to side under the influence of the coil, to which it is attached by fine threads.

And the beauty of the invention lies in this. The point of the "pen" does not touch the paper on which it writes. In the original instrument the inventor electrified the ink by current from a small "influence machine" which formed part of the apparatus, and that caused the tube to *spit out* the ink (I can find no better words) in exceedingly fine drops, so that it drew its ink line sharp and clear upon the paper without ever touching it.

In the instruments in use to-day the same result is obtained by causing a little appliance just like the mechanism of an electric bell to vibrate the tube as it works.

The action, of course, is this:—While no current is coming in from the cable the pen draws a straight line down the centre of the paper strip as it is drawn by a little motor past the point; but the moment a positive current comes along, the pen is pulled to one side, and the line therefore slopes in that direction. When that ceases, the pen tends to return to the centre, and so the line slopes back again; a second positive current will send the pen towards the same side again, and again the line slopes in that direction, while a negative current will pull the pen right over to the other side, making the line slope that way, and so on. Thus the message is written down by the recorder on the paper strip in the form of a wavy line quite unintelligible to

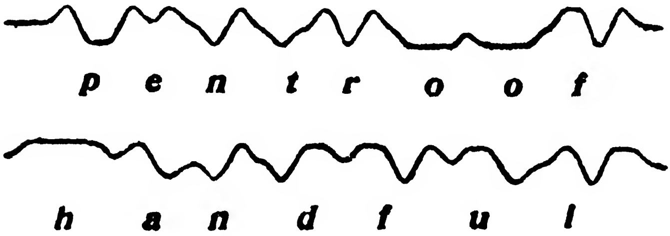


FIG. 27.—Siphon Recorder Signals.

the ordinary mortal, but as clear as the finest copperplate writing to the trained operator.

At the sending end a paper strip also plays a part. Instead of sending the message direct by means of a key, the operator works it off on an instrument known as a Perforator. This has three keys, which he presses with his fingers much as a typewriter is operated. The middle one makes a hole in the centre of the strip of paper, while the left-hand one makes a central hole and one above it as well, and the third a central hole and one below it. After each movement of a key the paper strip moves on automatically a little way. Thus is produced a strip with a continuous line of holes down the centre and other holes at odd intervals. A centre hole by itself means a space at the end of a letter, while the other holes mean each of those on one side a positive signal and each of those on the other a negative.

This strip is then fed into a Transmitter, which sends off the signalling currents to the cable in accordance with the perforations on the strip. In some cases, too, it sends off after each signal the proper "curbing current."

But another method is often used now to overcome the trouble caused by the residual charges in the cable. It is a kind of homœopathic remedy, for the trouble arises because the cable is itself a condenser, and the cure is also a condenser. The signals are actually sent through condensers.

Now this calls for a little consideration. A condenser, let me remind you, is two conductors with an insulator between—the two conductors are thoroughly insulated from each other. Yet the battery is connected to one plate of a condenser and the cable t the other. There is therefore a distinct break in the continuity of the circuit, and yet the signals get through. Let us see how this can be.

Assume a state of things illustrated in the accompanying diagram, in which the two parallel lines represent the two plates of a condenser and the space between the insulation. When we depress the key so that current can flow from the positive pole of the battery to the left-hand plate, that plate tends to become charged. To use our "fluid analogy," we may think of the force of the battery trying to *heap up*

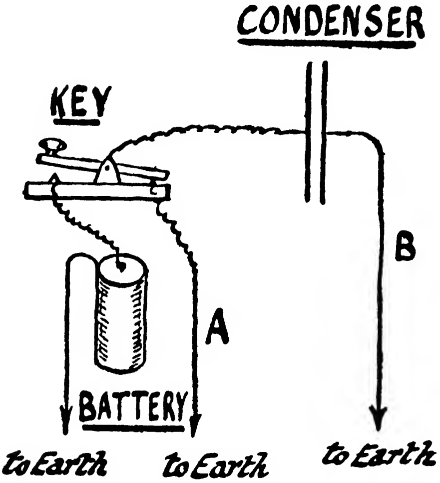


FIG. 28.—This Diagram shows how a Condenser works. The Key in the Position shown causes it to discharge, *via* wires A and B and the Earth. By pressing the Knob of the Key we can cause the Battery to charge the Condenser.

the electricity on that plate. Owing, however, to some wonderful sympathy between the two plates—a sympathy which laughs at insulation—it is unable to do this unless it can at the same moment *drive out* an equal quantity of electricity from the other plate. We need to think of both plates being charged to a certain extent to commence with, but charged equally so that they are in equilibrium. Then it is easy to picture to ourselves the little pump which we call the battery forcing an excess of electricity on to the one plate and the mysterious influence forcing the other plate to deplete itself to an equal extent.

But the right-hand plate cannot deplete itself in this manner unless there be somewhere to which the expelled electricity can go. By connecting it to earth we can provide this way of escape, and then our condenser is free to become charged by the action of the battery.

Now let us see what this amounts to. We depress the key: instantly there is a rush of current to the left-hand plate; equally quickly there is a rush of electricity *from* the right-hand plate to the earth. The condenser is charged, and in the process of charging there has been a momentary rush of current right round the whole circuit in spite of the break in it between the two plates of the condenser.

Then let us, by releasing the key, switch the battery out of it altogether, and connect the left-hand plate directly to earth. Instantly there is a rush of current the reverse way, the surplus (or positive charge) on the left-hand plate rushing to earth while an equal current rushes from the earth at the other side to restore the normal state of things in the right-hand plate. Or, to employ the usual phraseology, the positive charge will pass to earth through wire A and the negative charge will pass to earth through wire B. You will remember that we have already decided to regard the *sending* of a "negative current" as the same thing as *receiving* a "positive current," and in just the same way, when we speak of a negative charge passing *to* earth, we are but using a convenient way of indicating a positive current passing *away from* the earth.

Thus, you see the charging and discharging of a condenser,—the former when we connect the two plates together with the battery in between them, and the latter when we connect them directly together. In the former case the current travels towards the positively-charged plate and away from the negative; in the latter it passes the reverse way.

But you must understand that the quantity of electricity which constitutes the charge is very small. It varies, as has been explained already, according to the capacity, but in the largest condenser it is never very much; therefore the amount of current which passes along a circuit in which there is a condenser is very small. In fact, it is so small that we can hardly call it a current at all; it is better termed an impulse. In an ordinary circuit a steady stream may flow, but when there is a condenser in it, it is only possible to send these very short impulses. An electric current, we may say, cannot pass through a condenser, but an electric impulse can.

And now we can extend our diagram a little, so as to show a cable with a condenser at either end. Each of them has one plate connected to the cable, while the other is connected to the instruments. There would, of course, be a transmitter and a recorder at each end, but for the sake of simplicity a recorder only is shown at one end and a battery and key at the other.

Suppose now that the key be depressed; current will rush upwards and charge plate A positively. That will charge negatively—in other words, expel electricity from—plate B, which will rush through the cable and charge positively plate C, while the electricity expelled from plate D will pass to earth through the recorder.

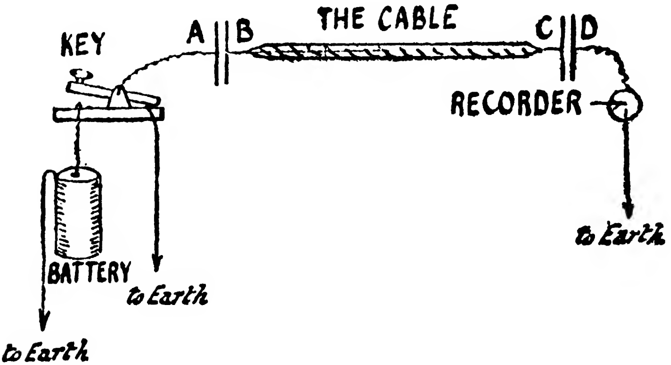


FIG. 29.—This Diagram shows how the Electrical Impulses pass to and from the Cable through Condensers.

Then imagine the key to be released from the pressure of the operator's hand, so that the back end of it descends and connects the cable to earth, instead of to the battery. Instantly both condensers will discharge, and an impulse will pass through the whole circuit in the reverse direction to the first. The second impulse will be exactly equal to the first, for it will be simply a restoring of the electrical equilibrium which the first upset, and so it will act as a curbing current of exactly the right strength.

It is easy to see, too, that if the battery were reversed so that its negative pole were connected to plate A, the whole series of charges would be reversed, and the final result would be exactly the same except that the recorder would be worked in the opposite way, and so would indicate a negative signal instead of a positive one.

Of course, the transmitter makes all these various connections between the battery, plate A, and the earth, automatically.

The condensers used are very simply made of a pile of sheets of tinfoil with waxed paper between them. Alternate sheets of foil are connected together—that is to say, the first, third, fifth, and so on, are joined, and the second, fourth, sixth, and so on, in like manner, so that one lot form one plate and the other lot the other plate. The area of the plates, or in other words the capacity, can therefore be made large or small as desired by using a larger or smaller number of sheets of foil.

I have dwelt at some length upon this question of condensers, because, for one thing, it is a branch of electrical knowledge which is both interesting and little known, and for another, it will enable us to understand that most wonderful feat by which two messages can be sent over one cable at one and the same time.

Before passing to that, however, there is another very interesting little device used in connection with cables which it might be well to mention. Even with the use of condensers and curbing currents, the difficulty of the charge remaining in the cable and slowly trickling out is not entirely obviated. Consequently there are two currents, as it were, passing from the receiving end of the cable—one the sudden impulse which brings the signal, and the other the slow outpouring of the remains of several previous signals. If the latter be allowed to accumulate, they will after a time be sufficient in volume to smother, so to speak, the former, and so if some kind of valve can be introduced which will permit the accumulated charges to be constantly trickling out to earth without going through the recorder, it will be of great advantage. Of course, it must at the same time not allow the sudden signalling impulses to pass, or they will take that way to earth leaving the recorder alone, which would never do. But fortunately there is just such a thing in existence. A coil of insulated wire of certain proportions will allow a slow and steady current to pass through it, but will effectively stop a sudden impulse. Just before reaching the recorder, therefore, the wire is forked, one prong of the fork leading to the recorder, and the other to earth through one of these "Inductance" coils, as they are termed. On arriving at the junction, the sudden impulses have to take the path which leads through the recorder, for the other way is blocked to them, but the others, which are not wanted in the recorder, find an easy path, which they readily take, to the earth, without going to the recorder at all. So, we see, a condenser permits a sudden impulse to pass, but not a steady current, and an inductance coil the reverse. These two separately, or in combination, are often of great use in telegraphic matters.

And now we can turn to that marvellous arrangement whereby one cable can be made to do the work of two, so that a transmitter and a recorder can be at work at both ends at the same time, the messages appearing to pass each other in the cable. They do not really do this, for it is quite impossible for two electric currents to flow in opposite directions in the same cable at the same time, but the effect is just the same as if it did.

This is called "Duplex" working, and to understand it we must again have recourse to a diagram.

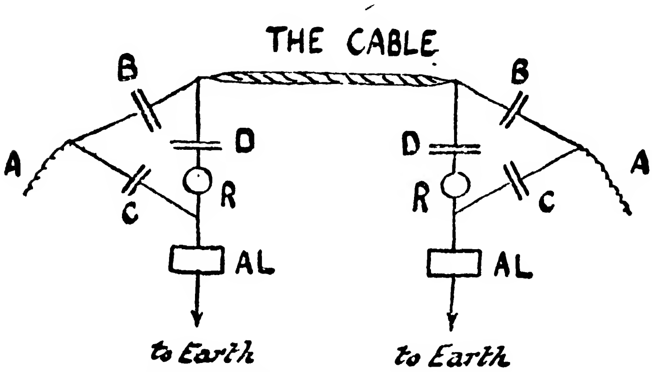


FIG. 30.—This Diagram shows the Principle of the Marvellous Arrangement whereby two Messages can pass along a Cable simultaneously. R, Recorder. AL, Artificial Line.

The current from the battery passes along wire A until it comes to a junction where it has the option of two courses, one *via* condenser B to the cable, and the other *via* condenser C to an "artificial line," as it is termed. This is an ingenious arrangement of tinfoil sheets, through which the current has to pass, adjusted so that, both as to resistance and capacity, it closely resembles the alternative path through the cable and the recorder at the other end. Consequently the current or impulse divides itself and passes both ways equally, one impulse going to the cable and another of equal strength going to the artificial line, and so to earth. That part of the current which goes along the cable duly reports itself at the other end by means of the instruments there.

And it is necessary that we should notice now the third wire known as the "Bridge," in which are inserted the condenser D and the recorder. The current from the battery to the cable passes one end of this wire, and that from the battery to the artificial line passes the other. These two are of equal strength, and therefore do not pass along the bridge at all, for if either of them attempts to do so it finds itself opposed by the other.

If we had two streams flowing a little distance apart, and we connected them together by means of a ditch, the water in the latter would be perfectly stagnant so long as the waters of the two streams were at the same level. Water could not flow along it from either stream, because it would be opposed by the water of the other stream. And in precisely the same way the two equal streams of electricity flowing past the ends of the bridge leave it stagnant simply because they are equal.

Therefore the recorder does not respond to signals sent from its own end.

When, however, current arrives from the distant end, it not only charges condenser B, but also condenser D, and in order to do so has to pass through the recorder, thereby registering the signal. So we see how, although there is the same network of wires and condensers at both ends, forming channels, all of which seem at first sight equally open to the current, it is only an incoming current which passes over the bridge and so works the recorder.

But now see what happens when currents are despatched from both ends simultaneously. Under those conditions they oppose each other's passage, so that no current passes along the cable at all. Instead, the currents which would otherwise have passed along the cable escape across the bridges, and so the recorders are both worked just as if the currents had passed each other.

Thus, if we called the two ends X and Y, we may say that when X sends a signal to Y he works Y's recorder, and *vice versa,* but when they both signal to each other, neither works the other's recorder, but each compels the other to work his own, which, for practical purposes, is the same thing.

In the above description, I have assumed that the two currents are of the same sign. If one sends a positive signal and the other a negative signal, instead of no current flowing along the cable, twice the normal current passes, which upsets the electrical balance usually existing at the ends of both the bridges, with the result that both recorders are worked as before.

Although we have not even now exhausted the wonders of submarine cables and their uses, it is time for us to turn to another subject.

CHAPTER XXII

UNDER-WATER WORK WITHOUT DIVERS

REFERENCE has been made already to many kinds of work carried on under-water by means of divers, but that does not by any means exhaust the tale of wonders, for, without men going below the water at all, many marvellous things have been constructed. And strangely enough, the most remarkable feature of many of these feats of engineering is the apparent simplicity of the methods employed; it is their colossal scale which makes them wonderful.

It sometimes happens that the building of a breakwater by the concrete block method already described is not possible. Where the floor of the sea is moderately hard—hard enough to form a strong foundation, but not too hard to be levelled by the divers—this mode of procedure is the best. But it may be too hard to be thus trimmed, or too soft to bear the weight of the blocks.

In such cases the difficulty is sometimes overcome by making a mound of stones. Barges laden with suitable material are taken to the site, and the stones thrown overboard until a solid heap of stones reaches above low-water mark. Then upon this mound a superstructure can be built up in the ordinary way.

One advantage of this method is that the sea itself arranges the stones, packs them together, removes those which are lying at too steep an angle, and places them in such positions as they will naturally tend to keep.

The famous breakwater at Plymouth was so constructed. It is merely a mound of stones with a kind of paving laid on the upper part to form a smooth surface, on which the waves will not be able to get much hold, and which will therefore resist their tendency to loosen the topmost stones.

The breakwater at Alexandria is made entirely of loose stones and large blocks of concrete; but the latter are not laid like bricks, they are simply tumbled on to that side of the mound which is subject to the heaviest assaults from the waves, so that by their great weight they may resist the attack better than smaller stones could.

Sometimes after structures have been built by other methods, stones roughly thrown into the water are very useful, for the currents may scour away the material from under the foundations of a structure and so threaten its stability, and in such cases a heap of large stones against the part affected may stop the trouble before it has become too serious.

Of course the precise action of the waves at any point is too uncertain to be successfully predicted in all cases. Wind, tide, the distance and shape of the nearest shores—these and other considerations as well—all affect the question; and they are so complex that no one can be sure what the waves can or cannot do at any particular point. Consequently the most carefully designed works of this description are apt to fail at times.

When it is intended to construct works which are subject to wave action, a gauge is sometimes put up beforehand in the endeavour to measure the force which the waves usually exert at that spot. An arrangement somewhat like the buffer of a railway carriage is so fixed that the waves will beat against it and tend to drive it in against the force of a spring. As it is driven back it makes a mark, so that an inspection after a storm can tell how far the buffer has been driven in. And from that the hardest blow given by the waves can be calculated.

For example, suppose that the area of the buffer be a square foot, and the strength of the spring be such that it takes a ton to drive it in 3 inches. Then, if on inspection it be found that the buffer has been driven in 3 inches, it is seen at once that the heaviest blow from the waves was one ton per square foot.

It is on record that at Peterhead in Scotland a mass of masonry weighing 3300 tons was moved bodily by the waves, which must have exerted a force equal to two tons on every square foot of the area exposed to their action.

At the same place blocks weighing 41 tons were moved although they were 37 feet below low water. Indeed it seems as if the depth to which the action of the waves extends must have been somewhat underestimated in the past, for, besides the above and several similar incidents, at the Bishop Rock lighthouse, in the Scilly Isles, sand was found after a storm which could only have come from the bottom of the sea, at that point 150 feet below the surface.

And not only did the waves thus fetch up sand from such a depth, but they threw it on to the gallery of the lighthouse, 120 feet above the surface of the water.

So the waves have their effect 150 feet down and 120 feet up in the air, at least. It may be more.

The fact that the waves can thus move small particles of sand, however, at these great distances from the surface, does not imply that their action is powerful enough to do any harm to a strong structure at those distances. It was only the spray which carried the tiny grains of sand to the lantern on the Bishop Rock. Nevertheless solid waves of the height of 40 and 50 feet have been actually measured, and as such a wave would of necessity consist of some thousands of tons of water it is easy to see that a blow from such a moving mass must be something terrific.

In some places a foundation is made for a breakwater on a rough rocky bottom by means of bags of concrete. At Newhaven, for example, enormous bags made of jute, each holding a hundred tons of concrete, were carefully lowered from barges on to the sea floor where the breakwater was to go. Several layers of these formed a mound reaching to just above low water and then upon that the vertical part of the breakwater was built of concrete at low tide in the ordinary way, just as if it had been a concrete wall on land.

The weight of the upper layers of bags causes the lower ones to bed themselves down nicely upon the rough bottom, and enough cement squeezes out of the bags to join them all together into a strong and solid structure.

Small breakwaters have been made by simply fixing two wooden partitions in the water reaching to above low-water mark, and then throwing concrete into the space between them until it was entirely filled.

The mounds of loose stones, or "rubble," to use the technical name, are in some cases covered on the top and sloping sides with a covering of blocks of concrete carefully laid like bricks by means of cranes, while in other cases a vertical wall of concrete blocks has been built upon the top of a rubble mound.

The form of crane known as a Titan, which is commonly used for setting these huge blocks, has already been described, but it may be interesting to add here an ingenious means by which isolated breakwaters are commenced. The Titan, it will be remembered, stands upon that part of the breakwater which has been finished, and reaches over to the part which is being built. But what is to be done when no part of the work has been accomplished?

If the breakwater starts from the shore, it is quite easy, but very often they are quite isolated. In those cases a caisson is sometimes used to commence with. This is sunk as described in an earlier chapter, and filled with concrete. Then upon its top the Titan is erected, and by its aid the wall of concrete blocks is started. A very convenient way is to place the caisson in the centre of the proposed breakwater, so that as soon as one Titan has built a piece of wall and vacated the top of the caisson, a second Titan can be erected in its place to work in the opposite direction. Thus from the central position of the caisson the two Titans can work simultaneously, each building one half of the breakwater.

The mention of caissons reminds us of the foundations of bridges. These, too, are sometimes formed of rubble mounds. The beautiful Waterloo Bridge in London is so supported. The old Westminster Bridge was built in wooden boxes sunk on to the bed of the river, the sides being removed when the work was finished. The present Westminster Bridge was founded in cofferdams.

A method exactly similar to Brunel's way of sinking the shafts for the Thames Tunnel is often very effective too. The supports of the bridge are of iron or steel, cylindrical in form, and they are put together in sections. When a few sections are together the whole thing is lowered down on to the river-bed, and heavy weights are applied which tend to force it down into the earth. In some cases the ground is of such a nature that it forms a water-tight joint with the iron, and then the water having been pumped out, men can go down inside the cylinder and dig away the material at the bottom, whereupon the cylinder sinks more and more. My readers who have read the earlier chapters will see at once that with the help of compressed air this could be done with any sort of earth, but what I am now referring to are the cases where compressed air and divers are not needed.

Even in porous soil the diver can sometimes be dispensed with, for the inner material can be dredged out, while the cylinder is full of water, either with a grab or with a specially arranged bucket dredger.

In sandy soil cylinders and piles can often be well founded by means of a jet of compressed air or water. This is forced down pipes from the surface, and blows the sand away from the end of the cylinder, allowing it to find its way down by weight alone, yet, when it is finished, and the sand allowed to settle down again, it holds it quite tightly.

At the mouths of rivers and harbours there are often to be seen small breakwaters stretching out well to seaward. There are generally two of them parallel, and they seem to be a continuation of the river itself, reaching out into deep water.

Their purpose is to prevent the river mouth from becoming blocked. The prevailing winds and the drift of the sea bring quantities of shingle along and pile it up all along the coast, including the bar at the mouth of the river. If it be strong, its current may be capable of clearing this away for itself, but often that is not so. Those of my readers who know Great Yarmouth on the east coast of England, will be aware of the curious manner in which the river Yare, after making straight for the sea, suddenly, when within a few yards of its goal, turns off southwards, and ultimately enters the sea at Gorlestone, four miles away. That is an actual instance of what I have been saying. The river used to run straight into the sea, but its mouth becoming blocked it had to find an outlet elsewhere.

Now, when this is likely to happen, the parallel jetties just referred to are useful, for they cause the water at every tide to run swiftly up and down, and so scour out the river mouth. They can also be so placed that they tend to divert the currents of the sea which bring the shingle along and cause them to deposit their loads at some unimportant point.

They are not therefore true breakwaters, but mainly form a directing channel for the tidal current as it flows into and out of the river day by day. They are called "training works," for they train the current.

The natural mouths of the rivers which are thus treated are generally very wide—indeed it is because of their wideness, and the consequent spreading out of the waters before they reach the sea, that the waters have not sufficient force to keep the river mouth clear, and for the same reason the land upon which these jetties have to be erected is often of very soft stuff, the loose matter which the river has been bringing down for ages past.

Consequently a curious form of construction has sometimes to be employed, involving the use of what are called "fascine mattresses."

These are bundles of brushwood tied together with the pliant strands of willow such as baskets are made of (or other trees if they are more easily procurable), until a large mattress-like structure is formed. When finished, the mattress is floated out to where the jetty is being built, and from boats all around it stones are thrown upon it till it sinks. Then another is sunk upon the top of it with more stones, until a mound is formed of alternate layers of mattress and stones. The river soon fills up the interstices in the mattresses and among the stones with silt, which acts as a preservative to the brushwood, and keeps it from rotting. In fact, woodwork which is kept from access to the air will last for very long periods.

These mounds, therefore, are brought up to the level of the lowest tides only, for above that level the fascines might rot. The upper parts, therefore, are built upon the mounds, of timber, concrete, stone, or whatever may be deemed suitable for each particular case.

The special virtue, it will be noticed, of this form of structure is that the mattresses tie the stones together, distributing the weight evenly upon the soft material on which the structure stands, and also preventing the river from washing the stones away.

The fascine is, I believe, a Dutch idea, arising from the fact that in their flat low-lying country they had, early in history, to become expert fighters of the sea, which they drove back from their country with a marvellous system of mounds and dykes, the model for all other people to follow who have had similar conditions to contend with.

MAKING A FASCINE MATTRESS

Natives constructing a mattress for use in the harbour works at Rangoon

Another and very interesting under-water worker is the Suction Dredger. Imagine a stout strong ship like a large tug with a curious nozzle affixed to its bows. Near this nozzle there is a strange-looking object, something like a huge auger such as carpenters make big holes with. When at work the nozzle and auger are let down into the water until they touch the bottom, and then the auger is set to work. Digging its way down it loosens the earth and stones, which are then sucked up through the nozzle. For the latter is but the inlet to a huge pump on board the vessel—a pump of the kind known as "centrifugal"—which can suck up great lumps of earth, heavy pieces of stone, and indeed anything which is likely to be lying about on the bed of the sea. Having sucked them up into itself, it then throws them out again, either into a barge alongside or through a long line of pipe to the shore.

In outside form these pumps look very like enormous snail-shells. The inlet is just at the centre while the outlet corresponds exactly with the outlet which the snail provides for itself. Inside it there is a kind of paddle-wheel, which spins round the water and anything else which it may contain at a high speed. Now we all know that when you stir a liquid round it tries to get to the side—away from the middle—and so the contents of the pump seek the outlet at the edge, and, finding it, pass out with considerable energy. To fill their place other liquid is drawn in at the centre, and so the constant stream is kept up. So powerful is the stream of water that it can carry with it stones weighing a hundredweight or more, and force them along miles of pipe.

The pipe is made in short lengths hinged together and supported upon pontoons so that it floats upon the water as the dredger moves about.

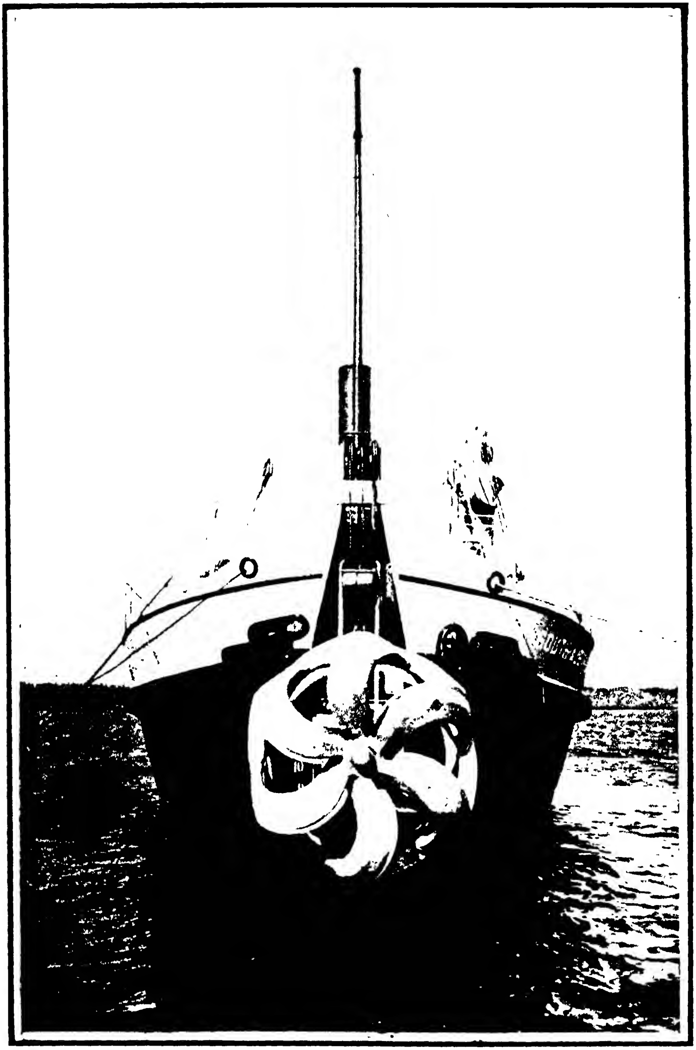
Thus not only çan deep channels be cut, but low-lying land can be raised by directing the stream of water with its earth and stones on to it. For years past two powerful boats of this kind have been at work improving Bombay Harbour, clearing out channels and building up what has hitherto been waste land.

The same sort of thing is done in some kinds of gold-mining. Many of the rivers of the world contain much gold among the sand of which their beds are formed. The sand itself is but fragments of rock from the higher reaches of the river. The rocks have been gradually broken, and the tiny pieces washed down, and the little pieces of gold which used to be in the rocks have come too, and there they lie now.

It may be worth while to seek for these little bits of gold or it may not; it all depends upon how much of it there is in every ton of sand, and how much it costs to raise a ton of sand and sort it over to find the gold. And that is where the use of the suction dredger comes in, for it is perhaps the cheapest of all ways of getting the sand up into the boat or to the shore, where it is put through machines which pick out the gold and throw away the rest.

Further, among the under-water work done without divers, perhaps some of the most interesting is the building of the foundations of those great lighthouses which stand like sentinels at the danger points to warn ships to keep away from rocks or to guide them into safety, often with their foundations well below the level of the waters amid which they stand.

Perhaps the best-known lighthouse in the world is



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A BURROWING SHIP

This striking object is the huge auger-like tool with which the suction dredger cuts up the mud at the bottom so that it can suck it up with its pumps.

the Eddystone, which stands upon one of a group of rocks at the entrance to the English Channel. The story of this famous light is in itself almost the story of the modern lighthouse. The first one to be built on the rock was erected in the seventeenth century, the light being exhibited first in 1698; but in a great storm in 1703 it was destroyed, and a specially pathetic touch is given to the incident by the fact that its designer, a famous architect named Winstanley, happened to be in it at the time, and perished with it.

The second one, like the first, was of wood, and was designed by a silk mercer of London named Rudyerd, assisted by two shipwrights named Norcott and Smith. The light was first shown from this in 1708, and, though we might be inclined to suspect the value of a structure of this kind, designed by a silk mercer, it was evidently a very sound piece of work, for it stood nearly fifty years, and even then its end came not from the assault of the waves, but from an internal mishap—it was set on fire and burned.

Winstanley's was entirely of wood. Rudyerd's was mainly of wood, but a little granite work was introduced to give it stability. In the next one, which was built by the great engineer Smeaton, who, it will be remembered, was one of the first to use the diving bell, stone entirely displaced wood, and nowadays every rock lighthouse, almost without exception, is constructed of stone—generally granite.

Anyone standing to-day upon the Hoe at Plymouth, made famous by Drake and his game of bowls, and looking out towards the sea, can, if the day be clear, see what looks like a tall factory chimney rising from the waves in the far distance. Just to the right of it, too, will be noticed a short structure of the same sort. While behind, on the Hoe itself, is an unmistakable lighthouse tower, which, however, does not show a light at night.

The short tower is the stump of Smeaton's tower, which, having endured the storms of a century, had to have its upper parts removed, since the rock upon which it stood became shaky. The upper part it is which stands upon the Hoe, not as a lighthouse now, but as a memorial of the services which Smeaton rendered to his fellow-creatures; while the tall object upon the horizon is the present Eddystone, built upon a more solid part of the rock. It first showed its light in 1881, and will probably continue to do so for centuries to come, as Smeaton's light would be showing to-day had not the rock given way under it.

Five thousand tons of masonry were carried out to this stormy islet, and there built up into the great tower, and when we think of that great weight and the fact that the rocks are almost submerged at high tide, we can see what a difficult undertaking it must be to construct the necessary foundations for such structures. Fortunately, in most cases, the fact that the rocks have resisted the action of the waves for ages renders it almost certain that they themselves are sound and well able to carry the tower so long as it be well founded upon them. The first thing to do is to treat the rough irregular surface of the rock in such a way as to produce a level platform upon which the tower can stand. This is generally done by cutting the sloping parts into level steps, and laying rectangular blocks of granite upon them until a large level platform has been formed. These blocks are set with the strongest and best cement, and in addition iron bolts are often passed through them and let deep into the solid rock, thereby holding them down very firmly.

Upon this solid foundation the tower itself rises. It, too, is of granite blocks, not only set in the strongest cement but dovetailed and keyed together. Each ring is carefully made at the works ashore; the pieces are marked, and then they are taken out to the site and put together just as the parts of a child's picture puzzle are fitted one into another.

The cutting of the steps in the rock has to be done with the greatest care and by laborious methods, too, for such drastic means as blasting must be avoided for fear of weakening the rock itself.

Often this work can only be done in fine weather at the low water of spring tides. The latter occur on two or three days in every fortnight, so that if the weather is then bad a whole month may often go by without any work being possible. In some cases it has been practicable to erect a cofferdam around the spot, and work under its protection at all tides; but in the majority of places the sea would make short work of a cofferdam, unless it were built as carefully and as strongly as the foundations themselves, and under those conditions one may as well build the foundation straight away.

At the Eddystone, when the present tower was built, a wall was first erected round the site, about 7 feet high. It was quickly done, at the lowest tides and with quick-setting cement. At high water the sea came over it and filled the space inside, but it had the effect of saving time, for as the tide receded, as soon as the top of the wall became clear of the surface, powerful pumps on the attendant ship emptied the water out, and work commenced. It could then continue while the tide had gone down to its lowest and risen again to the top of the wall. Thus the men were able to work for about four hours at every tide instead of perhaps an hour.

The base of such towers is always made as broad as possible. The present Eddystone is 44 feet in diameter at the base, while the Vierge Island tower, off the coast of France, one of the largest in the world, is 52½ feet. Sometimes they have straight sides tapering inwards towards the top, but more often the sides proceed upwards in a graceful curve familiar to us all from the well-known pictures of lighthouses. These curves used to be started from the bottom, but it was found that they had the effect of causing the waves to sweep upwards, running up the tower as it were, and sometimes obscuring the light for a moment. So the present practice is to make the bottom part cylindrical up to well above high-water mark. That has the effect of cutting the waves in two, the halves of which pass one on either side of the tower with but little tendency to run up it. The curved part starts from the top of this cylindrical part.

Lighthouse towers are usually made solid for some distance up. The Eddystone is solid for 25 feet, and the Bishop Rock in the Scilly Isles (probably the most exposed lighthouse in the world) for 47 feet above high water. The entrance to the tower has therefore to be high up, and the lighthouse keeper ascends to his "front door" by means of a ladder. This leads him into a room, the lowest one of a number according to the height of the tower. They are all the same size, the thickness of the walls diminishing as the height increases. Above the entrance room there will be an oil store, then perhaps another, above that a room for general storage, a living room, a bedroom, an engine room (for working the fog-horn), and topmost of all the service room just beneath the lantern.

In concluding this chapter it may be interesting to mention some cases not of construction under water but of destruction.

In making a canal or in deepening a river it is often necessary to remove rock. We know already how this can be blasted by divers, but there are other ways of doing it. One is by means of enormous chisels. Mighty bars of steel, with points made of armour-piercing steel such as is used for the points of large naval shells, can be let fall upon the rock, and it has to be hard rock indeed which can withstand such blows. The bars are anything from 6 to 15 tons, and they are let fall from a height of 6 to 10 feet.

A special boat is generally rigged up for the purpose with a hole or well in the centre through which the bars can be manipulated. The bars are fixed in a kind of frame so that their fall is guided and they are bound to fall in the required direction and upon the required spot. An engine lifts them up, and they fall of their own weight. On the average two cubic feet is dislodged at every blow and since a blow can be given about every half minute it is clear what a great amount of work they can do. The broken pieces have to be removed afterwards by a grab dredger.

Rock destruction on a large scale was performed some time ago in some rocky reefs at the entrance to New York Harbour. An area of 12 acres had to be cleared, and the method of doing it was this. A shaft was sunk into the rock, and from it small tunnels or galleries were constructed until the whole mass was honeycombed. Then large masses of explosive were put in place, the water was admitted to the tunnels, and finally by means of electricity the explosives were fired. The commotion which took place must have been literally an earthquake, for the whole mass of rock was shattered so that it could be removed by dredgers.

CHAPTER XXIII

SALVAGE

THE salvage of wrecked ships is an important business. Some nine million pounds worth of ships and cargo are wrecked annually round the coasts of Great Britain alone. Of that amount, of course, a great deal is irrecoverably lost, but a great deal can be saved.

Speaking generally, the ship is not worth saving, for she is probably so much damaged that it is cheaper to build a new boat than to raise and repair the one that is sunk. That is not always the case, however; everything depends upon the amount of the damage, and the ease with which she can be recovered. As we shall see presently, there are cases in which a ship has been broken in two, yet the two parts have been recovered and put together again. In at least one other case a ship was cut into two parts by a collision—a large part and a small one—and the large part was raised while the small part was made anew and fitted on to it.

In most cases, where the depth is not too deep for divers to work, it is worth while to recover parts of the hull—the brass fittings, for example, and anything else of valuable material, while nearly every general cargo contains something of value which is worth an effort to regain. Many ships carry large sums of money in the form sometimes of coin and sometimes of bars of gold and silver, and that is always saved if possible. The *Oceana*, wrecked a while ago off the south coast of England, had on board the vast sum of £150,000, which was successfully recovered.

Salvage is about the most varied kind of work imaginable, for ships of all kinds are wrecked in all kinds of places in all kinds of weather, and under all kinds of conditions. The salvage man, therefore, needs to be a man of the widest experience, and of great ingenuity, for he cannot read up in a text-book what is the correct thing to do in any particular case. He simply has to go to the wreck, find out all he can about it, and then invent his methods to suit the particular task which is in front of him. Nearly every salvage undertaking is different from any other.

And not only must the man in charge be thus original and inventive, but he must have at hand all manner of appliances, so that whatever he finds to be the best plan to work upon, he may be able to set about it at once. He may light upon a fortunate spell of fine weather, and he must be prepared to take advantage of it. There is often no time to send for special tools or appliances.

Therefore a salvage ship has a marvellous collection of all manner of appliances, and materials adapted for all kinds of work.

When a ship is wrecked and the insurance people have paid the owners for their loss, what is left becomes the property of the former. That is, of course, if it be a merchant ship. Warships are not insured, and so they remain the property of the Government. In the latter case the naval authorities themselves may undertake the task of salvage, but even they sometimes employ one of the salvage companies, while the insurance people always do. Thus there are, in almost every maritime country, people, generally limited companies, who undertake the work of salvage, and they have ships fitted out ready for the purpose.

These salvage steamers are usually small strong vessels with good engines, so that they can go anywhere and do anything. They have large and well-fitted workshops on board, and stores of lifting tackle and tools of all sorts, plenty of timbers, chains, cement, bolts, iron, ropes by the ton, powerful electric lamps, explosives, diving apparatus, pneumatic machines for drilling and other work under water, electrical apparatus of various kinds—indeed, it would be almost impossible to say what they do *not* carry against some sudden emergency.

But, perhaps, the most important part of all the salvage plant is the pumps. Powerful pumps of the centrifugal type, with portable steam engines or oil engines to drive them, are essential. The Liverpool Salvage Company, one of the most important salvage organisations in the world, have pumps capable of lifting in all 60,000 tons of water an hour, and the air-compressors are scarcely less important than the pumps for water.

So much for the appliances. The methods employed may be divided roughly into two kinds. If the wreck lies in shallow water, shallow enough for divers to work easily, then they are sent down to recover what is worth recovering, or to patch up the vessel so that she may be raised. That is one kind. The second class contains those cases in which the wreck lies so deep down that divers are of little use. In such instances, it may be possible to fish the wreck up with ropes. We will talk about the shallow ones first.

To commence with a small ship, there was the *Fleswick*, a coal steamer which sank in collision in Cork Harbour, Ireland. She weighed in all about 600 tons when in the water, and she lay on sloping ground, with her bow 26 feet under the surface, and her stern 40 feet below. She was on her side, and lay pointing towards the land. Divers were sent down, and reported as to her condition, after which it was decided to pump air into the ship so that she would nearly float, and then to draw her gradually into shallower water. So the divers went down, and closed up all the openings in certain parts of the ship which it was thought would hold air. Air pipes were passed down into these, and the air-compressors on the salvage steamer pumped air into them so as to expel the water and give the ship a tendency to rise. Meanwhile, wire ropes were passed under the stern of the vessel, and carried up to a hulk or big barge on which were winches, by which the ropes could be hauled up. Other ropes too were fastened to the ship and carried to winches ashore.

So after a while, what with the air inside the ship and the hulk pulling upwards at the stern, the wreck was lifted sufficiently for the shore ropes to draw her slowly towards the land and into the shallower water.

Then ropes attached to her stern and to the shore enabled her to be pulled round until she lay parallel with the shore, and finally in a similar manner she was pulled over into an upright position, preparatory to being patched up and finally taken away for complete repair.

When a ship lies upright in shallow water a "cofferdam" is sometimes used. We are already familiar with one use of this word, and here it means very much the same thing. A waterproof wall of timber is erected on the deck of the ship. It may be an upward extension of the bulwarks all round the ship or simply a rectangular structure erected over one of the hatchways. The lower parts of these walls are fixed by divers to any convenient places on the ship where there may be something to fasten them to, while the upper edges of the walls are above the water. When all is ready the pumps on the salvage vessel begin to clear the water out of the cofferdam and out of the ship too, and as they do so the ship gains buoyancy until she floats. Of course the hole which caused her to sink must be stopped up, or the water would get in that way, but that, as we shall see presently, is a very common performance in salvage operations.

The cofferdam, then, enables the water in the hull to be pumped out so that she once more floats of her own accord, after which, if conditions are favourable, she may be towed to a shipyard and properly repaired.

Where there is ample rise and fall in the tide, that is often made to assist in the operations. Several hulks are floated over the wreck, and ropes depending from them are fixed by divers to the unfortunate vessel below. At low tide the ropes are pulled tight, and then as the water rises they rise with it and lift the wreck off the ground. The whole flotilla are then towed to a shallower place, and the operation repeated until at last the wreck is in such shallow water that she can be patched up by divers or at low tide.

In the case of a small vessel it is sometimes enough for divers to take down and place in the hold a number of empty barrels or even india-rubber bags of air. The buoyancy thus given to her enables her to rise or to be drawn into shallower water. The same thing on a larger scale is the use of cylinders, or camels, as they are called sometimes. These are something like the large cylindrical boilers which we sometimes see being drawn through the streets. They are filled with water and so sunk down to the vessel, to which they are attached by some suitable means, after which air is pumped into them to expel the water and to give them buoyancy.

In all cases where it is at all possible the use of ropes under or round the vessel is avoided, for it is so liable to damage her, and in many cases, even, it is calculated to break her up. The shock of the collision, or whatever it was that sank her, has probably weakened her, and if lifted by ropes she is very liable to break in two.

When a vessel is lost through stranding on a rocky reef, the rock on which she ran is very often a great trouble, for the ship is spitted as it were upon a projecting rock, and before she can be got off again that must be removed. Probably it has to be blasted away a little at a time, very carefully, so as not to damage the ship, and then she has to be patched up afterwards.

These patches play a very important part in salvage work. How they are made depends entirely upon the circumstances of each particular case. One way is to make a strong timber patch as near the ship's side as possible. This is taken down by divers, and put into its place. A bolster made of canvas stuffed with oakum is put all around its edge between it and the ship, to make the joint between them water-tight, and it is fastened on by bolts. This bolting is a puzzling matter at times, but it is generally simplified by using hook bolts—bolts, that is, which, instead of a head, have a hook on the end. The ends of the bolts then hook on to the sides of the rent in the ship's plates. Of course the bolts only have to hold the patch in place, for the action of the water when the ship is pumped out is inwards and tends to hold the patch on.

In other cases an iron patch is made from particulars and measurements procured by the divers. Often holes have to be drilled, too, in the ship to fix the patch, for sometimes the hook bolts have nothing to catch on. Compressed air drills are a great help in a case like this. They are like little steam engines, but worked by air, very small so that they can be carried and controlled by a single man, but strong enough nevertheless to be able to drill a hole in iron very much more quickly than a man could do it by hand.

It is in making patches, too, that cement comes in very useful. There is a particular kind of cement made in the Isle of Wight, which sets very quickly even under water, and which has a peculiar power for holding on to iron. Many a leak has been stopped up under water by its means.

Sometimes the leaks cannot be got at, especially when the ship is aground. Straw, oakum, all sorts of things may then be poked into the leaks from a distance. But even that is sometimes impossible, and then the pumps are set to work to draw the water from inside the ship and so cause a current of water outside towards the leak, as the water flows in to take the place of that pumped out. Then suitable floating loose material thrown into the water is sometimes drawn into the leak, and so it becomes stopped.

In some instances every opening in the ship is closed except the hole in the bottom which has caused her to sink, and by means of compressed air the water is driven from the upper part of her until she floats in spite of the great gash which sank her.

Vessels full of cargo which go ashore on sandbanks often find themselves, when the tide falls, supported at the middle on the bank with the ends unsupported, and since no ship is built to stand such a strain they then break in the middle. In many cases a bulkhead or wall of timber can be built in the end of each, which will enable them to be floated and put together again.

Perhaps the most famous instance of salvage in recent years is that of H.M.S. *Gladiator*, which was sunk after collision with an American liner in the Solent, just off the entrance to Southampton Water.

She lay in the water upon her wounded side, so to speak, with her deck almost vertical and her undamaged side above the surface. It was feared that she might slide down into deeper water, and so the first thing done was to fasten her by means of great anchors to prevent any tendency to slip.

It was a most difficult problem because the tides ran very strongly just where she lay, and yet they did not rise and fall sufficiently to give any assistance in the lifting operations. Moreover, she was so near the shore that tugs and salvage ships had little room to manœuvre between her and the land. If she had been a merchant ship she would probably have been blown up and removed piecemeal, but although it cost a large sum of money the naval authorities preferred that she should be recovered whole.

First of all, the guns and other heavy things which could be detached were taken off her. Then funnels, ventilators, and other projecting objects which might have been in the way during the later stages of the work, were got rid of. And the methods of doing this were somewhat drastic. For example, the funnel was simply lassoed with a powerful steel rope and just pulled off by main force. Other parts which could be removed no other way were cut by exploding small charges of a blasting material called "gelignite" close to them—a method of cutting away projecting pieces, it may be remarked, not at all uncommon in salvage operations.

Meanwhile holes were cut in the upper side of the ship large enough for the divers to get through into the inside of the vessel. They thus were able to close water-tight doors, plug up openings in the ship's interior, fix wooden covers over the hatchways and other openings in the deck, and do other things with a view to making the hull water-tight against the time when they should attempt to pump the water out of her.

Powerful steam capstans were at the same time fixed up on shore. No temporary trivial jobs were these either, for they were fixed upon concrete foundations, for which holes had to be excavated 14 feet or so deep. Boilers had to be fixed, too, to supply them with steam and pipes to bring fresh water.

While all this was going on, the men at Portsmouth Dockyard were making seven steel cylinders, the largest of them 75 feet long and 12 feet in diameter. Together the seven were reckoned to be able to lift 900 tons. Each of them had valves to admit water to sink them and air to raise them. Some were divided into compartments inside, so that they could be made to sink evenly, for otherwise they might have been inclined to go down endways. Though made of steel, they were covered on the outside with timber so that they should not be dented in by collision against anything.

There were three salvage ships in attendance, besides quite a flotilla of hulks and tugs.

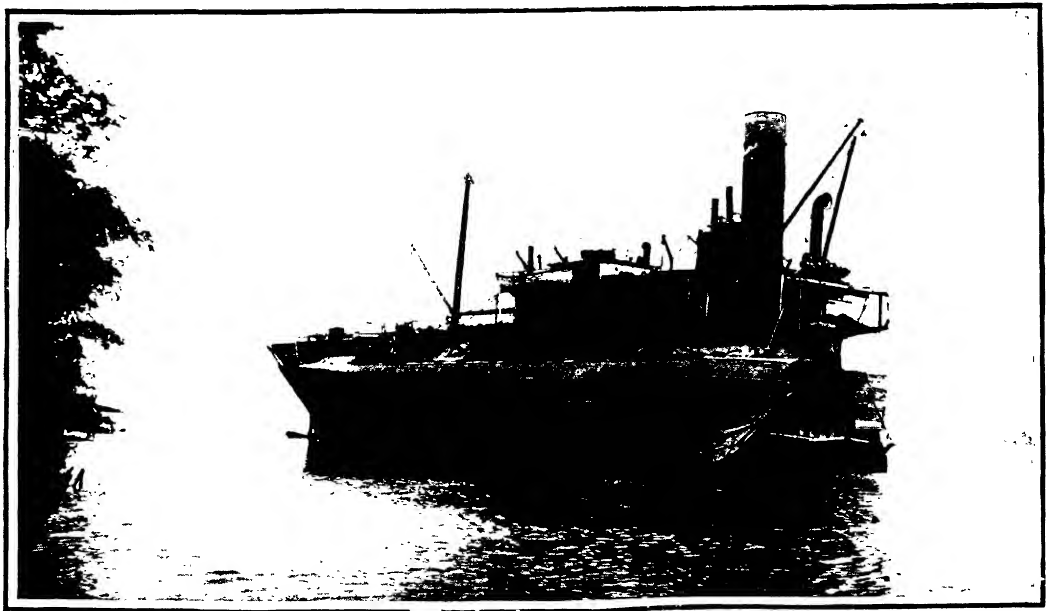
By slow and laborious methods steel wire ropes were got under the wreck, and arrangements were specially fitted to the ship's side to hold them. By these means the cylinders were attached to the ship, five on one side and two on the other. The idea was to pull her upright, and it was feared that after that she might turn right over on to her other side and the two cylinders were placed there to prevent this.

Efforts to pull the ship into the shallower water nearer the shore, for which purpose the powerful steam capstans ashore had been provided, did not meet with much success, and so it was decided to upright her where she was.

So the five cylinders were sunk and attached to the under side by ropes, while the other two full of air were attached to the upper side, and strong ropes were fastened to the ship's masts wherewith to help to pull her upright. Cofferdams were also fixed in places upon the deck, to enable the pumping to be the better carried on.

Hundreds of tons of iron weights were also placed on the ship, so that they should tend to pull her into an upright position and yet should fall off as soon as she reached it, and not pull her over on to her other side.

Then, when all these elaborate arrangements were



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HALF A SHIP

This ship has been cut in two and sunk in collision. The two halves were patched up by divers and raised. Here we see the after part floating serenely by itself.

completed, the water was pumped out of the watertight parts of the ship and out of the submerged cylinders, until at the right moment two steamers, each holding one of the ropes attached to the masts, started to pull away, and the great ship slowly assumed her proper upright position.

She was still too low in the water, however, resting on the bottom in fact, and so more cofferdams were constructed so that more water could be pumped out of her until at last she was afloat, and with a salvage vessel on either side, like an invalid supported by the arms of two friends, she slowly made for Portsmouth Harbour, which she reached in safety, there to go into dry dock for examination.

This marvellous feat of salvage was due largely to the efforts of Captain Young, the chief surveyor to the Liverpool Salvage Association, who superintended it all.

And now we can turn to an example of deep-water salvage, in which the wreck had to be fished for with ropes and gradually drawn into shallow water.

The British torpedo boat No. 99 sank off the coast of South Devon in 25 fathoms of water, and as she lay just where the fishing boats from Brixham near by performed trawling operations, the Admiralty decided to have her moved. For, of course, it is unpleasant for a fisherman to catch a torpedo boat in his nets—it is apt to be rather bad for the nets.

Now 25 fathoms is well on towards the limit below which divers cannot go, and it is beyond the limit for doing much work. For divers to have gone down and patched up the ship would scarcely have been possible, but they were able to descend and inspect the wreck sufficiently to tell just a few facts as to how she lay which showed those above the best way to go about their work.

When the torpedo boat went down, a larger ship which was at hand, after rescuing the crew, put a buoy to show the spot. So the salvors knew where to look for her. Then they sounded around the place with an ordinary lead and line, such as sailors use for telling the depth of water in which their ship floats. As I have remarked in another place, it is wonderful how a man with the line in his hands can "feel" the bottom many feet below him, and so they felt all about this wreck with the lead and line, and were able to find out quite a lot of information as to just how she lay, and so on. Then a brief visit below by a diver confirmed the idea which had been formed, that one end projected upwards so that a rope could be got under.

Then a powerful steel rope was taken by two steam tugs, one of which held each end, and, letting it down into the water, like a child's skipping rope on an enormous scale, they drew it slowly along the bottom until it caught under the projecting end of the vessel.

This operation was repeated until four steel ropes were under the ship, and these being pulled taut by the vessels above at low tide, the wreck was lifted as in a great swing, and slowly carried into shallower water. Frequent repetition of this brought her eventually on to a convenient part of the neighbouring beach, and there it was found that they had only got half of her; the other half had evidently dropped off while they were carrying the ship along.

So the part which had been recovered was hauled up on the beach above low water, and there patched up until she was seaworthy enough to be towed round to the more sheltered waters of Torbay, there to be made ready for a voyage to Plymouth.

Meanwhile a kind of fishing excursion set off to find the other part, and this again was done by the simple method of two ships dragging a rope along the bottom. By good fortune a rope was got round it, and one of the vessels in attendance, being fitted with what is called horn-tackle, was able to lift this part right out of the water. This horn-tackle will be familiar to all my readers who live near a large port, for the port authorities nearly all possess wreck-lifting lighters, in which this is a prominent feature. Two short beams project over the vessel's bows, carrying a strong pulley wheel, over which ropes can be passed, and from which they are free to fall clear of the ship into the water below. Such boats are sometimes called mooring lighters, for they are used to lift up and lower down the heavy anchors which form the permanent moorings for ships in harbours.

So, carrying the portion of wreck drawn up close under the horn, for all the world like a dog carrying a stick in his mouth, this vessel took it to Devonport, and the task of raising No. 99 was complete.

Some romantic stories can be told of attempts, some of them successful and others not, to recover treasure from ships, some of which had been submerged for many years. For example, in Tobermory Bay in Scotland, there lie the remains of one of the ships of the Spanish Armada. It was not really a Spanish ship, but was the flagship of a Florentine squadron which went to assist the Spaniards. Its name was the *Florencia*, and it is believed that it was blown up by a certain Scottish chieftain, Donald McLean by name, who was a captive on board. Treasure amounting to millions is said to have been lost, and several attempts have been made to recover it. Some little success has attended the efforts of the divers who have been down, and the work is still going on at intervals, one of the latest ideas being the use of a suction dredger to clear away the sand under which the treasure is thought to lie and to bring up the coveted coins which, their casks having rotted away, are believed to be lying loose in the sand. The possible reward is so great that men are likely to keep on making the attempt, but the results have so far been so small that it seems likely that the work will go on for many years to come.

But it is not always so. Alexander Lambert, the hero of the Severn Tunnel exploit, descended to the wreck of the *Alphonso XII.*, in 160 feet of water, off the Canaries. He blasted away parts of two decks, and eventually penetrated into the bullion room, from which he succeeded in taking seven chests of treasure worth £70,000, while another diver recovered £20,000 more.

A Spanish diver, Angel Erostarbe, got up £10,000 worth of silver bars from the wreck of the *Skyro* in over 170 feet of water off the boisterous coast of Spain. In spite of the great depth, the exposed position, and the powerful currents, he went down, blasted his way to where the silver lay, and ultimately brought it up to the surface. The achievement is one of the most remarkable on record, both for bravery and for skill.

The *Hamilla Mitchell* went down, near Shanghai, with £50,000 in coin aboard. She was in such deep water that she was given up as hopelessly lost, but by the enterprise of Captain Lodge, an experienced salvage man, it was recovered. Taking with him an up-to-date outfit of diving apparatus and two skilful Liverpool divers, he went out, sought the wreck, found it, and the divers got up £40,000. Then the operations were interrupted in a rather alarming way, for, on the horizon were seen a large number of white sails, which a little thought showed to be a fleet of pirates, bearing down upon the salvage vessel. It had been impossible to take a large ship amongst the rocky reefs where the wreck was, and so the party were in a comparatively small boat—a sailing boat, too, which could not sail for the wind was light. So anchor had to be slipped, and the party had to row for their lives, even the tired divers, after their sojourn below, having to take their places at the oars. Fortunately they escaped the pirates, and were able to return and finish their task later.

Even larger sums than those I have mentioned have been taken from wrecks, but they are not of much interest, for the depth of water has been such as to make them quite simple. We have seen enough of under-water work to realise that, given fine weather (which can generally be got by waiting for it), freedom from strong currents, and not too much depth, there are few things that expert divers cannot do.

It may be sufficiently interesting, however, to mention in conclusion a few cases in which vast sums of money and valuable cargo have been thus recovered. From the *Malabar*, £300,000 in bullion (bars or ingots of the precious metals) was salved; from the *Darling Downs* £100,000 worth of wool; from the *Queen Elizabeth* cargo and specie (that is coins) valued at £120,000, and from the *Oceana* £150,000 in specie.

CHAPTER XXIV

THE DIVER AT WORK

SO far we have examined the diver's dress and have viewed him at work, but only as if from a distance. It still remains to come close to him, as it were, into his boat, and watch him go down to his work.

He generally dives from a small rowing boat because of the ease with which such a craft can be put into exactly the right position for him to drop straight down to his work. A ladder is generally hung over the side to enable him to get in and out easily, but it is only a short one, and so he soon reaches the bottom of it, after which he slides down a rope. This is called the "shot rope," and it descends straight from the boat down to a heavy weight at the bottom of the water. Arrived at the bottom, he finds spliced on to the shot rope another called the "distance line," which he keeps in his hand as he walks about, and which enables him to find his way back to the shot rope whenever he wants to. He is so nearly the same weight as the water which he displaces that when in water he has scarcely any weight at all, and so it is very easy to climb up and down the shot rope. Moreover, his attendants above have hold of him in two ways. They hold the air-pipe by which he gets his air, and the life-line, which is attached to his dress, with either of which they can pull him up if he wants them to.

If his helmet is not fitted with a telephone there is a code of signals agreed upon between the diver and his attendants, by which he can tell them certain things and they him. The following is a very usual code:—

From Diver to Attendant.

On life-line.
One pull = I am all right.
Two pulls = Send me a slate (on which to write a message).
Three pulls = Send me a rope.
Four pulls = I am coming up.
On air-pipe.
One pull = Less air.
Two pulls = More air.
Four pulls = Haul me up.

From Attendant to Diver.

On air-pipe.
One pull = Remain where you are.
Two pulls = Go straight ahead.
Three pulls = Go to the right.
Four pulls = Go to the left.
On life-line.
One pull = Are you all right?
Two pulls = Am sending a slate.
Three pulls = You have come up too far. Go down slowly.
Four pulls = Come up.

And besides the above, of course, special signals may be agreed upon appropriate to each particular case.

To send down a slate the attendant ties it *in* the life-line, and then pays the latter out. The diver gathers it in until the slate reaches him, after which the attendant pulls it up again, with the diver's message on it.

In addition to all the various works which have already been mentioned, there are certain special things for which divers are employed. On warships, for example, which are abroad on a long commission, and which have not the usual facilities for cleaning, divers can go down and scrape the under-water parts. A common accident, too, is to get something entangled in a ship's propeller, and again divers are the only means by which the screw can be cleared while the vessel is still afloat.

For working underneath a ship, platforms are slung by means of ropes from the ship's sides, and on these the divers stand.

Diving dresses may be used also for working in fumes or smoke. The rescue apparatus now employed after colliery explosions are really simplified forms of diving dresses. They generally take the form of helmets only, for the dress part is not necessary except in water, and the helmet, even, may be reduced down until it is merely a mask covering the eyes, mouth, and nose, and connected to an air-renewing arrangement like that belonging to the self-contained diving dress.

But perhaps one of the strangest works that a diver has ever been set to do was to save a cathedral from destruction. It occurred at Winchester (England) some years ago.

The ancient cathedral there is built upon foundations about 10 feet deep. It is evident that the old monkish builders were stopped at that level by their excavations becoming filled with water, so they placed in the bottom of the trenches layers of beech trees, which they then covered over with chalk, and so formed the foundations upon which they reared the beautiful structure which stands to this day. All this was done seven or eight centuries ago.

And after standing for so long, in quite recent years in fact, it became evident that something was "giving" in the foundations, and that the ancient pile was becoming unsafe.

So a hole was sunk a distance away to see what the earth was like on which it stood, and it was then found that the beech logs rested upon 6 feet of marly clay, which in turn was upon a peat bog 8 feet 6 inches thick, supported upon a bed of flinty gravel.

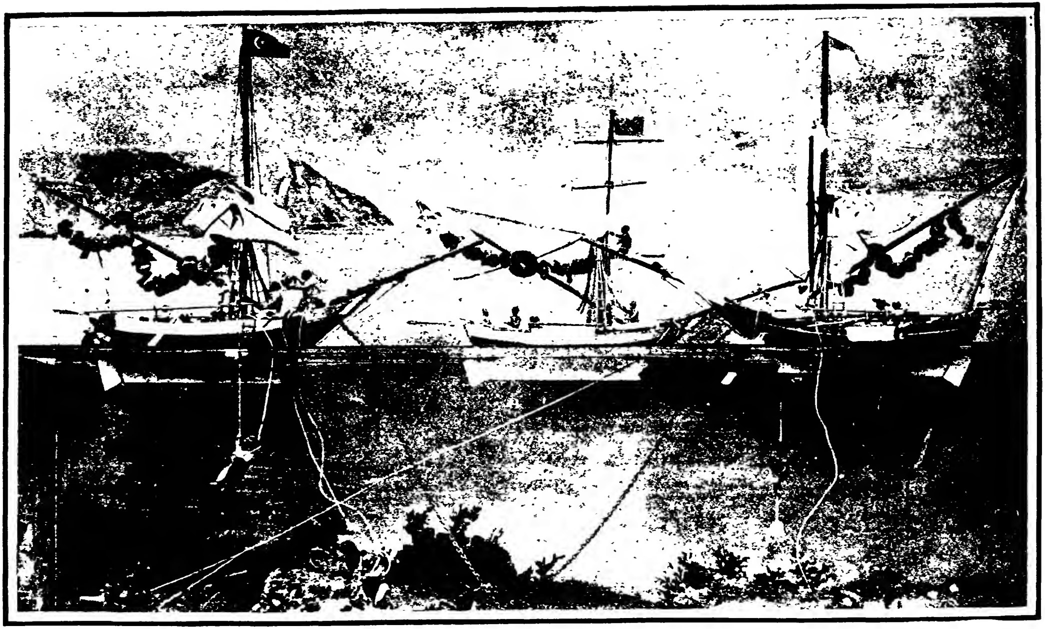
Now the gravel, deposited long ago by the agency of water and therefore solid and compact, was well able to carry the great weight of the cathedral, which the clay and peat were not able to do. Indeed, it seems strange that these should have upheld their burden for so long. The problem therefore which faced those in charge of the work was to remove the clay and peat and in their place to put concrete from the beech trees down to the gravel. But the difficulty was the water, which, it will be remembered, is met with at the level of the beech logs. To pump it away would probably be to suck loose material from under the cathedral sufficiently to bring it down, so the only other alternative was to leave it there, and work in it by means of divers.

So the old chalk foundations are first made strong by forcing grout, very liquid cement, into them with compressed air, as it is forced behind the linings of underwater tunnels. Then when this is well set, a short piece of excavation is made under the beech logs. The diver removes for a length of about 6 feet all the clay and peat until he gets right down to the gravel. Then concrete in bags is handed down to him, and, laying these side by side and in several layers, he encloses the space which he has excavated with a complete coating of cement concrete. He constructs, in fact, a waterproof chamber reaching from the old foundations down to the gravel, and when all is set the water can be safely pumped from the interior of this chamber and it can be filled with concrete or masonry in the ordinary way. That being finished, another waterproof chamber is made in like manner, adjoining the first, until by slow degrees the foundations of the whole cathedral are carried down through the treacherous layers of clay and peat on to the solid bed of gravel below, and that in all probability will carry them safely until they crumble away possibly thousands of years hence.

On the northern coasts of Australia, and in a lesser degree in other parts of the world, many divers are at work getting pearls from the sea. In the Australian fishery alone 800 to 900 boats are employed, besides the larger craft which attend upon them much as the fish carrier steamers attend upon the deep-sea fishing fleets in the North Sea.

The boats are luggers of about ten to twelve tons, and each carries a Japanese or Manila diver, and a small crew besides. The apparatus, which is of the best, is supplied from England.

There are two kinds of oysters for which they seek. One, the pearl oyster, is valuable for the little pearls which



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SPONGE DIVERS AT WORK

This picture gives an idea of the work of the sponge divers, some of whom use diving dresses, while others work naked, as shown.

are found inside. If any little piece of grit gets into the shell, or if a worm bores its way through the shell, as some can do, the oyster is thereby irritated, and to ease itself it covers the particle of grit or the end of the hole with a matter which it is able to produce, and which hardens into a pearl. When such an oyster is opened the pearl is found attached to the shell.

More valuable pearls still are sometimes found in the body of the oyster itself, where they are formed in the same way, the little creature covering with the smooth hard substance something which caused it trouble.

The other kind is called the mother-of-pearl oyster. It too contains similar pearls sometimes, but they are not what is looked for: they are found every now and then as a sort of happy accident. In this case the shells themselves, which are much larger, are valuable, for they are the material from which those beautiful "mother-of-pearl" ornaments are cut.

In Ceylon and the Persian Gulf the divers for pearls work naked, practice enabling them to remain under water for as long as two minutes.

It may surprise many to learn that a little fishing for pearl oyster goes on off the coast of Scotland.

Sponges, too, are got in several parts of the world, both by helmet divers and naked divers, as well as by dredging and harpooning, the latter being performed with a kind of fork upon the end of a long handle.

And with the oyster and sponge divers we come to the end of our subject. Of all forms of work which man is capable of, perhaps none is more romantic or more interesting than that connected with the sea and the great expanses of water; and that part of it which is mainly or entirely beneath the surface is certainly not the least enthralling. I trust that I have been able to make it real to my readers, have quickened their interest in it, and have widened their knowledge and their sympathies by telling them of these wonderful works upon which so many of their fellow-creatures are engaged.

APPENDIX

HOW A SUBMARINE CABLE IS MADE

THE first part of the cable is the core of fine copper wires. The copper is of the finest possible quality, for if it were not it would offer unnecessary resistance to the current. It is obtained by means of electricity. It is interesting that this fine copper so much needed for electrical purposes should be produced by an electrical process.

Ordinary refined copper has about one per cent. of impurity in it, which is not good enough, so a slab of such copper is hung in a bath of certain chemicals with a thin plate of copper near it. Then a current of electricity is led to the slab, from whence it flows through the liquid to the sheet and away again. In passing it carries with it tiny particles of pure (absolutely pure) copper, which it deposits upon the plate. When the latter has thus received a good coating, it is taken out of the bath and the pure copper is torn off it. By this process, which is known as "electrolysis," even the one per cent. of impurities is got rid off, being left in the bath.

The pure copper is then rolled between rollers into the form of thin rods, which are then drawn through holes in steel dies to convert them into wire. One end of the rod is poked through the hole, and is then gripped by a machine which pulls it steadily through until one comparatively short rod becomes a comparatively long length of wire.

Then a number of wires have to be twisted together into the tiny wire rope which forms the core of the cable. This is done in a machine which, though wonderful in its effect, is marvellously simple in its principle.

There are say seven separate wires or strands in the core, so seven reels of wire are mounted in the machine. Six of them are fixed round the outside of a revolving frame, while one is at the middle. One end of each of the seven wires is taken through a guide, and thence led to a drum on which the twisted strand is wound, and as the strand is thus drawn away from the machine the frame with the reels upon it goes round and round. The wire from the middle reel goes straight to the guide, while the other six wires are wound round it by the turning of the frame. Nothing could be simpler or more perfect in its action.

The large reel or core is then taken to the gutta-percha covering machine. In this the core is drawn through a die, a kind of taper tube, into which, as it passes, the gutta-percha is forced by a screw. So as the wire passes through the die the covering of gutta-percha is pressed all round it, and it emerges on the other side completely enclosed in a perfect coating of gutta-percha. A bath of cold water, into which it passes as it leaves the die, makes the covering hard and strong, and it then winds on to another reel ready for the next operation.

This consists of wrapping it with yarn so that the protecting wires of iron when put on shall not damage the gutta-percha. There are two layers of this yarn, wrapped on round and round, but in opposite directions. They are put on just as the six wires are wound round the one, the yarn being placed on reels in a revolving frame which turns as the core is drawn along through the centre of it. Two separate machines are needed for this, one for each layer, and the simple fact of their turning in opposite directions produces the desired result of one layer being wrapped the opposite way to the other.

Thence the half-finished cable goes straight to another machine, which twists round it the thick steel wires which form the sheathing. These are galvanised, that is to say, coated with zinc to keep them from rust; but since galvanising is not a perfect preservative against sea water, the cable then has a coating of a tarry mixture for further protection. Even then it is not finished, for it still goes on from machine to machine receiving a layer of tape wound on as before, then more compound, then more tape wound the opposite way to the first lot, finally passing into a shower-bath of cold water to cool it and harden it, finishing up with a coat of whitewash to prevent it from sticking when coiled in the storage tank.

From the time that the coating of the core with gutta-percha is finished, the process is a continuous one, the cable passing straight from one machine to the next, and finally into the tank.

The shore ends, which are more liable to damage than the deep-water part, often have a few more layers than those I have described, but they are put on in the same way. These shore ends generally have two lots of protecting steel wires (or rather they are iron in that case), one outside the other. Steel wires are used for the deep-sea part because they are so strong, while good iron wire, being more flexible, is preferred for the ends.

The manufacture of submarine cables is carried on almost exclusively on the banks of the Thames a little below London. The works there are of great capacity, a single factory being capable of making an Atlantic cable in less than three months.

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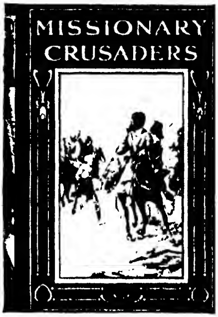

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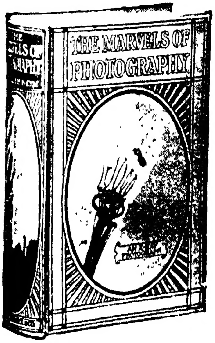

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