THE MARVELS OF SCIENTIFIC INVENTION


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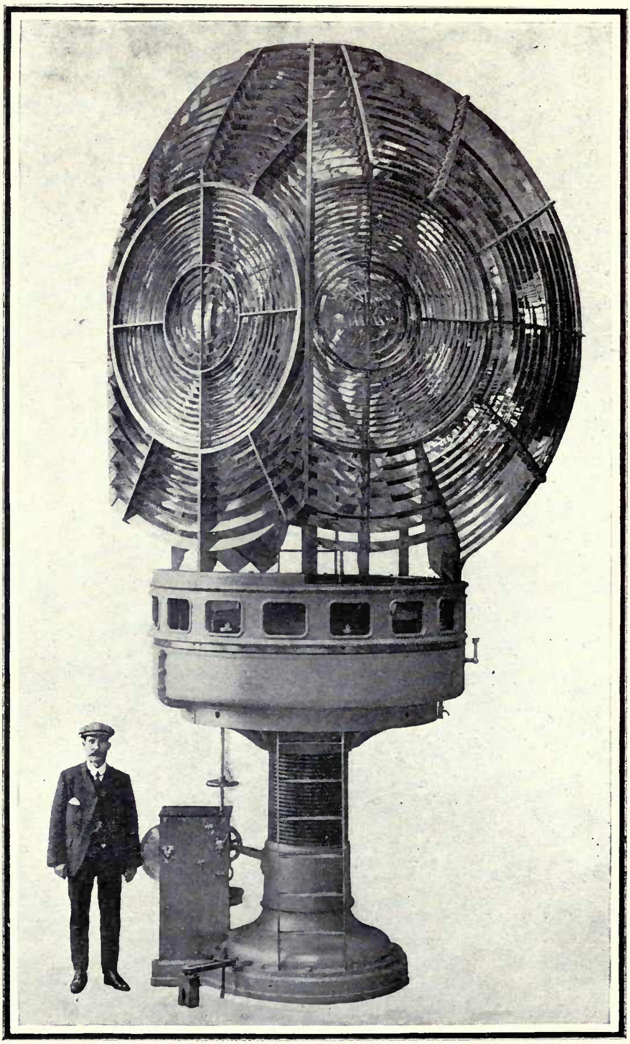

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A HUGE LAMP

The marvellous arrangement of lenses and prisms which enables the lighthouse to send out its guiding flashes, with the mechanism for turning it. Made for "Chilang" Lighthouse, China

Frontispiece

MARVELS OF SCIENTIFIC INVENTION

AN INTERESTING ACCOUNT IN NON-TECHNICAL LANGUAGE
OF THE INVENTION OF GUNS, TORPEDOES, SUBMARINES
MINES, UP-TO-DATE SMELTING, FREEZING, COLOUR
PHOTOGRAPHY, AND MANY OTHER RECENT
DISCOVERIES OF SCIENCE

BY

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"ENGINEERING OF TO-DAY," "MECHANICAL INVENTIONS
OF TO-DAY," "THE ROMANCE OF SUBMARINE
ENGINEERING," *&c., &c.*

WITH 32 ILLUSTRATIONS & DIAGRAMS

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MARVELS OF SCIENTIFIC INVENTION

CHAPTER I

DIGGING WITH DYNAMITE

MOST people are afraid of the word explosion and shudder with apprehension at the mention of dynamite. The latter, particularly, conjures up visions of anarchists, bombs, and all manner of wickedness. Yet the time seems to be coming when every farmer will regard explosives, of the general type known to the public as dynamite, as among his most trusty implements. It is so already in some places. In the United States explosives have been used for years, owing to the exertions of the Du Pont Powder Company, while Messrs Curtiss' and Harvey, and Messrs Nobels, the great explosive manufacturers, are busy introducing them in Great Britain.

It will perhaps be interesting first of all to see what this terror-striking compound is. One essential feature is the harmless gas which constitutes the bulk of our atmosphere, nitrogen. Ordinarily one of the most lazy, inactive, inert of substances, this gas will, under certain circumstances, enter into combination with others, and when it does so it becomes in some cases the very reverse of its usual peaceful, lethargic self. It is as if it entered reluctantly into these compounds and so introduced an element of instability into them. It is like a dissatisfied partner in a business, ready to break up the whole combination on very slight provocation.

And it must be remembered that an explosive is simply some chemical compound which can change *suddenly* into something else of much larger volume. Water, when boiled, increases to about 1600 times its own volume of steam, and if it were possible to bring about the change suddenly water would be a fairly powerful explosive. Coal burnt in a fire changes, with oxygen from the atmosphere, into carbonic acid gas, and the volume of that latter which is so produced is much more than that of the combined volumes of the oxygen and coal. When the burning takes place in a grate or furnace we see nothing at all like an explosion, for the simple reason that the change takes place gradually. That is necessarily so since the coal and oxygen are only in contact at the surface of the former. If, however, we grind the coal to a very fine powder and mix it well with air, then each fine particle is in contact with oxygen and can burn instantly. Hence coal-dust in air is an explosive. It used to be thought that colliery accidents were due entirely to the explosion of methane, a gas which is given off by the coal, but it has of recent years dawned upon people that it is the coal-dust in the mine which really does the damage. The explosion of methane stirs up the dust, which then explodes. The former is comparatively harmless, but it acts as the trigger or detonator which lets loose the force pent up in the innocent-looking coal-dust. Hence the greatest efforts in modern collieries are bent towards ridding the workings of dust or else damping it or in some other way preventing it from being stirred up into the dangerous state.

So the essential feature of any explosive is oxygen and something which will burn with it. If it be a solid or liquid the oxygen must be a part of the combination or mixture, for it cannot get air from the surrounding atmosphere quickly enough to explode; and, moreover, it is generally necessary that explosives should work in a confined space away from all contact with air. So oxygen, of necessity, must be an integral part of the stuff itself. But when oxygen combines with anything it usually clings rather tenaciously to its place in the compound and is not easily disturbed quickly, and that is where the nitrogen seems to find its part. It supplies the disturbing element in what would otherwise be a harmonious combination, so that the oxygen and the burnable substances readily split up and form a new combination, with the nitrogen left out.

Of all the harmless things in the world one would think that that sweet, sticky fluid, glycerine, which most of us have used at one time or another to lubricate a sore throat, was the most harmless. As it stands in its bottle upon the domestic medicine shelf, who would suspect that it is the basis of such a thing as dynamite?

Such is the case, however, for glycerine on being brought into contact with a mixture of sulphuric and nitric acids gives birth to nitro-glycerine, an explosive of such sensitivity, of such a furious, violent nature, that it is never allowed to remain long in its primitive condition, but is as quickly as possible changed into something less excitable.

Glycerine is one of those organic compounds which is obtained from once-living matter. Arising as a by-product in the manufacture of soap, it consists, as do so many of the organic substances, of carbon and hydrogen, the atoms of which are peculiarly arranged to form the glycerine molecule. To this the nitric acid adds oxygen and nitrogen, the sulphuric acid simply standing by, as it were, and removing the surplus water which arises during the process. So while glycerine is carbon and hydrogen, nitro-glycerine is carbon, hydrogen, nitrogen and oxygen. In this state they form a compact liquid, which occupies little space.

The least thing upsets them, however. The carbon combines with oxygen into carbon dioxide, commonly called carbonic acid gas, the hydrogen and some more oxygen form steam, while the nitrogen is left out in the cold, so to speak. And the total volume of the gases so produced is about 6000 times that of the original liquid. It is easy to see that a substance which is liable suddenly to increase its volume by 6000 times is an explosive of no mean order.

But the fact that it is liable to make this change on a comparatively slight increase in temperature or after a concussion makes it too dangerous for practical use. It needs to be tamed down somewhat. This was first done by the famous Nobel, who mixed it with a fine earth known as kieselguhr, whereby its sensitiveness was much decreased. This mixture is dynamite.

It will be seen that the function of the " earth " is simply to act as an absorbent of the liquid nitro-glycerine, and several other things can be used for the same purpose. Moreover, there are now many explosives of the dynamite nature but differing from it in having an active instead of a passive absorbent, so that the decrease in sensitivity is accompanied by an increase in strength. For example, gelignite, which is being used for agricultural purposes in Great Britain, consists of nitro-glycerine mixed with nitro-cotton, wood-meal and saltpetre. The wood-meal acts as the absorbent instead of the kieselguhr, while the nitro-cotton is another kind of explosive and the saltpetre, one of the ingredients in the old gunpowder, provides the necessary oxygen for burning up the wood-meal. Nitro-cotton is made in much the same way as nitro-glycerine, except that cotton takes the place of the glycerine. Cotton is almost pure cellulose, another organic substance, like glycerine insomuch as it is composed of carbon and hydrogen, but, unlike it, containing also oxygen. Treated with nitric acid it also forms a combination of carbon, hydrogen, oxygen and nitrogen, which is called nitro-cotton, nitro-cellulose, or gun-cotton.

It may be asked, why, if these two substances are thus similar, need they be mixed ? The answer is that although alike to a certain degree they are not exactly the same, and the modern manufacturer of explosives in his strife after perfection finds that for certain purposes one is the best, and for others another, while for others again a combination may excel any single one.

For some work another kind of explosive altogether is to be preferred. This is based upon chlorate of potash, a compound very rich in oxygen, which it is prepared to give up readily to burn any other suitable element which may be at hand. A well-known explosive of this class is that known as cheddite, since it was first made at a factory at Chedde, in Savoy.

For the sake of simplicity, however, I propose in the following descriptions to refer to all these explosives under the common term "dynamite," since that will probably convey to the general public an idea of their nature better than any other term or terms which I could choose.

So now we come to the great question, how can the modern farmer benefit by the use of high explosives such as these? The answer is, in many ways. Let us take the most obvious one first.

A farmer has been ploughing his land and growing his crops upon it for years. Perchance his forefathers have been doing the same for generations. Every year, for centuries possibly, a hard steel ploughshare has gone over that ground, turning over and over the top soil to a depth of six to eight inches. Each season the plants, whatever they may be, grow mainly in that top layer. They take the goodness or nourishment out of it and it eventually becomes more or less sterile. By properly rotating his crops he mitigates this to a certain extent, in addition to which he restores to the land some of its old nitrogenous constituents by the addition of manure. Yet, do what he will, this thin top layer is bound to become exhausted. And all the while a few inches lower down there is almost virgin soil which has scarcely been disturbed since the creation of the world.

Nay, more, that virgin soil, with all its plant food still in it, is not only doing little for its owner, it is positively doing him harm. For every time his plough goes over it it tends to ram it down flat; every time a man walks over it the result is the same; every horse that passes, everything that happens or has happened for centuries in that field, tends to make that soil just below the reach of the ploughshare a hard, impervious mass, through which only the roots of the most strongly growing plants can find a way, and which tends to make the soil above it wet in wet weather and dry in dry weather. Thus roots have to spread sideways instead of downwards; or, growing downwards with difficulty, each plant has to expend vital energy in forcing its roots through the hard ground which it might better employ in producing flowers or fruits. And there is no natural storage of water. A shower drenches the ground. In time it dries, through evaporation into the air, and then when the drought comes all is arid as the Sahara.

That hard subsoil is known by the term "hard-pan," and, as we have seen, it is produced more or less by all that goes on in the field. Even worse is the case—a very frequent one too—wherein there is a natural stratum of clay or equally dense waterproof material lying a few feet down.

Beyond the reach of any plough, this hard stratum can be broken up by the use of dynamite. The usual method is to drive holes in the ground about fifteen to twenty feet apart and about three or four feet deep, right into the heart of the hard layer. At the bottom of each hole is placed a cartridge of dynamite with a fuse and a detonator. This latter is a small tube containing a small quantity of explosive which, unlike the dynamite, can be easily fired, and initiates the detonation of the cartridge.

When these miniature earthquakes have taken place all over a field a very different state of things prevails. The "hard-pan" has been broken. The explosive used for such a purpose has a sudden shattering power, whereby it pulverises the ground in its vicinity rather than making a great upheaval at the surface. The sudden shock makes cracks and fissures in all directions, through which roots can easily make their way. Moreover, it permits air to find an entrance, thereby aerating the soil in such a way as to increase its fertility. The heat, or else the chemical products of the explosion, seem to destroy the fungus germs in the ground. Finally a natural storage of water is set up. Heavy rain, instead of drenching the upper soil, simply moistens it nicely, while the surplus water descends into the newly disturbed layers, there to remain until the roots pump it up in time of drought.

It is stated that an acre of hay pumps up out of the soil 500 tons of water per annum, so it is easy to see what an important feature this natural water-storage is.

Farmers say that their crops have doubled in value after thus dynamiting the subsoil.

This operation has been spoken of as a substitute for ploughing, but that may be put down to "journalistic licence," for while it truly conveys the general idea, it is hardly correct. The ordinary plough turns over about eight inches, the special subsoil plough reaches down to about eighteen inches, but the dynamite method loosens the ground to a depth of six or seven feet. Corn roots if given a chance will go downwards from four to eight feet. Potatoes go down three feet, hops eight to eighteen feet and vines twenty feet, so it is easy to see how restricted the plants are when their natural rooting instincts are restrained by a hard layer at a depth of eighteen inches or so.

The holes are made by means of a bar or drill. A great deal depends, of course, upon the hardness of the soil. Sometimes a steel bar has to be driven in by a sledge-hammer. At others a pointed bar can be pushed down by hand. In some cases it will be found that the best tool to employ is a "dirt-auger," a tool like a carpenter's auger, which on being turned round and round bores its way into the earth. However it may be done, one or more cartridges of dynamite are lowered into the finished hole, one of them being fitted with the necessary detonator and fuse. Then a little loose earth or sand is dropped into the hole until it is filled to a depth of six inches or so above the uppermost cartridge. Above that it is quite safe to fill the hole with earth, ramming it in with a wooden rammer. This is called "tamping," and it is necessary in order to prevent the force of the explosion being wasted in simply blowing up the hole. What is wanted is that the explosion shall take place within an enclosed chamber so that its effect may be felt equally in all directions. The holes are generally about an inch and a half or an inch and three-quarters in diameter.

There are two ways of firing the charges. One is by means of fuses. The detonator is fastened to one cartridge and a length of fuse is attached to the detonator, which passing up the hole terminates above the ground. The fuse is a tube of cotton filled with gunpowder, and it burns at the rate of about two feet a minute. Thus if three feet of fuse be used the man who lights it has a minute and a half in which to find a place of safety from falling stones.

The other way is by electricity. In this case an electric fuse is attached to the cartridge and two wires are led up the hole. These are connected to an electrical machine, which causes a current to pass down into the fuse, where, by heating a fine platinum wire, it fires the detonating material with which it is packed. This detonating material in turn fires the dynamite.

The advantage of the electrical method is that twenty or thirty holes being simultaneously connected to the same machine can all be fired at once.

And now let us think of another kind of farming, in which fruit trees are concerned. With a large tree the need of plenty of underground space for its roots would seem to be more important even than in the case of annual plants like wheat. Yet we know very well that the usual procedure is to dig a small hole just about big enough to accommodate the roots of the sapling when it is planted, while the ground all round is left undisturbed. The assumption is that the tree will, in time, be able to push its roots through anything which is not actually solid rock. So much is this the case that one authority has thought fit to warn tree-growers in this picturesque fashion. "When planting a tree," he says, "forget what it is you are doing, and think that you are about to bury the biggest horse you know." How many people when planting any tree dig a hole big enough to bury a horse? It is fairly safe to reply, only those who do it by dynamite.

By permission of Dupont Powder Co., Wilmington, Delaware

First Effect of the Dynamite

Clearing a field of tree stumps by blowing them up with dynamite.—*See* p. 16

The method of working is to bore a hole nearly as deep as the hole you want to blast. At the bottom place a powerful charge, far stronger than you would use for "subsoiling," as just described. That will not only blow a hole big enough for you to put your tree in, but it will loosen the ground all around the hole for yards. The main debris from the hole will fall back into it, but that will not matter much, since, being all loose, it is an easy matter to remove as much as is necessary to plant the young tree. The advantages are the same as those enumerated in the previous case—namely, the loosened ground gives more scope for the roots—apple-tree roots want twenty feet or so—the ground holds moisture better, and the explosion kills the fungus germs. In addition to these there is the advantage that to blast a hole like this is cheaper than digging it.

And that the advantages are not merely theoretical is shown by the fact that trees so planted actually do grow stronger, bigger and quicker than precisely similar ones under the same conditions, but set in the ordinary way with a spade.

And not only do new trees thus benefit; old trees can be helped by dynamite. Many an existing orchard has been improved by exploding dynamite at intervals between the rows of trees. Care has to be taken to see that the disturbance is not so violent or so close as to damage the trees, but that can be easily arranged, and then the result is that the soil all around the trees is loosened, the roots are given more freedom and the water-storing properties of the ground are greatly improved.

Again, how often a farmer is troubled with a pond or a patch of marshy ground right in the midst of his fields. It is of no use, and simply serves to make the field in which it occurs more difficult to plough and to cultivate—besides being so much good land wasted. Now the reason for the existence of that pond or marsh is that underneath the surface there is an impervious layer in which, as in a basin, the water can collect. Make a hole in that and it will no more hold water than a cracked jug will. And to make that hole with dynamite is the easiest thing in the world.

If the pond be merely a collection of water which occurs in wet weather, but which dries up quickly, there simply needs to be drilled a deep hole and a fairly strong explosion caused at the bottom of it. How deep the hole must be depends upon the formation of the earth at that point, and how low down is the stratum which, being waterproof, causes the water to remain. It is that, of course, which must be broken through, and so the explosion must be caused at a point near the under side of that layer. With a little experience the operator can judge the position by the feel of the tool with which he makes the hole. If the pond is permanent but shallow, men can wade to about the centre, there to drill a hole and fire a shot. If it be permanent and deep, then the work must be done from a raft, which, however, can be easily constructed for the purpose. Once broken through, the water will quickly pass away below the impervious stratum and useless land will become valuable.

The same may be done on a larger scale by blasting ditches with dynamite. This is in many cases much cheaper than digging them. A row of holes is put down, or even two or three rows, according to the width of the proposed ditch. In depth they are made a little less than the depth of the ditch that is to be. And for a reason which will be apparent they are put very close together, say three feet or so apart. Preparations may thus be made for blasting a ditch hundreds of feet long and then all are fired together. The earth is thrown up by a mighty upheaval, a ditch being produced of remarkable regularity considering the means by which it is made. The sides, of course, take a nice slope, the debris is thrown away on both sides and spread to a considerable distance, so that, given favourable conditions and a well-arranged explosion, there is constructed a finished ditch which hardly needs touching with spade or other tool.

It not being feasible to fire a lot of holes electrically, the limit being about thirty, the simultaneous explosion of perhaps hundreds has to be brought about in some other manner, and usually it is accomplished by the simple device of putting the holes fairly near together and firing one with a fuse. The commotion set up by this one causes the nearest ones to " go off," they in turn detonating those farther on, with the result that explosion follows explosion all along the line so rapidly as to be almost instantaneous.

A farmer who is troubled by a winding stream passing through his land, cutting it up into awkward shapes, can straighten it by blasting a ditch across a loop in the manner just described. In the case of low-lying land, however, ditches are obviously no use, since water would not flow away along them. In that case the principle suggested just now for dealing with an inconvenient pond can sometimes be used, for if the subsoil be blasted through at several points it is very likely that water will find a way downwards by some means or other.

And the list of possible uses is by no means exhausted yet. A man opening up virgin land often finds old tree stumps his greatest bother. He can dig round them and then pull them out with a team of horses, but by far the simpler way is with a few well-placed dynamite cartridges, for they not only throw up the stump for him, but they break it up, shake the earth from it, and leave it ready for him to cart away or to burn.

Boulders, too, can be blown to pieces far more easily than one would think. The charges may be put underneath them as with the tree stumps, but in many cases that is not necessary, all that is needed being some dynamite laid upon the top of the rock and covered with a heap of clay. So sudden is the action of the explosive that its shock will break up the stone underneath it. Yet another way, perhaps the most effective of all, is to drill a hole into the stone and fire a charge inside it. It behoves the onlooker then to keep away, for the fragments may be thrown three or four hundred feet, a fair proof that the stone will be very thoroughly demolished.

Even in the digging of wells explosives may be useful. In that case the holes are made in a circle, and they slant downwards and inwards, so that their lower ends tend to meet. The result of simultaneously exploding the charges in these holes is to cut out a conical hole a little larger in size than the ring and a little deeper than the point at which the explosion took place. The bottom of that hole can be levelled a little and the operation repeated, and so stage by stage the well will proceed to grow downwards.

The thought that naturally occurs to one is this. All the operations described may be very well, the cost may be low, and the effect good, but are they sufficient to compensate for the risks necessarily dependent upon the use of explosives? The doubt implied in that question, natural though it be, is based upon prejudice, with which we are all more or less afflicted. The art of making these explosive substances has been brought to such a pitch that with reasonable care there is no risk whatever. The greatest possible care is used in the factory to see that all explosives sent out are what they are meant to be, and that they can therefore be relied upon to behave according to programme and not to play any tricks. That is the first step, and what with competition between makers, Government inspection, and searching inquiry into the slightest accident, and the desire of each maker to keep up the credit of his name, it is safe to say that modern explosives may be relied upon to do their duty faithfully. The second step in the process of securing safety is that the powerful explosive, the one that does the work, is made very insensitive, so that it is really quite hard to explode it. With reasonable care, then, it will never go off by accident. On the other hand, the sensitive material, which is easy to "let off," is in very small quantities, so small that an accident with it would not, again with reasonable precautions, be a serious matter.

Fuse, too, is very reliable nowadays. The man who lights the fuse may be absolutely sure that he will have that time to get to a place of safety which corresponds to the length of fuse which he employs. With electrical firing, too, it is quite easy to arrange that the final electrical connection shall not be made until all are at a safe distance, so that a premature explosion is impossible.

In many of the cases described, the shock takes place almost entirely within the earth and there is very little debris thrown about.

Indeed the only danger which is to be feared with these operations is about on a par with that which every farm hand runs from the kick of a horse. Any careful, trustworthy man could be quite safely taught to do this work, and with the assistance of a labourer he could do all that is necessary. Given a fair amount of intelligence, too, he would take but little teaching. Altogether there is no doubt that the use of explosives is going to have a marked effect upon farming operations in the near future.

CHAPTER II

MEASURING ELECTRICITY

THERE are many people whose acquaintance with electricity consists mainly in paying the electric light bill. To such the instruments whereby electricity is measured will make a specially interesting appeal.

Current is sold in Great Britain at so much per Board of Trade Unit. To state what that is needs a preliminary explanation of the other units employed in connection with electric currents.

The public electricity supply in any district is announced to be so many volts, it may be 100, 200 or perhaps 230, but whatever it be, it is always so many "volts." Then the electrician speaks lightly of numbers of "amperes," he may even talk of the number of "watts" used by the lamps, while occasionally the word "ohm" will leak out. Among these terms the general reader is apt to become completely fog-bound. But really they are quite simple if once understood, and, as we shall see in a moment, there are some very remarkable instruments for measuring them, some of which exhibit a delicacy truly astonishing.

It is well at the outset to try and divest ourselves of the idea that there is anything mysterious or occult about electricity. It is quite true that there are many things about it very little understood even by the most learned, but for ordinary practical purposes it may be regarded as a fluid, which flows along a wire just as water flows along a pipe. The wire is, electrically speaking, a "hole" through the air or other non-conducting substance with which it is surrounded. A water-pipe being a hole through a bar of iron, so the copper core of an electrical wire is, so far as the current is concerned, but a hole through the centre of a tube of silk, cotton, rubber or whatever it be. Electricity can flow through certain solids just as water can flow through empty space.

Water will not flow through a pipe unless a pressure be applied to it somewhere. In a pipe the ends of which are at the same level water will lie inert and motionless. Lower one end, however, and the pressure produced by gravity—in other words, the weight of the water—will cause it to move. In like manner pressure produced by the action of a pump will make water flow. On the other hand, when it moves it encounters resistance, through the water rubbing against the walls of the pipe.

Similarly, an electrical pressure is necessary before a current of electricity will flow. And every conductor offers more or less resistance to the flow of current, thus opposing the action of the pressure. Before current will flow through your domestic glow-lamps and cause them to give light there must be a pressure at work, and that pressure is described as so many volts.

A battery is really a little automatic electrical pump for producing an electrical pressure. And the volt, which is a legal measure, just as much as a pound or a yard, is a certain fraction of the pressure produced by a certain battery known as Clark's Cell. It is not necessary here to say exactly what that fraction is, but it will give a general idea to state that the ordinary Leclanche or dry cell, such as is used for electric bells, produces a pressure of about one and a half volts.

Thus we see the volt is the electrical counterpart of the term " pound per square inch " which is used in the case of water pressure.

A flow of water is measured in gallons per minute. An electrical current is measured in coulombs per second. Thus the coulomb is the electrical counterpart of the gallon. But in this particular we differ slightly in our methods of talking of water and electricity. Gallons per minute or per hour is the invariable term in the former case, but in the latter we do not speak of coulombs per second, although that is what we mean, for we have a special name for one coulomb per second, and that same is ampere. One ampere is one coulomb per second, two amperes are two coulombs per second, and so on.

There is no recognised term to denote the resistance which a water-pipe offers to the passage of water through it, but in the similar case with electricity there is a term specially invented for the purpose, the ohm. Legally it is the resistance of a column of mercury of a certain size and weight. A rough idea of it is given by the fact that a copper wire a sixteenth of an inch thick and 400 feet long has a resistance of about one ohm.

The three units—the volt, ampere and ohm—are so related that a pressure of one volt acting upon a circuit with a resistance of one ohm will produce a current of one ampere.

A current can do work; when it lights or heats your room or drives a tramcar it is doing work; and the rate at which a current does work is found by multiplying together the number of volts and the number of amperes. The result is in still another unit, the watt. And 1000 watts is a kilowatt. Finally, to crown the whole story, a kilowatt for one hour is a Board of Trade unit.

So for every unit which you pay for in the quarterly bill you have had a current equal to 1000 watts for an hour. To give a concrete example, if the pressure of your supply is 200 volts, and you take a current of five amperes for an hour, you will have consumed one B.T.U.

Perhaps it will give added clearness to this explanation to tabulate the terms as follow:—

Volt = The unit of pressure, analogous to "pounds per square inch" in the case of water.

Coulomb = The measure of quantity, analogous to the gallon.

Ampere = The measure of the "strength" of a current, meaning one coulomb per second.

By permission of *Dupont Powder Co.*

A FINE CROP

Celery grown on soil tilled by dynamite.—*See* p. 24

Watt = The unit denoting the power for work of any current. It is the result of multiplying together volts and amperes.

Kilowatt = 1000 watts.

Board of Trade Unit = A current of one kilowatt flowing for one hour.

In practice the measurements are generally made by means of the connection between electricity and magnetism. A current of electricity is a magnet. Whenever a current is flowing it is surrounded by a region in which magnetism can be felt. This region is called the magnetic field, and the strength of the field varies with the strength that is the number of amperes in the current. If a wire carrying a current be wound up into a coil it is evident that the magnetic field will be more intense than if the wire be straight, for it will be concentrated into a smaller area. Iron, with its peculiar magnetic properties, if placed in a magnetic field seems to draw the magnetic forces towards itself, and consequently, if the wire be wound round a core of iron, the magnetism due to the current will be largely concentrated at the ends of the core. But the main principle remains—in any given magnet the magnetic power exhibited will be in proportion to the current flowing.

The switchboard at a generating station is always supplied with instruments called ammeters, an abbreviation of amperemeters, for the purpose of measuring the current passing out from the dynamos. Each of these consists of a coil of wire through which the current passes. In some there is a piece of iron near by, which is attracted more or less as the current varies, the iron being pulled back by a spring and its movement against the tension of the spring being indicated by a pointer on a dial.

In others the coil itself is free to swing in the neighbourhood of a powerful steel magnet, the interaction between the electro-magnet, or coil, and the permanent magnet being such that they approach each other or recede from each other as the current varies. A pointer on a dial records the movements as before.

In yet another kind the permanent magnet gives way to a second coil, the current passing through both in succession, the result being very much the same, the two coils attracting each other more or less according to the current.

Another kind of ammeter known as a thermo-ammeter works on quite a different principle. It consists of a piece of fine platinum wire which is arranged as a "shunt"—that is to say, a certain small but definite proportion of the current to be measured passes through it. Now, being fine, the current has considerable difficulty in forcing its way through this wire and the energy so expended becomes turned into heat in the wire. It is indeed a mild form of what we see in the filament of an incandescent lamp, where the energy expended in forcing the current through makes the filament white-hot. The same principle is at work when we rub out a pencil mark with india-rubber, whereby the rubber becomes heated, as most of us have observed. The wire, then, is heated by the current passing through it, and accordingly expands, the amount of expansion forming an indication of the current passing. The elongation of the wire is made to turn a pointer.

A simple modification makes any of these instruments into a voltmeter. This instrument is intended to measure the force or pressure in the current as it leaves the dynamo.

A short branch circuit is constructed, leading from the positive wire near the dynamo to the negative wire, or to the earth, where the pressure is zero. In this circuit is placed the instrument, together with a coil made of a very long length of fine wire so that it has a very great resistance. Very little current will flow through the branch circuit because of the high resistance of the coil, but what there is will be in exact proportion to the pressure. The voltmeter is therefore the same as the ammeter, except that its dial is marked for volts instead of for amperes, and it has to be provided with the resistance coil.

Instruments of the ammeter type can also be used as ohmmeters. In this case what is wanted is to test the resistance of a circuit, and it is done by applying a battery, the voltage of which is known, and seeing how much current flows.

All the voltmeters and ohmmeters mentioned owe their method of working to what is known as Ohm's law. One of the greatest steps in the development of electrical science was taken when Dr Ohm put forward the law which he had discovered whereby pressure, current and resistance are related. The reader will probably have noticed from what has already been said about the units of measurement—the volt, the ampere and the ohm—that the current varies directly as the pressure and inversely as the resistance. That is the famous and important " Ohm's law " and anyone who has once grasped that has gone a long way towards understanding many of the principal phenomena of electric currents.

But the instruments so far referred to are of the big, clumsy type, suitable for measuring large currents and great pressures. They are like the great railway weigh-bridges, which weigh a whole truck-load at a time and are good enough if they are true to a quarter of a hundredweight. The instruments about to be described are more comparable with the delicate balance of the chemist, which can detect the added weight when a pencil mark is made upon a piece of paper. Indeed beside them such a balance is quite crude and clumsy. They may be said to be the most delicate measuring instruments in existence.

We will commence with the galvanometer. The simplest form of this is a needle like that of a mariner's compass very delicately suspended by a thin fibre in the neighbourhood of a coil of wire. The magnetic field produced by the current flowing in the wire tends to turn the needle, which movement is resisted by its natural tendency to point north and south. Thus the current only turns the needle a certain distance, which distance will be in proportion to its strength. The deflection of the needle, therefore, gives us a measure of the strength of the current.

But such an instrument is not delicate enough for the most refined experiments, and the improved form generally used is due to that prince of inventors, the late Lord Kelvin. He originally devised it, it is interesting to note, not for laboratory experiments, but for practical use as a telegraph instrument in connection with the early Atlantic cables.

Before describing it, it may sharpen the reader's interest to mention a wonderful experiment which was made by Varley, the famous electrician, on the first successful Atlantic cable. He formed a minute battery of a brass gun-cap, with a scrap of zinc and a single drop of acidulated water. This he connected up to the cable. Probably there is not one reader of this book but would have thought, if he had been present, that the man was mad. What conceivable good could come of connecting such a feeble source of electrical pressure to the two thousand miles of wire spanning the great ocean; the very idea seems fantastic in the extreme. Yet that tiny battery was able to make its power felt even over that great distance, for the Thomson Mirror Galvanometer was there to detect it. Two thousand miles away, the galvanometer felt and was operated by the force generated in a battery about the size of one of the capital letters on this page.

This wonderful instrument consisted of a magnet made of a small fragment of watch-spring, suspended in a horizontal position by means of a thread of fine silk, close to a coil of fine wire. When current flowed through the coil the magnetic field caused the watch-spring magnet to swing round, but when the current ceased the untwisting of the silk brought it back to its original position again.

So far it seems to differ very little from the ordinary galvanometer previously mentioned, but the stroke of genius was in the method of reading it. With a small current the movement of the magnet was too small to be observed by the unaided eye, so it was attached to a minute mirror made of one of those little circles of glass used for covering microscope slides, silvered on the back. The magnet was cemented to the back of this, yet both were so small that together their weight was supported by a single thread of cocoon silk. Light from a lamp was made to fall upon this mirror, thereby throwing a spot of light upon a distant screen. Thus the slightest movement of the magnet was magnified into a considerable movement of the spot of light. The beam of light from the mirror to the screen became, in fact, a long lever or pointer, without weight and without friction.

The task of watching the rocking to and fro of the spot of light was found to be too nerve-racking for the telegraph operators, and so Lord Kelvin improved upon his galvanometer in two ways. He first of all managed to give it greater turning-power, so that, actuated by the same current, the new instrument would work much more strongly than the older one. Then he utilised this added power to move a pen whereby the signals were recorded automatically upon a piece of paper. The new instrument is known as the Siphon Recorder.

The added power was obtained by turning the instrument inside out, as it were, making the coil the moving part and the permanent magnet the fixed part. This enabled him to employ a very powerful permanent magnet in place of the minute one made of watch-spring. The interaction of two magnets is the result of their combined strength, and that of the coil being limited by the strength of the minute current the only way to increase the combined power of the two was to substitute a large powerful magnet for the small magnetised watch-spring. This large magnet would, of course, have been too heavy to swing easily and therefore the positions had to be reversed.

So now we have two types of galvanometer, both due originally to the inventions of Lord Kelvin. For some purposes the Thomson type (his name was Thomson before he became Lord Kelvin) are still used, but in a slightly elaborated form. Its sensitiveness is such that a current of a thousandth of a micro-ampere will move the spot of light appreciably. And when one comes to consider that a micro-ampere is a millionth part of an ampere this is perfectly astounding.

But there is a more wonderful story still to come, of an instrument which can detect a millionth of a micro-ampere, or one millionth of a millionth of an ampere. It is not generally known that we are all possessors of an electric generator in the form of the human heart, but it is so, and Professor Einthoven, of Leyden, wishing to investigate these currents from the heart, found himself in need of a galvanometer exceeding in sensitiveness anything then known. Even the tiny needles or coils with their minute mirrors have some weight and so possess in an appreciable degree the property of inertia, in virtue of which they are loath to start movement and, having started, are reluctant to stop. This inertia, it is easy to see, militates against the accurate recording of rapid variations in minute currents, so the energetic Professor set about devising a new galvanometer which should answer his purpose. This is known as the "String Galvanometer."

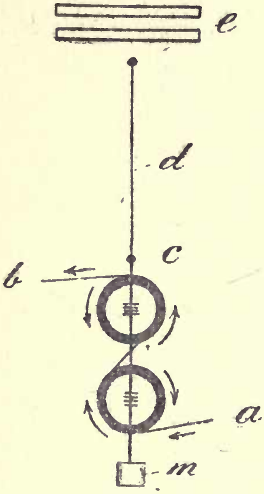


Fig. 1.—This shows the principle of this wonderful Galvanometer invented by Lord Kelvin in its latest form. Current enters at *a*, passes round the coils, as shown by the arrows, and away at *b*. A light rod, *c*, is suspended by the fine fibre, *d*, so that the eight little magnets hang in the centres of the coils—four in each. The current deflects these magnets and so turns the mirror, *m*, at the bottom of the rod. At *e* are two large magnets which give the little ones the necessary tendency to keep at "zero."

The main body of the instrument is a large, powerful electro-magnet, in shape like a large pair of jaws nearly shut. Energised by a strong current, this magnet produces an exceedingly strong magnetic field in the small space between the "teeth" as it were. In this space there is stretched a fine thread of quartz which is almost perfectly elastic. It is a non-conductor, however, so it is covered with a fine coating of silver. Silver wire is sometimes used, but no way has yet been found of drawing any metallic wire so thin as the quartz fibre, which is sometimes as thin as two thousandths of a millimetre, or about a twelve-thousandth of an inch. A hundred pages of this book make up a thickness of about an inch, so that one leaf is about a fiftieth of an inch. Consequently the fibre in question could be multiplied 240 times before it became as stout as the paper on which these words are printed.

The current to be measured, then, is passed through the stretched fibre and the interaction of the magnetic field by which the fibre is then surrounded, with the magnetic field in which it is immersed, causes it to be deflected to one side. Of course the deflection is exceedingly small in amount, and as it is undesirable to hamper its movements by the weight of a mirror, no matter how small, some other means of reading the instrument had to be devised. This is a microscope which is fixed to one of the jaws, through a fine hole in which the movements of the fibre can be viewed. Or what is often better still, a picture of the wire can be projected through the microscope on to a screen or on to a moving photographic plate or strip of photographic paper. In the latter case a permanent record is made of the changes in the flowing current.

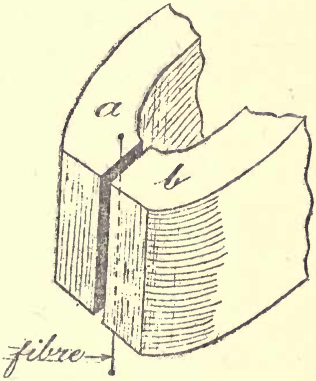


Fig. 2.—Here we see the working parts of the "String Galvanometer," by which the beating of the heart can be registered electrically. The current flows down the fine silvered fibre, between the poles, *a* and *b*, of a powerful magnet. As the current varies, the fibre bends more or less.

An electric picture can thus be made of the working of a man's heart. He holds in his hands two metal handles or is in some other way connected to the two ends of the fibre by wires just as the handles of a shocking coil are connected to the ends of the coil. The faint currents caused by the beating of his heart are thus set down in the form of a wavy line. Such a diagram is called a "cardiogram," and it seems that each of us has a particular form of cardiogram peculiar to himself, so that a man could almost be recognised and distinguished from his fellows by the electrical action of his heart.

The galvanometer has a near relative, the electrometer, the astounding delicacy of which renders it equally interesting. It is particularly valuable in certain important investigations as to the nature and construction of atoms.

The galvanometer, it will be remembered, measures minute currents; the electrometer measures minute pressures, particularly those of small electrically charged bodies.

Every conductor (and all things are conductors, more or less) can be given a charge of electricity. Any insulated wire, for example, if connected to a battery will become charged—current will flow into it and there remain stationary. And that is what we mean by a charge as opposed to a current.

Air compressed into a closed vessel is a charge. Air, however compressed, flowing along a pipe would be better described as a current.

Imagine one of those cylinders used for the conveyance of gas under pressure and suppose that we desire to find the pressure of the gas with which it is charged. We connect a pressure-gauge to it, and see what the finger of the gauge has to say. What happens is that gas from the cylinder flows into the little vessel which constitutes the gauge and there records its own pressure.

And just the same applies with electrometers. Precisely as the pressure-gauge measures the pressure of air or gas in some vessel, so the electrometer measures the electrical pressure in a charged body.

Further, some of the charged bodies with which the student of physics is much concerned are far smaller than can be seen with the most powerful microscope. How wonderfully minute and delicate, therefore, must be the instrument which can be influenced by the tiny charge which so small a body can carry.

It will be interesting here to describe an experiment performed with an electrometer by Professor Rutherford, by which he determined how many molecules there are in a centimetre of gas, a number very important to know but very difficult to ascertain, since molecules are too small to be seen. This number, by the way, is known to science as "Avogadro's Constant."

Everyone has heard of radium, and knows that it is in a state which can best be described as a long-drawn-out explosion. It is always shooting off tiny particles. Night and day, year in and year out, it is firing off these exceedingly minute projectiles, of which there are two kinds, one of which appears to be atoms of helium.

Some years ago, when radium was being much talked about and thena mes of M. and Madame Curie were in everyone's mouth, little toys were sold, the invention, I believe, of Sir William Crookes, called spinthariscopes. Each of these consisted of a short brass tube with a small lens in one end. Looking through the lens in a dark room, one could see little splashes of light on the walls of the tube. Those splashes were caused by a tiny speck of radium in the middle of the tube, the helium atoms from which, by bombarding the inner surface of the tube, produced the sparks.

Now if we can count those splashes we can tell how many atoms of helium are being given off per minute. And if then we reckon how many minutes it takes to accumulate a cubic centimetre of helium we can easily reckon how many atoms go to the cubic centimetre. But the difficulty is to count them.

So the learned Professor called in the aid of the electrometer. He could not count all the atoms shot off, so he put the piece of radium at one end of a tube and an electrometer at the other. Every now and then an atom shot right through the tube and out at the farther end. And since each of these atoms from radium is charged with electricity, each as it emerged operated the electrometer. By simply watching the twitching of the instrument, therefore, it was possible to count how many atoms shot through the tube—one atom one twitch. And from the size and position of the tube it was possible to reckon what proportion of the whole number shot off would pass that way.

The result of the experiment showed that there are in a cubic centimetre of helium a number of atoms represented by 256 followed by seventeen noughts. And as helium is one of the few substances in which the molecule is formed of but one atom, that is also the number of molecules.

And now consider this, please. A cubic centimetre is about the size of a boy's marble. That contains the vast number of molecules just mentioned. And the electrometer was able to detect the presence of those *one at a time*. Need one add another word as to the inconceivable delicacy of the instrument.

In its simplest form the electrometer is called the "electroscope." Two strips of gold-leaf are suspended by their ends under a glass or metal shade. As they hang normally they are in close proximity. Their upper ends are, in fact, in contact and are attached to a small vertical conductor. A charge imparted to the small conductor will pass down into the leaves, and since it will charge them both they will repel each other so that their lower ends will swing apart. Such an instrument is very delicate, but because of the extreme thinness of the leaves it is very difficult to read accurately the amount of their movement and so to determine the charge which has been given to them.

In a more recent improvement, therefore, only one strip of gold-leaf is used, the place of the other being taken by a copper strip. The whole of the movement is thus in the single gold-leaf, as the copper strip is comparatively stiff, and it is possible to arrange for the movement of this one piece of gold-leaf to be measured by a microscope.

The other principal kind of electrometer we owe, as we do the galvanometers, to the wonderful ingenuity of Lord Kelvin. In this the moving part is a strip of thin aluminium, which is suspended in a horizontal position by means, generally, of a fine quartz fibre. Since it is necessary that this fibre should be a conductor, which quartz is not, it is electroplated with silver. Thus a charge communicated to the upper end of the fibre, where it is attached to the case, passes down to the aluminium "needle," as it is called. Now the needle is free to swing to and fro, with a rotating motion, between two metal plates carefully insulated. Each plate is cut into four quadrants, the opposite ones being electrically connected, while all are insulated from their nearest neighbours. One set of quadrants is charged positively, and one set negatively, by a battery, but these charges have no effect upon the needle until it is itself charged. As soon as that occurs, however, they pull it round, and the amount of its movement indicates the amount of the charge upon the needle, and therefore the pressure existing upon the charged body to which it is connected. The direction of its movement shows, moreover, whether the charge be positive or negative.

A little mirror is attached to the needle, so that its slightest motion is revealed by the movement of a spot of light, as in the case of the mirror galvanometers. Instruments such as these are called "Quadrant Electrometers."

My readers will remember, too, the "String Galvanometer" already mentioned. The same idea has been adapted to this purpose. A fine fibre is stretched between two charged conductors while the fibre is itself connected to the body whose charge is being measured. The charge which it derives from the body causes it to be deflected, which deflection is measured by a microscope.

In all cases of transmission of electricity over long distances for lighting or power purposes the currents are "alternating." They flow first one way and then the other, reversing perhaps twenty times a second, or it may be two hundred, or even more times in that short period. Some electric railways are worked with alternating current, and it is used for lighting quite as much as direct current and is equally satisfactory.

In wireless telegraphy it is essential. In that case, however, the reversals may take place *millions* of times per second. Consequently, to distinguish the comparatively slowly changing currents of a " frequency " or " periodicity " of a few hundreds per second from these much more rapid ones, the latter are more often spoken of as electrical oscillations. And these alternating and oscillating currents need to be measured just as the direct currents do. Yet in many cases the same instruments will not answer. There has therefore grown up a class of wonderful measuring instruments specially designed for this purpose, by which not only does the station engineer know what his alternating current dynamos are doing, but the wireless operator can tell what is happening in his apparatus, the investigator can probe the subtleties of the currents which he is working with, and apparatus for all purposes can be designed and worked with a system and reason which would be impossible but for the possibility of being able to measure the behaviour of the subtle current under all conditions.

One trouble in connection with measuring these alternating currents is that they are very reluctant to pass through a coil.

One method by which this difficulty can be overcome has been mentioned incidentally already. I refer to the heating of a wire through which current is passing. This is just the same whether the current be alternating or direct.

One of the simplest instruments of this class has been appropriated by the Germans, who have named it the " Reiss Electrical Thermometer," although it was really invented nearly a century ago by Sir William Snow Harris. It consists of a glass bulb on one end of a glass tube. The current is passed through a fine wire inside this bulb, and as the wire becomes heated it expands the air inside the bulb. This expansion moves a little globule of mercury which lies in the tube, and which forms the pointer or indicator by which the instrument is read. As the temperature of the wire rises the mercury is forced away from the bulb, as the temperature falls it returns. And as the temperature is varied by the passage of the current, so the movement of the mercury is a measure of the current.

Another way is to employ a " Rectifier." This is a conductor which has the peculiar property of allowing current to pass one way but not the other. It thus eliminates every alternate current and changes the alternating current into a series of intermittent currents all in the same direction. Rectified current is thus hardly described by the term continuous, but still it is "continuous current" in the sense that the flow is always in the same direction, and so it can be measured by the ordinary continuous current instruments. The difficulty about it is that there is some doubt as to the relation between the quantity of rectified current which the galvanometer registers and the quantity of alternating current, which after all is the quantity which is really to be measured. How the rectification is accomplished will be referred to again in the chapter on Wireless Telegraphy.

But to return to the thermo-galvanometers, as those are termed which ascertain the strength of a current by the heat which it produces, the simple little contrivance of Sir William Snow Harris has more elaborate successors, of which perhaps the most interesting are those associated with the name of Mr W. Duddell, who has made the subject largely his own. Besides their interest as wonderfully delicate measuring instruments, these have an added interest, since they introduce us to another strange phenomenon in electricity. We have just noted the fact that electricity causes heat. Now we shall see the exact opposite, in which heat produces electrical pressure and current. And the feature of Mr Duddell's instruments is the way in which these two things are combined. By a roundabout but very effective way he rectifies the current to be measured, for he first converts some of the alternating current into heat and then converts that heat into continuous current.

If two pieces of dissimilar metals be connected together by their ends, so as to form a circuit, and one of the joints be heated, an electrical pressure will be generated which will cause a current to flow round the circuit. The direction in which it will flow will depend upon the metals employed. The amount of the pressure will also depend upon the metals used, combined with the temperature of the junctions. With any given pair of metals, however, the force, and therefore the volume of current, will vary as the temperature. Really it will be the difference in temperature between the hot junction and the cold junction, but if we so arrange things that the cold junction shall always remain about the same, the current which flows will vary as the temperature of the hot one. The volume of that current will therefore be a measure of the temperature. Such an arrangement is known as a thermo-couple, and is becoming of great use in many manufacturing processes as a means of measuring temperatures.

In the Duddell Thermo-galvanometers, therefore, the alternating current is first led to a " heater " consisting of fine platinised quartz fibre or thin metal wires. Just above the heater there hangs a thermo-couple, consisting of two little bars, one of bismuth and the other of antimony. These two are connected together at their lower end, where they nearly touch the heater, but their upper ends are kept a little apart, being joined, however, by a loop formed of silver strip. This arrangement will be quite clear from the accompanying sketch, and it will be observed that the loop is so shaped that the whole thing can be easily suspended by a delicate fibre which will permit it to swing easily, like the coil in a mirror galvanometer.

It is indeed a swinging coil of a galvanometer formed with a single turn instead of the many turns usual in the ordinary instruments, and it will be noticed from the sketch that there is a mirror fixed just above the top of the loop.

This coil, then, with the thermo-couple at its lower extremity, is hung between the ends of a powerful magnet much as the fibre of the Einthoven Galvanometer is situated. The alternating current to be measured comes along through the heater. The heater rises in temperature. That warms the lower end of the thermo-couple. Instantly a steady, continuous current begins to circulate round the silver strip which forms the coil, and that, acting just as the current does in the ordinary galvanometer, causes the coil to swing round more or less, which movement is indicated by the spot of light from the mirror. A current as small as twenty micro-amperes (or twenty millionths of an ampere) can be measured in this way.

Mr Duddell has also perfected a wonderful instrument called an Oscillograph, for the strange purpose of making actual pictures of the rise and fall in volume of current in alternating circuits.

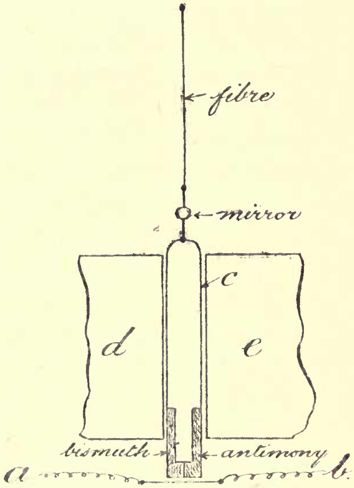


Fig. 3.—The "Duddell" Thermo-galvanometer.

In this remarkable instrument *alternating* current enters at *a*, passes through the fine wire and leaves at *b*. In doing this it heats the wire, which in turn heats the lower end of the bismuth and antimony bars. This generates *continuous* current, which circulates through the loop of silver wire, *c*, which, since it hangs between the poles, *d* and *e*, of a magnet, is thereby turned more or less. The amount of the turning indicates the strength of the *alternating* current.

To realise the almost miraculous delicacy of these wonderful instruments we need first of all to construct a mental picture of what takes place in a circuit through which alternating current is passing. The current begins to flow: it gradually increases in volume until it reaches its maximum: then it begins to die away until it becomes nil: then it begins to grow in the opposite direction, increases to its maximum and dies away once more. That cycle of events occurs over and over again at the rate it may be of hundreds of times per second. Now for the actual efficient operation of electrical machinery working on alternating current it is very necessary to know exactly how those changes take place—do they occur gradually, the current growing and increasing in volume regularly and steadily, or irregularly in a jumpy manner? Engineers have a great fancy for setting out such changes in the form of diagrams, in which case the alternations are represented by a wavy line, and it is of much importance to obtain an actual diagram showing not what the changes should be according to theory, but what they really are in practice. It is then possible to see whether the "wave-form" of the current is what it ought to be.

Once again we must turn our thoughts back to the string galvanometer. In that case, it will be remembered, there is a conducting fibre passing between the ends or poles of a powerful magnet, the result of which arrangement is that as the current passes through the fibre it is bent by the action of the magnetic forces produced around it. If the current pass one way, downwards let us say, the fibre will be bent one way, while if it pass upwards it will be bent the opposite way. Suppose then that we have two fibres instead of one, and that we send the current up one and down the other. One will be bent inwards and the other outwards. Then suppose that we fix a little mirror to the centre of the fibres, one side of it being attached to one fibre and the other to the other. As one fibre advances and the other recedes the mirror will be turned more or less. Consequently, as the current flowing in the fibres increases or decreases, or changes in direction, the mirror will be slewed round more or less in one direction or the other.

The spot of light thrown by the mirror will then dance from side to side with every variation, and if it be made to fall upon a rapidly moving strip of photograph paper a wavy line will be drawn upon the paper which will faithfully represent the changes in the current.

In its action, of course, it is not unlike an ordinary mirror galvanometer, but its special feature is in the mechanical arrangement of its parts which enable it to move with sufficient rapidity to follow the rapidly succeeding changes which need to be investigated. It is far less sensitive than, say, a Thomson Galvanometer, but the latter could not respond quickly enough for this particular purpose.

CHAPTER III

THE FUEL OF THE FUTURE

WE now enter for a while the realm of organic chemistry, a branch of knowledge which is of supreme interest, since it covers the matters of which our own bodies are constructed, the foods which we eat and the beverages which we drink, besides a host of other things of great value to us.

Although the old division of chemistry into inorganic and organic is still kept up as a matter of convenience, the old boundaries between the two have become largely obliterated. The distinction arose from the fact that there used to be (and are still to a very great extent) a number of highly complex substances the composition of which is known, for they can be analysed, or taken to pieces, but which the wit of man has failed to put together. Consequently these substances could only be obtained from organic bodies. The living trees, or animals, could in some mysterious way bring these combinations about, but man could not. The molecules of these substances are much more complicated than those with which the inorganic chemist deals. The important ingredient in them all is carbon, which with hydrogen, nitrogen and oxygen almost completes the list of the simple elements of which these marvellous substances are compounded. In some cases there appear to be hundreds of atoms in the molecule.

If one takes a glance at a text-book on organic chemistry the pages are seen to be sprinkled all over with C's and O's, N's and H's, with but an occasional symbol for some other element.

Another feature of this branch which cannot fail to strike the casual observer is the queer names which many of the substances possess. Trimethylaniline, triphenylmethane and mononitrophenol are a few examples which happen to occur to the memory, and they are by no means the longest or queerest-sounding.

Another peculiarity about these organic substances is that a number of them, each quite different from the others, can be formed of the same atoms. Certain atoms of hydrogen, sulphur and oxygen form sulphuric acid, and under whatever conditions they combine they never form anything else. On the other hand, there are sixty-six different substances all formed of eight of carbon, twelve of hydrogen and four of oxygen. This can only mean that in such cases as the latter the atoms have different groupings and that when grouped in one way they form one thing, in another way some other thing, and so on. This explains the extreme difficulty which the chemist finds in building up some of these organic substances.

Every now and again we are startled by some eminent man stating that the time will come when we shall be able to make living things, when the laboratory will turn out living cows and sheep, birds and insects, even man with a mind and soul of his own. Yet one cannot but feel that such men, no matter how great their authority, are simply "pulling the public's leg," to use a colloquial expression. For they hopelessly fail to make many of the commonest things. In many cases where they wish to produce an organic substance they have to call in the aid of some living thing to do it for them, even if it be but a humble microbe. For the microbes perform wonderful feats in chemistry, far surpassing those of the most eminent men. Hence the latter very sensibly use the microbe, employ it to work for them, just set things in order and then stand by while the microbe does the work.

Thus most things can be analysed—that is to say, taken to pieces—while many things can now be synthesised—that is to say, built up from their constituent atoms—but still a great many remain, and among them the most important, the synthesis of which completely baffles man. One of the most useful and widespread substances, for example, cellulose, is, at present at least, utterly beyond us. We do not even know how many atoms there are in the cellulose molecule. The molecules may, for all we know, contain thousands of atoms. Indeed many of these organic matters have very large molecules.

And even if the chemist were able to make all kinds of organic matter, he would still be as far off as ever from making *living* matter. Indigo used to be derived entirely from plants of that name. One of the greatest triumphs of the organic chemist was when he produced artificial or synthetic indigo. But he is as far off as ever from making the indigo plant. It is claimed that "synthetic" rubber is exactly the same as natural rubber, although some users say it is not quite the same. Still, if it be so, it is dead rubber, not the living part of the plant. The time, then, is infinitely far distant when the chemist will be able to make anything with the characteristics of life—namely, to grow by accretion from within and to reproduce its kind. The most wonderful product of the laboratory is dead. At most it simply resembles something which *once* was alive.

But that is somewhat of a digression. This dissertation on organic chemistry was simply intended to lead up to the question of liquid fuels, all of which are organic.

In the life of to-day one of the most important things is petroleum. This is a kind of liquid coal. Just how it was formed down in the depths of the earth is not clear. One idea is that it is due to the decomposition of animal and vegetable matter. Another is that certain volcanic rocks which are known to contain carbide of iron might, under the influence of steam, have in bygone ages given off petroleum, or paraffin, to use the other name for the same thing.

In many parts of the world these deposits of oil are obtained by sinking wells and pumping up the oil. In others the liquid gushes out without the necessity of pumping at all. This is believed to be due to the fact that water pressure is at work. Artesian wells, from which the water rushes of its own accord, are quite familiar, and are due to the fact that some underground reservoir tapped by the well is fed through natural pipes, really fissures in the rock, from some point higher than the mouth of the well. Now supposing that a reservoir of oil were also in communication with the upper world in the same way, the descending water would go to the bottom, underneath the lighter oil, and would thus lift it up, so that on being tapped the oil would rush out.

Another source of mineral oil is shale, such as is to be found in vast deposits in the south-east of Scotland. This shale is mined much as coal is: it is then heated in retorts as coal is heated at the gas-works: and the vapour which is given off, on being condensed, forms a liquid like crude petroleum.

In all these cases the original oil is a mixture of a great number of grades differing from each other in various ways. They are all "hydro-carbons," which means compounds of carbon and hydrogen, and they extend from cymogene (the molecules of which contain four atoms of carbon and ten of hydrogen) to paraffin wax, which has somewhere about thirty-two of carbon to sixty-six of hydrogen. For practical purposes their most important difference is the temperature at which they boil, or turn quickly into vapour.

This forms the means by which they are sorted out. In a huge still, like a steam-boiler, the crude or mixed oil is gradually heated, and the gas given off is led to a cooling vessel where it is chilled back into liquid. The lightest of all, cymogene, is given off even at the freezing-point of water. That is led into one chamber and condensed there. Then, as the temperature rises to 18° C., rhigolene is given off: that is collected and condensed in another vessel. Between 70° and 120° petroleum ether and petroleum naphtha are produced, and they together constitute what is commonly called petrol. Between 120° and 150° petroleum benzine arises. All the foregoing taken together constitute about 8 to 10 per cent. of the whole crude oil. Then between 150° and 300° there comes off the great bulk of the oil, nearly 80 per cent., the kerosene or paraffin which we burn in lamps. Above 300° there is obtained another oil, which is used for lubrication, also the invaluable vaseline, and finally, when the still is allowed to cool, there remains a solid residuum known as paraffin wax. This process is known as fractional distillation, and it will be noticed that it consists essentially in collecting and liquefying separately those vapours which are given off at different ranges of temperature. For our purpose in this chapter we are mainly concerned with the petrol and the kerosene.

Many efforts have been made in times gone by to use kerosene for firing the boilers of steam-engines. In naval vessels a great deal is so used at the present time. But the chief method of employing oil for generating power is to use it in an internal combustion-engine. These machines have been dealt with at length in *Engineering of To-day* and *Mechanical Inventions of To-day* and so must be simply mentioned here. They consist of two types. In one, which is exemplified by the ordinary car or bicycle motor, the oil is gasified in a vessel called a carburetter or vaporiser and then led into the cylinder of the engine, together with the necessary air to enable it to burn. At the right moment a spark ignites the mixture, which burns suddenly, causing a sudden expansion, in other words, an explosion. Thus the power of the engine is derived from a succession of explosions. If the fuel be petrol it vaporises at the ordinary temperature of the engine and needs no added heat. With kerosene, however, heat has to be employed in the vaporiser to make it turn readily into a gas.

The other method is employed in engines of the new "Diesel" type, in which the cylinder of the engine, being already filled with hot air, has a jet of oil sprayed into it. The heat of the air causes it to burst into flame, causing an expansion which drives the engine.

An important feature in the latter type of engine is that the oil is very completely burnt, so that very heavy oils can be used, oils which, if employed in an engine of the other kind, would choke up the cylinder with soot. In other words, the range of oils which can be used in this new kind of engine is much wider than is possible in the others. The latter may be likened to a fastidious man who is very particular about his food, while the former resembles the man of hearty appetite who can eat anything. And just as a man of the latter sort is more easily provided for by the domestic authorities, so the Diesel engine makes the problem of the provision of liquid fuel much simpler.

For it must never be forgotten that the provision of liquid fuel for the world is by no means a simple matter, since the supply is by no means adequate. The output runs into thousands of millions of gallons, and the whole world is being searched for new fields of oil, and yet it is all swallowed up as fast as it can be produced, while the coal mines do not feel the competition. A year or so ago the United States and Russia between them (and they are the greatest producers) obtained 5,000,000,000 gallons of oil, seemingly an enormous quantity. But, on the other hand, Great Britain alone produces over 250,000,000 *tons* of coal per annum. If, therefore, liquid fuel is to displace coal, as some people lightly think it is going to do, the supply will have to be multiplied many times. In the amount of heat which it is capable of giving the coal of Great Britain alone beats the oil produced by the whole world.

And another thing to be borne in mind is that as the coal miner goes down to the seam and sees for himself what is there, while the oil producer simply stays at the surface and draws it up with a pump, the coal man knows far more as to how much there is still left than the oil man does. We know that the coal deposits will last for many years to come, even if the production go on increasing, whereas the oil supply may fall off in the near future instead of increasing.

And in both cases we are using up capital. Coal is not being made on the earth now, at any rate in any appreciable quantity. The stage of the earth's history favourable to the formation of coal mesaures has long gone by. And the same probably applies to oil.

It is interesting in this connection to note that coal itself is to a certain extent, or can be at all events, a source of oil. When coal is heated in order to make it give up its gas, or to turn it into coke, vapours are given off which on cooling become coal-tar. At one time regarded only as a crude sort of paint, this is now the source from which many chemical substances are obtained, varying from photographic chemicals to saccharine, a substitute for sugar. So valuable are these products that there is a brisk demand for the tar, in other directions than the manufacture of oils, but oils of various kinds are also obtained from it.

The first step in the operations is fractional distillation, after the manner just described for petroleum. The first " fraction " is " coal-tar naphtha." Then follows " carbolic oil," after that " heavy " or " creosote oil," anthracene oil, and finally there remains in the still on cooling a solid residue known as coal-pitch. The naphtha, on being distilled again, gives, among other things, benzine, from which the famous aniline dyes are made, and which is useful in many industries. Creosote is largely employed as a preservative for wood, being forced into the timber under high pressure, so that it penetrates right into it and tends to prevent rotting, no matter how wet it may be. Railway sleepers are thus treated, small truck-loads of them being run into a cast-iron tunnel which is then sealed at both ends, while the creosote is forced in by powerful pumps. After such treatment they can lie nearly buried in the damp ballast for a long time without any deterioration.

These coal-tar substances are all very similar to petroleum and its products, hydrocarbons, compounds of hydrogen and carbon in various proportions. Many of them could be used for fuel.

By permission of *Dupont Powder Co.*

APPLE TREE PLANTED WITH A SPADE

This apple tree was planted in the ordinary way with a spade. Compare its size with that in following illustration at p. 48.

But since they are based upon the supply of coal, which is itself limited, they cannot, however they may be used, do more than stave off the evil day when the supply will be exhausted.

Quite different is it with alcohol, which it seems likely may be the fuel of the future. Some people will be inclined to exclaim "What a pity to burn it!" since to many the word conveys ideas of another sort altogether. There are many nowadays, however, who, like the writer, have none but a scientific interest in it. To such whisky, for example, is but "impure" alcohol, and it is without the "impurities" that it may become of vast use to the world, thereby possibly repaying man for some of the harm which in the past it has inflicted upon him.

Alcohol, again, is a hydrocarbon. It is really more correct to speak of it in the plural, as "alcohols," since there is a large group of substances all of the same name. Two of these are of the greatest importance, methyl alcohol and ethyl alcohol. The former is obtained from wood, hence it is sometimes called wood spirit. Wood is strongly heated in an iron still, and the methyl alcohol is given off in the form of vapour, which on being collected and cooled condenses into liquid. It is exceedingly unpleasant to the taste: if it were the only kind there would be no consumption of alcohol as a drink.

The second kind mentioned is obtained by the agency of germs or microbes, and the story of its production is so interesting as to demand a little space.

We will commence with the maltster. He performs the first part of the operation. Starting with ordinary barley, by the action of heat, aided by natural growth, he produces the raw material on which the brewer may work. Now barley, like all grain, is largely made up of starch, and although starch will not make alcohol, it can be turned into sugar, which will. So the task of the maltster is to commence the change of the starch in the grain into sugar.

First of all it is soaked in water and spread upon floors and heated until it begins to sprout. There is a little part in each grain called the endosperm, which is the embryonic plant, and the starch is really the food provided by nature to nourish the growing endosperm until such time as it shall be strong enough to draw its nourishment from the soil. In order that it may not be washed away prematurely, the starch is locked up by nature in closely fastened cells, and, moreover, it is insoluble, so that water cannot carry it away. The endosperm, however, has at its disposal certain substances known as enzymes (and it increases its store of these as it grows), one of which is able to dissolve away the walls of the cells, to unlock the treasures, as it were, while the other turns the insoluble starch into soluble matter, in which state the growing organism is able to make use of it as food.

So as the grain sprouts upon the maltster's floor this process is going on—the cells are being opened and their contents converted from starch into soluble matters. Then, when the growth has gone far enough, the grain is transferred to a kiln, where it is subjected to heat, by which the growth is stopped. The living part of the grain is, in fact, killed. That is mainly to stop the young plant from eating up the altered starch, which it would do if allowed time, but which the brewer wants to be kept for his own use.

The maltster's task is now finished, and we come to the brewer's. The first thing he does with the malt is to crush it between rolls, thereby liberating thoroughly those substances which have been formed from the starch and which he intends to turn into sugar. Having crushed it, he places it in the "mash tun," a large tank of wood or iron, in which it is mixed with water and subjected to heat. While in this vessel the enzymes become active again and turn the soluble starch, or a part of it, into a kind of sugar.

The liquid drawn off from the mash tun, containing, of course, the sugar, is subsequently boiled, numerous flavouring matters (including hops) are added, and then it is cooled again, ready for the final process—fermentation.

This takes place in a large vat or " tun " and is brought about by the agency of yeast which is added to the liquid.

Now yeast is a multitude of microscopic plants round in shape and about one three-thousandth of an inch in diameter. Though so small, this little organism is really quite complicated in its structure, and within its little body there are carried on complicated chemical changes which baffle entirely the most learned chemist to imitate. Further, he has yet to find out how the little yeast plant does it. He not only cannot imitate the process, he does not know what the process is. These little organisms multiply mainly by the process of " budding." A new one grows out of the side of each old one, rapidly reaches maturity, breaks away and commences an independent existence. No sooner is it free than it in turn gives birth to another. Indeed so great is its hurry to propagate itself that sometimes the new cell begins to throw out a bud before it has itself separated from its parent. It is therefore easy to see that yeast increases in quantity by what some call " leaps and bounds," but which the mathematically minded know as geometrical progression.

The particular form of sugar with which we are concerned here is known as " dextro-glucose." This the yeast splits up into alcohol and carbonic acid gas. The latter bubbles up to the surface, and escapes into the air, while the alcohol becomes dissolved in the watery liquid. It is believed that the yeast performs this operation not directly, but by the production of certain enzymes, which in their turn act upon the sugar.

The liquid so formed is beer. But since it is alcohol with which we are concerned, and not beer, many details connected with its manufacture have been omitted. Enough has been said, however, to show that by comparatively simple processes grain of all sorts, in fact, anything which contains starch, and such things are to be found in world-wide profusion, can be turned into alcohol. All the really intricate chemical functions are performed readily and cheaply by living organisms. All man has to do is to set up the conditions under which the organisms can work.

In the process just described only a portion of the starch in the grain is converted into sugar, hence the percentage of alcohol in beer is comparatively small. If all the starch be converted a liquid much stronger in alcohol is produced, and if that be distilled, so as to separate the spirit from the water with which it is mixed, there results whisky. Brandy, likewise, is the spirit distilled from wine, rum from molasses, and so on. In all these familiar beverages the essential feature is this same alcohol, of the variety known as ethyl alcohol.

It will be noticed that in the making of beer the alcohol is actually formed in water. There is a sugary water which under the action of the yeast becomes an alcoholic water. And this indicates a very useful feature about the liquid when used for industrial purposes. A tank full of petrol is extremely dangerous, so much so that the storage of petrol is hedged about by all manner of precautions. The danger is that it gives off an inflammable vapour and that if it once begin to burn there is practically no possibility of putting it out. Being lighter than water, it simply clothes with a layer of fire any water which may be thrown on to it. The water in such circumstances simply serves to spread the flaming petrol about and so to make matters worse. Now alcohol, with its partiality for the companionship of water, behaves quite differently. True, it also may give off an inflammable vapour, but if a quantity of it catch fire it can be extinguished in the usual way by a fire-engine. The water and alcohol immediately combine—the alcohol becomes dissolved in the water just as sugar may do, and as soon as the percentage of water in the mixture becomes considerable the burning stops.

It may be that some readers will have discovered this fact for themselves without knowing precisely what it was. It is a common dodge with amateur photographers if they want to dry a negative quickly to immerse it in methylated spirit. The spirit seems to take the water out of the film and, itself drying quickly, leaves the negative in a perfectly dry condition in a few minutes. Now after using spirit in that way it is useless to put it in a spirit stove or lamp. It will not burn. Methylated spirit is alcohol, and the reason why it has such a quick drying action is that it and the water in the wet film quickly mix. After immersion the film is wet, not with water merely, but with a mixture of a lot of spirit and a little water. Hence the speed with which it evaporates. And the non-inflammability of the mixture is due to the presence of the water.

Methylated spirit only differs from the alcohol in alcoholic beverages in that something is added to make it undrinkable. Owing to the craving for it, which is so widespread, and the doubtful effect which it has on certain citizens, most states regard it as pre-eminently a subject for taxation, thereby on the one hand bringing in a good revenue, and on the other discouraging its too free use. But those considerations apply only to drinkable alcohol. That which is to be used for industrial purposes is not in any way a legitimate object for taxation. Hence the problem arises of making a form of alcohol which shall answer all the needs of the industries which use it, and at the same time be so repulsive to the senses that no one can possibly drink it. This result is achieved by adding some of the methyl alcohol derived from the vapour given off by wood when heated. Commonly known as "wood spirit," this is so unpleasant that it renders the mixture of no use for drinking, and so it can safely be freed from taxation.

Unfortunately this spirit has less heating value than petrol. That means that a given quantity of each liquid will produce more heat in the case of petrol than in the case of alcohol. Indeed the difference is about two to one. Hence an engine to give out a certain horse-power would need to have its cylinders twice as big if it were to use alcohol instead of the other fuel. There is a certain compensation, however, in the fact that alcohol is very easily compressible.

In modern internal combustion-engines much of the efficiency is due to the explosive charge which is drawn into the cylinder being compressed into a small space before it is fired. It was the discovery of the value of compressing the gas which made the gas-engine so formidable a rival to the steam-engine, and the wonderful performances of the Diesel engines are due very largely to the fact that the air is compressed in the cylinder to a very high pressure. The jet of oil burns in highly compressed air. And because of the facility with which alcohol can be compressed it is said to be more effective as a source of motive power than would be expected from its comparatively feeble heat.

Thus we may sum up the possibilities of the future. Coal, petroleum and their derivatives exist in limited quantities in the world, and so far as we can see the vast drafts which we are taking from them are not being replaced, indeed at this stage of the earth's development cannot be replaced, by any more. Sooner or later we must come to an end of them. Is it not comforting, therefore, to know that there is another source of fuel at hand, inexhaustible, since it can be produced as needed. We have only to set the sun and the ground to work to produce grain, rice, potatoes, or any of the myriad substances which contain starch, and from that, by simple and well-known processes, we can obtain a cheap, safe and reliable fuel. Indeed there seems nothing but the ultimate loss of sunlight, countless millions of years hence, which can ever check the supply of this valuable commodity. What has doubtless, in many cases, been a curse in the past may turn out to be the great boon of the future.

CHAPTER IV

SOME VALUABLE ELECTRICAL PROCESSES

STUDENTS of that branch of science known as physics are coming to the conclusion that electricity plays a much more important part in the universe than was supposed. They are led to believe that electrical attraction is the cement which binds together those exceedingly minute particles out of which everything is built up. Whether electricity binds them together or not, it is certain that electrical action can in some cases *separate* those particles, and this process of separation provides a means of carrying on some very remarkable and useful industrial processes.

Let us imagine a vessel filled with water to which has been added a little sulphuric acid, while suspended in it are two strips of platinum. There is a space between the strips, so that when their upper ends are suitably connected to a source of electric current that current flows from one strip to the other *through the liquid.*

That is an example of the apparatus for carrying out this electrical separation in its simplest form, and it will facilitate the further description if the names of various parts are enumerated.

The process itself is electrolysis ; the liquid is the electrolyte, while the strips are the electrodes. The individual electrodes, again, have special names, that by which the current enters being the anode and that by which it leaves the cathode. It is not difficult to remember which is which if we bear in mind that the current traverses them in alphabetical order. Since, however, it may not be easy for the general reader to carry all these terms in his mind, we will, when it is necessary to differentiate between the two electrodes, call one the in-electrode and the other the out-electrode.

Returning now to our imaginary apparatus, let us turn on the current. At first nothing seems to be happening, although suitable instruments would show that current was flowing. Soon, however, little bubbles appear upon the electrodes, and these grow larger and larger, until they detach themselves from the platinum to which they have been adhering, float up to the surface and burst. The question which naturally arises is, What do those bubbles consist of? Are they air?

If we take means to collect the gases which formed them we get an unmistakable answer. The bubbles which arise from the in-electrode are oxygen, those from the other hydrogen. If we allow our apparatus to work for some time, and collect all the gas which arises, we shall find that there is twice as much hydrogen as oxygen. We shall also find, as the process goes on, that the quantity of water diminishes.

Perhaps I may be allowed at this point to remind my readers that water is a collection of minute ultra-microscopic particles called "molecules," each of which is formed of three smaller particles still called "atoms." Of the three atoms two are hydrogen and one oxygen. Water therefore consists of hydrogen and oxygen, there being twice as much of the former as there is of the latter.

We see, therefore, that electrolysis gives us hydrogen and oxygen in exactly those proportions in which they occur in water, and since we also see that as these gases appear the water itself disappears, we are led to conclude that the current is splitting up the water into the gases of which it is formed.

But the strange thing is that this will not work with pure water. We have to add something to it. In the case of our imaginary experiment it was sulphuric acid. What part does that play?

This is not fully understood, but we may be able to form a mental picture of what is believed to happen as follows.

The in-electrode is surrounded by a vast assemblage of these tiny molecules, most of them those of water, but a few those of the acid. The latter are more complex in their structure than the former, but they too contain hydrogen. Current flows into the electrode and instantly hydrogen atoms from the *acid* molecules crowd round it, like boatmen at the seaside anxious to secure a passenger. Each takes on board a quantity of electricity and with it darts across the intervening space to the other electrode. Arrived there, it gives up its load and, its work done, remains lying upon the electrode until enough others like unto itself have gathered there to form a bubble and so escape. These hydrogen atoms are thought to be the *craft which carry the current through the liquid* and enable it to pose, as it were, as a conductor of electricity, which in reality it is not.

But where does the oxygen come from ?

To find the answer to that we must add a second chapter to our story. When the hydrogen " boats " took on board their load of electricity they left their former associates, and these forthwith " set upon " neighbouring water molecules and with the audacity of highwaymen stole from them enough hydrogen atoms to take the place of those they had lost. Thus the acid molecules became complete once more, while the scene of the conflict near the in-electrode was strewn with the remains of the water molecules from which the hydrogen atoms had been stolen. These remains, of course, would be oxygen, and they, collecting together on the electrode, would eventually be in numbers sufficient to form bubbles and so escape.

Thus it may be the acid which really does the work, yet because of its subsequent raid upon the water it is the latter which disappears, and it is the materials of the latter which are bought to the surface in the bubbles.

And there we see the mechanism whereby, so it is believed, electric current can pass through otherwise non-conducting liquids. And the important point, as far as practical utility is concerned, is that the passage of the current is accompanied by a splitting up of something or other, either the water or something in it, the materials of which are deposited, one on one electrode and the other on the other.

And now we can proceed to those useful applications of electrolysis, the commonest of which, perhaps, is electroplating.

We have seen how electrolysis causes hydrogen, probably out of the acid, to be deposited upon one electrode. Suppose that, instead of an acid, we put in the water one of those substances known to chemists as a " salt," the commonest example of which is ordinary table salt. This well-known condiment is caused by the interaction of hydrochloric acid and the metal sodium and will serve to illustrate what all salts are.

All acids are compounds of hydrogen and something else, and their biting action is due to the readiness with which the " something else " evicts the hydrogen and takes in a metal in its place. Thus hydrochloric acid, given the opportunity, gets rid of its hydrogen and takes in sodium, thereby forming chloride of soda or common salt.

Another example is the gold chloride familiar to photographers. This is the result of the action of certain acids upon gold, wherein the acids throw out their hydrogen and take in gold instead.

To sum up, then, a salt is just the same sort of thing as an acid, like the sulphuric acid which we used in our " experiment," except that some metal has taken the place of the hydrogen.

It is not surprising, then, to find that if we put a salt in the electrolyte instead of an acid we get a similar result. In the one case hydrogen is deposited upon the out-electrode, in the other the metal. In the former case, since hydrogen is a gas, it forms bubbles and floats away, but in the latter the solid metal remains a thin, even coating upon the electrode. That is the principle of electro-plating.

The electrolyte consists of a suitable solution containing a salt of the metal to be deposited, and it is placed in an insulating vessel or vat. The articles to be plated form the out-electrode, so that they have to be suspended in some convenient way from a metal conductor by conducting wires. Of course they are entirely immersed in the liquid. The in-electrode is sometimes a plate of platinum (the reason that expensive metal is used being that it is unaffected by the chemicals) or else a plate of the metal being deposited. In the former case, the solution becomes weaker as the work proceeds, and more salt has to be added. In the latter, however, the strength of the solution remains unchanged, for by an interesting interchange the in-electrode adds to it just what it loses by deposition upon the other one. The effect is therefore just as if the current tore off particles from the one and placed them upon the other.

This is believed to be due to the agency of the oxygen which in the case of the electrolysis of water becomes free, but which in this case forms with the metal electrode a layer of oxide upon its surface, this oxide being then dissolved away by the liquid. Thus as fast as the metal is deposited upon the out-electrode its place is taken by more metal from the in-electrode.

In some processes it is desired to deposit metal upon a non-conducting surface, and it is evident that such cannot be used as an electrode. Nor is it any use to attempt to deposit upon anything except an electrode. The only thing to do, then, is to make the object a conductor by some means. Models in clay, wax and plaster, once-living objects like small animals, fruit, flowers or insects, can, however, have a perfect replica made of them by electrical deposition, by the simple method of coating the surface to be plated with a thin layer of plumbago. This skin, although extremely thin, is a sufficiently good conductor to make the process possible. Process blocks for printing are copied in this way, so that a particularly delicate example of the blockmaker's art need not be worn down by much pressing, copies or "electros" being made off it for actual use in the press.

The original block is a plate of copper on which the picture is represented by minute depressions and prominences. On this a layer of soft wax is pressed, so as to obtain a perfect but reversed copy. Having been coated with plumbago, this is then put into a vat containing a solution of copper salts and is used as the out-electrode, the other being a plate of copper. When the current is turned on the copper is thus deposited on the wax until a thin sheet of copper is formed which is an exact but reversed copy of the wax, a direct copy, that is, of the original block.

The back of this thin sheet is then covered with molten lead or type metal to fill up any depressions and to give it sufficient strength. Anyone who has seen one of these "half-tone" blocks covered with minute depressions so slight that they can scarcely be seen, yet so perfect that a beautiful print can be obtained from them, will realise the wonderful power of this electrolytic process, the marvellous accuracy with which the original is copied, and the unerring way in which the electric current carries the particles of copper into every one of the myriad recesses in the wax.

Another specimen of the marvellous work of this system is the wax cylinder of the phonograph. The sound is produced by a needle trailing along a groove of varying depth cut in the surface of the cylinder. This groove forms a spiral, passing round and round like the thread of a screw, and it encircles the cylinder one hundred times in every inch of its length. Consequently, at any point one may take, there is but one one-hundredth of an inch from the centre of one turn to the centre of the turn on either side of it. And at its deepest the groove is less than one-thousandth of an inch deep. The phonograph itself cuts the first "master" record, as it is termed, and the problem is to take a number of casts off this model of such delicacy and accuracy that every variation in that exceedingly fine groove shall be faithfully reproduced. Such a task might well be given up as hopeless, but with the help of electrolysis it is accomplished easily and cheaply.

To attempt to press anything upon the surface of the "master" would but smooth out the soft wax and obliterate the groove altogether. To apply anything softened by heating would be to melt it. But electrolysis, without tending in any way to distort or damage the delicately cut surface, deposits upon it a surface of metal from which thousands of casts can be made. The gentle fingers of the electricity overlay the soft wax with the hard, strong metal with a minute perfection almost beyond belief.

To commence with, the master record is placed upon a sort of turntable in a vacuum and turned round in the neighbourhood of two strips of gold-leaf strongly electrified. By this means the gold is vaporised and a perfect coating of gold is laid upon the wax. This is far too thin to be of any use, except to render the cylinder a conductor, for the coating is so fragile that it is no stronger than the wax itself. It enables the cylinder, however, to be electro-plated with copper until it is surrounded by a strong metallic shell a sixteenth of an inch thick. It takes about four days to deposit this thickness. The copper shell is then turned smooth in a lathe and fitted tightly into a brass jacket. A little cooling causes the wax record to shrink sufficiently to free it from the copper shell and allow it to be lifted out. A copper mould is thus formed in which any number of additional records can be cast. The molten wax is simply introduced into the inside, and allowed to set; the inside is bored out in a lathe, and then with a little cooling it shrinks and can be withdrawn, a completely finished record, every tiny depression or swelling in the original master being reproduced with an accuracy almost incredible.

Another valuable use to which this process is put is the purification of metals. The electro-chemical action works with unerring precision: it never mistakes an atom of iron for an atom of copper, for example. Passing through a solution of copper salt, the current deposits only copper.

For modern electrical machinery and apparatus copper is required of the utmost possible purity, for every impurity adds to its electrical resistance, in other words, diminishes its value as a conductor. Consequently thousands of tons of "electrolytic" copper, as it is termed, are produced every year. The electrodes used are plates of ordinary copper. A coating of pure metal is deposited by electrolysis upon the out-electrode from the other one. When the deposit is thick enough the out-electrode is taken out and the deposit torn off it, the union between the two being sufficiently imperfect for this to be done without difficulty. The metal of which the in-electrode is made has already been purified by other processes, until it contains but one per cent. of foreign matter, and by this means even that small percentage is entirely got rid of. The impurities fall to the bottom of the vessel in the form of "slime," which is periodically removed.

And not only is electrolysis thus unerring in picking out certain atoms from among a mixture, but there is an exact relation between the work done and the quantity of current used. Consequently it forms a very exact method of measuring currents. The method of measuring current by the strength of the magnetic field which it produces has been mentioned already, and such measurements can be checked by electrolysis. Thus the practical definition of the ampere is "that current which when passed through a solution of silver nitrate in water will deposit silver at the rate of ·001118 gramme per second."

The electric accumulator or secondary battery, one of the most useful appliances, is the result of electrolysis reversed. Many large electric-lighting plants have in addition to their generating machinery a large battery of secondary cells, which, being kept charged, are able to help the machinery in times of heavy demand, or even to supply the whole current needed for, say, half-an-hour, so that the whole of the machinery could, in the event of an accident, be shut down for that time and the supply maintained from the batteries.

This would be sufficient in many cases for fresh machinery to be brought into action or emergency arrangements to be made.

It may be that this book is being read by someone seated serenely in his arm-chair while engineers and workmen at the generating station are working in frantic haste to set right some sudden breakdown before the batteries are run down. The batteries may have saved the town half-an-hour's darkness.

Large telegraph offices are fitted with secondary batteries. Many motorists owe the ignition which keeps their engines at work to secondary batteries. It is secondary batteries which keep the wireless apparatus at work on a wrecked vessel after the engines have stopped. Indeed secondary batteries are one of the most beneficent inventions. And if only they could be made in a lighter form than is possible at present their value would be infinitely increased.

We have seen how the passage of current through acidulated water produces hydrogen and oxygen. If those gases be collected in closed vessels over the water, so that they remain in contact with the water, as soon as the current is stopped a reverse action sets in. The gases tend to recombine with the electrolyte and in so doing to give back a current equal to that which formed them. Fig. 4 shows the construction of what is called a voltameter, in which the gases arising from the electrodes are collected in little glass vessels placed just above them. Such an apparatus enables us to see easily how the accumulator works. The picture shows the battery which is effecting the separation of the oxygen and hydrogen. If that be disconnected, and the wires joined, as shown by the dotted line, a current will flow back until the oxygen and hydrogen have returned into the solution again. The apparatus will, in fact, work like an ordinary battery, except that instead of a plate or rod of zinc a mass of hydrogen will form the essential part.

An appliance such as a voltameter is not of much use for the practical purpose of storing large quantities of electrical energy, because the surfaces of the electrodes are so small and the surfaces where liquid and gases are in contact are small too. It is clear that the larger the electrodes are the wider will be the passage for the current, just as a wide road can accommodate more traffic than a narrow path. We may regard the electrodes as like gateways through which the current passes. By making them large, therefore, we enable a large current to pass, and consequently permit electrolysis to take place with great comparative rapidity.

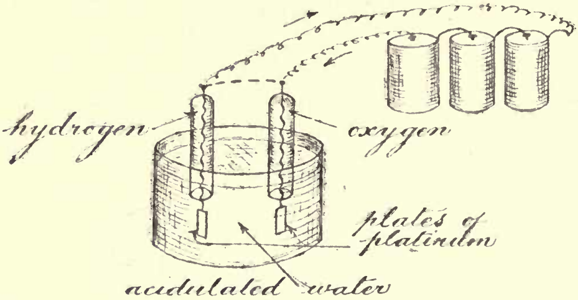


FIG. 4

The "plates," as the electrodes in a secondary battery are termed, are generally large metal plates. Experiment has shown that lead is the best for this purpose. It has also been found that it can be improved by making it porous, since the inner surfaces of the pores are so much added surface through which current can pass into the electrolyte. There are various ways of producing this porosity, which need not trouble us here, however. It will suffice for our purpose to understand that an ordinary secondary cell consists of two lead plates, with the largest possible surface, immersed in a liquid, generally a dilute solution of sulphuric acid in water.

To charge the battery, current is sent to one plate, through the liquid to the other plate, and so away. A thin film of hydrogen is thus formed upon the outgoing plate, while oxygen is formed at the incoming one. Since the hydrogen is spread over such a large area, it does not accumulate sufficiently for much of it to rise to the surface. Most of it remains adhering to the plate. The oxygen combines with the lead of its plate and so is safely stored up there in the form of oxide of lead. This storage of hydrogen upon the one plate and oxygen on the other cannot go on indefinitely, and so as soon as the limit is reached the cell is fully charged. Passage of further current is then simply waste.

The dynamo or primary batteries which are used for charging having been disconnected, the two plates can be connected together through lamps, motors, or in any other desired way, and the current will then flow out again, the opposite way to that in which it entered, just as a stone thrown up in the air returns the opposite way. The current which comes out is, in fact, a sort of reflex action arising from that which went in, the mechanism by which it is produced being the reabsorption of the oxygen and hydrogen into the electrolyte.

Whether a cell is fully charged or not is ascertained by weighing the electrolyte, an operation which at first sight seems to have nothing whatever to do with the matter. It arises from the difference in weight between water and sulphuric acid, the latter being the heavier. We have seen that while a little acid must be added to water before it can be electrolysed, it is the water which is ultimately resolved into its constituent gases. Hence the result of electrolysis is to increase not the amount, but the proportion of acid. Therefore it increases the weight of the electrolyte. This weight is ascertained by means of a "hydrometer," a glass tube, stopped, and loaded with some small shot at its lower end. On the upper part is engraved a graduated scale, so that the exact depth to which it sinks can be easily read. This depth will, of course, vary with the specific gravity of the liquid, and so the depth recorded by the scale will be an indication of the proportion of acid, and that in turn will show how far the process of charging has progressed.

Accumulators are, or have been hitherto at any rate, very troublesome things. They are apt to lose their power. If not properly charged they are easily damaged. Too rapid charging or too rapid discharging, standing for a while only partly charged—all these things have a bad effect, in extreme cases even destroying them altogether. Because of the use of lead they are terribly heavy too, so much so that for traction purposes they are of very little use, for a large amount of the energy stored in the accumulators is then used up in hauling them about.

Yet what a field there is for the successful accumulator! Take the one instance of the electrification of a railway. If good light and efficient accumulators were to be had, no alteration at all would be necessary to the permanent way. The engines or motor carriages would need to go periodically to a depot to be re-charged, but that could easily be arranged. Such things as conductor rails, overhead conductors and so on would be needless.

The world has therefore been interested for years in the rumour that T. A. Edison was engaged upon this problem, and at last he has produced his accumulator, by which he has removed many of the difficulties, if not all. Instead of a case of glass or celluloid, as is usual with the older cells, his cells are enclosed in strong boxes of nickel steel. The positive plate consists of nickel tubes filled with alternate layers of nickel hydroxide, while the negative plate is formed of prepared oxide of iron in a nickel framework. The electrolyte is a solution of potassium hydroxide. The chemical action and the electrical reaction is, of course, on the same principle precisely as in the older cells, but it is claimed that the Edison cells are "fool-proof"—that is to say, they cannot be damaged by careless handling, and they appear to be a little lighter. Thus the problem is partly solved, and with that as a fresh starting-point someone may sooner or later give us a secondary battery which is light as well as strong.

If any would-be scientific inventor reads these words there is a suggestion for a promising line of investigation.

CHAPTER V

MACHINE-MADE COLD

ONE of the most remarkable adaptations of scientific knowledge is the " manufacture of cold." At first that phrase seems strange, but it is really quite legitimate. There are machines at work at this moment which are turning out cold as if it were any other manufactured article. It is not that they manufacture cold water or cold air, it is the cold itself which they produce.

Of course, cold has no real existence, since it is simply a negative quantity, an absence of heat, yet its effects are so real that we are in the habit of talking of it as if it were a reality, and in that sense we can regard it as a product of manufacture.

Moreover, we see in this a conspicuous instance of the interdependence of invention and science, for scientific principles were first adapted to produce cold, and then artificial cold was employed in scientific investigations, whereby the rare gases of the atmosphere have been discovered, as we shall see presently.

In *Mechanical Inventions of To-day* I have dealt with the uses which can be made of heat as a motive power. Here we have in some sense a reversal of the process. In the heat-engine the expenditure of heat produces motion. In the refrigerating machine motion produces heat, on the face of it a strange way of producing cold. Yet it is by the production of heat in the first instance that we are ultimately able to obtain the cold.

One way to make a thing cold is to place it in contact with ice. But that process suffers from severe limitations. In the first place, we may not be able to procure ice when we want it. And in the second place, we may want to produce a temperature much lower than that of ice.

Now a machine can produce any degree of coldness, almost down to the "absolute zero," the point at which a body is absolutely devoid of any heat whatever, the condition in which its molecules are absolutely still. That point is 274° C. *below* freezing-point. Freezing-point on that scale is "zero," and so this *absolute* zero is *minus* 274°. Or, to put it another way, freezing-point is 274° *absolute* temperature. The absolute zero has never been reached, and there is reason to believe that it never can be quite reached, but by methods about to be described a temperature within a few degrees of it has been attained. And all of this can be done without any cooling agent colder than water at an ordinary temperature.

There are several systems, but the one which illustrates the principle most simply is that in which carbonic acid gas is the "working fluid." This is a very compressible gas, and so is well fitted for the purpose. First of all a pump or compressor compresses it. That has the effect of heating it. Such we might expect from the fact that heat is molecular activity: when by compressing the gas we force the molecules closer together, they naturally hit each other and the sides of the containing vessel harder than they did before, and the increased activity is manifested as increased heat. So the first effect, as was remarked just now, is to produce, apparently, increased heat.

But then the hot compressed gas, by being passed through a coil of pipe surrounded by cold water, can be robbed of that heat. According to the speed at which it traverses the coil it will be more or less cooled: by causing it to travel slowly it can be brought down almost to the temperature of the water. So we start with the gas at atmospheric pressure and at somewhere about atmospheric temperature too. This we convert into compressed gas at a high temperature. After cooling it we have compressed gas at a moderate temperature.

Then, to complete the process, we let the gas expand again. Now just as compressing a gas heats it, letting it expand cools it. If we compressed it and then expanded it again we should be just as we were to commence with. But since, in between the two operations we extract a quantity of heat by means of the cooling water, we get at the end a very much lower temperature than that with which we started.

We cannot cool the gas without compressing it, because heat will only flow from one body into another when the second is cooler than the first. But by making the gas hot temporarily by compression we enable the water to draw some heat from it, and then, allowing it to sink back to its original state, we get practically the old temperature, less what the water has extracted. The principle is really absurdly simple when one once gets to understand it. The application is not so simple as far as the designer of the machine is concerned, for he has to adjust the various parts to exactly the right shape and dimensions, so that they may work well with one another and produce the desired result with the minimum expenditure of power.

To the observer, however, and to the user too, the finished machine is wonderful in its simplicity. The principle is illustrated diagrammatically in Fig. 5.

In the centre is the compressor. Its action forces the gas along the pipe to the right and down into the condenser. As it flows downwards through the coil there cold water enters at the bottom of the tank, flows upward past the coil and escapes again at the top. Thus the coil is kept in contact with *cold* water.

Passing then through the bottom of the tank the gas travels from right to left through the "regulating valve" and into an arrangement almost exactly similar to the condenser but called the evaporator. Here the gas expands and suffers a great fall in temperature. This cold is communicated to liquid circulating in the tank which forms a part of the evaporator, and this liquid can be circulated through pipes into any rooms to be cooled or around vessels of water which it is desired to freeze. This liquid, which acts as the carrier of the cold, is called "brine," and is water to which is added calcium chloride to keep it from freezing.

Now the observant reader may have noticed that there is no apparent reason for the name of the left-hand vessel. It will be quite clear, however, when I explain that although I have spoken of the working fluid all along as gas, I have only done so to avoid bringing in too many explanations at once. It is actually liquid for a good part of its journey. Carbonic acid gas liquefies at a very moderate temperature and pressure, and so while it leaves the compressor as a gas it becomes liquid in the condenser and remains so until it has passed the regulating valve. Then it begins to expand into gas once more, and in that state it passes back to the compressor.

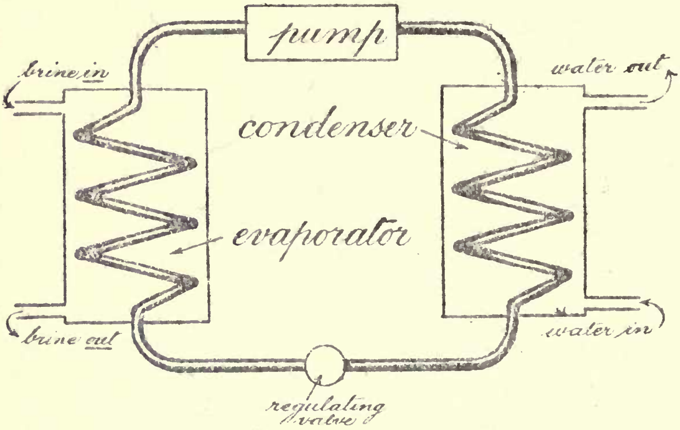


Fig. 5.—This diagram shows the working of the Refrigerating Machine. The pump compresses the gas and drives it through the coil in the condenser, where it is cooled by water. It passes thence through the coil in the evaporator, where it expands and cools the surrounding brine.

There is a pressure-gauge on the pipe leaving the compressor and another on the one entering it. A comparison of the readings on these two tells how the apparatus is working. The difference between them indicates how much compression is being given to the gas. Assuming that the compressor is working at a constant speed, this compression can be regulated to a nicety by the valve: close it a little and the compression will increase: open it a little and the compression will decrease. By this means the degree of cold produced can be varied at will.

This is the way in which many ships are enabled to carry cargoes of frozen meat. The chambers in which the meat is stowed are insulated—that is to say, their walls are made as impervious as possible to heat. Then the brine is carried into the chambers in pipes, cooling them much as the hot-water pipes heat an ordinary public building.

Or another method is to carry the pipe which constitutes the evaporator into the chamber to be cooled. A third way is to dispense with brine and to blow air through the coils of the evaporator, whereby the air is made to carry away the cold to wherever it is needed.

Ice can be made easily in moulds of metal or wood around which brine circulates. If made of ordinary water the ice is likely to be cloudy and opaque, which is quite good enough for many purposes. In cases where it is desired that it should be clear, the water is agitated during freezing, or else distilled water is used. To enable the blocks to be got out of the moulds it is sometimes arranged to circulate warm brine for a few moments.

Ice skating rinks are formed by making, first, an insulating layer of sawdust, slag-wool or something of that sort (those by the way, being the materials generally used for insulating cold chambers) underneath the floor. The floor, too, is made waterproof and then upon it is laid as closely as possible a series of iron pipes. Water is flooded on to the floor until the pipes are covered to a depth of several inches, and then brine is pumped through the pipes. In time the water freezes, and so long as the brine circulates it remains so.

But although the "CO_2 process" described above is the simplest illustration of the principle, there are other systems. In one very popular form ammonia gas is the "working fluid." This is liquefied by pressure and cooling with water, being subsequently expanded just as described above.

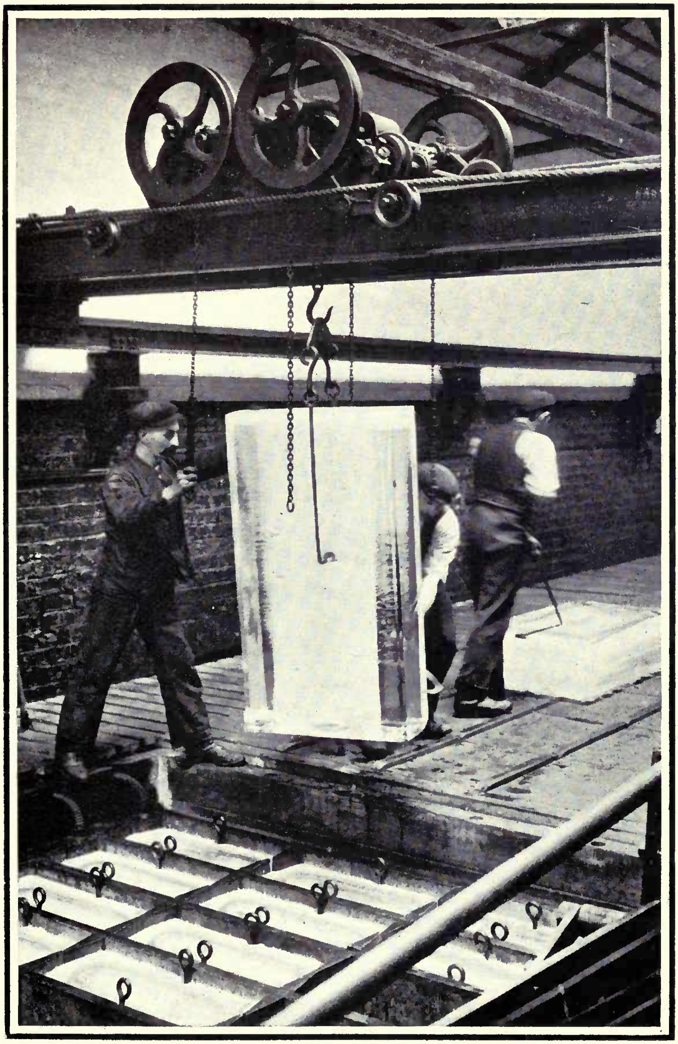
Another much-used system is the "ammonia-absorption" process, in which the ammonia is not liquefied, but when under pressure is absorbed by water, returning to gas again when the pressure is released.

But the degree of cold attained in these commercial machines is as nothing to the extremely intense cold generated on the same principles in the liquid-air machine, which is found in every well-equipped physical laboratory.

Briefly, this consists of a coil of many turns of small tube enclosed in a small double vessel, the space between the inner and outer skins of which is packed with insulating material. A compressor pumps air in at the top of the coil at a pressure of from 150 to 200 atmospheres. An "atmosphere," it may be remarked, is a unit often used in scientific matters, meaning the normal pressure of the atmosphere, which is, roughly speaking, 15 lb. per square inch. Hence 200 atmospheres is about 3000 lb. per square inch.

Of course air so highly compressed as that is hot, but after it has passed down the coil and has escaped from the valve which liberates it at the bottom it is much cooler. But that is only the beginning of the operation. The expanded, and therefore cooled, air finds its way upward through the turns of the coil down which the following air is coming. That, expanding in its turn, is colder still, because of the cooling action of the first air, and so the process goes on.

This is perhaps easier to understand if we imagine that the air comes through the coil in gusts and we notice what happens to each succeeding gust. The first comes down, expands, cools and ascends, thereby cooling the second gust as it comes down. The second then, after expansion, will be cooler than the first was. That in its turn will cool the third, and so the third after expansion will be cooler than



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MACHINE-MADE ICE

Here we see a huge block of ice being lifted (it may be on a hot summer day) from the mould in which it has been made

the second. And that will go on, each succeeding gust being cooler than the one before. And although the flow of air is continuous, and not in gusts, the result is just the same: it goes on getting cooler and cooler until at last the air comes out in its liquid form. This liquid collects in a little chamber formed at the bottom of the vessel which contains the coil and can be drawn off when desired.

Air in its liquid state looks very much like water. In fact it is difficult to get chance observers to believe that it is not water. It boils at a temperature far below the freezing-point of water, so that liquid air if placed in a cup made of ice will boil furiously. Ice is so much the hotter that it behaves towards liquid air as a very hot fire does to water.

The feature of the above machine, it will be noticed, is that no cooling water is required, as in the refrigerating machine, although the principle of the two is the same. The coil is the " condenser " and the vessel in which it is enclosed is the " evaporator," and so the cold air produced by the process in the evaporator cools the coil of the condenser. Thus it is " self-intensive," as the makers call it.

Hydrogen can be liquefied in a similar machine, except that it needs a little preliminary cooling with liquid air. Liquid hydrogen is the coolest thing known approaching the region of absolute zero.

And now we can turn to the wonderful discoveries which have followed upon the manufacture of liquid air.

To make the story complete we need to go back to the time of Priestly and Cavendish, early in last century. They investigated the atmosphere and showed that it consisted of oxygen and nitrogen in certain invariable proportions, with under certain conditions a small proportion of carbonic acid. These facts were so well authenticated, and they seemed to explain everything so satisfactorily, that it was quite thought almost up to the end of the nineteenth century that there was nothing more to learn about the atmosphere.

Nevertheless there was an idea in the minds of some scientists that there must be another group of elements somewhere, the existence of which was then undiscovered, but it was never dreamed that these were in the air.

Soon after the weights of the atoms had been found a medical student named Prout in an anonymous essay called attention to the fact that there were curious numerical relationships between them. Speculation on the subject went on for many years, until in 1865 the great Russian chemist Mendeléeff published his conclusions. He had arranged the elements in the form of a table *in the order of their atomic weights.* The table consisted of twelve rows of names forming eight vertical columns, and the remarkable thing was that all those elements which fell into any particular column, although their atomic weights were very widely different, had similar properties. This enabled him to *predict* the discovery of certain new elements, for the table contained a number of blank spaces. Three elements *have been found* since, and their atomic weights and properties are just such as to fill three of the blank spaces. One blank space, it is thought, may be filled some day by the gas coronium, which like helium has been discovered in the sun, but unlike it has not yet been detected here. When it is, there is the place in the table which it may fill. The table then commenced with what is still called Group 1, but for reasons too complicated to explain here it appeared as if there must be a group before that, a group the chief characteristic of which would be the inactivity of the elements included in it. These were expected to be of various atomic weights, but these weights, it was anticipated, would so occur in the intervals between the others that they would all fall into a new column to the left of "Group 1."

In the year 1892 Lord Rayleigh was investigating the question of the density of a number of different gases, including, so it happened, nitrogen. Now there are several ways of procuring nitrogen. One is to get it from the atmosphere by ridding it of the oxygen with which it is normally mixed. Another way is to split up some compound, such as ammonia, of which it forms a part, in such a way as to catch the nitrogen and leave the other elements with which it was combined elsewhere.

Lord Rayleigh tried both ways, and he found that the nitrogen from the atmosphere was denser than that derived from ammonia. Sir William Ramsey then carried the matter a step further. He heated atmospheric nitrogen in the presence of magnesium, under which conditions some of the nitrogen combines with the latter element to form nitride of magnesium. That, it was found, made the remaining nitrogen denser still. The explanation then seemed obvious. Suppose we imagine a mixture of sawdust and iron filings: it will be heavier than an equal quantity of pure sawdust. And if we contrive to take away some of the sawdust from the mixture we shall find that what is left is heavier still, when compared with an equal bulk of pure sawdust. For it is clear that as we take away sawdust we thereby increase the proportion of the heavier iron filings and so we make the mixture heavier.

Applying a similar process of reasoning to these discoveries, the conviction grew that the nitrogen of the air was not pure, but that it had mixed with it a small proportion of some other gas of greater density. They soon succeeded in isolating this denser gas, to which they gave the name of argon. Its atomic weight was found, and, wonderful to relate, it was such that argon fell into a new column to the left of Group 1, as had been anticipated.

The discovery of argon was announced in 1894. The next year Sir William Ramsey, investigating a gas which had been discovered locked up in the interstices of a mineral called clevite, was able to state that it was helium, the element which had been previously noticed by the spectroscope in the sun. Like argon, it was found to be extremely inactive, and its atomic weight turned out to be such that it too fell into the "Zero Group."

In 1898 Professors Ramsey and Travers found two more gases in the air, krypton and neon, and a little later still, there was found mixed with the krypton a further new gas, xenon. All of these had their atomic weights found, and fell into that new column in the periodic table.

But what has all this got to do with liquid air? The two subjects are closely related, for it is by liquid-air machines that these rare gases are now obtained, and it was from liquid air that the last three were first discovered.

For air, as we well know, is a mixture of gases, and when extreme cold and pressure are applied these gases liquefy, each behaving according to its own nature. They do not all liquefy at the same time, nor on being relieved from the pressure and heated do all evaporate again at the same temperature. Although they emerge from the liquid-air machine in the form of a single liquid, it is really a mixture of liquids, each with its own boiling-point.

In an earlier chapter we saw how petroleum can be separated into its various constituents, such as petrol, by fractional distillation, advantage being taken of the difference in the "boiling-point" of the various "fractions." The boiling-point of a liquid is, of course, the temperature at which it turns freely into vapour, and just as petroleum when heated gives off first cymogene, next rhigolene, then petrol, benzine, kerosene and so on, in the order named, so liquid air, when it is evaporated, gives off its different constituents in order. Nitrogen, oxygen, argon, helium, krypton, neon and xenon can all be separated each from the others in this way, by "fractional distillation." The heat from the surrounding objects is allowed to get at the liquid, and the gases are then given off in the order of their boiling-points.

And thus we see how the mechanical production of cold has assisted in the pursuit of pure science. The newly-found gases are not of any great use at present. They are so inactive that possibly they never will be, with one exception, and that is neon. If an electric discharge be made to pass through a tube filled with this gas, a beautiful glow is the result, and it is just possible that neon tubes may become the electric light of the future. That is only a prediction, however, and a hesitating one at that.

The inactive elements may become of value in explosives. We have seen how important nitrogen is in these dangerous substances, the chief feature of which is their instability—their readiness, that is, to change into something else—which instability is due to the reluctance with which nitrogen enters into them. Now nitrogen, though inactive, is much less so than these others, and if a way should ever be found of inducing them to enter into a compound, that compound will probably be an extremely powerful explosive.

CHAPTER VI

SCIENTIFIC INVENTIONS AT SEA

THE safety of our fellow-creatures has always been a strong stimulus to our inventive faculties. The occurrence of a bad railway accident, and, roughly, its nature, can be inferred from the files of the Patent Office, for such an event brings men's thoughts to devising ways and means of preventing a recurrence, and an avalanche of such inventions descends upon the patent department in consequence. In like manner a particularly distressing accident to a lifeboat some years ago brought out many inventions for the improvement of those romantic craft. Many of the inventions which arise under these conditions are, of course, utterly worthless, but some of them "come to stay."

It is not surprising, therefore, when we think of the almost innumerable wrecks which happen, even with modern shipping, that human ingenuity has been extremely busy in devising ways for bringing more of safety and less of risk into the lives of those who go down to the sea in ships. Of these perhaps none is more fascinating than the modern lighthouse, with its tall tower, its brightly flashing light, standing undisturbed in the wildest storm, quietly and persistently sending forth its guiding rays, no matter how the elements may be buffeting it. There is something specially attractive in this perfect embodiment of quiet strength and devotion to duty.

Of course, its origin is very ancient. One of the earliest inventions, no doubt, was the bright thought of a very primitive man who lit a fire on a hill to serve as a guide to some belated friends out in their fishing canoes. From some such beginning the modern lighthouse, a magnificent product of the science of civil engineering and the science of optics, has arisen.

Of the difficulties encountered in the construction of lighthouse towers on outlying rocks much has been written. The historic Eddystone, for example, has quite a voluminous literature of its own. Of the light itself, however, much less is known.

It will be interesting first to note the different purposes for which a light may be required, and then see how the apparatus of the lighthouse is made to serve these purposes.

There is the "making" light, perched, if possible, upon some high eminence, deriving its name from the fact that the sailor sights it as he is "making" the land. Vessels approaching England from the south-west by night first see the light at the Lizard. The transatlantic vessels know they are approaching land by catching sight of the Fastnet Rock light off the coast of Ireland. Cape Race light serves in the same way for those about to enter the St Lawrence and Navesink for the entrance to New York harbour. All such as these have to be of the greatest power practicable, so that they may be visible not only at the longest possible distance, but also under unfavourable conditions, such as haze and slight fog. No light, of course, can penetrate thick fog, but in light fog and haze a powerful light can be seen at considerable distances. For the same reason these lights must be high up, or the curvature of the ocean's surface will limit their range. A light elevated 100 feet above the sea-level will be visible nearly 16 miles away, but if only 50 feet up it will be invisible at 13 miles. To be seen 40 miles away it must be as high as 1000 feet.

But then again height is in some cases a disadvantage, for sometimes fog hovers a little distance above the sea, while below it the air is clear, and the higher a light may be the more likely is it to have its lantern immersed in a floating cloud of fog. Many readers familiar with the south coast of Britain will remember that the light which used to show on the summit of Beachy Head is there no more, but has been replaced by a tower at the foot of the cliffs, the reason being that it may be below the clouds of fog which are prevalent at that point.

But the mention of Beachy Head introduces us to another class of lights, known as " coasting " lights, since they are intended to lead the mariner on from point to point along a coast. It will be seen at once that in many cases they do not need to be visible at such great distances as the making lights. When the mariner has sighted the Lizard, for example, he knows where he is. In order that he may learn that important fact as soon as possible it is desirable that that light should have the greatest possible range, but having thus located himself, when he begins to feel his way along the English Channel he is guided by the coasting lights, and so long as they are of such range that he will never be out of sight of one or two of them that will be sufficient. Thus the Beachy Head light, in its present low position, has a sufficient range for its purpose, with the added advantage of more freedom from obscuration by fog. Thus we see how the local conditions and the purpose of each particular light have to be taken into consideration in determining its position and power.

The Eddystone, again, is an example of a further class. It simply serves to denote the position of a group of dangerous rocks. Its function is not so much guidance, although no doubt it often serves for that, but for warning. The Lizard light beckons the on-coming ship to the safety of the English Channel; the Eddystone warns it away from danger. The latter, therefore, and similar lights are " warning " lights.

Right at the entrance to the English Channel, that greatest of all highways for shipping, there lie the Scilly Isles. This group comprises some few islands of fair size from which we draw those plentiful supplies of beautiful spring flowers, but it also includes a large number of rocky islets which have sent many a strong ship to its doom. On one of the islets, therefore, the Bishop's Rock, there now stands a very

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A COLD STORE

Interior of a cold store, in which meat and poultry are kept good and fresh by the use of machine-made cold. – *See* p. 67

powerful light which exemplifies many whose purpose is the double one of welcoming the mariner as he approaches our shores and at the same time warning him of a local danger. Such are both making and warning lights.

Of no less importance, though less impressive, are the guiding lights, which guide the ships into and out of harbours and through narrow channels. These are generally arranged in pairs, one of the pair being a little way behind and above the other. Thus when the sailor sees them both, one exactly over the other, he knows he is on the right course.

Sometimes lighthouses have subsidiary lights as well as the main light, to mark a passage between two dangers, or to give warning of some danger. The subsidiary lights are often coloured, and they are generally " sectors " showing not all round a complete circle, or even a considerable portion of one, but just in one certain direction. They are generally shown from a window in the tower lower down below the main light.

Finally, it is important to remember that every light must be distinguishable from its neighbours. Hence every one in any given locality has a different " character " from all the others. This character is given to it by means of flashes. Instead of showing, as the primitive lights did, a steady light, the modern lighthouse exhibits a series of flashes, the duration of which, together with the intervals between, give it its distinctive character. This flashing arrangement has a further advantage over the steady light. Each flash can be made more powerful than a steady light could be. But of that more later.

The actual source of light varies with circumstances. The electric arc is, as we all know, a very powerful light, in fact it can be made the most powerful of all, but its light is decidedly bluish. Now the time when a light is most of all needed is when the weather is thick. Fogs varying from a slight haze to a thick pall of darkness are of very common occurrence, and the lighthouse light must be able as far as possible to penetrate them.

As a matter of fact clean fog, such as one gets at sea, is not by any means opaque. The black fogs of the great cities are another matter, but they are not the sort which afflict the mariner. On a foggy day in the open country or by the sea it is often particularly light; indeed the light is of a peculiarly diffuse nature which gives a nice even illumination to everything. Thus we see that fog is really transparent, but it diffuses the light. It does not stop the light rays, but simply bends them about and scatters them in all directions. Thus we can see nothing through the fog, yet a flood of light reaches us through it. In its effect it is like that " crinkled " glass which is often used for partitions between rooms, which lets light through, but which cannot be *seen* through.

We see, then, that the effect which a fog produces is mainly to refract the light rays. Each little drop of water (for it must be remembered that fog is myriads of tiny drops of liquid ; it is not vapour) acts like a minute lens, and bends the rays which pass through it. And the more blue a ray is the more it is bent. On the contrary, the more red it is the less is it bent. When a beam of light is analysed in the spectroscope the red rays are bent least and the blue rays most, so that the red rays fall at one end of the spectrum and the blue at the other.

Now we only *see* a thing when light rays proceeding from every part of it fall straight (or nearly so) upon our eyes. Consequently, since red rays are bent and scattered by the fog less than blue rays are, a red light will be more easily seen through a fog than a blue one. It might seem from this that a red glass put in front of a light would make it better for this purpose, but that is not the case, for the simple reason that filtering the light through red glass does not really make it any redder than it was before : it simply makes it look redder by extracting from the original light all except the red. But a source of light which is *naturally* reddish is so because it is more plentifully endowed with red rays, while a bluish light like the electric arc is naturally deficient in red rays. Consequently we should be inclined to expect from theory that the electric arc would not be a good light for a lighthouse, since it would lack penetrating power in foggy weather. Some readers may have noticed themselves, in towns where electric lights and gas lamps are in use near each other, that the latter, though relatively feebler under normal conditions, seem to give more light in fog. And experiments show that this is really the case. So although there are some lighthouses with electric arc lights, that which is now believed to be the best is an oil lamp of special design, using a mantle of the Welsbach type.

The oil is stored in strong steel reservoirs into which air is pumped by means of a pump not unlike those used to inflate bicycle tyres. By this means a pressure is maintained upon the oil of about 65 lb. per square inch. This forces the oil up a pipe and drives it in a jet into a vaporiser, a tube heated from the outside so that in it the oil is turned into gas. This gas then rises to the burner and heats the mantle, just as the gas does in the ordinary incandescent gas light. Indeed in the case of lights on the mainland near a town the gas from the town main is often utilised. But this simple arrangement for using vaporised oil, as will readily be seen, can be employed anywhere. A little of the gas produced is led through a branch pipe and burnt to heat the vaporiser. To start the apparatus the vaporiser is heated with a little methylated spirit. Thus everything is quite self-contained and so simple that there is little to get out of order. The largest size of lamp will give 2400 candle-power, with an expenditure of 2¼ pints of oil per hour, just common oil, too, of the kind used with ordinary wick lamps.

Having got a source of powerful light, the next thing is to collect that light and throw it in the direction required. For the light proceeds from the lamp in all directions (practically), and much of it would be entirely wasted could it not be collected and guided in the required direction.

The earliest attempt at this was to use a reflector of bright polished metal. In the most improved form these were made to that peculiar curve known as a parabola. This is a curve obtained by cutting a cone in a certain way, wherefore it is one of the "conic sections," and its particular appropriateness for this work resides in the fact that if a light be placed at a certain point known as the "focus" all the diverging rays which fall upon the reflector will be reflected in the same direction, parallel to each other. An ordinary spherical mirror would reflect them either back to the lamp or in diverging directions.

At any distance the beam from the parabolic reflector will be more intense than that from the spherical one, since the rays will be closer together. But even with the parabolic one there is some diffusion, for the simple reason that whereas the focus is a mathematical point (position without magnitude) the most concentrated form of light known has a considerable magnitude. Hence the rays proceeding from the centre of the mantle are reflected as per the theory, but those from the outlying parts of it are somewhat diffused. This difficulty cannot possibly be overcome, and hence even in the finest examples of lighthouse architecture the flashes are not quite sharp and clear-cut. There is a central moment, so to speak wherein the flash is almost blinding in its intensity, but it is preceded by a period of growing brightness and succeeded by one of decreasing light.

In the modern apparatus, however, metallic mirrors are entirely dispensed with, their place being taken by reflecting prisms of glass. The metallic ones had to be continually rubbed to keep them clean, and this soon dulled their brightness, while the glass prisms need only to be wiped carefully, which operation has little effect upon their surface.

It may come as a surprise to some that reflecting prisms are possible. The idea of refraction through a prism is quite familiar. Such forms the essential principle of the spectroscope. Refraction is explained to every school child in order to account for the rainbow. But *reflection* by a piece of the clearest glass seems a contradiction in terms almost. Yet it is only a question of shape. In some prisms the light is simply bent as it passes through. In others it is bent twice, so that it leaves the prism just as if it had been reflected off a mirror. Both devices are used in the lighthouse. Let us see how they are combined so as to perform the work to be done.

Take first of all the case of a light upon an isolated rock where the warning is needed equally all round. All that is necessary here is to pick up those rays which, if left to themselves, would fall upon the water near the foot of the tower, and those which would waste themselves skywards, and then to gather all the rays into several bundles or beams. We will suppose a simple case in which the light is supposed to give flashes at regular intervals.

We are in the topmost room of the lighthouse, the lantern, as it is called. In the centre there stands the murette or pedestal. In this several columns support a circular platform on the top of which there moves what we might call a turntable, which in turn bears a frame of gun-metal into which are fitted a maze of glass bars triangular in section and curved to form concentric circles. The whole structure, possibly, is of great size. From the floor to the platform is as high as an ordinary man. Indeed around the turntable there is a gallery which forms a roof over our heads, so that it is only after mounting some iron steps on to this gallery that we are able to examine the glass part.

As we ascend we notice that the walls of the chamber as far up as the gallery are formed of iron plates, while above that there is a metal framework filled in with glass panes, and above all a dome-shaped roof.

Having reached the platform we proceed to examine the glass, and we find that the metal framework forms a cage with four sides, each approximately flat, but really slightly spherical. Each of these sides is called a "panel." In the centre of each is a lens. Peeping through the interstices between the prisms, we perceive that the lamp is inside this structure, exactly in the centre, so that its light shines directly through the central lens or bull's eye. Around this bull's-eye are many circles of glass bar, forming refracting prisms. Around this again are more bars in the form of segments, which together form circles, some being refracting prisms and others reflecting prisms. All the light rays from the lamp which fall on any one prism are deflected, so that they proceed approximately in the same direction. Those prisms in the upper part lay hold of the rays which would otherwise go up into the sky. Those at the bottom collect those which would fall near the foot of the tower. So scarcely any are lost. But for the fact that the lamp itself is comparatively large and not a theoretical point, as already explained, the beam from this panel would be perfectly straight, parallel, and of uniform density everywhere. As it is, it widens slightly as it proceeds, but, practically speaking, we might call it a solid beam of light.

Each of the panels sends forth such a beam, so that they strike out in four directions from the central lamp much as four spokes from the hub of a wheel.

Then descending once more to the floor from which we started, we see that among the columns there is a large clockwork arrangement, the purpose of which is to drive round the turntable and all that it carries—in the language of the lighthouse engineer the "optical apparatus" or, more briefly, "the apparatus." And as this turns the radiating beams of light sweep round the horizon and in succession strike into the eyes of any mariner who may be within range. Each time a beam strikes him he sees a flash. If the apparatus revolve once a minute he will see four flashes every minute, one from each panel.

Let us consider, then, the advantages of this wonderful mechanism, with its cunning arrangement of prisms. It is these latter, of course, which are the important thing. The rest, the mechanical portion, is simply for the purpose of holding them and turning them at the proper speed. In the first place, the contrivance gives us flashes instead of a steady light; it gives the lighthouse its "character." Then again it enhances the brightness of the light. Instead of shining all round, the light is concentrated in four special directions, and the light which would be wasted upwards or downwards is saved and brought into use.

But suppose that the lighthouse we are considering be near the shore, so that there is no need for it to throw any light in one—the landward—direction. Then we should see inside the revolving framework with its prisms a fixed frame with reflecting prisms which would catch any rays going from the lamp in the direction of the land and simply hurl them, as it were, back into the flame. Thus the intensity of the flame becomes increased by those rays thrown back which would else have been wasted.

Or suppose that the character of the light is such that the flashes have to be at irregular intervals. Then the framework, instead of being symmetrically four-sided, would be of an irregular shape.

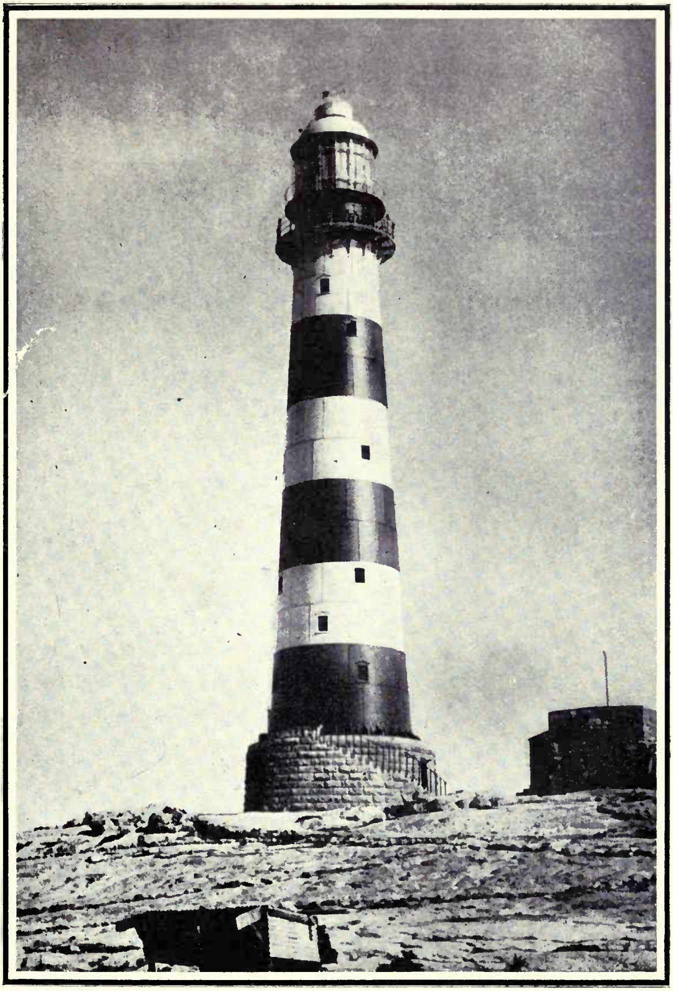
And that brings us to a beautiful feature of the mechanism of the apparatus. We have been discussing a four-panel arrangement. Suppose that we were to reduce it to three. Then, since all the light would be concentrated into three beams instead of four, each beam would be more intense. We should thereby have increased the range of our apparatus without any increase in the cost of oil—for nothing, as it were. But to get the same namber of flashes per minute we should have to drive it round so much the faster. But increased speed means increased burden on the keepers who have to wind up the heavy weights which operate the clockwork. So there is a limit to the speed which can be attained.

But if friction can be almost eliminated the apparatus can revolve at a high speed without throwing undue burden upon the men. But how can friction thus be got rid of? Messrs Chance Bros., the great lighthouse constructors, of Birmingham, have done it, almost entirely, by floating the apparatus on mercury. The turntable has on its under side a large ring which nearly fits a cast-iron trough on the top of the pedestal. In this trough there is mercury, so that upon the liquid metal the apparatus floats as if upon a circular raft. The table with its lenses, prisms and other fittings may weigh six or seven tons, yet it can be pushed round by one finger.

The various sizes of optical apparatus are known as "orders." One of the "first order" has a focal distance of 920 millimetres. This means that there is that distance between the centre of the lamp and the bull's-eye. They descend by successive stages down to the sixth order, with a focal distance of 150 millimetres, while the most important lights are of an order superior even to the so-called "first," termed the "hyper-radial," the focal distance of which is 1330 millimetres.

A recent example of a hyper-radial light is at the well-known Cape Race in Newfoundland. It revolves once every 30 seconds, giving a flash of 3 seconds every 7½ seconds. The optical apparatus weighs seven tons.

Most lighthouses are fitted with fog signals of some kind which have a distinctive character the same as the lights. Some are horns blown at intervals by compressed air often obtained from a special air-pump driven by an oil-engine. Another thing is to let off detonators at stated intervals. But perhaps the most interesting of all is the submarine telephone. The trouble with audible signals is that they are apt to vary as the conditions of the atmosphere change. For, strange though it may appear, the air which is the natural medium by which sounds are carried to our ears is really a very bad substance for the purpose. Water is much superior. A swimmer who cares to try the experiment of lying upon the water with his ears immersed while a friend beats a gong under the water some distance off will be astounded at the result. So many modern ships are fitted with under-water ears, waterproof telephone receivers, really. One is fixed each side of the vessel, the wires from them being led to telephone receivers near the bridge. Many lighthouses and lightships in like manner are fitted with



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DASSEN ISLAND LIGHTHOUSE, CAPE OF GOOD HOPE

This lighthouse, 80 feet high, is built of cast-iron plates, bolted together

under-water bells which can be rung at intervals. The sounds so conveyed through the water are always the same. Atmospheric or similar changes have no effect upon them. And, moreover, the officer can tell which side of his ship the bell is. If it be on his port-side it sounds louder in his port telephone, and vice versa. By turning his ship until he hears them equally he knows that he is pointing directly to or from the bell. Thus if the bell belong to a warning light he can steer confidently right away from the danger even in the thickest fog.

But science has not only provided the mariner with lights of marvellous power and of strange distinctive characters, and reliable sound-signals for foggy weather, it has also found him a reliable compass, but that is worthy of a chapter to itself.

CHAPTER VII

THE GYRO-COMPASS

THE magnetic compass has been for ages the mariner's guide over the trackless waters. In cloudy weather it has been his only means of knowing the direction in which his craft was heading. Indeed, it is not too much to say that the maritime commerce of the world was based upon the behaviour of that little piece of magnetised steel.

It has always, however, been subject to certain faults. To commence with, it points, not to the geographical north, but to the "magnetic pole," a point some distance from the geographical pole, and one, moreover, which is not quite permanent. The fact that the magnetic pole varies its position is impressively shown by the fact that a special department at Greenwich Observatory is continually employed, by the aid of delicate self-recording instruments, watching and setting down its fluctations. And the premier observatory of the world, it should be remembered, exists primarily, not in the interests of pure science, but as a department of the British Admiralty in order to study matters of interest to navigation. Thus we have testimony to the importance of these little vagaries on the part of the magnetic compass.

But in addition to these inherent faults there is a new source of error in the magnetic compass which man has introduced himself by making his ships of iron instead of wood. Every ship of the present day is a huge magnet. A piece of iron left in the same position for a length of time becomes polarised, which is to say that it acquires the properties of a magnet; and two magnets always exert an influence upon each other. Consequently the ship, after lying for perhaps a year in one position, during the period of building, becomes itself magnetic and interferes with its own compass.

Then, again, our methods of ship construction aggravate this trouble. It is believed that every molecule of iron is itself a minute magnet with a north and south pole of its own. These lying in confusion in the mass of unmagnetised iron neutralise each other, so that the mass, taken as a whole, does not exhibit any magnetic power. But if by some means the whole of the millions of millions of molecules can be set the same way—with all their north poles in one direction, and their south poles in the opposite direction—then they will all act together. Instead of neutralising each other they will then help each other, and under those conditions the mass of iron will possess that peculiar power which is distinctive of a magnet. So long as a piece of iron is left in the same position the magnetism of the earth is thus acting upon the molecules. Just as it tends to place the compass needle north and south, so it does with every molecule in the iron mass. And if, while lying still, the iron be hammered, the shaking of the molecules due to the hammering loosens them as it were and assists the earth's power in pulling them into position.

One has only, then, to watch the riveting up of a ship, and to see the vigorous way in which the riveters wield their hammers, to realise that when the thousands or even millions of rivets have all been finished the material of that ship will have had the very best possible chance of becoming magnetic.

To make matters worse still, ships are often loaded with great weights of iron among their cargo. That, too, may affect the compass. On warships there are the heavy guns, each weighing, with its turret, hundreds of tons, and they move, so that their effect upon the compass is not always the same, but may vary from time to time. And finally one may mention the electrical machinery in a modern ship consisting largely of powerful magnets.

Altogether, then, it is not surprising that the old magnetic compass is somewhat unreliable. It has to be coaxed into doing its duty. Pieces of iron and magnets have to be disposed about it to counteract these disturbing influences with which it is surrounded. Before a voyage experts have to come on board to adjust the compasses, and even then there is reason to believe that the instrument sometimes plays the ship false.

It is not to be wondered at, then, that the naval authorities in particular throughout the world have welcomed the advent of a new compass which appears to possess none of these drawbacks. It points to the geographical north, to the actual pivot, if one may so speak, upon which the earth turns. It is non-magnetic, so that the presence of iron or magnets even in its immediate neighbourhood has little or no effect upon it. On the other hand, it has to be driven by a current of electricity, and it seems just possible that in some great crisis it might fail, although every provision is made for alternative sources of supply in case of one failing, and there is always the possibility of falling back upon the old magnetic compass should the new one go wrong.

In principle the improved compass is, like its older brother, simplicity itself. The latter is but a small piece of iron magnetised ; the former is nothing more than a spinning-top.

It is rather strange that although the spinning object has been a familiar toy for years, and that, moreover, its behaviour has been the subject of investigation by some very eminent scientific men, it is only of recent years that its principles have been put to practical use.

Everyone is familiar with the fact that a round block of wood will support itself upon a comparatively tall peg so long as it is rapidly rotating. And that is but one of the curious things which a rotating body will do. For example, imagine a wheel mounted upon an axle the ends of which are supported inside a ring, while the ring again is supported on pivots between the two prongs of a fork, the fork being free to swivel round in a socket. The wheel is then free to move in any direction. Technically, it is said to have "three degrees of freedom." It can spin round, its axle can turn over and over with the pivoted ring inside which it is fixed, while it can also swing round and round as the fork turns in its socket. Assuming that the joints are all perfectly free, that the pivots move in their sockets with perfect freedom—which, of course, they do not—then a wheel so mounted could move in any direction under the influence of any force that might act upon it. Now a wheel so mounted if left alone remains in precisely the same position so long as it goes on rotating. If it be turning sufficiently quickly its tendency to remain will be strong enough to overcome the friction of any ordinarily well-made instrument. Consequently a wheel of that description has been used to demonstrate the rotation of the earth, it remaining still (except, of course, for its rotating movement) while the earth has moved under it.

Could we entirely eliminate the effects of friction that might be used as a compass, for it could be set, say with its axle pointing north and south, at the commencement of the voyage, and it would remain so despite all the evolutions through which the ship might go.

But there is a better scheme even than that, based upon the peculiar behaviour of a revolving wheel when it has only *two* degrees of freedom. Suppose that we dispense with the ring employed in the previous arrangement, pivoting the ends of the axle between the prongs of the fork. The wheel is then free to rotate, and its axle can slew round through a complete circle by the turning of the fork in its socket, but there can be no tilting of the axle. Being thus deprived of one of its movements the gyroscope with three degrees becomes a gyroscope with two degrees of freedom, and in that form it supplies the need for an efficient and reliable compass.

The secret of the whole thing is the curious fact that a gyroscope with two degrees of freedom exhibits a keen desire to place its axis parallel with the axis of the earth. Owing to the shape of the earth, a device such as has been described, with its fork standing up vertically, cannot possibly have its axis really parallel with that of the earth, except on the Equator. Still it gets as nearly parallel as possible. To be scientifically accurate, we ought to say that it places it own axis " in the same plane " as that of the earth.

To understand this we need to realise that all movement is relative. In ordinary language, when we say a thing is still we mean that it is still in relation to the surface of the earth, but since the earth is moving the stillest thing, apparently, is really travelling at enormous speed.

Saint Paul's Cathedral in London, or a tall sky-scraper in New York, would usually be regarded as supreme instances of immobility. It would be hard to find better examples of stationariness, as we ordinarily look at things. Each stands, firm and strong, upon a horizontal base. Yet each is really turning a somersault every twenty-four hours. The plateau upon which St Paul's stands, though it seems still and motionless beneath our feet, is continually tilting; its eastern edge is continually going downwards and its western edge upwards, as the earth performs its daily spin. It is only a north and south line which does not share in some degree this continual tilting action. Every plane, large or small, so long as it remains horizontal, is being tilted thus, down at the eastern edge and up at the western. And the plane in which the axle of a gyroscope with " two degrees " is free to move is a horizontal plane. Owing to its being held between the prongs of the fork, while it can swing round to point north, south, east or west, or towards any point between them, it cannot deviate from the horizontal plane. Therefore such axle is always being tilted by the motion of the earth, *except when it happens to be lying exactly north and south.*

Now for a reason which is too complex to go into here a gyroscope strongly objects to having its axle tilted in this manner. If it be compelled by superior force to submit to tilting, it tries to wrench itself round sideways. Anyone who has a gyroscope top and cares to try the experiment will feel this action quite easily. Hold the spinning-top in your hand and turn it over so as to tilt the axle, when it will, if you are not careful, twist itself out of your grasp.

So a gyroscope of the kind we are considering, when the motion of the earth tilts its axis, turns itself round in its socket until at last it reaches the north and south position, when the tilting, and therefore the twisting, ceases. Hence the axle of the gyroscope if left to itself (the rotation of the wheel being maintained the while) will place itself in a north and south direction. And, moreover, it will keep in that direction. It will take some force to slew it round into any other. And if moved into any other by some extraneous means it will restore itself to the old position again.

Hence a wheel thus arranged has all the attributes which we need for a mariner's compass. But unfortunately there are mechanical difficulties in the way of using such a simple contrivance for that purpose.

Chief of all these is the fact that it is not what engineers call "dead-beat." That means that it will not go to the proper position and then remain there quite still. Instead, it will first slightly overshoot the mark, which being followed by the reverse action, it will come back and overshoot it just as far in the opposite direction. Instead, therefore, of a steady pointing, always in the same direction precisely, it will oscillate more or less, the exact north and south line being the mean or average position, the centre of the oscillations.

It would of course be possible to damp this, to apply a break as it were, if the apparatus were to remain stationary. For example, if the whole concern were immersed in water the resistance of the liquid would restrain any quick movement of the axle, yet it would not prevent it from slowly finding its true position. Thus the oscillations would be reduced to such a small range as to be for practical purposes negligible. But the drawback to a device of that kind, applied to a gyroscope on board ship, would be that the axle would be carried round to some extent every time the ship turned. As she changed direction it would more or less carry round the water with it; that in turn would carry the gyroscope, and so the direction of the latter would be for a time untrue. It would in course of time regain its accuracy, but in the meantime it would be leading the ship astray.

Consequently the application of this, in itself wonderfully simple, idea, to this extremely important purpose was accompanied with a difficulty which was for a long time insuperable.

But all was overcome at last by the genius of Dr Anschutz, of Hamburg, whose firm were the first to turn out the practicable article. Taking advantage of another movement of the gyroscope when arranged as has been described, and using the revolving wheel itself as a centrifugal fan, he was able to make the wheel blow air "against itself," as it were, when in any position other than north and south. Thus, if it deviates towards the east, this jet of air tends to blow it back; if it turns westwards the jet again comes into operation, tending to bring the erring gyro back to its proper place; and so the tendency to oscillate is checked.

The finished instrument as it is installed on the latest warships is, of course, quite different in detail from the simple contrivance which we have been considering so far, although it is the same precisely in principle. The essential part is a heavy metal wheel combined with which is an electric motor which keeps it rotating at a speed of 20,000 or so times per minute.

The bearings of the wheel are supported upon a metal ring which floats upon the surface of a trough of mercury. Thus friction is brought down almost to the irreducible minimum. The only place where the wheel and its supports touch anything solid is at one delicately made pivot which serves to keep the floating mechanism in the centre of the mercury basin, and to prevent it from rubbing against the side of it. The current which drives the motor reaches it through this pivot and leaves through the mercury. Thus arranged, although the floating part is of considerable weight, a very slight force indeed is enough to move it; while, looking at it the other way, we can see that the ship might turn rapidly to right or to left, carrying round the mercury bowl with it, without turning the floating part at all. Thus the gyroscopic action is very free indeed to exercise its function of keeping the contrivance pointing always in the one way.

The float has mounted upon it a compass card much like that of the ordinary magnetic instrument, and the sailor reads it in precisely the same way. To outward appearance there is little essential difference; in one case there is a magnet under the card to keep it still, in the other there is the float with the revolving wheel mounted upon it.

It is customary to have one "master compass" of this kind on a ship, with an electrical repeater in each of the steering positions. As the "master" turns in its casing it sends a rapid series of currents to all the others, causing them to turn in unison with it. The "master" is fitted in some safe part of the ship where it is least likely to be the victim of any accidental damage.

CHAPTER VIII

TORPEDOES AND SUBMARINE MINES

IT is sad to think how much scientific skill and learning has, during the Great War, been devoted to killing people. It used to be thought that one day a great scientific invention would arise, of such deadly power that for ever afterwards war would be unthinkable ; its horrors would be such that all nations would shrink from it. That prophecy, however, has not been fulfilled, nor are there any signs of it. On the contrary, each scientific achievement in the realm of warfare is quickly countered by another : so much so that with all our science in the manufacture of weapons, and our skill in using them, warfare in the twentieth century is if anything less deadly in proportion to the numbers engaged than it used to be.

There are, however, two weapons which in this war have reached a deadly efficiency which they did not seem to possess before, and to which satisfactory antidotes have not yet appeared.

These two are the submarine mine and the torpedo. The latter, particularly, had been a dismal failure previously, but as the weapon of the submarine it has now established itself. It is, however, only in connection with the submarine that it has achieved any measure of success, and, as there are strong indications that very soon the submarine itself will be robbed of its terrors, it is quite likely that the reign of the torpedo will be brief.

Although it has only just made itself felt seriously in warfare, the torpedo is a fairly old idea. In fact we can trace the general idea of it back to very ancient times. The modern weapon, however, dates from the year 1864, when an

Austrian inventor approached an English engineer named Whitehead with a request to take up his idea. Mr Whitehead had at that time a works at Fiume, on the Adriatic, and it was really his genius that developed the crude idea into a practicable invention.

Thus there came into existence the Whitehead Torpedo, now used in a great many navies, and also the Schwartzkopff, which may be regarded as the German variety of the same thing.

Speaking generally, it may be described as a small automatic submarine boat. Externally, it naturally follows somewhat the lines of a fish. Deriving its name from that curious fish which is able to give electric shocks from its snout, it likewise carries on its nose that appliance whereby it gives a shock, not electric it is true, but equally deadly, to anything which it may touch.

Since no man-made mechanism can approach the marvellous action of the fish's fins and tail, the propulsion is achieved by a propeller like that of a steamboat, but of course on a very small scale. A single propeller, however, would tend to turn the torpedo over and over in the water, and so it has two, one behind the other, driven in opposite ways, so that the turning tendency of one is neutralised by that of the other. The blades of the propellers are, however, set in opposite ways, so that although rotating in different directions they both push the torpedo along.

Behind the propellers, again, there are rudders for steering. One steers to right or left, as does that of an ordinary ship, while two others are so placed that they can steer upwards and downwards.

So there we have the general picture of the outside: a smooth, fish-like body with a "sting" in its nose, propellers at the rear to drive it along, and rudders to guide it.

Inside are various chambers. One contains the explosive which blows up when the nose strikes something. This "head," as it is termed, is detachable, so that it can be left off until it is really required for war. The peace-head, which is of the same size, shape and weight as the war-head, is what the torpedo carries during its earlier career. With this it can be tried and tested in safety, the war-head being substituted when the real business of the torpedo begins.

Another chamber contains the compressed air which furnishes the motive power. This also serves to give buoyancy.

Another chamber, again, contains the engines, beautiful little things of the finest workmanship almost exactly like the finest steam-engine, but of course very small in comparison.

In the early stages the range of the torpedo was limited by the amount of compressed air which it could carry. At first sight there seems no reason why any limit should be placed upon this, but in practice there are often limitations in engineering matters which are not apparent on the surface. For example, to increase the air chamber would mean enlarging the whole torpedo, calling for more propulsive power and larger engines, and these larger engines would call for more air, thus defeating the object in view. Forcing more air in by using a higher pressure, in a similar way would necessitate a thicker chamber, to resist the higher pressure. This would add weight, calling for more buoyancy. Thus there seemed to be a practical limit beyond which it was impossible to go.

The difficulty was overcome, however, in a very cunning way. When the engines have used some of the air, and the store is somewhat exhausted, chemicals come into action which generate heat, which is imparted to the air which is left. This heat expands the air, producing in effect a larger supply of it, and enabling the torpedo to make a longer journey.

Steering in a horizontal direction—that is to say, to left or right—is done by a gyroscope. The action of a rotating wheel is discussed in the last chapter, and it is not necessary here to say more than this : a rotating wheel always tries to keep its axle pointed in the same direction. Just at the moment of starting such a wheel is set going inside the torpedo, and its arrangement is such that, should the torpedo swerve to the left, the gyroscope operates the rudder and steers it back. In the same way, if it tends to turn to the right, the ever-watchful gyroscope brings it to its true course once more. The effect of the gyroscope, therefore, acting upon the rudder, is to keep the torpedo faithfully to the direction upon which it is started.

The up and down rudders are likewise controlled quite automatically, but in a different way. Their function, clearly, is to keep the thing at a certain uniform level. Without such control a torpedo would be equally likely to jump out of the water altogether, or to go downwards vertically and bury its nose in the mud. The depth at which it is to move is determined beforehand, certain necessary adjustments are made, and the torpedo then pursues its even way, neither coming to the surface nor driving beneath its target.

For this purpose there is first of all a " hydrostatic valve." This little appliance, which is open to the action of the water, responds to changes in pressure. The pressure at any point under water is exactly proportional to the depth. At ten feet, for example, it is precisely ten times what it is at one foot. So the hydrostatic valve is adjusted to set the rudders straight when the water-pressure upon it is a certain amount. If, then, it dives downwards the pressure increases and the valve operates the rudders so as to bring it upwards, while if it rise too high the decrease of pressure causes it to be guided downwards.

This action, however, is too sudden and violent, so that with it alone the torpedo would proceed by leaps and bounds. After being low it would come up too suddenly, overshoot the mark, only to be steered downwards again equally suddenly.

The valve, therefore, is combined with a pendulum, whose action tends to restrain these too sudden changes, with the result that under the influence of the two things combined the torpedo keeps fairly well to an even course, only varying upwards or downwards to an extent which is negligible.

Finally, there is an interesting little feature about the firing mechanism which merits a description. The actual firing is caused by the driving in of a little pin which projects at the nose of the torpedo. Suppose that, in the process of pointing the torpedo and launching it upon its course, that pin were to be knocked accidentally, an awful disaster would result. It must be provided against, therefore, and the method adopted is beautiful in its certainty and simplicity.

Normally, the firing-pin is fixed by a screw so securely that no accidental firing is possible. There is, however, a little propeller-like object associated with it, which is driven round by the water as the torpedo is pushed through it, and this unscrews, and thereby releases the pin. The little "fan" has to rotate a certain number of times before the pin is released, and it is quite impossible for this number to be accomplished before the torpedo has proceeded to a safe distance from the ship which fires it. On board the ship, therefore, and so long as it is near the ship, it is quite safe, but by the time it reaches its target it is ready to explode.

As far as is known, the foregoing description gives a true general description of the torpedoes now in use. Those of different powers may vary in detail, but, broadly, they are as just described.

There are others, however. The Brennan, for instance, was once adopted and largely used by the British for harbour defence. This was controlled from the shore by wires. It was driven, so to speak, with wire reins, and thus guided it could fairly hunt down its prey, turning to right and to left as required.

Of greater scientific interest, perhaps, still, is the "Armorl" wireless controlled torpedo. This is the invention of two gentlemen, Messrs Armstrong and Orling, whose first syllables combine to form the title of the torpedo.

Of this, two very interesting features may be mentioned. Firstly, the wireless control. In the chapter on Wireless Telegraphy there is described the coherer, a simple little apparatus which we might describe as a door which is opened by the " waves " which travel through the ether from the sending apparatus. Whenever the key of the sending apparatus is depressed these waves travel forth, and when they fall upon the coherer it " opens." Normally, the coherer is shut, but when acted upon by the incoming waves it opens and lets through current from a battery, which current can be caused to perform any duty which we may wish. Thus, ignoring the intermediate steps, we get this: whenever the sending key is depressed current flows through the coherer and performs whatever duty is set before it.

And now picture to yourself a tooth wheel with four teeth. A catch normally holds one of the teeth, but when the catch is lifted for a moment it lets that tooth slip and the next one is caught. At every lifting of the catch the wheel turns a quarter of a turn. Then imagine that that catch is operated by an electro-magnet energised by the current which passes through the coherer. We see, then, that every time the sending key is depressed the wheel turns a quarter turn.

Attached to the wheel is a little crank which turns with it, and the pin of this crank fits in a slot in the end of a bar like the tiller of a boat. Suppose that, to commence with, the tiller is straight, so as to steer the boat straight. Depress the key, the wheel turns a quarter turn and the tiller is set so as to steer to one side, say the left. Another pressure upon the key and a second quarter turn brings the tiller straight again. Yet another pressure, another quarter turn, and the tiller is steering to the right. Thus by simply pressing the key the correct number of times the torpedo can be made to travel in any desired direction.

The second ingenious feature of this weapon is the means by which it is made visible to the man who is controlling it from the shore or ship. Probably the reason why these torpedoes are not used more is that the man who guides them is of necessity himself visible. He has to be posted somewhere where he can follow its course, or he has no idea how to steer it. Consequently, he would be an object for attack by the enemy. Such a torpedo would be useless in a submarine, for the submarine would need to come to the surface in order that the observer might get a sufficiently good view to be able to steer the torpedo, and we all know that when upon the surface a submarine is a very vulnerable craft.

But that is by the way. The point is how to make the torpedo very clearly visible while it is still under water. A short mast might be used, but that would be liable to be shot away. The inventor had a happy inspiration when he made it blow up a jet of water, like a whale does. This jet is quite easy to see, yet no shot can destroy it. Compressed air blows up this tell-tale jet which the observer can see, and by its means he can guide the torpedo at will.

A submarine mine may be regarded as a stationary torpedo. It consists of a metal case filled with a powerful charge of explosive which floats harmlessly in the water until some unfortunate vessel strikes against it, when it blows up with sufficient force to make a hole in the stoutest ship.

There are two classes of mine: one which is laid in peace time, to protect harbours and channels; and the other, which is laid during actual warfare.

The former are anchored in a more or less permanent way. The services of divers are used to place them in position. In some cases they float well down in the water, out of the way of passing ships, but come up nearer the surface when needed. This result is achieved by having an anchor chain of such a length that when fully extended the mine floats a little way under the surface, just high enough to be struck by a passing ship, together with what is called an "explosive link." The link is used to loop together two parts of the chain, and so, in effect, to reduce its length. Wires pass from the link to the shore, and when an electric current is sent along these wires the link bursts asunder, liberates the chain, and the mine floats up to the full length of its chain.

Another plan is to let the mines float high up always, but to fire them, not by the touch of the ship but by electricity from the shore. In this way a safe channel is kept for friendly vessels, while an enemy can be destroyed.

Necessarily, those mines which are hurriedly laid in war time are very different from these. To be of much use, a mine must be concealed below the surface. If it floats upon the water it will be visible, and can be avoided, or, at all events, easily picked up. It is practically impossible to set a floating object at a certain depth in the water, except by anchoring it to another, heavier, object, which will lie at the bottom. Therefore mines have to be anchored in some way.

But the sea varies in depth, so that the length of the anchor chain must be varied, or else some of the mines will be on the surface, thereby advertising the presence of the mine-field, while others will be below the depth of even the biggest ship. In warfare, however, mines need to be laid quickly. There is no time to sound for the depth and then to adjust the length of cable accordingly. Hence the mine must be so made as to set itself correctly at a pre-determined depth.

Possibly some readers may think that such things might be made to float, of themselves, at the right depth. It is a fact, however, that a thing either floats upon the surface of water or falls to the bottom. Water is practically incompressible, so that the water at the bottom of the sea is no heavier than that near the surface. The conditions which prevail in air and allow a balloon to float at any desired height do not apply. The only thing, in this case, is to have an anchor chain or rope of the right length.

So let us picture a mine-laying ship steaming along, probably in the dead of night, surreptitiously laying mines in the hope that the enemy will run into them on the morrow.

Along the deck of the ship are small railway lines, and on these lines stand what appear to be trains of small trucks, each truck having small wheels to run on, and each bearing a large round metal ball. As the ship travels along, the crew, handling these deadly things quite freely, as if they were innocent of any danger, propel them along to the stern, and at regular intervals push one overboard. That is all.

The freedom with which the men handle them is not folly, for they are then quite harmless. Nor need they trouble about the length of rope, for that adjusts itself. Just tumble the things overboard, and in due time they anchor themselves at the right depth and set themselves in the right condition for blowing up any ship which may get amongst them.

The truck-like object upon wheels is not the mine itself: it is the sinker which lies at the bottom of the sea. The round ball which it bears is the mine, and the two are connected together by a wire rope. To commence with, this rope is coiled upon a drum in the sinker, which drum is either held tightly or is free to revolve according to the position of a catch. That catch is held open, so that the drum is free, by a weight at the end of a short rope. Let us assume that that rope is ten feet long.

Then, when the whole thing is tumbled into the water, the weight sinks first ten feet below the sinker, which, being more bulky in proportion to its weight, follows downwards more slowly. While sinking, the weight is pulling upon its rope and holding open that catch, so that the drum pays out its rope and the mine lies serenely upon the surface. As soon as the weight touches bottom, however, the pull on the short rope ceases, the catch grips the drum, no more rope is paid out, and the sinker, in settling down its last ten feet, has to drag the mine down too. Thus, quite automatically, by what is really a beautifully simple arrangement, the mine becomes automatically anchored at a depth below the surface equal to the length of the short rope. By making that rope the desired length, the depth of the mine under the water can be fixed.

There are various methods of firing these mines, all of which work perforce by the concussion of the ship itself. In some cases the sudden tilting over causes an electric contact to be made, and permits a battery in the mine to cause the explosion. Another way is to furnish the mine with projecting horns of soft metal, inside which are glass vessels containing chemicals. The ship, striking a horn, bends it, breaks the glass, and liberates the chemicals which cause the explosion.

In the type of mine largely used by the British Navy there is a projecting arm pivoted on the top of the mine and projecting from it horizontally. The mine itself rolls along the side of the passing ship, but the arm simply trails or scrapes along. Thus the mine turns in relation to the arm, and a trigger is thereby released, which fires the mine.

In this, be it noted, the ship only pulls the trigger, so to speak, and releases a hammer which does the work, just as the trigger of a gun releases the hammer. The motive force which makes the hammer do its work when the trigger is "pulled" is the pull on the anchor rope. That arrangement has a virtue which is not apparent at first sight.

Since it is the pull on the anchor rope which actually fires the mine, it follows that if such a mine break away from its moorings it instantly becomes harmless.

Safety for the men who lay the mines is secured in several ways. One is by the use of a hydrostatic valve. The firing mechanism is locked until the pressure of water releases it, and that pressure does not exist until the mine is several feet under water. Another way is to seal up the firing mechanism with a soluble seal made of some substance such as sal-ammoniac. The mine cannot then explode until it has been under water long enough for the seal to be melted.

It now remains to relate how these mines are swept up and removed, yet there is very little really to tell, for the process is so exceedingly simple. So far as is generally known, no method has been found that is superior to the primitive plan of dragging a rope along between two ships so as to catch the anchor ropes. The vessels employed are usually of very light draft, so that they stand a good chance of passing over the mines themselves, and the rope used is as long as possible, so that a mine, if exploded by being caught in the loop of the rope, explodes so far away as to do no harm.

When dragged to the surface the mines are exploded from a distance by shots from a small gun, or even from a rifle. In the case of those mines which have horns, a blow from a bullet is enough to break the glass and cause explosion, and in all cases mines seem sooner or later to succumb to a sharp blow. Thus they are destroyed, by their own action, at a safe distance from the sweepers. Accidents happen, however, and mine-sweeping is no job for anyone but the bravest.

It has been somewhat difficult to crowd a description of torpedoes and mines into the small space of one chapter, and so many details have had to be omitted, but the above descriptions give the broad, general principles underlying practically all forms of these terrible weapons.

CHAPTER IX

GOLD RECOVERY

THERE has always been something very fascinating about gold. Even in ancient times it was prized above all other things, and apparently it was comparatively plentiful. It is estimated, for example, that King Solomon possessed over £4,000,000 worth of it, while the little gift which the Queen of Sheba brought him was of the handsome value of £600,000, so that she too must have been plentifully supplied with it.

Probably it was more easily come by in those days, owing to the richness of the primitive deposits, the best of which, perchance, have been worked out. In one respect gold differs from all other metals (with the single exception of platinum, which is scarcer still) in that it appears naturally as gold, not as ore. The little pieces of gold lie in the mine ready to be picked out, and so if the deposit in which it occurs be near the surface, and the particles be of any considerable size, they are sure to be found. A savage may be, and often is, very anxious to secure weapons and tools of iron, little knowing that the very ground upon which he stands is possibly of iron ore. He covets the single article of iron, and in some cases is willing to give much gold for it, or ivory, or some such treasure, while thousands or millions of tons of iron lie at his feet, only he does not recognise it, nor would he know how to utilise it if he did.

For iron, like all other metals except the two just referred to, is found naturally in combination with something else, generally oxygen, and the combination bears no resemblance at all to the metal. The red rust so familiar to us on iron is a combination of iron and oxygen, and it is fairly typical of the kind of state in which iron is found in the earth. Nor would anyone recognise copper ore, lead ore, tin ore, or any of the ores, any better than iron ore. All are difficult to recognise. It is said that the highest compliment that a Cornish miner—the finest metalliferous miners in the world come from Cornwall, or are the product of Cornish influence—the highest compliment that such a man can pay to another is to say that "he knows tin," meaning that he can tell tin ore when he sees it.

Contrasted with these other metals, gold is easy to find. It does, it is true, under certain conditions, form chemical compounds with other things, as, for instance, in gold chloride, which is present in sea-water, but it does not oxidise as the others do, and so when it is in the earth it is in the bright yellow grains such as (if they be large enough) can easily be recognised at sight.

And it is often found in beds of loose gravel, alluvial deposits, as they are termed. In such cases the gold is to be had simply for the picking up. Sometimes a lucky find occurs in the form of a big nugget, but more often the metal lies in tiny grains at long distances apart, so that a ton of gravel has to be sorted over to find a paltry ounce or so of gold. Yet so desired is it that gold will always fetch its price, and an ounce to the ton (even less) is sometimes worth getting.

But in the early history of the world there were possibly particularly generous deposits with plenty of gold in good-sized pieces, and such would be quickly discovered and worked by primitive man. No doubt the chieftains of those days took much, if not all, of the gold that their people found, and more powerful chiefs and kings would, in turn, either by force or in trade, take it from the weaker, so that it is not surprising to learn that some of the mighty kings and potentates of long ago were well supplied with gold.

Yet there are few things more useless. Its value in the first instance was probably entirely due to its beautiful colour, and the fact that it does not easily tarnish. For this reason, coupled with the fact that it was by no means plentiful, men liked to deck themselves with it, not only adding to their " beauty " by so doing, but advertising to their fellows the fact that they were men of wealth, men who possessed what few others had, or at all events possessed it more abundantly. These three basic facts about gold, its beauty, its freedom from deterioration and its comparative scarcity, give it its peculiar status among the commodities of commerce, in that for it, and for it alone, there is a continuous and universal demand. No gold-mining company ever shut down its properties because of the falling off in the demand for gold. No one ever had to hawk gold about to find a purchaser ; it is always saleable.

And hence its value to humanity as the great medium of exchange. When a tailor wants bread, as has been pointed out by a great political economist, he does not go searching for a baker who happens to need a coat. If he did, he might starve before he found one. Instead, he gives his coat to anyone who needs one, no matter what his trade may be, taking gold in exchange. Then he goes with confidence to the baker, knowing full well that he, in turn, will be perfectly ready to give bread in exchange for gold. That is the principle upon which gold, and in a few cases silver, has become the foundation of trade. We use it for toning photographs and a few other things, but, practically speaking, it is useless stuff, yet certain special circumstances have given it a special function in civilised society, and so governments now make it up into little flat discs, putting their own special stamp upon them as a guarantee of size and quality, and it is by handing those little discs about that we carry on our trade. Or even where we use no actual disc, we pretend that we do, and use a piece of paper the value of which we say is so many discs, but that value depends entirely upon the fact that someone has guaranteed, on demand, to give so many discs for it.

And the strange thing about it is that although this usefulness of gold depends upon its rarity, we lose no opportunity of looking for new sources of supply, and so diminishing that rarity. As has been said, gold is present in sea-water, although no one knows how to get it out, except at a cost which makes it not worth while. But suppose that some genius found a way, and gold thus became twice as plentiful as it is now, the world would be no better off. Everything would cost twice as much as it does now; that is all. A pound is merely so much gold. If gold be twice as plentiful people will want twice as much of it in exchange for what they have to sell. Yet, all the same, the man who could solve that problem of getting gold from sea-water, or from anywhere else, in fact, would be hailed as a benefactor, and for a time at least he would reap a generous harvest.

Even as it is, science has done much for the production of gold. Not, as in other metals, in finding ways for extracting it from its ores, for, strictly speaking, it has none, but in finding ways of catching the tiny particles of metal from the "gangue," as it is called, the rock or earth in which they are embedded. The trouble is that they are so small, so infinitesimally small, almost.

There are two great types of place where gold is found. In the alluvial deposits, the beds of old rivers, the gold is quite loose. The convulsions of ages ago have, in many cases, elevated these beds, until now they are on the sides of mountains. In such cases the loose, gravelly stuff of which they are composed is washed down by a powerful stream of water from a huge hose-pipe terminating in a nozzle called a "monitor." This process, called "hydraulicing," brings down everything into a pond formed at the foot of the hill, and in some cases a boat or raft is floated upon the pond with machinery on board for dredging up the material. Often a powerful centrifugal pump sucks up the water through a pipe reaching to the bottom of the pond, bringing gravel and gold with it. Arrived in this way upon the raft, it all goes on to separating tables, by which the gold, being heavier, is divided from the gravel, which is lighter. These tables will be referred to again later.

In non-alluvial workings the gold is embedded in rock of some kind, such as that called quartz. This is hard, somewhat of the nature of granite, and before the gold can be liberated it has to be crushed to the likeness of fine sand, so that the tiny grains of gold can be captured. The quartz is found in veins or lodes, fissures, evidently, in the original crust of the earth, produced probably as the earth cooled. These have been gradually filled up by hot volcanic streams of water, which carried not only the gold in solution but also the materials of which the quartz is formed. It used to be thought that the veins were the result of hot liquids forced up from below by volcanic action, the rock and metal being themselves in the liquid state through intense heat. It is now more generally held that water was the vehicle by which the materials were brought in, and the vein formed. The gold in the alluvial deposits, too, is now thought to have come there in solution in water, and not by the erosion and washing down of rocks higher up the original river.

However that may be, and it is the subject of discussion among geologists and metallurgists, there the gold is to-day, firmly fixed in the hard rock, and the problem which confronts the metallurgist is to get it out with the least expense. The old historic way of breaking up the quartz rock is with what are called "stamps," pestles and mortars on a huge scale. There are a number of vertical beams of wood, each shod with iron, fixed in a wooden frame, so that they are free to slide up and down. Running along behind these stamps is a horizontal shaft with projections upon it called cams. There is one cam for each stamp, and as the shaft turns slowly round this projection catches under a projection on the stamp, and after lifting it up a short distance drops it suddenly. Thus, as the machine works, the stamps are lifted and dropped in rapid succession. The rock is fed into a box into which the feet of the stamps fall, and thus it is pounded until it is quite small. Meanwhile a stream of water flows through the box and carries away the finely broken particles through a kind of sieve which forms the front of the box, and which allows the fine, small pieces to escape, while holding back the larger ones and keeping them until they too have been crushed.

An average stamp will weigh 600 to 700 lb., and the repeated blows of such a hammer are enough to pulverise the hardest rock.

Machines such as these have been employed since the sixteenth century, at all events, and the improvements of modern times are only as regards details. It may well be wondered, then, why such an old device is still in use and how it comes about that it has not been displaced by something newer and better. The answer, which is an instructive one, well worth bearing in mind by many inexperienced inventors, is that it is so simple. It can be shipped in comparatively small parts, and so taken cheaply to any outlandish place. A good deal of it can be made roughly of wood, so that if native timber is available it can be made partly at the mine, and carriage costs saved. Finally, it is so easy to work and to understand that the most inexperienced workman can handle it, and there is so little that can go wrong that the most careless attendant cannot damage it.

In the bottom of the boxes there is placed some mercury, for which gold has a curious affinity. If a particle of gold once gets into contact with the surface of the mercury it will not get away again easily. Thus the mercury catches and holds many of the gold particles which are liberated when the rock is broken up.

As it reaches the required fineness, then, the crushed rock escapes from the stamp machine and flows away in the stream of water, and although much gold is caught by the mercury, it is by no means all. The stream is therefore directed over tables formed of copper sheets coated with mercury, so that additional opportunities are given to mercury to catch the grains of gold. Moreover, the table, which, by the way, is placed at a slight incline, is broken at intervals by little troughs of mercury called riffles, which assist in the depositing and catching of the metal particles.

But even then all the gold is not captured. The crushed rock is now like sand, and some of the grains still contain gold, which has not been detached by the crushing. The gold, however, makes such grains slightly heavier than the others, and because of that they can be separated. The old way is to use a blanket table, a table, that is, covered with coarse flannel or baize, the hairs of which catch these heavier particles as the water stream carries them along, the lighter particles escaping. The grains so caught form what are known as "concentrates," since in them the gold is concentrated.

The concentrates are subsequently treated as we shall see later.

Now we can see how modern scientific methods have supplemented the old ways. Take first the case of the stamp mill or stamp battery. In spite of that prime virtue of simplicity which has kept it at work almost unchanged for centuries, it has its weaknesses, and no doubt for some purposes crushing mills are better. Of these there are a great variety, several of which depend for their action upon centrifugal force, or, as it is more correctly termed, "centrifugal tendency." In these crushing mills there is a ring, generally of steel, inside which are suspended one or more heavy iron rollers. The shafts which carry these rollers are attached by their upper ends to the driving mechanism on the top of the mill, and when that is set in motion the rolls are carried round and round inside the ring. Because of the centrifugal tendency, they swing outwards, pressing heavily against the inner surface of the ring. The rock is fed in in such a way that the rollers, as they roll round the inside of the ring, repeatedly travel over it and crush it.

In another type of mill, called the ball mill, the principle is different. There you have a cylinder of steel which turns upon a horizontal axis. This cylinder is partly filled with steel balls of various sizes, and as the mill turns, the rock, being mixed with these balls, is pounded and broken up. As the mill turns over and over the balls fall upon the pieces of rock, thus producing a fine powder. Other mills, again, are but refined editions of the common mortar mill so often seen where building operations are going on, in which heavy iron rollers travel over the material to be crushed as it lies in a round pan.

The blanket table, too, gives place at the modern mine to the "vanner," of which there are several varieties. Essentially they are much the same, and a description of two will serve to give an idea of them all. Let us take the "Record" vanner.

Imagine a large table formed of wood, the upper surface covered with linoleum. It is fixed on slides so that it can move to and fro endwise. It is given a slight slope in the direction at right angles to its length—that is to say, one edge is a little lower than the other. The material is fed on at one end, at the higher edge, and naturally tends to run down and off at the lower edge. It is restrained somewhat from doing this by the presence of rows of riffles or ridges running lengthwise. Nevertheless it does in a short time find its way off the table at the lower end. But all the time that it is at work the table is being slidden backwards and forwards on the slides. By a simple but curious mechanism it is arranged so that it moves quickly in one direction and slowly in the other, with the result that the heavier particles of sand—those which contain gold—are carried to the farther end of the table. Thus, as has been said, all the stuff is fed on to the higher edge and carried down by the water, until it falls off at the lower edge, but during the journey from edge to edge the peculiar motion of the table causes the different kinds of sand to separate themselves, so that the concentrates fall off near one end, and the rest near the other end.

Another interesting example of ingenuity is the well-known "Frue" vanner. In this the table is a broad, endless band of india-rubber, extended upon two rollers, one of which is slightly higher than the other. The stream of water and crushed ore flows on at the upper end, and runs down to the lower, the lighter particles being carried down and dropped off at the *lower* end, while the heavier rest upon the band. Meanwhile the turning of the rollers carries the band slowly along, so that the heavier particles gradually ascend and are carried over at the *upper* end. To assist in the separation, the whole concern is given a side-to-side shaking motion while it is at work.

We have seen so far how the ore is crushed, and the coarser grains of gold got out of it by the aid of mercury. The mixture of mercury and gold is termed amalgam, and the process of extracting gold by mercury is called amalgamation. The gold is actually dissolved in the mercury, and so when the amalgam has been (as it is periodically) collected from the plant, it has to be filtered and then evaporated in a retort. The mercury vapour is caught and condensed back into a liquid, while the gold is left in the retort. In fact the amalgam is distilled in order to separate the gold and mercury.

But when all that is done we still have the concentrates from the vanners, or whatever be used, to deal with. Mercury is useless with them, for the gold is covered probably with a coating of the other substances, whatever they may be, with which it has been associated, or else there is mixed with the gold some substances which make amalgamation impossible, or at least difficult.

Often roasting is necessary before anything more can be done. If arsenic or sulphur be present, for example, they interfere with the recovery of the gold, and roasting will disperse them. So the concentrates are passed through great furnaces, in which they are heated in contact with air until these objectionable matters have been oxidised or burnt.

Then finally we come to some process by which the remaining gold is dissolved out from its admixtures in some solvent liquid from which it can be subsequently precipitated. This is rather interesting, because it means that man has adopted, to recover this gold from the ore, the very method which it is believed nature employed to put it there.

As already said, the latest idea is that the gold was carried into and deposited in the lodes where it is now to be found by water—that the gold was actually dissolved in water at the time. But, of course, gold in its metallic state will not dissolve in water. Salts of gold, however (the meaning of the term salt, as applied to a metal, has been explained earlier), will dissolve in water, as every photographer who makes up his own toning solution knows from experience. Gold will not dissolve in water, but chloride of gold will. And so the gold must have been carried to its resting-place as a salt, and converted into the metallic form after arrival. In the same way, to recover these finest particles of all, it has to be converted back into a salt; then that salt must be dissolved and drained away from the other stuff; and, finally, the gold must be thrown out of solution again in some way. The great example of this operation is the familiar "cyanide" process.

The word familiar is appropriate to this matter in only one way, however. Holders of shares in mining companies, for example, may hear about it repeatedly at shareholders' meetings and in prospectuses, but very few have any clear idea as to what it is. So I cannot be accused of telling an oft-told tale if I devote a short space to its consideration.

The combination of one atom of carbon and one atom of nitrogen is called cyanogen.

If cyanogen be given the chance it will take unto itself an atom of hydrogen, producing the deadly hydrocyanic or prussic acid. Alternatively, if potassium be brought into combination with it, there results potassium cyanide, which, with the assistance of water and oxygen, can dissolve gold.

In applying this scientific fact to the purpose of recovering gold from the concentrates, the latter are placed in vats with a weak solution of the cyanide in water. The time during which they are allowed to remain depends upon the size of the gold particles. If they be comparatively large, it stands to reason that it must be longer than if they be small, for they will take longer to dissolve. After the proper time, which is found by experiment, the liquid is drawn off, and in some cases the concentrates are given a second dose to ensure that the gold shall be thoroughly removed and none left undissolved. If the material being operated upon be very fine, as it often is, forming what the mining people call " slimes," then mechanical stirrers have to be used in the vats to keep the stuff moving, as otherwise the cyanide would not get to all the particles and some would not be acted upon.

The liquid, having been the appropriate time in the vat, is drawn off, placed in wooden tanks or boxes, and fine shreds of zinc are added to it. Discs of sheet zinc are put into a lathe and a fine shaving taken off them, and it is these fine shavings which are used. Now zinc, as we know from the fact that it is the essential part in electric batteries, has very pronounced electrical properties, and it is believed that these come into play here. At all events the gold becomes deposited upon the zinc, while the zinc itself is to a certain extent eaten away by the solution. The result is (*a*) a solution weaker than it was before, (*b*) the remains of the shavings, and (*c*), at the bottom of the box in which this process takes place, *a dark mud.* That black mud, on being heated, produces the bright metallic gold, and the object of the whole operation is achieved. The solution is then led to another tank, brought up to its proper strength again and is ready to be used once more, while the remains of the shavings are used for the next batch of material to be treated.

In some cases the crushed ore straight from the crushing mill is cyanided, in others it is simply the remains left over from the previous amalgamating process which is thus treated. All depends upon the nature of the material in question.

There are other chemical methods besides the cyaniding, but it is the chief. It has been found specially useful with the Johannesburg ores, and to it the South African goldfields owe a great deal of their success.

There is a more modern form of it, although the whole process is quite novel, having been introduced only in the nineties of last century. This development, it is almost wearying to repeat, is electrical. Instead of the zinc shavings being used to precipitate the gold out of the solution, the process is electrolytic. A lead anode is used while the process is carried on in a box the bottom of which is covered with mercury, which forms the cathode. The precipitated gold is thus amalgamated, the amalgam being removed at intervals, retorted, and the gold recovered.

The idea of recovering gold from the waters of the sea is certainly a most attractive one. To some, it is true, the suggestion may bring thoughts the reverse of pleasant, for there have been several partially successful attempts to delude the public with specious promises of vast dividends to be gathered in the form of pure gold from the inexhaustible sea. Still, there is something in it, and some day the dreams may be realised.

The quantity of gold dissolved in sea-water is so small that in 200 cubic centimetres it is impossible to detect it, even by the most delicate tests known. The quantity needs to be multiplied threefold before the quantity of gold becomes even detectable, to say nothing of being recoverable.

A writer in *Cassier's Magazine*, a few years ago, related how he had actually obtained gold from the water of Long Island Sound. But whereas he got two dollars' worth, it cost him over 4000 dollars to do it. No company will ever be floated on results such as that. From the mud of a creek near New York, however, he did a little better, for there ten dollars' worth of gold only cost 379 dollars. A company promoter would still look askance at even that comparatively successful undertaking.

As usual, authorities differ, but there is a consensus of opinion that in every ton of sea-water there is from one-half to one grain of gold, besides silver and iodine.

It seems as if the water were able to dissolve that amount and no more. If, as has been suggested earlier in this chapter, all the gold which is now found in mines and in gravel beds was carried there in water, it is probable that the sea obtains its gold from the same original sources, and that, just as the hot ocean of ages ago carried its burden of gold in solution, so the colder water of to-day has its share, the cold water naturally carrying less than the hot did.

It is quite likely, then, that, could we find out how to rob the sea of its precious metal, it could replenish its store from some secret hoard of its own. But even if it could not, it would make little difference to us, since what it holds is far more than we could ever use. Put it at half-a-grain per ton: there are 4205 million tons in every cubic mile of ocean, and 300 million cubic miles of water in the ocean. If all the gold that man has ever handled were to be dissolved in the sea, no chemist would be able to discover the fact. On the other hand, if that half-grain per ton which we believe to be in the ocean now were to be recovered we should have about 40,000 million tons of gold, a prospect which is enough to make the political economist turn pale with apprehension.

What is required is some substance which, on being added to sea-water, will combine with the gold, and then be precipitated—that is to say, fall to the bottom. The precipitate —that which falls to the bottom—would need to be heavy, so that it would fall quickly and not necessitate the water being left standing for long periods. It would need to be cheap, too, or easily recoverable, so that it could be used over and over again. And, finally, it would need to be such that the gold, having been captured by it, could be easily obtained from it.

Given such a precipitant, the process of recovering the gold would be simple and cheap. Tanks would be formed in sheltered bays and inlets. At every tide these would be filled, and when full the precipitant would be added. The tide falling, the water would run out again and leave the precipitate on the floor of the tanks, whence it could be removed by scraping. Simple treatment would release the gold from its partner, which would then be returned to the tanks to act as the precipitant once more. Thus by simple means, the tide itself assisting, the gold could be obtained from the sea.

And there is nothing inherently impossible about this suggestion. The necessary precipitant may exist, awaiting discovery. A large works operating in this manner would produce, it is estimated, about thirteen tons of gold per annum. It looks as if it would be a bad day for the Rand when that discovery is made.

And there is yet another possibility, though less alluring than what has just been described. The American writer mentioned a little while back got a better return from the mud of a creek than from the water itself. In all probability this is due to the action of organic matter carried down by streams, or in some other way introduced into the waters of the creek whence the mud was obtained. This organic matter would possibly have an effect as a precipitant upon the dissolved gold, causing it to be thrown out of solution and deposited in the mud. Thus the mud around our shores, and particularly in the creeks and estuaries, may be potential gold mines whence in time to come we may draw supplies of the precious metal. The cyanide or some similar process may be needed in order that we may extract the metal from its enclosing mud, but the time may not be so very far distant when dredging for gold may be a regular occupation at, for example, the mouths of the Thames and the Hudson.

CHAPTER X

INTENSE HEAT

MANY of the useful and interesting manufacturing processes of to-day are based upon the intense heat which science has taught the manufacturer how to produce. Tasks which our forefathers dreamed of, but were unable to accomplish, are easy to-day because of the facility with which great heat can be generated. The " burning fiery furnace " "seven times heated " is as nothing to some of the temperatures which are now obtained in the ordinary course of things.

The greatest heat of all is that of the electric arc. Two conductors, generally rods of carbon, are placed with their ends touching, and the current is turned on so that it passes from one to the other. Then they are gradually drawn apart. As the gap widens the current experiences more and more difficulty in passing over this non-conducting gap, and great electrical energy has to be employed to keep it going. Now that wonderful law of the Conservation of Energy decrees that no energy can ever be lost. It can only be changed from one form into another. Therefore the energy expended upon the arc is not lost, but is converted into heat. It is that heat, acting upon the small particles of carbon which are torn off the ends of the rods, which gives us the arc light.

As a matter of fact nearly all artificial light (and natural light too for that matter[1]) is due to heat. The heat sets the molecules in violent agitation, which, acting upon the corpuscles in the atoms, sets them in violent motion too, so that light is often the companion of heat. Some substances give light more readily than others, under the influence of

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[1] The glow-worm is an example of the few exceptions.

heat, and we may reasonably believe that they are those whose corpuscular arrangements are such that they can be readily accelerated by the molecular action.

To take a familiar instance, coal-gas is mainly " methane," one of the many combinations of carbon and hydrogen, and when it is burnt in air the hydrogen and oxygen combine, liberating heat, which causes the carbon liberated at the same time to glow. As each methane molecule breaks up the carbon atoms are thrown out, forming solid particles of carbon, and it is they really which give the light. It is therefore the combustible gas heating the solid particles of carbon which forms the luminous part of the gas flame. The non-luminous part of the flame, near the burner (I am now speaking of the old-fashioned burner), is the burning gas before the carbon particles have had time to heat up.

And the old gas flame, as we know, is now being rapidly displaced by the incandescent mantle, the reason being simply that Von Welsbach discovered how certain rare minerals gave a more brilliant light when heated than particles of carbon do. In other words, it is easier to accelerate the motion of the corpuscles in ceria, thoria and the other ingredients of the mantle, than it is those of carbon. Consequently, they sooner reach that degree of agitation which will send forth electro-magnetic waves of the high frequency necessary to produce the sensation of light.

For this reason the mantle heated by gas gives as bright a light as the carbon particles in the electric arc, although the latter are subjected to a much more intense heat.

But the arc can be, and often is, used as a source of heat, apart altogether from the light which it gives. In Sweden, for example, where coal is rare, but water-power plentiful, the power of the waterfalls is made to smelt iron. Hence the waterfalls are sometimes termed the " white coal " of that country. Needless to say, it is the ubiquitous electricity which performs the change from the force of falling water into heat.

The furnaces are in shape much like those in which iron is smelted with coal—namely, tall chimney-like structures at the bottom of which is the fire. In the " arc furnaces " there are, passing in through the side, near the bottom, a number of electrodes, and between these a series of arcs are formed. Coke and ironstone are thrown in from the top into this region of intense heat, and there the iron is liberated from the oxygen with which it is combined in the ore. Liberated, it flows out through a spout at one side of the furnace.

But the question will arise in the reader's mind: Why is coke needed in an electric furnace? It is for metallurgical reasons. The heat of the arc loosens the bonds between the iron and oxygen, but it needs the presence of some carbon to tempt the oxygen atoms away. Therefore coke, as the most convenient form of carbon, has to be there. It is there, however, in much smaller quantity than it would be in an ordinary furnace. It is not there as fuel, but simply as the " counter-attraction " to draw the oxygen atoms away from their old love.

The arc is also used for welding pieces of iron together, for which purpose it is eminently suitable, since what is wanted is intense heat at a particular point. But perhaps the reader will be wondering by this time what the heat of the arc is. It has been repeatedly referred to as " intense," but something more definite may be demanded. In theory it is unlimited. Apply more pressure—more volts, that is—thereby driving more current across, and the temperature will rise. It is only a question of making dynamos large enough, and driving them fast enough, and any temperature is possible. But there are practical difficulties which limit the degree of heat. One is the melting-point of the furnace itself. Fire-clay melts at about 1700° to 1800° C. So in a furnace which has to be lined with fire-clay that is about the limit.

In welding two pieces of iron together, the iron, of course, defines what the limit shall be. It needs to be heated to “welding heat” and no more—that is, a little short of melting—so that the parts to be joined are soft, and, with a little hammering, will join thoroughly together. If too much heat were to be applied the parts would melt away. But the heat of the arc can be controlled by simply varying the current, and so the right heat can be applied at the right place, than which little more is wanted.

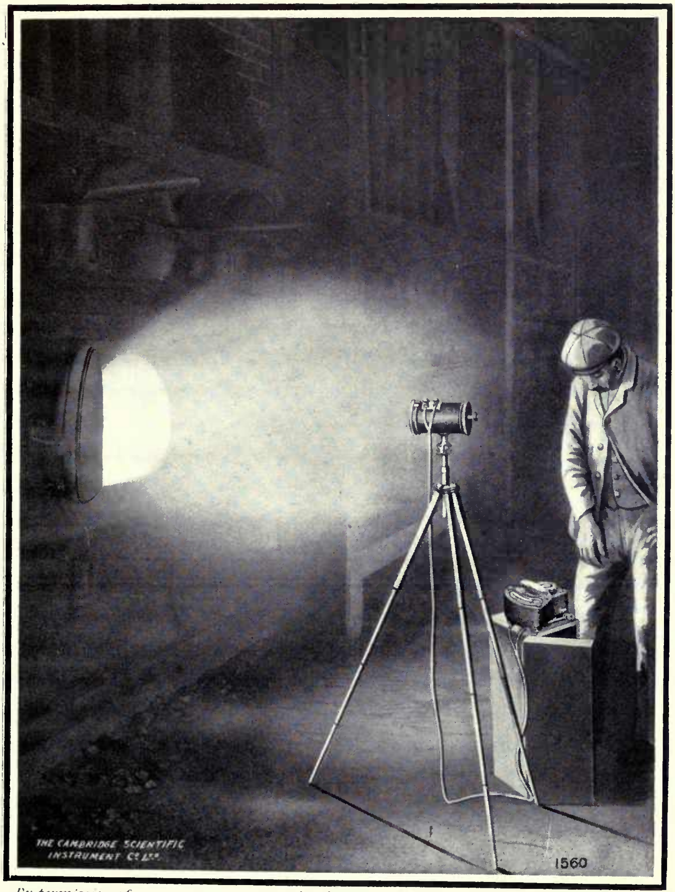
One very simple way of doing this is for the workman to hold one of the “electrodes”—a rod of carbon suitably insulated—in his hand. The current is led to it through a flexible wire. The iron itself is made the other electrode by being gripped in a vice which is itself insulated but connected to the source of current. Thus on bringing the point of his rod near to the part to be heated the man causes an arc to be created there. By moving the rod he can move the arc about, heating one part more than another, distributing his heat if he wants to do so over a larger area, or keeping it to a small one, just as he wills. On reaching the right heat the rod is withdrawn, the arc destroyed, and the iron can be hammered just as if it had been heated in a fire.

Yet another way still is known as “resistance” welding. In it an enormous current at an extremely low voltage is used. The fundamental principle is the same, since the heat is formed by forcing current past a point over which it is reluctant to pass. That point of poor conductivity is the ends of the two bars to be joined. They are placed just touching, but since an imperfect contact like that always offers considerable resistance to the flow of a current, the passing current needs only to be made large enough for great heat to be generated.

This is exceedingly pretty to watch. We will suppose that the article to be operated upon is the tyre of a wheel. The bar of iron has already been bent by rollers into the correct curve and the two ends are touching. Brought to the machine, it is gripped, each side of the junction, in the jaws of an insulated vice and the current is turned on. In a few seconds the place where the two ends are just touching begins to glow. Rapidly it increases in brightness until in about half-a-minute it is at welding heat. Then one vice, which is movable, is forced along a little by a screw, so that the ends are pressed firmly together, a little judicious hammering meanwhile helping to complete the job. Then the current is switched off and the complete tyre taken out of the machine. The current used has a force comparable with that which operates domestic electric bells, but in volume it is thousands of amperes. Alternating current is used, and it is obtained from a transformer or induction coil. In such a case the primary part of the coil is made of many turns of fine wire, so that little current passes through it, while the secondary part is but one or two turns of thick bar. Thus the voltage generated in the secondary is very little, but since the secondary has an almost negligible resistance the current caused by that small voltage is enormous. Such an arrangement is in industrial realms generally called a transformer, the term induction coil being employed more for those things of a similar nature intended for the laboratory. The one just described is, moreover, a " step-down " transformer, since it lowers the voltage, to distinguish it from " step-up " transformers, which raise the voltage.

And the " resistance " principle is also applied in another way to large furnaces, such as those for refining iron. In these the resistance of the iron itself is utilised to generate the heat. Of course, it should be well understood, heat is always generated in everything through which current flows. There is no perfect conductor, and so every conductor is more or less heated by the passage of current through it. Some energy needs to be expended to drive current, even along large copper wires, and that energy must be turned into heat in the wires. If the same volume of current be forced along iron wires of the same size, the heat will be greater, since iron is but a poor conductor compared with copper, the relation being about as one to six. And if the iron be hot the resistance will be still more, for it stands to reason that when heated the molecules, being farther apart, will be the less easily able to exchange corpuscles. We have the best reasons for believing, as has been suggested already, that a current of electricity is but a flow of corpuscles, and so we are not surprised to hear that, as a general rule, the hotter a thing is the less does it conduct electricity.

So imagine a circular trough of fire-clay or other heat-resisting material filled with fragments of iron, or, it may be, with iron barely above melting-point, which has come from another furnace, where it underwent the previous process. Circling inside or outside this trough is an enormous coil of wire through which currents of electricity are alternating. That is the "primary" of a transformer, and the "secondary" is—the iron itself, in the trough. If it be, as it often is, in the form of scrap, or broken pieces, the heat will begin to show itself where the pieces touch each other. The currents generated in the trough, by the coil outside, will, of course, pass from piece to piece and the points of contact, since they offer the greatest resistance, will show signs of heat. This will increase until the pieces begin to melt. As the separate fragments merge into the molten mass the resistance will in one way decrease, for the imperfect contacts between the pieces will give place to the perfect contact throughout the mass of liquid metal. But for another reason—namely, the increase in heat—the resistance will increase. And all the while the alternations in the primary coil will be pumping currents, as it were, round and round the ring of molten iron. Whether the resistance increase or decrease, the current will do the opposite, so that heat will be generated whatever happens. For as resistance decreases current increases, and vice versa. And the slightest variation in the strength of the primary current will have its effect upon the secondary, and therefore on the heat generated. So, by simply regulating the primary current, the temperature of the metal can be controlled to a nicety. And such furnaces have the immense advantage that there is no possibility of deleterious substances in the fuel getting into and spoiling the metal, a thing which may very easily



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MEASURING HEAT AT A DISTANCE

This wonderful instrument, the Fery Radiation Pyrometer, although itself some distance away from the furnace, is telling the temperature of its hottest part

happen during the manufacture of high-class steels, alloys of iron in which the exact quantities, purity and proportions of the ingredients are of the utmost importance.

Hence these " induction furnaces," as they are called, are frequently used quite apart from any question of utilising water-power. And they will probably be used still more as time goes on.

For one thing, they may become valuable adjuncts to the older form of iron and steel furnaces, from which they will obtain their power free, gratis and for nothing. In districts such as Middlesbrough they could generate more electricity than they have any use for. The ordinary iron furnaces belch forth flames which are really good useful gas (carbon monoxide) burning to waste. Many of the furnaces are covered in at the top, and this gas is led away to heat boilers for the steam-engines or to drive large gas-engines, but in a large works there is more of this waste gas than they know what to do with. Now that could, and probably will ere long, be turned into electricity by means of gas-engines and the current used for making steel in induction furnaces.

It will probably surprise many to know that these enormous currents which can thus heat great masses of metal until they melt are no danger at all to the men who work with them. A man might dip an iron rod into the trough of metal and he would scarcely feel the shock. And the same is true of the welding machine, which can be touched in any part without fear. The reason, of course, is that, broadly speaking, it is volume of current which does harm, and the resistance of the human body is so great that with the small voltages used, the volume which can pass is negligible. It should be mentioned, however, that the volume of current in lightning is also small, but we know that it is capable of inflicting terrible injury. Lightning, however, is in a class by itself. Our terrestrial voltages are baffled by an air-gap of a few inches, but lightning springs across a gap miles wide. Its voltage must, therefore, amount to millions, and the ordinary rules relating to earthly currents do not apply.

But other sources of heat besides electricity are at the disposal of our manufacturers nowadays. Pre-eminently there is the flame of some gas burning with pure oxygen. The oxyhydrogen jet has been known for many years as the best means of producing the light for a magic lantern. Such a jet impinging upon a pencil of lime causes the latter to glow with a dazzling white light.

But the oxyhydrogen jet is now employed in many factories for the welding of metals. This is known as fusion welding, since the two parts are actually reduced to liquid. The usual way to go about this work is to bevel off the ends or edges to be joined. Suppose, for instance, that we wanted to weld two pieces of brass pipe together. We should first file or otherwise trim the edges to be joined until when put together they form a groove practically as deep as the metal is thick. Then with a stick of brass wire in the left hand, and an oxyhydrogen blowpipe in the right, we should direct the flame from the pipe on to the metal until, at one point, the sides of the groove were beginning to melt. Then, inserting the point of the wire into the groove, we should melt a little off it. Thus we should work all round the joint, melting the sides of the groove and filling in with melted metal from the wire, until the whole groove had been filled up and the metal added had been thoroughly amalgamated with that on either side.

As a matter of fact, if it were brass which we were working on we should probably use the cheaper though less pure form of hydrogen—coal-gas—so that it would really be "oxycoal-gas" that we should use and not oxyhydrogen. The latter is used, however, notably for the fusion-welding of lead, or "lead-burning," as it is termed.

The blowpipe is a brass tube about a foot or eighteen inches long, with two passages in it, one for the oxygen and the other for the other gas. The gases are brought to one end of it through rubber pipes, while at the other end there is a nozzle in which the gases mingle and from which they emerge in a fine jet.

The oxyhydrogen flame has a temperature of about 2000° C., hot enough to melt fire-clay. That does not matter in the case of welding, however, since the molten metal is very small in quantity at any given moment, and is allowed to cool before it can run away. It would be an awkward temperature to deal with, nevertheless, in a furnace. It seems strange that it does not burn the nozzle of the blowpipe, but the fact that it does not is, it is believed, explained by the fact that the expansion of the gas, as soon as it emerges from the hole out of which it shoots, causes a comparatively cool space just there, shielding it from the intense heat farther on.

An exceedingly interesting use of the oxyhydrogen flame is in the manufacture of artificial rubies. These stones are made in Paris by a very simple means. The necessary chemicals are prepared and ground to an exceedingly fine powder. This is then allowed to fall through an oxyhydrogen flame. Thus there is no need for a crucible capable of withstanding this high temperature, since the melting takes place as the particles are in the act of falling. When they reach the support prepared to catch them they have cooled somewhat. Stones so called are real rubies—artificial, but not shams. They possess every property of the ruby from the mine.

Another product of the oxyhydrogen flame is the quartz fibres which are used for suspending the needles in the finest galvanometers. The quartz is melted, in this case a crucible being employed. An arrow is then dipped in the liquid quartz and immediately "fired" into the air. The thick treacly liquid is thus drawn out into a thread of such fineness that a microscope is necessary to find it with.

Hotter even than oxyhydrogen is the oxyacetylene flame, which at its hottest point reaches nearly 3500° C. The gas, which is another of the combinations of carbon and hydrogen (its molecules containing two atoms of each), is easily made by allowing water to come into contact with calcium carbide. The latter, which is CaC_2, is made by heating coke and lime together in the intense heat of an electric furnace. This accounts largely for the great heating power of acetylene, for since great heat is necessary to cause the elements to combine great heat is given out by them when they ultimately separate. Here again is the conservation of energy. The heat energy of the electric furnace is largely expended in forcing these two elements into partnership. They are, as it were, given a large amount of capital in the form of heat. It ceases to be sensible heat, becoming latent in the compound, but still it is there. So a lump of calcium carbide, with which many readers are familiar, has vast stores of heat locked up within it. When water comes into contact with the carbide the partnership is broken, but the heat is not liberated then, since another partnership is formed, which still retains the old heat-capital. The calcium in the carbide is displaced by the hydrogen from the water, and so C_2H_2 comes into being, while the rejected calcium consoles itself by entering into combination with the equally forsaken oxygen from the water, forming CaO, which is but another name for lime.

Then the acetylene (C_2H_2) is mixed with oxygen in the blowpipe and burnt, under which conditions the pent-up heat, borrowed originally from the electric furnace, is brought into play. With this flame the harder metals can be fused and welded. Wrought iron, cast iron, steel in all its forms, all can be melted by the oxyacetylene flame, almost as easily as snow by a hot iron. The fusion welding of these metals is then carried on just as already described for brass.

By means of a special blowpipe, wherein an excess of oxygen is introduced at the hot point, hard steel plates can be cut to pieces almost as easily as a grocer cuts cheese. Even thick, hard armour-plate can thus be cut, almost the only way, indeed, in which it can be cut.

And for purposes such as welding and cutting this flame has an interesting and peculiar advantage over all other kinds of heat. When a metal is heated in the air there is usually trouble from oxidation. The domestic poker, for example, after it has been left to get red-hot in the fire is seen to be coated, in the part which has been heated, with scales which will flake off if the thing be struck. Those scales are oxide of iron, caused by the union of iron and oxygen when the poker was hot. But if the heat be applied by the oxyacetylene flame that will not happen. The oxygen and the carbon from the acetylene will burn, and if the supply of the former be properly regulated it will be entirely used up in the process. The hydrogen from the acetylene is, strange to say, unable to unite with oxygen at such a high temperature as that of the oxygen and carbon, so that it passes on beyond the oxygen-carbon flame and ultimately burns on its own account with the oxygen from the atmosphere in a second flame surrounding the first. Thus there is a double flame: inside, a little pointed cone of white flame, that is the oxygen and carbon; and outside that a bluish flame, the hydrogen and the atmospheric oxygen. The latter flame forms a kind of jacket entirely enveloping the former. And so when one melts metal by means of the white cone the hydrogen jacket shields the molten metal from oxygen and prevents the oxidation. Only one who knows the bother caused by oxidation whenever metals are heated can realise the wonderful advantage of this.

And now we can turn to even another source, also quite modern, of high temperature.

If the oft-quoted "man in the street" were asked the two commonest things on earth he might possibly name oxygen as one, and so far he would be right, but the chances are much against his naming aluminium as the second. If he did not, however, he would be wrong. Aluminium and oxygen form alumina, of which are constituted the sapphire, the ruby and other precious stones, but alumina is most commonly found in combination with silica, or silicon and oxygen. This compound is called silicate of aluminium, and of it are formed clay and many rocks. The reason why the metal aluminium was until recently rare and expensive was because of the great difficulty of disentangling the metal from this rather complex combination. And these two commonest elements have, under certain conditions, a rare affinity for each other. They join forces with such energy that great heat is given out in the process. This, again, we may regard as an example of the conservation of energy. Heat had to be used up, apparently, in separating the aluminium and oxygen as they were found together in the natural state. And that heat reappears when they combine together again. This is a most useful principle, for if heat has disappeared anywhere in the course of some operation, we know that in all probability, if we go about it the right way, we can get that heat back again, perhaps in a more convenient form. That is so in this case at all events.

Now aluminium will not readily combine with atmospheric oxygen, but it will readily do so with oxygen from the oxide of a metal. So if we put into a vessel some oxide of iron and some finely powdered aluminium, and give it some heat at one point, just to set the process going, the whole mass will burn with intense heat. And when the burning is finished the crucible will be found to contain (1) some molten iron, the oxide of iron with the oxygen gone, and (2) some oxide of aluminium or alumina, in the form which we call corundum, a very hard substance which in a powdered form is used for grinding hard metals. We start, you will notice, with a pure metal and an oxide. We finish with a pure metal and an oxide, only the oxygen has changed its quarters, having passed from the iron to the aluminium. And in the course of the change a vast amount of pent-up heat has been liberated. Aluminium is thus a fuel, strange though it may seem to say so, just as coal is. Coal, however, is willing to pair off with oxygen from the air, while aluminium, more fastidious, will only accept it as partner when it can steal it from another combination.

But the practical result is eminently satisfactory, for the action of the aluminium and iron oxide is to leave us with a crucible full of molten iron at a very high temperature. And this can be used in various ways.

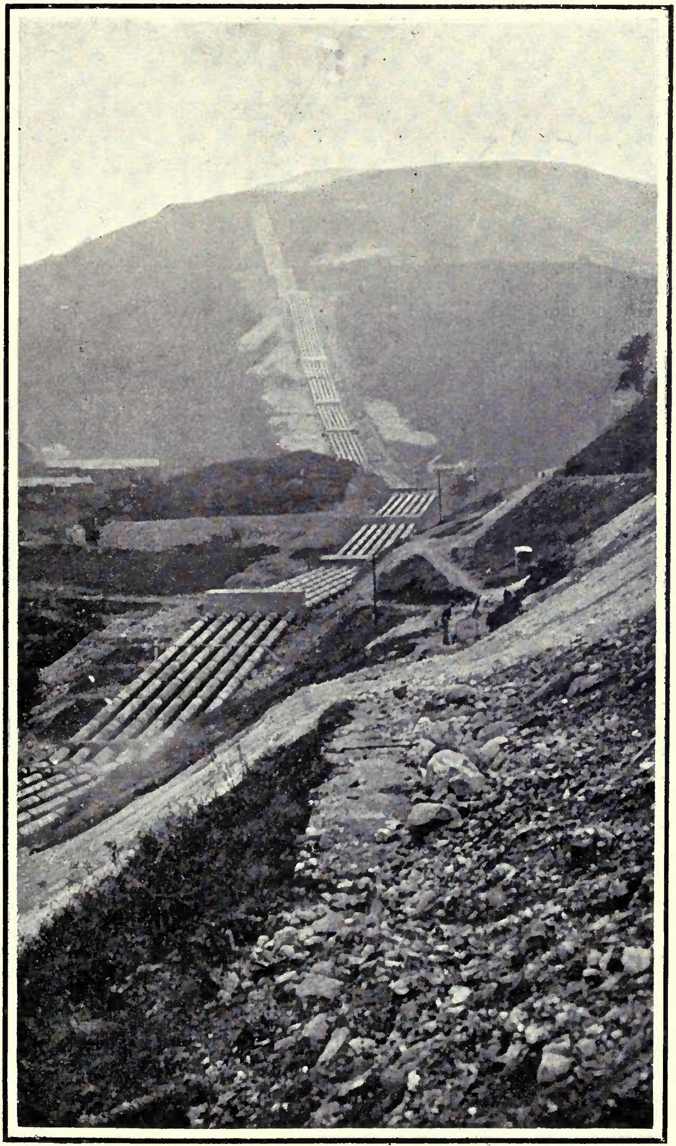
Tramway rails, for example, can be joined together by it. A mould is formed around the ends of two rails, where they "butt" together, and into this mould a quantity of the melted iron can be poured. So hot is it that it partially melts the ends of the rails, and then, amalgamating with them, it forms a perfectly homogeneous connection between them.

The same method can be applied to the repair of iron structures of all kinds. The propeller shaft of a ship, for example, sometimes breaks on a voyage. Such a catastrophe is fraught with the most serious consequences, unless it can be quickly repaired. Thermit, as this process is called, is perhaps the only means whereby, under certain conditions, this can be accomplished.

The extraordinary heat of the metal produced in this way is demonstrated by the fact that if it be poured on to an iron plate an inch thick it goes clean through it. It melts its way through instantly.

But although such high temperatures are at the command of the modern manufacturer, there are some things—indeed many things—which still baffle him, the diamond, for example. It is true that diamonds of small size have been made, but larger ones have so far defied all efforts.

One very interesting fact about this may be mentioned in concluding this chapter. Sir Andrew Noble, a member of the great firm of Armstrong, Whitworth & Co., of Elswick, tried the experiment of exploding some cordite, a high explosive, inside a steel vessel of enormous strength. He thus produced what is believed to be the highest temperature ever produced on earth. It is reckoned to have been 5200° C., and the pressure at the same time was, it is calculated, 50 tons per square inch. His intention was not to make diamonds, but Sir William Crookes predicted that diamonds would be the result. For the cordite consisted mainly of carbon, which, as is well known, is the material of which the diamond is formed, and the combination of high temperature and high pressure is just what is needed, so it is believed, to bring the carbon into this particular form. And true enough, on the iron being examined after the explosion, there were seen tiny diamonds. For larger ones even higher temperatures and greater pressures are, no doubt, necessary, and as the diamond, like gold, has a peculiar fascination for mankind, so the efforts to manufacture it will continue. In years to come the means may be found of creating these extreme conditions of temperature and pressure, and so another of the problems of the ages will be solved.



By permission of *the British Aluminium Co*

A STRIKING FEATURE OF MODERN ALUMINIUM WORKS

For the production of aluminium water power is required. Water is stored at a high level and is then brought down to the factory in pipes. The illustration shows the pipe track recently laid down for this purpose at Kinlochleven in Argyleshire. The six pipes, each of which is thirty-nine inches in diameter, run down the hillsides for one mile and a quarter

CHAPTER XI

AN ARTIFICIAL COAL MINE

THOSE countries which are blessed with a plentiful supply of coal are periodically shocked and saddened by a terrible calamity—an explosion in one of the mines, in which often scores of poor fellows lose their lives, and hundreds of widows and orphans find themselves without a breadwinner. One has only to recall that heart-rending calamity of the Courrières mines in France, where over a thousand lives were lost, to realise how important is the question of the cause and the cure of the colliery explosion.

It used to be thought a settled matter that these were due to the accidental ignition of a gas called, scientifically, "methane," but by the miners "fire-damp." This undoubtedly does collect in many mines, and since it is much the same as the domestic coal-gas (indeed methane forms the bulk of coal-gas) it is not surprising that the explosions were attributed to it. At times shots were fired, to blast down the coal, and although the greatest precautions are taken to prevent any accident resulting, it seems certain that explosions have occasionally followed the firing of shots. But still more dangerous is the adventurous miner who, for some reason, opens his safety lamp. It is lit for him before he enters the workings, and locked up, so that, theoretically, he cannot tamper with it; but it has to be a cleverly devised lock that cannot be picked in some way, and with the carelessness born of long immunity from accident these are got open sometimes, with, it may be, disastrous results.

Even a spark struck from a miner's pick may ignite the gas; or a spark from some electrical machine used in the mine. That is one of the reasons why electrical apparatus is suspect in colliery matters and machines worked by the less convenient and more costly means of compressed air are preferred.

In some such manner the fire-damp is ignited, and then there follows the fiery blast, which, sweeping through the narrow galleries and passages which constitute the workings, simply licks up the life of the men whom it encounters. Others, in byways and sheltered corners, escaping the burning cloud of flame, are poisoned by the deadly fumes of carbon monoxide which it leaves when its force is spent. While others, perchance the most unfortunate of all, are saved for a time, but, being imprisoned by falls from the roof and walls, die a lingering death of hunger and slow suffocation. A colliery explosion is one of the ghastliest events imaginable, the only relief from which is the noble heroism with which the survivors, from the mine managers to the humblest workmen, crowd round the pit-mouth, eager to risk their own lives for the faint chance of saving some below. Not infrequently these brave volunteers only share the fate of the men they would rescue.

Now all that, as I have said, used to be put down to the effect of the fire-damp. But it dawned upon men's minds some years ago that the damage seemed to be out of proportion to the power of the gas. Modern mines are well ventilated by large fans, which impel great volumes of air through all the workings. The air currents are cunningly guided by partitions or " brattices," so that every nook and corner shall be scoured out by the plentiful draught of pure fresh air. Consequently the amount of explosive gas which can collect in any one place is but small. How, then, can so small a volume of gas do so large an amount of damage ?

Coupled with this was the fact that explosions take place in flour mills, where there is no gas, and experimenters had found in their laboratories that almost any burnable substance, *if ground up finely enough* and blown into a cloud, would explode. Coal-dust would naturally do this. Indeed anyone throwing the dust from the bottom of the coalshovel upon a fire will see for himself how quickly such dust will burn, and, as has been pointed out in an earlier chapter, an explosion is but rapid burning.

So the blame was largely transferred from the shoulders of the fire-damp to those of the clouds of coal-dust which collect throughout the workings of a mine.

But then a difficulty arose from the fact that there is dust in all mines, yet some districts are quite free from explosions. And such districts are those where there is little or no fire-damp. These two facts seem to be explainable in one way, and in one way only. It must be that the gas first of all explodes feebly, and so, stirring up the dust lying along the roads and passages, prepares the way for the powerful, deadly explosion of coal-dust which follows.

But that was only a guess, and the matter was of such importance that it needed something more certain than mere assumption. So the Mining Association of Great Britain decided to have a series of experiments which should settle once and for all what part the coal-dust played in these catastrophes, and how best they could be prevented.

It was at first thought that an old mine might be utilised for the experiments, but there was the difficulty that such always become wet after work has ceased in them, and so the dust would not behave normally. Moreover, the work would be extremely dangerous and the results difficult to observe. Then a culvert was suggested built of concrete, partly buried in the ground, but that too was dismissed. Finally it was decided to make an imitation mine of steel, using old boiler shells with the ends taken out.

The sum of £10,000 was subscribed for the purpose by the coal-owners of Great Britain, and the great work was carried out at Altofts, in Yorkshire, close to a colliery where a terrible disaster occurred in 1886.

Here the great tube or gallery was built. Roughly the shape of a letter L, one leg is over 1000 feet long, while the other is 295 feet. The longer leg is 7½ feet in diameter and the shorter 6 feet. At the end of the shorter part a large fan is installed which can force 50,000 to 80,000 cubic feet of air per minute through the structure, so producing the conditions of a well-ventilated mine. The shorter length has several sharp turns in it for the purpose of breaking the force of the explosion along that part, and so shielding the fan from damage, while a tall chimney is provided there, so that, the door being shut to cut off the fan, the gases from the explosion can find a harmless way out.

Inside the tube, shelves are fixed along the sides so as to reproduce the effect of the timbering in a real mine, upon the beams of which the dust finds lodgment. Props were put up too, just as they would be in the real mine. Everything, in fact, was done to make the place as perfect a replica as possible of actual underground workings.

And then, added to this huge and costly structure, was an outfit of scientific instruments worthy of the important investigations which were to be carried on.

To grasp the purpose and working of these we need to remind ourselves of the aims and intentions of the experiments. First of all it was desired to find out how various quantities and qualities of coal-dust behaved. The dust was laid along the floor of the tube and along the shelves. A small gun fired at some point in the tube raised a cloud of this dust just as the gas explosion in the real mine would do. Then another gun was fired to explode the dust-cloud. So far all is quite simple and easy. But to do that would be of no value without the means of finding out exactly what resulted from the explosion. And that is the function of the instruments.

To commence with, there is the great wave or tide of force or pressure which surges along the gallery immediately the cloud bursts into flame. How fast does that wave travel? How long is it after the explosion before the shattering effects of it are felt a hundred yards away? To solve that problem electrical contact-breakers are fixed at intervals of fifty yards along the gallery. Each of these consists of a cylinder with a piston inside it something like, shall we say, a cycle pump.

The piston, held down normally by a spring, is blown upwards by the force of the explosion. The spring is adjustable, and so it can be arranged that the feeble force of the gun cannot lift the piston, but the more powerful coal-dust explosion which follows can.

Thus when the explosion takes place these contact-breakers are operated in succession. The one nearest the seat of the disturbance is operated first; next the one fifty yards farther away; then the one a hundred yards away, and so on. The moments when they work will tell the speed at which the blast travels along the gallery. But it travels with great speed, and so to measure and record the exact moment when each contact-breaker is moved is a matter of no little difficulty. Electricity, however, makes this, like so many other things, comparatively easy.

There is an apparatus used in astronomical observatories called a chronograph, which registers, within a small fraction of a second, the moment when a star seems to pass across a wire in the "transit circle," the telescope by which the positions of stars are determined and the exact time kept. The observer sits with his eye to the telescope, watching the apparent movement of the star. In his hand he holds a small "push," pressure on which by his fingers operates a minute pricker, which acts upon a moving strip of paper. The paper travels along with the utmost steadiness and regularity, while a clock drives a sharply pointed pricker on to it every two seconds. Thus the clock marks out the paper into lengths, each of which represents two seconds. But the other pricker, worked electrically by the observer's hand, also makes its mark upon the paper, and so, while the regular marks indicate intervals of two seconds, each irregular one marks the time of a transit or passing of a star across the wire. An examination of the strip subsequently enables the times of a transit to be seen with great accuracy, from the position of the corresponding mark between two of the *regular* marks.

And the same principle was applied to the circuit-breakers of this artificial mine. Normally, current flows through the circuit-breaker, but the lifting of the piston breaks the circuit (whence the name of the contrivance), and that breaking of the circuit and consequent cessation of the current operates the chronograph. By a cleverly constructed device, the details of which are too complicated to set out here, each circuit-breaker in turn makes its mark on the same strip, so that the distances apart of these marks show the time taken by the force of the explosion to travel fifty yards. Meanwhile the clock goes on making its regular marks (in this case every half-second), so that they form a scale by which the other intervals can be measured very exactly.

The chronograph used here is more accurate than that in use at Greenwich Observatory, the reason being that in this case the recording currents are sent mechanically by the contact-breakers operated by the explosion itself, while in the case of the astronomer the human element comes in. To watch a moving speck of light and to tell exactly when it crosses a fine line is by no means easy, and so to tell the time within a tenth of a second, is about the limit of possible accuracy. The instrument we have been referring to, however, can register the time which a gaseous wave moving 3000 feet per second takes to travel fifty feet. In other words, the circuit-breakers can be operated so fast that when only a sixtieth of a second intervenes between the action of one and that of the next the chronograph can duly record the fact.

The records of the chronograph can be made in two ways: one by a pen on a piece of paper tape, and the other by a scratch on a piece of smoked paper.

So by that means the progress of the "force" of the explosion can be measured. It is necessary also to time the movement of the "heat" of the explosion, for the two may not travel together, and the difference between them may let in some light as to the nature and behaviour of the explosion. So for this second purpose a second set of circuit-breakers are used. Each of these consists of a strip of thin tinfoil stretched across the gallery. Being placed edgeways to the moving current of gas, the force of the explosion has no effect upon it, but the heat instantly melts it. Normally, current flows through the strip, and so the melting is signalised by the cessation of the current, which event is recorded by the chronograph.

Thus the speeds at which the force and the heat of the explosion travel are ascertained. Another important fact which needs to be found is the amount of the force, or the pressure, at different points. For this purpose pressure-gauges can be connected to the gallery at the desired spots by means of flexible tubes. This flexible tube is necessary in order that the vibration of the steel shell, due to the explosion, shall not be communicated to the instrument. The pressure, finding its way along the flexible pipe, raises a piston against the force of a spring, and the distance to which it is raised forms, of course, a measure of the pressure inside the gallery at the point to which the tube is connected. The pressure is recorded by the action of the piston in moving a style which just touches against the surface of a moving paper. There are three styles in all marking this paper. The first is the one just mentioned. The second is held down on to the paper by an electro-magnet energised by current flowing through a fine wire stretched across the gallery just where the explosion originates. This fine wire is broken at the moment of the explosion, whereby the current is cut off and the style raised. It therefore makes its mark until the moment the explosion occurs, and then leaves off. The end of that line, therefore, shows the time of the explosion. Meanwhile the first style is drawing a straight line, but as soon as the pressure begins to be felt by the pressure recorder this style moves and the line slopes upward. Upward it goes as the pressure increases, until it has reached its height, after which it descends, until the style is drawing a straight line once more. Thus the rise and fall of the line represents the rise and fall of the force of the explosion.

Then comes the matter of time. How soon after the explosion occurred did the pressure begin to be felt? How long did it take to reach its maximum and how long to die out again? These questions need answers which the apparatus so far described does not give. True, the speed of the paper may be known approximately, but all that I have described will occur within the space of a fraction of a second, and it is difficult to tell the speed of the paper with sufficient accuracy. Therein we see the purpose of the third style. It is attached electrically to the "tenth-of-a-second time-marker." This consists of a weight suspended at a height. The force of the explosion lets it drop. The moment it starts to fall it causes the style to make a mark on the paper. When it has fallen a certain distance the style makes another mark. And the distance that the weight falls between the making of the two marks is so adjusted that the space between them on the chart represents exactly a tenth of a second. Thus a scale is formed upon the chart by which the other times can be measured. There is the line terminating at the moment of explosion; the straight line changing into an up-and-down curve, representing the time and the variation of the pressure; finally there are the two marks representing a tenth of a second by which the other marks recorded upon the chart can be interpreted.

But the mere pressure and velocity of the explosion form but a part of the knowledge desired. How the explosion is formed, whether or not the coal-dust is burnt up entirely, whether, indeed, it be the dust itself which burns or coal-gas given off by the dust under the heat of the preliminary explosion, what the gas is which is left by the explosion at various stages—these are important things to be known, and they can only be ascertained by taking samples of the gases in the gallery at different moments during and after the explosion. To obtain these samples bottles are used, but the question is how to get them filled at just the right time. Into the shell of the gallery holes are drilled, and to these the metal bottles or flasks are screwed, a pipe leading from the mouth of each bottle well in towards the centre of the gallery. The end of this tube is closed by a cap of glass above which there stands poised a little hammer. Controlling the hammer is an electrical device called a "contact-maker," so arranged that just at the desired moment the hammer falls, breaking the glass, and admitting a sample of the gas in the gallery, the bottle and its tube having previously had the air exhausted from them, so that on the glass being broken the gas is sucked in.

At the same moment a weight falls, attached to the end of a cord, and this, on reaching the end of its tether, closes the end of the tube, and the sample is imprisoned until such time as the bottle can be disconnected and taken away to the laboratory for its contents to be analysed.

The contact-makers are of two kinds. In one the pressure of the explosion raises a piston which completes a circuit allowing current to flow through the very fine wire which prevents the fall of the hammer. This fine wire being fused by the current, the hammer falls and does its work. The other kind, which are used when the force of the explosion is not enough to raise a piston, is operated by one of the tin-foil circuit-breakers. A magnet, being energised by current passing through the foil, holds up a curved bar over two cups of mercury. Broken by the heat of the explosion, the foil cuts off this current, de-energises the magnet, and allows the bar to fall with its ends in the mercury. This completes another circuit, permitting current to pass to the fine wire, whereby the hammer is released. By connecting a bottle to a contact-maker at a distance the sample can be obtained at any desired period of the explosion. If, for instance, the sample is to represent the immediate products of combustion, it is placed near to the contact-maker. Then the sample is drawn in practically at the moment of explosion. If, on the other hand, it is the after-damp that is to be sampled, then the bottle would be connected to a contact-maker a long way from the seat of the explosion, with the result that its glass cap would not be broken until some considerable time had elapsed after the explosion has passed the bottle. The time also during which the bottle is drawing in its sample can be adjusted by varying the length of the cord to which the weight is attached.

And last of all must be mentioned the employment of a kinematograph, capable of taking twenty-two photographs per second, for observing the effects at the ends of the gallery (see illustrations).

Thus records are obtained of the force and heat of the explosion, its mechanical and thermal effects upon the walls of the gallery, or, if it were in a real pit, the effects which it would have in shaking and in heating the workings, and the men labouring in them. This and the analysis of the gases producing and produced by the explosion, derived from the contents of the bottles, give sound data upon which can be built up reliable theories as to the nature of colliery explosions and the way to prevent them, results which could be obtained in no other way. No one can help being struck with the thoroughness and ingenuity of the means adopted to these ends, and it is no exaggeration to say that it is a splendid example of thoroughly scientific methods applied to an important industrial investigation. It will be interesting to conclude this account with a brief mention of some of the results to which these painstaking efforts have led.

First in importance the fact is placed beyond doubt that coal-dust, which in bulk will only burn slowly, will, when well mixed with air, explode. And no combustible gas need be present to aid in the explosion.

The dust-raising gun, by blowing some dust into a cloud which was ignited by the second gun, caused an explosion powerful enough to do all the damage experienced in the most disastrous natural explosions. So it is practically certain that the function of the gas is but that of the first gun, to raise the cloud of dust.

A typical experimental explosion may be briefly described. On the cloud-raising gun being fired a small cloud of dust was driven out of the ends of the gallery, even that end at which the fan was blowing air *in*. In other words, the current of air was checked, even reversed, by the preliminary shock. This cloud was, of course, shown by the kinematograph.

Then when the second gun was fired, and the real coal-dust explosion occurred, there was first a cloud of dust shot out larger than the other one, to be followed by a cloud of flame 180 feet long. These also were recorded by the kinematograph. The sound was heard seven miles away.

Pressures as high as 92 lb. per square inch were recorded, and the force of the blast was found to travel well over 2000 feet per second.

In many cases, strange to say, the effects were very slight at the seat of the disturbance, the force seeming to increase as the wave travelled along the gallery. Probably the dust had not time to burn completely but only partially at the first onset. Where props or timbers checked the flow of the flaming gases there the damage was most, for no doubt the eddies caused the air and coal to be particularly well mixed at such points. An encrustation of coke was found on the sides and the timbers after all was over, probably because there was not sufficient air to burn all the dust, and some was only heated into coke to be deposited on the nearest surface, where the tarry matters would make it stick.

Finally, the most important, perhaps, of all, it was demonstrated that an admixture of stone-dust with the coal-dust made it non-inflammable. If a small zone were treated in this way, stone-dust being mingled with the other, the explosion became stifled at that point. True, the poisonous after-damp swept on beyond, so that men there might have been poisoned by it, but the stone zone would certainly save them from the direct effects of the blast. If, however, stone-dust be mingled with coal-dust all along the gallery, then no explosion at all would occur, again proving that it is the coal-dust which does the damage.

In the colliery adjoining the experimental gallery this plan had been in use for years. Soft shale is ground to fine powder, and is sprinkled wherever coal-dust has collected. It is just strewn by hand, giving the workings the appearance of having been roughly whitewashed. And since that has been done there has been no explosion in that pit. The experiments showed beyond doubt that that was no chance occurrence. They showed that in some way not thoroughly understood this addition of stone-dust renders the coal-dust harmless. It may be that it merely dilutes it. It may be that in some way it takes some of the heat and so prevents the coal particles becoming hot enough. It may be that, being a little heavier, it checks the formation of the dust-cloud. However that may be, there is no doubt now that stone-dust is the salvation of the miner so far as explosions are concerned.

Water sprinkled upon the coal-dust, by laying it and keeping it from forming a cloud, has the same effect, but it is less convenient, for the simple reason that water evaporates, while stone-dust stays where it is put.

CHAPTER XII

THE MOST STRIKING INVENTION OF RECENT TIMES

PROBABLY no invention has made such a sensation during recent years as wireless telegraphy. And since it is the direct outcome of the most abstruse, purely scientific investigations, there could be no more appropriate subject for a place in this book.

For many years there has been a belief in the existence of a mysterious something to which has been given the name of "The Ether." Totally different, it should be noted, from the chemical of the same name, it is entirely a creature of the intellect. None of our senses give us the slightest direct indication of its existence. No one has either seen, felt, heard, smelt or tasted it. Yet we feel that it must exist, for the simple reason that some things which our senses do tell us of are utterly inexplicable without it.

It was originally thought of in connection with light. Standing at night upon the top of a hill, we see the lights of a town a mile away. How is it that those distant gas or electric lamps affect our eyes? They are a mile away; and the idea that one object can affect another *at a distance* is one which the human mind refuses to accept. We feel compelled to believe that there is something in contact with the source of light which is affected first, and through which the disturbance, whatever it may be, is conveyed to our eyes, with which it must also be in contact. We feel that there must be a something stretching from our eyes to the distant objects, by which the light is carried. Of course the air fills the space referred to, but that cannot be the carrier of light, for if we look through a glass vessel from which the air has been exhausted we see distant objects undimmed. We also have good reason to believe that the air belongs specially to our globe, and does not extend upwards for more than a few miles. Consequently it cannot be air which brings sunlight and starlight. We are forced to fall back, therefore, upon the belief in something, of which we have no other knowledge, which must fill all the vacant spaces in the whole universe, passing, even, between the particles of which ordinary matter is composed, reaching as far as the remotest star, able to penetrate everything, and consequently not excludable from the most perfect vacuum. It is something so different from anything of which we have any direct knowledge that one is tempted sometimes to doubt whether there must not be some other explanation of light. In order to transmit light at the speed at which we find that it does in fact travel, the ether must be more rigid than the hardest substance we know of. Many, many thousand times more rigid, indeed. Yet it seems to offer no resistance to the passage of the planets through it. Still, there is no other alternative, so far as men can conceive, and we are compelled, therefore, to believe in the existence of the ether.

The first things discovered by the telescope were the larger satellites of Jupiter. With that precision for which astronomers are noted, they soon drew up time-tables, showing not only the past movements of these bodies, but also their future ones. They were soon puzzled, however, by the obvious fact that the moons of Jupiter were not working according to schedule, to use a railway expression. They got later and later for a time, and then gradually quickened up until they got too fast. Then they slowed down again. This repeated itself, and is going on still, with this difference, however, that the cause has been discovered and the schedules amended accordingly. The solution of the puzzle was that when the earth and the great planet are on the same side of the sun they are some 186 millions of miles nearer together than when they are on opposite sides of the sun. The evolutions of the satellites are quite regular, according to the astronomers' calculations, but they seemed to the earthly astronomers to vary, because of the time which light took to traverse that 186 millions of miles. When the two bodies were nearest together the occurrences seemed to happen about 1000 seconds (16 minutes) earlier than when they were farthest apart. Consequently it became evident that light took 1000 seconds to travel 186 million miles, or that, in other words, it moved at the prodigious speed of 186 thousand miles per second. That discovery was, of course, many years ago, but experiments since have proved the figure mentioned to be about right.

It put beyond question the fact that the action of a distant light upon the eye was not an "action at a distance," for such action, were it possible, would take effect at once. Seeing that light passed from the distant satellites at a definite velocity, and took a certain time to reach us, it was evident that it was, during that time, passing through a medium of some sort, and that medium must be the ether, for no alternative explanation will suffice.

So it became recognised that light really consists of waves or undulations of some sort in the ether; that a distant, luminous body set these waves going; that they travelled with a definite velocity, and then, striking our eyes, produced the sensation known as light. Many things were found out about light in the years which followed the discovery of its velocity. The lengths of the waves were ascertained—that is to say, the distance from the crest of one to the crest of the next. The different lengths were sorted out and found to give rise to different colours, while longer waves, which produced no sensation of light, were found to carry heat, thereby explaining how the heat reaches us from a distant fire, or from the sun.

Of the actual nature of the waves, however, little was known, although there was a vague idea that they were connected in some way with electricity, at which point in the story there comes in the famous name of James Clerk

Maxwell, a professor of Cambridge University, who in 1864 produced before the Royal Society the explanation of the nature of the waves and their connection with electricity and magnetism. That in itself was a wonderful achievement, but far more wonderful still is the fact that he truly predicted the existence of longer waves than any then known, which no one knew how to cause, or how to detect if caused. That prediction has since been fulfilled. The long waves have been found; we know how to make them and how to perceive their presence. They are the messengers which carry our wireless messages.

The discovery of these, at that time unknown waves, on paper, by simply calculating and reasoning about them, is more marvellous even than the feat of Adams and Le Verrier in discovering a planet on paper before anyone had seen it. It established Maxwell among the heroes of science for all time.

A magnet acts upon a piece of iron some distance away. The pull must be transmitted through some kind of ether. A current of electricity behaves in the same way, acting precisely as a magnet, with power to affect things at a distance. Again an ether is necessary. A dynamo works by moving a magnet past a wire which it does not touch, thereby generating current in it. There again an ether is necessary to transmit the effect from the one to the other.

Taking, then, the known magnetic effects of an electric current and the electrifying effects of magnets, he was able to show that the same ether accounted for all, and for the transmission of light as well, that, in fact, there was but one ether which performed all these various duties.

He proved from the known facts about electricity and magnetism that waves such as he imagined would, in fact, move with the speed of light. And once knowing the nature of the waves, he asserted that in all probability there were others of which men had then no practical knowledge.

Maxwell's theory soon set experimenters searching for the means of producing the long waves which he had predicted would be found.

Several authorities had before then stated their belief that the current derived from a Leyden jar was not simply a flow in one direction. They suggested, and gave grounds for the belief, that the current surged to and fro for some time before it settled down ; that it swung to and fro, indeed, like a pendulum.

There may be some of my readers who are unacquainted with this interesting piece of electrical apparatus the Leyden jar. It is a convenient form of what is called an electrostatic condenser. This is two conductors, generally in the form of two plates with an insulator between them. In the Leyden jar the insulator is a glass jar, while the "plates" are coatings of tinfoil, one inside and the other outside. On connecting one coating to one pole of a battery, and the other to the other pole, they become charged, one positively and the other negatively. One, that is, acquires an excess of electricity, while the other becomes deficient to an exactly similar extent. When the two are afterwards connected by a wire the surplus on one flashes through it to make good the deficiency on the other.

Rushing first of all from positive coating to negative, electrical inertia causes it to overshoot the mark and to recharge the jar with the charges reversed. Then current begins to flow back again, doing the same several times over, until at last equilibrium is established.

The power to absorb and hold a charge of electricity, which is the characteristic of a condenser, is called "capacity."

What, then, is "electrical inertia"? I have already referred to the effect which the creation of a magnetic field around a current has upon neighbouring conductors. It also has an effect upon itself. As soon as the current begins to flow it builds up the magnetic field, and in the process some of its energy is exhausted. On the original current ceasing, however, the magnetic field collapses back on to the conductor once more and in so doing restores that energy. This occurs whenever current flows, but it is specially noticeable in long conductors, like submarine cables. In them the battery has to act for a considerable time before any current reaches the farther end. It is in the meantime employed in building up the magnetic field around the wire. Then when the battery has ceased to act the current still comes flowing out at the farther end—the magnetic field is giving back the energy expended upon it. Thus a current is reluctant to start flowing through a conductor, and, having started, is disinclined to stop. This is called " inductance," and it has exactly the same effect upon the current that inertia has upon a body. What inertia is to a material body inductance is to an electric current.

And lastly, the resistance which the conductor offers to the passage of the current is precisely analagous to the friction of the water in a pipe.

So, we see, the " capacity " of the two coatings of the jar and the inductance which occurs in the connecting wire cause the current to oscillate to and fro for a while when the jar is discharged, which surging or oscillation is ultimately stopped by the resistance of the wire. The two coatings and the wire form what is called an oscillatory circuit.

We can now resume our story.

After much experimenting Hertz, of Carlsruhe, discovered the fact that when a discharge was taking place in an oscillatory circuit tiny sparks passed between the ends of a curved wire held some distance away. His apparatus is illustrated in Figs. 6 and 7. The former, which is termed nowadays a " Hertz Oscillator," is simply two metal discs almost connected by a thick wire. The wire is broken, however, at the centre, and the two halves terminate in two metal balls. Each ball is connected to one terminal of an induction coil. Now the current comes from an induction coil in a series of spurts. It is not an alternating current exactly (since every alternate current is so feeble as to be negligible), but is practically an intermittent current always in the same direction. Thus we may call one the positive end of the coil and the other the negative. A short current comes along with every backward movement of the little vibrating arm which forms a part of the apparatus. This breaking of the "primary" circuit may take place perhaps fifty times per second, so that the intermittent "secondary" currents will succeed each other at intervals of a fiftieth of a second, or even less. The brain reels at the attempt to think of a fiftieth of a second, but it is really quite a long interval as these things go, and during that interval quite a lot happens. For the current first of all charges the two plates as a condenser.

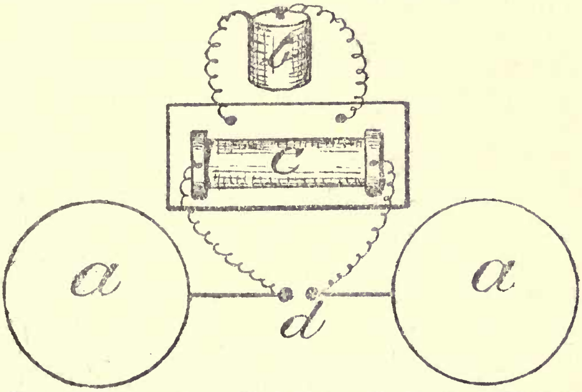


FIG. 6.—The apparatus by which Hertz made his discoveries, hence called the Hertz Oscillator. *a a* are metal plates; *d* is the spark-gap between the two metal balls; *b* is the battery, and *c* the induction coil.

When they are as full as they will hold the current overflows, as it were, across the gap between the two balls.

Now an air-gap—a gap that is filled with air, between two conductors—is a very strong insulator. But when current has once broken through it it becomes a fairly good conductor. Hence as soon as the first spark has passed between the two knobs the plates become connected almost as if a wire were passed from one to the other. And there we have quite a good oscillatory circuit. There is capacity at each end and a fairly long length of wire to provide the inductance. Consequently that breakdown of the insulation of the air in the spark-gap is followed by electrical oscillations which take place with inconceivable rapidity. Yet because of the resistance of the spark-gap, which is considerable even after it has been broken through, the oscillations do not continue for long. They have died away long before the lapse of a fiftieth of a second, when the next impulse comes along from the coil. In the meantime the air-gap regains its insulating properties, and so, on the arrival of the next impulse, the whole thing occurs once more.

Thus a little train of oscillations is produced for every impulse from the coil. Every train causes a corresponding disturbance in the ether, and sends off a train of electro-magnetic waves, and these, falling upon the distant wire, generate in it a train similar to that which brought them into being. These trains, in Hertz' simple apparatus, manifested themselves in the form of minute sparks leaping across the small gap between the ends of the curved wire (Fig. 7).

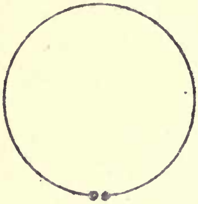


FIG. 7.
Hertz "Detector."
It was with this simple apparatus that Hertz discovered how to detect the "wireless waves."

It was in 1888 that Hertz made this discovery of a way to detect long electric waves. He subjected the matter to many more experiments and found that the waves have many points in common with light rays. He found that they were reflected from certain surfaces, just as light is reflected from the surface of a mirror. He made prisms which were able to bend them as light waves are bent by a prism of glass. Some things appeared to be transparent to them, as clear glass is to light, while others are opaque. It does not follow that the same things which reflect light waves reflect electric waves, and so on. The latter can pass through a brick wall, for example. But the same divergence is to be observed between light and radiant heat, of which the action of glass is a familiar example. Clear glass will let light through almost undimmed, yet we use it for fire-screens to shield us from too much radiant heat. The important fact is that all three—light, radiant heat and Hertzian waves—in addition to travelling at the same speed, are reflected, absorbed or refracted, according to precisely the same principles. This is almost perfect testimony to their essential identity.

The difference between them, as has been said already, is the distance from crest to crest of the waves—the "wave-length," that is. And the reader will wonder by what manner of means this mysterious dimension can be ascertained. In spite of its seeming mystery the method is very simple.

It is based upon the fact that two sets of similar waves travelling at the same speed in opposite directions interfere with one another in a peculiar way. Suppose that one set of waves travel along to a reflector and strike it vertically; then another set will travel back from the reflector exactly similar to the first, except that their direction will be opposite. And the result will be that at certain intervals they will exactly neutralise each other, so that at those points there will be no wave-action appreciable at all. Those points where no action is to be perceived are called "nodes," and they are exactly half a wave-length apart.

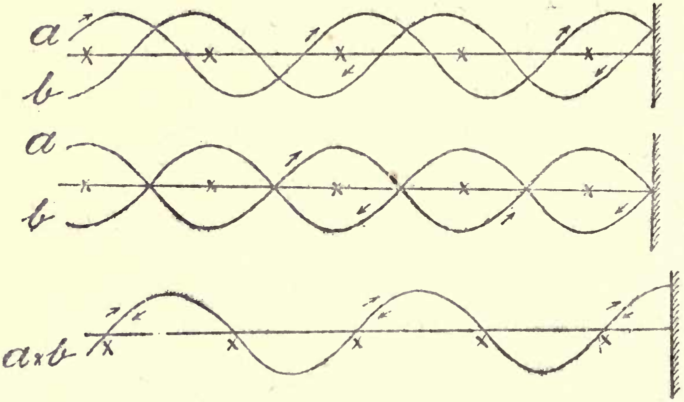
This will be quite easily understood from the accompanying diagrams. In each of these diagrams the set of waves marked *a* are supposed to be moving from left to right, while those denoted by *b* are reflected back and are moving from right to left. It will be noticed that each wavy line has a straight line drawn through it, dividing it into alternate crests and hollows, which line is known as the axis of the waves.

Now notice that in Fig. 8 there are points marked ×, where the *a* waves are just as much above the axis as the *b* waves are below it, and vice versa. Hence at those points the two sets of waves will neutralise each other.

Now turn to the next figure, which, be it remembered, shows the same waves a moment later, when they have moved a little farther on in their respective journeys, and it will be seen that there, too, are places marked × where the two sets of waves neutralise each other. And the same with the third diagram.

And finally observe that the places marked × are always the same in all the diagrams—that is to say, they are always the same distance from the line on the right-hand side, which denotes the reflector. It will be clear, too, that each node is half a wave-length from the next.

Thus it can be shown that at every moment, and not merely at the three indicated in the diagrams, the two sets neutralise each other at the nodes, that the nodes are always in the same places and half a wave-length apart.



Figs. 8, 9 and 10.—These diagrams help us to see how the "wireless waves" are measured. The *a* waves are supposed to be moving from left to right and the *b* waves from right to left. At the points marked × they neutralise each other. It is then easy to discover those points and the distance apart of any two adjacent ones is half the "wave-length."

N.B.—In Fig. 10 the *b* waves fall exactly on top of the *a* waves.

Everywhere else, except at the nodes, there is action more or less energetic, but *there* is perpetual calm.

But how can we tell where the nodes are? When we recollect that they are points at which no wave-motion at all takes place it is easy to see that we shall at those points get no spark in our detector. So what Hertz did was to set his oscillator going so that it threw waves upon a reflecting surface and then move his detector to and fro in the neighbourhood until he found the nodes. Between the nodes, as will be seen by an inspection of the curves once more, there are other points at which the wave-action will be twice as great as with the single wave, and so at those points the response of the detector would be especially energetic.

This mutual action between an incident wave and a reflected wave is termed "interference," and by it the wave-lengths of all the ethereal waves have been measured. The plan used in the case of light waves, although the same in principle, is somewhat different because of the extreme shortness of the waves.

So the experiments of Hertz not only showed that long electric waves existed, but that they were in all essentials similar to light, and their wave-lengths were ascertained. On that basis has been built up modern wireless telegraphy.

It may be interesting to mention at this point a very curious, and in a sense pathetic, incident. Professor Hughes, whose name is associated with certain well-known instruments for ordinary telegraphy, nine years before Hertz' discovery noticed that a microphone was affected by the action of an induction coil some distance away. He himself attached some importance to the matter, but he allowed himself to be dissuaded from following up the discovery by other scientists, more eminent than himself at the time, who thought that it was not a promising field for investigation. But for the influence of these friends he would possibly be the hero of this story in place of Hertz.

Professor Silvanus Thomson has said that he too noticed the sparks produced at a distance when a Leyden jar was discharged, but he makes no claim to precedence over Hertz, since, seeing the phenomenon, he did not perceive its real meaning, while Hertz, though a little later in time, realised the profound significance of it.

Hertz himself in his account of his experiments is generous enough to assert that, had he not discovered the waves when he did, he is quite certain that Sir Oliver Lodge would have done so.

Before proceeding to describe the principal apparatus used in the wireless station I should like to devote a little space to the explanation of a term which will come up again and again, and which represents that which is responsible, in the main, for the marvellous advances which the art of sending wireless messages has achieved in the last few years. I refer to "resonance."

It will be a great help if the reader will try for himself a simple, inexpensive little experiment. Stretch a string horizontally across a room and on to it tie two other strings so that they hang down vertically a little distance apart. To the ends of the two strings tie some small objects—a cotton reel on each will answer admirably. They will thus form two pendulums, and, to commence with, they should be just the same length. Having rigged all this up, give one pendulum a good swing. It will impart motion of a to-and-fro variety to the supporting string, which in its turn will pass that motion on to the other pendulum. In a very short time, then, the second pendulum will be vibrating like the first. Indeed the *whole* motion of the first will shortly become transferred to the second, so that the second will be swinging and the first still. Then the second will re-transfer its energy back to the first, and so they will go on until the original energy given to the first pendulum is exhausted. The point to be observed is the quickness with which one pendulum responds to the impulses given it by the other, and the ease with which the energy of the one passes to the other.

Now reduce the length of one pendulum. On setting the first in motion a certain irregular spasmodic action is to be observed in the second, but it is very different from the "whole-hearted" response in the previous instance. In the former case the second one responded naturally and readily to the first. Now its response is reluctant in the extreme. It moves somewhat because it is forced to, but it is apparently unwilling. Energy has to be *impressed* upon it. There is no readiness, because there is no sympathy between them.

That sympathy between the two equal pendulums is "resonance." The same occurs between two violin or piano strings when they are "in tune."

The explanation is that a pendulum has a certain natural frequency which depends upon its length. Another pendulum of the same length, arranged as just described, therefore imparts impulses to it at just the frequency which is natural to it. Consequently the effect is a cumulative one, and it responds quickly. Impulses at any other frequency tend more or less to neutralise each other. In the same way a string, of a certain length and a certain tension, has a frequency peculiarly its own, and it will respond to another similar string because the other gives its impulses at its own natural frequency.

It is on record that an engine in a factory happened to run at precisely the same speed as the natural frequency of the building, with the result that after a little time the structure shook so much that it collapsed.

Now electrical circuits in which currents oscillate have a natural frequency of their own. That frequency depends upon the two electrical properties of the circuit: capacity and inductance. And if you want to set up an electrical oscillation in any circuit you can best do it by giving it impulses at intervals which agree with its natural frequency.

Sir Oliver Lodge seems to have been the first to appreciate fully the effects of resonance in wireless telegraphy. It is strange that in England the work of this eminent man in "wireless" matters is not more fully recognised. When wireless telegraphy reached the point at which the public became interested, Marconi was just coming to the front and so, for ever, will his name be foremost in the public estimation. Indeed more than foremost, for in the minds of many he monopolises the credit for this invention. Many people are under the impression that he is the one and only, or at any rate the original, inventor of wireless telegraphy.

Now Marconi has done exceedingly valuable work in this field. Moreover, he has been the means of placing the affair on a good commercial footing. But all the same he is by no means the original or only inventor. While admitting that he is a remarkable man, who has done wonders, it is only common justice to refer to the others whose contributions to the solution of the problem are possibly of equal value. And, of these, few can compare with Sir Oliver Lodge.

But to return to the question of resonance. At first the distances over which messages could be sent were but small. Now a marconigram can be flung across a hemisphere. At first little could be done by day, work had to be done mainly at night. Now communication passes by day and night alike. Yet in principle, and in many details, the instruments are unaltered from what they were several years ago. The main source of all this improvement is the use of resonance.

To enumerate broadly the apparatus used for the dispatch and receipt of messages the following list will be useful :—

Transmitting End

(1) An Antenna, consisting of a number of wires raised to a considerable height above the ground.
(2) A Spark-gap, consisting of a series of metal balls with gaps between them, the outer ones being connected to the antenna and to the induction coil.
(3) A powerful Induction Coil with batteries or other source of current to work it.
(4) A Telegraph Key, by which the induction coil can be started and stopped at will.

Receiving End

(1) An Antenna precisely similar to the other.
(2) A Coherer or other " oscillation detector."
(3) A Receiving Instrument which may be a writing telegraph instrument, a telephone, any of a number of ordinary telegraph instruments, or a galvanometer.

Transmitting and sending instruments are, of course, installed at both ends and either of them can be connected to the antenna at will by the simple movement of a switch.

The antenna plays the part of one of the metal plates in the Hertz oscillator. Early experiments were made with Hertz apparatus, but the range of such a contrivance is very limited. For one thing, it neglects to take advantage of the earth. It is little realised what an important part the earth plays in the carrying of wireless messages. A very great step was taken when Marconi dispensed with one of the plates of Hertz, and used the earth instead; while the other plate gave place to the elevated wires, the most familiar part of the apparatus to most people.

The condenser is thus formed by the earth as one plate, the elevated wires as the other, and the intervening air as the insulator. The "capacity" must be exceedingly small in such an apparatus, but it is sufficient; while the long lines of electrical force stretching from the high antenna to the earth produce waves of great carrying power. Lastly, when the earth forms a part of the condenser the waves cling to it, so that instead of being largely dissipated into space, they move along the surface of the earth. The advantage of this is obvious.

At first it was customary to place the spark-gap in the wire leading from the antenna to the earth, as in the accompanying sketch. Later, however, it was found better to place the coil and spark-gap in a local circuit in which the oscillations are first produced. These oscillations pass through a coil which is interwound with another one connected to the antenna and to earth, and thus the local oscillations, as we might call them, induce similar oscillations in the antenna, just as the fluctuations in one part of an induction coil induce fluctuations in the other. Indeed the coil in the local circuit and the one in the antenna circuit actually constitute an induction coil.

The advantage of this is that by introducing condensers the capacity of which can be varied, and coils the inductance of which can be varied, into the oscillation circuit it becomes possible to " tune " the circuits effectively. Thus resonance comes into play and the power expended can be made to produce the maximum effect.

Some attempts have been made to displace the induction coil in wireless telegraphy altogether by a specially made dynamo. These machines can produce either alternating or continuous currents, in fact the alternating current dynamo is really simpler than the more familiar continuous - current machine. The difficulty is, however, to run it sufficiently fast to produce sufficiently rapid alternations. Nicola Tesla made an alternator (to give the alternating current dynamo its short title) which could produce 1500 alternations per second, while Mr W. Duddell made one which produced 120,000, but neither was satisfactory for the work in question. Could such a machine be made, it would be invaluable, for it will be apparent that a continuous succession of waves would be formed by it and not a succession of short trains of waves such as is produced by the induction coil and spark-gap. The difficulties are not electrical, but mechanical. It seems doubtful if a machine will ever be made to run with sufficient rapidity which would not knock itself to pieces in a very short time.

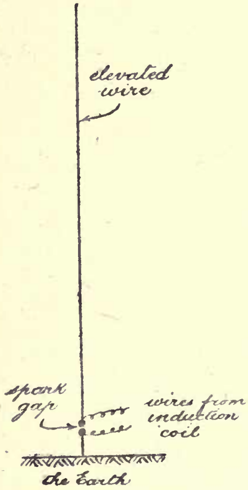


Fig. 11.—The simplest form of wireless antenna.

Small alternators are used sometimes, however, to supply alternating current to the primary of an induction coil, or transformer, as it is more often called in its larger sizes. The interrupter is only needed when the primary current is continuous—from batteries, for example. Alternating current needs no interrupter, and so that bother is removed. The alternations of a hundred or so per second, which are quite the common thing with alternators, are just what is needed to excite an induction coil. Consequently small machines of this kind are to be found in many stations.

A Danish inventor, Valdemar Poulsen, has adopted an altogether different method of producing electrical oscillations, which method is the distinctive feature of his mode of telegraphy. He takes advantage of a curious effect of passing current between two rods, one of which is carbon, so as to form an arc such as we see in arc lamps.

My readers are already familiar with the term "shunt" in connection with electrical matters, and so will perceive at once what is meant when a second circuit is said to be arranged as a shunt to the arc. The accompanying diagram will in any case make the matter clear.

The current comes along from the battery or continuous-current dynamo to a hollow rod of copper which, to prevent it being melted, has cold water continually circulating inside it. Thence the current jumps across to a carbon rod, forming an arc between the two rods, and returns whence it came. In its journey it traverses the coils of an electro-magnet, the poles of which are one each side of the arc. This tends to blow the arc out, as a puff of wind blows out a candle, an effect which a magnet always has upon an electric arc.

The shunt consists of a wire leading from the copper to the carbon rod with a condenser and an inductance coil inserted in it. The latter coil also forms one part of that coil by which the oscillations in the local circuit are transferred to the antenna.

The electrical explanation of what happens when the current is turned on to an arrangement like this is rather too complex to set out here. It depends upon a curious behaviour of the arc. It is really a conductor, yet it does not behave as ordinary conductors do, and the result is that the continuous current flowing through the arc is accompanied by an oscillating current in the shunt circuit. And the important feature of the arrangement is that these oscillations are continuous, in one long train, not in a succession of trains. The advantage of this has already been referred to.

One other feature of the apparatus just described should be mentioned, since it will seem curious to the general reader. For it to work properly it is necessary that the arc should be enclosed in a chamber filled with hydrogen or a hydro-carbon gas. Coal-gas is generally used.

Hertz' original discovery was that small sparks could be seen to pass between the ends of a curved wire when the electric waves fell upon it. Such "spark detectors," as they are called, are useful in the laboratory, but not for practical telegraphy.

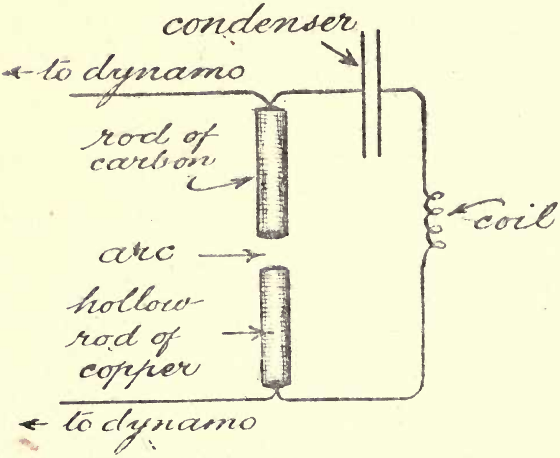


Fig. 12.—Diagram (simplified) showing how Poulsen generates oscillations. Current from a dynamo flows through the arc, whereupon currents oscillate through the condenser and coil (as described in the text).

Several people seem to have noticed in years gone by that a mass of loose metal filings, normally a very bad conductor of electricity, became a much better conductor when an electrical discharge of some sort occurred near by. The demand for a wireless receiver had not then arisen, however, and so the discoveries were not followed up. Consequently it remained to be rediscovered by Branly, of Paris, in 1890. He placed some metal filings in a glass tube, the ends of which be closed with metal plugs. Lying loosely together the filings would not conduct the current of a small battery from one plug to the other, but when a spark occurred not far away they suddenly became conductive and allowed it to pass. Several years after this Sir Oliver Lodge took up the idea as a receiver for wireless messages, and believing that its action was due to the waves causing the filings to cling together, he christened it "Coherer."

Marconi succeeded in making a very delicate form of this, although working on strictly the same lines.

The trouble with a coherer is that when once it becomes conductive it remains so unless the filings be shaken apart. Lodge therefore arranged for the tube to be continually struck by clockwork or by a mechanism like that of an electric bell. Marconi effected a further improvement by making the current passing through the coherer control the striking mechanism, so that the latter is normally quiet but administers one or two taps at just the right moment.

Sir Oliver Lodge and Dr Muirhead devised another detector which, though quite different in form, is really much the same in principle. A steel disc with a sharp knife-like edge is made to rotate above a vessel of mercury. The edge just touches the mercury but no more. On the top of the mercury there floats a thin layer of oil, a bad conductor. Now as the disc revolves it picks up on its edge a film of oil, which it carries down into the mercury. The film adheres so tightly that it prevents the moving disc from actually touching the liquid metal. Thus, under normal conditions, the two are electrically insulated from each other by the film of oil and no current can pass from mercury to disc. Oscillations, however, caused by incoming electric waves, are able to break through the oil film and so bring disc and mercury into contact, whereupon the current flows. The constant movement of the disc restores the oil-film as soon as the oscillations cease.

The reason why these detectors act as they do is not quite understood. One suggested explanation is that the oscillating currents heat the particles and so partially weld them together. Another is that adjacent particles become charged as the plates of a minute condenser, and so are drawn tightly together as the plates in an electrostatic voltmeter are drawn towards each other. Supposing that the original non-conductivity of the loose filings be due to the film of air which may surround them, either of these things would account for the film being broken or squeezed out, resulting in better contact and improved conducting power. But both suggestions seem to be contradicted by the fact that if the pieces in contact be of certain substances the coherer works the opposite way. Under those conditions the conductivity is normally good, but the influence of the incoming waves causes it to become bad.

In 1896 Professor Rutherford, now of Manchester, described some discoveries which he had made as to the magnetic effects of oscillations. A simple little contrivance which he had constructed was operated by the discharge of a coil half-a-mile away, at that time a great performance. This detector was simply an electro-magnet with a steel core instead of the usual soft iron core. The reason the latter is used in the ordinary magnet is that it loses its magnetism the moment the current ceases to pass through the coil with which it is surrounded, while a steel core retains its magnetism. For most purposes a steel core would render an electro-magnet useless, but in this case it was desired that the core should be permanently magnetised. So a current was first passed through the coil to magnetise the core, and then the coil was connected to a simple form of antenna while a swinging magnet was brought near so that the magnetic power of the core would be indicated and any change made apparent. The effect of the discharge half-a-mile away was to *de*magnetise the core slightly. This was shown by the movement of the swinging magnet, and so the first "magnetic detector" was found.

But here, perhaps, I ought to explain the use of the antenna at the receiving station—its function at the sending end has already been made clear. The electro-magnetic waves, coming from the distant transmitter, strike the receiving antenna and in so doing *set up in it oscillations such as those which set them in motion.* For every oscillation in the sending antenna there will be another, similar in every respect except that it will be feebler, in the receiving antenna. And the oscillations are here led to the detector, of whatever form it may be, and in it they make their presence felt.

In some few cases a Duddell thermo-galvanometer has been employed as the detector, in which the oscillating currents report themselves directly. In coherers the detector works by causing the oscillating currents to control a continuous current from a battery and it is the latter which actually gives the signal, but there are a number of extremely interesting means which have been invented to detect the oscillating currents by their heating effect.

R. A. Fessenden, for instance, has perfected one which is a marvel of delicate workmanship. He depends upon the heating of a wire by the currents passing through it. Such heating is the result of the electrical force acting against resistance, and the difficulty is that if the resistance be great it will almost entirely kill the faint oscillating forces in the receiving antenna, while if, on the other hand, it be small, the rise in temperature will be inappreciable. So he encloses a fine thread of platinum in a glass bulb from which the air is exhausted. The platinum wire is first of all embedded in a wire of silver: the silver wire is given a core of platinum, in fact. Then the compound wire is drawn down until it is so thin that the platinum core is only one and a half thousandths of an inch in diameter. A short length of this compound wire is then bent into a U-shaped loop and its ends connected to thicker wires. Finally the bottom of the loop is immersed in nitric acid, which eats away the silver at that point and leaves the bare platinum. Thus is produced a very short length (a few millimetres) of exceedingly thin platinum wire supported at its ends by comparatively thick wires.

Being so short, this wire does not offer much resistance, and consequently does not materially check the oscillations. At the same time, since it is so fine, it does offer some resistance, and finally, since what heat is generated will be in an exceedingly small space, it will be appreciable there. A telephone is arranged so that its current also passes through the fine wire, and every slight variation in the temperature of the platinum wire, by varying its resistance, varies the current through the telephone. And exceedingly slight variations can be detected by sound in the telephone. Thus the oscillations generated in the antenna affect the heat in the wire; that affects its resistance; and that again affects the telephone, which, finally, affects the ear of anyone who is listening to it. It must be understood, however, that this is not a wireless telephone, for the sounds heard are not articulate but merely long and short sounds, representing the dots and dashes of the "Morse Code."

Electrolysis provides us with another form of detector. An exceedingly small platinum wire forms one electrode and a large lead plate the other, and both are immersed in dilute acid. The passage of current from a local battery sets up electrolysis, and so stops itself by forming a film of oxygen on the small electrode. This film, however, is broken by the oscillating currents from the antenna, so that as long as they are coming the battery current can flow, but as soon as they cease the battery current stops itself again. Thus the flowing and stopping of the oscillating currents is exactly copied by the current from the battery, which current is led through a telephone or a sensitive galvanometer.

It may occur to readers to inquire why the oscillating currents are not passed direct to a galvanometer. The answer is that because they are oscillating a very sensitive galvanometer is not possible.

True, the Duddell thermo-galvanometer has been mentioned in this connection, but although it is a beautiful instrument it cannot compare for delicacy with the direct-current galvanometers. The latter are easily a *hundred thousand times* more sensitive. But the trouble can be overcome by "rectifying" the oscillating currents, by passing them through a "unidirectional" conductor—one, that is, which passes current one way only. These remind one of a turnstile as installed at certain public places, which let you out but will not let you in unless you pay. In fact they will not let you *in* at all. In like manner "rectifiers" will only allow those currents to pass which are flowing in one direction, and so they cut out every alternate oscillation, thus producing something very like continuous current, which can be detected by the very delicate galvanometers which are usable where continuous currents are concerned, or more often by a telephone receiver. The rectifying conductors are in many cases crystals, hence these detectors are called "Crystal Detectors." Carborundum is a favourite for this purpose.

And that brings us to the important question of the secrecy of wireless communication, and the measures taken to prevent confusion from the number of independent messages flying through the air at the same time.

This can be largely achieved by the aid of resonance. Trains of waves flung out by one antenna may strike several other antennæ, but unless the latter are in tune with the sending apparatus they will probably not be affected appreciably. Let one of them, however, be in tune, and it will pick up easily the message which is not noticed by the others. It is as if three people watching a distant lamp were affected by a form of colour-blindness which rendered them practically blind to all colours except one. Suppose one could see red only, the other blue and the third yellow. A light sent through a blue glass being robbed of all rays except the blue ones would be visible only to the man who could see blue. The man who could see blue would, in like manner, be quite blind to light sent through red or yellow glass. Each of them, in fact, could be signalled to quite independently of the others by simply sending him rays of the colour to which his eyes were sensitive. In precisely the same way each wireless receiver is or can be made most sensitive to waves of a particular length and practically blind to all others. The operator can adjust his apparatus for certain prearranged wave-lengths, and so he can communicate with secrecy to stations whose wave-length he knows. The change, of course, is made by altering the capacity, or inductance, or both. The instruments can be so calibrated that it is quite easy to make the alteration.

Then, antennæ can be so constructed that messages can be received with most readiness from one particular direction. In others, they can be received from any direction, but the direction can be discovered. This, it will be easy to see, is of great value to ships in a fog.

Antennæ made with a short vertical part and a long horizontal part radiate best in the direction away from which their horizontal part points. This is of great advantage in stations which are built specially to communicate with other particular stations. In such cases the antenna is carefully built, so as to point in the required direction. Such antennæ also receive more readily those signals which come from the direction away from which they are pointing.

Reference has been made already to the interesting fact that wireless communication is easier at night than in the daytime. That is probably because of the "ionisation" of the atmosphere by the action of sunlight. Along with the visible sunlight there comes to us from the sun a quantity of light known as "ultra-violet," since it makes its effect known in the spectrum of sunlight beyond the violet, which is the limit of visibility at one end of the spectrum. We cannot see it but it affects photographic plates powerfully. It has energetic chemical powers, and it has the ability to make the air more conductive than it is ordinarily. Comparatively little of it penetrates our atmosphere, but it must exercise a good deal of influence a little higher up. Now readers will remember that the process by which electromagnetic waves are propagated is checked when the waves strike a conductor. The energy in the waves is then employed in causing currents in the conductor instead of forming more waves. And so partially conductive air forms a partial barrier to the waves. The effect is not appreciable in the case of the tiny waves of light and heat, but it is in the case of the long " wireless waves." Everyone has seen the waves of an advancing tide coming up a sandy beach, and has noticed how the dry sand (a good conductor of water) sucks up and destroys the foremost ripples. In like manner are the wireless waves " sucked up " by the partially conductive atmosphere. But the effect of the ultra-violet light does not last long, and so, at night-time, it disappears. Therefore messages can be sent better at night than by day.

For wireless *telephony* what is wanted is a continuous uninterrupted train of waves, such as those from the " Poulsen arc," and a receiver of the magnetic type. The coherer is no good for this purpose, since it either stops the current entirely or lets it flow copiously. The magnetic detectors, however, respond to the variations in the strength of the incoming waves. As the latter increase or decrease in strength so does the magnetic detector give out stronger or weaker signals. So a telephone transmitter of the ordinary type is made to vary the strength of the oscillations at the sending end, while an ordinary telephone receiver is placed in series with the detector at the receiving end. Thus every slight variation corresponding to sound waves spoken into the transmitter is reproduced in the receiver.

It is strange that wireless telephony has not made greater progress, for it may be said, on the word of one of the greatest authorities, that wireless telephony is simpler and easier than telephony through a submarine cable. In the latter there are almost insuperable obstacles caused by the capacity and inductance of the circuit, while in the wireless method there is very little difficulty.

There are, of course, several so-called " systems " of wireless telegraphy in use. There is the Marconi in Great Britain; the secret Admiralty system in the British Navy; the De Forest in the United States; the Telefunken in Germany, not to mention the promising Poulsen system. And there are still others. But it would be futile to attempt to explain how they differ from one another in a work like this. In principle they are alike. The precise forms of instrument used may vary, but even there there is much in common between them. As time goes on there will inevitably be a tendency to more and more uniformity. That is always the case, for some things are inherently better than others, and rival systems, although each is working along its own lines, always come to very much the same result in the end. Without making any comparisons, it is safe to say that if the Telefunken system, for example, has any points of superiority over the Marconi, the latter will sooner or later find out the fact, and will modify their apparatus accordingly. In all probability this will operate both ways, and some things which the German system is now using will give place to those which the British have in operation.

In another very modern industry this is very apparent. Having attended and carefully studied several annual exhibitions of flying machines, I have noticed with great interest how the varying types of a few years ago are merging into the more or less uniform types of to-day. And it has been the same with wireless telegraphy, and will be still more so in the future.

The best means of generating the waves and the best means of detecting them at a distance—that is the whole problem, and all the workers in it will sooner or later come to much the same conclusions as to which are the best ways.

Patents may do a little to delay this, but not much. For one thing, patents only last a few years. For another, a patent only covers a particular way of doing a particular thing. A machine that is termed "patent" is often the subject of a hundred patents, each covering a particular little point. It is well-nigh impossible to patent a whole machine. A general principle cannot be patented, only a particular application of that principle, and so there are in a great many cases little variations of a patented method which are quite as good as the patented one, and which can be used freely. So even patents will not have much effect, in all probability, upon this unification process.

But, however that may be, there is no doubt that the whole world owes a deep debt of gratitude to the men who have worked out this most beneficent of inventions. It is difficult to think of a single one which has ever brought such a load of benefits to poor, struggling humanity as this has. The ship in distress, the lighthouse man on his lonely islet, the explorer in the Polar regions, the pioneer settler in the new lands—in fact, just those who most need some connecting link with their fellows—are the people to whom the wireless telegraph brings aid and comfort. All honour to the men who have done it.

CHAPTER XIII

HOW PICTURES CAN BE SENT BY WIRE

THE sending of a message by telegraph is easily understandable. Various combinations of two simple signs, such as short sounds and long sounds, can readily be made to indicate letters by which the words can be spelt out.

Nor does the sending of sound over a wire make a very great demand upon the credulity. We all know that sound consists of innumerable little waves in the air, and by the simplest of devices these can be converted into variations in an electric current, which variations, by means equally simple, can be made to re-convert themselves back into sound waves at the other end.

But to transmit a picture is another matter altogether. It seems barely possible in the case of a drawing such as a pen-and-ink sketch, which consists of a comparatively small number of definite lines; but with a shaded sketch or a photograph, with its gradations of light and shadow—to transmit such would seem to be beyond the bounds of possibility, did we not know that it has been done. The description of the methods will therefore constitute a not uninteresting subject for a chapter.

It is worthy of remark that an attempt along these lines was made many years ago by a man named Caselli, and a description of this pioneer apparatus will form a good introduction to the later developments.

In Fig. 13 we see a square which represents a sheet of tin-foil, upon which is drawn, in non-conductive ink, a simple geometrical figure. The ink may be grease, or shellac varnish, indeed there are many substances which are available for use as an insulating ink. Across the square there are a number of parallel dotted lines, but these, it must be understood, are not actually drawn upon the foil—their purpose will be apparent in a moment.

Suppose that we connect the foil to one pole of a battery, and the other pole by a flexible wire to a metal pen or stylus. If we place the point of the pen in contact with the foil, we make a complete circuit, through which, of course, current will flow. But if, with it, we touch one of the non-conductive lines, there will be no current.

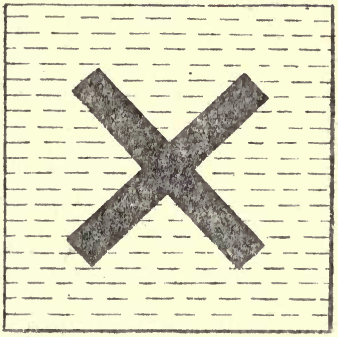


FIG. 13

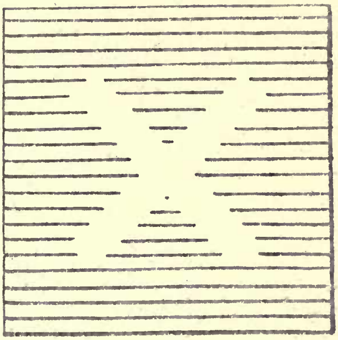


FIG. 14

Taking a ruler, then, let us draw the point of the stylus across the foil in a series of parallel straight lines. It is these excursions of the stylus which the dotted lines are intended to represent. For nearly the whole of the time current will be flowing ; but whenever the stylus is crossing one of the lines of non-conductive ink there will be a momentary cessation. Thus, the reader will begin to perceive, we obtain what we may call an electrical representation of the figure drawn upon the foil.

And now let us turn to Fig. 14. There, too, is a square, but in this case it is not foil, but paper which has been soaked in prussiate of potash. The reason for introducing this chemical is that it is susceptible to electrical action. Whereever current passes through it, it becomes changed into

Prussian blue, so that if we place the point of a pen upon the paper, and cause current to flow out of that point through the paper, there we get a blue dot. If, while the current is flowing, we draw the pen along, we get a blue line.

Fig. 13 therefore represents in principle the sending apparatus of Caselli's writing telegraph, while Fig. 14 represents the receiving instrument. The two pens are connected together by the main wire, in such a manner that, when the point of the one is in contact with the bare foil current flows out of the other and into the paper; but as the former crosses an ink line all current ceases.

If, then, while the sending pen is drawn line by line across the foil, the other is drawn at the same speed, line by line, across the chemically prepared paper, we shall get on the latter a series of lines as shown in Fig. 14 almost continuous, but broken here and there. Each breakage represents a passage of the sending pen across a line, and taken together, as will be seen, they constitute a reproduction of the geometrical figure drawn upon the foil. As shown, the lines are rather far apart, and so the reproduction is not a very good one. They are only drawn so, however, in order that the principle may be shown the more clearly. They may be drawn so that they overlap, and then the effect is very much better, the received picture being almost an exact reproduction of the other.

It will be noticed that an essential to the success of this method is that the two pens should move in perfect unison, and that was the great difficulty. Caselli used an arrangement of pendulums, the best thing available at the time.

The reproduction is, in photographic language, a negative, a somewhat unsatisfactory feature of the method. A simple modification, however, of the electrical connections will reverse that, so that the reproduction shall be a positive. There are two ways of cutting off a current from any particular circuit. One is to interpose a resistance, through which current cannot pass in an appreciable quantity, and the other is to provide a second path for the current so much easier than the first that practically all the current will pass that way, leaving the first circuit, to all intents and purposes, free. It is as if a farmer wished to stop people passing across a certain field. Two methods would be open to him : one to put up a high gate over which no one would dare to climb, and the other to provide a short cut so much more pleasant and convenient than the old path that no one having the choice of the two ways would think of going the old way.

What the farmer would call a short cut the electrician calls a short circuit, and a short circuit is often a more convenient way of cutting off a current than a switch which interposes resistance. At all events, in a case like this, a short circuit enables that to be accomplished which would be very difficult by any other means.

In the apparatus as already described the battery had to drive the current along a long wire, terminating at the distant receiving instrument, whence the current returned via the earth. The foil and pen, acting as a kind of electrical "tap," controlled this. When foil and pen touched, the tap was open and current flowed. When the line of non-conductive ink interposed itself, the tap was off and the flow ceased.

But connect the battery directly to the wire, and place the foil and pen in a short branch circuit, and the whole thing is reversed. Then the opening of the "tap" sent current to the other end ; now the opening of the tap causes it to flow round the short branch and leave the main wire. Then the closing of the tap stopped the current reaching the farther end ; now it causes it to do so. In fact, the entire action of the apparatus is completely reversed, and the bare parts of the foil become represented by blank paper, while the insulating lines produce the marks. In short, a positive results instead of a negative.

Such was the scheme of Caselli years ago. It is mentioned here at some length, since the principle of it is largely re-used in an improved form in the most successful of modern apparatus for a like purpose.

It undoubtedly was a very excellent scheme, simple and effective, which ought to have succeeded; but it did not do so, for the sufficient reason that at that time knowledge of electricity and skill in constructing delicate mechanism were not so highly developed as they are to-day. For success, as has already been said, one thing was essential, and that thing very difficult to obtain—a perfect synchronism between one stylus and the other. If the one were but the slightest degree "out of step" with the other, failure followed inevitably.

So the electrical transmission of sketches dropped for the time being. More recently a perfectly successful solution of the problem has come in another way altogether. This apparatus, at first called the telautograph, but now known as the telewriter, it will be more convenient to refer to later.

Of modern systems for the transmission of pictures the most successful, probably, are the Korn telautograph and the Thorn-Baker telectrograph.

Both of these are able to transmit very fair reproductions of photographs besides line drawings. The difficulty with photographs is, of course, that many parts of them are not of equal blackness or whiteness, but shade off gradually from one into the other. Take the case of a simple portrait. Part of the subject's face will be pure white, while the side in shadow will be comparatively dark. There is no hard and fast line between the two, but by a gradation through an infinite number of shades the one tones into the other. How can it be possible to convey that, more or less mechanically, over a wire? The solution is due to the fact that the eye will blend together a number of distinctly different shades, if properly arranged, into a gradual change. Really the change is step by step, but the effect is apparently quite continuous. This can be seen in the "half-tone" illustrations in this book. Close examination will show that such a picture is cut up into small squares. In the pure white part the squares are invisible, while in the perfectly black parts, if there be any, they are so merged into one another as to be inseparable. But everywhere else in the picture it will be seen that there are squares each with a dot in the middle. In the darker parts the dots are large; in the lighter ones they are small. We get the effect almost of colour, although the picture is done entirely in black ink. The eye does not see the individual dots when we are just looking at the picture; we have to examine it very closely to find them. Yet they are there all the time, and it is simply the peculiar action of the eye which sees beautiful half-tones, shading imperceptibly one into another, whereas in real fact there are only a vast number of equidistant dots, all equally black.

We see, therefore, that it is possible to split up a picture of any kind into a number of small squares and to treat each square as being of equal darkness throughout. Then, if we can communicate by wire that particular degree of darkness to a distant station, where the small parts can be put together in their proper order and given their correct shade, the picture as constructed at the receiving end will be something like that at the sending end. And we have only to make the size of each separate square small enough to obtain a copy which will resemble the original very closely indeed.

In the early days it was actually proposed to telegraph pictures by ordinary telegraphy, using this principle. The suggestion was to agree upon a code of twenty-six shades, each called by a letter of the alphabet. One shade was to be *a*, the next *b*, and so on. Then the picture was to be divided up into squares, and the particular shade of each square telegraphed by means of the corresponding letter. The shades thus communicated were to be put together at the receiving end, on a prearranged system, and so the picture was to be built up. Given plenty of time, that scheme might be moderately successful, but to get a really good reproduction the subdivision needs to be so minute, and the number of squares, therefore, so immense, that it would be quicker to send the picture by train than to telegraph it by such laborious means. In a fairly coarse half-tone block the squares are, say, 2500 to the square inch. That number of letters would therefore have to be telegraphed for every square inch of picture transmitted, to say nothing of the difficulty of building up a picture of such a great number of parts and giving to each the desired shade. That idea, abortive though it is in its crude form, illustrates very clearly the fundamental principle on which this work is done.

The problem is really to devise a machine which will do that same thing rapidly and automatically divide up the original into a large number of squares, and then send an electric current to represent each square, such current by its strength to indicate the shade of the square : and finally a similar instrument is needed to act as receiver, and to reproduce those squares in the proper order, giving to each its correct shade.

In practically all of them the mechanism is rotatory, the original being placed upon a drum which turns round under a stylus, or its equivalent, while the stylus gradually travels along from end to end after the manner of the needle of a phonograph, or else the same result being achieved by the drum itself having an endwise movement as well as a rotative one. The receiving instrument is of similar form, and both must start together, move at the same speed and indeed preserve a perfect correspondence with each other.

If the distance be great between the two there may be difficulties due to the "retardation" of the currents passing between them. Electricity does not pass through long wires, particularly if they be under the sea, with anything like the quickness which we are apt to think. Over a short line and under favourable circumstances the receipt of a telegraph signal at the farther end is practically instantaneous, but on long lines, and under certain conditions, that is far from being the case.

Then something has to be done to quicken the action of the current, or else the receiving drum must be made to lag behind the sending drum by the requisite amount. In some cases, too, the transmitting apparatus loses a little time in sending off the currents, and that, too, has to be allowed for, so that, all things considered, the reader will see that the successful solution of this problem is hedged about with many subtle difficulties which are probably only appreciated by those who are well acquainted by sad experience with the little vagaries of both electricity and mechanical devices. Neither of them does quite what we want it to do; each suffers from little faults, which in the case of a delicate problem like this, where a difference of a hundredth of a second would be fatal to success, introduce difficulties almost insuperable.

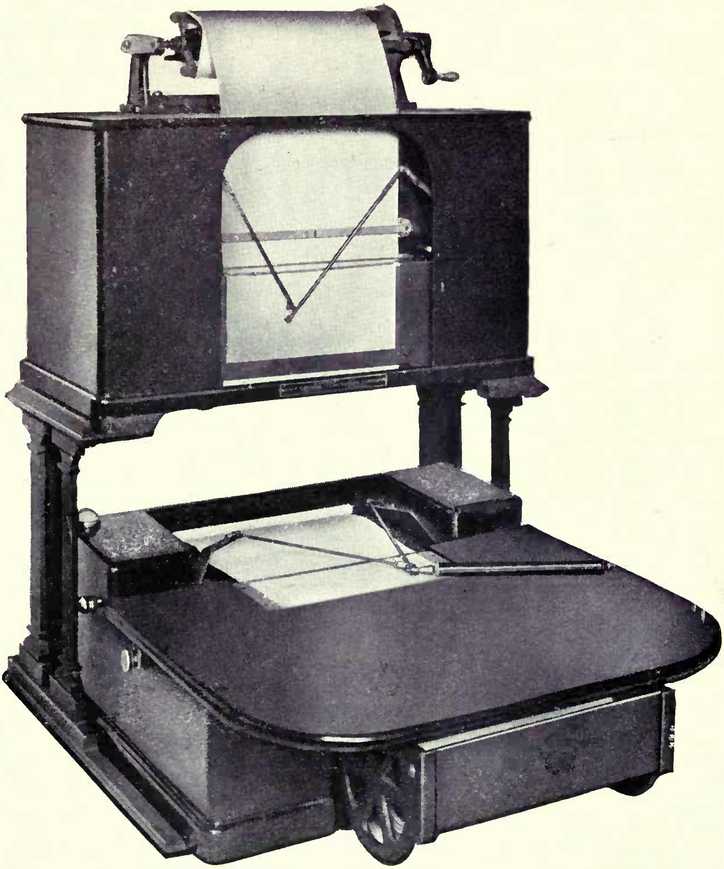
To transmit line drawings, Professor Korn uses a sending instrument very like that of Caselli. The picture is placed, either by hand or photographically, upon a sheet of copper foil, which is fixed round the rotating cylinder, the lines being formed of non-conducting material. The foil being electrified and the stylus connected to the "line" or main wire, currents pass to the farther end just as in the old apparatus.

At the receiving end the drum is covered with photographic paper and enclosed in a light-tight box. Through a hole in this box a fine pencil of light passes from a lamp, suitable lenses being used to ensure that the pencil shall have, as it were, a very fine point, producing a very small spot of light upon the paper. If the light remains quite steady, the drum meanwhile rotating, a line will be drawn by it upon the paper which will be visible when the latter is developed. Since the drum not only turns upon its axis, but also moves endwise one hundredth of an inch at every revolution, this line will be a spiral, the turns of which will be one hundredth of an inch apart. Thus the paper will be blacked, practically uniformly, all over. Should the intensity of the light vary, however, the line will at times be lighter than at others, while, should it be cut off altogether for a moment, then there will be a corresponding gap in the line, and it is easy to see that if these lighter parts or gaps occur in the correct places they will form a picture. In other words, by controlling that light we can build up a picture upon the paper. The question is how to control it.

Professor Korn uses a form of the Einthoven galvanometer already described. Instead of the silvered fibre generally employed in this instrument, a silver wire is fitted, the movement of which partly or entirely cuts off the pencil of light.

The Korn transmitter for photographs is quite different, although the receiver is practically the same as what has just been described. The basis of it is a peculiar power possessed by the metal selenium when in a certain state. This, like all metals, is a conductor of electricity, but of course offers resistance in some degree. Now the special feature of selenium is that its resistance is reduced if light shine upon it. Suppose, then, that current be flowing through a mass of selenium and that the latter be suddenly illuminated brightly, the resistance will at once fall and the current increase. On the other hand, should the light falling upon the selenium diminish, its resistance will increase and the current flowing through it will decrease. In short, given a suitable arrangement, the current flowing in a circuit of which a selenium " cell " forms a part will increase or decrease with the increase or decrease in the light falling upon the cell.

A while ago the papers were telling striking stories of a way by which blind people, so it was said, were to be recompensed for the loss of their sight—a new sense, as it were, was to be given them by which they could " hear " light, even if they could not see it. All this had reference to this curious property of selenium, it being, of course, an undoubted fact that it will vary an electric current in accordance with the variations in the light, and if that current be led through a telephone receiver a man, by holding that to his ear, could, in a sense, hear the variations in the light.



THE TELEWRITER

This remarkable instrument transmits actual writing and drawings, the receiving pen copying precisely the movements of the sending pen

In the Korn transmitter for photographs selenium is employed as follows:—A transparent photograph is made, on a celluloid or gelatine film, and this is fixed upon a glass cylinder mounted as already described. A pencil of light falls upon this in much the same way as in the case of the receiver just described, and, as the cylinder revolves, describes a fine spiral line all round and round it.

Moreover, the light passes right through the photograph and falls upon a mirror inside, off which it is reflected on to a selenium cell. At every moment, then, the light is falling upon some small part of the photograph, and the amount of it which gets through and ultimately reaches the selenium depends upon the density of that part.

Current, meanwhile, is flowing from a battery through the selenium, and thence over the main wire to the distant station. As the light pencil traces its spiral path over the rolled up photograph every variation in the density of the picture is reproduced as a variation in the current through the selenium. This, at the remote end, operates the Einthoven galvanometer, the movements of which vary the shade of the spiral line being drawn upon the photographic paper.

This process takes place with remarkable celerity, so that in a few minutes the innumerable variations constituting a complete photograph can be transmitted and faithfully recorded at the distant end of the wire.

But perhaps the most successful of these methods is that known as the telectrograph. It is surprisingly like the scheme of Caselli in principle, and forms another example of the fact that good ideas often fail through lack of the proper means to carry them out. Mr Thorne-Baker, the inventor of the telectrograph, has had at his disposal accumulated stores of knowledge and skill which did not exist in Caselli's time. Consequently the former has made a brilliant success where his predecessor produced only an interesting but somewhat ineffective attempt.

Reference has been made already to the half-tone blocks wherein a host of small dots of varying sizes make up a picture. Now instead of parallel rows of dots parallel lines of varying thickness will give very much the same result. The former are made by photographing the picture through a sheet of glass ruled with two sets of lines at right angles to each other. The latter can be made by using a screen with lines one way only instead of two ways. It is therefore quite easy for a blockmaker to produce a "process block" wherein lines are used instead of dots. For this particular purpose, however, it is not an ordinary block that is needed, although it is in essentials very similar. The picture to be transmitted is photographed through a screen as if a half-tone block were to be made. The negative so obtained is then printed by the gum process on to a sheet of soft lead and, after washing, the picture remains upon the lead in the form of lines of insoluble gum on a background of bare lead. A squeeze in a press drives the gum into the lead, and so gives the whole sheet a smooth surface over which a stylus will ride easily, but which is, nevertheless, made up of conductive parts and non-conductive parts, the latter forming the picture.

The lead sheet is then put upon a revolving cylinder and turned under a moving stylus in the manner with which we are now familiar. The sheet is placed with the lines lengthwise of the cylinder so that current passes to the stylus except as it passes over the breadth of the lines, and so similar lines are built up at the distant end.

The receiving mechanism is of the electro-chemical type which Caselli used. The current passes from the receiving stylus to the paper, and there makes its mark in a way that will be understood from the description of the earlier apparatus.

The supreme advantage of this method of working, over that of Professor Korn, is that the operator can see what he is doing. To obtain good results, a number of electrical adjustments have to be made, and whether he has got them right or wrong can be seen as soon as the picture begins to grow upon the receiving paper. If a little readjustment be needed the operator sees it and can set things right before the really important part of the picture begins to appear, whereas with the Korn apparatus he does not know what is happening at all, since he can see nothing until the picture is finished and the photographic paper has been developed.

It will be apparent, too, to anyone who has carefully considered the wireless telegraphy chapters, that it ought to be possible to make the sending stylus or its equivalent control a wireless transmitter and a wireless receiver to operate the receiving stylus, so as to be able to send pictures by "wireless." Experiments to this end have been made with some measure of success, and sooner or later we are almost sure to hear that the difficulties, which are by no means small, have been overcome.

But we cannot conclude this chapter without a fuller reference to that marvellous invention, the telewriter.

In this a man makes a sketch with a pen on a piece of paper, or maybe he writes a message, and simultaneously a pen, hundreds of miles away if need be, does precisely the same thing. The receiving instrument draws the sketch line by line, or it transcribes the message in the actual handwriting of the sender. A little touch, almost weird in its naturalness, is that every now and then the receiving pen leaves the paper and dips itself into a bottle of ink, after which it resumes its work at the very spot where it left off.

Now how the complicated lines and curves, the strokes and dots which make up a written language, even the little shakes and defects which give each man's writing a personality of its own, how all these can be sent over a wire is at first sight very difficult to understand. The inventor of this apparatus has discovered an extremely simple way of doing it.

But even he does not attempt to do it with one wire, it should be said, for he uses two. This is no drawback when, as is often the case, it is used in conjunction with a telephone, for the latter, to be effective, also requires two wires. Years ago single wires were employed for telephones as for telegraphs, the circuit being completed through the earth. But the difficulty arose that every wire through which currents flow is apt to induce currents in neighbouring wires—the induction coil is based upon that fact—and so messages in one wire were overheard on others, or, what was perhaps more annoying still, the dots and dashes passing in a telegraph wire would produce loud noises in a telephone wire that happened to be near. The use of two wires, however, entirely removes that trouble, for the neighbouring current then induces two currents instead of one, one in each, and it so happens that these are opposed to each other, so that they neutralise each other. So every telephone wire now is double and therefore is ready, as it were, to have the telewriter fitted to it.

But even with two wires the difficulty seems insuperable until we remember that the most complex of curves can be resolved into two simple movements.

The sending pen, with which the original writing or drawing is done, is attached to the junction of two light rods. The farther end of each rod is attached to the end of a light crank fixed so that it can rotate or oscillate, after the manner of cranks, in the plane of the desk upon which the paper lies. All the joints mentioned are of the hinge nature, so that as the pen is moved about the rods turn, more or less, one way or the other, the two cranks. This simple mechanism, it will be observed, carries out very effectively the principle just mentioned, for it resolves the motion of the pen, no matter how complicated it may be, into a simple rotating motion of the two cranks.

So the cranks turn this way or that as the draughtsman makes his picture, and it is very easy to arrange that their movement shall vary the strength of two electric currents, whereby we obtain electric currents varying in accordance with the movement of the cranks.

This is done by making each crank operate a variable resistance or rheostat. When in its extreme position on one side the crank permits current to flow freely, but as it moves over to the other extreme position the resistance in the path of the current is increased. Such an arrangement is a common feature in electrical apparatus.

So current from a battery flows to the two wires leading to the distant station, each passing through the rheostat connected to one of the cranks. We may think of the rheostats as taps which can be turned on or off by the action of the cranks. Let us imagine that crank *a* is in the position when the current flows freely—when the electrical "tap" is fully open; then a strong current will flow along wire *a*, returning to the sending battery via the earth. As that crank is moved the current will gradually be reduced, until, if it be moved right over to the other extreme, the current will be at its feeblest.

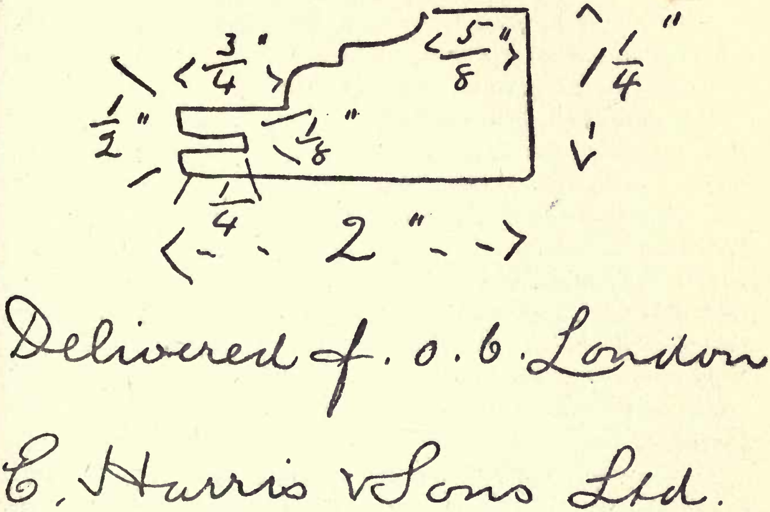


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FIG. 15.—A Message received by Telewriter.

Arrived at the other end, this current passes to a device which we may describe simply as a magnet so arranged that its action pulls round a crank against the restraining action of a spring.

Now the stronger the current the more does that magnet pull and the farther does the receiving crank turn. The sending crank varies the resistance, the resistance varies the current, the current varies the strength of the receiving magnet, and the magnet varies the position of the receiving crank. Properly adjusted, then, the motion of the crank at the one end is communicated through that long chain of causes and effects, until at last it is repeated *exactly* by the movement of the crank at the other end.

The same thing occurs simultaneously over each of the two wires, crank *a* at the sending end communicating over wire *a* to crank *a* at the other end, while crank *b* communicates its motion over wire *b* to the other crank *b*. Each sending crank is closely imitated in its every action by the corresponding one at the distant station.

The two receiving cranks are connected by light rods to the receiving pen in precisely the same way that the sending pen is connected. Consequently, not only are the separate movements of the two cranks repeated at the remote station but the complex movements of the sending pen, which gave rise to the actions of the cranks, are also conveyed to, and repeated by, the recording pen. The movements of the first pen are resolved into rotating motions by the two cranks, these are transferred to the other cranks, and their movements are in turn converted back into the written curves.

Thus as the pen in the artist's hand draws his sketch, so does the automatic hand at the other place, it may be at a great distance, repeat faithfully his work, and the sketch grows line by line simultaneously at both ends.

There is not space here to detail how, by another current superposed upon those referred to already, the receiving-pen is made to dip itself periodically into the inkwell at the will of the sender. By a cunning use of alternating current this is done without in any way interfering with the action of the cranks as described above.

But of course there is a severe limitation to the usefulness of this machine, inasmuch as the drawing has to be made at the time of transmission, and it can only be "put on the wire" by the hand of the artist himself.

CHAPTER XIV

A WONDERFUL EXAMPLE OF SCIENCE AND SKILL

IN the preceding chapter reference was made to the fact that for the successful sending of pictures "by wire" one thing was necessary above all others. That one thing consists in making two machines, perhaps hundreds of miles apart, start working together, stop together and, when working, turn at exactly the same speed. Let the reader just picture the problem to himself, and ask himself how such an arrangement can be possible. Let him think of a town two hundred miles away and then meditate on the possibility of making a machine working in his own room and another in that distant town maintain perfect unanimity in their movements. The result of such reflection will probably be the assertion that such a thing is beyond the bounds of possibility. Then he will find the following description of how it is done extremely interesting.

In the first place it must be understood that each machine is driven by an electric motor. The motors are designed to run at 3000 revolutions per minute, and they drive the cylinders of the machines through gearing so arranged that the latter turn at 50 revolutions per minute.

Now of all machines perhaps the most docile and easily managed is the direct-current electric motor. Each such machine is made with a view to its working at a certain speed, but that can be varied within certain limits, by simply varying the force of the current which drives it. And that force can be very easily varied by the use of an instrument called a "rheostat" or variable resistance. We are all familiar with the way in which the engine-driver regulates the speed of a locomotive, by means of a valve in the steam-pipe. The opening and closing, more or less, of the valve enables the speed to be changed at will and adjusted to a nicety. The rheostat is to the electric current what the valve is to the steam; it can be opened and closed, more or less, as necessary. By it the current driving the motor can be made stronger or weaker, and as that change is made so does the speed of the motor change accordingly. Thus we see that there is at hand the means of setting a motor to work at any desired speed.

The difficulty, however, is to tell when the desired speed has been attained. One can count the revolutions of a machine at two or three revolutions per minute with a certain amount of accuracy, but fifty revolutions per minute are more than one could count correctly. Still less could we count the 3000 revolutions every minute of the motors. Thus, even if we had the two motors side by side, we should have extreme difficulty in making them work at the same speed exactly. One might be doing 3000 while the other did 2990 or 3010 and we should be none the wiser. And when we separate the two by a distance of many miles, the task of synchronising them is even worse.

But fortunately there is a simple contrivance by which we can tell very accurately the speed of a motor. The reader has already been familiarised, in previous chapters, with the difference between direct or continuous electric currents and alternating ones. It is the continuous sort which is used to drive these motors, but a slight addition to the machine will make it so that while direct current is put in, to drive it, alternating current can be drawn out of it. Two little insulated metal rings are fitted on to the spindle of the machine, and these are connected in certain ways to the wires of the motor; then against these rings, as they turn, there rub two little metal arms, called, because of their sweeping action, brushes; and from these brushes we can draw the alternating current.

For our present purpose the importance of this lies in the fact that the rate at which that current will alternate depends upon the speed of the motor. As the motor increases or decreases in speed, so will the rate of alternation increase or decrease. So that if we can measure the rate at which the current drawn from the motor is alternating, we shall know from that the rate at which the machine is working.

This we can do by the aid of a "frequency meter." The working of this is based upon the acting of a tuning-fork. Everyone knows that a given tuning-fork always gives out the same note. The note depends upon the rate at which the fork vibrates, and the reason that one fork always gives the same note is because it always vibrates at the same rate. That rate, in turn, depends upon its length. If one were to file a little off the end of a tuning-fork, its note would be raised, because its rate of vibration would become faster. Similarly, lengthening the fork would result in a lower note being given. Thus, a tuning-fork, or any bar of steel held by one end, and free to vibrate at the other, gives us a standard of speed which is very reliable. And it so happens that we can easily use a set of such forks to test the rate of alternation of an alternating current.

Generally speaking, alternating current is no use for energising a magnet. The chief reason for that is that the current tends to get choked up, as it were, in the coil. Alternating current traverses a coil very reluctantly indeed. It is, however, possible to make an electric magnet of special design which will work sufficiently well with alternating current to answer our present purpose. And it will be clear that just as the alternating current itself consists of a series of short currents, so the force of the magnet will be intermittent; it will give not a steady pull, as is usually the case with magnets, but a succession of little tugs. There will, in fact, be one tug for every alternation of the current.

A simple form of motor fitted up as just described, and rotating at 3000 revolutions per minute, would give out 100 alternations per second. If, then, such current were employed to energise a magnet, that magnet would give 100 tugs per second.

So a small steel bar of the right length to give 100 vibrations per second can be fixed with its free end nearly touching such a magnet, and when the current is turned on it will very soon be vibrating vigorously. For the tugs of the magnet will agree with the natural rate of vibration of the bar. And just as the two pendulums described in Chapter XII. responded readily to each other, so the bar responds readily to the pulls of the magnet. But increase or decrease the rate of alternation ever so slightly, and that sympathy between magnet and bar is destroyed. The bar will not then respond. It will only answer when the pulls of the magnet and the natural rate of vibration of the bar exactly correspond.

So it is usual to place five or six such bars with their ends near the one magnet. The lengths of the bars vary slightly, so that the rates of vibration are, say, 98, 99, 100, 101, 102 respectively.

Let us, in imagination, adjust the speed of a supposititious motor until we get that which corresponds to 100 alternations.

We switch on the current and at first, possibly, we get no response from any of the vibrating bars. Just a touch to the handle of the rheostat and we notice that bar 102 shows signs of life. We see then that our first speed was much too fast, and that reducing it has brought it down to 102, which is still a little too fast. Just a little more movement of the handle, and 102 begins to relapse into quiet, while 101 shows animation. A little more movement and 101 gives place to 100, and then we know that our motor is working at the desired speed. If our motor had been too slow to commence with, it would have been 98 which first got into action, but the method of adjustment would have been precisely the same.

And thus we see the whole scheme. We regulate the speed by the rheostat, and meanwhile that tell-tale stream of alternating current comes flowing out of the motor to indicate to us what the speed is, while the " frequency meter," with its various vibrating bars, interprets to us the message which the alternating current brings to us. So by watching the meter we know when we have got the speed that we desire.

But even that is only half the battle. We have seen how to make a machine turn at any desired speed, and so we can adjust any two, so that they revolve at the same speed, but we have not seen how to start and stop the two machines at the same time.

First of all, it must be understood that in the case of the receiving machine there is a friction clutch, as it is termed, between the motor and the cylinder which it is driving. That means that while, under ordinary circumstances, the motor drives the cylinder round, we can, if we like, hold the latter still without stopping the motor. When we do so, the connection between the two simply slips.

So if we fit a catch on the cylinder which is capable of holding it from rotating, we can still start the motor, and the latter will work. Then, the moment the catch is released the cylinder will begin to turn too. The commonest form of " friction drive " is the flat leather belt upon two pulleys, which everyone has seen at some time or other in a factory. And it will be quite easy to conceive how, if one of the driven machines were to stick, the belt might simply slip upon one of the pulleys, yet, as soon as the machine became free again, it would rotate just as it did before. It is just the same with what we are considering. The motor works continuously at its proper speed, but the cylinder can be stopped when desired by the catch.

Combined with the catch is an electro-magnet, and through its coils there flows the current of electricity which is engaged in printing the picture on the cylinder. If a magnet be arranged to attract another magnet, it will do so only when the energising current flows one way. When it flows the other way, it does not attract. Therefore it is easy to arrange matters so that the printing current, though passing through the coil of the magnet, shall not pull open the catch. But if that current be *reversed* in direction for a moment the magnet gives a pull, open flies the catch, and away goes the cylinder upon its revolution.

Thus, we see, all that is necessary to start the receiving cylinder is to reverse the current for a moment.

And now let us turn our attention to the sending machine. Upon its cylinder there is an arrangement which automatically reverses the current flowing to the main wire once in every revolution. Normally the current flows to the wire as described in the last chapter, carrying by means of its variations the details of the picture for reproduction by the receiving machine at the other end. But for an instant once in every revolution that current is interrupted and a current sent in the opposite direction instead. This the sending machine does of itself, quite automatically.

And now the reader knows of all the apparatus; it remains only to see how the different parts work in combination.

Standing by the sending machine we first of all turn on the current, which goes coursing along the wire to the distant station. Then we set the motor to work and the cylinder begins to rotate. Before it has completed a single revolution the "reverser" is operated, and just for a moment the reverse current goes to the wire. On arrival at the other end that lifts the catch and the receiving cylinder starts. That first partial revolution of the sending cylinder counts for nothing. Real business begins when the reverser first acts, and that is the moment when the receiving cylinder also begins to move. Similarly, when the sending cylinder stops it sends no more reversed currents, and so the receiving cylinder is caught by the catch and not released.

So starting and stopping are quite automatic. The same arrangement enables a continual readjustment of the relative speed of the two cylinders to take place. With all the best devices, the tuning-forks and the rest, it is still impossible to attain perfect unanimity, but the variation in a single revolution cannot be enough to matter; it is only when the error in one revolution goes on multiplying itself that serious difference might arise, and that is prevented in the following beautifully simple way.

The motor which drives the receiving drum is so regulated that it travels *slightly faster* than does the other. Thus the receiving cylinder completes every revolution slightly in advance of the other, and consequently it is stopped and held by the catch every time. The catch retains it, of course, until the reverse current arrives and releases it. Thus not only does the sending cylinder start the other when the operations first commence, but it does so every revolution. Every revolution, therefore, the two cylinders start together.

So the two cylinders are set, according to the frequency meter, at as nearly as possible exactly the correct speeds, and the action of the reverser, the reverse current and the catch, ensures quite automatically that at the commencement of every revolution there shall be perfect agreement between the two. No accumulation of errors can possibly occur, and the problem, though apparently so difficult, if not insuperable, at first sight, is surmounted.

CHAPTER XV

SCIENTIFIC TESTING AND MEASURING

SCIENCE, whether it be of the pure variety, that which is pursued for its own sake—for the mere greed for knowledge—or applied science, the purpose of which is to assist manufacture, is based entirely upon accurate testing and measuring. It is only by discovering and investigating small differences in size, weight or strength that some of the most important facts can be brought to light. There are some problems, too, that defy theory, since they are too complicated; they involve too many theories all at once, and such can only be solved by accurate tests. And all these necessitate the use of very ingenious and often costly devices.

Electrical measuring instruments were of sufficient importance and interest to warrant a chapter of their own, but there are many others of great value, and not without interest to the general reader.

For example, some years ago there was a collision in the Solent, just off Cowes, between the cruiser *Hawke* and the giant liner *Olympic*. The cause of this was a subject of dispute and of litigation; the theorists theorised; some reached the conclusion that the *Hawke* was to blame, and others the *Olympic*; and where doctors disagree who shall decide? It was wisely decreed that tests should be made to settle the question.

The main point was this. The officers of the *Hawke*, by far the smaller vessel, averred that they were drawn out of their course by suction caused by the movement of so large a ship as the *Olympic* in the comparatively narrow and shallow waters of the Solent; in other words, that the

Olympic in moving through the water caused a swirling, eddying motion in the water, tending to draw a lighter vessel towards itself. And that is just one of those problems with which theory is unable to deal. So it was transferred to the National Physical Laboratory at Teddington, near London, for investigation by experiment.

At this institution, which is a semi-national one, there is a tank constructed for purposes such as this. The word tank leads us to underestimate its size somewhat, for it is 494 feet long and 30 feet wide. It is solidly constructed of concrete, with a miniature set of docks at one end, and a sloping beach at the other.

On either side are rails upon which run trollys which support the ends of a bridge which spans the whole. This bridge can be propelled along, by means of electric motors operating the wheels of the trollys, from one end of the tank to the other, at any desired speed, within, of course, reasonable limits, and from it may be towed any model which it is desired to test.

The models used are usually made of wax, by means of a machine specially designed for the purpose. It should be explained that the plans of a ship consist of a series of curves, each of which represents the contour of the vessel at one particular height. For example, if you can imagine a ship cut horizontally into slices of uniform thickness, then each slice could be shown on the drawing (the " shear plan," as it is termed) by a curved line. Near the keel the lines would, of course, be almost straight, but they would bulge more and more as they occur higher up. And what this machine is required to do is to make, quickly and economically, a wax model which shall be an exact reproduction, on a small scale, of the vessel under discussion. It may be—it most often is—a ship as yet unbuilt, the behaviour of which it is desired to test. Or it may be an existing vessel, as it was in the case mentioned just now. However that may be, the model is made from the drawings.

A block of wax rests upon a table, while the drawing is spread upon a board near by. A pointer is moved by hand along one of the lines, and its movement is repeated by a rapidly revolving cutter which cuts away the wax to a similar curve. By suitable adjustments the cutter can be made to magnify or reduce the size, so as to produce any desired scale. Thus every line is gone over and a similar curve cut in the wax at the correct height. Of course this only produces a lump of wax shaped *in steps*, as it were, but it is then quite easy to trim it down by hand, so as to produce a smooth model of the ship, perfectly accurate in its shape, and a copy on a small scale of the vessel portrayed on the drawing.

It can also be hollowed out, ballasted with weights inside, and so made to sink to any desired level, thereby representing the vessel when fully loaded, half loaded and so on. All sorts of unequal loading can be produced if needed, indeed every condition of the real ship can be imitated in the model.

It can then be towed to and fro in the tank by the travelling carriage described above. The speed of towing can be varied by changing the speed of the motors which drive it. The force needed to pull the model through the water is measured by means of a dynamometer which registers the pull on the towing apparatus.

A matter very often needing investigation is the shape and size of the wave thrown up by the bow of the vessel, and of that left behind her, known as the " bow wave " and the " stern wave " respectively. These waves represent wasted energy, for they are no use and are produced actually by the power of the engines of the ship as they drive her along. The ideal ship would cause no waves, but since that is a degree of perfection impossible even to hope for, the shipbuilder has to content himself by so designing his ships that these waves shall be as small as possible.

The waves are recorded photographically, in some cases by the kinematograph.

Some of the large shipbuilders have their own tanks, and so have the naval authorities of the great naval Powers. The one at Teddington was established through the munificence of a famous British shipbuilder, Mr Yarrow, who not only defrayed the cost of construction, but gave an endowment to assist in its upkeep. It is intended to serve the needs of the smaller builders who have not tanks of their own, and also for the investigation of matters of general interest to shipbuilders, and for such tests as that relating to the *Hawke* and *Olympic*. In this last-named case, of course, two models were made, one to represent each ship, and they were towed along in such a way as to imitate very closely the movements of the ships at the time when they collided. It was as the result of these tests that the *Olympic* was ordered to pay damages to the Admiralty, it being held that she was the cause of the accident.

A very interesting investigation of this kind was recently carried out in the tank at the United States Navy Yard. The port of New York consists very largely of jetties projecting out from the banks of the river. With the growth of the Atlantic liner the old jetties had become too short, and questions arose as to the elongation of them. If it were done, how would it effect the current in the river, and the handling of shipping generally? If, on the other hand, it were not done, what would be the effect of the ships lying with their ends projecting out into the stream unprotected by a jetty.

To determine these points the experimental tank was converted into a model of the New York Harbour, or at all events of that part in connection with which these questions arose.

A false floor was put in, so as to make the depth exactly right in proportion to the width. Little model jetties were arranged to represent exactly the real ones, while against them were moored model vessels, so that the effect upon them could be observed as the model of the large vessel was towed past.

In addition to this, special appliances were arranged for finding out what the disturbance might be which the movement of a giant liner produces under the surface as well as above it. For this purpose buoyant balls were employed, moored at various distances below the surface, from which thin rods projected upwards, the movement of which rendered visible the movements of the submerged balls and therefore the effects of the under-water currents.

All these things had to be observed at one and the same time—the moving model itself, the models alongside the jetties, the commotion on the surface, the swayings to and fro of the rods attached to the submerged floats—all, or most of which, at all events, it was impossible to make self-recording. Yet, seeing that it was of the utmost importance that the relations between all these things should be observed, and recorded from time to time as the model was towed along, it is evident that something must be done, and a cunning use of the kinematograph solved the problem quite easily. At various points commanding a good view of the model harbour and its shipping these machines were placed, and so several series of photographs were obtained, by the study of which all the different movements could be seen and compared. A large dial too was rigged up upon the travelling carriage by which the model was towed, a finger on which denoted the distance which the carriage had travelled at any moment. This large dial came into each photograph, of course, and so each picture bore upon itself a clear record of that particular moment in the voyage of the model to which it referred.

Thus we see an instance of how the very latest and most up-to-date methods of amusement are sometimes applied to serve very practical purposes.

Akin to the experiments upon ships are aerial experiments to determine matters connected with the navigation of the air. At Barrow-in-Furness the great firm of Vickers, shipbuilders and armament manufacturers, and latterly builders of aerial craft for the British Admiralty, have erected a machine for testing the efficiency of aerial propellers and other things of a kindred nature. Upon the top of a tall tower there is pivoted a long arm of light iron framework. To the end of this a propeller can be fixed, so that as the arm revolves there is produced almost exactly the same conditions as those which prevail when a propeller drives an aeroplane or steerable balloon.

By means of suitable mechanism the propeller can be turned at any desired speed, with the result that it drives the arm round and round upon its pivot on the top of the tower. The force which the propeller thus exerts can easily be measured, and so can be determined such questions as the most efficient speed for each type of propeller, the power which any particular one can develop, the best form for each particular need, and so on.

Materials, too, require the most careful testing, in order that they may be put to the best possible use in modern machinery and structures. For example, anyone can measure the strength of a spring, but what do we know as to its lasting power? Springs often have to form part of a machine in which they are stretched and compressed millions of times, and the question arises as to what is the best shape and material for the purpose. If may be that the spring which works best a few times will be the first to become "weary," for with repeated strain such things as steel get tired, just as the human frame does. Now that is a matter which will yield to no calculation, the only way to determine it is actual test. So a mechanism has to be employed which will extend and compress the spring over and over again, just as it will be in actual use, with a counter of the nature of a cyclometer to count how many times it has been subjected to this distortion. Then the apparatus is set going and left to itself for hours, or even for days, during which time it may work the spring millions of times. This may go on until it breaks, or else it may be done a prearranged number of times, and then the spring taken out and tested by other means to see how its strength has been affected.

Metal bars are often subjected to sudden blows, light in themselves but oft repeated. The point to be determined then is how many times the blow may fall before permanent injury is done to the bar. To investigate such matters we have the "repeated-impact" machine. The bar is held in a suitable holder, under a hammer which gives it a blow, the force of which can be easily regulated, at regular intervals, the number of blows being counted by a suitable recording mechanism. Ultimately the bar breaks, under a blow the like of which it can endure singly without any apparent strain at all. The machine, by the way, can be caused to turn the bar round to some degree after each blow, so that it is struck from all directions in succession.

The microscope, too, has established its place in the testing laboratory. It is a very valuable adjunct to chemical and mechanical tests.

Suppose, for example, that a bar of steel is being investigated; it can be put into a machine and pulled until it breaks in two. The machine registers the amount of the pull which was applied. Or a small piece can be put under a press and compressed to any desired degree. It can also be tested by impact or even pulled apart by a sudden blow, as described in *Mechanical Inventions of To-day*. The bar can be supported by its ends and loaded or pulled down in the centre, so that its power of resisting bending can be determined. It can be judged, too, from its chemical composition. Steel, in particular, depends for its properties very largely upon its chemical composition. The difference between cast-iron, wrought-iron and steel, also the differences between the innumerable varieties of steel, are due almost entirely to the admixture of a certain percentage of carbon with the metal. This can be ascertained by chemical analysis. This form of inquiry has the advantage over the more purely mechanical methods in that the latter, for the most part, have to be applied to the bar as a whole, whereas the quality may vary in different parts, the surface in particular being liable to differ from the interior. In such cases, one analysis can be made of a piece cut from the surface and another of a piece from the centre.

And it is here, too, that microscopical analysis comes in. For this purpose a piece is sawn off the bar, and the end ground perfectly smooth. This is then washed in a suitable chemical, such as a mild acid, which acts differently upon the different materials of which the "metal" is built up, thereby rendering them visible one from another. A photograph taken through a microscope then shows the structure of the metal; how the different constituents are built together.

This is known as metallographic testing, and its advantage as compared with chemical analysis is that the latter shows, as we might say, what are the bricks of which the thing is built, while the former shows how the bricks are arranged. Indeed it is hardly correct to speak of the advantage or superiority of one over the other, since each is the complement of the other, supplying the information which the other fails to give.

And there are other mechanical tests which have not yet been mentioned. There are machines which twist a bar so as to discover its power to resist torsion, there are others which apply a downward pressure on one part of the bar and an upward one on an adjacent part, so as to show its capabilities in withstanding shearing strain.

Moreover, many of these tests are nowadays, in a well-equipped testing-house, carried out in conjunction with the use of heat. It stands to reason that a part of a machine which will have to work under considerable heat may have to be of different material from a part which works under a normal temperature. In some cases the bar is surrounded by a spiral wire through which electric current is passing, and by the regulation of this current any desired temperature can be set up in the bar. Or it may be placed in a bath of hot oil in such a way that the bar shall be raised to any temperature required, without interfering with the machinery which exerts the tension or pressure, or whatever it be.

Years ago such elaborate tests as these were never thought of. There are certain well-known figures, to be found in all engineering text-books, which give what stresses different materials ought to be able to stand, and these were, and are still, to a large extent, relied upon, it being taken for granted that the material used will be up to the average standard. In large and important works, however, the testing has been developed upon scientific lines, so that it is known from actual experiment what each particular thing is capable of. This not only means security but economy, for it is sometimes found that a substance is stronger than it is thought to be, and so things made of it can be designed to give the requisite strength lighter and cheaper than they would have been otherwise.

Some of the machines employed are of enormous strength, capable of exerting a pull or a compression of, it may be, 100 tons or more. They are often made, too, with self-recording appliances, whereby the course of the test is set down automatically upon a chart. For example, when a bar is being tested for tension, it is desirable to know not only the actual pull under which it came in two, but the behaviour of the test piece during the period before that. It begins to stretch as soon as the tension is applied, theoretically at all events, and if the metal were perfectly ductile it would stretch continuously as the load increases, until at last the breaking stress is reached. But in actual practice it probably stretches somewhat by fits and starts, and a record of that fact will be of great value in estimating the strength of the material in actual work. For such, an automatically made record, which can be studied at leisure, is of the utmost importance.

But perhaps the finest instance of scientific methods in manufacture is to be found in the methods by which standard parts of machines are measured, so as to ensure that they shall be interchangeable.

It may surprise the casual reader to be told that an absolutely exact measurement is an impossibility. It is safe to say that out of a million similar articles—articles made with the intention that they shall be exactly alike—there are no two which are, in fact, absolutely similar. They may be made with the same machines and the same tools, handled by the same man, but machines and tools wear or get out of adjustment, while man's liability to err is proverbial. Astronomers are the greatest experts in the art of measurement, and they recognise the possibility, nay, the probability, of error so frankly as to make every measurement several times over; if it be an important one they make it, if possible, a great many times over, and then take the average of the results. By this means they eliminate, to a certain extent at any rate, the error which cannot be avoided. That process is to allow for errors on the part of their instruments, for the most part. To deal with personal errors another method is used as well, for it is known that some observers have a natural tendency to err on one side more or less, while others tend to make mistakes in some degree on the other side. This tendency to err is known as the "personal equation" of the observer, and there are machines and tests by which the personal equation of each man can be determined, or perhaps it would be more correct to say estimated, so that in all observations made by him the proper allowance can be added or deducted.

But of course it would be extremely difficult to apply such methods in a workshop. It would never do to have to measure everything several times over, hoping that the average would come out in such manner as to indicate that the thing being measured was the size required. Instead, therefore, of wasting time seeking an accuracy which is known to be unattainable, the manufacturing engineer adopts a scientific system of measurement wherein a certain amount of inaccuracy is determined upon as permissible, and then simple appliances are used to see that it does, in fact, fall within those limits. For instance, a round bar is to be made, say, an inch in diameter. Now we know from what has just been said that, when made, we have no means of telling whether the bar is really and truly an inch in diameter or not. We consider, then, what it is for, and decide, say, that it will be near enough so long as we are sure that it is not larger than one inch plus one thousandth, nor less than one inch minus one thousandth. So long as it does not exceed or fall short of its reputed size by more than one thousandth of an inch, then we know that it will answer its purpose.

Now, having come to that decision, we can build up a system upon which any intelligent workman can proceed, with the result that all the inch bars which he makes will be the same size within the limits of $\frac{1}{1000}$ over or under, so that the greatest possible difference between any two will be $\frac{1}{500}$.

This system involves the use of two gauges for every size. The man employed upon making one-inch bars has a plate with a hole in it $1\frac{1}{1000}$ inches in diameter and another hole $\frac{999}{1000}$ of an inch in diameter. One of these is the "go in" gauge; the other is the "not go in." So that all he has to do, in order to be quite sure that his work is right, is to see that it can be poked through one of these holes, but not through the other. No trouble at all, it will be observed, adjusting fine measuring appliances, simply a plate with two holes in it, and the workman can be sure that he is turning out articles every one of which is practically correct, with no variation beyond a slight inequality too small to matter.

And probably at some other part of the factory there is a man making articles each of which has a hole in it, into which this bar must fit. How does he manage? He is provided with a gauge somewhat the shape of a dumb-bell, one end of which is slightly larger than the other. One is the "go in" end, the other the "not go in" end. If the hole which he makes will permit the former to enter, but will refuse admittance to the latter, then he knows that that hole is sufficiently near its reputed size to answer its purpose.

By permission of *The Mining Engineering Co., Sheffield*

A MINERS' RESCUE TEAM

These men are equipped with breathing apparatus which enables them to pass safely through the deadly fumes after an explosion, to rescue their unfortunate comrades

In the instances mentioned, a thousandth of an inch either way has been mentioned as the limit of inaccuracy, or the "tolerance," as it is sometimes termed, but often the limits are much narrower than that. The gauges themselves are a case in point, for they must be true within, say, a ten-thousandth, or even less. And they too are checked by master gauges of a finer degree of accuracy still, being made by the most laborious methods, and checked over and over again, so as to reach the utmost limits in the way of correctness.

So this methodical "scientific" system of "limit gauges" is based upon the principle of having one gauge limiting the error one way and another defining it in the other. Anything simpler or more effective it would be impossible to conceive. It is due very largely to this system that many manufactured articles are now so much cheaper than they used to be. For it enables each individual part to be made wholesale on a large scale, by machines specially adapted to the work, operated by men specially trained to work them, with the practical certainty that these parts when assembled together will fit each other.

In conclusion, there is another very interesting instrument which was first made for a purely utilitarian use—namely, the investigation of the methods of making coloured glass—but which has since been applied to some interesting problems in pure science. It is called the "ultra-microscope."

It must first be pointed out that there is a limit to the power of the ordinary microsocpe, beyond which the skill of the optician cannot go. He is baffled at that point not because of any lack of ability on his own part, but because of the nature of light itself. An opaque object, unless it be self-luminous, which few things are, can only be seen by reflected light. Generally speaking, we see things because they reflect in some degree the light which falls upon them. But light consists of waves, and when we reach an object so minute that its diameter is about half the wave-length of light, then we cannot see it because it is unable to reflect the light on account of its smallness. We can see this any day by the seaside, or by a river or large pond. There it is evident that the waves and ripples are reflected by such things as large stones, wood posts or anything of any size which come in their way; but when a wave encounters an object much smaller than itself it simply swallows it up, as it were, flows all over it or around it, without being in any way reflected by it. And it is just the same with the waves of light; they are unaffected by obstacles below a certain size, and so are not reflected by them. For this reason things smaller than about a seven-thousandth of a millimetre cannot possibly be seen by a microscope in the ordinary way.

But if an object can be made self-luminous, then it can be seen, whatever its size, if the magnifying power of the microscope be great enough. So this ultra-microscope, as it is called, is really an ordinary microscope of the highest power possible, with an added apparatus for making the tiny particles which are being sought for self-luminous. This is done by directing upon them a pencil of light of exceeding intensity. Generated by powerful arc lamps, the light is concentrated by a system of lenses until it is of an almost incredible brightness, after which it falls upon the object.

Now at first sight this seems to be no different from the usual procedure with a microscope, and there appears to be no reason why it should be more successful, but the explanation is this: light is a form of energy, and the waves of this very intense beam, falling upon the object, throw it into a state of violent agitation, by virtue of which it shines, not with reflected light, but with light of its own. It is not that the waves are reflected, but that they so shake up the particle that it gives off light waves itself. And thus it comes within the range of human vision.

In this way, not only have the very small particles of colouring matter in glass been seen individually, but it is thought that the actual molecules of matter have been seen, or if not the molecules individually, little groups of molecules, dancing and capering about, just as scientific people for years have believed them to be doing, although they could not see them. So here we have an instance in which manufacture has aided science—an inversion of the usual order of things.

CHAPTER XVI

COLOUR PHOTOGRAPHY

PHOTOGRAPHY has introduced many of the general public to a branch of practical science which otherwise they would never have cared much about. The action of light upon certain chemicals, the subsequent action upon the same of other chemicals, such as developers, toning solutions and so on, form a very well-known region of the domain of science. And this is, too, a branch of chemistry in which the practical inventor has been very busy. The efforts, therefore, which have been made to invent ways of producing photographic pictures which shall give to the objects their natural colours, will probably be of special interest in a book like this.

Of these there are two very well-known systems, and to them we will mainly confine our attention.

It should first be pointed out, however, that what we are discussing is quite different from the simple "orthochromatic" plates which are used by many photographers. These latter are coated somewhat differently from other plates, with a view to their giving a more realistic picture, but the result is still in one colour. They are, in fact, a little more sensitive to differences in colour than ordinary plates, so that colours which appear, when the latter are used, very much the same, appear, when orthochromatic plates are employed, a little different. But the difference in colour in the object photographed is only, even then, represented by a difference in shade in the picture. The object is, it may be, in many colours, in all the colours, very likely, but the picture is only in one.

And the step from that to a coloured picture is a very long one. True, the solution of the problem is very simple in principle, yet the practical difficulties are so great that even now they have not been entirely overcome.

Let us first of all examine the principle. Sunlight, by which photographs are usually taken, appears to the eye white and colourless. It is not really so, however, as can be proved by analysing it with the spectroscope. In this instrument a flat beam of light, having passed through a narrow slit, falls upon a prism of glass, from which it emerges as a broad band, known as the "spectrum." This band can be seen upon a screen, or can be examined through a telescope. So far from being white and colourless, it consists of the most lovely colours. At one end of the spectrum is a beautiful red, which, as the eye travels along, imperceptibly merges into orange, which in turn merges into yellow, after which we find green, blue, indigo and violet, in the order named. These seven are known as the "primary colours," but it is quite a mistake to suppose that there are seven clearly defined and distinct colours. The colours so change, one into another, that their number is really infinite. The seven names indicate seven points in the spectrum, whereat the colours are sufficiently distinct from others to warrant a separate name being given to them. We call the starting colour red, for example, and as we pass our eyes along we perceive a constant change, and when that change has become sufficiently pronounced to justify our doing so, we call the new colour "orange." Continuing, we find the orange changing into something else, and when it has gone far enough, we bring in a third name, yellow, and so on to the violet. Thus we see the division into seven colours is arbitrary, and only for our own convenience, since the whole number of colours is innumerable.

Passing through a prism is not, however, the only means by which white light can be split up. When the sun shines upon a blue flower, for instance, the blue petals perform a partial separation; they reflect the blue part of the sunlight, and absorb all the rest. A red flower likewise reflects the red part of the sunlight and absorbs the rest. It is because things can thus discriminate, reflecting some kinds of light and absorbing the remainder, that we perceive things in different colours.

It follows, therefore, that when we look upon a landscape, or a field of flowers, we receive into our eyes an enormous variety of coloured lights. The white sunlight furnishes each thing we see with a flood of white light, and each thing according to its nature, reflects more or less. A white flower reflects the whole, a pure black object reflects none, but the great majority of things reflect some part or other of that infinite variety of which white light really consists.

So a view at all varied sends to our eyes a variety of colours, almost as manifold as the colours of the spectrum, which, as has been said, are infinite. And the task of reproducing them, or even of producing a similar general effect, upon a piece of paper seems at first sight beyond the bounds of possibility.

But fortunately there is a way by which we can produce, approximately at all events, the intermediate colours by mixtures of the others. The second colour of the spectrum, for example, orange, can be obtained by mixing its neighbours on either hand—namely, red and yellow. We can, indeed, imitate very closely the imperceptible change from red to yellow through orange, by skilful mixture of red and yellow pigments. First there is the pure red, then just a suggestion of yellow is added ; more and more yellow brings us to orange ; after which by gradually diminishing the amount of red we reach the pure yellow. Next, by introducing blue pigment, we can gradually change the yellow into green, and further manipulation of the same two colours will lead us on to pure blue. Indeed by mixtures of red, yellow and blue we can obtain almost all the perceptible varieties of colour.

And it must be remembered that when, by mixing blue and yellow pigments, we get the effect of green, that is only the result of an optical illusion. The particles of which the yellow pigment is made remain yellow, and the particles of blue remain blue. The one sort reflect yellow light to our eyes, the other sort reflect blue light, and owing to what in one sense may be called a defect in our vision, these two mingling together look as if the whole were green. In the spectrum we see real green light; from green paint made by mixing yellow and blue, we only see an imitation or artificial green. If the particles were large enough, we should see the yellow and the blue ones quite separate, but since they are too small for us to see at all, except in the mass, our eyes blend the whole together into the intermediate colour.

Thus we see that, although the variety of colours is infinite, we can for practical purposes reproduce as much difference as our eyes can perceive by the judicious blending of three —namely, red, yellow and blue.

And there is a further fortunate fact—we can filter light. The red glass with which the photographer covers his dark-room lamp looks red, and throws a red light into the room, because it is acting as a filter to the light proceeding from the lamp behind it. The lamp is sending out light of many colours, but the glass is only transparent to the red. It holds up all the others but lets the red pass freely. So if we were to take a photograph through a red screen, we should get on the plate only those parts which were more or less red in colour. For example, if we thus photographed a group of three flowers, one red, one orange and one yellow, the red one would come out prominently, the orange one would come out faintly, and the yellow one not at all.

Then suppose we took the same picture again through a yellow screen. In that case the yellow flower would be prominent, the orange would again be faint, but the red would be absent.

Having got, in imagination, two such negatives, let us make two carbon prints, one off each. And let the print off the first negative be red, while that off the second is yellow. Let each be, in fact, of the same colour as the screen through which the picture was taken. Finally, let the two films be placed in contact one upon the other. On holding the two up to the light, what should we see?

We should see a red flower, for there would be a red flower clearly defined upon one film coinciding with a blank transparent space upon the other film. We should see, too, a yellow flower, for a clearly defined yellow flower on the second film would coincide with a clear space upon the first. We should see also an orange-coloured flower, for there would be a faint red image of it, and a faint yellow image of it, one on each film, lying one over the other, producing the same effect as a mixture of yellow and red pigments. Thus by taking two negatives through two coloured screens, and then colouring the prints to correspond, we can obtain three colours in the finished picture.

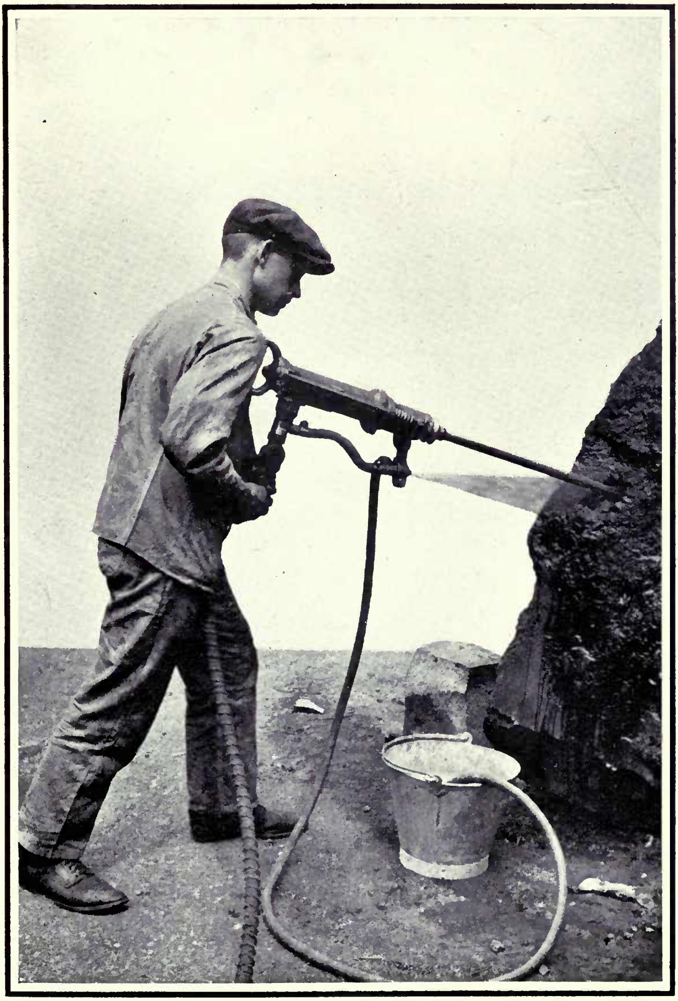
By taking a third negative, through a blue screen, we could add immensely to the range of colours obtainable. Indeed, with three films, red, yellow and blue respectively, made through three screens of the same colour, a variety of colours practically infinite can be obtained.

So the principle is quite simple; the difficulty is in carrying it out. For the three kinds of light have not the same photographic power, and so to avoid upsetting the "balance" of the colours different exposures would be required for each. Then there is the difficulty of so manipulating the films as to get them one over another exactly. Anyone who has tried the handling of carbon prints will readily realise how difficult this would be. It is possible and has been done, but the process is too uncertain and too laborious to be of general use.

But the same result can be attained more or less automatically, as the following descriptions will show.

Let us turn to the Lumière autochrome process, by which the results desired can be in a large measure attained by methods of manipulation comparatively simple.

The plates used for this are of a very special nature. In the first place, there is the basis of glass, but upon that there is laid what we might term the selective screen. This



By permission of *The Mining Engineering Co., Ltd., Sheffield*

PNEUMATIC HAMMER DRILL

This tool is used by miners for making holes in hard rock, preliminary to blasting. Note the spray of water, which prevents the stone dust rising and getting into the miner's lungs.—*See* p. 220

is a layer of starch grains, of exceeding smallness. The size of them is as little as a half a thousandth of an inch and there are about four millions of them on every square inch of plate. Next, upon the screen of starch grains is a layer of waterproof varnish, while over that is the ordinary sensitive emulsion such as forms the essential part of the usual non-colour plate.

Now the starch grains which form the screen are, before they are laid on, stained in three colours. Some are blue, some red, and some a yellowish-green, which experience shows is preferable to pure yellow. The differently coloured grains are well mixed, and when the screen is held to the light and looked through the effect is almost that of clear glass. That is because red rays from the red grains, and green and blue rays from the grains of those colours, all proceed to the eye mingled together.

This plate is placed in the camera differently from the usual way, since the glass side is turned towards the lens. The light, therefore, after entering the camera, passes through the glass, then through the screen, and finally falls upon the sensitive film.

Suppose, then, that the camera were pointed to a red wall; red light would fall upon the plate and, passing through the red grains, would act upon the sensitive film behind them. The blue and green grains, on the other hand, would stop those rays which fell upon them, and so those parts of the sensitive film which they cover would remain unaffected by light. Then, if that plate were to be developed, a dark, opaque spot would be produced upon the film under each red grain, the film under the other grains remaining transparent. Hence, when held up to the light and looked through, the plate would appear a greenish-blue, for all the red grains would be covered up.

In like manner, if the wall were blue instead of red, a greenish-red plate would result, while if it were green, the plate would be a purple, the result of the combination of red and blue.

But this, it will be seen, is a topsy-turvy effect, the exact opposite of what we want, so that it is fortunate that by a simple chemical method we can set it right. After a first development in the ordinary way the plate is placed in another bath and exposed to strong daylight, with the result that those parts which were darkened by the first development become clear and the parts which were clear become opaque. Thus, after this twofold development of the photograph of the red wall, we find ourselves in possession of a red plate, in which only the red grains are visible, since all the others are covered up by opaque parts of the sensitive film. The photograph of the blue wall will also, after it has been subjected to the double development, show blue only, and the same with the green.

But suppose that instead of a red wall or a blue wall we focus our camera upon one which is half red and half blue. Then it is easy to perceive that we shall get a plate which is half one colour and half the other. Moreover, it follows that a wall covered with a mosaic of red, blue and green would give us a plate duly coloured in the same way.

But when we go a step further and photograph, say, a landscape, which may contain a vast range of colours, we find a difficulty in believing that they can all be rendered by the simple process of covering or leaving uncovered grains either blue, red or green. It can be done, however, since the other colours may be made up of two or more of these three in varying proportions. For example, should there be something in the landscape of a darker, more blue, shade of green than the green grains, then the light proceeding from that object, while passing freely through the green grains upon which it falls, will slightly penetrate the neighbouring blue ones as well, and so at that point on the plate there will be not only green grains visible, but some of the blue grains partly visible also. The light from the blue grains will enter the eye along with that from the green grains, and by so doing will add just that amount of blue to the green as to give it the right shade.

After this manner is the whole picture built up. It is, of course, really a mosaic, consisting entirely of little coloured patches, but since they are so small none can be seen individually, all merging together in the eye so as to form a picture in which colours change imperceptibly from one into another.

To sum up, then, what happens is this. We start with a layer of coloured grains; the action of taking and developing the photograph covers up some of these grains and leaves others exposed, and the action of the light is such that those which are left visible produce a picture closely resembling the original, not only in form but in colour.

But there is one other interesting point about this process which deserves mention. The differently coloured lights are not of the same power photographically. Red light, as we know well, is very weak in this respect, wherefore, we use it in the dark-room. A faint red light will have no perceptible effect upon a plate unless it be exposed to it for some time. Blue light, on the other hand, is very active, and were the blue and red lights to be allowed to act equally on the autochrome plate, the result would be much too blue. It is therefore necessary to handicap the blue light, as it were, by placing a " reddish-yellowish " screen either just in front of, or just behind, the lens to cut off a proportion of the blue rays.

The other very successful process is known as the Dufay dioptichrome process. It differs very little from the Lumière except in detail, the selective screen being formed of small coloured squares instead of by a mass of little grains.

In both, it will be noticed, the result is a single positive. It is not, as in ordinary photography, a negative off which any desired number of positive prints can be made. And, moreover, it is a transparency: it cannot be viewed except by light shining through it. The results are, however, extremely beautiful, when well done, and anyone who cares to try either of these methods of working will be well repaid for the trouble involved.

CHAPTER XVII

HOW SCIENCE AIDS THE STRICKEN COLLIER

NOTHING is more characteristic of the present age than the care which is, quite rightly, expended upon the comfort and safety of those who do the manual labour of the community. The stores of scientific knowledge and skill are drawn upon freely for this end, and some very interesting examples can be given of the truly scientific methods which have been evolved, not only for preventing injuries of any kind, but for succouring those who may, despite those precautions, fall victims to disease or accident.

An example has already been given of the scientific investigation into the nature of colliery explosions and the best means of preventing them. We have seen there how expense has been poured out lavishly in fitting up the experimental gallery or artificial pit, and how the most cunning mechanical and electrical devices have been pressed into the service in order to find out just what happens when an explosion occurs. It has been related how these investigations have revealed with certainty the true cause of the explosions and thereby led the way to their prevention.

But with it all there is still an occasional disaster, occurring, sometimes, at the best and most carefully managed collieries. And therefore it is still necessary to provide for rescuing the unfortunate men who are affected.

It is worth remark, here, that colliery explosions are, all things considered, a very rare occurrence. Because of their dramatic suddenness, and the number of lives which are commonly lost in a single disaster, we are apt to magnify their severity in our minds and to picture the life of the miner as a very hazardous one. In point of fact, the expectation of life, as the insurance people call it, is quite as great among the coal-miners as among any class of manual labour. And of those who do meet an untimely end there are more lost through isolated accidents, involving one or two men, than in the great disasters.

To meet these isolated cases science is almost powerless. For the most part, they are due to falls of material from the roof of the mine, or some simple accident of that kind, caused by an error of judgment or lack of care on the part of fellow-workmen, and the only safeguard against such is the most careful and systematic supervision, which, in Great Britain at all events, is rigidly applied. The underground staff are very carefully organised with this end in view, and the whole is supervised by Government inspectors. No amount of scientific investigation or invention will help much in these matters.

With the explosion or fire, however, it is different, for there subtle forces and strange chemical influences come into play with which science is specially well fitted to deal.

To a great many people the first news of organised, trained and scientifically equipped rescue parties came at the time of the terrible Courrières disaster in France, when over 1000 men lost their lives. For then a party with apparatus hurried from Germany and played a prominent part in the rescue operations. But unfortunately the glamour of their performance was somewhat dimmed by the fact that after they had done all they could, and had gone home again, more men were rescued. Many, reading of that fact, were inclined to scoff at the "new-fangled" ideas, thinking that after all the old way of working with a party of brave but untrained and often ignorant volunteers was better than the new way of working with equipped and trained men. It certainly did seem as if the former had succeeded where the latter had failed. But that was quite a mistake, as subsequent events have shown, and in all probability it was due to the fact that the uninstructed party were local men, thoroughly familiar with the mine in which they were working, its geography and its special local conditions, whereas the trained men came from far away.

At all events the pioneer work of the Germans in the matter of rescue teams has been amply justified by the fact that other people have copied them, and none more thoroughly than the mining authorities of Great Britain. Indeed we see here another instance of the remarkable way in which the British people, though a little slow to take up a new idea, do take it up when it has once been established, and in such a way that they are soon among the foremost in its use. The Germans, all honour to them, started the rescue teams, but at this moment there are rescue teams and stations for their training in Britain second to none in the world. Of these there is a splendid example in the Rhondda Valley, in South Wales, supported and worked by the owners of the pits in that district, besides others at Aberdare, in the same neighbourhood, at Mansfield, to serve the collieries in Derbyshire and Nottinghamshire; indeed rescue stations are now dotted throughout the mining districts.

The general idea of these stations is as follows. The building is centrally situated in the district which it is intended to serve, and in it are kept an ample supply of the necessary appliances, in the shape of breathing apparatus, which enables men to walk unhurt through poisonous gas, reviving apparatus, by which partially suffocated men can be brought round again by the administration of oxygen, together with quantities of that valuable gas in suitable portable cylinders. Everything which forethought can suggest as even possibly useful in an emergency is kept in a constant state of readiness. And all the while a swift motor car stands ready to carry them to the scene of operations.

But the appliances are of little use without men to work them, who know them and can trust them. The case of David, who felt able to do better work with his sling and stone than in all the panoply of Saul's armour, because he "had not proved it," is typical of a universal human instinct.

A man feels safer unarmed, or simply armed, than he does with the most elaborate weapons in which he has not learned to have confidence. And therefore the men who may be called upon to work this apparatus are first taught to have confidence in it. Each station has its instructor, who is usually also the general superintendent of the station, and "galleries" in which the instruction can be carried out.

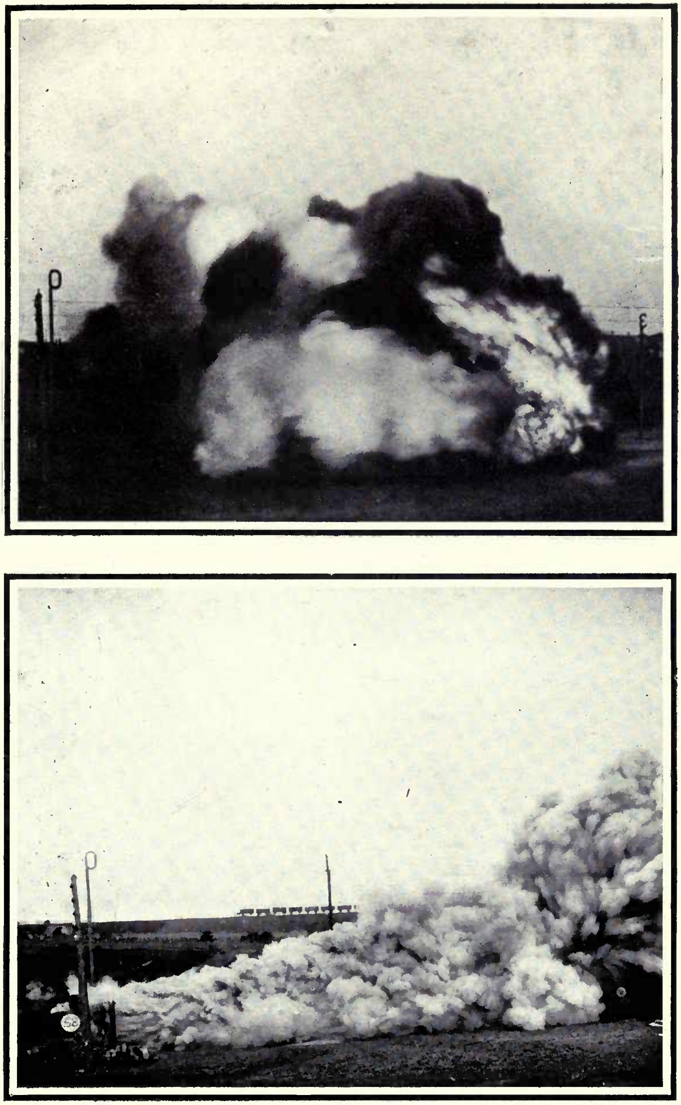
Volunteers are called for in each colliery and a number of the most suitable men are chosen to undergo training, preference being given, very naturally, to those who are already trained, as fortunately so many workmen are nowadays, in ambulance work.

These chosen men then repair at intervals to the station to undergo a proper course of instruction. The instructor, often an ex-non-commissioned officer in the Royal Engineers, accustomed, therefore, to engineering matters, and also to systematic discipline, there puts them through a course of drill the object of which is to teach them to work together as a squad under the orders of a properly constituted chief. Thus when called upon in some emergency there will be no confusion, but each man will know what to do, and a few short words of command from the chief will serve better than the long explanations which would be necessary with an undisciplined body. It welds the individual men, as it were, into a smoothly working machine, thereby increasing the efficiency of the whole. And arrangements are made whereby, should the leader fail, another man steps into his place of authority at once and without question.

Then, having thus brought them under a suitable discipline, the instructor takes his men into the experimental gallery. This may be described as a long, low, narrow shed, in which are timber props and beams, rails on the floor, heaps of coal, all things, in fact, which may tend to make it closely resemble the actual workings of a coal-mine after they have been shaken and shattered by the force of an explosion.

The great difficulty, in a real disaster, arises from what are known as "falls." The roof of the mine is normally supported by timbers, and these the explosion moves, so that in places many tons of the earth of which the roof of the mine consists will fall and block completely the " roads " or tunnels which communicate from the shaft to the places where the men are at work. These, of course, have to be removed or burrowed through before the men imprisoned in the distant workings can be reached. The rescue party do not, of course, wait to clear away the whole of this debris, only just enough to enable them to crawl through or over it, but even then it often represents the waste of precious hours, and the expenditure of great exertions, to get past a "fall." So at intervals "falls" are made in the gallery, in order that men may be practised in dealing with them.

It may be interesting to give a brief statement of the training undergone by the men at the Mansfield Rescue Station. In that case, it should be stated, the gallery is made double, so that men can go one way and return the other back to their starting-point. Having donned their breathing apparatus, they enter the gallery, which, by the way, is filled with smoke and foul gas. Passing along it, they encounter two falls, which they must get over or through ; then they have to set twelve timber props as might be necessary to maintain the safety of a damaged road in the mine ; all that they do three times over. Then they are required to bring up and lay 250 bricks, a thing which might also be necessary in an actual emergency, after which they have to fix up " brattice cloth " in a part of the gallery. One of the first duties, of course, for a rescue party is to restore the circulation of air in the mine, and brattice cloth is a rough kind of cloth which is put to guide the air currents. That done, they have to take a dummy representing a man of 14 stone, put it on a stretcher, and carry it round the gallery and over the falls. Finally, they restore the timber, bricks and cloth, and their turn of work is done. The total time required for this is two hours, and during the whole of that period they are, of course, breathing not the natural air, but the artificial



By permission of *W. E. Garforth, Esq., Pontefract*

An Aritficial Coal Mine

These two photographs show the clouds of flame and smoke issuing from the mouth of the "Artificial Coal Mine" during the experiments described in the text

atmosphere provided for them by the apparatus with which each man is provided. The chief point of this part of the training, as has been remarked already, is to accustom the men to the wearing of the apparatus and to doing work in it. By this means they gain confidence in it, and get to know that it will not fail them in the time of trial.

The course of instruction consists of ten drills such as has been described, after which the men are called up twice a year, just to refresh their memories.

One side of the gallery is glazed, so that the instructor can watch his men at work without of necessity being inside himself, and there are emergency doors as well, which can be opened to let a man out should the ordeal be too much for him. The necessary "fumes" are generated in a stove and driven into the gallery by a fan. The stations are beautifully fitted up, with baths for the men to wash after their somewhat dirty experience in the gallery, and everything is done for their convenience and welfare.

The advantage of this systematic training of a great number of men is that there are men at each colliery who can be called upon when needed. The team of strangers, as has been remarked, partially failed at Courrières, largely because they were strangers, but when every colliery has a team ready, composed of its own men, then clearly there is the greatest chance of success. The central station of the district is the training-ground where the men go from all the collieries to get the experience and instruction, and where a reserve store of appliances is kept. In many cases, of course, the collieries have their own appliances, so that work can be begun at once, without having to wait for that from the rescue station, but the latter forms a reserve in case of need, and, being kept under the care of an expert, it is naturally always in the best possible working order.

To give an idea of the cost of these stations, it may be stated that the one at Porth, in the Rhondda Valley, cost, including equipment, £7000, while the one at Mansfield cost £3000. This first cost and the expense of maintenance is borne by the collieries of the district in proportion to the quantity of coal which they raise.

And now we can turn to the apparatus itself, without which the organisation already described would be of little value.

There are several makes of these, but a description of the particular apparatus used at the two stations mentioned will serve as an illustration. The purpose, of course, is to give the wearer an atmosphere of his own, which he can carry about with him, and which will render him quite independent of the ordinary atmosphere and quite indifferent to the poisonous nature of the gases around him. To this end his mouth and nostrils must be cut off from the outer world altogether. There are two ways of doing this. In the one there is used a helmet, or perhaps mask would be the better term. This fits right over the man's face, an air-tight joint being made between the helmet and his head by means of a rubber washer which can be inflated with air. The inflation is accomplished by squeezing a rubber ball on the right-hand side of the helmet. In the centre is a glass window through which he can see easily, and since this is apt to become clouded by the dampness of his breath there is a wiper inside, which can be turned by a knob on the outside, so that by simply turning his knob with his hand he can clean the window at any time that may be necessary. Two soft pads inside the helmet bear one on the man's forehead and the other on his chin, and these, working in conjunction with a strap which passes right round the back of his head, keep the thing firmly in position. In addition there is combined with the helmet a leather skull-cap which, being continued down behind, gives good protection to the head and neck.

The other form of apparatus consists of a mouth-piece and nose-clip. The mouth-piece, as its name implies, fits in the man's mouth, being supported and kept in position by a strap passing behind the back of his head. Combined with it is a little screw clip which closes his nostrils. The man also wears a leather skull-cap, from which straps depend to bear the weight of the mouth-piece and its attached tubes, so that the weight does not fall upon his mouth.

Either of these arrangements, it is clear, cuts him off from communication with the outer air, but that is only half the problem, for he must be given a substitute or he will be suffocated.

This part of the appliance he carries, knapsack fashion, upon his back. First there is a rectangular case, called the regenerator, with, below it, two small cylinders of compressed oxygen. A suitable arrangement of pipes connects these together, and to the helmet or mouth-piece as the case may be.

When the man exhales, as we all know, the air which he then discharges from his lungs is deficient in oxygen and instead contains carbonic acid gas. The latter must be got rid of and replaced by pure oxygen. The exhaled air is therefore led down a pipe to the regenerator, where it comes into contact with several trays of caustic soda, a chemical which has a great affinity for carbonic acid. The result is that the latter gas is extracted from the impure air, finding a more congenial home in the caustic soda. It is then necessary to restore the normal quantity of oxygen, and so, as the air passes on, it meets, in a little apparatus known as an injector, a spray of pure oxygen from the cylinders. Thus, after being purified and re-oxygenated, the air passes on through more pipes to the helmet or mouth-piece, to be breathed once more. The apparatus contains sufficient oxygen and caustic soda for this to go on for a space of two hours.

But during times of extra exertion a man needs more air than at others, for which provision has to be made, and so on his chest the rescuer carries a flexible bag divided into two compartments. Through one of these the exhaled air passes on its way to the regenerator, while through the other the oxygenated air flows on its way to the man's mouth. When he is breathing hard, then, during a moment of extra exertion, and when, therefore, he is turning out bad air faster than it can be purified, and drawing in pure air faster than it can be produced, this bag comes to his aid. From the store of oxygenated air in one side of it he draws the extra which he requires, while the other side stores up temporarily the excess of vitiated air, until the regenerator is able to overtake its work. Thus at all times, whether breathing ordinarily or heavily, the apparatus can respond to his demands.

The spray of oxygen as it escapes from the cylinders into the injector has the effect of driving the air along, so that the circulation through the tubes and the regenerator is automatic, and the foul air flows away from the man's mouth and the new air comes back to him quite without effort on his part. As time goes on, of course, and the stored oxygen becomes used up, the pressure in the cylinders falls, which fall, shown upon a little pressure-gauge, tells the man how much longer time he has before he must return for fresh supplies of oxygen and soda. Fresh cylinders of oxygen can be connected up very quickly in place of the empty ones, while a fresh regenerator can be put in, or new caustic soda supplied, in a very short time.

The superintendent of the Mansfield station has invented what is termed a "self-rescue" apparatus, to be used in conjunction with that which has been described above. It is simpler and lighter than the rescue apparatus, and will not keep a man supplied with air for more than an hour or an hour and a quarter. Moreover, it is not automatic, since the flow of oxygen has to be controlled by the man himself. Since, however, it consists only of a mouth-piece, a breathing-bag and a cylinder of oxygen, it is very portable, and may well be carried by a rescue party for the use of any men who may be discovered alive beyond the danger zone. It may well happen, indeed it often has happened, that a remote part of a mine, although cut off from the shaft by passages full of "afterdamp," as the foul gases caused by the explosion are termed, may itself contain fairly pure air in which men can live for a long time. If such men be reached, the difficulty is to get them through the passages containing the bad air. Consequently a rescue party which carried one or two of these light forms of apparatus could equip such men with them and then they could pass out with safety.

Another use, the one, in fact, from which the appliance draws its name, is the facility with which, by its aid, a man could set right a chance defect in his ordinary rescue apparatus. Suppose, for example, that a fully equipped man found something wrong, whereby he was prevented from getting his proper supply of purified air. Then, if the party had one of the self-rescue sets with them, he could slip off his helmet or mouth-piece, quickly replacing it, for a time, with the self-rescue mouth-piece. This might enable him to reach safety, or even to put the other apparatus right and then don it once more. The whole thing can be packed up into a small tin case which can be slung over one shoulder, and with the oxygen cylinder slung over the other one the complete outfit can be carried quite easily by a man in addition to what he is wearing himself.

Still another form of breathing appliance may well be taken on these rescue expeditions, and that is the reviving apparatus, for use upon those who have apparently ceased to breathe. In this case a mask is put over the sufferers' mouth and nose, and then the turning of a lever into a certain position causes oxygen to escape from a cylinder in such a way as to cause a suction which empties the man's lungs of the bad gases which have laid him low. That done, another movement of the lever and a deep breath of oxygen flows into his lungs in their place. Thus by alternating the positions of the lever an artificial respiration is set up far more effective than can possibly be attained by the ordinary method of moving the man's arms and pressing his chest. Indeed there are cases, such as when his arms or ribs are injured, when the ordinary method is impossible, but it is hard to imagine an instance when this beneficent apparatus could not be used, and so long as there be any spark of life left in the poor fellow there seems to be every reason to expect a complete revival as the result of its use.

Of course there are many other places where poisonous gases are likely to be met with, such as gasworks, chemical-works, limeworks, and so on, where this apparatus may be kept with advantage, in case of accident.

Indeed all that has been described above has its use apart from colliery explosions, although they are the outstanding opportunities for its employment. Old workings, tunnels which have been empty for a time, sewers—all these have, on occasion, to be entered, not to mention houses full of smoke, or factories full of chemical fumes, all of which form cases in which the rescue apparatus would find useful employment.

CHAPTER XIX

HOW SCIENCE HELPS TO KEEP US WELL

ONE branch of science—medical science—concerns itself almost entirely with health, but it would be out of place to refer to such matters here, even if the present writer were capable of doing justice to the subject. A new medicine or a new method of operating upon a suffering patient would be quite correctly described as a scientific marvel, but it is not of such that this chapter deals, but rather with those great works by which the engineer, often taught by the medical man, promotes the health of a whole community.

Most important of these, perhaps, is the provision of pure water. Some places are more fortunately situated than others in this respect, being near streams flowing down from mountains clear and unpolluted, which can be drunk after the minimum of purification. Others have to make use of the waters of a moderately clean river, as London does those of the Thames and Lea, in which cases the greatest care has to be exercised in the filtration of the liquid before it can be sent out through the mains for domestic consumption.

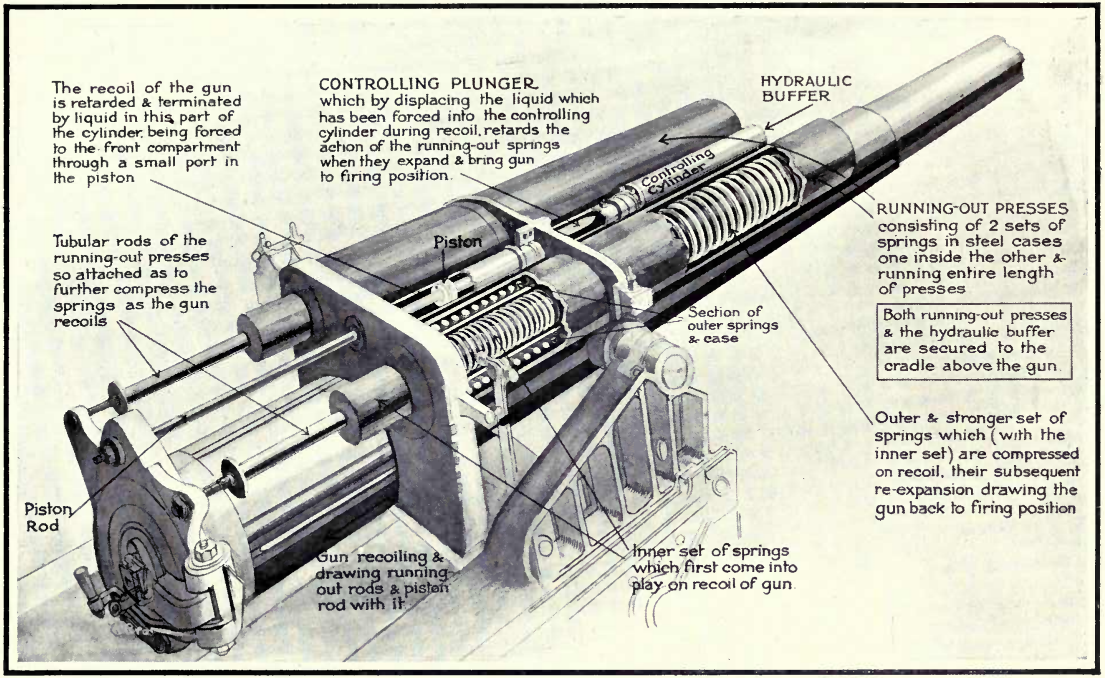
In this particular domain invention has been comparatively slow. There are novel pumps, it is true, for handling the water, such as the Humphrey Gas Pump, which the Metropolitan Water Board (London) have installed for filling their great reservoirs at Chingford. In these an explosion of gas is the motive force. Water flows by gravitation into a huge iron pipe closed at the top but open at the bottom. It is so arranged that a quantity of gas shall be entrapped in the upper end, which, being exploded by an electric spark, drives the mass of water out. Some of it, together with a quantity of fresh water, presently comes surging back, entrapping a fresh supply of gas and causing a new explosion; and so it goes on over and over again. The particular pumps at the waterworks referred to discharge about fourteen tons of water at each explosion, of which there are nine every minute.

The special effect of these machines, however, is not to improve the public health so much as to relieve the public pocket, for their chief feature is that they work more economically than any other kind of pump.

The filters, by which the water is purified, are simply layers of sand, much the same as have been in use for many years, although in some cases chemistry is brought in and the work of the filters aided by the action of precipitants. These are substances which combine in some way with the impurities in the water, and carry them to the bottom of the tank or reservoir, while the pure water remains to be drawn off from the top.

This is also the most usual method by which water is softened. Hardness in water is due to the presence of certain salts which are dissolved out of the ground as the water percolates through it, and which are absent from rain-water. To get rid of these the hard water has chemicals mixed with it in a tank, from which it flows slowly through another tank. The effect of the added chemicals is to convert the soluble salts in the water into insoluble particles, which then tend to fall down to the bottom of the containing vessel. The slow passage through the second tank is intended to give the particles time to settle.

Finally, to make sure that these have been all got rid of, the water traverses a filter, and then it is for all practical purposes as soft as rain-water. Some people are frightened of this artificially softened water, on the ground that chemicals have been added to it, supposing, apparently, that when they use such water they are really employing a chemical solution. That is quite wrong, however, for the added chemicals, combining with the "hardness," form substances



Sectional View of Hydraulic Buffer and Running-out Presses of a 60-pounder Gun

which are quite easily extracted from the water altogether. If we liken the hardness to a number of pickpockets in a crowd, and the added chemicals to a number of policemen who come in to arrest the said pickpockets, finally leaving the crowd free from both pickpockets and policemen, we get a simple illustration of what takes place.

But almost equally important as the provision of pure water is the effective dealing with the drainage of a large town. Much offensive matter flows under the streets of our towns and cities, and if it is not to become a nuisance it must be scientifically dealt with.

Years ago the drains of London simply emptied themselves into the Thames, until, in 1864, two large drains were constructed, one on each side of, and approximately parallel with, the river, to intercept the old drains and to carry their contents to points many miles down towards the sea. Even that, however, by no means abated the evil, for it simply transferred it to a new place. The river was as foul as ever.

William Morris, in *News from Nowhere*, pictures the catching of salmon in the Thames off Chelsea, while one of London's prominent citizens, referring to what was being done in the direction of purifying the river, jocosely promised the members of Parliament a little fly-fishing at Westminster. Equally remote, it is to be feared, from actual accomplishment, these two prophecies do certainly indicate the tendency of events, for science has enabled the authorities to relieve the long-suffering river of much of the pollution which they used to thrust into it.

The first great step was the introduction, in 1887, of a treatment in principle very like that just described for softening water. The liquid from the drains is gathered into large reservoirs, where chemicals are added to it, causing the heavier matter to be precipitated in the form known as "sludge."

The liquid portion, or "effluent," as it is called, which is left is discharged into the river just as the tide is ebbing, so that it is carried right away, and, being comparatively inoffensive, it pollutes the river very little indeed. The sludge, on the other hand, is pumped into special steamers, which carry it down to a certain spot off the Thames Estuary, where they drop it into the sea. The currents at the particular spot chosen are such that none of it returns to the river.

For a similar purpose electrolysis has been employed. In this process the sewage is made to flow between two iron plates which are connected up to a source of electric current so that they form electrodes, while the sewage is the electrolyte. The current decomposes the liquid sewage, causing chlorine and oxygen to be deposited upon that plate which forms the anode. This deodorises and purifies the sewage, in addition to which iron salts are formed on the iron plates, the effect of which is to precipitate the solid particles. Thus the same result is achieved as when chemicals are used, the main difference being that instead of chemicals being added, they are produced by the passage of the current.

But, from the scientific point of view, the most interesting process of all is that in which bacteria or microbes are brought into the service. The fact is familiar to most people that there are certain minute organisms which cause terrible diseases. It is not so well known that there are still more of them whose action is extremely beneficent. The writer has seen these minute living things described in a popular book as "insects," but they really belong to a low order of plant life, and, as has been said in an earlier chapter, in spite of the lowliness of their status in the order of creation, they are able to accomplish certain chemical processes which baffle the cleverest men. They are particularly good, or some of them are at any rate, at forming compounds in which nitrogen forms a part. Further, they can be divided into two classes, the aerobic and the anaerobic. The former work best in air, while the latter need an absence of air while they perform their functions. After which preliminary explanation we can proceed to describe how they are induced to carry on this valuable work for mankind.

The sewage flows first of all into a tank from which light and air are excluded as far as possible. There the anaerobic microbes flourish and multiply, and in the course of their life work they convert the sewage into an inoffensive liquid. After an appropriate interval the liquid passes to filter-beds, where it trickles over and through beds of coke, the effect of which is to aerate it very thoroughly, whereby the aerobic microbes come into action, completing the good work, so that nothing is left except a clean, colourless and odourless liquid. Indeed it is more than that, for the microbes have turned the offensive matter into nitrogenous compounds which, as we have seen in a previous chapter, are the best fertilisers. Hence this effluent, if placed upon the soil, is of great value.

The advantage of this to towns which are not blessed, like London, with a broad river and the sea near at hand needs no explanation.

The bacteria necessary to carry on the process are always present in sewage, and after any particular plant has been in operation for a little while there results an accumulation of them, so that the process becomes more and more active as time goes on. Mechanical ingenuity has so arranged matters that a sewage disposal plant on this system can be made quite automatic, requiring little or no attention for months together, the raw sewage flowing in at one end, while the odourless, harmless effluent pours out at the other.

And, moreover, so powerful is the action of these beneficent bacteria that should disease germs come down in the sewage they soon destroy them. No chemicals are needed, for the bacteria replenish themselves. No sludge is left, everything being turned into the harmless effluent. And, it may be said once more, disease germs are destroyed. Of all the valuable inventions of modern times this is surely not one of the least.

CHAPTER XIX

MODERN ARTILLERY

EVEN as late as the time of the Crimean War guns, even the largest, were made of that extremely common material, cast-iron. In fact, so far as material went, there was no difference between a gun and a water-pipe.

It was the need for some material possessing strength comparable with that of steel combined with the ease of production of cast-iron which led Sir Henry Bessemer to experiment in the manufacture of steel. Out of those experiments came Bessemer steel and its near relative, Siemens steel, two materials of universal application at the present time, so that to the needs of the artilleryman we owe two inventions which have proved of infinite value in peace as well as in war.

If any particular piece of ordnance can be said to be the prime favourite with the English-speaking peoples, it is the big naval gun. With both British and Americans the navy takes pride of place ; both nations are given to contemplating with pleasure the number of dreadnoughts which they possess, and the distinguishing feature of a dreadnought is the large number of big guns which it carries.

Of the latest of these gigantic weapons one may not speak, but much is already public property concerning the 12-inch gun which the original *Dreadnought* carried, and whch is probably followed in its general features by the still greater guns of the most recent ships.

A gun is spoken of by its "calibre," which means the inside diameter, or, to use another expression, the size of the "bore." So the "12-inch" naval gun is 12 inches in the bore. Its length is in some cases 45 calibres and in others 50 calibres. In other words, some are 45 feet long and others 50 feet.

Why the difference ? someone may ask. The answer is that the longer ones are an improved type. The extra length gives longer range and harder hits, as is quite apparent after a little thought. The explosive " goes off " and forthwith commences to drive the shell towards the muzzle. So long as it is in the gun the shell is being pushed faster and faster, but so soon as it leaves the muzzle the pushing ceases and the shell is left to pursue its course with its own momentum. Therefore, generally speaking, one may say that the longer the gun the faster will be the speed of the shell as it leaves the muzzle, the farther will it go and the harder will be the blow at a given range.

Incidentally this explanation reveals the need for different kinds of explosive. The propellant whose function it is to drive the shell out of the gun is different from that with which the shell is itself filled. The former needs to act comparatively slowly, so that it may continue its pushing action during the whole time that the shell is travelling along the gun. It might be ever so powerful, but were its action too sudden it would simply tend to burst the gun, without imparting very much speed to the shell. On arrival at its destination, however, the shell needs to burst suddenly and violently.

Another interesting question arises at this point. Seeing how fast is even the slowest speed at which a projectile travels, how can it be possible to measure the rate at which a shell issues from one of these monster guns. Needless to say, it is electricity which makes a thing apparently so difficult really quite easy.

Near the gun is set up a frame with a wire zigzagging to and fro across it, in such a manner that when the gun is fired the shell is bound to cut the wire. Electric current is made to pass through this wire on its way to a suitable house in which are recording instruments, where it energises a magnet and so holds something up. Now it is easy to see that as soon as the shell cuts the wire the current will stop, the magnet will " let go " and the " something " will drop.

At a certain distance farther on there is a second frame with wires upon it, through which passes a second current, which is also led to the instrument house, where it again operates a second magnet.

When the first magnet releases its hold it drops something, to wit, a long lead weight. When the second magnet lets go it permits a second weight to fall against the first and make a dent or scratch upon it. The longer the interval between the action of the two magnets the higher up upon the lead weight will the scratch be. The apparatus, in short, will register the distance fallen through by the lead weight between the breaking of the wire in the first frame and the breaking of the wire in the second frame.

Now a falling object, if only it has such weight that the resistance of the air is negligible, falls according to a well-understood law, which law it obeys with the utmost accuracy. Therefore the distance fallen by the weight between the passage of the shell through two points gives a very accurate record of the time taken to travel from one to the other. Of course several such frames can be used if desired in the same way.

But to return to the gun itself. It is not merely one piece of metal but several tubes beautifully fitted one inside another. Moreover, in the British gun at all events, between two of the tubes there is a space filled with " wire."

This wire is perhaps better described as steel tape, and is of the finest material for the purpose, flexible and tremendously strong. It is wound round and round one of the tubes until there are many miles of it on a single gun. It is wound tightly, too, by means of special machinery.

The purpose of the wire is to resist cracking. The solid steel tubes may crack, and, as is the way with all cracks, these will tend to grow longer and longer. The many turns of wire, however, will not crack. Even if a few turns should break, the damage will not spread, and the gun can probably go on as if nothing had happened.

The material of which these guns are made is nickel chrome gun steel. Steel is ordinarily an alloy of iron and carbon, but this metal also contains traces of nickel and chromium, which make it specially suitable for its special purpose.

Each of the tubes of which the gun is formed start as an ingot, a mere lump of metal, but roughly shaped. The requisite mixture is obtained in a furnace and the molten metal is run out into a mould. The ingot is heated again and pressed under enormous hydraulic presses until it is approximately the shape required. This pressing not only produces the desired shape, it also improves the quality of the metal.

The rough forging is then bored out, to make it into a tube. One is inclined to wonder why the ingot is not cast hollow to commence with, and so save the labour of boring it all out later. The explanation of this is that certain impurities are always present in the metal and these always gather together in the part which sets last. Now in a solid block or ingot it is clear that the centre is the part which will set last, and hence that is the part where the impurities will congregate. Then, when the centre part is all bored out the impurities are entirely removed.

The tube is shaped externally by being turned in a lathe.

The innermost tube is not simply smooth. There is a spiral groove, called the " rifling," running round and round, screw fashion, inside it. The purpose of this is to give the shell a spinning action which causes it to keep point foremost throughout its flight. But for this the shell would tend to turn over and over, resulting in uncertain and inaccurate flight.

The shell is a little smaller than the bore of the gun, but near its base it has an encircling band of soft copper, which band is a tight fit in the gun. The soft copper crushes into the " rifling," whereby the shell obtains its spinning action.

The large guns are mounted in pairs, each pair on a turntable, by the movement of which to right or left they are trained upon the distant target. The turntable is surrounded by a wall of thick armour and is covered by an iron hood or roof.

In addition to being turnable to right or left, there is, of course, provision for raising or depressing the direction in which each gun is pointing. They need always to point more or less upwards, and the particular angle depends upon the range or distance of the object aimed at. This is ascertained by range-finding instruments and communicated to the officers in the turrets, as the covered turntables are called. The guns are then elevated or depressed to suit the range.

Each gun rests upon a cradle which is itself fitted upon a slide. When it is fired it " kicks " backwards, against the force of a buffer of springs, or a hydraulic or pneumatic cylinder. Thus after each shot the gun moves backwards upon the slide, but the hydraulic apparatus brings it back again into position for firing almost instantaneously.

In naval guns all the movements, including that of the turntable, are by power, either hydraulic or electric, or a combination of the two. The loading is also by power.

The shells and ammunition are kept well down towards the bottom of the ship, under each turret. Lifts bring them up from there to a chamber just beneath the turntable, known as the working chamber. Here a small quantity only is kept, and that for as short a time as possible before it is sent up by other hoists straight to the guns themselves. The hoists are so arranged that, no matter how they may be elevated or depressed, the ammunition is delivered exactly opposite the breech, as the rear end of a gun is termed. Then a mechanical rammer pushes it straight in.

The breech of the gun is closed by a beautiful piece of mechanism called the breech-block. It is really a huge plug which securely closes the end of the gun, a partial turn after it is in place fixing it firmly enough to resist all

Rifles of Different Nations

(*See* Appendix)

the force of the explosion. Yet it can be freed and swung back upon hinges in a few seconds. At the same moment that it is opened a jet of air blows into the gun, clearing out all effects of the recent explosion.

The process of firing one of these guns may thus be summarised. The turntable is swivelled to right or left until the gunners, looking through the sights, which are really telescopes, see the object straight in front of them. Meanwhile the sights have been set according to the range—that is to say, they have been so set in relation to the gun itself that when they point directly at the target the gun will be pointed upwards at exactly the right angle for that range. The whole thing, therefore, gun and sights combined, is tilted upwards or downwards as may be necessary until the sights point directly at the object aimed at. Then at a signal the gun is fired by electricity. The shock causes the gun to slide backwards upon its supporting slide, but the buffers, having taken the shock automatically, return it to its position again; the aim is thus undisturbed and it is ready for the next shot. These enormous guns can be fired at the rate of one shot every fifteen seconds.

Field guns are in principle very similar to these, only, of course, they are much smaller and are mounted upon carriages, so that they can be quickly moved from place to place. It must be borne in mind, however, that there are in the case of land guns two distinct types. Field guns, like naval guns, fire straight at their target; howitzers or mortars fire upwards with a view to letting the shell fall on the target from above. The latter are, generally speaking, short, fat, stumpy guns, as compared with the long, slender field guns.

In the field all guns have to be loaded by hand. The elaborate system of hoists which enables the great naval guns to be loaded with such rapidity is obviously impossible. That has to be compensated for by the skill and quickness of the gunners themselves, and it is indeed astonishing to see with what deftness they can handle the heavy and dangerous projectiles.

With all guns, of whatever kind, range-finding is of the utmost importance. No projectile, however fast it may travel, really moves in a straight line. It must be fired more or less upwards in order to compensate for the downward pull of gravity. If the elevation be insufficient the shell will fall short; if it be too much it may go beyond the mark, or it may fall short, according to circumstances. Just the right elevation is absolutely essential for good shooting. And for that to be achieved the range must be known with the utmost possible accuracy.

There are various systems and instruments used for this purpose, but all depend upon the same principle. It is the principle underlying all surveying and all astronomy; indeed it is the only possible principle for measuring a distance when you cannot actually go and lay a measure upon it or by it.

It is based upon a peculiar property of a triangle. In the case of every triangle which has straight sides, if we know the size of two of the angles and the length of one of the sides we can easily calculate all that there is to be known about that triangle. We unconsciously use the principle when we judge a distance with our eyes. We focus each eye separately upon the object which we are looking at. In other words, each of our eyes looks along a straight line terminating in the object. Those two lines, together with a line joining our two eyes, form a triangle. The line between our eyes is the "base," the line of which we know the length, while the directions in which we point our eyes give us the angles at each end of the base. From this we are able to judge the distance of the object. Of course there is probably not one of us who knows the length of that natural "base" in inches, but that does not matter in this case, since it is always the same whatever we may look at, and so the mere inclination of the eyes gives us a means of comparing distances. When we judge by the eye alone, what we really do is to draw upon our experience and consciously or unconsciously compare the distance which we are estimating with some others which we already know.

In surveying, a telescope is set up at one end of a base-line and pointed first at the other end of the base-line and then at the distant object. A scale with which the instrument is provided gives us the size of the angle between the two. Then the same thing is done at the other end of the "base" and the similar angle there is obtained. The length of the base being known, the distance of the remote object can then be calculated.

In the same way two observations can be made, one at each end of a ship, the length of the ship forming the base-line. Or an instrument can be made by which two observations can be made simultaneously by the same man.

This is done by means of mirrors which are turned so that the same object is seen in both of them, apparently in a straight line. The extent to which one of them has to be turned gives the angle, and the instrument forms the base.

Anyone with the slightest geometrical experience will perceive at once that the best results are obtained when the base-line is of considerable length, and hence small portable range-finding instruments such as can be easily carried and used by one man are necessarily less accurate than an arrangement such as has been suggested above, where two observers work simultaneously from the two ends of a ship.

In many cases, however, the self-contained instrument is the only one which it is possible to use, and when the instrument is well made and in experienced hands the results are surprisingly good.

As used in surveying, for example, where the base-line may be anything, according to circumstances, and the angles may likewise vary at both ends, elaborate trigonometrical calculations have to be performed to arrive at the desired result. If, however, the base-line be always the same, and one of the angles be always a right angle, the distance of the distant object will vary with the remaining angle. Indeed the scale by which that angle is measured can be made to give not degrees, but the distance of the object. Portable range-finders, therefore, in many cases have one reflector set for a right angle and only one of the reflectors movable. The instrument then shows the distance of the object at a glance.

This is impossible in the case of two separate observations on a ship. In that case the base is always the same, but since the ship cannot be set at right angles to the object whenever a range has to be found, both angles have to be measured. There is, however, a beautifully simple little mechanism in which two pointers are set one to each of the two angles, and the distance is then shown instantly.

APPENDIX

A DESCRIPTION OF THE RIFLES SHOWN AT PAGE 240

THE **German Mauser** can fire forty rounds a minute—more than any other rifle used in the war. The rifle is of the 1898 pattern, weighs 9 lb. 14 oz. with bayonet fixed, and is sighted from 219 to 2187 yards. The magazine holds five cartridges, packed in chargers. As the rifle is not provided with a cut-off, it cannot be used as a single-loader. With its long barrel and long bayonet it gives a stabbing length of 5 ft. 9 in.—8 in. longer than the British.

The Austrian Rifle is the Mannlicher. This rifle is very fast in action as a snap back and forth of the wrist is sufficient to operate it. It is, however, more trying for prolonged work, owing to the throwing of the strain only on the wrist. Without the bayonet the rifle weighs only 8 lb. 5 oz., the lightest of all, yet the bullet—244 grains—is the heaviest used by any of the belligerents. The rifle is sighted from 410 to 2132 yards, and the barrel has a four-groove rifling.

The British Lee-Enfield—Mark iii—is the outcome of the South African War. It is not too long for horseback and is yet quite efficient for infantry. The barrel is 25 in. long and has five grooves in the rifling. It is sighted from 200 to 2800 yards. The rifle is fitted with a magazine which holds ten cartridges packed in chargers, each of which contains five rounds, so that the magazine is filled with ten rounds in two motions. The rifle is also fitted with a cut-off, which enables it to be used as a single-loader. It is altogether a most efficient weapon.

THE FRENCH LEBEL is of the 1886–1893 pattern, and with bayonet fixed is longer than any other rifle. It weighs, without bayonet, 9 lb. 3½ oz. The tube magazine under the barrel contains eight cartridges; it takes, of course, longer to charge than a magazine loaded with a charger. It does not fire as many shots a minute as some of the other rifles in the field. The position of the magazine is indicated by the crosses. The rifle is sighted from 273 to 2187 yards, and the bullet weighs 198 grains.

THE BELGIAN ARMY uses the 1889 pattern Mauser, which weighs just over 8 lb. and is sighted from 547 to 2187 yards. The magazine holds five cartridges carried in clips; not having a cut-off, the rifle cannot be used as a single-loader. It has four grooves in its rifling and measures 4 ft. 2¼ in., or, with the bayonet, 4 ft. 11¾ in. The bayonet is short and flat.

THE "3 LINE" NAGANT of Russia is ¼ lb. heavier than the British rifle and is over 7 in. longer. The triangular bayonet is always fixed and never removed from the rifle. The magazine of the rifle is of the box type and holds five cartridges. The rifle is capable of discharging twenty-four bullets to the minute. A useful feature is the interrupter, which prevents jamming of two cartridges.

THE ITALIAN MANNLICHER-CARCANO is of the 1891 pattern. It weighs, without bayonet, just over 8 lb. 6 oz. and measures 50¾ in. The barrel, 30¾ in. long, has a four-groove rifling. The box magazine, fixed under receiver without cut-off, holds six cartridges. The magazine holds six rounds, and the rifle is capable of discharging fifteen rounds a minute.

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