INVISIBLE
POWERS
OF
NATURE

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By E. M. CAILLARD.

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PREFACE.

THE object of this little book is to create in its readers a sufficient interest in physical science to lead them to the study of more advanced works on the same subject.

Professor Balfour Stewart, in the preface to his "Primer on Physics," says that "the authors of the 'Science Primers on Physics and Chemistry' feel that the thing to be aimed at is not so much to give information, as to endeavour to discipline the mind in a way which has not hitherto been customary, by bringing it into immediate contact with Nature herself." The present writer is of opinion that to awaken the desire for such discipline is one great means of ensuring that it will be welcomed and submitted to; and, therefore, that, in the first place, interest should be excited by supplying elementary information, not perhaps of the precise kind or in the precise manner which a man of science considers most necessary to beginners, but that which the beginners themselves chiefly care to have. It has seemed to her that, without experiments, and even without diagrams, both of which may be baffling where classes cannot be attended or special teaching be had, it would be possible to convey, in narrative form, a general and rudimentary idea of the nature and causes of phenomena of daily occurrence, so far as they are known. At the same time, the very plan which she proposed to herself, and which she has endeavoured to follow out, precludes the little volume which is the outcome of her efforts from accomplishing the work of an ordinary primer, or from being treated as such. It is not, properly speaking, a lesson-book at all, though it might very possibly be found suitable as a "holiday task" in schools where such are given. It is simply a narration, or rather a series of narrations, made with a view to attracting the interest of beginners. Nevertheless, great care has been taken to ensure perfect accuracy, and to omit no detail necessary to the intelligent understanding of those elementary matters with which alone the writer has attempted to deal; and though, on account of the untechnical form of her work, too great preponderance may seem to be given to some branches of a subject over others of really equal importance, this has not been carelessly done, but still in the endeavour, by dwelling principally on what would most strike the mind untrained in science, to stimulate it to that more detailed and systematic study for which the materials are now so rich, and which so surely brings its own reward.

E. M. C.

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INTRODUCTION.

THIS book is intended for readers who love to hear of wonderful things, but who prefer the wonders of truth to the wonders of fiction. Everyone enjoys a good story, and most of us delight in the beautiful fancies of Hans Andersen, the gorgeous imaginations of the "Arabian Nights," and the extraordinary and exciting adventures narrated by Mr. Rider Haggard. Such tales transport us into a different world, where new marvels await us at every step; but there is one drawback to our enjoyment—the world which we are shown is an invented, not a real one, and when we come back to our actual surroundings, we are apt to think them dull and commonplace. "How I wish it were all true!" is the exclamation of many a young reader when the exciting romance is closed and everyday life asserts itself once more.

Now, it is a pity we should think the fancy world so much more interesting than the real one, because it is in the latter we must live and work, and therefore it is the latter which we ought to care about most. I believe we all should do so if we knew it as it is, but we are very ignorant about it; we only see just the outside, and though that is in truth wonderful enough to rouse our curiosity and interest very much, we are so used to it that we hardly give it even a moment's attention; yet every wind that blows, every sunbeam that shines, could tell us more wonderful things by far than the cleverest story-inventor. I have listened to a few of these wonderful things, and now I want you to listen to them too. In order to prove how strange and interesting the very commonest occurrences that go on around us are, I shall try to show you some of the marvels they conceal—*i.e.* conceal from the careless and frivolous, for they do not conceal but display them to those who have the earnestness to ask questions, and the patience to look for answers. Such people never speak of the "commonplace world we live in." To them it is full of wonder and beauty, for they have been shown by the "Invisible Powers of Nature" something of their majesty and glory. It is of these Invisible Powers I am about to tell you. Their names are perhaps familiar enough—Gravitation, Heat, Electricity, you know these. Now we will see if they cannot become something more than names; and though it is but a slight glimpse I can give you of their working, I shall hope that in the future, many among you will attain to a far higher, wider view, and will perhaps be able to help others to do the same.

E. M. C.

THE INVISIBLE POWERS OF NATURE.

CHAPTER I.

GRAVITATION.

Newton the discoverer of gravitation—Work of gravitation to give weight—Molecular formation of bodies—Each molecule separately acted on by gravitation—Possibility of counteracting gravitation—Definition of force—Resistance of the air—Force of gravitation is increased by mass—Varies with distance—Law of variation.

I AM afraid the name at the head of this chapter will make you feel inclined to skip it altogether, for no doubt GRAVITATION is an old friend to whom you do not consider you need any fresh introduction. We are not always, however, so intimately acquainted with old friends as we imagine, as, if you will have the patience to read on, you may find in this case.

No doubt you are familiar with the story of Newton and the apple, and have often heard how the simple fact of an apple falling from the tree under which he was sitting, called his attention to the problem that had long perplexed scientific men, viz. why things, when unsupported, should always fall to the ground. Not only did Newton, after much study, and years of patient waiting and expectation till his theory could be proved and verified, discover this, but he also discovered why the stars and planets move in a certain fixed way and no other, for it is this same gravitation which governs them. We must, however, confine our attention to the work of gravitation on earth; and that its very name tells us, for it comes from the Latin word, *gravis*, "heavy." The work of gravitation is to give weight, so that objects are obliged to fall down to the earth. They are, in fact, attracted by it, and the earth is, in the same way, attracted by them, only they are far too small to show their power by making the earth move towards them as they are obliged to move towards it.

Before telling you anything about the way in which gravitation works, I must ask a question.

Here is a bullet, made, as every one knows, of lead; but of how many pieces of lead ?

One.

No, that is quite a mistaken idea. A bullet is not made of one, nor of ten, nor of a hundred separate little pieces of lead, but of thousands and thousands, all holding close together, and so small, that if one were by itself, it could not be seen, even through the strongest microscope.

This seems extraordinary. A bullet looks like one undivided piece of lead, and yet it is really composed of all these countless morsels; and not only lead, but everything you can mention, is made in the same way, even to your own bodies.

These invisible particles are called MOLECULES, and a collection of them forming one piece of anything is called a BODY. Thus, a table is a body formed of molecules of wood, a fender is a body formed of molecules of steel or iron, and so on.

Since these molecules are so small, you might naturally suppose that gravitation would act upon them *collectively*, *i.e.* upon the whole number of them contained in one body, and not upon every molecule separately. This is a mistake, however. Each molecule in a body distinctly feels itself drawn towards the earth, and all those contained in the same body are (if it is made of one substance) drawn towards the earth with the same amount of strength.

If, however, gravitation draws all bodies and all molecules down to the earth, how is it that we are able to throw things *upwards?*

That is because the upward force of the throw is stronger for the time being than the downward force of gravitation, and as long as it so continues the object thrown goes on rising. Yet all the while it is still being attracted to the earth, and therefore, as the impetus of your throw spends itself, the object rises more and more slowly, because that attraction is gaining more power over it, till at last it stops rising altogether and begins to fall again, completely under the mastery of gravitation once more. The greater the strength which is used in throwing the object up, the higher it will rise before the relentless force of gravitation brings it down; but there is no strength great enough to overcome gravitation altogether; it is always finally victorious.

And here it is necessary that I should explain to you a word which I have already twice used—FORCE. When we speak of *forcing* a person, we mean obliging him to do something which, left to himself, he would not have done. By force, in its scientific sense, very much the same thing is intended. Force is whatever sets a body which is at rest in motion, and also whatever brings one which is moving to rest; and, as you must know by experience, bodies never either move, or stop moving, of their own free will. Something outside themselves starts their movement, or brings it to an end. This something is force. As with gravitation, however, so with every other force, it may be counteracted by an opposing force of equal strength. A book lying on a table cannot be brought to the ground by gravitation, because the downward force of the latter is counteracted by the supporting force of the table.

Some things fall faster than others, which would make us suppose gravitation has more power over them. Is this the case ?

In one sense, yes. Lead is more powerfully attracted towards the earth than paper; but that would only make it heavier to lift, and require a much stronger support to hold it up. It is from quite a different cause that a bullet falls faster than a piece of paper, for were they thrown into the air together, and the action of gravitation not interfered with, they would touch the earth at the same moment. What prevents this ?

It is the air. You would not have thought this possible, perhaps, for no doubt you are in the habit of thinking little of the strength of the air, and are surprised to hear it makes so much difference to the powerful force of gravitation; but you will not feel so astonished if you think how difficult it is to stand against a high wind, which is nothing but the air moving against you very hard, like the strong, swift current of a river. Even when the air is still it has a great deal of power, and if it were not always trying to hold things up, while gravitation is drawing them down, they would fall much faster than they do. The air can support some things much better than others, and you will easily see one reason why.

The greater the quantity of air which is able to get underneath anything, the stronger, of course, its support is. In a substance like lead, the molecules forming it are all so very close together that only a little air can get underneath, compared to the immense quantity of molecules it has to hold up, consequently its support is weak, and the lead falls fast, whereas in a substance like paper, whose molecules are not so densely packed, a great deal of air can get underneath, and so its support is strong, and the paper falls slowly. This is not, however, the only or the chief reason why the air is better able to support some things than others. You will find it in a later chapter, when explanations enabling you to understand it have been given.

We know now two things concerning gravitation. They are, firstly, its *work*, which consists in drawing all things down towards the earth; and, secondly, the unequal resistance it has to encounter from the air.

But I must mention two more equally important matters. The first is, that the force of gravitation is increased by the *mass* of the bodies between which it is exerted. Mass does not mean size. This you must already know; for though you might have a sheet of paper ten feet square, you would never think of calling it *massive;* yet you would feel the term to be rightly applied to a block of stone not a quarter so big. By the mass of a body we mean the quantity of matter contained in it; and since, the more matter there is, the more molecules there are for gravitation to act on, it follows that the more massive a body is, the more forcibly it can attract and be attracted, *i.e.*, the *heavier* it will be.

Lastly, the strength of gravitation varies with distance. The further a body is away from the earth, the less powerful is the attraction between the two; and the nearer a body is to the earth, the more powerful is the attraction. This variation of the force of gravitation is governed by a fixed law, which was discovered by Newton, and it is such, that if the distance between two bodies is doubled, the attraction between them is four times less; if trebled, nine times less, and so on. This law is expressed by saying that gravitation varies inversely as the square of the distance.

CHAPTER II.

GRAVITATION (*continued*).

Bodies kept in their right position by gravitation—Attractive force acts in a vertical direction—Centre of gravity—Line between centre of gravity and the earth must be inside the base—Two ways of supporting bodies—Tendency of centre of gravity to place itself as low as possible—Three states of equilibrium—Centre of gravity centre of weight—The balance.

In the last chapter I told you in a general way what the work of gravitation is; but there is still something for you to hear about it. As yet we have only said that things are *kept on the earth* by gravitation; but we must notice, besides, that when there, they are also kept in their right place and position. Think how awkward it would be if, instead of your feet only remaining on the ground, your whole body were obliged to be there; and if the tables and chairs were always lying on their sides, instead of standing upright as they are intended to! We are so much accustomed to seeing people and things in their right position, that it does not occur to us to ask how they are kept in it; but this is the question I am going to answer, and you must acknowledge, now I have reminded you of it, that it is a very important one.

There is a simple law laid down by gravitation, and all people and things who obey it are kept in their right place and position; but all that disobey it are left to go tumbling and sprawling about anyhow. This law I will try and explain. Though you know nothing about it, you are obeying it every day, as you do many other laws of the invisible powers of nature.

First I must tell you that the force of gravitation always attracts things to the earth in a vertical line. We know this, because if we let an object fall without throwing or pushing it in any direction, it moves towards the ground in a perfectly straight line; it does not bend or curve in any way in falling. Now, you remember, no doubt, my telling you that the way in which gravitation draws bodies to the earth (or to the *centre* of the earth, as it really is, for there the strongest force of attraction lies) is by attracting every molecule contained in them separately. Every body has one particular point connected with it called the CENTRE OF GRAVITY, through which the whole united strength of these separate attractions between its molecules and the earth passes, and at this special point the body is consequently drawn more forcibly towards the earth than at any other. Now, so long as the straight line between this point and the earth is inside that portion of the body which is its *base*, or supporting part, the body will not fall; but it falls at once if by any movement or change of position the line is thrown *outside* its base. The reason is, that as the centre of gravity is the point at which the body is drawn the most powerfully towards the earth, it is the point at which support is most necessary; and consequently, if the latter fails exactly where it is needed, only one thing can happen—the body must fall.

You, for instance, are supported by your feet, and as long as you stand in such a way that the line between your centre of gravity and the earth passes straight down between them, you can keep your balance, but directly this law is transgressed, down you must inevitably go. If you do not believe me, try to stand on your heels and lean your whole body backwards, and you will soon find you are very much in the wrong indeed!

What is true for your bodies is equally true for all others, only bodies with different shapes and in different positions require different kinds of supports. It will be quite enough for our purpose if I just tell you that if a body has only *one* support, the line between its centre of gravity and the earth must pass through that support; but if it has several, the line passes through the space contained between them.

You will easily see, I am sure, that the larger the base of a body is, compared to the rest of its bulk, the more steadily it will stand, because there will be so much less chance of the straight line between its centre of gravity and the earth being thrown outside that base. It is for this reason you feel so much safer when standing on two feet than on one, and that a flower vase with a wide foot is so much less likely to be upset than one with a narrow foot.

You can understand, too, why even a strong man may be knocked down if some one runs against him suddenly with great force. The blow causes him to stagger, and in doing so the line passing between his centre of gravity and the earth is thrown outside his feet, which are his base; and, consequently, unless by some instinctive movement he instantly recovers a position in which this line will again be *inside* his base, he must fall.

You will remind me, however, that I promised to tell you how this law about the centre of gravity is able, when properly obeyed, to keep things in their right position, as well as from actually falling.

One answer to this is, that the nearer the straight line between the centre of gravity and the earth is to the centre of the body's base, the steadier the body will be; and it will be steadiest of all when the line passes exactly through the *very* centre of the base. The reason is that, when this happens, the point which *needs* the most support (*i.e.* the centre of gravity) and the point which is able to *give* the most support (*i.e.* the central point of the base) are in a straight line *with each other*, as well as with the earth, and therefore the strongest support is under that part of the body which most requires it.

There is something else, however, which affects steadiness of balance, and, in order to explain it to you, I must remind you that there are two ways in which bodies can be supported—from underneath (as we have seen), and from above. The way in which a body can be supported from above is by being suspended or hung, as a chandelier is from the ceiling of a room, or a picture against its wall. Now, if any body, no matter of what shape or size, is freely hung, so that it is only supported from one point, and can consequently take up what position it chooses, it will at once prove the truth of what I have just told you about a body being best supported when its centre of gravity, and the central point of its support, are in a straight line with each other, by so placing itself that its centre of gravity will be exactly below the point from which it is hung. This is not all, however; it will also place itself in such a way as to bring its centre of gravity as low as possible.

On account of this tendency of the centre of gravity always, if possible, to make the body to which it belongs take up the position which will bring it nearest to the earth, there are three ways in which bodies can be balanced, or held in EQUILIBRIUM—equilibrium meaning even balance,—stable, unstable, and neutral.

A body is in STABLE EQUILIBRIUM when its shape or position is such, that its centre of gravity is rather low, and is consequently moved upwards when the body is shaken or tipped up a little. Directly the body is let go, it returns to its old place, in order that the centre of gravity may be brought back to its lower position. A chair is in stable equilibrium, so is a box or a plate standing on the floor or table.

A body is in UNSTABLE EQUILIBRIUM when its centre of gravity is rather high, because then any movement will be likely to place it in a position in which the centre of gravity would be lower; and, therefore, on being let go, the body will not return to its former position, but will take up some other, or perhaps fall down altogether if it is unsupported. A stick balanced on the finger is in this state, and you know how difficult it is to keep that from falling!

The NEUTRAL, or "anyhow" state of equilibrium, is that in which the shape and position of the body are such that, if it were moved, the centre of gravity would be neither lower nor higher, and therefore a change of position would make no difference to its steadiness or unsteadiness of balance. A ball or marble rolled about on the floor is in this state.

The place occupied by the centre of gravity in any body depends entirely on the shape of the body. It is always exactly in the centre of the *weight* of the body, and that is why it is called the centre of *gravity* or of *heaviness.* In a round object like a ball, which is of the same thickness and composition throughout, the centre of gravity is in the very middle, so that you would pass through it if you were to cut the ball in half. In a stick, thick at one end and thin at the other, on the contrary, the centre of gravity would be in or near the thick end, so that by cutting the stick into equally long halves, you would not pass through its centre of gravity as you did with the ball. If you want to accomplish this, you must carefully find out which is the exact point in the stick at which you could balance it across your finger or the back of a chair; then if you cut the stick in two at this point, you will have cut through its centre of gravity, because the two parts will be of precisely the same weight.

The use of the balance, by which we find out the weight of objects, is a practical application of the tendency of the centre of gravity to place itself as low as possible. When the two scale-pans of the balance are empty, or when equal weights are in each, the centre of gravity will be a little raised if the beam (*i.e.* the rod from which the scale-pans hang) be tilted, and therefore it returns to its original position again when it is let go. But if unequal weights are in the scale-pans, the position of the centre of gravity is altered, and moved towards the side of the heavy scale-pan, so that the beam cannot now recover its usual position till the weights are again made equal.

CHAPTER III.

MOLECULAR ATTRACTION.

Molecules and atoms do not touch—Held together by molecular attraction—Which is known by three names—Definition of cohesion—Of chemical affinity—Of adhesion—Universal attraction.

YOU remember, I hope, how, when speaking of gravitation, I told you that every single thing you could think of was made of thousands and thousands of little tiny pieces called molecules. Did it not strike you as very strange that all these numbers of molecules should be able to hold together as firmly and closely as they do in a bullet, for example, and never fall apart? You will think it more wonderful still when you hear that they do not even *touch* each other, but are separated by quite a considerable space, in comparison with their extreme smallness, which you know is such as to prevent their being seen even through the strongest magnifying glass; yet, small as these molecules are, even they are not made of one piece, but of two or sometimes more, which are called atoms, and which are never found alone, but always two or more together, making a molecule. A collection of molecules, as I have already told you, is called a BODY; and as the meaning of body is a thing made up of more or less different parts, it is quite appropriately used in this instance. The molecules are all the different parts of the body which they form. Now, all the molecules making the bodies, and all the atoms making the molecules, do not touch each other even in such hard, close substances as stone and iron, but remain only side by side. How can this be?

Think of gravitation, and the way in which it draws all things down to the earth by the power of attraction which exists between them. It is a force very like this which draws all these molecules towards each other. In fact, so like, that it is the same, only the name is different; it is MOLECULAR ATTRACTION.

Yes, and a very long name too, I hear you say. But only just think what an amount of work molecular attraction has to do, and you will allow the name is deserved. All molecules in the earth itself, and in all earthly bodies, are held together by this force, which carries on the same work throughout the whole universe. If it were to cease, even for an instant, the entire creation would fall to pieces and be utterly destroyed. As with gravitation, however, so with molecular attraction, we are going to confine our attention to what happens in our own sphere, and not even attempt to carry our observation beyond it. On earth, then, we know this force by three different names, which define the three different kinds of work it has to do.

The first of these is COHESION. It is by cohesion that molecules of the same kind are held together—molecules of iron to molecules of iron, molecules of wood to molecules of wood, and so on. In some bodies this force of cohesion is much stronger than in others, for the simple reason that in the one case cohesion has everything its own way, whereas in the other, it has to contend with all its might against a second great power which is trying to make the molecules fly away from each other, and about which you will hear a great deal later on. It is on account of the different strength which cohesion possesses in different bodies that we distinguish three states in which they can exist. Those in which cohesion is strongest, and which are consequently very close, firm substances, like iron and stone, we call SOLIDS. Those in which its strength is very much weakened, in fact, almost neutralized by the force it has to contend with, we call LIQUIDS, and you know well how easily *they* can be divided and scattered about. You have only to remember the last time you upset a jug of water, and saw its contents running freely all over the floor or table, to be fully convinced of this. The least touch will scatter a liquid in all directions; whereas if we do overturn a solid body, at least we can feel sure that it will not alter its shape, and that the whole of it will remain in one place—unless, indeed, it is made of china or glass, and is broken by the fall. The third kind of bodies we call GASES. In them cohesion is completely overcome, and consequently their molecules rush away from each other with all the speed they can muster, and, if they are confined within too narrow a space, will burst what contains them, sooner than remain in such close company. Air and steam are examples of gases.

The second name by which molecular attraction goes is CHEMICAL AFFINITY, and it is used when particles even smaller than molecules, and of different kinds, are drawn together. Such particles are called atoms. Sometimes we find molecular attraction doing both kinds of work in the same body at the same time. For instance, molecules of water are held to molecules of water by *cohesion;* but each of these molecules is made up of atoms, which are composed of two different kinds of gases, and they are held together by chemical affinity. We might almost compare this latter to friendship, which you know makes people who are quite unlike choose each other's society and companionship in preference to that of others; for just in this sort of way chemical affinity draws those atoms together which have something sympathetic, as it were, in their nature and composition. This sympathy or friendship of certain atoms for certain others leads to many curious and interesting results, and it is with them that the science of chemistry occupies itself; but as it does not so much concern the subjects which we are considering in this book, I shall say no more about it, and we will turn to the third name by which molecular attraction goes.

This is ADHESION, and is used to express the kind of attraction which goes on between the molecules of two bodies pressed together, or even in some cases allowed to touch—*i.e.* to be so close together that the distance between them cannot be seen; for under the rule of molecular attraction no one thing ever really touches any other thing, as I have already told you; they are only side by side, however near they may seem.

Adhesion can join solids to solids very strongly, as when two bullets are pressed very hard together, till at last they unite and make only one bullet, or as when we join pieces of wood with glue, or china with cement.

Adhesion can also join solids to liquids, though not nearly so strongly. If you have ever been in a room with iron bars before the windows, you may have noticed that after a heavy shower of rain, drops of water remain hanging to the bars, and though they look as if they would fall every minute, they often remain some time before they do so. It is adhesion which keeps them hanging to the bars.

This same adhesion can also join solids to gases, as you can tell when you see the inside of a glass bottle full of water, covered with little bubbles. They are bubbles made of the air which was left sticking to the sides of the bottle when the water was poured in and drove the rest of the air out; for though, I dare say, you are in the habit of looking on air as nothing, it is a very decided something, and wants room to itself just as much as water does, for which reason the two could not remain in the bottle together.

And now that I have told you something about molecular attraction, and the three different names it bears for the three different kinds of work it has to do, I will bring this chapter to a close. But first I want you to remember that really and truly it is the same force throughout, only acting in rather different ways; also that it is one and the same with gravitation; for as the work of molecular attraction is to draw molecules to each other, so it is the work of gravitation to draw bodies to the earth, and the earth and the planets towards each other and towards the sun, and the sun and the whole of the solar system (*i.e.* all the planets which move round the sun) towards some other centre never yet discovered, and round which probably all the systems of stars and planets which exist are revolving. So that you see gravitation and molecular attraction rule over the whole universe, and being as they are different actions of the same force, you will not be surprised to hear that they have a name which they share between them, viz. UNIVERSAL ATTRACTION; and that means the great ever-working power by which all atoms, all molecules and all bodies are constantly being drawn towards each other.

CHAPTER IV.

BODIES AND THEIR PROPERTIES.

Definition of "properties"—Of impenetrability—Of extension—Of divisibility—Of porosity—Physical and sensible pores—The filter—Compressibility—Elasticity—Difference between elasticity of solids and of liquids and gases—Inertia—Mobility—The use of friction.

THIS chapter has a curious title, "Bodies and their Properties." You know by this time, however, that by "bodies," I do not mean *human* bodies, but every separate collection of molecules; and since everything you see is such a collection, it follows that everything you see is a body, and some things you do not see as well.

But, now, can you tell me what a property is?

"Something which belongs to any person as his or her very own," you say.

Quite right; and nothing, you know, can be more completely our own than those qualities we have of mind and body, by which people know us, first of all, to be human beings, and then by which they distinguish us from each other. Well, it is about the qualities or properties by which we know bodies to be bodies, and by which we know one kind of body from another kind of body, that I am going to tell you; and we will begin by those which all three kinds of bodies—solids, liquids, and gases—possess in common, just as all human beings have arms and legs, and the power of laughing and crying.

The first of these general properties of bodies is such a very self-evident thing that I expect you will burst out laughing when I tell it you. It belongs to molecules and atoms as well as bodies, and it is that no two of any of these can be in one and the same place at one and the same time. You cannot fill a glass full of water and then full of wine, unless you first pour out the water; nor can you make two chairs, two tables, or two persons stand in the same place at the same moment. It is an unalterable law that two things must take up more room than one, and therefore they cannot occupy the same space at the same time. This very simple property is called IMPENETRABILITY, because no two atoms, molecules, or bodies can penetrate or get into each other in such a way as that they shall only take up the space of one.

But if it is true that two things cannot be in the same place at the same time, it is equally true that one thing can only take up a limited amount of room. You may roll up a large piece of wadding into a very small ball, and it will still take up some space; or you may spread it out to its full extent, but you cannot spread it *more* than that; neither can water, when allowed to flow freely about as it chooses, cover any amount of space; it will stop somewhere, however widely it spreads. Everything must take up some room, and nothing can take up more than a certain amount of room (even gases, though they seem able to fill an almost unlimited space, are subject to this law); and this property of one thing being only able to take up or *extend* over a certain space is called EXTENSION, and belongs equally to bodies, molecules, and atoms.

The third property is DIVISIBILITY, and belongs only to bodies and molecules. It is the power of being divided into parts. Perhaps you may never have noticed it, but this property of divisibility seems almost endless. Take a piece of paper and tear it into as small pieces as you like, and still there is no reason why they should not be made smaller. Or crumble a piece of bread between your fingers. What thousands and thousands of crumbs you soon get! Yet every one of these is perfectly capable of being divided again. Well, every body, however firm and solid, can be divided just like paper and bread, only the stronger it holds together, the more force is required to separate it into parts. Wood must be cut with a knife or chopped with a hatchet. Stone must be sawn, or broken with an axe or hammer; but it can be reduced to powder if it is hit hard enough and long enough. And all metals, too, can be divided, only they are so completely under the dominion of cohesion that we have to call in the aid of that opposing force to which I have referred before, but not explained, in order to liberate them. Often we cannot even see particles which have been divided from bodies, but they make their presence known in another way. No doubt you have often noticed that if a strong smelling flower or scent has been in the room, the smell will remain after what has caused it has been taken away. That is because tiny particles have remained behind, too small to see, but not to smell. In fact, all smells perceived at a distance are caused by these same invisible particles which are divided from the body giving out the scent, and floating in the air for a long way round it.

The fourth property of bodies you will think very curious, and it will help you to understand better what I have told you of the way they are composed. Have you ever heard of the pores in your skin—the little invisible holes through which the moisture of your body oozes out? You can see it sometimes when you are very hot, and you can see the pores also through a microscope. Well, all bodies, not yours only, have these little pores; but, unlike those in the skin, they are never seen, even through the strongest magnifying glass, for they are the little tiny spaces which lie between the molecules. Since they are thus invisible, I dare say you wonder how we know they exist. Exactly in the same way that we know there are pores in the skin; moisture oozes through to show us. If a piece of chalk is thrown into water, bubbles rise to the surface, caused by the air which was in the pores of the chalk being expelled by the entrance of the water; and not only chalk, but stone, iron, gold—in fact, all substances are porous, and some kinds of stone are very remarkably so. Perhaps you may have noticed on the stone-paved floor of a farm-house or cottage room, spots of damp, when the weather has been very wet, and if you ask the reason, the good woman will tell you that the stones are "heaving," or "sweating." She is quite right, too, for they are letting the moisture from the ground underneath ooze through them, just as the moisture of your body oozes through your skin.

Metals possess this property of POROSITY in a much less degree than chalk, wood, and many kinds of stone, and it often requires very great pressure applied to them, to enable the moisture of any liquid contained in them to ooze through at all; but metals are porous nevertheless, and it is only the extreme smallness of the pores, caused by the molecules being so closely held together by cohesion, which prevents moisture oozing through them easily. It is the fact of all bodies containing these pores which makes us certain that they must be made up of separate molecules in the way I have told you; for if there are spaces, there must of course be little pieces between which the spaces come, and these little pieces are the molecules.

Now, though the pores of which I have been speaking, and which are called PHYSICAL PORES, are never seen, there are others, called SENSIBLE PORES (*i.e.* pores which can be perceived by the senses), which are seen; only, then they are not little spaces between the molecules across which molecular attraction can act, but regular holes which put an end to its power,—for molecular attraction can only make itself felt when the spaces between the molecules are so small as to be completely invisible even with the microscope. Directly they are large enough to be seen the power of molecular attraction ceases. Sensible pores are found in sponge, pumicestone, and many other substances, and they are made use of in a very familiar way—I mean the filter. Filtered water is simply water which has been made to pass through some specially porous substance (such as felt) which lets the liquid run through it, but keeps back any little particles of solid matter floating about in it, and making it impure and unwholesome. In animals and plants sensible pores serve the useful purpose of letting moisture both in and out; plants also *breathe* through their pores.

After porosity comes a property which is caused by it—COMPRESSIBILITY, *i.e.* the power bodies possess of being squeezed up into a less space than they naturally occupy. This is of course done by pressing the molecules nearer to each other, and so making the spaces between them smaller. Some bodies are much more compressible than others. Gases possess this property to a very great extent, liquids very slightly, and solids more slightly still.

The next property is ELASTICITY, *i.e.* the power all bodies have of returning to their own shape, when they have been pressed out of it. I use the word "pressed" because it applies to solids, liquids, and gases alike. Only solid bodies can be pulled or bent out of their shape. I dare say you never thought that iron and steel were elastic at all; but they are. Have you never seen a marble dropped on a stone pavement bound off it again? And have you never read, in accounts of battles, of wounds being given by "spent balls"? These spent balls are cannon balls, which, when the force with which they were first sent flying out of the cannon begins to spend itself, touch the ground, but rebound off it again, and continue to hop along as if they were made of indiarubber for some time before they begin to roll and finally come to a standstill. Now, the same reason makes the indiarubber, the stone, and the iron balls rebound off the ground. When they strike against it, they get flattened where the contact takes place, and in the effort to return to their proper shape, they give a spring which carries them up into the air. Solids, however, though they are all elastic, cannot be made to alter their shape to any extent we please. If a certain point is passed, they either break, or cannot return to their original form again when left to themselves. This is not the case with liquids and gases. However much their shape is altered by pressure, they can always return to it again with the utmost ease; they are *perfectly* elastic.

And now I have told you about all the properties which belong to bodies in general, except two, which I need only just mention, and which belong to molecules and atoms as well, in fact (like impenetrability and extension), to every particle of matter in the universe—matter being that which we are able to perceive with our bodily senses. These two properties are INERTIA and MOBILITY. Inertia means that no body, if left entirely to itself, would ever begin to move; and mobility, that, under the same circumstances, if once set moving, it would never stop. Bodies never are left to themselves, however, there are so many mighty and invisible forces constantly at work about them. The name of the one which prevents their going on moving for ever when they have once started is FRICTION, or rubbing. Bodies in motion are always rubbing against something; if they are on the ground, they rub against that; if in water, against that; if in the air, against that. And this constant rubbing, which hinders the ease and quickness of their movement, ends by putting a stop to it altogether—*fortunately;* for if it were not for this useful force of friction, we should always feel as if we were walking on ice, and a thing once set in motion over the ground would never stop, but go on rolling as you see a glass marble do over a polished table.

CHAPTER V.

PROPERTIES OF SOLIDS.

Definition of solids—Elasticity of solids—Hardness.

Now, I am rather afraid you are beginning to think my explanations a little long, and are wishing I would tell you at once about those great Invisible Powers of which you are expecting to hear, instead of lingering over the properties of bodies; but you must be patient for a little while. You see, these bodies are subjects of the great empire ruled over by the natural forces, and unless you know something about them, you will not understand all the wonderful things I hope to tell you further on. I will promise, however, to make my explanations as short as possible, and I think you will find some of them more curious and interesting than you expect.

We have already seen what are the properties which all bodies—solids, liquids, and gases—share alike; and now we must speak of those properties by which we distinguish these three different kinds of bodies from each other.

First come the solids. By a SOLID is meant something which will not alter its size or shape without a great deal of difficulty. There are certainly some soft solid bodies of which this cannot be said; but they are not *perfect* solids. A perfect solid is a thing like stone or iron, and you know what a great deal of strength is required to make *them* change size and shape. It seems almost impossible, but it is not so really, or you would not see so very many articles in constant use made of metal and stone, all differently and artificially shaped. Stone can be cut and sawn, as you know, and we shall find out by-and-by how the shape of metals is altered.

There are other properties of solids besides this one of keeping their size and shape, but they all, except one, which will be mentioned presently, are connected with the three different kinds of elasticity possessed by solid bodies, which are called into play either by *pulling, twisting,* or *bending,* and I hardly think you would care to listen to an explanation of these yet—though some day I hope you will. You can understand, however, that many things which you consider very elastic, are, from one point of view, much less elastic than others which, at first sight, do not appear elastic at all. It requires very little strength to make gutta percha change its shape, therefore it is not wonderful it should easily return to it again. With many solid bodies, on the contrary, and especially with nearly all metals, it requires very great strength to make them change their shape even a little; and yet they always return to it again if they have not been pulled, bent, or twisted beyond the limit or ending point of their elasticity. Therefore the strength of that elasticity must be very great, for it is equal to that which was able to change the shape of the body in the first instance; and this will make you understand how it is that iron, for example, possesses a far greater strength or power or FORCE OF ELASTICITY, to enable it to return to the same shape again, than gutta percha, whose shape is so much more easily altered to begin with. For the same reason gases, which from their enormous capability of compression and expansion have been called ELASTIC FLUIDS, possess less force of elasticity than most solids.

The only property of solids which is not connected with their elasticity is HARDNESS, and it means the amount of resistance one solid body offers to being scratched or worn away by others. A diamond is the hardest of all things, for it can scratch everything, and nothing can scratch it except another diamond, which fact has caused the saying, "Diamond cut diamond." Wood, though it is hard to the touch, is not so really, for it can be scratched and worn away easily; a mouse's teeth are strong enough to get through it, as we all know. Some kinds of stone, too, are much softer than others. Granite is the hardest of all; pumice stone, on the contrary, is very soft, so is Bath stone, until it has been exposed some time to the air, when it hardens.

CHAPTER VI.

PROPERTIES OF LIQUIDS.

Liquids keep their size—Slightly compressible—Can communicate pressure—Such pressure equally transmitted in all directions —Bramah press—Buoyancy of liquids—Weighing in water—Specific gravity—Liquids find their level—Capillarity.

THE first thing to notice about liquids is that they KEEP THEIR SIZE—not their shape, for, as we have already seen, there is no kind of jug or basin, however odd its form may be, that water will not fill quite easily, adapting its shape at once to all the peculiarities of what holds it.

It is quite different with regard to size. You know nothing will induce a pint of water to go into a half-pint tumbler, or make a tea-cup hold as much milk as a breakfast-cup. In fact, liquids can be compressed only so slightly, and with such great difficulty, that for a long time they were not supposed to be compressible at all. Now, however, we know that they are, though to an almost imperceptible degree.

It will interest you, perhaps, to hear that it was owing to this obstinacy of liquids in keeping their size that the porosity of metals was first found out.

To discover if liquids were compressible, a hollow golden ball was filled with water, and was then subjected all over its surface to a very strong, equal pressure. If any part of the golden ball had bent in, that would have shown that the water had been squeezed into a smaller compass. Instead of this, however, the golden ball remained exactly the same in shape and size, but drops of moisture appeared outside it like dew. Rather than be compressed, the water had oozed through the tiny pores of the gold.*

The next special property of liquids is that they can COMMUNICATE PRESSURE; that is, if a liquid—water, for example—is pressed down in one part of its surface, it will press upwards and outwards in every other part, and the harder it is pressed down the harder it will press up and out.

This pressure is not only communicated through the whole body of liquid in which it takes place, but it is also *equally* communicated. It is not

* This experiment was made in Florence, in 1661. More than twenty years before, however, Francis Bacon obtained the same result with lead; and since then experiments have been made on the other metals.

stronger in one part, and less strong in another, but exactly the same everywhere. Even though only a very small part of the surface (say a square inch) were pressed down in the first instance, and there were left as many as 100 or 1000 square inches for the upward and outward pressure to act on, all this comparatively immense surface would be pressed up and out with the same strength as that with which the one square inch had been pressed down.

Hitherto I have been speaking of what takes place when the pressure is able to act in all directions; but, if we choose, we can prevent this by placing the liquid (water, let us say) in a closed vessel, with only two outlets. It will then, of course, not be able to move up or out at any other part of its surface, except just where these outlets are placed. If they are closed by movable vertical plugs, or *pistons,* of the same size and weight, and we push one a little down, the other is instantly pushed up exactly as much as the first has been lowered. It has been acted on by all the pressure there is room for the water to exert, and if we replace one of these pistons by another, having a surface twice, three times, or ten times as large, we shall still find that it will rise as high as the small piston has been pushed down, and this even if it has a weight on it. It is important to know, however, how great a weight the large piston can raise, and we will therefore suppose that we have a small piston with a surface one inch square, and a large piston with a surface ten inches square. If on the small piston we place a weight of one pound, it will press down one square inch of water with the force of one pound, and this will cause an upward pressure to take place under the large piston of one pound to each square inch of its ten square inches of surface. Therefore the large piston will be able to raise a weight of ten pounds, and if it had a surface of one hundred inches, it would be able to raise a weight of one hundred pounds. In fact, for every square inch of surface added to the large piston it will be able to raise an extra pound, because the water will have another square inch on which to exert its upward pressure of a pound's force.

If, instead of the two pistons being vertical, one of them is horizontal, on pushing the latter inwards, the vertical piston is raised; or if we commence by pushing the latter down, the horizontal piston is driven outwards, showing us clearly that the pressure is communicated in every direction, though it may only be able to produce a visible effect in one.

This property of liquids is very useful, for by means of it we are able to lift up exceedingly heavy weights, and to use an immense pressing or squeezing force through the action of a machine made exactly on the principle of the closed vessel full of water, with two vertical pistons, such as I have just described. This machine is called a BRAMAH PRESS, from the name of the man who invented it. Its small piston may be made so as to bear a ton weight, and then, if the large piston is given a surface one hundred times that of the small piston, when the latter is pushed down the former will either be able to raise a weight of one hundred tons, or to press against bales of wool or cotton with the force of one hundred tons, and they then get packed pretty tightly.

The next thing I have to tell you is what causes the BUOYANCY or supporting power of liquids. If you have ever bathed in the sea, or in a river where the water is deep, you will know something about this supporting power. In deep water it is quite difficult to keep on your feet. And, in the same way, if you plunge your hand into a bucket full of water, it requires a decided effort of strength to get to the bottom, the water supports your hand so much.

Our old friend gravitation is the cause of this. It draws liquids downwards just as it draws everything else, and where the water is contained in something which prevents its getting any lower, such as a jug, a bucket, or the bed of a river or pond, the under layers of water are pressed down by those above them, which feel the action of gravitation, but can get no lower because they are supported by the water underneath. But I have already told you that if water is pressed down in any part of its surface, it presses up and out in every other part. Well, the *whole* surface of the upper layers of water is pressed by gravitation against the *whole* surface of the under layers, and weighs them down. The outward pressure caused by this cannot take effect, for the sides of the vessel or the banks of the pond or river prevent the water from spreading; therefore the whole strength of the pressure takes effect upwards, and is equal to that with which the water is being pressed down; and so we have in a body of still water two distinct and exactly opposite pressures always going on, one down and one up, and it is the upward pressure which causes the buoyancy of the water. Now, of course, as you know, there are other liquids besides water, and the denser any of these are—the heavier they are, and, therefore, the greater will be the downward pressure caused, and, consequently, the greater the upward pressure also, and the more buoyant, or strong to support, the liquid.

In other words, the *heavier* a liquid is, the more buoyant it will be. Mercury, or quicksilver, allows iron to float on its surface; but without going so far as that, different kinds of water show very different degrees of buoyancy. Sea-water, owing to the salt it contains, is far denser and more buoyant than fresh water; and the water of the Dead Sea, in Palestine, possesses this property to such a remarkable extent that a man could not sink in it.

You will easily see one thing which must happen in consequence of the supporting power of liquids. It is, that a body when in them, must lose some of its weight, or rather, must appear to do so, because it is being supported by them; just as, if you are holding something heavy in your hand, you do not feel its weight if you rest your hand on a table, in the same way in which you would if you held your hand up in the air, though the weight of the thing itself has not really altered.

Generally speaking, bodies are weighed in air; and you know, of course, what a balance is like—an upright rod of iron or brass, with another placed crosswise near the top, from the ends of which hang two scale-pans exactly balancing each other when empty. Into one you put whatever you want to weigh, in the other, pound or ounce weights, till the two scale-pans are exactly equal again. With a very small alteration, just to enable what you want to weigh, to hang from underneath the scale-pan, instead of lying in it, the same balance will do for weighing in water. The substance to be weighed being hooked on to one scale-pan underneath, is allowed to sink quite into a vessel of water. Then weights must be put into the other scale-pan till both are equally balanced, and you will find the substance is lighter than if it had been weighed in air.

The amount of weight which a body loses when weighed in water is always the same as the weight of the water it displaces. Now, the displaced water would, if it could be made solid, be seen to be of exactly the same size and shape as the body which displaces it. It is said to be of the same volume as that body. You know, however, that two things which are exactly the same size and shape are not by any means always exactly, or even nearly the same weight. And we may therefore put a body into water and find that the displaced water is either lighter, heavier, or the same weight as the body itself. If it is heavier, the body floats ; because, as it is not strong enough to displace *more* than its own weight of water, water remains underneath it, and forces it upwards. If the displaced water is lighter than the body, the latter sinks, because, not having all its weight taken away, gravitation can still draw it downwards. If the displaced water and the body are the same weight, the body neither sinks nor floats, but remains just under the surface, where it can be pushed about in any direction, like a thing actually without weight. This weighing in water is made use of to find out whether metals are pure (*i.e.* unmixed with any other substance) or not. By first weighing a piece of metal in air, and then in water, we see exactly how much weight it loses in the latter. As another metal would lose either more or less weight, if what we think to be pure gold, for instance, loses more weight than it ought, we know it is not pure, but mixed with something else, for gold is the heaviest of all metals except platinum.

This way of discovering the purity of metals has been known more than two thousand years. A philosopher, named Archimedes, was then asked by his king whether a crown sent by the goldsmith was of pure gold. After puzzling for a long time, it is said that one day, when Archimedes was in his bath, the idea of weighing in water struck him, and he was so pleased that he rushed into the streets just as he was, shouting, "Eureka! Eureka! I have found it out! I have found it out!" The crown was weighed, and discovered not to be of pure gold; and weighing in water has been in use ever since. The amount which any substance weighs more than the weight of its own volume of water is called its SPECIFIC GRAVITY, because each special substance loses its own special proportion of weight in water, which is different to the proportion lost by any other substance. Thus a piece of gold, of whatever size or shape, will always lose one-nineteenth of its weight in water. Therefore we say that the specific gravity of gold is nineteen, because it weighs nineteen times its own volume of water.

There are two other properties of liquids which need mention. The first is the power all liquids have of FINDING THEIR LEVEL, *i.e.* of placing themselves so as to have a flat and even surface. You know that you never see still water with a slanting surface. And if you were filling with water a flower vase which had, springing from the same bottom and opening into one another, differently shaped stems and cups, reaching to different heights (such as you often see in drawing-rooms), you would find that you could only fill any of them up to the height to which you are able to fill the lowest. If you try to go on pouring after that, the water will overflow from the lowest stem, instead of continuing to fill the high ones, because water cannot rise above its own level. This property of liquids always to have a perfectly level surface is of great use to engineers, to whom it is often very important to know what points along the earth's surface are exactly of the same height above it. If they could not discover this, our roads would be very uneven.

Now, if they can manage to look along a line of still water, or of any liquid, they know that all the points they see along this line are perfectly level, and by means of two simple little instruments—the *water-level* and the *spirit-level*—an engineer is able to carry about the means of testing the evenness of the surface of the ground in this very manner.

I said just now that liquids could not rise above their own level. There is one way, however, by which they do so, viz. through CAPILLARITY, the last property of liquids which I shall mention. Its name comes from *capillus*, the Latin for "hair," and is given because this quality of liquids is best seen when they are made to touch hairy or fibrous substances, such as cotton and linen. If you dip the corner of a towel or handkerchief into water, the water rises into it, and wets quite a large piece; and the longer it remains in the water, the more of the towel will get wet, because the latter draws the water so powerfully towards it that gravitation is overcome, and the water rises in spite of it. Sugar, sand, sponge, glass, wood, and many other substances act on water in the same way, and it is partly by capillarity that plants are able to draw moisture from the ground, and that the sap which nourishes them rises and spreads into their stems and branches.

All liquids are drawn by capillary attraction towards some substances, but not towards the same. For instance, mercury will not only not rise into a handkerchief or a sponge, but it will not even wet them; yet it will wet gold, and even remain sticking to its surface, because the gold attracts it.

CHAPTER VII.

PROPERTIES OF GASES.

Invisibility of gases—Great power of expansion—Compressibility —They possess weight—Exert pressure—The atmosphere—Buoyancy of the air—Torricelli's experiment—Weight of the air—It varies—The barometer—Pressure of the air can raise water—The pump.

I HAVE now to tell you about the properties of GASES. Some they share with liquids, but in others these two kinds of bodies are very different indeed.

As a rule, you cannot see gases, properly so called. *Vapours,* which are liquids made into gases for the time, can be seen sometimes, but only when they have tiny little drops of liquid as fine as dust mixed with them. You can see steam coming from a kettle, but you cannot see air, though you can feel it, and thus know that it is a real thing.

The great distinguishing property of gases is their power of EXPANSION—that is, getting bigger and bigger, through their molecules separating further and further apart—to almost any extent. Now, a liquid cannot do this. If you fill a bottle half full of water, the other half will be full of air—for you may take it as a fixed rule that any space not filled by something else is filled by air, if the latter can by any means get to it; if, however, you take out the air—which can be done by means of an air pump—and close the top of the bottle, so that no more air can get in, there will be nothing left in one half of the bottle; yet you will not see the water expand and fill this empty space. The case would be very different if you were to take out the water, and leave the bottle half full of air; the latter would instantly fill the whole bottle, for gases—and we take air as an example of them all—not only can expand to any extent, but their inclination is always to do so directly they have an opportunity. Therefore, if anywhere there is a perfectly empty space, and a small amount of air is let into it, that small amount instantly expands so as to fill the whole space.

Gases seem as if they had no notion of leaving room for their neighbours as liquids and solids have; they are much the most selfish of the three kinds of bodies—at least, so it seems at first sight; but, on further consideration, we may feel inclined to change our minds; for liquids and solids, though they do not begin by taking up so much room as gases, are very much less accommodating about giving up what they have once got and consider as their own by right! Air fills a whole room; and yet if you shut up this room so tight that no air can escape, it will make no difficulty about squeezing itself to this side and that, so as to allow you to put in as many pieces of furniture along with it as you please. But only think what a fuss there would be if the room were filled with water instead of air! It would be quite as much, and probably more than you could do to squeeze in a carpet as thin as a newspaper; and as to a bed or a sofa, the thing would be impossible unless you let out some water first. You see, we must not judge by appearances, for the apparently selfish gases are not selfish at all really. They take up a very large amount of space if it is not wanted by something else, but if it is they are quite ready to give it up. The fact is that, as I have already told you, gases are the most compressible of all bodies, and this is quite as much a distinguishing property of theirs as the power of expansion.

The same amount of pressure which will make a body of water one two hundred thousandth part of an inch smaller, will make a body of common air of the same volume one half smaller. Compressed gases, however, are always trying to escape from their bondage if they possibly can, and the pressure they exert against whatever contains them is so great that they often burst it, and rush out with tremendous force. This is what occasions explosions in coal mines. The coal gas has perhaps been imprisoned for years in a hole in the coal seam, and then a stroke of the miner's axe, or else the enormous outward pressure of the gas itself, suddenly sets it free. It rushes out, sometimes filling half the mine, and the unfortunate workmen are either suffocated, if the gas is of the kind they call "choke damp," or burned alive if it is "fire damp," which ignites immediately it comes in contact with the least spark of fire.

The next thing to be noticed about gases is that they have weight—or, in other words, they, like solids and liquids, are under the power of gravitation, and are drawn by it towards the earth. If this were not the case, the whole body of air which surrounds our earth would rush away and vanish into space, and we should have no air left to breathe; but as it is, gravitation holds that down in its place for us, as it does everything else.

Owing, however, to the constant tendency of the molecules of gases to separate from each other as far as possible, gravitation has less power over them than it has over solids and liquids, which cohesion keeps together; and, consequently, gases are much lighter than the other two kinds of bodies. One hundred cubic inches of air (a cubic inch is an inch high, an inch wide, and an inch thick) weigh thirty-one grains. The same amount of water would weigh over four pounds, for water is seven hundred and seventy times as heavy as air.

Gases, like liquids, exert pressure, and the whole body of air which surrounds our earth—the *atmosphere*, as we call it—presses upon its surface, just as the water of the ocean presses upon its bed. This being the case, you will wonder how it is we do not feel the weight of the air, which of course is pressing heavily upon us who live at the bottom of the air-sea. The reason is that the pressure of air, like that of water, acts with equal strength in all directions, so that you have not only a column of air pressing you downwards, but air all round and underneath you, the pressure of which holds you up and supports you.

Now, you remember, I hope, my telling you that, owing to the downward pressure caused by gravitation in water, an upward pressure takes place, which makes water buoyant or supporting, and causes things plunged in it to lose some of their weight. Exactly the same thing happens with air. It also has a downward and an upward pressure, and is therefore buoyant, causing all things plunged in it to lose as much weight as the weight of the air they displace; just as things plunged in water lose as much weight as the weight of the water they displace. If you throw a thing into the air which is heavier than the air it displaces, it will fall, or *sink*, in the air-sea, and the greater its weight compared to that of the displaced air, the faster it will sink. If the object is lighter than the air it displaces, it rises as air balloons do; if both are of the same weight, the object neither falls nor rises, but floats about at the mercy of every current of air. This is exactly what happens to balloons when they have risen a certain distance from the earth's surface; for then the molecules of air are less closely pressed together, and the air is consequently lighter, so the balloon, instead of continuing to have less weight than the air, has the same—*i.e.* apparently no weight at all —and is driven here and there by every changing wind. If this difficulty could be overcome, people would be able to guide balloons about as they like, which they cannot do now, and then I dare say you would often have a journey in one.

I have been explaining to you about the pressure of the air, but you do not yet know exactly how strong this pressure is, and the best way to tell you will be by describing an experiment which was first made in 1643, by Torricelli, a pupil of Galileo.

You must imagine a hollow glass tube, thirty-six inches long, and filled *quite full* with mercury, one end being open and one closed. The experimenter places his thumb on the open end of the tube, which he turns upside down, and places in an uncovered basin also containing mercury, being careful not to move his thumb till the open end of the tube is well underneath the mercury in the basin, that no air may get in. Then he takes away his thumb, and with the other hand holds the tube upright in the basin of mercury, not allowing it to touch the bottom.

And now what happens? You would expect—wouldn't you?—to see the tube remaining quite full of mercury, as it was when it was put into the basin. But no; instead of this the mercury sinks down till it is only thirty inches above the level of the mercury in the basin; and if the tube were forty or fifty inches high, instead of thirty-six, or even a hundred, the same thing would happen—the mercury would still sink till it was only thirty inches above the level of that in the basin.

Now, why is this? There is no air *in the tube* to press down the mercury, nor can any get in, for the top of the tube is closed; but we know that there is air pressing on the mercury *in the basin*, and forcing it up into the tube; and therefore it ought to rise into the tube till the vacant space at the top is filled.

This is what it would do if it could; but it cannot, for the fact is that all the pressure the air can use is required to keep the mercury at the height of thirty inches. It has not strength to do more, and that is why the mercury in the tube sank down when it was placed in the mercury in the basin. Yet, if you think a minute, you will see that the pressure of the air must be very strong to hold up a column of mercury thirty inches high, for mercury is thirteen and a half times heavier than water. There is nothing else to keep it up, for the bottom of the tube is open, and if it were not for the pressure of the air on the mercury *outside* the tube, forcing up the mercury *inside* the tube, the latter would at once sink to the same level as the mercury in the basin. When the height of thirty inches is once reached, however, the pressure of the air which is pushing the mercury up, and the downward pressure of the mercury itself exactly balance each other, so the latter cannot move either way. But now, as two things which exactly balance each other must be the same weight, it follows that the weight of the column of mercury, thirty inches high, and the weight of the air whose place it has taken must be the same. Supposing the interior of the tube to be one inch square, this weight is fifteen pounds. Therefore on every square inch of the earth's surface there is pressing a weight of fifteen pounds.

After this explanation, which I am afraid you find rather difficult, I will tell you something which will astonish you, though, if you have understood what you have just read, you ought to be prepared for it. It is that the pressure of air which each one of your bodies is supporting is equal to a weight of eight or nine tons, or perhaps more if you are big and tall! A grown up man of about middle height is being pressed upon with a weight equal to sixteen tons! And now you see what a very fortunate thing it is that the air presses equally in all directions, for if it did not, and you had to carry about a load of so many tons weight on your heads, I don't think you would walk very far! As it is, this great weight helps to support you with as much strength as it bears you down, and therefore you don't feel it at all.

I dare say, though, you wonder it does not crush you into a shapeless lump; and, indeed, it does seem strange at first sight; but really and truly our bodies are so strongly made that they would be able to bear even a much greater pressure than they do without being crushed; besides which the pores of our bodies are full of air, which tends to press or blow us out with exactly the same strength as that with which we are being pressed in.

And now we must go back to our basin of mercury, and our tube with the column of mercury thirty inches high, for I have something more to tell you about the latter.

You will easily understand, I am sure, after all I have said, that the column of mercury in the tube will only remain fixed at the height of thirty inches as long as its own pressure and the pressure of the air are exactly balanced. If the air were to become suddenly lighter, it would not continue to support the mercury at thirty inches. The mercury would again sink till its own weight and that of the air were once more even.

If, on the contrary, the air were to become heavier, it would be able to support a column of more than thirty inches. Now, changes in the weight of the air do actually take place, and it is owing to them we are able to make observations about the weather by the *barometer*, which is made on the very principle of the glass tube and the basin of mercury I have just explained to you. According to whether the air is heavier or lighter—and, therefore, the pressure on the mercury in the basin or *cistern* of the barometer stronger or less strong—the mercury in the tube rises or falls; and, by noticing the changes which follow in the weather upon changes in the barometer, we can foretell by its means what weather we are likely to have. In the same way the barometer is used by scientific men to find out the exact weight of the air at any particular height above the surface of the earth, or rather above the level of the sea, for that is the point from which such measurements always start. One thing you, yourselves, could, I am sure, tell me now about the barometer, viz., that the higher up we go from the earth's surface, the lower the mercury will fall, the reason being that the pressure of the air is less because we are nearer to the top of our air-sea—for our atmosphere does not extend away into space for ever; it comes to an end at a certain distance from the earth's surface, and, therefore, the higher we rise in it (as when we go up a mountain or in a balloon), the weaker its pressure becomes—just as you know the pressure of water is much less near the surface of a pond or a bucket, than near the bottom.

You must not think from what I have said that every barometer is exactly like the one I have explained to you. There are other kinds; and though they are all made so as to be acted on by the weight of the air, it is not necessary that mercury should be always used. In fact, there are some barometers which are made without any liquid whatever. The *aneroid* is one of these, and as it is extremely accurate, and very sensitive to any difference in the pressure of the air, it is coming more and more into use. The barometer I have described to you, however, was the first invented, and was in use a long time before any other kind; and it is still very often seen.

This is enough about the barometer; but I want you, nevertheless, to think once more of our tube and its column of mercury thirty inches high. As I have already told you, mercury is very heavy indeed—in fact, the heaviest of all liquids; and you will easily understand that the same amount of pressure which raises mercury to the height of thirty inches would raise a lighter liquid very much higher. If, therefore, you can imagine Torricelli's experiment being tried with water, instead of with mercury, you would require to have a tube more than ten yards high instead of one; for the pressure of the air is able to raise water to the height of ten yards, or thirty feet. There it comes to a standstill, just as the mercury does at thirty inches, for the contrary pressures of the air and the water exactly balance each other, and so the water cannot move either way.

This power which the pressure of the air has to raise water is made very useful in the pump, and I will try and give you some idea how it is done.

Looking back upon the barometer, you will remember that if the upper end of the tube is not closed, no mercury will rise into it from the cistern, because the pressure of the air is acting inside as well as outside the tube. If we want the mercury to rise, the first thing we must do is to expel the air from the tube, and close it at the top, so that the pressure of the air may only be felt on the mercury outside; then we shall at once see the tube fill up to the height of thirty inches. Now, exactly the same remarks apply to water. If we want to raise it out of the earth by means of a pump, that pump must first consist of a hollow tube open at the bottom, and sunk below the surface of the water in the well. Then we must drive out the air in the tube and close it at the top, so that the water may rise into the empty space; and finally, we must make an arrangement by which the water can get into the barrel of the pump (which is the part you see), and out by the spout.

All this is done by very simple contrivances, which you will find fully explained in every elementary book on physical science. I will not, therefore, tell you more about them here, as this is already a long chapter, and contains as it is more than one explanation which you may have found rather difficult to understand clearly. I hope, however, that you have not been tempted to miss it, for if you have, you will not be able to understand many things told later on.

CHAPTER VIII.

HEAT.

What heat is—Two classes of motion—Vibration—Heat vibration—It spreads—Circular waves of water—Of ether—Radiation—Heat communicated by conduction—Conducting power of solids—Of liquids—Of gases—Convection—The trade winds—All substances contain heat—Touch no test of temperature.

AND now, at last, we have come to another of the Invisible Powers of Nature—those powers which are present everywhere, yet never seen; which are beyond our understanding, yet some of which we can control and make our servants. Though we men and women pass away, and change, and die, they are always the same; they never grow old, or weak, or tired, nor ever will as long as God continues to uphold this mighty universe which He has made. The name of the invisible power I am going to tell you of to-day is HEAT, and before I can describe the work done by it I must try and explain its nature.

You know what *being* hot is, don't you? and you know the sort of things that *make* you hot. Running about is one thing that does so, jumping is another. But these two actions are not heat; they only make you feel that which we call heat. In the same way, the sun is not heat, and a fire is not heat. They make you *feel* heat, but they are not the actual thing itself.

What is this actual thing, then? What is heat? You cannot tell me, I know, so I must tell you. Heat is a kind of motion, of which I must try and give you a clear idea.

Motion can be classed under two heads. There is the motion which causes the thing which moves to change its place, as you do when you are running; and there is the motion which, however strong or quick, does *not* cause any change of place.

When a top is spinning, it does not change its place, though it goes round very fast.

Now, it is a kind of motion not causing change of place which is the motion of heat in bodies able, like the sun or a fire, to give out heat. All round the body there is an onward movement happening, which I shall describe to you presently, and which is caused by the motion going on in the body itself, but that does not make it change its place. You do not see a fire trotting round the room when it is lighted, in order to make the room warm, nor a lamp walking about on the table. Yet both these things are hot, and are therefore moving, since heat is motion. The kind of motion they have is called VIBRATION. Vibration is *swaying*, and can take place either up and down, or backwards and forwards. In the vibration caused by heat, it takes place up and down, and very fast—so fast that the vibration becomes a kind of quivering. A heated body, whether it is a burning coal, a lamp, or the sun, is quivering all through. Every one of its little molecules is vibrating with a strong, quick motion, and the hotter the body is the quicker the molecules move. But this is a movement which takes place altogether *inside* the body. You do not see the latter change its place either up or down, backwards or forwards. It remains just where it is, and the only thing that happens to it is, that as it grows hotter, it grows *larger*. On this point I shall have a good deal more to tell you by-and-by; but for the present we must keep to the motion of heat, *i.e.* to heat itself, and not to its work.

You understand, then, that a heated body is one whose molecules are all vibrating very fast indeed; and it is not so selfish as to keep this heat-motion to itself, as you know quite well, for if you put your hand near a lamp it feels hot directly, and when a fire is lighted it will soon warm a whole room. The reason is that the heated body causes the motion which is going on in itself to spread to all that surrounds it.

"But how?"

Ah! if you want to know that, you must have a little patience, and be willing to listen to an explanation. If you *will* listen to it, it will reward you, I am sure.

To begin with, you must transport yourselves, in imagination, away from heat and books, to the banks of a pond whose waters are perfectly still and smooth, and think you see some one take up a stone and throw it right into the middle. What will happen? "There will be a great splash" you say. Of course there will be a great splash; but what besides? When that is over, will the pond be quite calm and quiet again? No; for you see that, beginning from the place where the stone fell in, there are circles of ripples, each one larger round than the one before it, which go on spreading and spreading till, if the pond is not too large, they will cover its whole surface. These ripples are circular waves caused by the disturbance the stone produced amongst the quiet molecules of water when it fell in. It set them, or some of them, rather, vibrating up and down; these, again, made all those near them vibrate up and down, and so the motion went on spreading as we have seen.*

Well, a heated body makes a disturbance, just as a stone falling into water makes a disturbance, and causes circular waves to spread round it just in the same way. "But what does it make a disturbance in?" The stone disturbed the water, and the ripples it caused were made of water; but what does a heated body disturb, and what are the ripples it causes made of?

It disturbs something which has never been seen or heard, and yet which scientific men feel sure exists, because only through its existence can some of the most wonderful things in nature be explained and understood. This something, which is far lighter and more impalpable than air or any gas, but with which all space and all bodies are surrounded and filled, is called ETHER.

When a body is heated, and its molecules are all

* See p. 102, description of wave-movement.

vibrating with the heat-motion, it is just as if a stone had been thrown into the sea of ether; wave after wave goes forth, spreading and spreading, and communicating the motion of heat, and therefore heat itself, on all sides till the body begins to cool. Then gradually the waves die away, till, when the body has quite cooled, they cease altogether. There is no more motion, and there is no more heat.

All bodies which give forth heat do it in this way, by waves sent forth from them in circles, and this without changing the temperature or hotness of the air which surrounds them; for if you are sitting with your back to the fire, and find its heat disagreeable to you, as many people do, you will cease to feel it, if a screen is placed between you and the fire. Now, this would not be the case if the fire had made the air itself so hot as to be unpleasant to you, because then the fire being still there, and still continuing to heat the air which fills the whole room, the screen could make no difference. The reason why it does, is that it turns back the waves of ether which strike against the side of it nearest the fire. Therefore on the other side the ether is comparatively still, and there is much less heat.*

* See p. 107, Interference.

This way bodies have of giving forth heat without increasing the temperature of the surrounding air, *i.e.* without making it hotter, is called RADIATION. Radiation is the power of giving forth rays, and we can speak of a ray of heat just as we can of a ray of light; in fact, some rays of heat are rays of light, as you will see when we come to speak of light. Now, do you not think heat is a very wonderful thing? We might almost say it gives life, for the power of motion is a sign of life, and it is this very power which it gives.

I must not let you suppose, however, that radiation is the only way by which a heated body can part with its heat to another. It is the only way it can do so from a distance, but not when it is actually able to touch other bodies. If you put a poker into the fire, not only the end actually in the fire will become hot, but the heat will gradually find its way all along the poker, till, if you leave it long enough, the handle will be too hot for you to touch. In the same way, if you have very cold hands, and a person with warm hands takes yours and holds them, they will become warmer. Heat given in this way is said to be CONDUCTED, *i.e.* led as it were from one body to another.

Solids are mostly very good conductors of heat, metals especially so. Some substances are very bad conductors, however. Of these we may name wool and fur; and that is why they are used for winter clothing. Being bad conductors of heat, they keep that which your body gives forth from escaping into the open air, and therefore the heat you make you are able to keep for your own use and comfort. For the very same reason, however (that they are bad conductors of heat), woollen materials will keep ice from melting in summer, because they prevent the warmth of the outer air from getting to it.

Liquids have far less power of conducting heat than solids. An instance of this is the Gulf Stream, which you know is a hot stream of water rising in the Gulf of Mexico, and flowing thousands of miles through the ocean, losing its heat only very gradually. Even when it reaches the shores of Britain it still retains enough heat to make quite a difference to our climate.

Now if water could conduct heat easily, this would not be the case, for the Gulf Stream would then at once part with its heat to the cold waters of the ocean surrounding it, and before it had gone far would be no hotter than they are, for it would have given all its heat away.

Gases are even worse conductors of heat than liquids, and, in fact, it was supposed for a long time that they were not conductors at all. It has been discovered now, however, that they do possess this power in an extremely small degree.

Since liquids and gases are heated neither by radiation nor conduction, you will wonder, I am sure, how they are heated. It is by a third process, called convection, and you can understand it very easily.

I have already told you that when a body is heated it expands. When you place a kettle of water on the fire, the heat coming from underneath heats the lowest molecules of water first; they expand, grow lighter, and rise to the top; while the cold, heavy molecules sink to the bottom to get heated in their turn, and in their turn rise to the top to be again replaced by cold ones. This process goes on through set after set of molecules, till all the water is heated; and you can understand now why, if we want to make a kettle of water boil, we must put it *on* and not *under* the fire; for in the latter case the top molecules of water would get heated first, and, being lighter than the rest, would remain there, those under them not being able to get hot at all, or only very slowly, since conduction would be the only way in which heat could reach them; and water, as you know, is a very bad conductor.

Air is heated in the same way as water, *i.e.* by convection, and this accounts for a great many currents or *draughts* of air. For instance, you have often heard people say, "There is a draught up the chimney," which simply means that the heated air of a room rises up through the chimney, and the cold outer air from above sinks down to replace it.

We see the same thing repeated on a large scale in the winds. At the Equator, where the sun acts with most power, the air gets very hot, and rises high up. It is replaced by cold currents of air coming from the North and South Poles, so that there are two continual *tides* of air running one towards the poles and one from the poles. These latter are called the *Trade Winds.*

Sometimes you cannot feel heat, and then I dare say you think there is no heat to feel; but this is a great mistake.

There is nothing, not even ice, which does not contain *some* heat, only in certain things the amount is small and inactive. In others, which really possess a good deal of heat, we do not feel it, because of its inactive state. Neither must you suppose that you can judge of the temperature or hotness of anything by touching it. I dare say you doubt this, so I will let you try for yourselves.

Here are three basins of water; one of them contains very hot, and the other very cold water. About the third I shall tell you nothing, for I want you to tell me, presently.

Now, one of you put your hands into the basin with hot water, and another into the basin with cold water, and hold them there a minute. I see you don't like the experiment, for one of you is getting boiled, and the other frozen; so take your hands out again, and put them into this third basin. Now tell me what the water in that is like. Why, dear me! here is one of you complaining it is "so cold," and the other "so hot." Really, you are very difficult to please! I must call some one else, and let him decide which is in the right. "The water is neither cold nor hot; it is lukewarm." That is what he says, and he is quite right; but neither of you could feel that, because one of you put very cold hands into it, and the other very hot hands, so to the one with cold hands the lukewarm water felt hot, and to the one with hot hands, cold.

You see, therefore, you cannot judge by your *touch* of the temperature of anything, for you will judge of it according to your own temperature at the time; you cannot help it. The question therefore arises, How can we judge of the temperature of bodies, since our touch deceives us?

Only by the actual changes which an alteration in the temperature of bodies causes to take place in them. The easiest of these to observe are expansion (*i.e.* getting bigger) and contraction (*i.e.* getting smaller), and before I can describe to you the thermometer—which is the instrument by which we measure temperature—I must tell you a little about this expansion and contraction of bodies; but that must be in the next chapter, for I think you have had enough of heat for one time.

CHAPTER IX.

HEAT (*continued*).

THE THERMOMETER.

Heat, the enemy of cohesion—Expansion and contraction of bodies—The way a thermometer is made—Theometric scale—Centigrade—Fahrenheit.

YOU remember, perhaps, my telling you that one of the Invisible Powers of Nature is the great enemy of cohesion, and that between the two a continual fight is going on. Heat is this enemy, and you will soon see how.

You already know that the stronger cohesion is in a body, the closer its molecules are together. Therefore, the very first thing heat tries to do, in order to overcome cohesion, is to get the molecules a little further apart; and since this, of course, makes the spaces between them larger, it follows that a body must *expand* as it gets hotter, as I have already told you is the case. All bodies, whether they are solids, liquids, or gases, do this; and when they begin to cool again, they contract and go back to their original size.

Of the three different kinds of bodies, gases expand most, and solids least, under the influence of heat. Liquids hold the middle place, and therefore they are the best fitted for making thermometers, which, as I have already told you, are the instruments used for measuring temperature (*i.e.* seeing how hot a body is). And now I am going to tell you how a thermometer is made, and the way to use it.

You must picture to yourselves a narrow glass tube. At one end it enlarges into a bulb; the other end is left open. The tube is then heated over a spirit lamp, and, consequently, the air inside it becoming heated too, quickly expands, and some of it escapes by the open end. This process is repeated several times, and then the open end of the tube is plunged into a vessel of mercury, in the same way as the tube of a barometer. Owing to there being very little air in the tube, a small quantity of mercury rises into it, and passes into the bulb, which is uppermost. The tube is then taken out of the mercury, and placed bulb downwards over a flame, the heat of which causes the mercury in the bulb to get hotter and hotter, and finally to boil. All the while it is getting hotter it is expanding, and as the glass bulb in which it is contained does not expand so fast or so much as the mercury, the latter is obliged to rise into the tube in order to find room enough, and when it begins to boil both tube and bulb are filled with vapour or steam of mercury, which has driven out the remaining air in the tube in order to get all the space to itself.

The open end of the tube is then again placed in the vessel of mercury; the vapour with which it is filled contracts, and more mercury rises into it, and passes on to the bulb, till both are filled with mercury. The open end of the tube is then carefully closed, that no air may get in, and the mercury it contains is allowed to cool (for, having entered a very hot glass tube filled with hot vapour, it became heated also), when it contracts, and sinks much lower down. Directly the least heat is brought to bear upon it, however, it begins to rise again. Holding the bulb in your hand is enough to cause it to do so, and then the colder air of the room will make it sink again afterwards.

Our thermometer is therefore made, only we need marks on the tube to show how much the mercury rises and sinks for different temperatures.

In order to know where to make these marks, the bulb of the thermometer is first plunged into a basin of melting ice, and when the mercury has ceased to fall, a mark is made on the outside of the tube at the point to which it has sunk. Then the bulb is placed in a vessel of boiling water, when, of course, the mercury rises very fast. As soon as it stops, another mark is made on the tube at the point which it has reached, and the space between these two marks is divided by fine lines into one hundred equal parts, called *degrees*. A zero, or 0, is marked on the line to which the mercury sank in melting ice, and 100 on the line to which it rose in boiling water. Every tenth line between 0 and 100 is then numbered; more lines and numbers are added below 0 to denote greater degrees of cold than freezing water, and more above 100 to denote greater degrees of heat than boiling water, and our thermometer is made and ready for use.

The kind which I have described to you is called the CENTIGRADE, or hundred-stepped thermometer, because it takes one hundred steps to get from freezing to boiling water. There are two others made on exactly the same principle as the centigrade, but their numbers run differently, because they do not make the point at which water freezes, their zero.

These are the FAHRENHEIT and the RÉAUMUR, called after the names of their inventors. The centigrade thermometer, being the simplest, is nearly always used by scientific men, and I shall follow their example in this little book; but the Fahrenheit is mostly used in England for ordinary purposes, and I will therefore tell you that it takes 180 degrees to get from freezing to boiling water, instead of 100, and that its zero stands at 32 degrees below the freezing point of water. This zero is fixed at the temperature which, when the Fahrenheit thermometer was first made, in 1714, was supposed to be the lowest possible to obtain. Since then, however, it has been found that far lower temperatures than this can be produced, and there is therefore no reason for keeping to the Fahrenheit scale.

When you want to find out the temperature of any body, you must place the thermometer on it, if it is a solid, and in it, if it is a liquid or gas, and leave it there till the mercury in the tube has ceased to rise or to fall, as the case may be. The point at which the mercury remains at rest will be that of the temperature of the body you are testing.

Before leaving the subject of the thermometer altogether, I must tell you that the amount of heat required to make water boil is not always the same. It depends on the pressure of the air, which, as you know, grows less as we mount in the air-sea. Therefore, on the summit of a high mountain, water, instead of requiring a heat of 100 degrees (marked 100° on the thermometer) to make it boil, boils at 85°, or less. At the bottom of a deep mine, on the contrary, where the pressure of the air is greater than at the surface of the earth, it does not boil till the thermometer stands at over 100°.

The reason why the boiling point of water, and indeed of all liquids, alters according to the pressure of the air, is because the latter naturally tends to keep the molecules together, and is therefore an ally of cohesion. Consequently, when the pressure is greater than usual, heat has to make a longer and harder fight before it can succeed in driving the molecules apart; whereas, when the pressure is less than usual, the victory is comparatively easy.

CHAPTER X.

HEAT (*continued*).

Power of heat in solids—In liquids—In gases—Bodies able to change their state—Water can become steam—And ice—Many other bodies can change into all three states—Exceptions—Latent heat—Latent heat of water—Evaporation—Expansion of solids at melting point—Exceptions—Water—Iron—Heat, the force used to change the shape of metals—Steam engines—Heat a form of energy—Mechanical equivalent of heat.

I HAVE already told you that there is no body, however cold to the touch, which does not contain a certain amount of heat, only in some all active power is taken away from it by cohesion.

This is the case with solids. Cohesion has gained a complete victory in them over heat, and therefore is able, in spite of it, to draw their molecules very close together; for you must understand quite distinctly that the fights between heat and cohesion are always to see which force shall get the molecules under its control. Cohesion is always trying to draw them closer, and heat is always trying to drive them further apart. In solids, then, cohesion is the conqueror.

In liquids neither of the two wins the victory; it is a drawn battle. And so the poor little molecules, not knowing which master to obey, lie side by side in a very helpless way, neither able to draw very close to each other, nor to fly very far apart.

In gases the victory is with heat. It routs cohesion completely, and consequently the molecules rush away from each other with all the speed they can muster.

You see, therefore, that what makes the difference between solids, liquids, and gases is simply the greater or less power heat has in them. This being the case, I am sure you will at once see we have found a reason why bodies should be able to change from one state to another, for if I can increase the power of heat in a solid body, why should it not become a liquid? And if I still go on increasing the heat, why should not the liquid become a gas?

Now, this is what is constantly happening. I am sure that hardly a day passes without your seeing a liquid body turn into a gas; and nothing more wonderful is wanted for this transformation than a kettle of water placed on the fire. The steam which comes out of it is water in the form of a gas, or VAPOUR—for we distinguish between bodies which are naturally gases and those which are not, by calling the latter *vapours*. Then every winter you see a liquid body become a solid; for ice, as you well know, is nothing but frozen water, *i.e.* water which has lost so much heat that cohesion is left triumphant, and binds its molecules together into a solid state.

Water, then, is able to change into all three states in which bodies exist—solid, liquid, and gaseous—through the increase or decrease of heat; and so can many other bodies, only the same amount of heat will not have the same effect on one body as on another. Thus, metals can be melted into liquids, just as ice can be melted into a liquid; but it requires a much greater degree of heat to melt iron or gold than ice. Yet it can be done; and if the heat is still increased after they become liquid, they will turn into vapour. There are some bodies, however, for which we cannot find or make a heat strong enough really to liquefy them. Carbon, or the solid part of coal, when heated, is an example; though, no doubt, if sufficiently great heat could be produced, it would melt. In the same way there are some bodies for which enough cold has never been found to freeze them, or, I should say, enough heat has never been able to be taken away—for you must not suppose cold to be a thing in itself; it is simply absence of heat. Pure alcohol, *i.e.* the very strongest kind of spirit, cannot lose enough heat to be frozen into a solid, neither can enough be taken from air to turn it into a liquid.

The point at which a liquid becomes a vapour is called its BOILING POINT; that at which a solid becomes a liquid, its MELTING POINT; and that at which a liquid becomes a solid, its FREEZING POINT.

The temperature of the melting point and the freezing point are the same for the same body; so that if you were to put a thermometer into a basin of melting ice, and another into a basin of freezing water, the mercury in both would stand at zero.

There is one thing to be specially noticed with respect to a body changing its state. When once it begins to do so, its temperature never alters again till the new state is reached. Thus, when ice begins to melt, however great the heat may be which is causing it to melt, a thermometer placed in it will not rise above zero till *all* the ice has become water; then the mercury will begin to rise again, and continue to do so (if the heat be sufficiently strong, and continue long enough) till boiling point, or the point at which water passes into steam, is reached. There it will again come to a standstill, and rise no more till all the water has become steam.

You may, perhaps, ask what has become of the rest of the heat? Why, when it is melting ice, does it have no effect on the thermometer when zero is once reached? We know that more heat keeps passing into the ice; why does it not, then, raise the temperature? Because it has other work to do. Heat, like human beings—if they are wise—does not care to have too much to do at once; and as to melt ice requires a certain amount of strength, it employs all it can get for that one object till it has accomplished it. Though its work makes no show on the thermometer, therefore, it is nevertheless going steadily on all the time; for, you see, it consists in turning the ice into water, or melting it, not in raising its temperature. Exactly the same remarks apply to boiling water as to melting ice. When the boiling point of water, *i.e.* 100°, is reached, the whole of the available strength of heat goes to turn the water into steam, and therefore the thermometer is at a standstill till all the water has become steam. Heat, working in this hidden way, is called LATENT HEAT.

The amount of latent heat which a liquid requires in order to remain a liquid, and which a vapour requires in order to remain a vapour, can be measured. If you take a pound of pounded ice, and a pound of water at 79°, and mix the two, you will get two pounds of water at 0, which you know was the temperature of the ice to begin with. Therefore the *whole* of the 79 degrees of heat has been absorbed in turning the ice into water, and is now being used to keep it water; so that a pound of ice requires as much heat to liquefy it as will raise one pound of water at 0 to 79 degrees, or make 79 pounds of water one degree hotter. Therefore we say that the latent heat of water is equal to 79. But now, water turning into steam also uses up heat during the process, and the amount it uses is equal to 537, *i.e.* it takes as much heat to turn one pound of water at 100° into steam at 100° as to raise 537 pounds of water one degree in temperature.

You see, therefore, that a good deal of heat is required both to turn ice into water and water into steam; and, consequently, unless heat of very great power is used, it takes a good deal of time to do so—which is a very fortunate thing for us; for, otherwise, there would be violent floods after every hard frost, through the ice turning into water all at once; and continual explosions in our kettles and boilers, through the water becoming steam all at once; while, as to a steam-engine, we could never venture to have one.

The reason why there should be latent heat is explained when we know that heat is a form of motion. When this motion first enters a lump of ice, it is all used up to force the ice particles further apart; and not until it has done this sufficiently to cause them to liquefy does it begin to impart to them its own vibration. Then it does so; yet still they feel the force of cohesion holding them together, and, struggle and quiver as they may, they cannot get free till boiling point is reached. Then comes cohesion's second great defeat, and the water particles all fly away from each other as fast as they can. Yet cohesion is a watchful enemy, and still has to be guarded against; and therefore the heat motion is once more used up to drive the molecules asunder, and not to increase their vibration till every particle of water has turned into steam.

Every liquid has its own latent heat, but it is quite sufficient for our present purpose that you should know about that of water, so we will not enter further into the subject; and when you come to study it really, you will learn the way in which the latent heat of different liquids is determined.

I do not want you to suppose, however, that water gives off no steam until its temperature has reached boiling point. You know yourselves this is not the case, for you must often have seen steam coming from water which was not boiling. This steam is produced by EVAPORATION, which is a much slower process than EBULLITION, or boiling, but is due like it to heat. In evaporation, only just the surface layers of liquid are turning into vapour. In ebullition, the whole liquid is doing so at the same time, as you can see by looking at boiling water in a glass vessel. When boiling point is reached, you observe great bubbles of vapour bursting out from the very bottom of the vessel, whereas beforehand steam only escaped from the top. If you have not the opportunity of boiling water in glass, you can yet satisfy yourselves of the truth of what I am saying by noticing how, when a kettle is on the fire, no steam comes out of the spout till the water begins to boil. This is because the spout is connected with the under layers of water, and, therefore, no steam can escape from it till they are at boiling point.

We do not need extra heat to cause evaporation, though it takes place faster with extra heat. Any liquid left exposed to the air evaporates. You do not see it giving out steam, but its quantity gradually grows less and less, till, if left long enough, it completely disappears. It is floating about in the air as a vapour. Some liquids evaporate very much quicker than others. If a little ether is poured on your hand, it vanishes almost immediately, and at the same time you feel a very cold sensation in your hand, as if it were being pretty well frozen. That is because the ether, wanting to evaporate as fast as it could, took the heat from your hand to help it to do so. If you had been holding water, it would have evaporated much more slowly, and you would not have felt the same keen sensation of cold.

All liquids, when they are turning into vapours, absorb or drink in heat, whether they are evaporating or boiling. All gases and vapours turning into liquids give out heat, on the contrary; you see they do not want it when they are cooling, so they part with it to whatever is near them. Those liquids evaporate most quickly which have the lowest boiling point, and those most slowly which have the highest. Clouds are formed by evaporation; the heat of the sun turns a small part of the water of the ocean into vapour, which rises in the air till the latter cools and condenses it, *i.e.* turns it into water again, and then it descends on the earth in the form of rain.

I have already told you that all bodies expand under the influence of heat, and when the temperature of a solid nears the point at which it will become a liquid, the expansion goes on more rapidly. At the actual moment of its liquefying, a still greater expansion takes place, because, of course, the molecules of a liquid are further apart than those of a solid, and must therefore require more space. It follows, then, that a liquid body will take up more room than the same body in a frozen or solid state, since it continues to grow bigger and bigger from the time its temperature first begins to rise, till its melting point is reached. When it is allowed to cool again, it contracts, as the cooling process goes on, till, when it is quite frozen and solid, it has returned to the size it had before it began to be heated.

There are, however, some exceptions to this rule, of which the principal is water. When its heat decreases it follows the general law, and contracts until it reaches the temperature of 4°. Then contraction stops, and the water begins to expand again till its freezing point, zero, is reached; consequently, ice takes up *more* instead of *less* room than water, and is also lighter—which you may easily find out for yourselves by noticing that when water is freezing the ice rises to the surface, and the liquid water sinks to the bottom. This is a most fortunate thing for the poor little fishes, for, in consequence of it, they are able to live through hard winters, when all the surface of their ponds and rivers is frozen; for underneath the sheet of ice which keeps them prisoners there is liquid water, the temperature of which is no lower than 4°, and which only gets converted into ice very slowly, because the cold of the outer air is kept from reaching it by the ice above. It would be a very different matter if ice were heavier than water, for then, as each successive layer froze, it would sink to the bottom, and the cold of the air would freeze the next, so that very soon the whole of the water in a pond or river would become one solid mass of ice in which nothing could live.

Freezing water expands with great force, and if it is contained in something which does not allow enough room for its increase in volume, that something stands a very good chance of being broken. I am sure you have all heard of the bursting of water-pipes during a hard frost, though I dare say you did not know the reason. Now you do; it is because there is not room enough in the pipes for the same quantity of solid water, or ice, as liquid water, therefore the ice makes room for itself by bursting the pipes. It is owing to the same cause that you see great cracks in the ground during a frost; the water in it freezes and expands, and having no room to do so to its full extent, forces the soil apart to get more. Even rocks are split asunder in this way, and the mortar of a wall may be loosened from the same cause.

Water is not the only liquid which expands when it becomes solid. Liquid iron does the same; and for this reason it can be cast, *i.e.* poured into a mould when it is hot, and then left to cool. As it does so it expands and fills up the crevices of the mould, so that when it is taken out in a solid form it is exactly of the same shape as the mould. For this reason if coins were made of iron they could be cast. Being made, as they are, of gold, silver, and copper, they have to be stamped, for these three metals do not expand as they become solid, like iron; they contract, and, consequently, if poured into a mould, they would shrink away from it instead of filling it up more as they cooled.

Speaking of metals being cast reminds me that when I was telling you about the properties of solids, we found that to change the shape of metals requires a great deal of strength, and I promised to tell you what force we get to help us. You know yourselves now, I am sure, it is heat.

If you have ever stood at a blacksmith's forge, you must have seen him heat horse-shoes in the fire till they are red-hot, and then lay them on the anvil and bend or twist them into any shape he pleased. That is because the hard iron had become soft under the influence of heat. If it had been heated still more, it would have begun to melt, as you know.

Well, many metals are worked or *wrought* into shape in the same kind of way as the blacksmith works the horse-shoe. Sometimes they are beaten, sometimes they are pulled and twisted. Through the power of heat we are able to fashion and shape them as easily as moist clay or wax.

The process of *casting* I have already mentioned to you. You have seen something of the same kind done if you have ever watched a cook make a jelly. You know she pours the liquid jelly into a mould, and there leaves it. When it is quite cold, she turns it out, and there is her jelly standing firmly by itself in the same shape as the mould.

But we do not only use the power of heat to help us to work metals. There is one very important service it renders us which I must not forget to mention. Can you guess what it is? I think so, if you try.

What is it that makes steam-engines move? Steam, isn't it? Whether the engines are moving ones—*locomotives*, as they are called—or whether they remain stationary themselves, and only cause wheels and machinery connected with them to move, like those in a manufactory, we know that they are all alike worked by steam; and this steam, as you are well aware, is produced by heating water up to boiling point, when it turns into steam.

Now, I am not going to give you an explanation of the way in which steam-engines are made, nor of how they do their work, for that would entail a longer and more difficult explanation than you would care to listen to. I simply want to show you, by reminding you of the great quantity of work done through the agency of heat, how much we are indebted to it, and what an invaluable servant this Invisible Power of Nature is; for it is, in fact, the invisible motion and energy of heat transformed into visible motion and energy which draws our railway trains and works the machinery of our factories. Heat, being a form of motion, must also be a form of ENERGY, *i.e.* it must possess the power of doing actual work; and as we have seen all through these chapters, it not only possesses this power, but is continually using it. The work done by steam-engines is only a different manifestation of the same energy which began by turning the water in their boilers into steam.

Of course the amount of work heat is able to do (or to change itself into, for that is nearer the truth) entirely depends on the amount of heat there is to do it, and, after careful experiments, scientific men have found out that the same amount of heat always does the same amount of work; and, in like manner, that the same amount of work (used for that purpose) always produces the same amount of heat. By these experiments it has been proved that as much work is done in raising one pound of water 1° centigrade in temperature, as in lifting it through 1392 feet, or in lifting 1392 pounds through one foot. This is called the *mechanical equivalent* of heat, *i.e.* the working equal of heat; and its discovery was of the utmost importance to science, both theoretically and practically, for it gave the most clear and decided proof of what is shown in many other ways—that no energy is ever really lost, but only changes form. Many common facts pointed to this conclusion long before it became a scientific theory. When on a cold winter's day some one takes your hands and rubs them, or you yourself clap them together, what becomes of the energy used in rubbing or clapping? Is it lost? No; it is changed into heat, as you have often experienced. Again, when a pond is frozen all over, except in one small part where you see the ducks patiently swimming to and fro, what becomes of the energy they are expending? That also is changed into heat; for by moving the water as they swim, they cause the water particles to rub against each other, and this friction changes to heat in the water, and prevents it from freezing; just as the rubbing of your hands changes to heat in your hands.

Heat is not the only thing, however, into which the energy of motion can be transformed, as we shall find further on. There is a wonderful connection between some of the Invisible Powers of Nature—a connection so close and intimate that, in spite of the wide difference which exists between them at first sight, we cannot help feeling they are united in some way which, when rightly understood, may prove that after all they are but different manifestations of the same force. Some day, I hope, you will study this subject for yourselves, for it is but a slight hint I can give you of it now, only just enough to rouse your interest and make you wish to know more. This book tells you but very little of any of the Invisible Powers of Nature, and of the marvellous things there are to learn concerning them. It is only meant to show how much that is wonderful underlies what we consider the "commonest" occurrences of daily life.

CHAPTER XI.

LIGHT.

Light apparent everywhere—Some rays of heat are visible—Luminous bodies give out heat—Light is radiant heat made visible—Is therefore a form of motion—Light-vibration quicker than heat-vibration—How light travels to us from the sun—Motion in the ether, light—Stillness, darkness—Description of wave-movement—Water-waves—Wave-shapes in a rope—Ether-waves like water-waves—Speed with which light travels—Shadows caused by interference.

AND now we have come to the most wonderful and interesting of all those powers of Nature about which I am trying to tell you. For the most part, though we see their work and its effects so clearly, they themselves are invisible; but this is not the case with LIGHT. Light is something whose beautiful and glorious presence is apparent everywhere, and that not only on our earth, but in the whole of God's great universe; something with which we are so familiar that, in our ignorance, we might fancy we had little to learn about it. But that is a very great mistake often made about other familiar things besides light.

Before attempting to tell you what light *does* (which I dare say you think you know), there is another question to be answered—what it *is*.

You remember, no doubt, what we found out heat was—a particular kind of motion; and perhaps you remember also my telling you that some rays of heat (such as those coming from a fire or the sun) were *light, i.e.* could be seen. Now, if you come to think of it, you will notice that no body gives out light without also giving out heat, and many bodies which do not naturally give out light, if they are sufficiently heated will do so. Thus a lump of coal when first placed on the fire is quite dark, but as its heat increases you begin to see a dull red light coming from it, which grows more and more vivid as the coal becomes hotter, till, when it is what we call "red-hot," it glows with a bright yellow-red light. Some bodies (iron, for instance), if they continue to be heated after they have reached the "red-hot" stage, become "white-hot," and the light they give out then is white and strong, something like that of the sun.

You see, therefore, that heat and light have a great deal to do with each other; in fact, their connection is a very much closer one than that of relationship, for they are one and the same thing. Light is radiant heat made visible, and therefore you will know, without my telling you, that light is *motion.* It is a very rapid vibration which takes place first in the body giving forth the light, and then is communicated by it to the surrounding ether, through which it moves in circular waves, as long as the disturbance which first caused the motion continues, *i.e.* as long as the body giving forth light—or LUMINOUS BODY, as it is called—goes on vibrating and making the ether round it vibrate.

The difference between a body giving out dark radiant heat, and one giving out visible radiant heat, or light, is that in the latter the vibrations are very much quicker than in the former, and the more vivid is the light, the more rapid are the vibrations.

You can now understand how the light of the sun travels to us. The sun is an enormous luminous body, quivering all through with the heat-motion intensified to light. It is therefore the centre of a great disturbance in the vast ocean of ether which surrounds it, and in which it causes countless millions of ripples or waves of light, which go on spreading and spreading till, after a journey of ninety millions of miles, they reach the surface of our earth, which they cover as the waves of the sea cover the sand.

I want you clearly to understand, however, that whether there is light or not, the ether is always there; for it is not the ether itself which is light, but its motion. Therefore, when the darkness of night comes, it means simply that the ether is still; there is no more motion, so there is no more light. In order to explain to you about this more clearly, I want you thoroughly to understand what a WAVE-MOVEMENT really is, and I think you will easily do so.

I dare say you have often stood by the sea and watched the waves rolling in. At such times have you ever noticed what a stick does if you throw it into the water? First of all you see it sink into the trough or hollow between one wave and its neighbour, then it rises up to the crest of the next wave, and sinks down to the hollow again; and so it goes on rising and falling, often making little or no progress either from or towards the shore. If you watch carefully, you will see that if the tide is neither going out nor coming in, but "just on the turn," as people say, the stick will remain in the same place for some time. Though it rises to the crest and sinks into the trough of wave after wave, they have not the power to make it change its place; and even if the tide is coming in, and you do see the stick advancing towards the shore, it is not one wave which brings it there; many pass it and roll up to your feet before, at last, one washes the stick in with it. It is, in fact, not the *waves* which bring you back the stick at all, but the onward movement of the tide, which is much slower.

Now, the reason why the waves cannot bring you back the stick is because, though their *shapes* are moving forward, the water which makes them is *not* moving forward.

In a wave of water, all the little molecules which make it are vibrating up and down from the trough to the crest of the wave, and this vibration of theirs causes the set of molecules next them to vibrate too in the same way, and to the same height. The wave shape, therefore, passes from one set of molecules to another, while the molecules themselves do not move forward at all, but simply up and down in the same place. If you could imagine one wave only on the surface of the sea, it would travel forward in this way through set after set of molecules till it reached the shore, making them all vibrate in turn, the set behind sinking to rest as the set in front took up the movement. But now, as you know, there is not one wave, but a countless number of waves on the surface of the sea. That is because not one series of vibrations only is given to the molecules, in the first instance, but a great many, so as soon as they have done moving up and down for one wave-shape, they have to begin again for the next; and they go on vibrating and passing forward wave-shape after wave-shape, until the wind, or whatever cause disturbed the first set of molecules, ceases; then they gradually stop, and the water is at rest again.

There is an illustration which may help you to understand how a wave-shape moves forward. Suppose that you had a rope, and that while you were standing still you took up one end of the rope and shook it. The shake would pass on right through the rope, and the movement you imparted at one end would not cease till it had arrived at the other. But the rope would not change its place either forwards or backwards; it would remain just where it was. A moving shape would have passed throughout its whole length, and yet the rope would be in the same place. This is just what happens to the sea or a lake. The wind shakes the molecules of water, and causes the wave-shape to start, as you do in the rope when you shake the rope; and once started, it goes on till it comes to the end of the water, as the wave-shape in the rope does till it comes to the end of the rope—unless, indeed, the shore is a long way off, and the disturbance caused by the wind is slight, or only lasts a short time. Then the vibrations in the water molecules may not be strong enough to pass through set after set without getting so weak that they die away altogether before the wave-shape has had time to be transmitted to them all, and so reach the edge of the lake or sea.

Now, waves of light pass forward in exactly the same way as waves of water. The wave-shape is transmitted from one set of ether molecules to another, while the molecules themselves do not advance. The only difference is that the ether molecules, instead of vibrating slowly over a large space, vibrate very quickly over an exceedingly small space. There are many thousands of waves of light in one inch, and the distance from the crest of one wave to the crest of the next is about the ten thousandth part of an inch. These tiny wave-shapes are passed forward with the most extraordinary speed, which means to say that light travels very, very fast—so fast, indeed, that it was thought for a long while to do so instantaneously, *i.e.* to take no time at all for any journey it had to perform, however long. We know now, however, that a wave of light from the sun takes eight minutes to reach our earth; and, as the sun is 90,000,000 miles away from us, in order to accomplish this vast journey so rapidly, light moves at the rate of 186,000 miles a second. These waves of light are circular, like the ripples which form on a pond round the place where a stone has been thrown in, and the reason why they continue to spread in both cases is that the vibration of *one* molecule is enough to give rise to a wave-movement; and as each molecule communicates this movement to all those near it, and these again to all those near them, the space in which the motion is taking place keeps constantly enlarging.

The sun, the moon, the stars, lamps, candles, and, in fact, all luminous bodies, give forth their light in circular waves in the same way; but, in the case of the moon, the light, as we know, is much more feeble than in that of the sun, while the stars are so very far away that only a few of their light-waves ever reach us at all; and those have often been travelling for years before they do so, in spite of the enormous speed with which light journeys.

All this time I have been speaking to you of light as if it shone everywhere with the same strength. But you know this is not the case, for there are shadows to take into account. If you sit with your back to the window, you will not see to write or draw comfortably, even though the sun may be shining. If you hold a screen between yourself and a lamp, all its light cannot reach you; you are in the shade.

Now, what is it that causes shadows?

You will tell me they are caused by a body which does not let light pass through it (an *opaque* body), being between you and the source from which the light comes.

Quite true; but does it not occur to you that if light travels in waves in the way I have told you, these waves must wash round obstacles as waves of water do round a rock; and if they do, why should there be shadows?

For this reason. Waves of light certainly do wash round obstacles, such as your bodies or a screen, but they are acted on by them as the waves of the sea are by a breakwater. You know what happens in that case; the waves come dashing against the breakwater, but, as they cannot get through it, they are turned back upon the other waves behind them, which they cross and intersect in every direction, and in this way the force of the waves is so much broken that the water on the other side of the breakwater is comparatively calm. The latter has, by turning back the waves in their onward course, made them interfere with each other in such a way that they have lost a great part of their strength.

It is just the same with waves of light. They strike against some opaque body, and are turned back upon each other; then they cross and intersect each other in the same way, so that a great part of the wave motion is wasted, and on the opposite side of the object the ether is much calmer. The consequence of this is partial darkness, or a *shadow*. If the ether were quite calm, there would be complete darkness, as there is on a moonless and starless night.

If, however, you have watched carefully how the waves turned back from a sea-wall behave with regard to the advancing ones, you must have noticed that the result of interference is not always to make the water calmer. Every now and then you see two waves unite when they meet, and make one large wave. This happens when the waves meet in such a way that crest joins crest and furrow furrow; for they then become one wave, with a crest twice as high and a furrow twice as deep as either had singly. If ether waves meet in this way they make a stronger patch of light. If, however, two waves (whether of water or ether) meet so that crest joins furrow, and furrow crest, then one wave is lifting the water or ether up just where the other is sinking it down, and the result is a calm spot, *i.e.* a level in water, and darkness in ether.

You see, therefore, that there are two ways in which waves can interfere with each other—they can increase each other's size and strength, or they can do away with each other; and I want you to remember this clearly, for it will be of great importance in helping you to understand some of the things which I have to tell you about light.

CHAPTER XII.

LIGHT (*continued*).

REFLECTION AND REFRACTION OF LIGHT.

Reflection of light from polished surfaces—Definition of a ray of light—Sunbeam reflected from a mirror—Angle of reflection equal to angle of incidence—Reflection of light enables us to see natural objects—Refraction—Light travels in a straight line—Is bent on passing into medium of different density—Prism—Lens—Focus—Burning-glass—Illustration of the action of a burning-glass—Practical uses of lenses—Photographer's lens—Reversed image formed by lens—Mirrors—Plane—Convex—Concave.

FROM what you have read in the last chapter, I am sure you understand that waves of light striking against any surface are turned back from it, or REFLECTED, as it is called. When the surface is smooth and polished, we can see this reflection. You know how looking-glasses, silver cups and dish-covers, polished wooden tables, and many other objects give back the light which falls on them, and become, as it were, a source of light themselves; and it is on this very principle that you so often see reflectors put behind lamps. The lamp's light may be almost doubled in this way; and since light and radiant heat are the same, heat also can be reflected like light.

The best way to understand something about this subject is to observe how a single ray of light behaves when reflected. A *ray* means the straight line of light which comes from a single luminous point. In some states of the atmosphere you can see such lines being sent out on all sides by the sun. What we call "sunbeams" are rays of light, and you can easily experiment on a sunbeam. The next time one comes dancing into the room, catch it on the surface of a hand-mirror. You will see that the sunbeam, instead of pursuing its former path, will be sent off in quite a different direction, and this direction will be changed every time you move your mirror. The reason of this is that the direction taken by a *reflected* ray of light depends entirely on the angle it makes before reflection with the object on which it falls. You cannot understand this very well without some knowledge of geometry, and therefore I shall not attempt any further explanation. It is sufficient at present for you to know that the path of a reflected ray of light is always on the *same* *slope*, and in an *opposite direction* to the path of the ray before reflection. This is expressed by saying that the angle of reflection is equal to the angle of incidence.

Though you cannot as yet enter into the laws of the reflection of light, you are constantly seeing some of their results. In fact, if it were not for the property which light has of being reflected, you would not be able to see anything but light itself; all the objects on which it falls, and which you now distinguish so clearly—trees, houses, animals, people—would be quite invisible. This, no doubt, sounds a very strange assertion, and yet it is perfectly true; for it is not the light coming straight from the sun which makes you see all the objects you do see, it is the light which comes from these objects themselves after the sun has first given it them. They do not (unless they have smooth, polished surfaces) reflect the light exactly in the same state in which it falls on them; but still they reflect it, and so you see them. This is a very curious and interesting subject, and, in a later chapter, I shall be able to tell you a little more about it. In the meanwhile we will go on to another very important property possessed by light, viz. that of REFRACTION, or being bent.

As a rule, light moves forward in a perfectly straight line, without any twists or bends, as you can easily prove by holding a screen between your eyes and the sun or a candle. Their rays do not reach you, being turned back by the opaque object you are holding to intercept them. This would not be the case if they moved in bends and curves, for then they would get over the top or round the sides of the screen. As this never happens, we feel sure that light travels in a straight line; and it continues to do this as long as it is passing through anything of the same density (*i.e.* the same closeness of make) throughout, such as air of one temperature, and, even when it is passing through things of different density, so long as its path is quite vertical, or quite horizontal. If, however, a slanting ray of light passes from air into water or glass, both of which are denser than air, it is bent into a *less* slanting direction than that which it was following before; and on leaving them and entering the air again, it is bent in a *more* slanting direction than during its passage through them. You can get a good example of refraction by plunging a straight stick into water on a slant. The stick will look as if it were bent or broken just at the place where it enters the water.

Light is not always refracted in the same way. If it passes through a piece of flat glass (like a window-pane) it takes, on leaving the glass, exactly the same direction it was following before; but this is not the case if the piece of glass is shaped like a wedge, thick at one end and thin at the other, for then the rays of light, on leaving it, are bent towards the thick end of the PRISM, as it is called. Therefore if the thick end of the prism is turned upwards, the rays of light take an upward slant on leaving it; if downwards, a downward slant. Consequently, if you put a prism in the path of a sunbeam coming through the window of a room, the sunbeam will fall on the wall in quite a different place to what it would have done if there had been no prism.

Prisms are not always wedge-shaped; they are sometimes round, thick in the centre and thin at the edges, and they are then called LENSES. A number of rays of light passing through a lens, being all, as they leave it, bent towards the thick central part, are, of course, also bent towards each other, and, consequently, meet at a certain distance from the lens at a point called the focus, where all their strength is concentrated, so that if you were to place your eye just at this spot, the light would be much more intense than at any other place through which the rays pass. I do not advise you, however, to try the experiment of putting your eye at the focus of a lens, unless, indeed, the latter be very small and weak; for luminous rays are, as you know, heat rays also, and, therefore, not only would you find much more *light* at the focus, but much more *heat*, and your eye might chance to get terribly hurt. You have no doubt often heard of a burning-glass. Well, a burning-glass is simply a lens through which bright rays of sunlight are made to pass, and at the point where they meet, *i.e.* at the focus of the lens, small light objects, such as bits of paper or straw, can be set on fire. If the lens is a powerful one, there might be enough heat at the focus to cook a mutton-chop, so that, with nothing but the sun and a piece of glass to help you, you might dispense with the kitchen fire sometimes for your dinner!

I remember, as a child, receiving a very curious and practical illustration of a burning-glass. On a table placed before the window in our drawing-room stood a large, clear glass vase full of water, which bulged out very much at the centre, and was, in fact, not at all unlike a big lens in shape. At a short distance behind this vase was a very pretty little pink leather work-case, which belonged to myself. One day I discovered a large burn on the corner of the work-case nearest the vase. No one could imagine how it came there, and at last some one suggested that the housemaid must have put a candle too near the work-case and set it on fire. She was called and questioned, but denied that any such accident had happened, and the burn remained a mystery. A few days afterwards, however, my grandmother came into the room on a bright sunny morning. The blinds had not been pulled down, and the great glass vase was receiving its full share of the sunrays which were streaming through the window. As she neared the table she saw a suspicious smoke rising up, and on coming quite close found the work-case on fire! You may imagine it was never put so near the glass vase again, and, in fact, if I remember rightly, the vase itself was banished to a different part of the room, in case any other accidents should happen.

All kinds of practical uses are served by lenses, for as the slightest change in the shape of a lens will change its focus, it follows that by means of such variations of shape, we can manufacture an almost endless number of lenses, no one of which will affect the rays of light passing through it exactly in the same way as another, *i.e.* no one of which will have the same focus. Microscopes, telescopes, spectacles, and, in fact, optical instruments of all descriptions, are made with lenses of different shapes and sizes, sometimes combined with mirrors; and there is hardly a branch of scientific study which does not owe a deep debt of gratitude to the lens in some form or other. There is one connection in which I think you must often have heard of it—I mean photography. Every one in these days has his or her photograph taken, and, therefore, I do not think you can have escaped being placed opposite the well-known black box, with its protruding end pointed towards you. At this end there is a lens, through which a small image of you is thrown upon a prepared glass plate, on which the sun forms your likeness in black and white. I must reserve the explanation of how this is done for a later chapter; but, in the meanwhile, we may learn something of the little image of yourself which is thrown through the lens on the plate behind. In the first instance, it is a ground glass plate, not specially prepared, which the photographer uses. He wishes to see, before taking your likeness, if you are exactly in the right position.

If you were to put your head under his black cloth (which I dare say you have done when a friend, about to be photographed, was sitting opposite the lens instead of yourself), you would see on the ground glass plate a small but exact image of the person in front of the lens; form, colouring, every little detail is perfect, but the image is upside down.

The reason is very simple. Your friend, like yourself, and like all other bodies, human or not, reflects rays of light which make him visible; but through such a narrow passage as the lens of the photographer's box, only quite a few of these rays can find their way. Those coming from the head and the upper part of the person enter the lens in a *downward* slanting direction, therefore they fall on the lower part of the glass plate. Those rays entering the lens from the feet and lower part of the person do so in an *upward* slanting direction, therefore they fall on the upper part of the glass plate. The consequence of this is that the whole image of the person is reversed, the head and shoulders appearing at the bottom, and the feet at the top. At any time you can produce a little topsy-turvy picture of this kind. You have only to go into a carefully darkened room, bore a small hole through one of the shutters rather low down, and if you place a sheet of white paper opposite the hole, you will see a little reversed likeness of the house, tree, or whatever may be standing in front of the window.

Before quite closing this chapter, I must say a word about mirrors. You know that if you look at yourself in a flat mirror you get an exact reflection of yourself, not only as to colour, but size and form also. Furthermore, your image appears exactly as far behind the glass as you yourself are in front of it. If you recede, your image recedes; if you advance, it advances also. You have seen this so often that most likely you have never realized what a curious fact it is; and I have now drawn your attention to it merely to tell you that its explanation lies in those laws of the reflection of light which you can only understand by the help of geometry. If we want to find out the reasons of some of the commonest occurrences of everyday life, we must often enter into studies which at first sight seem to have very little to do with them; and that is one reason why we should be willing to learn everything we can, because we never know what interesting and important things it may throw light upon in after-days. This is a digression from the subject of mirrors, however, and it is time to return to them again.

All mirrors are not flat, or PLANE. There are two other kinds—CONVEX, or outward-curving mirrors, and CONCAVE, or inward-curving mirrors. Looking into these, you do not see your image reflected the same size as yourself, nor even in the right proportions. It is distorted, and often very small, and you would be sorry indeed to have to own it as your exact likeness. The reason of this difference between objects seen in flat and in curved mirrors, is that the latter reflect the rays of light which fall on them in quite a different way to the former. In fact, they have foci, and the appearance of any object as reflected by a curved mirror depends on the position the object holds with regard to the focus. A spoon will give you a rough idea of the effect produced by the two kinds of curved mirrors—its outside representing a convex, and its inside a concave, mirror.

CHAPTER XIII.

THE GIFT OF LIGHT TO NATURE.

The colour of a ray of daylight white—Separated on passing through a prism—Newton's discovery that one white ray of sunlight is composed of seven coloured rays—The rainbow—Solar spectrum—Spectral colours the only ones in Nature—Reflected light that which gives bodies their colour—Light-waves of different length are of different colours—Soap bubbles—Colours of thin plates—Of striated surfaces—Cause of colour-interference—Transparent bodies—Geraniums black at night—White paper can be made to appear any colour of the spectrum—Effect of candle-light on colour.

CAN you tell me what this gift is? I expect not; and by-and-by I will tell you instead. But, first of all, answer me another question—What is the colour of sunlight, or daylight?

"White," I hear every one answer.

Well, yes; an undivided ray of sunlight is white; but if it is divided, what then?

You "don't know;" and you don't know how we can divide a ray of sunlight. I will tell you.

Every time that a ray of light passes through a prism, or anything which acts like a prism, it is separated into the different parts which go to make it up as a whole, or DISPERSED, as it is called; but in order to see the result properly, this is what you must do. Go into a room with wooden shutters, close them carefully, and shut the door, so as to darken the room quite. Then bore a small round hole in one of the shutters, rather high up, so as to get light through it straight from the sun. A thin ray of daylight will enter, and make a little round, white patch on the opposite wall. Then put a prism in the path of the ray, so that it cannot reach the wall without passing through it—what will you see?

What you ought to expect to see is the very same thing which the great Sir Isaac Newton, who made this experiment many years ago, expected to see. He knew that the ray of light on entering and leaving the prism would be refracted in the way I told you in the last chapter; and he therefore thought he should see the little round patch of light in a different place on the wall to that which it occupied when there was no prism. But what happened? The round patch disappeared altogether, and in its place he saw a long strip of light, no longer white, but divided into seven beautiful bands of colour, which lay in the following order—violet, indigo, blue, green, yellow, orange, red. What could this mean?

Well, Sir Isaac Newton guessed what it meant, and never rested till he had proved by experiment that he was right. It meant that every ray of white sunlight is made up of seven coloured rays, and that, owing to these coloured rays possessing the power of being refracted in different degrees on leaving the prism, some get more and some less bent out of the direction they were following, and consequently they fall on the wall in different places. This separation of the white ray into its seven coloured parts is called DISPERSION.

To prove that a ray of sunlight does indeed contain all these colours, we can, after dispersion, reunite the coloured rays again, and make them form one white ray. This is done by placing a second prism in their path, in such a position that on leaving it they are refracted back so as to follow the same direction they were taking before they entered the first prism. Then we have the single white ray restored. Another way of proving the same thing is by painting a cardboard disc with the seven colours I have mentioned, running in strips from the centre to the edge. If the disc is made to turn round very fast, it will appear no longer coloured, but white. The reason is that the eye has not time to distinguish the colours separately, and therefore they blend together and form white.

You know now how it is that you see such bright, pretty colours in cut glass. The latter acts like a prism, and disperses the rays of white light as they leave it to come to your eye. You know also what causes the rainbow, which God told men to look at as a pledge of His mercy and forbearance to them. The sunlight, passing through the drops of water in a cloud, is refracted by them just as it would be in passing through a prism, and the consequence is that glorious coloured arch which you have so often admired.

The colours of the seven rays composing a ray of white sunlight are called SPECTRAL COLOURS, and the image they make on the wall after leaving the prism, the SPECTRUM. Spectra can be obtained from stars as well as from flames and other sources of artificial light; therefore, that given by daylight is called the SOLAR SPECTRUM, to distinguish it from others. The spectra of artificial lights, however, only possess a few of the colours of the solar spectrum, and always most of that one which gives its hue to the light from which the spectrum is obtained. Thus, a ray of light from an ordinary candle, which is very yellow, contains most yellow in its spectrum; the spectrum from a blue flame would have most blue, and so on.

Now, the colours of the solar spectrum are those which we see in greater or less vividness, and in a thousand different shades in every object which has colour; for there are no others, as I will show you directly. The gift which light bestows on Nature, then, is *colour*. Without light no such thing would exist; and only imagine what a dull, sad world it would be if everything were absolutely colourless! It is the transforming power of light which gives their beautiful hues to sky and clouds and mountains; it is through light that every flower receives its delicate or brilliant painting, and every leaf its own tint of green.

How is this? you will ask. Have not these things colour in themselves? The light which shines on them reveals their colour, we know; but surely that colour itself is their own.

No; this is not the case. No object in Nature has any colour of its own; light not only reveals, but bestows it, and all which the objects receiving this gift have to do in the matter is to choose, as it were, in which colour light shall clothe them. I will try and tell you how they manage this.

You must begin by understanding that the light which gives bodies their colour is not that which they keep (for they do keep some), but that which they reflect. Light falling on a body divides itself at once into two portions. One of these does not enter the body at all, but is reflected at once from the surface, and is always white, even in the case of black bodies. The second portion enters the body; *i.e.* the motion which is going on in the ether *round* the body is communicated to the ether *in* the body, every atom and molecule of which is surrounded by ether. Therefore, since motion in the ether means light, and this motion is going on inside as well as outside the body, there must be *light* inside as well as outside it. These waves of light inside the body are terribly interfered with by each other; they have no scope at all for free play, and if you think one minute, you will see why. They are so very, very tiny that every one of the molecules contained in the body acts as a breakwater to them, and they are consequently thrown back on each other, and cross and recross each other's paths in every direction. The result is that a great many of these little light-waves are quenched, or put out altogether, and these form the portion of light which the body keeps. There is still, however, some remaining which is not quenched. What becomes of it? It is reflected backwards and forwards from molecule to molecule, till at last it reaches the surface of the body again, and from that it is reflected outwards. It is *this* light which meets your eye when you look at the body, and whatever colour *it* is, is the colour the body appears to you.

But why, you ask, should this light now be coloured? It was white when it entered the body; and though we can easily understand that, owing to the interference of the little waves of light with each other, a great many must be quenched, and therefore less light be reflected from the body than originally entered it, still that does not explain why what remains should not be white.

In order to make you understand this, I must tell you that the waves of light are of different lengths. By the *length* of a wave of any kind is meant the distance between its crest and that of the next wave, so that long waves would be few and far between, whereas short waves would be crowded together. *Short* waves are caused by a rapid vibration, *long* ones by a slow vibration; and as the coloured waves of light forming the spectrum all vibrate at a different rate, so also they are all of different lengths. Violet waves are the shortest. Then follow in regular gradation, indigo, blue, green, yellow, and orange, each a little longer than those immediately before them, till we come to red, which are the longest of all. Very, very short are the longest, however; for it would take 36,918 of the "long" red waves to cover one inch of space, while of the "short" violet ones, 64,631 would be required! It seems almost absurd to use the word "length" in reference to such very minute distances, does it not? It is owing to the different lengths of the waves of light, however, that some are quenched by some bodies and some by others; and it will amuse and surprise you to hear that one of the very best ways to understand something of how the different colours are produced, is to blow soap-bubbles and watch them! I dare say you have often done this, though without any scientific intention, and have noticed the beautiful rainbow tints which appear on the thin film of the soap-bubble. If it is a very perfect one, and settles down steadily where no draught of air can reach it, these colours appear in alternate bands, beginning with a dark spot at the top, and gradually fading as they near the bottom, till they vanish altogether. The cause of these colours I will try and explain to you. The film of a soap-bubble is of different thicknesses in different parts, and when it is at rest the thinnest portion will be at the top, and the thickest at the bottom, because the soapy liquid of which it is made is always sliding downwards. When waves of white light strike on the bubble, some, of course, are at once reflected from its outer surface; the rest enter the film, which obliges them to slacken their speed, because it is denser than air; and when they reach its inner surface, and are about to pass into the air contained in the bubble, some of them are again reflected and turned back on the advancing waves, which they must meet, as you know, in one of two ways—either crest must join crest, and the two waves unite and make one large wave, thus causing an increase of light, or else crest must join furrow, and a calm ensue, or light be extinguished. This is just what happens in the film of the soap-bubble. Sometimes the waves from the outer surface meet those from the inner surface in such a way as to increase their light, sometimes in such a way as to extinguish it. Since some of these light-waves are longer than others, however, a greater thickness of film is wanted to quench them, and, therefore, at every different thickness of the film appears a different colour. Thus, if the thickness of the film allows the rising *red* waves to meet each other from the opposite surfaces, a streak of red light appears on the soap-bubble, because all the other coloured waves are of the wrong length to meet in this way, and consequently extinguish each other, and leave the red ones masters of the field. Where a yellow streak appears, the same thing has happened to the yellow waves; where a green, to the green, and so on.

Soap-bubbles are not by any means the only example of these sort of colours, which are called the COLOURS OF THIN PLATES. Any sufficiently thin film will produce them, and if you take a bottle of turpentine and pour its contents into a pond, you will see the flashing of these colours all over the water, on which the turpentine floats and forms a thin film. The colours vary as the thickness of the film varies through evaporation.

Mother-of-pearl, which you might think owed its colours in the same way to the presence of a thin film on its surface, obtains them differently, however. It is made of exceedingly thin layers, and when these are cut across by the polishing of the shell, their edges are exposed, and are like a number of very, very fine scratches on the surface of the shell. The waves of light are reflected from side to side of these furrows, and the shorter ones are extinguished; but the longer ones remain, and so we see streaks of different coloured light. If mother of pearl is carefully stamped on black sealing-wax, its colours will appear on the wax, because the tiny grooves which cause them have been impressed on it. You can also produce the same kind of colours by making very fine scratches on a piece of glass. They are called the COLOURS OF STRIATED SURFACES, and the beautiful tints on a duck's neck or on the black tail feathers of a cock, are caused in the same way.

You see, then, that whenever we can trace the cause of the appearance of colour, we find that it comes through interference; and we may therefore feel pretty sure that all bodies are coloured by it, though we cannot prove the fact in the same decided way as we can in the case of the soap-bubble and of mother-of-pearl.

Up to this time we have been speaking only of OPAQUE BODIES, *i.e.* those through which light does not pass to the opposite side—which we cannot, in fact, see through; and you can, I am sure, tell me what is the opposite to opaque—TRANSPARENT. Objects through which light passes without seeming to lose any of its brilliancy are called transparent. Water is one of these, and glass is another. You must not imagine, however, that light can pass through any thickness of water or glass. Such is not the case; and, in fact, always in passing through them, a very small quantity is quenched, but it is so small that you do not perceive any difference. This would not be the case, however, if a very great thickness of water were placed in the path of light. Then you would find the light nearly or quite quenched; and in some parts of the ocean, where the water is very pure and deep, it looks almost black for this reason. The same thing would happen with a sufficient thickness of glass, only that thickness would have to be very great indeed. You see, therefore, that actual transparency does not exist. Things which we *call* transparent only require to be thick enough, in order to become as opaque as wood or iron.

Now, white glass and water, of which we have been speaking, allow all the rays of the solar spectrum to pass through them, or, in other words, are transparent to them all; but coloured glass, as you know, acts differently. If you look through a piece of red glass, everything you see will have a red hue over it. This is because the red glass quenches nearly all the violet and blue rays, but allows the red ones to pass through it intact, and therefore you see everything with this red tinge. If you could get a piece of glass which would really quite quench all except the red rays, the effect would be different again. You would now see everything which appeared red in white light look a far more vivid and intense red, and everything else would appear black. This, if you think of it, is a proof of what I have already told you, viz. that no object has colour in itself. If it had, the colour of the light falling on it would make no difference to *its* colour. As long as you could see it at all, it would remain of the same colour, whether yellow, red, or blue light shone on it. Moreover, you would be able to see it in the dark, because, as all colour is light, if bodies possessed colour of their own, they would also give forth light of themselves.

There is a very simple and convincing proof which you can easily obtain of the fact that no object has any colour in itself. You know how exceedingly bright and vivid is the hue of a bed of scarlet geraniums in full flower. Go and look at it when night is coming on, and there is only just light enough left to make out the forms of the blossoms. They will appear quite black. That is because the beautiful bright red in which they are clothed all day belongs not to themselves but to the light which falls on them, and therefore when one vanishes the other must vanish too.

You can prove the truth of all colour being given by light in another way. Take a piece of white paper, and place it in one after another of the coloured rays of the spectrum. As you pass it through each colour, it will take that one as its own. Thus, in the green part of the spectrum it will appear green, in the blue blue, and so on. If instead of a white you take a coloured strip of paper, say red, what will happen? On placing it in the red part of the spectrum, it will appear a more intense red than ever, but in all the other colours it will appear black. A blue or green strip of paper would, in the same way, appear a brighter blue or green if placed in these parts of the spectrum, and black in all the others. This is because the red paper is only able to reflect the red rays of the spectrum, and the blue only the blue ; therefore, when placed in any except these, they are obliged to confess how entirely they owe their brilliant colours to light by appearing without them.

The fact that objects have no colour of their own explains why they so often look different by candle-light to what they do by daylight. Thus you know blue appears green, and white and pale yellow can hardly be distinguished. The reason is that the light given by a candle contains very few blue rays and a great preponderance of yellow ones. I think, however, I must not tell you any more about light and colour at present, for you have a good deal to remember already, so we will leave the rest for another chapter.

CHAPTER XIV.

LIGHT (*continued*).

SOMETHING MORE ABOUT COLOUR.

Mixing of colours—In paints—In the spectrum—Complementary colours—A great deal of white in the spectrum—Compound colours—Fundamental colours—Difference between mixing paints and spectral colours—Impurity of natural colours—Heat-rays of the spectrum—Chemical rays—Photography—Spectral analysis.

HAVE you ever painted? Some of you must, I am sure; and, in fact, I hear several voices answering "Yes" to my question. Well, if you have painted, you must know something about mixing colours.

"Of course we do. We know that blue and yellow make green, and red and blue make violet, and—— "

Stop—stop! that will do. I see you know something about mixing paints, so now I will try if you know or can guess anything about mixing the colours of the spectrum, of which I told you so much in my last chapter. You say that yellow paint and blue paint make green. Very well. Now, if the yellow ray of the spectrum were to fall on the same place as the indigo ray, what do you suppose would happen?

"They would mix and make a green ray," you answer.

No, you are wrong; at least, you are wrong in saying they would make *green,* for they do not. They make *white.*

"White! what, blue and yellow make white?"

Yes, they do indeed; and presently I will tell you why. But first I want you to know that every colour in the spectrum has another colour, as it were, belonging to it, and when these two are mixed they make white. Thus red and greenish blue make white, so do orange and Prussian blue, yellow and indigo, greenish yellow and violet. Each of these colours is called COMPLEMENTARY to the colour with which it makes white. They are, as it were, the complement or fulfilment of each other. But now, not only does one pair of complementary colours make white, but two pairs also make white. Thus, if we mix orange and Prussian blue, we get white, as you know; and if we add to orange and Prussian blue, red and greenish blue, we also get white ; just as, when all the colours of the spectrum are mixed, they form white. What does this show us ? I think it shows that each colour of the spectrum must contain a certain amount of white ; and if a colour which already has a great deal of white in it is mixed with another colour which has a great deal of white, the result is that the two together contain more white than they do colour, and therefore they appear pure white. It is the very same cause which makes the seven colours of the spectrum, when combined, appear white. There is such a great preponderance of white in the mixture that everything else is lost in it.

But now, supposing we mix complementary colours in different proportions from what we ought to do to make white, what will happen then ? In that case they do not make white, but some hue which lies in the spectrum between the two colours which are complementary to each other. Thus red and greenish blue make white ; but if we put too little red, or rather, if instead of making one of the deep red rays fall over the greenish blue, we replace it by one of the pale red ones which are nearer orange in hue, we shall not get white, but some tint of yellow lying between the deep red and the greenish blue which is its complement.

You see, therefore, that some of the colours of the spectrum are not single colours in themselves, but are made up of other colours, not mixed in the right quantities to make white. There are four of this kind of colours—COMPOUND COLOURS, as they are called, in the spectrum. They are, orange, yellow, blue, and indigo. Orange and yellow lie between red and green; blue and indigo lie between green and violet. Red, green, and violet, then, seem to hold very important positions in the spectrum, and so, in fact, they do. If you look back to the list of complementary colours I have given you, you will see that red and violet, which lie at the opposite ends of the spectrum, have nearly the same complementary colours. That of red is greenish blue; that of violet greenish yellow. Both violet and red require a great deal of green in their complementary colours, in order to make white when mixed with them. And, in consequence of this, if we take pure green and combine it with red and violet, these three colours together will make white. Now, you know already that complementary colours mixed in different proportions to those required for white make other hues which lie between them in the spectrum; and you know also that between red, green, and violet, which are complementary, lie the four other colours of the spectrum, which must, therefore, be made by different combinations of red, green, and violet. This is, in fact, the case. From these three colours mixed in different proportions, we can get all kinds of tints; but they themselves cannot be obtained by any mixture. They are therefore called FUNDAMENTAL COLOURS, because they are the foundation of all others.

And now I think it is time I should go back to the paints again, and tell you why it is that in mixing them such different results follow to those obtained by mixing the colours of the spectrum. The reason is, that in combining the latter we make an addition—we add one coloured light to another coloured light; but in mixing paints, though we seem to be adding colours together, it is really subtraction that is going on all the time.

Paints, like everything else, obtain their colour by quenching some rays of light and reflecting others. Thus blue paint quenches all except the blue rays which it reflects; yellow, all except the yellow which it reflects. If, then, we mix these two paints together, the blue rays of the blue paint are all quenched by the yellow, and the yellow rays of the yellow paint are all quenched by the blue; and if, indeed, these paints had actually reflected no rays of light whatever, except those which gave them their colour, the result of their mixture would be *black*, because no colour at all would be left. As a fact, however, both the blue and yellow paints, besides reflecting the rays of those colours, reflected also a small quantity of green which your eye could not distinguish; but now that the paints have quenched each other's blue and yellow rays, the green of both still remains, and is reflected to your eye. You see, therefore, in reality it is not by adding yellow to blue that we have obtained green, but by taking both away.

The same remarks exactly apply to all other mixtures of colour in paints. Thus, with red and blue, which you told me made violet, the real fact of the case is, that when mixed the red paint quenches all the blue rays of the blue paint, and the latter quenches all the red rays of the red, and then violet remains, because both the blue and red paints reflect a few violet rays, just as the blue and yellow reflect a few green ones.

From this you see that very few natural colours can be pure, or, in other words, not more or less mixed with some other colour. And this is, in fact, the case; and, in consequence of it, almost endless varieties of tints and hues are produced.

The spectrum has other properties besides that of colour. One is *heat*, and a very curious fact is that the most powerful heat rays are invisible. If a thermometer is placed in one after another of the colours of the spectrum, beginning with the violet, we find that it rises as it is moved towards the red, and just outside the red the temperature is highest of all. This shows very clearly that there are "dark" red rays which have more heat power than any of the visible rays. Beyond the violet are other invisible rays, which possess quite a different property. You must often have noticed how coloured objects, such as carpets and curtains, fade when they are exposed to the light. This is owing to the action of certain rays, called chemical rays, which cause changes to take place in the composition of substances exposed to their influence, and consequently in their colour also. The most intense chemical rays are just outside the violet, and it is owing to them that we obtain sun pictures, or photographs, to which I referred in a former chapter. The prepared plate of glass there spoken of, is one which has been dipped into nitrate of silver, which turns black when exposed to the action of light. When you stand in front of the photographer's box, your image, as you already know, is received on a lens which you see pointed towards you, and is thrown on the glass plate behind. There the chemical rays decompose the nitrate of silver, those parts of the plate turning blackest where the strongest light has fallen. Thus a likeness in black and white is formed on the plate, and is rendered permanent by having certain chemical solutions poured over it. On this plate, however, which is called the *negative*, all the light parts of your person come out black, and all the dark parts white; but afterwards other impressions are taken from it, by placing it in the sun, and under it paper prepared with nitrate of silver. Then the shades appear in their right places, because more light can get to the paper through the white parts than through the black parts of the glass, and therefore the nitrate of silver under the latter is most decomposed, and turns blackest.

Before we leave the spectrum altogether, there is one more thing to mention concerning it. By experimenting upon the solar and other spectra with the greatest care and patience, scientific men have been enabled to make some very wonderful discoveries about the composition of the sun (which contains many of the same substances as our earth, such as iron and hydrogen) and other heavenly bodies, and also to find out new metals. You would no doubt like to know how this is done, but the subject is one of too great complication and difficulty, to enter into in a book written so completely for beginners as this one. The method employed is called SPECTRAL ANALYSIS, and in order to understand anything about it, some knowledge of chemistry is required. Spectral analysis is, however, one of the most interesting and fruitful of all the scientific studies of the present day, and no doubt in the future will be the means of discoveries even more striking than those which have already been made.

CHAPTER XV.

THE GIFT OF SIGHT.

Light valueless without sight—The brain the part of the body which really sees—Use of the nerves—Impressions given to the brain by them supposed to be in all cases one of motion—Vibrations of light communicated to the optic nerve—Through optic nerve to the brain—Colour distinguished through faster or slower vibration—Dark rays of light—Retina acts as a lens—Images of natural objects all that we really see.

THERE is one very important thing with regard to light which I have not yet mentioned. I have been telling you a great deal about light itself, but I have said not one word of how it enables us to *see;* and without the power of sight, the whole universe might be full of radiance and colour, but they would be of no avail to us; we should be living in the midst of light, and yet for us it would not exist. The second great gift of which I have to tell you, then, is SIGHT.

You know very well that we see with our eyes. To understand all that has been discovered about the way in which we do so, is a whole study in itself, and I can say but a few words to you on the subject; still, I hope they will teach you something.

First, I must begin by telling you that though we say truly that we see with our eyes, hear with our ears, and smell with our noses, still we can only do this because through our eyes, ears, and noses, certain impressions are conveyed to the brain—the part of our bodies able to know and understand; and *in the brain* these impressions are turned into sight, hearing, and smell. In fact, the brain is the master, and the other parts of the body are servants, collecting information and sending it to him. They do not understand the information themselves, but the *brain* does, and therefore *you* do, because your brain belongs to you. The way in which information is sent to the brain by the different parts of the body is through the nerves. Our whole body, inside and outside, is full of nerves, all of which have their proper work appointed for them, as messengers to and from the brain. We have nothing to do with the latter at present, however; it is with the nerves which carry information *to* the brain that we are concerned; and if they did not exist you would be in a very poor plight indeed, for you would not know whether you were holding anything in your hand, or whether your feet were on the ground or off it—in fact, you would never feel, see, or hear anything at all. There are the nerves of smell, of hearing, of taste, of sight, and of touch; and through what they tell the brain you are able to smell, to hear, to taste, to see, and to feel. They make no mistake as to their work either, for you never find yourself seeing with your ears, or smelling with your eyes.

But, now, what message do the nerves give the brain? how do they manage to tell it that there is something going on which is important for it to know? I am sure this is the question you are longing to ask, and I will try to answer it for you as well as I can.

It is thought that *in all cases* the impression the nerves give the brain is one of motion, and in the case of sight you will easily understand it must be so. You know, now, that light itself is motion, and I have told you something of the extraordinary speed with which waves of light travel, and also of their extreme smallness. Thousands and thousands of these tiny light-waves strike upon the eye in one second, and they set vibrating a delicate membrane (or skin) lying behind that part of the eye which you see, and which is called the RETINA. This membrane is covered with a fine net-work of nerves, all branching from one special nerve, called the OPTIC NERVE, which connects the retina with the brain; and in this way the knowledge of the motion going on in the retina is conveyed to the brain, and this knowledge the brain turns into sight.

I dare say you will think I have given you but a poor and imperfect description of this most mysterious process, and you are right; but you must wait till you are able to enter upon a real study of the subject before you can gain any very clear idea of its details, and even then I doubt if you will ever learn that which you want most to know. You see I am guessing at your thoughts, and I think I am guessing right when I say that the question you would like best of all to have answered is, why should the motion caused in the eye by light, and conveyed to the brain by a nerve, become sight? That is just what I cannot tell you, any more than I can tell you why a seed planted in the ground grows into a tree; nor can any one else, not even the wisest and most learned man on earth. We know a little about *how* these things happen, but we do not know *why* they happen. At present that is a secret open only to God. Perhaps some day, as human knowledge goes on increasing, men may discover some of these wonderful "whys" which are hidden from them now; but till that time comes we can only bow our heads before the great mysteries of Nature, and humbly acknowledge our ignorance.

Up to this time I have not said anything to you as regards sight, except as the power to distinguish between light and darkness—to know that there is such a thing as light; but sight does far more for us than this. It enables us to tell one colour from another, and to know the shape and form of every object brought under our notice. How is this?

Well, as far as *colours* are concerned, we are able to distinguish them from each other because the waves of light vibrate with a different amount of speed, and it is their quicker or slower vibration which, making the motion they give to the membrane behind the retina different, causes that conveyed by the optic nerve to the brain to be also different, and the brain translates these changes in the rate of vibration into the various *colours*. The waves which vibrate the fastest give the impression of violet to the eye and brain; those which vibrate the slowest, the impression of red; and the other colours lie between in the order of the spectrum.

The eye, however, is not sensitive to *all* rates of vibration. Some are too quick to affect it, and some too slow; and this is the reason why, beyond the extreme violet and extreme red, there are *dark* rays of light. They are so because in the former case they vibrate too quickly, and in the latter too slowly to produce any impression on the eye. In the solar spectrum, the yellow light, which is nearly in the centre, is decidedly the most vivid. On one side the colours die into the violet, on the other side into the red, both of which are much less bright than yellow. The reason of this decrease of brightness is because the rate of vibration is becoming quicker on one side and slower on the other, and so gradually approaching the point at which it will be too quick or too slow to affect our sense of sight at all.

The different rates of vibration, then, enable us to distinguish colour; but how do we know the difference between one form and another?

All I can tell you about this is that the things we see are thrown upon the retina of the eye in the same kind of way that they are reflected upon a lens. We have, in fact, a little picture of them in our eye; the nerves tell the brain this, and the brain under-stands the picture in such a way that we *see* it, and that is the same to us as if we really saw the object which causes the picture, though, in fact, we never do so. We never see anything but its reflection!

You must find this hard to believe, I am sure. It must seem very strange to you to think that you really never see actual trees, houses, and people, but only their pictures. Yet it is true, nevertheless, and may well make us think of those words spoken long ago by one whom God taught, though he was not learned according to man's present notion of learning—the words which tell us that we are "fearfully and wonderfully made."

And now we must bid farewell to light, about whose wonderful doings the last few chapters have been telling you. I hope you are sorry, so sorry that you will come back to learn more as soon as you are able. Perhaps some of the explanations I have given you may have seemed rather difficult to understand, but you must not mind that. The most beautiful views are those we see from the hill-tops; and when you come to an explanation rather harder than usual, you must just think you have a stiff bit of climbing to do, and will be well rewarded when you get to the top.

CHAPTER XVI.

SOUND.

The gifts of sound—Sound a wave-motion—Transmitted through the air—Vibrations are longitudinal—Illustration of marbles in a groove—Sound-waves spread in all directions—Speaking-tubes and speaking-trumpets—Sound takes time to travel—Speed affected by the temperature of the air—Liquids and solids transmit sound—Solids with most rapidity—Reflection of sound causes echoes—Sound can be brought to a focus.

You have read something of what light does for Nature and for man; how to it alone belong all those radiant and various hues in which every object is clothed, and how to it we are indebted for knowing anything of the beauty by which we are surrounded, since to all its other gifts is added that of sight; and perhaps you have tried to realize what a sad and terrible place this world would be if light were not. I have now to tell you of something no less important than light, and to which we owe gifts quite as precious. You know what I mean, for the name stands at the head of this chapter. It is SOUND; and just as without light creation would be blind and colourless, so without sound it would be deaf and voiceless. An utterly silent world! Think what that means! No speech, no laughter, no music; no song of birds or murmur of insects; no ripple of streams or happy rustling of summer breezes in their leafy home; nothing but a dreary, voiceless blank. The gifts of sound would appear of priceless value indeed if they were only to be won through hard labour and struggle; but, as it is, they are lavished freely on every side, and the very abundance of our possession makes us regard it lightly. But you do not want to hear any more moralizing, I am sure; you would rather listen to what I have to tell you about sound, and I am quite ready to begin. It must be, however, with the question we have asked twice before with regard to heat and light. Before anything else, we found out what they were, and now we must inquire—What is sound?

Well, sound, like radiant heat and light, is *motion;* and, moreover, like them, it is a wave-motion, only in this instance the waves are not made of ether, but of something with which you are much more familiar —of *air*. You remember, I hope, what a wave-movement really is—a shape travelling forward through set after set of molecules, while the molecules themselves do not move on, but only vibrate either up and down or backwards and forwards. In waves of water and of light these vibrations take place up and down; in waves of sound they take place backwards and forwards. You can get a very good idea of the way in which a wave of sound moves along by taking a number of marbles, and placing them in a row in something which will serve as a groove for them, such as a very long pen-tray, and then drawing back one of the end marbles and giving its neighbour a good hit with it. You will see the marble thus struck, at once pass on the blow to the next, and then roll back to its old position, and remain still; the second marble passes on the blow to the third, the third to the fourth, each returning to its old position after its forward movement, and so on, till the last marble is reached, which, having no other in front of it, is pushed forward, and if the edge of the pen-tray did not keep it back, would probably roll over on to the table. Now, this is exactly how the particles of air which convey the wave of sound to your ear behave. Each of them makes a little movement forwards and backwards—forwards to hit its neighbour, and backwards to return to its old place; and in this way the blow which was given to the first particle passes on till it reaches the last, viz. that one which hits the membrane in the drum of your ear.

But, now, I need not tell you, I am sure, that the firing of a gun, the clapping of your hands, or any other cause which gives such a blow to the air as to result in sound, hits not one, but many particles, or molecules, as we ought rather to call them; and as these set in motion all those touching them, and these, again, all those touching *them*, the waves of sound spread in every direction, just as waves of water and light do. Therefore, when a shock producing sound is given to the air, it is heard not only in one, but in all directions round the spot where the shock was given. As the waves of sound spread, however, they grow less powerful, so that if the disturbance which first produced them is not repeated, they gradually die away. You know a sound which comes to you from a distance is not nearly so loud as one close by, and this is because it has been weakened so much by spreading all round. If the wave of sound can be prevented from spreading, it will travel a long distance without losing its strength. You can prove this for yourselves by speaking through an empty iron water-pipe or a long wooden tube. In these the waves of sound cannot spread, being held in all round by the sides of the pipe or tube, and therefore they lose none of their strength; and you could, if you chose, carry on a conversation with a friend through a pipe two or three thousand feet long, and yet never raise your voice. You have, I dare say, seen this done on a small scale through the tubes which in some houses connect the living rooms and the servants' offices together. The master and mistress can then speak their orders down the tube, and though the people who are in the same room with them cannot hear what they say, the servants in the room at the other end of the tube hear quite well; and a contrivance of this kind saves a great deal of bell-ringing and running up and down stairs.

The speaking-trumpet, which is so useful to captains of ships and others who require to make the voice heard at a considerable distance, is nothing but a tube which keeps the waves of sound from beginning to spread and, consequently, weaken directly they leave the mouth of the speaker. They are confined, at any rate, for a short distance, so that a greater volume of sound reaches the person towards whom the trumpet is directed than could do so if the mouth alone were used. You often see people make a speaking-trumpet of their hands when no better one can be had at the moment, and even so short a tube as that is better than none.

From what I have told you of the way in which waves of sound travel, I think you must already see that they take time to do so, as is, indeed, the case. Even waves of light do not, as we have seen, travel instantaneously, and sound moves forward very much more slowly; for, to all intents and purposes, the motion of light over any length of space afforded by our earth is instantaneous Its rapidity is such that it cannot be measured by the senses. This is not at all the case with sound. You must often have noticed that when a gun is fired some distance off, you first saw the flash, and then, a few seconds after, heard the report. Now, these few seconds which elapse between the flash and the report of the gun are the exact length of time it has taken the sound-wave to pass over the distance between the gun and your ear.

You see, therefore, that if we can find out how far sound travels in one second, we shall always be able to tell how far off a gun is fired by counting the number of seconds which pass between seeing the flash and hearing the report. Now, sound travels about 1100 feet a second; therefore, if we hear the report of a gun five seconds after seeing the flash, we know that it must have been fired about 5500 feet off, which is a little more than a mile. We can calculate the distance from us of a thunder-cloud in the same way. If the peal follows the lightning immediately, we know the cloud must be close overhead, but if ten or twelve seconds pass between them, it is a long way off, and we need fear no danger.

I do not want you to suppose, however, that sound always travels through air with the same rapidity. This is not the case. The temperature of the air has a great effect upon the speed with which sound moves through it. Air in which the thermometer stands at the freezing point of water (0° centigrade) transmits sound at the rate of 1090 feet a second. At one degree above 0° centigrade, the speed is increased to 1092 feet a second; at a degree higher still, the speed is 1094 feet; and, in fact, for every degree centigrade added to the temperature of the air, sound moves through it at an increased rate of two feet for every second. The reason of this is that as the air grows hotter, it grows more elastic, and therefore the vibrations of the sound-wave take place quicker.

Air is not by any means the only thing able to transmit sound. All other gases, and liquids, and solids as well, do so. The sound-waves pass through them exactly as they do through the air. Some shock causes the molecules of the liquid or solid to vibrate forwards and backwards, and that causes sound.

You can easily prove that solids transmit sound, by taking a long stick and putting one end to your ear while you get some one to scratch the other end. You will hear the scratching very distinctly indeed. I do not think you could so easily find a way of proving that liquids transmit sound; but if you ever learn to dive, you will find out that, when under the water, you can hear noises made on the surface—which shows, of course, that the sound has travelled through the water to your ear. You might try the same experiment by plunging your head into a pail of water, and then getting some one to speak to you; but perhaps that would not be altogether pleasant.

In some gases, and in all liquids and solids, sound travels far more rapidly than through air. For instance, if you were to put your ear to a rock being blasted at some distance off, you would hear two reports instead of one; the first would reach you through the rock, the second through the air.

I dare say this seems rather strange to you. You would have thought that as air is so much less dense than any liquid, and liquids in their turn so much less dense than solids, sound would have travelled fast through air, more slowly through water, and slowest of all through a solid body. I will tell you why this is not the case; and you must remember, to begin with, what I said just now with respect to the rate at which sound moves through air. The speed increases as the air (through rising in temperature) becomes more elastic; it is on the elasticity of the body transmitting sound that the latter depends for its greater or less speed. Now, in proportion to their density, liquids and solids are very much more elastic than air. Perhaps you may remember what has been said before about such substances as wood and iron having great elastic force. Owing to the large amount of strength required to displace their molecules in the first instance, a large amount must be exerted by the molecules themselves in order to return to their old position; and as they do this by their elasticity, the force of that elasticity is very considerable. I will now explain to you in what way this affects the speed with which sound travels.

When a shock is given to the *air* which causes its molecules to vibrate and produce sound, they are not obliged to exert themselves much in order to move forwards and backwards, so they do it in rather a lazy, languid sort of way, much as you might see a strong man dawdle over an easy job, and consequently the sound-wave passes forward slowly. When, however, a shock of the same kind is given to a metal or a piece of wood, then the molecules have to use a great deal of strength to get through their vibrations; and, therefore, the latter are done in a quick, energetic way—just as a man sets to in good earnest when he knows he has a hard piece of work before him—and the sound-wave is consequently passed forward rapidly.

There is one more thing I must tell you about sound before closing this chapter, viz. that it can be reflected like light; therefore, just as the reflection of light gives us an image of any object placed before a mirror in the mirror, so the reflection of sound gives us an image of sound, or, as we say, an ECHO. Echoes are caused by any obstacle encountered by the sound-waves, which throws them back upon themselves instead of allowing them to follow their onward course uninterruptedly. Walls, rocks, and cliffs send back echoes, as I dare say you have often proved for yourselves. I have had a splendid echo returned to me from a thickly wooded hill, on the opposite bank of a river by which I was standing. In large empty halls and rooms there is nearly always an echo. I say empty, because when they are full, either of people or furniture, there are so many obstacles to turn back the sound-waves that the latter cross and recross, interfere with and extinguish each other, as I have before told you that waves of light do. Consequently, the same room which has an echo when empty has none when full.

Sometimes the same sound-waves are reflected from more than one surface, and then we get a double or treble, instead of a single echo. A deep well, lined with smooth masonry, may give you an example of this. If you shout "Ha!" down it, you will hear a regular peal of laughter, and a single clap of your hands will sound like a violent hailstorm. You do not often find a well which would give you so good an example of multiple echoes as this, however, because, in general, the masonry lining a well is rough and uneven. Consequently, the sound-waves break and are weakened, often extinguished altogether, instead of being reflected as wholes. A very pretty instance of repeated echoes is sometimes heard in the

Swiss mountains, and is given by the notes of the Alpine horn as they are reflected from rocks at different distances. At first the echoes are loud and clear, but as they are repeated again and again they grow gradually fainter, and at last die away entirely, as if the sound which caused them were gradually retreating further and further up the mountains.

Clouds are able to reflect sound, and the rolling of thunder is in great part due to the echoes given back by the clouds; not altogether, because the passing of sound from thinner into denser air is enough to cause a slight echo, and during a thunderstorm the air is always very unequal in density.

Curved ceilings and walls have a very curious effect upon sound; in fact, they bring it to a focus, as curved mirrors do to light; and as the place of the focus depends on the shape of the curve, the echo or reflection sent back from a curved surface is often heard in quite a different direction from that in which the sound causing it comes. The secrets of the confessional have been inconveniently revealed in this way, and it is also the cause of whispering galleries, such as that in the dome of St. Paul's, which you must certainly have heard of, and have very likely tried for yourselves.

CHAPTER XVII.

SOUND (*continued*).

How we hear—Noise and music—To produce music the vibrations must be perfectly regular, and of a certain rapidity—Pitch of musical notes—Pitch to sound what colour is to light—High pitch means rapid vibration, low pitch slow vibration—The octave—Fundamental note—Stringed instruments—Rate of vibration of stretched strings depends on their length—Thickness—Weight—Division of stretched strings into vibrating parts—Bells—Rate of vibration depends on the diameter and thickness of metal.

IN this chapter we are going to try and see how sound works. I should hardly use the word "see," though; for if there is one thing more certain than another, it is that we cannot *see* sound; we *hear* it. Now, how do we hear it?

If you remember the explanation I gave you about sight, I think you will hardly need me to tell you how we hear.

Sound is, like light, a vibrating motion; only, to produce light, the vibrations take place in ether, and to produce sound they take place in air. The vibrations of the ether, as you know, impart an almost innumerable quantity of shocks to the retina of the eye, the retina passes on its vibrations to the optic nerve, the optic nerve to the brain, and the brain shows it feels this motion by enabling us to see. Exactly the same thing happens in the case of sound. The vibrations of the air impart a series of shocks to a membrane (called the tympanic membrane) stretched across the hollow of the ear, and closing that part inside called the "drum." This membrane passes on its vibrations through a series of little bones, a second membrane, and a wonderful organ called the labyrinth, which is filled with water, to the AUDITORY, or hearing nerve; the latter transmits them to the brain, and this time the brain translates the motion it feels into sound.

You see, then, that since what we understand by sound is a series of vibrations felt by the brain, any difference in the vibrations must cause a difference in the sound, and you know yourselves how extremely unlike each other sounds can be. If you knock down a set of fire-irons, you hear what we call *noise* (and a very ugly noise too). If some one plays the piano or the organ, you hear what we call *music.*

What is the difference between these two, noise and music?

Perhaps you will tell me that the one is a pleasant, and the other an unpleasant sound, which is very true; but that does not explain *why* some sounds should be pleasant and others the reverse. The fact is, that, in order to produce a musical note, the vibrations causing the sound must be of equal strength, and must follow each other with perfect regularity, *i.e.* there must be exactly the same interval of time, between each. When this is not the case, the ear receives a number of unequal, irregular shocks instead of smooth beats, and we become conscious of a harsh, disagreeable noise, instead of the melodious sound we call music. Any SONOROUS or sounding body may be musical also, if the shocks which it imparts to the air are perfectly regular, and also if they follow each other quickly enough for the effect of one not to have ceased before the next reaches the ear. A watch ticks with perfect regularity; yet the sound it produces is not music, because between each shock given to the air there is time enough for the vibration it causes to have died entirely away in your ear before the next follows it. Supposing the watch were made to tick as fast again as it now does, this would no longer be the case. The vibration caused by the first shock would not have ceased before another followed upon it, so that instead of hearing a distinct series of little ticks, their sound would be linked together, and produce a prolonged musical note.

Any sound which recurs again and again at a regular interval of time might become musical by having those intervals made sufficiently short. No doubt you have often noticed how, as a train leaves the railway station, the puffs of steam from the engine follow each other at first slowly, and then faster and faster, till you are unable to count them. If these puffs came a little quicker still, a sound like a powerful organ peal would issue from the engine. The flight of insects is accompanied by a musical sound (humming, or buzzing, we call it), because their wings beat the air with perfect regularity, and quickly enough not to allow one vibration to cease before the next succeeds it. The flight of birds is only noisy because, though their wings strike the air regularly, they do so too slowly to produce a musical note.

The words "musical note" remind you, no doubt, what a great variety of these there are, and how completely distinct they are from each other in quality of sound, or PITCH, as it is usually called. On a summer's day the whole air seems to be alive with music; there is the low, deep hum of bees, the shrill, chirping cry of grasshoppers and crickets, the "cooing" of the wood pigeons, the songs of the thrush, the blackbird, the linnet, and others of the feathered tribe; and all these you distinguish easily by means of that special quality of sound or pitch which each note possesses as its own. In the same way every note of a piano or violin produces its own distinct effect upon your ear, and you do not confound it with any other. Pitch is as important to sound as colour is to light, and difference of pitch, like difference of colour, is produced by a faster or slower vibration. You remember, perhaps, my telling you that the deepest colour in the solar spectrum, violet, is that produced by the waves of light which give the greatest number of shocks to the retina in one second. Well, in the same way the *highest* pitched notes are produced by those waves of sound which give the tympanic membrane the greatest number of shocks in one second, and the *lowest* pitched notes by those which give the fewest. Between these two extremes lie all the intermediate notes, just as all the intermediate colours lie between violet and red in the spectrum. It is worth while to notice, however, that the ear has a much greater range of sound than the eye has of colour, and, moreover, mixed sounds can be distinguished by the ear, whereas the eye cannot distinguish mixed colours; it only sees an alteration of hue or a change of colour caused by the mixture, and is quite unable to separate the ingredients.

In music, as no doubt you know, there is a very decided relationship between the sounds of different notes which their distinctive pitch does not at all destroy. The only example I will give you is that of THE OCTAVE. If you strike the middle C of the piano, and then the eighth note above it, you at once hear that they are related. In fact, they are (as we say) the same notes, only that the one is "an octave higher" than the other. If instead of striking the eighth note *above* the middle C you strike the eighth note *below* it, you notice the same relationship, only this time the second note is an "octave lower," instead of an "octave higher" than the first. The reason is that the eighth note above the middle C is produced by exactly double the number of vibrations in one second required to make the sound of the middle C itself, and the eighth note below is produced by half the number of vibrations in one second. The *sixteenth* note above the middle C gives us a sound *two* octaves higher than the latter, because the number of vibrations has again been doubled; the sixteenth note below, a sound two octaves lower, because the number of vibrations has been decreased in the same proportion. In fact, at every multiple of eight, either above or below the middle C, you obtain the sound of C again, only always at a different pitch, so many octaves higher or lower as the case may be. For every higher octave the number of vibrations is double that of the one preceding it; for every lower octave it is reduced one half.

The note which you make the starting point for your octaves (be it C, E, A, or any other) is called THE FUNDAMENTAL NOTE; and between the fundamental note and its octave lie the other musical intervals with which very likely you are practically acquainted, but I shall not enter upon them here. Their relationship to the fundamental note and to each other, and their harmony or discord when sounded together, depend entirely on their rate of vibration, and on the proportions these vibrations bear to one another. Even this slight attempt at explanation you will, I am afraid, find rather difficult, so we will leave the subject of musical intervals altogether, and turn our attention to musical instruments.

Those in most general use are of two kinds, STRINGED and WIND instruments. The piano and the violin are examples of the former, the organ and the flute of the latter.

The "strings" of an instrument are made either of metal wire or of catgut. They are stretched to a certain defined extent, and are tightly fastened at either end to a portion of the instrument. Between the two ends they may be left perfectly free (as in a harp), or they may pass across a "bridge," such as you see supporting the strings of a violin, in the centre. When these are rubbed (as with a violin bow), or struck (as by the little hammers in a piano), or plucked, *i.e.* pulled aside by the hand and suddenly let go (as is done to those of a harp or guitar), they are made to vibrate with perfect regularity and great rapidity, and this vibration being communicated to the surrounding air, music is the result.

You must not suppose, however, that it is the shocks given to the air by the strings themselves which produce the greatest part of the sounds you hear. In most instruments this is not the case, for the strings are too thin to make the air vibrate with enough strength to cause so great a volume of sound. Most instruments are therefore provided with sound-boards, *i.e.* with hollow wooden boxes, over which (as in the violin) the strings are stretched. Their vibrations then cause the soundboards and the air contained in them to vibrate also, and it is *these* which really set the surrounding air in motion and cause the music we hear.

It would be impossible for me to tell you in detail how the vibrations of the strings are regulated so as to produce the great variety of notes which you know every instrument is able, to a greater or less extent, to give forth. You could not understand this without entering into explanations which I fear you would find long and tedious, so we will not attempt them. I can just tell you, however, that the pitch of the notes in a stringed instrument depends on the *length*, the *thickness*, and the *weight* of the strings, and on the tightness with which they are stretched.

The longer a string is the more slowly it vibrates, and, therefore, the lower will be the note it produces. The shorter a string is the quicker it vibrates, and, therefore, the higher the note it produces. It is the same with thickness; a thick string vibrates slowly, a thin one quickly; therefore, a thick string gives a low note, and a thin one a high note. For instance, if you had two violin strings equally stretched and made of the same substance, but one half the length of the other, the short one would vibrate just twice as fast as the long one, and would give a note an octave higher. If the two strings were the same length, but one half the thickness of the other, the thin string would produce a note an octave higher than the thick one, because it would vibrate twice as fast. In the same way a slack string vibrates slower than a tight one, and therefore gives a lower note. No doubt you have often heard people speak of a piano or violin being "flat." This simply means that the strings of the instrument have become a little loosened, and therefore its notes are at too low a pitch. As to the *weight* of the strings, your own common sense would, I am sure, tell you that a heavy string must vibrate more slowly than a light one, and therefore produce a lower note.

All this time I have been speaking of the vibrations of *whole* strings; but before leaving the subject I must tell you that they are able to vibrate in *parts* as well as in wholes, and the number of vibrating parts into which a string divides, depends on the place where it is touched by the performer. It is because of this power of vibrating in parts that a single string is able to produce so many different notes as you know that of a violin can do.

Before closing this chapter, there is a class of musical instruments which must not go unmentioned, for to it belong some with which you are very familiar indeed, I mean BELLS. A bell, as you know, is a hollow piece of metal, with a tongue or clapper, also made of metal, hanging loosely inside. When the bell is swung to and fro, this clapper strikes each side of the bell alternately, by which means the metal is made to vibrate; its vibrations are imparted to the air, and a series of musical notes is the result. The more rapidly the bell vibrates, the higher, of course, is the pitch of its notes; and the rate of vibration depends on two things—the bell's diameter and the thickness of the metal of which it is made. The greater the diameter (or the width across), the slower is the vibration; the greater the thickness, the faster is the vibration. Thus supposing you had three bells, two rather large ones of the same diameter, but one of which was twice as thick as the other, and a third with only half the diameter of the first two, but as thick as the thick one. The large *thin* bell would give a note of a certain pitch, the large *thick* bell would give the same note an octave higher, and the *small* thick bell two octaves higher. You see, therefore, that a bell set in vibration does not follow the same laws as a stretched string, for if the latter is thick it vibrates slower, not faster, than if it is thin. The reason of this difference is that the vibrations of the string depend on the elasticity given to it by the force with which it is stretched; those of the bell depend on its own natural elasticity, as do the vibrations of all solid pieces of metal, wood, or glass used in musical instruments, whatever their shape may be.

CHAPTER XVIII.

SOUND (*continued*).

Wind instruments—Reason of their being so named—Effect on the sound of a tuning-fork produced by a hollow jar—Vibrations in resonant tubes—Mouth instruments—Reed instruments—Organ pipes—The human voice—Mixed sounds—Harmonics of a fundamental note—Fundamental notes the same in all instruments—Harmonics different—Sounding bodies are energetic.

UP to this time we have been considering musical instruments which, whether stringed or not, vibrate themselves, and, by communicating their vibrations to the surrounding air, cause the musical sounds we hear. The instruments I am now going to tell you about owe all their power of producing music to the air itself; and hence their name, WIND INSTRUMENTS. All wind instruments have a hollow part, and it is the air inside this which, being made to vibrate, and imparting its vibrations to the air outside, is the cause of the music. Before naming any special instrument, I want to explain to you something about the effect produced on sound by a tube filled with air.

I dare say you have seen a tuning-fork, and know what it is like; and certainly you have very often seen a common glass or china jar. Well, if you had a tuning-fork of the right pitch, and a jar of the right depth, on holding the tuning-fork over the jar, its note would be very much louder than if it were sounding in the open air of the room; and supposing that in the latter case its note had died away altogether, on placing it over the jar the sound would ring out again quite clearly. You see, therefore, that the effect of the hollow jar on the sound of the tuning-fork is to increase that sound very much. The reason is that the vibrations of the tuning-fork when held over the jar make the column of air inside vibrate in exactly the same way, and, consequently, this column strengthens the note of the tuning-fork, because it is giving out the same note itself, or, in other words, imparting the same motion to the outside air.

You must not suppose, however, that every jar will produce this effect on every tuning-fork. You might have a dozen tuning-forks, and hold them by turns over the same jar, and only one of them, or perhaps not one, would have its note strengthened. This is because the jar is not of the right depth to suit the pitch of the tuning-forks; it contains either too high or too low a column of air to be thrown into the same state of vibration as theirs, and, consequently, cannot make them sound louder. A tuning-fork of a low pitch, *i.e.* one which vibrates slowly, requires a deep jar; one of a high pitch, *i.e.* one which vibrates quickly, a shallow jar; and starting with a fork of any determined pitch as your fundamental note, you would have to double the height of your jar for every octave below that note, and shorten it by one half for every octave above. For instance, if you were to start with a fork requiring a jar eighteen inches deep to increase its sound, a fork pitched an octave lower would require a jar thirty-six inches deep; one two octaves lower, a jar seventy-two inches deep, and so on. In the same way, a fork pitched an octave higher than that sounding the fundamental note would require a jar nine inches deep; one two octaves higher, a jar four and a half inches deep. It is very wonderful how a jar of this kind, or, to speak more accurately, the column of air contained in the jar, is able to select that particular note whose rate of vibration is the only one which it can make its own, and which enables it to *resound*, as it is called; for if one hundred vibrating tuning-forks of different pitches were held over the same jar, it would only increase the sound of that one whose vibrations were the same as its own. What is still more wonderful, however, is that, without the help of any tuning-fork at all, a RESONANT (*i.e.* re-sounding) jar or tube may be made to give forth its note. All that is necessary is simply to blow across it; only you might have some difficulty in making the experiment succeed, because, in order to do so, the tube would have to be very narrow in proportion to its depth. If, however, you had a jar or tube narrow enough, on blowing across it you would hear a distinct musical note; on blowing rather harder (and thereby causing a more rapid vibration), a higher note would be heard, and you might, by carefully regulating the strength of the current of air coming from your mouth, obtain several notes, each of a different pitch, from the same tube. The reason why this very simple process is able to produce music is that your blowing causes a series of little vibrations to take place over the mouth of the tube, and the column of air within it, picking out that one which suits itself, vibrates according to it, and forces all the rest of the current to do the same, by which means the necessary motion is imparted to the outside air, and a musical note is the consequence.

You can now broadly understand the principle of wind instruments; they must consist of one or more tubes or pipes filled with air; there must be a contrivance to throw this air into vibration, and its vibrations must be so regulated that different notes can be produced. All this is done in a variety of ways, as you know by the great number of wind instruments you have heard and seen. They are, however, all divided into two classes—reed and mouth instruments.

In mouth instruments a current of air is made to enter at one end of a tube, which at the other may be either open or closed; and this current, by its motion, sets the air already contained in the tube vibrating, and causes music. The place where the current enters is called the *mouth.* The flageolet and the common whistle are mouth instruments.

In reed instruments the current of air, on entering the tube, makes a thin piece of wood or metal vibrate in such a way that it alternately opens and closes the hole by which the current enters the tube, and thus causes the air contained in the latter to vibrate and become musical. The bassoon and the clarionet are examples of reed instruments. The organ is both a mouth and a reed instrument, for its pipes are of both kinds. The pitch of organ pipes is regulated by their length, and the mouth pipes are made either open or stopped. In order that a stopped pipe may produce the same note as an open pipe, however, it must only be half as long.

Our own human voice is the most wonderful and interesting example of a reed instrument. At the top of the windpipe (the elastic tube which conducts the air from the mouth to the lungs), and nearly closing its opening into the throat, are elastic, sinewy bands, called the VOCAL CHORDS. When air is forced through them into the mouth, these vocal chords are made to vibrate and give forth different sounds, according to the greater or less amount of stretching they are undergoing. This stretching force which regulates the motions of the vocal chords is, of course, under our own control; and yet we never have to think about it. Our words come quite easily and naturally, each one having its own distinctive sound, and while we are speaking we trouble no more about the movements going on in our throats than about the shape the inside of our mouths is taking; and yet this, too, is of the greatest importance, for by altering the shape of the hollow of the mouth, it can be made to increase the sound of that special note given by the vocal chords which is most necessary to the word we want to utter. In fact, the mouth is the resonant tube of our human musical instrument, and most perfectly does it do its work.

And now for the last thing, I have to tell you about musical instruments, and which I have kept till the last because it applies to all equally.

Perhaps you remember my saying, when we were on the subject of light, that no natural colour is perfectly *pure,* but that all contain a greater or less mixture of some other colour. Thus we found that violet and red objects reflect a certain number of green rays, only so few in comparison with those which give them their colour that, unless the latter can be quenched, we do not see the green rays at all.

Just as colours are not pure, so musical notes are not pure; there is a mixture of other notes with them; but, as a rule, they are not heard, or heard only very indistinctly, because the louder sound of the fundamental note drowns them. If this can be taken away, however, or very much subdued, then we are able to hear the other notes which are sounding at the same time, and which are called THE HARMONICS of the fundamental note. If you have a good ear for music, you might perhaps distinguish the harmonics of a low note on the piano, struck singly and rather hard. First you hear only the fundamental note, then its octave is distinguished, then the other musical intervals in regular succession.

The reason why the harmonics of any note always mix themselves up with it in this way, is because the vibrating portion of an instrument (whether a stretched string, a solid piece of wood or metal, or a column of air) cannot vibrate as a whole without also vibrating in its parts. I have already told you that the strings of stringed instruments can be divided into separate vibrating parts, and each of these represents a different note. Now, not only *can* they be thus divided when the performer chooses, but they always do thus divide themselves in a different way for every fundamental note he plays, the consequence being that the harmonics of that note mix themselves with it, and give it the peculiar quality of sound which enables us to distinguish it from the same fundamental note played on any other instrument; for it is the harmonics of different instruments which cause the difference in their sound, not the fundamental notes. The latter, if they were *pure*, would all be the same, because they would all vibrate at the same rate; the harmonics of each kind of instrument, on the contrary, vibrate at different rates, and therefore have a different tone.

We must now leave the subject of sound; but before doing so, I want you to observe that sounding bodies, like heated and luminous bodies, are energetic. In the latter case we can transform the visible energy of motion into heat and light, and we feel or see it; in the former, into sound, and we hear it; so that different as sound and light are, we can trace them to a like origin, and are once more made to see the unity which runs through Nature.

CHAPTER XIX.

ELECTRICITY, FRICTIONAL AND INDUCED.

Nature of electricity unknown—Name derived from *electron*—Result obtained by rubbing sealing wax—And glass—Two kinds of electricity—Repulsion and attraction—Electrical separation—Conductors and non-conductors—They are electrified in different ways—Electrical machine—Induction—Opposite kinds of electricity always try to combine—Leyden jar—Identity of lightning and electricity—Action of points on electricity—Lightning-conductors—Forked, sheet, and globular lightning—Thunder.

We have now come to the last and the most mysterious of those natural agents which I have been trying to tell you about. Its name is ELECTRICITY, and its mysteriousness consists in this—that though we can observe its workings, and the laws by which it acts, with such accuracy as to enable us to make it our obedient servant, we have not the least idea what it really is. You have, no doubt, heard the term "electric fluid," and as in many respects electricity behaves like a fluid, scientific men have frequently assumed, for convenience' sake, that it is one (or rather two, as we shall see presently); but they have never yet been able to find out whether this is really the case or not. So far as any certainty about its nature goes, we are still in the dark concerning it.* With respect to its action, however, and to the laws which govern that action, a very great deal has been discovered, and of that the chief part within the memory of man.

The name "electricity" itself comes from *electron*, the Greek for "amber," because amber was the first substance which called attention to the existence of such a force. In ancient times it was found that amber (which is a kind of resin or gum), after it had been rubbed, was able to attract small, light bodies towards itself; and this property was called, after it, ELECTRICITY. All resinous substances can do the same thing, as you may easily prove by taking a stick of sealing-wax and rubbing it with a warm, dry woollen rag for a short time, and then placing it near

* Recent and most striking experiments made both in Germany and England appear conclusively to prove, however, that the electric and magnetic forces are propagated by the same medium as light, viz. the ether—and this is a great and very hopeful advance towards the possibility of obtaining some real knowledge respecting their nature.

some small pieces of paper. You will see the little bits of paper fly towards the sealing-wax, and remain sticking to it, as you have seen needles do to a magnet. By rubbing the sealing-wax you have caused it to become electrified, or charged with electricity; and in this state, it has the power of attracting the little bits of paper and charging them with electricity also. When this process is accomplished, the pieces of paper fall off the sealing-wax, and will not be attracted by it again for the time. If, however, besides the sealing-wax, you have a small glass tube or rod, and get some one to rub it for you with silk, in the same way that you do the sealing-wax with flannel, you will find that as soon as the latter repels the little pieces of paper, *i.e.* causes them to drop off it, the former is able to attract them instead, and they fly towards, and adhere to it in the same way as they did to the sealing-wax.

Now, this peculiar behaviour of the paper towards the wax and the glass shows us two things: first, that there must be two kinds of electricity, one produced by rubbing *resin,* and the other by rubbing *glass;* and secondly, that bodies having the same kind of electricity repel, and those having different kinds attract each other. These two sorts of electricity are called *resinous* and *vitreous;* they are also named POSITIVE and NEGATIVE, positive standing for vitreous electricity, and negative for resinous.

In objects which are in a natural state, these two kinds of electricity exist in exactly equal quantities, and what we really do when we rub the sealing-wax with flannel or the glass with silk, is to separate the two kinds from each other. In the former case, the positive electricity collects upon the flannel, and the negative on the sealing-wax; in the latter the positive electricity collects upon the glass, and the negative upon the silk.

You must not suppose, however, that the same substance is always electrified in the same way, for that would be a mistake. Glass rubbed with silk collects positive electricity, as we have seen, and the negative remains on the silk; but rubbed with cat-skin, it collects negative, and the positive remains on the cat-skin. You see, therefore, that a single substance cannot choose how it will be electrified, for that depends on some kind of relationship between it and whatever it is rubbed with.

You remember, no doubt, that when speaking of heat, we found some bodies were good, and some bad conductors. The same is the case with electricity. We find that it spreads with the greatest ease over some substances, while over others it does so only very slowly and imperfectly. The human body is a good conductor of electricity, as you can easily prove; for if, after having EXCITED (or charged with electricity) a stick of sealing-wax or glass, you hold it in your hand, it will very soon lose its surplus electricity, which will run off through your hand and body to the earth, the earth being a vast reservoir of both kinds of electricity, and always absorbing them if they have the chance of getting to it. If you were to hold the glass or sealing-wax in a pair of ordinary steel or iron tongs, exactly the same thing would happen, for iron, and, in fact, all metals, are good conductors of electricity; but if you were to use a pair of pincers tipped with glass, the electricity would not be able to escape in this way, because glass is a very bad conductor of electricity; in fact, it is what is called a NON-CONDUCTOR, or INSULATOR. This latter name is given to it because, in making experiments on electrified bodies, it is continually necessary to keep them from contact with any conducting substance, so that their electricity may not run away. This can only be done by surrounding them with some non-conductor, such as glass, when they are, as it were, isolated, or INSULATED, so far as their electrical condition is concerned, from everything round them, the air being a non-conductor, and, therefore, not allowing them to part with their electricity by its means. The earth is a very good conductor of electricity, so is water; and, in consequence of this latter fact, damp air and damp glass are not insulators, because their moisture provides a way for the electricity to escape. If we want to insulate an electrified body, we must take care that the air surrounding it and the glass, or other non-conducting substance on which it stands, are both dry.

A conductor and a non-conductor become charged with electricity by quite a different process. For instance, if we allow an iron rod to touch an electrified body, it becomes itself electrified over its whole surface, because iron is a conductor; but a glass rod and a stick of sealing-wax only become electrified in the one part which has been allowed to touch the excited body, because they are non-conductors; and if we want them to be electrified all over, we must bring the excited body into contact with every part of their surface.

With such poor appliances as sticks of sealing-wax and glass, and bits of flannel and silk, we cannot get enough electricity to be able to find out much about its action and effects. In order to do this, we require an ELECTRICAL MACHINE, *i.e.* a machine for producing electricity. One of the most ordinary kinds consists of a large glass plate fixed between two rubbers, and attached to a handle by which it can be turned round. A metal chain connects the rubbers with each other and the earth. When the glass plate is turned round, it becomes charged with positive electricity through the action of the rubbers, and the latter become charged with negative electricity, which, having an open path to the earth through the metal chains, immediately takes advantage of it, and escapes as fast as it is collected. The glass plate, however, is connected with one or two large pieces of metal supported on glass stands, and called the prime conductors of the machine. Being insulated, they are able to accumulate and keep a large quantity of positive electricity from the glass plate. When the conductors of the machine are thus charged, they will electrify anything made to touch them, or connected with them, with positive electricity.

Electricity can be produced in other ways besides friction and conduction. One is by a process called INDUCTION, which I will try and describe to you. Suppose that you have two metal bars, with glass supports to insulate them. One of these bars is in its natural electrical state, and therefore containing equal quantities of both kinds of electricity; and the other has been connected with the conductor of an electrical machine in action, and is charged with positive electricity. On approaching these bars to each other, the positive electricity contained in the one which is charged with it will attract the negative electricity contained in the other to the end nearest itself, and will drive away the positive to the opposite end; and if the bar were able to be divided into two parts (still remaining insulated), we should find that these two parts would be charged with the two different kinds of electricity—the one which had been nearest the positively electrified bar with negative electricity, and the one furthest from it with positive electricity. You see, therefore, that an excited body brought sufficiently near one in the natural state, has the power of electrifying that also by separating the two kinds of electricity it contains from each other. If the unexcited body were also uninsulated, *i.e.* connected with the earth by some conducting substance, no positive electricity would remain in it at all; it would be driven right away to the earth, and as long as the body remained near its positively electrified neighbour, it would itself be charged with negative electricity. Thus, electricity CONDUCTED from one body to another, or caused by *contact*, is different from electricity INDUCED by one body in another, or caused by *influence*. The former is of the same kind, the latter is of the opposite kind.

Now, the reason why a body electrified in one way is able to electrify another brought near it in the opposite way, is because the natural thing is for these two kinds of electricity to exist in exactly equal quantities in all bodies, as we have seen. Therefore, if a body has too much positive electricity, and too little or no negative, the positive will try as hard as ever it can to combine with the negative of any body near it, and the negative will try to get to the positive. If they cannot actually accomplish this, they will at least get as *near* each other as possible, and remain on the watch, as it were, for some fortunate circumstance to enable them to bring about their longed-for union. In the case of the bars of metal, we could very easily bring this fortunate circumstance about by approaching them closer to each other, for in that way the thickness of air separating them would become too slight to keep the electricities apart any longer. The force of their attraction would be so great that they would rush together, and their combination would be attended by a bright spark and a report. The same thing would happen if you were to bring your hand close to the prime conductor of an electrical machine in action; a spark would pass between your hand and the conductor, caused by the positive electricity from the latter and the negative electricity from your body uniting in the little space of air between them, and at the same moment you would feel a disagreeable pricking sensation in your hand. A much stronger effect than this would be produced on you if, instead of approaching your hand to the conductor of an electrical machine, you were to use it to discharge what is called a LEYDEN JAR. This is a common glass jar coated inside and outside with a thin layer of metal, and stopped with a cork through which is inserted a brass rod, often bent, and connected with the inside coating of the jar. The rod has a knob on the end protruding from the cork; and if the jar is taken in the hand, and the knob held against the prime conductor of an electrical machine at work, the positive electricity from the latter runs down the brass rod and collects on the inside coating of the jar, driving away that of the outside coating to the earth through the hand and body of the experimenter, leaving only negative behind. This process continues as long as the knob of the Leyden jar is held against the conductor, more positive electricity collecting on the inside coating, and more negative on the outside, until at last the two coatings are strongly charged with the opposite kinds of electricity, which cannot get at each other because of the insulating glass between. In order to enable them to combine, a DISCHARGING ROD is used. It is a metal rod, jointed in the centre, so that its ends can be brought as near to each other as the experimenter wishes, and these ends are provided with knobs. The rod is held by glass handles, and when one of its knobs is made to rest on the outside coating of the jar, and the other is brought near the knob connected with the inside coating, their opposite electricities combine, and a bright spark is seen and a report heard, after which the jar is found to be no longer electrified. If instead of using the discharging rod, the experimenter takes the Leyden jar by the outside coating in one hand, and places the other close to the knob connected with the inside coating, he becomes himself the discharger, and feels a smart shock through his whole body when the spark and report show that the union of the two electricities is taking place. If several people wish to feel the shock, they have only to join hands, and let the last person on one side take the Leyden jar in his hand, and the last person on the other touch the knob connected with the inside coating. The discharge will then take place through the bodies of all, and all will feel the shock. There will, however, be no spark if the outside coating of the jar and the knob connected with the inside coating be both actually touched either by the experimenter or the discharging rod, because then there is no barrier of insulating air for the two electricities to burst through before they can combine, and their union therefore takes place quietly and easily.

It was observing the spark from a Leyden jar which first led to the discovery that lightning and electricity are the same thing. Thunder-clouds behave towards each other and towards the earth exactly as we have seen that other electrified bodies do. Some particular cloud, owing to the state of the atmosphere, becomes (let us say) positively electrified.

Being in this state, it induces negative electricity in any other cloud near enough to feel its influence; and the attraction between the two opposite electricities causes the clouds to draw nearer to each other, that attraction becoming stronger as the distance across which it works grows less. At last the clouds are so close that there is no longer enough air between them to keep their electricities apart; they rush together, and their union is made known by a flash of lightning (which is neither more nor less than a huge electric spark) and by a peal of thunder (which is the sound caused by the sudden expansion of the air owing to the heat developed by the passage of the electricity). As long as this discharge takes place in a thunder-storm between two clouds, it is not dangerous; but if it takes place between a cloud and the earth, very disastrous consequences sometimes follow. You have no doubt heard of buildings being set on fire, and trees being struck by lightning. It is to protect the former that lightning conductors are used. They are simply metal rods pointed at the top, and projecting above the buildings to which they are attached; but in order to explain to you how they are able to be of use, I must first tell you that *points* have a very peculiar effect upon electricity. By their means, a very powerful, but silent and easy discharge is able to take place from the body to which they belong, for they have the power of allowing the passage of electricity in very much larger quantities than rounded or flat surfaces. There is a most amusing experiment which illustrates very well the action of points on electricity, so I will describe it to you. A large, long tassel, made of a number of strips of paper about a yard in length, is connected with the prime conductor of an electrical machine at work, and becomes charged with positive electricity. As soon as the different strips of paper are electrified they repel each other (as you know is always the case with bodies charged with the same kind of electricity), and soon, instead of hanging down, they stand straight out on end, like the hair of a wild savage, so as to get as far from each other as possible. The experimenter approaches his open hand to the tassel, and a few of the strips nearest him collapse a little, through the effect of the negative electricity passing from his body to the tassel. He then takes a needle and points it at the tassel, and immediately all the strips collapse at once, owing to the powerful stream of negative electricity which is thus brought to bear upon them, and which, by combining with the positive electricity from the electrical machine, completely neutralizes its effect. Their union takes place quite quietly, however; there is no spark and no report. You see, therefore, that the effect of points is to prevent sparks, for the latter are only caused by the sudden, violent union of the two electricities when they have been accumulating in large quantities, and have not been able to get at each other, and when they at last do so, the resistance they encounter during their passage through the air causes an outburst of heat and light.

Now, lightning being nothing but an immense electric spark passing between a cloud and the earth, through the negative electricity of the latter and the positive electricity of the former rushing into union, it follows that one or more good pointed conductors attached to any building will generally prevent its being struck by lightning, because so much negative electricity will flow from it that enough will not accumulate in the building to cause a discharge to take place between it and the thunder-cloud. The reason why it is so necessary that church-towers and other lofty buildings should be provided with lightning conductors is that they themselves are points rising from the earth's surface, and, like all points, they become very rapidly electrified by induction. Consequently, they attract the electricity in a thunder-cloud, and a discharge is very likely to take place between them and it; only, as they are bad conductors, it will not be an invisible and silent one, but there will be a vivid flash of lightning, a loud peal of thunder, and the electricity, on its way to the earth, will tear and rend the bad conductor which is obstructing its passage, causing utter destruction. All this is avoided by arming these badly conducting points with *good* conducting points, and it is a precaution which ought never to be forgotten.

Before leaving the subject of lightning altogether, it will interest you to hear why it does not always look the same. You hear of "forked" lightning and "sheet" lightning, and very often people say, "Oh, sheet lightning does not matter; only forked lightning is dangerous." The truth is that lightning is almost always forked, or, more correctly, branching. Moreover, its path is very often winding and crooked, for a reason which I will presently explain to you. "Sheet" lightning is nothing but the reflection on the clouds of a flash of forked lightning in a different part of the sky, and it is often seen in summer when the weather is quite clear and fair and no thunder can be heard. It is then called "summer lightning," and is, no doubt, the reflection of flashes from a very distant storm. The "forking" or branching of the lightning is supposed to be caused by one flash giving rise to others either at or almost at the same moment as itself. Its crooked path is owing to the electricity always choosing that way to the earth (or to a neighbouring cloud, as the case may be) which offers the smallest amount of resistance to its passage. If the space over which it has to travel be very short, the lightning flash may be quite straight; but if it is long, the flash is sure to wind about, for in that case there will probably be solid particles floating in the air, and certainly the latter will be in different states of electrification at different points, which all affect the amount of resistance offered to the passage of the electric fluid; and, therefore, as the latter always prefers, if possible, running round an obstacle to overleaping it, a crooked path and winding flash are the result. Whatever shape the flash may be, it is supposed to last only the fraction of a second, which seems marvellous indeed when we remember the intense vividness of the impression made on our brains by the objects seen by it.

There is another form of lightning, of which those amongst you who are fond of exciting stories about storms at sea may have read. In such stories you are told how, during very violent storms, "balls of fire" are seen floating at the mastheads, or creeping along the rigging of the ship, and finally exploding. This is "globular" lightning, of which the appearance is so very rare, and the accounts have been so much exaggerated, that for some time it was held to be fabulous. It is not so held now, however, for on more than one occasion it has been accidentally produced on a small scale by artificial means.

Another thing you must often have noticed about thunderstorms is the different sound of the thunder. Sometimes you hear a sharp, short "clap," at another a regular "rattle," followed perhaps by a long, heavy roll. The "clap" comes when the path of the lightning flash is short and straight, the "rattle," when it is long and winding, while the "roll" is caused by echoes from distant parts of the cloud, or from other neighbouring clouds.

I have as yet only spoken of two ways of producing electricity—by friction and by induction; but there is a third which must have a chapter to itself.

CHAPTER XX.

VOLTAIC ELECTRICITY—ELECTRIC CURRENTS.

Effect produced by strips of copper and zinc immersed in a solution of sulphuric acid—Current of electricity—Its direction through the liquid—Along the wires—Voltaic cell—Voltaic battery—Constant batteries—Electric currents can flow in any shape—Attract and repel each other—Law of attraction and repulsion—Strength of electric currents to attract and repel increased by passing along coiled wire—Rate at which they travel—Resistance encountered from bad conductors.

If a strip of copper and a strip of zinc are placed in a glass jar partly filled with water, into which has been poured a little sulphuric acid, and are then joined by means of copper wires, the top of the zinc plate will be found charged with negative, and the top of the copper with positive electricity, and at the same time the strip of zinc will be found to be slowly dissolving, while bubbles of hydrogen gas form on the copper strip. This chemical action goes on as long as the wires remain joined, and at the same time there is set up what is called a CURRENT of electricity. You know already that electricity can *flow*, because we have seen that if an electrified body is not insulated, its electricity all runs away to the earth. Now, this cannot take place with our zinc and copper strips, because they are insulated by the glass jar; so what does their electricity do instead?

Before answering this, I must remind you how very anxious bodies electrified in opposite ways are to part with their electricity to each other, and so return to their natural state again. Our zinc and copper plates are no exception to the rule. The zinc plate, which is the one most attacked by the sulphuric acid, is the place where positive electricity is produced, and there the current starts. It passes through the liquid (which is a conductor) to the copper plate, and there, if the zinc and copper plates were not joined by wires, it would stop, and the copper plate would continue to collect more and more positive electricity, sending its own negative electricity over to the zinc plate as a return compliment. The wires, however, quite alter the case. The current of positive electricity starts from the zinc plate, as I have said, and passes over to the copper plate; but instead of remaining there, it flows on into the wire fastened to the copper, from thence to the wire fastened to the zinc, and so back to the latter again. In this way the current continues flowing round and round as long as the wires are joined, its direction in the liquid being always from the zinc to the copper, and in the connecting wires from the copper to the zinc. This is the positive current; and when we speak of an "ELECTRIC CURRENT," it is always the positive one which is meant. But there is a negative current as well, and that flows in an exactly opposite direction to the positive. It starts from the copper plate and passes through the liquid to the zinc, then through the wires back to the copper plate again; but this current is generally quite ignored, and, as I have already said, you must always understand "electric current" to mean a flow of electricity taking place *from* the point where positive electricity is produced.

The glass jar I have been telling you about, with its sulphuric acid, and water, and strips of copper and zinc, is called a VOLTAIC CELL, because it was first invented by an Italian named Volta. When the wires are joined, a CIRCUIT is said to be made, or "closed." The circuit is broken, or "open," when they are unjoined. Volta improved on his single cell by joining several of the same kind together with conducting wires, finishing off the series by fastening a copper wire to the last copper plate on one side and to the last zinc plate on the other. This arrangement is called a VOLTAIC BATTERY. When these wires are joined, an electric current is set up which is much stronger than that caused by a single cell, the point where the wire is joined to the copper being called the POSITIVE POLE, and that where it is joined to the zinc the NEGATIVE POLE. This may seem strange to you, as you know it is the zinc plates which really produce the positive electricity; but then you must remember that in the *wires* the positive current flows from copper to zinc, not from zinc to copper; and therefore it is quite right to call the copper pole positive. It was soon found, however, that the current produced by Volta's original battery grew rapidly weaker, and finally ceased, on account of the wearing away of the zinc and the continually increasing deposit of hydrogen gas on the copper, for the hydrogen being a non-conductor prevented the flow of electricity from taking place. Batteries have therefore been made called CONSTANT BATTERIES, because in them the defects in the original battery have been remedied, and the currents they produce maintain the same strength for a long time together.

When an electric current is required, the most ordinary way of producing it is by means of some kind of voltaic battery, but you must not suppose it is the only way. In the next chapter you will hear of a quite different and most important one; and there are others which, though I cannot tell you about them here, are all most interesting and necessary to understand. In the meantime I want to tell you something about electric currents themselves.

In the first place, they can flow in any shape. You may have an electric current running along a straight wire, or you may have it flowing along one twisted into a hundred or a thousand coils. The coils do not stop its progress. They affect it in another way, however; they make it very much stronger to attract or repel, for flowing electricity, like electricity at rest, has the power of attracting and repelling. A current of electricity flowing in one direction (from north to south, let us say) attracts a current flowing in the *same direction;* but it repels one flowing in the *opposite direction,* i.e. from south to north. We know this, not of course by seeing the electric currents, for electricity is never seen, but by observing how wires placed side by side, though not touching each other, behave when electric currents are passing along them. If the currents are flowing in the same direction, the wires are attracted; if in an opposite direction, they are repelled; and as wires which have no electric currents passing along them take no notice whatever of each other, we feel sure that their doing so must be owing to the influence of the currents.

The strength of an electric current to attract or repel another current is increased when the wire through which it passes is coiled more than once. Thus, if you have a piece of wire coiled once and a piece of wire coiled twenty times, each with an electric current passing along it, the current in the wire coiled twenty times will be twenty times stronger to attract or repel than that in the wire coiled once. If there were one hundred coils, it would be one hundred times as strong.

The next thing to notice about electric currents is the extraordinary speed with which they travel. If you had a wire 1000 inches long, and another 1000 miles long, and started a current along each at the same moment, there would apparently be no difference between the time they reached their respective destinations. They would both seem to do so at the very instant of starting. I say *seem,* because electricity does not really travel instantaneously, though it appears to do so over any distance our earth can afford as measurement. Its true rate of travelling is 192,924 miles a second, or about the same as that of light.

From what I have already told you about insulators and bad conductors, I am sure it will not surprise you to hear that an electric current sometimes has a good deal of resistance to overcome on its journey. For instance, supposing that the liquid in the cells of a battery were a bad conductor, the electric current would have to spend a good deal of its strength in forcing its way through, and, consequently, it would be very much weakened when it arrived at the opposite side.

In the same way, if the wire is not a good conductor, it also resists the passage of the electric current and weakens it again, so that if it has a long journey to perform it may stop altogether before it reaches the end. If the badly conducting wire is short, and the electric current passing through it strong, the overcoming of the resistance to its passage is attended by heat, and in a very short time the wire will become quite red-hot. In fact, the passage of an electric current is always attended by more or less of an alteration in temperature, though not always by an increase.

You will see by what I have said that if we want to keep the strength of an electric current equal through the whole of its circuit, we must manage that it shall meet with as little resistance as possible; just as, if we want to keep ourselves from exhaustion at the end of a long walk, we try to avoid climbing hills and jumping over hedges and ditches. With all our care, however, we should probably come in a little tired, for even in moving along flat ground we have a certain amount of work to do. It is just the same with an electric current. There is no conductor so good that it does not offer a little resistance to the passage of electricity, and therefore the latter must do work to overcome it, and cannot, consequently, arrive at the end of its journey quite so strong as it set out, for some of its energy has been expended on the road. Nevertheless, with proper precautions, we can avoid a good deal of waste in this way. For instance, in a voltaic battery, the liquid should be a very good conductor (for liquids differ in this respect, some being much better conductors than others), and the different plates of metal not far apart. The wires connecting the opposite poles, too, should be made of the best conducting substance available, and not too thin, especially if they are long, because in that case so little electricity can flow through them compared with the distance it has to travel, that its progress will be retarded, and, perhaps, stopped altogether.

And now we will leave the subject of electric currents for the present; but we shall have to return to them again before long, for there are very many interesting and wonderful things to hear about them, a few of which I will try and tell you.

CHAPTER XXI.

MAGNETISM.

Definition of a magnet—The compass needle—Law of repulsion and attraction—Similarity of magnetism and electricity—Electro-magnets—Steel magnets—Bar and horse-shoe magnets—Distribution of magnetic force in magnets—Difference between magnet and magnetic substance—Magnetic induction—Magnetic field—Electric and magnetic induction contrasted—Magnetism of the earth—Magnetic poles—Aurora borealis—Magnetic storms—Magnetic fluctuations—Declination of the needle—Line of no variation—Magnetic maps—Inclination of the needle—Magnetic equator—Magnetic intensity—Magnetic elements—Magnets can be freed from the influence of the earth—Effect of electric currents on the magnetic needle.

I NEED hardly ask if you know what a magnet is, for I am pretty sure that, to a certain extent, you do. It is a piece of iron which has the power of attracting other iron, and one kind, called lodestone, possesses this property naturally. Lodestone magnets, however, are not so powerful as those made artificially, and therefore it is to the latter I shall be referring when I tell you what magnets can do.

You will want to know how artificial magnets are made, and you shall hear something about this presently. Meanwhile you can perhaps partly answer yourselves, for I dare say before now you have spoilt many needles by rubbing them against magnets, and thus making them into magnets also. A needle which has been thus treated acquires some very peculiar properties. In order to observe them, you must hang the needle by a thread tied round its centre, so that it may be free from the action of gravitation and turn in any direction it likes. You will then find that it will always place itself so as to lie nearly north and south. In fact, it will have become a compass needle such as guides sailors on their voyages, and its two ends are called POLES, that pointing to the north the NORTH POLE, and that to the south the SOUTH POLE. If a magnetic needle is allowed to approach another needle magnetized like itself, you will see that the north poles of these needles will repel each other, and the south poles will do likewise, but that the north pole of the one needle will attract the south pole of the other, and *vice versa*. In fact, we have here exemplified the invariable law that POLES OF THE SAME NAME REPEL, AND POLES OF OPPOSITE NAMES ATTRACT EACH OTHER.

This will, I am sure, remind you of electricity, for electricities of the same name repel, and those of opposite names attract each other. A still further likeness will strike you when you hear that the action of the poles of a magnet on the poles of another magnet, was formerly supposed to be due to the existence of two magnetic fluids which are combined in bodies in an ordinary state, and separated in magnetized bodies, and that these fluids repel themselves and attract each other. Indeed, you may possibly jump at the conclusion which, after years of study and experiment, many scientific men have determined to be the right one—that electricity and magnetism are one and the same force, manifesting itself in different ways. Whether this is really the case, time and more knowledge can alone prove.

Now, one of the ways of making magnets shows the relationship between electric currents and magnetism very strongly, and therefore I will give you a description of it here. I have already told you how an electric current can pass through coiled wire, and how its strength to attract or repel is increased in proportion to the number of coils it has to pass through. Well, suppose that inside a coil of copper wire, insulated by having silk wound round it, were placed a bar of soft (or wrought) iron, and that an electric current were made to pass through the wire. All the time that the current continued, the iron bar would act like a magnet—in fact, it would *be* one, for the close neighbourhood of the electric current would have induced magnetism into it If the current continues but a short time, the iron bar will lose its magnetic power directly it ceases; but if it goes on for a long while, the iron will only lose its magnetism by degrees. If instead of a bar of iron, a bar of steel is used, it does not lose its magnetic power when the current ceases, but is transformed into a permanent or lasting magnet. It cannot, however, be so highly magnetized as soft iron, and, therefore, when very powerful magnets are required, one or more bars of soft iron are enclosed in a coil of insulated wire, through which an electric current is made to pass whenever the iron is to be used as a magnet. Magnets of this kind are called ELECTRO MAGNETS, and are the most powerful of all. An ordinary steel magnet can either be made by placing a bar or needle of steel under the influence of an electric current for a time, or by carefully rubbing it with other magnets, or even by bringing it in contact with the latter.

Magnets can be made of any shape; but those most usually seen are the HORSE-SHOE, in which the poles are brought near together, and the BAR in which they are as far apart as possible. Horse-shoe magnets are very often provided with a keeper, *i.e.* with a piece of soft iron attached to the poles by the attraction they exert on it, that part of the keeper touching the north pole becoming a south pole, and that touching the south pole a north pole. A keeper prevents the magnet from growing weaker with the lapse of time, as it would otherwise do, for since while the two are in contact it becomes itself a powerful magnet, with poles of the opposite kind touching those poles which have magnetized it, it preserves and even strengthens by re-action the permanent magnet to which it is attached.

I have as yet only spoken of the poles of a magnet; but what about that part which lies between them? Has it also magnetic power? We find on approaching the needle to a magnet, that at each pole it is very strongly attracted; that as it is brought further from the poles towards the centre, the attraction grows weaker and weaker, and that in the very centre there seems to be no attractive power at all. If you were to place a magnet amongst a heap of iron filings, you would find that the latter would arrange themselves in thick tufts round the poles, thinning as they approached the centre, where there would be none. This would make you suppose that the magnetic force is confined to the poles; but you would be mistaken, for if the magnet were broken in half, it would make two perfect magnets, each with a north and a south pole; and if these halves were again divided, we should then have four perfect magnets. This is supposed to be because of the way in which the different molecules of a magnetized body are thought to arrange themselves under the influence of the magnetic force. They place themselves end to end, as it were, and every one of them is a little perfect magnet of itself. All the north poles of these molecules are pointing one way, and all the south poles the other way, and the result of this arrangement is to make each end of the whole magnet far more powerful to attract and repel than the centre; but at the same time the result is also to allow a magnet to be divided into any number of other perfect magnets.

A magnet always has poles, but many substances which are very sensitive to magnetism have not. For instance, a lump of iron strongly attracts a magnet, and is strongly attracted by it, but it has no poles. The magnetic force acts equally in every part of it, and bodies which behave like this lump of iron are called MAGNETIC SUBSTANCES, to distinguish them from real magnets with poles.*

In speaking of electricity, we found that an electrified body has an influence on other bodies near it. It induces in them the opposite kind of electricity to what it possesses itself. Magnets behave in exactly the same way. There is a certain space all round a magnet within which it is able to exert its influence, and which is called a MAGNETIC FIELD. Any magnet or magnetic substance placed within this limit, feels the influence of the magnet causing the field. If a bar of iron is placed with one of its ends in front of the north pole of a magnet, that end becomes a south pole, and the end furthest from the magnet a north pole, so then we have two magnets with opposite poles confronting each other.

It is worth while to notice one great difference between electric and magnetic induction. The former can only take place when the excited and non-excited

* It should be mentioned that a powerful magnet will produce an effect on many substances beside iron. Some it repels, and these are called *diamagnetic substances;* others it attracts, but on none is its influence so marked as on iron.

bodies are *near* each other. If they once *touch*, electricity flows from one to the other, and they are electrified in the same, and not in opposite ways. This is not the case with magnets. If a bar of iron is approached to a horse-shoe magnet, it becomes a magnet itself, with a north pole in front of the south pole of the horse-shoe, and a south pole in front of its north pole; but if the bar of iron is allowed to attach itself to the horse-shoe magnet, instead of remaining opposite to it, exactly the same effect is produced, only then all the strength of the induction is acting between the two magnets, and there will be no magnetic field. There will only be a small and weak one if the iron bar and the horse-shoe magnet are very near each other, but if they are far apart, it will be large and powerful.*

You remember my telling you that if a magnet is freely suspended, it will always take up a special position with respect to the earth; its north pole will always point nearly north, and its south pole

* There is also another great difference between permanent magnets and electrified bodies. The latter can only keep in a state of electrification *while they are insulated.* Magnets, on the contrary, do not need any special protection in order to keep their magnetism. It has no tendency to run away to the earth.

nearly south. But now you know that what causes a magnet to take up any special position of its own accord is the action of another magnet on it; for the north pole of one magnet will always move away from the north pole of another, but it will move towards the south pole, and the south pole will, in the same way, be repelled from another south pole, and attracted by a north pole. This being the case, if we see a magnet *always* (when able to do as it likes) turn one end towards the north pole of the earth, and one end towards the south pole, we can only come to one conclusion—that the earth itself must be a large magnet, with poles that attract and repel the poles of other magnets, according to the same law which governs them; and, moreover, that the magnetic poles of the earth must be in or near its geographical poles, since a magnet always turns, with respect to the earth, north and south.

This is, in fact, the case; and here I am obliged to confess that I think we English do a foolish thing in calling the pole of the magnetic needle which turns to the north, the north pole, and the one which turns to the south, the south pole, because exactly the reverse is really the case; for since poles of the same name repel, and poles of opposite names attract one another, it is of course the *south* pole of the magnetic needle which points towards the north magnetic pole of the earth, and its north pole which points towards the earth's *south* magnetic pole. Yet we always speak (with reference to the earth) as if its north magnetic pole attracted the north pole of the needle, and its south the south. This is very puzzling at first, and in other countries the mistake has not been made, or is rectified now. It is sometimes eluded in England by marking the pole which points to the north, and referring to the poles always as the "marked" and "unmarked" poles; but I shall use the ordinary mode of expression in this and the following chapters, asking you to bear in mind the explanation just given.

The subject of the earth's magnetism has been much studied during the latter part of this century, and a great deal of interesting and valuable information has been gained. In 1830, the exact spot of the north magnetic pole was found by Sir James Ross, and this discovery was soon followed by that of the south magnetic pole; but as the magnetism of the earth is subject to constant fluctuations, or ebbings and flowings, its strength varies at the same place at different times. Consequently, the magnetic poles do not always remain in the same spot, though they are always near the north and south poles of the earth. Some of these fluctuations in the earth's magnetism recur at stated intervals, every day, every year, and every set number of years. Others take place unexpectedly, owing to sudden accidental (or seemingly accidental) causes, of which the principal are earthquakes, volcanic eruptions, and the aurora borealis. All fluctuations of the magnetism of the earth, whether regular or sudden, are found out and observed by watching the behaviour of magnetic needles. The aurora borealis produces a very great effect on them, and that at a considerable distance. Magnetic needles in England feel an aurora which is only visible in the far north of Europe, and in the place where the aurora actually occurs, the needle is sometimes sent several degrees out of its usual position; for the way in which it shows that there is a magnetic disturbance, is by moving to the east or west of its usual place. Sudden disturbances, whether owing to the aurora or to any other cause, are called MAGNETIC STORMS, and they often occur at the same time in widely distant parts of the earth. A violent magnetic storm never takes place without a display of the aurora borealis in high latitudes; and in the same way, whenever the aurora is seen, there is always a magnetic storm. Moreover, it has been discovered of late years that there are remarkable connections between the sun and the magnetism of the earth, especially with respect to magnetic storms. Interesting as these latter are, however, they are not so important for our present purpose as those regular fluctuations of the earth's magnetism which cause the known and expected variations of the magnetic needle. It is of these that I am about to tell you.

I am sure you must have seen either a mariner's or a pocket compass, therefore I need not describe to you what a compass is like. If you have ever observed it carefully, you must have noticed that the needle does not point due north and due south. Its north pole lies more or less towards the west—at least, in any part of the seas or continents of Europe and Africa. In Asia, and in the greater part of North and South America, it lies towards the east. The difference between due north and south and the spot in the compass to which the needle actually points, is called the DECLINA-

TION of the needle. It varies in different places; it also varies in the same place at different times, slightly even at different hours of the day, owing to the regular and accidental fluctuations of the earth's magnetism. In certain places, however, the needle does really point north and south, and these places are connected together by an imaginary line (just as you know there are places connected by the imaginary line of the equator), called the LINE OF NO VARIATION. Instead of encircling the earth from east to west, however, as the equator does, the line of no variation encircles it from north to south, passing through the poles.

Just as there are geographical maps giving the lines of latitude and longitude, so there are magnetic maps giving the lines of equal declination and inclination, *i.e.* lines connecting those places on the earth's surface where the slant of the needle to east or west, and its dip to north or south, are the same. But, unlike a geographical map, it is impossible to make a magnetic map which will hold good for an indefinite number of years, because, owing to the ebbing and flowing of the earth's magnetism, the lines of equal declination and inclination are always changing. Nevertheless, scientific men can, by calculation, find out what these lines will be for a few years in advance, and make their maps accordingly.

A second thing to notice about the magnetic needle is that, however perfectly balanced it may be, its north pole dips a little downwards in the northern hemisphere, and its south pole in the southern. Now, according to the laws of gravitation, this ought not to be, for a body hung from the point which is its centre of gravity keeps a perfect balance. Why, therefore, is the magnetic needle unable to do so? Simply because the force exerted on it (when freely suspended) by the earth's magnetism overcomes that of gravitation, and draws that pole of the needle downwards which is attracted by the magnetic pole of the hemisphere in which it finds itself. This is a very clear proof that the magnetic force which compels the needle to point always one way is exerted by *the earth*, and not by anything above its surface, for in the latter case there would be no dipping. The amount which the needle dips out of the straight line with the horizon is called its INCLINATION, and just as there are certain places where there is no *declination,* so there are certain where there is no *inclination.* Like the former they are connected by an imaginary line, called the MAGNETIC EQUATOR, which follows, roughly, the course of the geographical equator, only with many up and down waves and curves. At the magnetic poles the needle actually stands quite upright.

The MAGNETIC INTENSITY of any spot on the earth's surface, *i.e.* the amount of magnetic force present in it, is measured by observing and making calculations on the oscillations or movements to and fro of the magnetic needle when it has been shaken, before returning to its usual position.

The declination and inclination of the magnetic needle at any particular place, and the magnetic intensity of that place, are called its three MAGNETIC ELEMENTS, and are the first things to find out when there are any magnetic observations to be made.

From what I have told you about magnets and their effect on other magnets, you must see that it is easy to set a magnetic needle free from the influence of the earth if we wish to do so. We have only to bring it near another magnet, exerting a force as strong or stronger than the earth itself is doing at that particular place, and our wish is fulfilled. In the latter case the needle will be directed by the more powerful magnet which has been brought to bear on it, instead of by the earth. In the former case, as the magnet and the earth are exactly counteracting each other, the needle will obey neither, but will be free to be directed by any third magnetic force which may be brought to bear on it.

And now I am going to close this chapter, as I did the last, by telling you something about electric currents, something which I could not enter into then because it had to do with the magnetic needle of which you had heard nothing.

You already know that the most powerful magnets are made by means of electricity, and I have pointed out to you how this shows us a very close connection between magnetism and electricity. What I am now going to tell you about, viz. the effect produced by an electric current on a magnetic needle, is a further proof of the same thing.

As we have seen, the magnetic needle lies nearly north and south. Imagine that you have such a needle suspended over a wire through which an electric current is passing. The needle no longer keeps its north and south position, but places itself so as to lie more or less across, or at right angles to the wire through which the current is moving, and it so remains as long as the current continues. Directly the latter stops the needle returns to its natural position, and if the current were set going, and broken off twenty or one hundred times in a minute, the needle would be disturbed out of its right place (or DEFLECTED, as it is called), and return to it again the same number of times in the same interval. Moreover it does not matter in the least how far the needle is off from the starting-point of the current. If you had a voltaic battery at one end of a room one hundred feet long, and carried its wires quite to the opposite end before joining them, and if you then suspended a magnetic needle over the wire at this further end, the effect produced on it would be just the same as on one suspended over the wire close to the battery. If your wires were carried one hundred or one thousand miles off, the needle would behave in precisely the same way, and there would not be even a second's interval between your setting the current going at one end of the wire, and its effect on the needle at the opposite end. In fact, with a sufficiently powerful current, you could cause a magnetic needle, any number of thousands of miles away from you, to deflect any number of times either to east or west, at your will. It is important to know, however, how the needle is made to deflect east and how west

This entirely depends on the direction of the flow of the current with reference to the needle, and is a little complicated to understand, but I will try and make it as clear as I can.

Imagine that you have a magnetic needle freely suspended, and therefore lying in its natural position with respect to the earth—north and south. Then imagine that exactly under the needle, and following the same direction, is a wire through which an electric current is passing from south to north. The north pole of the needle will be deflected to the west, *i.e.* to the left of the wire through which the current is passing. But now suppose that, instead of a current from south to north, we have one flowing from north to south; the north pole of the needle will then be deflected towards the east, *i.e.* to the right instead of the left of the wire. In these two cases the needle has been *above* the electric current; but now suppose that we suspend it so that it lies underneath the wire, and therefore *below* the current, its behaviour will be exactly reversed. When the current flows from south to north, the north pole of the needle will be deflected to the east, *i.e.* to the right of the wire, and when from north to south, to the west, *i.e.* to the left of the wire. You see, therefore, that if we want to alter the deflections of the needle, we must either place it in an exactly opposite position with respect to the current to what it was before, or we must reverse the current; and the latter is the simplest and easiest way. The deflections of the needle are greater or less, *i.e.* it moves more or less *across* the direction of the electric current, according to the strength of the latter. A strong current deflects the needle much more than a weak one, and as one of the ways to increase the strength of a current is by making it pass through coiled instead of straight wire, you would find all the deflections of the magnetic needle produced in a very marked way by placing it inside a coil of insulated copper wire, instead of over or under a straight wire; but they would still be regulated by the same laws. If the current were flowing from south to north through the top of the coil of wire, the north pole of the needle would be deflected towards the west; if from north to south, towards the east. And here I must explain that, in order to be "freely suspended," the needle need not always be hung from a thread. It may be swung upon a pivot, which, properly arranged, will have the same effect. Magnetic needles are of different shapes; the one most usually seen is of a thin lozenge shape. They are always made very light.

And now we will leave these general observations about magnetism and electricity, and see to what useful and practical purposes they have been applied.

CHAPTER XXII.

PRACTICAL APPLICATIONS OF ELECTRICITY AND MAGNETISM.

1. The electric telegraph—2. The telephone and microphone—3. Electric lighting—4. Electro-Metallurgy—Minor applications—Concluding remarks.

I. The Electric Telegraph.

This is, I am sure, the very first thing which will enter your minds when you try to think what practical purposes are served by electricity. In these days a telegram is almost as familiar a sight as a letter, quite as familiar to business men; and even old-fashioned people are beginning to get accustomed to the arrival of the yellow envelope containing a message which has travelled swiftly and mysteriously as thought, and yet, perhaps, announces no more important matter than that a friend cannot accept an invitation to dinner, or has missed his train!

It will not be difficult for you to understand in a general way how the electric telegraph works if you have read the foregoing chapters attentively, for in that case the principle is already clear to you, and a very little additional explanation will show how it is applied.

The real meaning of telegraphy is writing at a distance—in other words, making signals; and after all you have learned about the way a magnetic needle behaves when placed under the influence of an electric current, I am sure it will occur to you that if we want electricity to make signals for us, two of the principal things we shall require will be a current and a magnetic needle. The current is produced by means of some kind of voltaic battery; that called Daniell's is one of those most in use in England, because of its great constancy, *i.e.* its power of continuing to produce an electric current for a long time without any decrease of strength. The battery is stationed at the place from which the message has to be sent, and is more or less powerful according to the strength of current which is needed. If the current has to travel over some thousands of miles, it will, of course, need to be very strong, because, as we have already seen, it always has to do a certain amount of work on its road, in order to overcome the resistance which even the best conducting wire offers to its passage. This wire must always be insulated; but the way in which this is done depends on whether it is a "land line," or has to pass under the sea or a large river. Overland wires in England are made of iron, coated with a thin layer of zinc. The wire thus prepared is carried over the distance it has to traverse, by means of tall wooden posts (such as you see by the side of every railroad), on the upper part of which are fixed insulating supports made of glass or porcelain. When the wire has to pass under the sea, it is no longer made of iron, but of copper, and instead of a single wire, several are used, and are twisted together so as to form a kind of rope. This is then most carefully insulated, by being thickly coated with gutta percha and a composition made partly of gutta percha and partly of tar and resin. Then the whole is enclosed in steel wires, each of which is coated with hemp, and a thick strong CABLE is thus formed, able to resist the enormous strain put upon it when being lowered in mid-ocean, and the violence of the waves nearer shore.

You remember being told in Chapter XX. that for a circuit to be made or closed, *i.e.* for an electric current from a voltaic battery to be set going, it is necessary that the wire from the positive pole and that from the negative pole should be joined. You would, therefore, naturally suppose that if we want to send an electric current from London to York, let us say, we must have two wires carried over the distance from London to York, and there joined. This is not necessary, however. The *earth* is able to take the place of the second wire; and in order to close a circuit between London and York, all we need do is to fasten the wire from the negative pole of the battery in London to a copper plate, and bury it in the ground, which must be kept damp at that spot. The wire from the positive pole, on reaching the receiving station at York, is in like manner fastened to a copper plate and buried in damp earth. The circuit is then made, and the electric current begins to flow, and is ready to do our signalling work for us. And now comes the part played by the magnetic needle—or I should rather say, *needles*, for there are two, one at the sending and one at the receiving station.

Each of these needles is placed within a coil of wire, which coil is connected with the wire coming from the positive pole of the battery; and, consequently, directly the circuit is closed, an electric current passes through the coils, and both needles, though they may be hundreds of miles apart, are deflected at the same moment to east or west, according to the direction of the current through the coils. Now, if we have an arrangement by which we can very quickly and easily close and open the circuit, the electric current can be set flowing and stopped again many times in a minute, and the magnetic needles will be deflected and return to their natural position again just as many times, so that here we have at once the means of making our signals. We have only to arrange that so many deflections of the needle mean a certain thing (a letter of the alphabet, for instance), and more or fewer deflections other things or letters, and we can talk to a person thousands of miles away, as easily as we can to a deaf and dumb person on our fingers. If, however, we were only able to make the needles deflect in one direction, we should find our signalling rather tedious, for the only difference we could make to express different letters, would be in the number of strokes to one side given by the needles; but we need not confine ourselves to this, because by *reversing* the current, *i.e.* by making it flow in an opposite direction through the wire coils, we can cause the needles to make strokes towards the other side, and this gives us the power of using the two kinds of deflections for our signals.* Consequently, in a telegraphic apparatus there is always an arrangement made by which the current can be *reversed* as many times in a minute as is necessary, as well as one by which the circuit can be closed or opened. I do not explain these arrangements, because they are a little complicated and difficult to understand; but there are many books which tell you all about them, or, better still, you could get some scientific friend to take you over the telegraphic department of a post-office, and explain the various machines to you; for there are many different kinds, and some have not needles, but make their signs in other ways, though always through electro-magnetism, *i.e.* through currents of electricity acting on magnets.

The telegraphic apparatus most in use now is called the MORSE TELEGRAPH, from the name of its inventor; and its principal way of making signals

* The needle which is seen on the dial of a telegraphic apparatus is not the actual magnetic needle, the latter and its surrounding coil being inside the machine. The dial needle is attached by means of a fine straight wire to the magnetic needle, and the two consequently move together.

is by printing dots and dashes on a strip of paper which is uncoiled by clockwork machinery for it to write on. Thus A is represented as follows . — and B — . . . Some telegraphic instruments are able to print the message in the letters of the alphabet; one even to reproduce the handwriting of the sender; but these kinds are not much used.

II. The Telephone and Microphone.

The name of telephone is becoming almost as familiar as that of the electric telegraph, and you doubtless know that a telephone is an instrument by means of which it is possible actually to talk to a person many, perhaps hundreds of, miles away, and receive a verbal answer from himself. In large towns, nearly all business firms have the means of telephonic communication, and private persons often follow their example, so that we are now fast losing the sense of wonder which was felt when it first became possible to carry on a conversation in this way. The possibility of constructing such an instrument as the telephone was suggested by the fact, that whenever a bar of soft iron is magnetized or demagnetized a peculiar click is heard, showing that some movement in the molecules must take place;

and an inventor named Reiss was the first to make use of this property, by constructing a telephone which could transmit musical notes. This was soon followed by the appearance of one, invented by Bell, able to transmit words.

For the telephone as for the telegraph we need a battery, a circuit, and a means by which rapid alterations can be made in the current flowing through that circuit. In the telegraph, however, these alterations are caused by the machinery directed by the hand, and the movements transmitted by the electric current along the wire, from the sending to the receiving station, produce visible signs of some kind or other. In the telephone, the alterations in the current are caused by the voice of the person speaking the message, and sound-vibrations are transmitted along the wire to the ear of the person receiving the message. In the first telephones used, it was necessary to have, as in the telegraph, instruments exactly alike at the sending and the receiving stations, the place of the two magnetic needles described to you above being taken by two thin metallic plates. To one the message was spoken by the sender, and at the other heard by the receiver, the thin metallic plates sounding (or, more accurately, speaking) every time that they were magnetized and demagnetized, and also every time that the current was ever so slightly altered, which happened not only at each word uttered by the sender of the message, but at every different tone and inflection of the voice. You will remember that, in speaking of sound, we found that the tone or pitch of all musical notes depends on the number of vibrations made in one second. This is equally true of the human voice, and it is because the electric current is able to transmit every one of those vibrations from the sending to the receiving plate quite accurately, as to form as well as to number, that the telephone repeats not only the words, but every inflection of voice of the sender. This early form of the telephone, however, was found inconvenient, partly because the sound, though so perfectly reproduced, was very thin and weak, and it was necessary to place the ear quite close to the instrument at the receiving station, in order to distinguish anything at all. The invention of the MICROPHONE, or sound-magnifier, which followed very rapidly on that of the telephone, overcame this difficulty, and now the telephone principally used, and called the Gower-Bell telephone, is in reality a combination of the microphone and the telephone, the former being placed at the sending, and the latter at the receiving station. In order to understand the principle of the microphone, you must know that an alteration in the resistance encountered by an electric current in its passage through a telegraphic circuit, may be caused by an alteration in the pressure between two conductors, or semi-conductors, loosely touching each other, and included in that circuit. In a microphone there is always an arrangement of this kind, generally consisting of two pieces of carbon lightly resting on each other. Any vibration transmitted through these by the electric current, and making the pressure between them stronger or less strong, alters the resistance encountered by the current, and strengthens the sound vibrations transmitted to the receiving station, by adding to them vibrations exactly similar. A microphone is always provided with a sounding-board, which acts like the sounding-board of a musical instrument, and again greatly strengthens the vibrations. In this way the original volume of sound is very much increased, so that sounds which can only just be heard, or not heard at all by the unaided ear, are rendered quite distinct and even loud by the microphone, just as objects invisible to the naked eye are made clear by the microscope. In some microphones, if the ear is placed close to the sounding-board of the instrument, the walk of a fly across it seems like a regiment marching, and can be heard (though, of course, not nearly so loudly) at the receiver of a distant telephone.

III. Electric Lighting.

A third practical use to which electro-magnetism has been put, is that of electric lighting, which you know is taking the place of gas in many of our large public buildings, such as theatres and railway stations. In America and parts of the continent it is much more universally used than in England, and the streets of whole cities are illuminated by it.

You will remember that the cause of the electric spark and of a flash of lightning is the resistance which the two kinds of electricity have to overcome in order to rush together through a non-conducting or badly conducting medium such as dry air; and you have read also that an electric current always has a certain amount of work to do in overcoming the resistance which even the best conductor offers to its passage. You will therefore easily understand that, if an electric current is passing along a bad conductor, the resistance it encounters causes heat, and, if great enough, light also. A badly conducting wire will soon become red-hot, owing to the passage of an electric current. The principle of the electric light, therefore, is to introduce some place or places of great resistance in the path of a current, and at each of these there will be an outburst of heat and light.

There are two principal ways of electric lighting, the ARC and the INCANDESCENT. In the former, two pieces of pointed charcoal are connected with the opposite poles of a battery, joined for one instant (when the current begins to flow), and then separated, and left facing each other at a very short distance apart. When they are disconnected the current does not cease to flow, but its passage from one charcoal point to the other, during which it has great resistance to overcome, is marked by a most vivid and brilliant band of light, to which the name VOLTAIC ARC has been given. In order to keep this light steady, however, rather complicated mechanical contrivances are needed, because the carbon point connected with the positive pole consumes very rapidly, being, in fact, burned away, and unless the waste is supplied as fast as it takes place, the light flickers and may go out altogether. Even until quite recently unsteadiness was the great defect of the arc light, owing to the difficulty found in supplying the waste of the positive charcoal point with perfect regularity. Until this could be done, the resistance encountered by the electric current was constantly varying, and as a consequence the amount of light given varied also.

In the incandescent lamps, the charcoal points are replaced by fine filaments or threads of carbon in the shape of a horse-shoe, their ends being fastened to thick wires which pass through the small glass globes containing the carbon threads. These glass globes are emptied of air, and then hermetically closed to prevent any entering from the outside. The wires attached to the carbon threads are in their turn connected with the battery wires, and when the electric current is flowing, the resistance it encounters in the carbon threads produces so much heat that they rapidly become incandescent, *i.e.* in a state of what is commonly called "white heat," and they then give out a clear and brilliant light.

For electric lighting on a large scale, currents able to do a great deal of work are needed, and, in consequence, very powerful voltaic batteries were at first used. This caused electric lighting to be extremely expensive, because of the large quantity of zinc consumed, and until the invention of electro-magnetic machines, which are able enormously to increase the power for work of an originally weak current, and so to do away with the necessity of such strong batteries, electric lighting made but little way against lighting by gas, which it is now gradually superseding.

These electro-magnetic machines are called also DYNAMO-MAGNETIC machines (shortened into DYNAMOS), because they change mechanical power into electricity. They are constructed on a principle by which electro-magnets and electric currents are made to act and re-act on each other, always in such a way as to increase their strength to the highest possible point. Some dynamos are able to receive electricity and change it into work, as a steam-engine changes heat into work. It is hoped by their inventors that these machines will in time replace steam-engines for many purposes, but at present their cost is still too great to enable them to do so on any large scale.

IV. ELECTRO-METALLURGY.

The fourth practical use served by electricity you are also acquainted with by name, for though you may not happen to have heard the expression "electro-metallurgy," you certainly have that of "ELECTRO-PLATING," which is a .form of electro-metallurgy, the latter term signifying merely working on metals by means of electricity.

Electro-plating is covering one metal with a coating of another, through the same kind of chemical action set up in a voltaic cell. You already know that chemical effects are produced in this manner, because in Chapter XX. you were told that so long as the wires from the copper and zinc plates, which are immersed in the sulphuric acid and water, remain joined, the zinc will be found slowly dissolving, and bubbles of hydrogen gas will form on the copper.

The zinc plate dissolves because it is uniting with the sulphuric acid to form sulphate of zinc. During this process the water is decomposed, and hydrogen gas is set free and collects on the copper plate. Suppose, however, that the latter, though still connected by the wires with the zinc plate, were immersed in another vessel, containing a solution of sulphate of copper. In that case, instead of hydrogen gas collecting on the copper plate, more particles of copper would do so, and it would become gradually covered with another coating of copper drawn from the liquid in which it is immersed. Here, therefore, is a way by which copper can be deposited on copper. If, instead of this, we want *gold* to be deposited on copper, we must make a slightly different arrangement, because the electric current set up in the liquid will not be able to do this by itself. We want, in fact, two currents, and therefore require an outside battery besides the cells containing the liquid. To the negative pole of the battery we must connect the object to be gilded, immersing it at the same time in a vessel containing salts of gold. When the current is flowing, the pure gold will be set free and deposited on the object, which will gradually become covered with a layer of gold. This process takes time, however, and as the gold contained in the liquid would soon be used up, the waste is supplied as fast as it takes place by having a bar or plate of gold connected with the positive pole of the battery, and also immersed in the liquid, so that as the latter loses its gold by depositing it, the same quantity is given back by the dissolving of the solid gold.

Electro-silvering is done in exactly the same way as electro-gilding, with the difference, of course, that the solution must contain silver instead of gold, and that the solid piece of metal connected with the positive pole of the battery must be of silver also. Other metals besides silver and gold can be treated in this way, though the process is more often used with them, because articles having all the appearance of solid gold and silver, and serving the same purposes, can thus be produced at a very moderate cost.

I have now mentioned the most ordinary and important services rendered to us by electricity, except, indeed, that of ringing bells for domestic purposes, which is fast superseding all other arrangements of the kind. These bells are made to sound by an electric current acting on magnets. Electricity has also been made very useful medically, and, I grieve to say, equally useful for purposes of war, such as the firing of submarine mines and in torpedos. There are also electrical clocks, and various minor applications, which need not find a place here.

Even this short sketch of what electricity has already been made to do for us will have shown you one thing, viz. that in the future it is probably destined to become an even more active and useful servant of man than heat; for though we are able to change heat into work, we do not get so much work in return for the heat supplied as we do when using electricity in the same way for the electricity supplied. And, therefore, if once the cost of producing it could be made as small as the cost of producing steam, the latter would be quickly supplanted by electricity.

We are so used in these days to making the Invisible Powers of Nature perform our bidding, that it perhaps seldom occurs to us what a marvellous thing it is that we, who are so weak and insignificant in comparison, should be able to control them as we do. The old fairy-tale tells of a geni who was compelled to appear at the rubbing of a lamp and accomplish the commands of its owner. Through means almost as simple, we become the masters of a more wonderful slave than Aladdin ever dreamed of—Electricity. Yet as we may imagine that he sometimes trembled before the mighty being constrained to work his will, so may we well do before that great and mysterious Force which we have named and can make serve us, but of whose nature we know nothing, and the slightest infringement of whose laws may be attended by destruction and death.

One lesson, at any rate, we may carry away with us from the study of any of the Invisible Powers of Nature. If we want to control them, if we want to understand anything about them, we must first learn the laws by which they are ruled, and obey these in all our researches, faithfully and unswervingly. It is because we have been so long in even beginning to understand this, that the Invisible Powers of Nature have been so long in giving up the secrets which place them under our control. He who is their God and ours is the God of law and order; and the very accidents and catastrophes from which men have suffered through ignorant infringement of the natural laws, are meant to show them that they must consent to obey law and order themselves if they would be in harmony with the Universe of God and with Him who is its Author.

THE PHONOGRAPH, OR SOUND-WRITER.

EVEN since this little book has been preparing for the Press, a wonderful electro-magnetic invention has been perfected, by means of which words can be recorded, not in writing, but in *speech*, and reproduced at will. The PHONOGRAPH, or sound-writer, is the instrument by which this last miracle of science is accomplished, and its inventor is Mr. Edison, the great American electrician, to whom we owe so many other electrical marvels. The first idea of the phonograph flashed upon him when listening to the sounds made by the Morse recorder, as it printed the little dots and dashes which have already been described. These peculiar sounds, varying according to the written signs, are always made by the Morse machine, and a skilled person can tell by them what is being inscribed on the paper strip without looking at it. Mr. Edison found that when the machine was made to work so rapidly that the Morse signs could no longer be distinguished by the ear, a buzzing, musical sound was given out, which altered with the different characters, and was like an inarticulate language. He at once thought that if, instead of a roll of paper to be indented with printed signs, he could place a thin metal disc which should receive indentations caused by the sound-vibrations representing the human voice, articulate words would be the result. He made the experiment, and found that he was right, and that the machine, if spoken into, could exactly reproduce what was said. From this beginning has grown the wonderful instrument just introduced into England. The person speaking into the phonograph sets in vibration a very thin metal disc or *diaphragm* to which a small needle is attached, and at every vibration indents a revolving wax cylinder. The vibrations are thus, as it were, stored on the wax, and can be reproduced at any moment by placing the cylinder in a machine which so controls a magnetic needle that it falls into the indentations already made. This causes the diaphragm to which the needle is attached to vibrate in an exactly similar manner to the one whose movements were produced by the voice of the speaker in the first instance, and consequently the same words or sounds are heard again. Impresses are taken of the original cylinder to any number desired, and therefore the words once spoken into a phonograph can be repeated at a hundred or a thousand different places, to which they journey by post on these little waxen rolls.

Like the telephone, the phonograph reproduces exactly the pitch and intonation of voice of the person who has spoken into it, so that a man might send a message to another thousands of miles distant, and the latter would hear it spoken as if his friend were in the same room with him.

It is supposed that the phonograph will become useful in many ways to writers, to printers, and to business men; and also be a source of pleasure and amusement, for it can reproduce songs and instrumental music with the same accuracy as ordinary speech. To the blind it seems as if the phonograph might be a special boon, as its use would enable them to correspond with their friends or record their thoughts with even greater ease than if they had the keenest eyesight and the readiest pen at their disposal.

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