HERTZ'S EXPERIMENTS.[1]

II.

IN the last article, a general method of measuring the velocity at which a disturbance is propagated was described. It depended on being able to produce a regular succession of disturbances at equal intervals of time. These were made to measure their own velocity by reflecting them at an obstacle. Then, by the interference of the incident and reflected waves, a succession of loops and nodes are produced at intervals of half the distance a disturbance is propagated during the time between two disturbances. It is a general method applicable to any sort of disturbance that takes time to get from one place to another. It has been applied over and over again to measure the rate at which various kinds of disturbance are propagated in solids, liquids, and gases. It was applied in a modified form years ago, to measure the length of a wave of light; and, within the last year, some of the most beautiful experiments on photography ever described are applications of this principle by Herr Wiener and M. Lippmann.

There are three things essential to this experiment: (1) some method of originating waves; (2) some method of reflecting them; (3) some method of telling where there are loops and where there are nodes. We will take them in this order:—

(1) How can we expect to originate electric waves? If, when a body is electrified positively, the electric force due to it exists simultaneously everywhere, of course we cannot expect to produce anything like a wave of electric force travelling out from the body; but if, when a body is suddenly electrified, the electric force takes time to reach a place, we must suppose that it is propagated in some way as a wave of electric force from the body to the distant place. This, of course, assumes that there is a medium which is in some peculiar state when electric force exists in it, and that it is this peculiar state of the medium, which we call electric force, existing in it, that is propagated from one place to another. It must be carefully borne in mind what sort of a thing this is that we call the electric force at any place. It is not a good name—electric intensity would be a better one; but electric force has come so much into use, it is hardly to be expected that it can be eradicated now. Electric force at any place is measured by the mechanical force that would be exerted at the place if a unit quantity of electricity were there. It is not a force itself at all; it is only a description of the condition of the medium at the place which makes electricity there tend to move. The air near the earth is in such a condition that everything immersed in it tends to move away from the earth with a force of about 1·26 dynes for each cubic centimetre of the body, *i.e.* each cubic centimetre tends to move with a force of 1·26 dynes. Now the condition of the air that causes this is never described as volume force existing at the place, though we do describe the corresponding condition of the ether as electric force existing there: and as volume force existing would be a very objectionable description of the condition of the air when, being at different pressures at various levels, it tends to make bodies move with a force proportional to their volume, so electric force existing is a very objectionable description of the condition of the ether, whatever it is, that tends to make bodies move with a force in proportion to their electric charges. We know more about the structure of the air than we do about the ether. We know that the structure of the air that causes it to act in this way is that there are more molecules jumping about in each cubic centimetre near the earth than there are at a distance, and we do not know yet what the structure of the ether is that causes it to act in this remarkable way; but even though we do not know the nature of the structure, we know some of its effects, by means of which we can measure it, and we can give it a name. Although we know very little indeed about the structure of a piece of stressed india-rubber, yet we can measure the amount of its stress at any place, and can call the india-rubber in this peculiar condition "stressed india-rubber." As a matter of fact, we know a great deal more about the peculiar condition of the ether that we describe as "electric force" existing than we do about the "stressed india rubber"; and there is every reason to suppose that the structure of the ether is, out of all comparison, more simple than that of india-rubber.

When sound-waves travel through the air, they consist of compressions followed by rarefactions, and between them the pressure varies from point to point, so that here we have travelling forward a structure the same as that of the air near the earth, and waves of sound might be described as consisting of a succession of positive and negative "volume forces" travelling forward in the air: this form of expression would no doubt be objectionable, but still if all we knew about the properties of the air near the earth was that it tended to make bodies move away from the earth with a force proportional to their volume, it is quite likely that this condition of affairs near the earth might have been described as the existence of a "volume force" near the earth, and when it was discovered that this action was due to a medium, the air, it would have been quite natural to describe this state of the air as "volume force" existing in it: and then when waves of sound were observed it would be quite natural that they should be described as waves of "volume force," especially if the only way in which we could detect the presence of these waves was by observing the force exerted on bodies immersed in it, which was proportional to their volumes, and which we happen to know is really due to differences of pressure at neighbouring points in the air. We do not know what is the structure of the ether that causes it to exert force on electrified bodies, but we know of the existence of this property, and when it is in this state we say that "electric force" exists in it, and we have certain ways by which we can detect the existence of "electric force," one of which is the production of an electric current in a conductor, and the consequent electrification of the conductor, and if this is strong enough we can produce an electric spark between it and a neighbouring conductor. When a conductor is suddenly electrified, the structure of the ether which is described as electric force existing in it travels from its neighbourhood through the surrounding ether, and this is described as a wave of electric force travelling through the surrounding ether. It is desirable to be quite clear as to what is meant by the term a wave of electric force, and what we know about it. We know that it is a region of ether where its structure is the same as in the neighbourhood of electrified and some other bodies, and owing to which force is exerted on electrified bodies, and electric currents are produced in conductors.

We may, then, reasonably expect that, if it is possible to electrify a body alternately positively and negatively in rapid succession, there will be produced all round it waves of electric force—that is, if the electric force is propagated by, and is due to, a medium surrounding the electrified body, if electrification is a special state of the medium that fills the space between bodies.

(2) The next question is: How can we reflect these waves? In order to reflect a wave, we must interpose in its way some body that stops it. What sort of bodies stop electric force? Conductors are known to act as complete screens of electric force, so that a large conducting sheet would naturally be suggested as the best way to reflect waves of electric force. Reflection always occurs when there is a change in the nature of the medium, even though the change is not so great as to

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[1] Continued from vol. xliii. p. 538.

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stop the wave, and it has long been known that, besides the action of conductors as screens of electric force, different non-conductors act differently in reference to electric force by differing in specific inductive capacity. Hence we might expect non-conductors to reflect these waves, although the reflection would probably not be so intense from them as from conductors. Hence this question of how to reflect the waves is pretty easily solved. We are acting still on the supposition that there are waves at all. If electric force exist everywhere simultaneously, of course there will be no waves to reflect, and, consequently, no loops and nodes produced by the interference of the incident and reflected waves.

(3) The third problem is: How can we expect to detect where there are loops and where there are nodes? Recall the effects of electric force. It tends to move electrified bodies. If, then, an electrified body were placed in a loop, it would tend to vibrate up and down. This method may possibly be employed at some future time, and it may be part of the cause of photographic actions, for these have recently been conclusively proved to be due to electric force; but the alternations of electric force from positive to negative that have to be employed are so rapid that no body large enough to be easily visible and electrified to a reasonable extent could be expected to move sufficiently to be visibly disturbed. It is possible that we may find some way of detecting the vibrations hereby given to the electrified ions in an electrolyte; and it has recently been stated that waves originated electrically shake the elements in sensitive photographic films sufficiently to cause changes that can be developed. The other action of electric force is to produce an electric current in a conductor and a resultant electrification of the conductor. Two effects due to this action have actually been used to detect the existence of the wave of electric force sent out by a body alternately electrified positively and negatively. One of these is the heating of the conductor by the current. Several experimenters have directly or indirectly used this way of detecting the electric force. The other way, which has proved so far the most sensitive of all, has been to use the electrification of the conductor to cause a spark across an air-space. This is the method Hertz originally employed. *A priori*, one would not have expected it to be a delicate method at all. It takes very considerable electric forces to produce visible sparks. On the other hand, the time the force need last in order to produce a spark is something very small indeed, and hitherto it has not been possible to keep up the alternate electrifications for more than a minute fraction of a second, and this is the reason why other apparently more promising methods have failed to be as sensitive as the method of producing sparks. If two conductors be placed very close to one another in such a direction that the electric force is in the line joining them, their near surfaces will be oppositely electrified when the electric force acts on them, and we may expect that, if the force be great enough, and the surfaces near enough, an electric spark will pass from one to the other. This is roughly the arrangement used by Hertz to detect whether there are loops and nodes between the originator of the waves and the reflector.

Now arises the problem of how to electrify the body alternately positively and negatively with sufficient rapidity. How rapid is "with sufficient rapidity"? To answer this we must form some estimate of how rapidly we may expect the waves to be propagated. According to Maxwell's theory, they should go at the same rate as light, some 300 million of metres per second, and it is evident that if we are going to test Maxwell's theory we must make provision for sufficiently rapid electric vibrations to give some result if the waves are propagated at this enormous rate. The distance from a node to a node is half the distance a wave travels during a vibration. If we can produce vibrations at the rate of 300 million per second, a wave would go 1 metre during a vibration, so that, with this enormous rate of alternation, the distance from node to node would be 50 cm. We might expect to be able to work on this scale very well, or even on ten times this scale, *i.e.* with alternations at the rate of 30 million per second, and 5 metres from node to node, but hardly on a much larger scale than this. It almost takes one's breath away to contemplate the production of vibrations of this enormous rapidity. Of course they are very much slower than those of light: these latter are more than a million times as rapid; but 300 million per second is enormously more rapid than any audible sound, about a thousand times as fast as the highest audible note. A short bar of metal vibrates longitudinally very fast, but it would have to be about the thousandth of a centimetre long, in order to vibrate at the required rate. It would be almost hopeless by mechanical means to produce electric alternations of this frequency. Fortunately there is an electric method of producing very rapid alternate electrifications. When a Leyden jar is discharged through a wire of small resistance, the self-induction of the current in this wire keeps the current running after the jar is discharged, and recharges it in the opposite direction, to immediately discharge back again, and so on through a series of alternations. This action is quite intelligible on the hypothesis that electrification consists in a strained condition of the ether, which relieves itself by means of the conductor. Just as a bent spring or other strained body, when allowed suddenly to relieve itself, relieves itself in a series of vibrations that gradually subside, similarly the strain of the ether relieves itself in a series of gradually subsiding vibrations. If the spring while relieving itself has to overcome frictional resistance, its vibrations will rapidly subside; and if the friction be sufficiently great, it will not vibrate at all, but will gradually subside into its position of equilibrium. In the same manner, if the resistance to the relief of the strain of the medium, which is offered by the conducting wire, be great, the vibrations will subside rapidly, and if the resistance of the wire be too great, there will not be any vibrations at all. Of course, quite independently of all frictional and viscous resistances, a vibrating spring, such as a tuning-fork that is producing sound-waves in the air which carry the energy of the fork away from it into the surrounding medium, will gradually vibrate less and less. In the same way, quite independently of the resistance of the conducting wire, we must expect that, if a discharging conductor produces electric waves, its vibrations must gradually subside owing to its energy being gradually transferred to the surrounding medium. As a consequence of this the time that a Leyden jar takes to discharge itself in this way may be very short indeed. It may perform a good many oscillations in this very short time, but then each oscillation takes a very short time. To get some idea of what quantities we are dealing with, consider the rates of oscillation which would give wave-lengths that were short enough to be conveniently dealt with in laboratories. 300 million per second would give us waves one metre long; consider what is meant by 100 million per second. We may get some conception of it by calculating the time corresponding to 100 million seconds. It is more than 3 years and 2 months. The pendulum of a clock would have to oscillate 3 years and 2 months before it would have performed as many oscillations as we require to be performed in one second. The pendulum of a clock left to itself without weights or springs to drive it, and only given a single impulse, would practically cease to vibrate after it had performed 40 or 50 vibrations, unless it were very heavy, *i.e.* had a great store of energy or were very delicately suspended, and exposed only a small resistance to the air. A light pendulum would be stopped by com-

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municating motion to the air after a very few vibrations. The case of a Leyden jar discharge is more like the case of a mass on a spring than the case of a pendulum, because in the cases of the Leyden jar there is nothing quite analogous to the way in which the earth pulls the pendulum: it is the elasticity of the ether that causes the electric currents in the Leyden jar discharge, just as it is the elasticity of the spring that causes the motion of the matter attached to it in the case of a mass vibrating on a spring. It is possible to push this analogy still further. Under what conditions would the spring vibrate most rapidly? When the spring was stiff and the mass small. What is meant by a spring being stiff? When a considerable force only bends it a little. This corresponds to a considerable electric force only electrifying the Leyden jar coatings a little, *i.e.* to the Leyden jar having a small capacity. We would consequently expect that the discharge of a Leyden jar with a small capacity would vibrate more rapidly than that of one with a large capacity, and this is the case. In order to make a Leyden jar of very small capacity we must have small conducting surfaces as far apart as possible, and two separate plates or knobs do very well. The second condition for rapid vibration was that the mass moved should be small. In the case of electric currents what keeps the current running after the plates have become discharged and recharges them again is the so-called self-induction of the current. It would be well to look upon it as magnetic energy stored up in the ether around the current, but whatever view is taken of it, it evidently corresponds to the mass moved, whose energy keeps it moving after the spring is unbent and rebends the spring again. Hence we may conclude that a small self-induction will favour rapidity of oscillation, and this is the case. To attain this we must make the distance the current has to run from plate to plate as short as possible. The smaller the plates and the shorter the connecting wire the more rapid the vibrations; in fact, the rapidity of vibration is directly proportional to the linear dimensions of the system, and for the most rapid vibrations two spherical knobs, one charged positively and the other negatively, and discharging directly from one to the other, have been used. Hertz in his original investigations used two plates about 40 cm. square, forming parts of the same plane, and separated by an interval of about 60 cm. Each plate was connected at the centre of the edge next the other plate with a wire about 30 cm. long, and terminating in a small brass knob. These knobs were within 2 or 3 mm. of one another, so that when one plate was charged positively and the other negatively they discharged to one another in a spark across this gap. An apparatus about this size would produce waves 10 or 12 metres long, and its rate of oscillation would be about 30 million per second. As the vibration actually produced by these oscillators seems to be very complex, the rate of oscillation can only be described as "about" so and so. In a subsequent investigation Hertz employed two elongated cylinders about 15 cm. long and about 3 cm. in diameter, terminated by knobs about 4 cm. in diameter, and discharging directly into one another. Such an oscillator produces waves from 60 to 70 cm. long, and, consequently, vibrations at the rate of between 400 and 500 million per second. Most other experimenters have used oscillators about the same dimensions as Hertz's larger apparatus, as the effects produced are more energetic; but many experiments, especially on refraction, require a smaller wave to be dealt with, unless all the apparatus used be on an enormous scale, such as could not be accommodated in any ordinary laboratory. When we are thus aiming at rapid rates of vibration, it must be recollected that we cannot at the same time expect many vibrations after each impulse. If we have a stiff spring with a small weight arranged so as to give a lot of its energy to the surrounding medium, we cannot expect to have very much energy to deal with, nor many vibrations, and, as a matter of fact, we find that this is the case. The total duration of a spark of even a large Leyden jar is very small. Lord Rayleigh has recently illustrated this very beautifully by his photographs of falling drops and breaking bubbles. We cannot reasonably expect each spark to have more than from 10 to 20 effective oscillations, so that, even in the case of the slower oscillator, the total duration of the spark is not above a millionth of a second. It is very remarkable that the incandescent air, heated to incandescence by the spark, should cool as rapidly as it does, but there is conclusive evidence that it remains incandescent after the spark proper has ceased, and consequently lasts incandescent longer than the millionth of a second. What is seen as the white core of the spark may not last longer than the electric discharge itself, and certainly does not do so in the case of the comparatively very slowly oscillating sparks that have been analyzed into their component vibrations by photographing them on a moving plate. The incandescent air remaining in the path of such discharge is probably the conducting path through which the oscillating current rushes backwards and forwards. Once the air gap has been broken through, the character of the air gap as an opponent of the passage of electricity is completely changed. Before the air gap breaks down, it requires a considerable initial difference of electric pressure to start a current. Once it has been broken down, the electric current oscillates backwards and forwards across the incandescent air gap until the whole difference of electric pressure has subsided, showing that the broken air gap has become a conductor in which even the feeblest electric pressure is able to produce an electric current. If this were not so, Leyden jars would not be discharged by a single spark. All this is quite in accordance with what we know of air that is, or even has lately been, incandescent: such air conducts under the feeblest electric force. All this is most essential to the success of our oscillator. Only for this valuable property of air, that it gives way suddenly, and thenceforward offers but a feeble opposition to the rapidly alternating discharge, it would have been almost impossible to start these rapid oscillations. If we wish to start a tuning-fork vibrating, we must give it a sharp blow: it will not do to press its prongs together and then let them go slowly: we must apply a force which is short-lived in comparison with the period of vibration of the fork. It is necessary, then, that the air gap must break down in a time short compared with the rate of oscillation of the discharge; and when this is required to be at the rate of 400 million per second, it is evident how very remarkably suddenly the air gap breaks down. From the experiments themselves it seems as if any even minute roughnesses, dust, &c., on the discharging surface, interfered with this rapidity of breakdown: it seems as if the points spluttered out electricity and gradually broke down the air gap, for the vibrations originated are very feeble unless the discharging surfaces are kept highly polished: gilt brass knobs act admirably if kept polished up every ten minutes or so. One of the greatest desiderata in these experiments is some method of making sure that all the sparks should have the same character, and be all good ones.

(*To be continued.*)

THE ROYAL SOCIETY SELECTED CANDIDATES.

THE following fifteen candidates were selected on Thursday last (April 30), by the Council of the Royal Society, to be recommended for election into the Society. The ballot will take place on June 4, at 4 p.m. We print with the name of each candidate the statement of his qualifications.

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