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What is electricity?

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WHAT IS ELECTRICITY?

THEORIES.

NUMEROUS attempts have been made to explain the phenomena of electricity. As a general thing, these phenomena are so utterly unlike other phenomena that have been explained and are easily intelligible, that it has quite generally been taken for granted, until lately, that something very different from ordinary matter and the laws of forces applicable to it must be involved in the phenomena themselves. Consequently the term *imponderable* was applied to it, — something that was matter minus some of the essentials of matter; and as it was apparent that, whatever it was, it moved, apparently flowed, from one place to another, the term *fluid* was applied to it, a term descriptive of a certain form of matter. Imponderable fluid was the descriptive name applied to electricity. Newton supposed that an excited body emitted such a fluid that could

penetrate glass. When the two facts of electrical attraction and repulsion had to be accounted for, two theories were propounded, — one by Benjamin Franklin, the other by Dufay. Franklin supposed that electricity was a subtle, imponderable fluid, of which all bodies contained a certain normal quantity. By friction or otherwise this normal quantity was disturbed. If a body received more than its due share, it was said to be positively electrified : if it had less than its normal quantity, it was said to be negatively electrified. Franklin supposed this electric fluid to be highly self-repulsive, and that it powerfully attracted the particles of matter.

According to Dufay, there are two electric fluids, opposite in tendency but equal in amount. When associated together in equal quantities, they neutralize each other completely. A portion of this neutral compound fluid pervades all matter in its unexcited state. By friction or otherwise this compound fluid is decomposed, the rubber and the body rubbed exchanging equal quantities of opposite kinds with each other, leaving one of them positively, the other negatively

electrified. These two fluids were supposed to be self-repulsive, but to attract each other: so that, if two bodies be charged with either positive or negative electricity, such bodies would mutually repel each other; but if one was charged with positive, while the other was charged with negative electricity, the two bodies would mutually attract each other.

Either of these two theories may be used to illustrate the phenomena, and so have done good service in systematizing the facts. It is evident that both of them cannot be true, and it is in the highest degree probable that neither of them is true.

Some have supposed that there was a kind of electric atmosphere about every atom of matter; and still another theory, now advocated by Edlund of Stockholm, assumes that electricity is identical with the ether by which radiant energy, light and heat, is transmitted.

Before a correct judgment can be formed of the nature of any force, it is necessary to know what it can do, what kind of phenomena it can produce. Let us, then, take a brief survey of what electricity can do.

1st, It can directly produce *motion*, through the attractions and repulsions of electrified bodies, — as indicated by electrometers, the rotation of the fly-wheel, the deflection of the galvanometer needle. It has been proved by the mathematical labors of Clausius, and confirmed by experiment, that, when electricity performs any mechanical work, so much electricity is lost, annihilated as electricity.

2d, It can directly produce *heat*, as shown by passing a sufficient quantity of electricity through a fine platinum wire: the wire becomes heated, and glows, and it may even be fused by the intensity of the heat. The heat developed in the so-called electric arc is so great as to fuse the most refractory substances. If a current of electricity from a battery be sent through a thermo-pile, one of the faces of the pile will be heated. The heat of the spark from a Leyden jar may be made to ignite gunpowder, and dissipate gold into vapor. The heat produced by lightning is seen when a live tree is struck by a powerful flash: the sap of the tree is instantly converted into steam of so high a tension as to

explode the tree, scattering it in small fragments over a wide area. The tips of lightning-rods often exhibit this heating effect, being fused by the passage of too great a quantity of electricity.

In the early part of the present century it was demonstrated by Count Rumford, and also by Sir Humphry Davy, that heat was but a form of molecular motion. Since then the exact relations between the motion of a mass of matter and the equivalent heat have been experimentally determined by Joule, so that the unit of heat may be expressed in the motion of a mass of matter. This is deducible from a more general law, known as the conservation of energy. The application in this place is, that whenever heat appears through electric action, as in the above-mentioned places, we know that it still is only *motion* that is the product, only that this motion is now among the molecules of the body, instead of the motion of the whole body in space, as when a pith-ball moves, or a galvanometer-needle turns.

3d, It can directly produce *light*. This is seen in every spark from an electric machine, in the flash of lightning, and in the electric light.

It has been shown in numberless ways, that there is no essential difference between light and heat, and that what we call light is only the active relation which certain rays of radiant energy have to the eyes. In order to make this plain, suppose that a beam of light, say from the sun, be permitted to fall upon a triangular prism of glass: at once it is seen that the beam is deflected, and instead of appearing a spot of white light, as it did before it was deflected, it now appears as a brilliant band of colors, which is called the solar spectrum. If now this spectrum be examined as to the distribution of heat, by moving a thermo-pile through it from the blue end towards the red end, it will be noticed that the galvanometer-needle will be but slightly deflected at the blue end; but, as the thermo-pile is moved, the deflections are greater until it is past the red end, where the heat is greatest. On this account it has been customary to say that the red end of the spectrum was the heating end. With various pieces of mechanism the rays may be separated from each other, and measured; and then it appears that a red ray of light has a wave

length of about $\frac{1}{37000}$ in., and the violet ray about $\frac{1}{60000}$ in. The rays beyond the red have also been measured, and found to be greater in length uniformly as one recedes from the visible part of the spectrum.

In like manner, beyond the blue end the wave lengths become shorter and shorter ; and in each of these directions the spectrum that is invisible is much longer than the visible one. Now, it has also been found that where a prism of glass or other material is used to produce a spectrum, it distributes the rays very unevenly ; that is, towards the red end of the spectrum they are very much crowded, while towards the blue end they are more dispersed. Hence, if one were measuring the heating power of such a spectrum, many more rays would fall upon an equal surface of the thermo-pile at the red end than at the blue end ; therefore the indications of the galvanometer would be fallacious. Before any thing definite could be known about the matter, it would plainly be necessary to work with an equal dispersion of all the rays. This was effected a few years ago by Dr. Draper of New

York. He took the spectrum produced by diffraction instead of refraction, and measured that. In that way it was found that the heating power of the spectrum is equal in every part of it; and hence the pictures in treatises on physics that represent the heating power of the spectrum to be concentrated at the red end is not true save where the spectrum is irregularly produced. As for vision, the mechanical structure of the eye is such that radiant vibrations having a wave length between $\frac{1}{37000}$ in. and $\frac{1}{60000}$ in. can affect it, while longer or shorter wave lengths can not. Such waves we call light, but it is not at all improbable that some animals and insects have eyes adapted to either longer or shorter wave-lengths; in which case, what would be perfectly dark to us would be light to them. It is a familiar enough fact, that many animals, such as dogs, cats, rats, and mice, can see in the night. Some horses may be trusted to keep in the road in a dark night, when the driver cannot see even the horse itself. This has usually been accounted for by saying that their eyes are constructed so as to collect a greater number of luminous rays.

It is much better explained by supposing their eyes to be constructed to respond to wave-lengths either greater or less than those of mankind.

A ray of light, then, consists of a single line of undulations of a definite wave length, such that if it falls upon the eye it will produce sight ; if it falls upon a thermo-pile it heats it by just the same quantity that another wave-length would heat it ; if it falls upon matter in unstable chemical relations, it will do chemical work, depending upon the kinds of matter. A red ray is as effective for some substances as a violet ray is for others. The statement, then, so often lately made to do certain analogical work, namely, that a ray of light consists of three distinct parts, which may be separated from each other, and are called heat, light, and chemical properties, is simply untrue. What a ray will do, depends upon what kind of a structure it falls on ; and when it has done that work, of whatever kind it may be, it ceases to exist as a ray.

If, therefore, electricity can directly produce light, it is simply producing *motion*, as in the case of heat, the motion being of such a sort that the eyes of men are affected by it.

4th, It can produce *magnetism*. A current of electricity passing through a coil of wire makes such a coil a magnet, which will set itself in the direction of the magnetic meridian of the earth ; and, if a bar of soft iron be placed in the coil, it becomes the familiar electro-magnet ; and, if hardened steel be put in it, it becomes a permanent magnet.

This leads to the inquiry as to what magnetism is. We know that it can produce motion by its moving at a distance a piece of iron or another magnet. It will also sustain a mass of matter against gravity or some other contrary force. Through such mechanism as magneto-electric machines it produces electricity in great abundance, which again can be used to produce any of the effects of electricity, — moving bodies by attraction or repulsion, generating heat or light, or again making a magnet. But as all of these are but varied forms of motion, either of a mass as a whole, or molecular, can it be doubted for an instant, that what we call magnetism is but some form of motion? Must it not be either some form of matter, or some form of

motion? If it were a form of matter, then a magnet would only be permanent so long as it was not used; for use implies consumption of the force; and, if this be matter in any form, then in a given mass of matter there can be but a definite quantity of such magnetic matter, and consumption must lessen that quantity. As a matter of fact, there is no perceptible lessening of the power of a magnet when it is properly used. It is also a matter of fact, that neither motion of a mass, nor electrical effects, nor any other, can be produced by the action of a magnet alone. It is only when some form of motion has been added to its own property, that we get any kind of an effect from it: hence all effects due to its action are *resultants* of two forces, one of them being common motion of a mass of matter, and the other the energy of the magnet. Hence we infer that a magnet is a mechanism of such a structure as to change the direction and character of the motion which acts upon it. When the wheel of a common electrical machine is turned, the product is electricity,—a force very different from that which originates it. Ordinary mechanical

motion *goes in* ; electricity *comes out*, the latter being a modified motion due to the physical structure of the machine. In like manner, a magnet may be considered as a machine by means of which mechanical motion may be converted into some other form of motion. It is evident that molecular structure is chiefly concerned in this. If a bar of iron that exhibits no evidence of magnetism whatever be subjected to torsion, it will immediately become a magnet with poles dependent upon the direction of the twist. This developed magnetism will re-act upon a coil of wire, and so move a galvanometer needle. If the bar be permitted to recover its original condition, it will lose its magnetism, which will at once re-appear upon twisting the rod again. Now, when the rod is twisted, it is evident that there is a molecular strain in certain directions throughout the mass. The converse experiment illustrates the same thing. It has been found, that when a rod of iron is made magnetic by the action of a current of electricity circulating about it, and at the same time passing longitudinally through it, the rod is

slightly lengthened and twisted in a direction that depends upon the direction of the current. Moreover, if a permanent magnet be heated to a red heat, its magnetism is destroyed ; for such a heat allows the molecules to freely arrange themselves without any external constraint. Also, if a permanent magnet be suspended so as to give out a musical sound when it is struck, the magnetism will be much weakened by making it thus to vibrate. In this case, as in the other, the vibrations affect every molecule, and so enable them to re-adjust themselves to the positions they held before being magnetized. The same thing happens when a bar of iron is made magnetic through the inductive action of the earth. When this bar is held in the direction of the magnetic dip, it becomes but very slightly magnetized ; but, if it be so held that when it is struck with a hammer it will ring, that is, give out a musical sound, it will at once become decidedly magnetic. Evidently the earth's action tends to set the molecules of the mass in a new position, but cohesion prevents them from assuming it. When the molecules are made to vibrate,

they can assume such new positions more readily. The molecules of a magnet, then, are differently arranged from those in an unmagnetized piece of iron or steel ; and, for every new arrangement of the molecules of a mass of any kind, we always have some new physical property developed. The same identical substance may appear as charcoal, coke, plumbago, anthracite coal, and diamond. Hence a magnet is a machine in which other forces acting upon it are transformed in character, and re-appear as attractions and repulsions of other kinds of matter : this transformation cannot take place, and hence magnetism cannot become apparent, only upon the condition of another force acting in concert with it ; and, if at any time it may seem to be acting without such external force, it is done at the expense of the heat it has absorbed, and therefore the magnet must at such time be losing temperature proportional to the work done. This I have discovered to be true by making a magnet to exert its force in front of a thermo-pile, which uniformly exhibits a cooled face under such conditions. What the particular form of the motion may

be that we call magnetism, is not yet made out ; but that it is some form of motion, is very evident. The following experiments may throw some light upon it. Last August Mr. Kerr read a paper before the British Association of Science, in which was detailed the following experiment : The pole of an electro-magnet was nicely polished so as to reflect light like a mirror. A beam of sunlight was permitted to fall upon it, and be reflected to a convenient place for examination. A current of electricity was sent through the coil, which of course rendered the iron magnetic ; and it was noticed that the light that was reflected from the pole was circularly polarized : that is, the motion of a ray, instead of being a simple undulatory movement, was now made to assume such a motion as the water from a garden-hose has when the nozzle is swung round in a circle while the water is escaping from it. After reading the account of it, it occurred to me that the converse experiment might be tried ; that is to say, the effect of a circularly polarized beam of light upon a piece of steel. By concentrating a large beam of ordi-

nary plane polarized light with a quartz lens, and passing it through a quarter wave-plate at the proper angle, a powerful beam of circularly polarized light was obtained. At the focus of this beam a fine cambric needle without magnetism was placed so that the light passed it longitudinally. Ten minutes' exposure was sufficient to make it decidedly magnetic. Hence I infer that the motions which we call magnetic attractions and repulsions may be quite analogous to such helical motions; also, that these motions exist in ether, and evidently may be either right-handed or left-handed. Wind up on a pencil a piece of wire twelve or fifteen inches long, making a loose spiral. Bring the two ends of the spiral together; and note first that one is twisted to the right, the other to the left. If they be twisted into each other, they will advance very easily; but if a right-handed spiral were to be interlocked with another like it, and both turned in the direction of their spiral, they would separate rapidly. Applying this conception to a magnet, we might suppose that such spiral motions will be set up in the ether by the magnet, and

that such motions re-acting upon ordinary matter affect it as attraction and repulsion ; and thus we should have at least a conceivable mechanical explanation of the phenomenon.

There are numberless experiments which might be given to further exhibit the relation of mass motion to magnetism, but a single one more must

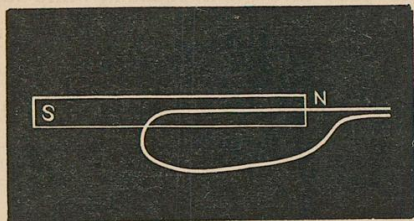


FIG. 5.

suffice. No rotation of a magnet upon its own axis can produce any effects upon a current that is exterior to it ; but if a loop of wire be kept stationary adjacent to a magnet, as in Fig. 5, while the magnet revolves, a current of electricity is produced ; and if the magnet be kept stationary, and the loop revolves, a current will also be produced, but in the opposite direction. Here, as in all the other cases, no electricity is

originated, save when motion is imparted to one or other of the parts. This experiment is due to Faraday.

From all these cases we can come to but one conclusion, that both electricity and magnetism are but forms of motion ; electricity being a form of motion in ordinary matter, for it cannot be made to pass through a vacuum, while magnetism must be a form of motion induced in the ether, for it is as effective in a vacuum as out of it ; electricity always needing some material conductor, magnetism needing no more than do radiant heat and light.

VELOCITY.

Measurements have been made of the velocity of electricity ; both that of high tension, such as the spark from a Leyden jar, and also that from a battery. The former was found to have a velocity over 200,000 miles a second, while the electricity from a battery may move as slowly as 15,000 or 20,000 miles a second ; but this is very largely a matter of conductors. Its velocity is seldom above 30,000 miles a second on ordinary

telegraphic lines. If the electricity be used to give signals, as in ordinary telegraphy, the time required varies nearly as the length of the line, and in any case is a much greater quantity. Prescott in his work on the telegraph states that "the time required to produce a signal on the electro-magnet at the extremity of a line of 300 miles of No. 8 iron wire is about .01 seconds, and that this time increases in a greater proportion than the length of the line; for example, on a line 600 miles in length it amounts to about .03 seconds." He also states that it varies much with the kind of magnet used, some forms of magnets being much more sensitive than others for this work.

Wheatstone proved a good many years ago that the duration of the electric spark was less than one millionth of a second. When a swiftly moving body can only be seen by an electric spark, or flash of lightning, it looks as if it were quiescent. Thus a train of cars rushing along at the rate of forty or fifty miles per hour appears sharply defined, — even the driving-wheels of the locomotive can be seen in detail, which is impos-

sible in continuous light, — and all seems to be standing still. In like manner will the sails of a windmill, which may be turning at a rapid rate, be seen apparently at rest. This is because in the short time during which they are illuminated they do not appreciably move.

I am not aware that any attempt has been made to measure the velocity of magnetism. If, however, it be a form of motion in ether, it is probable that the velocity is comparable to the velocity of radiant energy, light, which is equal to about 186,000 miles a second.