ously. Changes in temperature occurring on a large scale in our atmosphere, occurring in these gas jets, in our fires, in the axles of machinery, and in thousands of other places, are so familiar that we have ceased to wonder at them.

If we rub these two bodies together, the potential of the two is no longer the same. We do not know which one has become greater, and in this respect our knowledge of electricity is less complete than of heat. We assume that the gutta percha has become negative. If we now leave these bodies in contact, the potential of the cat's skin will diminish and that of the gutta percha will increase until they have again reached a common potential—that of the earth. As in the case of heat and cold, we may say either that this has come about by a flow of positive electricity from the cat's skin to the gutta percha, or by a flow of negative electricity in the opposite direction, for these statements are identical.

In case of our gas cylinders, the gas tends to leak out of the vessel where the pressure is great into the vessel where it is small. The heat tends to leak out of a body of high temperature into the colder one, or the cold tends to go in the opposite direction. Similarly, the plus electricity tends to flow from the body having a high potential, to the body having a low potential, or the minus electricity tends to go in the opposite direction.

[ENGINEERING.]

THE HYDRODYNAMIC RESEARCHES OF PROFESSOR BJERKNES.

By CONRAD W. COOKE.

WE have in former articles described the highly interesting series of experimental researches of Dr. C. A. Bjerknes, Professor of Mathematics in the University

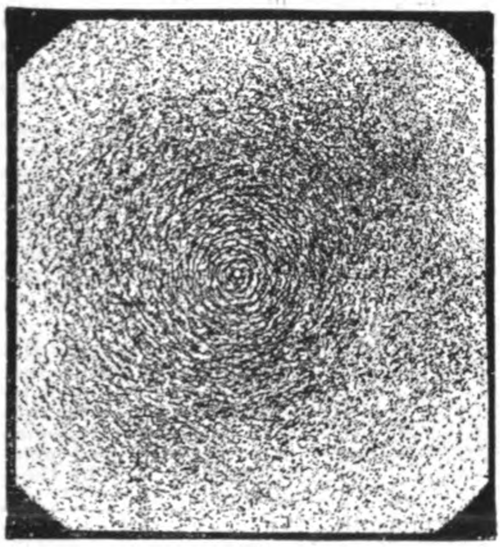
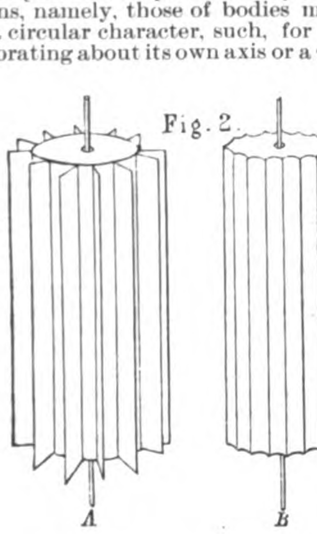


FIG. 1.

of Christiania, which formed so attractive a feature in the Electrical Exhibition of Paris in 1881, and which constituted the practical development of a theoretical research which had extended over a previous period of more than twenty years. The experiments which we described in those articles were, as our readers will remember, upon the influence of pulsating and rectilinearly vibrating bodies upon one another and upon bodies in their neighborhood, as well as upon the medium in which they are immersed. This medium, in the majority of Professor Bjerknes' earlier experiments, was water, although he demonstrated mathematically, and to a small extent experimentally, that the phenomena, which bear so striking an analogy to those of magnetism, may be produced in air.

Our readers will recollect that in the spring of 1882 Mr. Stroh, by means of some very delicate and beautifully designed apparatus, was able to demonstrate a large number of the same phenomena in atmospheric air of the ordinary density; and about the same time Professor Bjerknes, in Christiania, was extending his researches to phenomena produced by a different class of vibrations, namely, those of bodies moving in oscillations of a circular character, such, for example, as a cylinder vibrating about its own axis or a sphere around

Fig. 2.

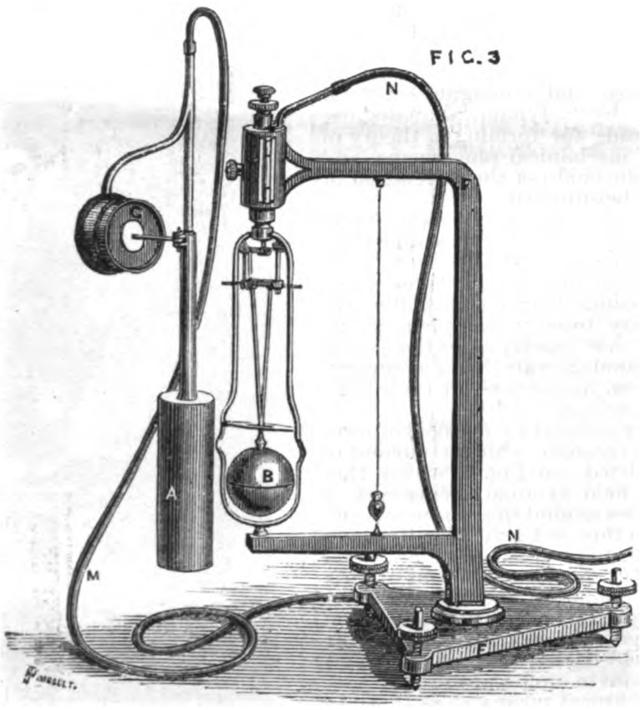


one of its diameters; some of these experiments were brought by Professor Bjerknes before the Physical Society of London in the following June. Since that time, however, Professor Bjerknes, with the very important assistance of his son, Mr. Vilhelm Bjerknes, has been extending these experimental researches in the same direction, and with the results which it is the object of the present series of articles to describe.

The especial feature of interest in all Professor Bjerknes experiments has been the remarkably close analogy which exists between the phenomena exhibited in his mechanical experiments in water and other media and those of magnetism and of electricity, and it may be of some interest if we here recapitulate some of the more striking of these analogies.

(1.) In the first place, the vibrating or pulsating bodies, by setting the water or other medium in which they are immersed into vibration, set up in their immediate neighborhood a field of mechanical force very closely analogous to the field of magnetic force with which magnetized bodies are surrounded. The lines

FIG. 3



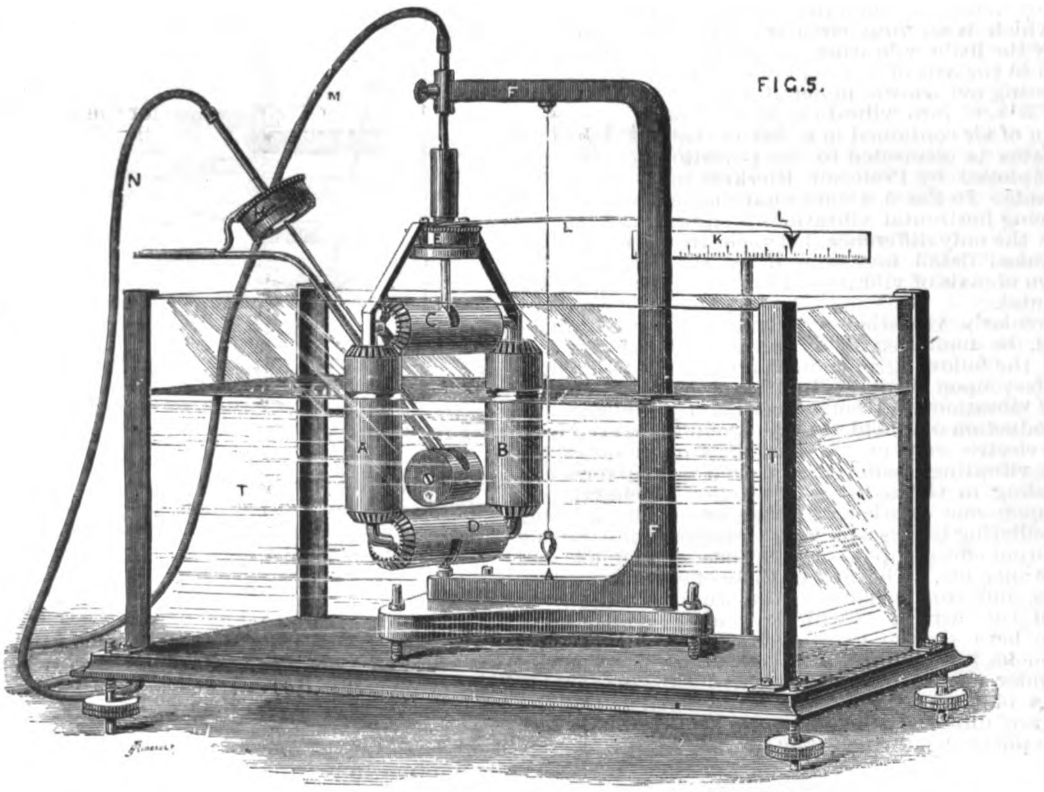
of vibration have precisely the same directions and form the same figures, while at the same time the decrease of the intensity of vibration by an increase of distance obeys precisely the same law as does that of magnetic intensity at increasing distances from a magnetic body.

(2.) When two or more vibrating bodies are immersed in a fluid, they set up around them fields of vibration, and act and react upon one another in a manner closely analogous to the action and reaction of magnets upon one another, producing the phenomena of attraction and repulsion. In this respect, however, the analogy appears to be inverse, repulsion being produced where, from the magnetic analogy, one would expect to find attraction, and *vice versa*.

(3.) If a neutral body, that is to say a body having no vibration of its own, be immersed in the fluid and within the field of vibration, phenomena are produced exactly analogous to the magnetic and diamagnetic phenomena produced by the action of a magnet upon soft iron or bismuth, its apparently magnetic or diamagnetic properties being determined by the specific gravity of the neutral body as compared to that of the medium in which it is immersed. If the neutral body be lighter than the medium, it exhibits the magnetic induction of iron with respect to polarity, but is nevertheless repelled; while if it be heavier than the medium, its direction is similar to that of diamagnetic bodies such as bismuth, but on the other hand exhibits the phenomena of attraction.

In this way Professor Bjerknes has been able to reproduce analogues of all the phenomena of magnetism and diamagnetism, those phenomena which may be classed as effects of induction being directly reproduced, while those which may be classed as effects of mechanical action, and resulting in change of place, are analogous inversely. This fact has been so much misunderstood both in this country and on the Continent

FIG. 5.

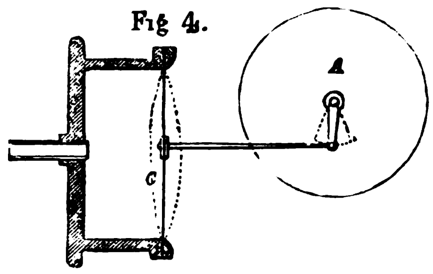


that it will be well, before describing the experiments, to enter more fully into an explanation of these most interesting and instructive phenomena.

For the sake of clearness we will speak of magnetic induction as that property of a magnet by which it is surrounded by a field of force, and by which pieces of iron, within that field, are converted into magnets, and pieces of bismuth into diamagnets, and we will speak of magnetic action as the property of a magnet by which it attracts or repels another magnet, or by which it attacks or repels a piece of iron or bismuth magnetized by magnetic induction.

The corresponding hydrodynamic phenomena may be regarded in a similar manner; thus, when a vibrating or pulsating body immersed in a liquid surrounds itself with a field of vibrations, or communicates vibrations to other immersed bodies within that vibratory field, the phenomena so produced may be looked upon as phenomena of hydrodynamic induction, while on the other hand, when a vibrating or pulsating body attracts or repels another pulsating or vibratory body (whether such vibrations be produced by outside mechanical agency or by hydrodynamical induction), then the phenomena so produced are those of hydrodynamical action, and it is in this way that we shall treat the phenomena throughout this article, using the words

Fig 4.



induction and *direct action* in these somewhat restricted meanings.

In the hydrodynamical experiments of Professor Bjerknes all the phenomena of magnetic induction can be reproduced directly and perfectly, but the phenomena of magnetic action are not so exactly reproduced, that is to say, they are subject to a sort of inversion. Thus when two bodies are pulsating together and in the same phase (*i. e.*, both expanding and both contracting at the same time), they mutually attract each other; but if they are pulsating in opposite phases, repulsion is the result. From this one experiment taken by itself we might be led to infer that bodies pulsating in similar phases are the hydrodynamic analogues of magnets having their opposite poles presented to one another, and that bodies pulsating in opposite phases are analogous to a presentation of similar magnetic poles; but it will be seen at once that this cannot be the case if three magnetic poles or three pulsating bodies be considered instead of only two. It is clear, on the one hand, that three similar magnet poles will all repel one another, while, on the other, of three pulsating bodies, two of them must always attract one another, while a third would be repelled; and, moreover, two similarly pulsating bodies set up around them the same lines of force as two similar magnetic poles, and two oppositely pulsating bodies produce lines of force identically the same as those set up by two magnets of opposite polarity. Thus it will be seen that there is a break in the analogy between the hydrodynamical and the magnetic phenomena (if a uniform inversion of the effects can be called a break, for it is, as far as Professor Bjerknes' experiments go, without an exception); and if by any means this inversion could be reinverted, all the phenomena of magnetism and diamagnetism could be exactly reproduced by hydrodynamical analogues; there would thus be grounds for forming a theory of magnetism on the basis of mechanical phenomena, and a very important link in the chain of the correlation of the physical forces would be supplied.

While the experiments of Professor Bjerknes upon pulsating and rectilinearly vibrating bodies and their influence upon one another illustrate by very close analogies the phenomena of magnetism, those upon circularly vibrating bodies and their mutual influences bear a remarkable analogy to electrical phenomena; and it is a significent fact that exactly as in the case of magnetic illustration, the analogies are direct as regards the phenomena of induction, and inverse in their illustration of direct electrical action.

If we examine the figure produced by the field of force surrounding a conductor through which a current of electricity is being transmitted (see Fig. 1), we see that iron filings within that field arrange themselves in more or less concentric circles around the conductor conveying the current. From this fact Professor Bjerknes and his son, reasoning that, to produce a similar field of energy around a vibrating body, the vibrations of that body must partake of a circular or rotary character, constructed apparatus for producing the hydrodynamic analogue of electric currents, in which a conductor transmitting a current of electricity is represented by a cylinder to which oscillations in circles around its axis are given by suitable mechanical means, so as to cause the enveloping medium to follow its motion and make similar rotative vibrations. In some of the earlier experiments in this direction, cylinders carrying radial veins (A, Fig. 2) or fluted longitudinally around their surfaces (B, Fig. 2) were employed with the object of giving the vibrating cylinder a greater hold of the liquid in which they were immersed; but it was found that these vanes or flutings had but little or no effect upon water or liquids of similar viscosity, and Professor Bjerknes was led to adopt highly viscous fluids, such as glycerin or maize sirup, both of which substances are well adapted for the experiments, being at the same time both highly viscous and perfectly transparent and colorless. In seeking, for the purpose of this research, a fluid medium which shall possess analogous properties to the luminiferous ether, or whatever may be the medium whose vibrations render manifest certain physical phenomena, it might be considered at first sight that substances so dense as glycerin and sirup could have but little in common with the ether, and that an analogy between experiments made within it and phenomena associated with ethereal vibrations would be of a very feeble description; but Professor Bjerknes has shown that the chief requisite in such a medium is that its viscosity should be great, not absolutely, but large only in proportion to its density, and if the density be small, the necessary viscosity may be small also. Neither is it necessary for the fluid medium to possess great internal friction, but what is necessary to the experiments is that the medium shall be one which is readily set into vibration by the action of the circularly vibrating cylinder; this property appears to be possessed exclusively by the more viscous fluids, and is, moreover, in complete accord with what is known of the luminiferous ether according to the theory of light. The property is rather a kind of elasticity, which ordinary fluids do not possess, but which facilitates the propagation of transverse vibrations.

One form of apparatus for the propagation of rotative oscillations is shown to the left of Fig. 3, and consists of a cylinder, A, mounted on a tubular spindle, and which is set into circular oscillations around its axis by the little vibrating membrane, C, which is attached to the axis of the cylinder by a little crank and connecting rod shown in detail in Fig. 4. This membrane is set into vibration by a rapidly pulsating column of air contained in a flexible tube M, by which apparatus is connected to the pulsation pump which was employed by Professor Bjerknes in his earlier experiments. In Fig. 5, a somewhat similar apparatus for producing horizontal vibrations is shown, and marked N H C, the only difference between them being one of mechanical detail necessitated by the change in the position of axis of vibration from the vertical to the horizontal.

If circularly vibrating cylinders, such as we have described, be immersed in a viscous fluid and set into action, the following phenomena may be observed: 1. The effect upon the fluid itself, setting up therein a field of vibration, and corresponding by analogy with the production of a field of force around a wire conveying an electric current. 2. The effect upon other circularly vibrating bodies within that field of force corresponding to the action and reaction of electric currents upon one another. 3. The effect on pulsating and oscillating bodies similarly immersed, illustrating the mutual effects upon one another of magnets and electric currents. The first of these effects is one of induction, and, from what has been said from an earlier part of this article, it will be understood that the analogy between the hydrodynamic and the electric phenomena is direct and complete. The effects classified under the second and third heads, being phenomena of direct action (in the restricted use of the word), are uniformly analogous to the magnetic and electric phenomena which they illustrate.

(*To be continued.*)

THE XYLOPHONE.

LIKE most musical instruments, the xylophone, had its origin in very remote times. The Hebrews and Greeks had instruments from which the one of to-day was derived, although the latter has naturally undergone many transformations. Along about 1742 we find it widely in use in Sicily under the name of *Xylorganum*. The Russians, Cossacks, and Tartars, and especially the mountain population of the Carpathians and Ural, played much upon an instrument of the same nature that they called *Diereva* and *Saloma*.

It appears that the xylophone was played in Germany as early as the beginning of the 16th century. After this epoch it was in use for quite a long period, but gradually fell into oblivion until the beginning of the present century. It was toward 1830 that the

FIG. 1.—METHOD OF PLAYING UPON THE XYLOPHONE.

celebrated Russian Gussikow undertook a grand artistic voyage through Europe, and gained a certain renown and received many honors due to his truly original productions. Gussikow possessed a remarkable *technique* that permitted the musical instrument which he brought into fashion to be appreciated for all its worth.

As the name, "instrument of wood and straw," indicates, the xylophone (which Fig. 1 shows the mode of using) consists of small pieces of wood of varying length, and narrow or wide according to the tone that it is desired to get from them. These pieces of wood are connected with each other by cords so as to form a triangular figure (Fig. 2) that may be managed without fear of displacing the parts. The whole is laid upon bands of straw designed to bring out the sounds and render them stronger and purer. The sounds are produced by striking the pieces of wood with a couple of small hammers. They are short and jerky, and, as they cannot be prolonged, nothing but pieces possessing a quick rhythm can be executed upon the instrument. Dances, marches, variations, etc., are played upon it by preference, and with the best effect.

The popularity of this instrument is making rapid progress, and it is beginning to be played in orchestras

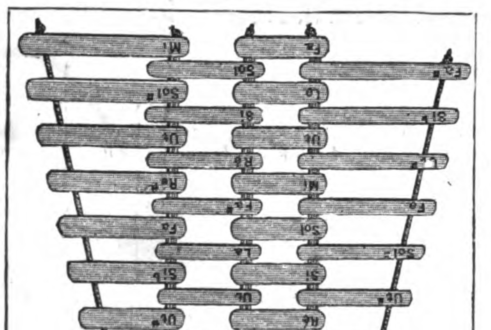


FIG. 2.—PLAN VIEW OF THE XYLOPHONE.

in France [as it has been in America for many years]. A method of using it has just been published, as well as pieces of music adapted to it, with piano, violin, orchestra, etc., accompaniment.

ELECTROTYPING.

THIS eminently useful application of the art of electrotyping originated with Volta, Cruickshank, and Wollaston about 1800 or 1801. In 1838, Spencer, of London, made casts of coins, and cast in intaglio from the matrices thus formed; in the same year Jacobi, of Dorpat, in Russia, made casts by electro deposit, which caused him to be put in charge of the work of gilding the dome of St. Isaac at St. Petersburg.

Electrotyping for the purposes of printing originated with Mr. Joseph A. Adams, a wood-engraver of New York, who made casts (1839–41) from wood-cuts, some engravings being printed from electrotype plates in the latter year. Many improvements in detail have been added since, in the processes as well as the appliances. Robert Murray introduced graphite as a coating for the form moulds. He first communicated his discovery to the Royal Institution of London, and afterward received a silver medal from the Society of Arts.

BLACKLEADING THE FORM.

The process of electrotyping is as follows: The form is locked up very tightly, and is then coated with a surface of graphite, commonly known as blacklead, but it is a misnomer. This is put on with a brush, and may be done very evenly and speedily by a machine in which the brush is reciprocated over the type by hand-wheel, crank, and pitman. A soft brush and very finely powdered graphite are used; the superfluous powder being removed, and the face of the type cleaned by the palm of the hand.

TAKING THE MOULD.

A shallow pan, known as a moulding pan, is then filled with melted yellow wax, making a smooth, even surface, which is blackleaded. The pan is then secured to the head of the press, and the form placed on the bed, which is then raised, delivering an impression of the type upon the wax.

The pan is removed from the head of the press, placed on a table, and then built up, as it is termed. This consists in running wax upon the portions where large spaces occur between type, in order that corresponding portions in the electrotype may not be touched by the inking roller, or touched by the sagging down of the paper in printing.

MAKING THE DEPOSIT.

The wax mould being built, is ready for blackleading, to give it a conducting surface upon which the metal may be deposited in the bath, superfluous blacklead being removed with a bellows. Blacklead, being nearly pure carbon, is a poor conductor, and a part of the metal of the pan is scraped clean, to form a place for the commencement of the deposit. The back of the moulding is waxed, to prevent deposit of copper thereon, and the face of the matrix is wetted to drive away all films or bubbles of air which may otherwise be attached to the blackleaded surface of the type.

The mould is then placed in the bath, containing a solution of sulphate of copper, and is made a part of an electric circuit, in which is also included the zinc element in the sulphuric-acid solution in the other bath. A film of copper is deposited on the blacklead surface of the mould; and when this shell is sufficiently thick, it is taken from the bath, the wax removed, the shell trimmed, the back tinned, straightened, backed with an alloy of type-metal, then shaved to a thickness, and mounted on a block to make it type-high.

A RECENT IMPROVEMENT

has been introduced, in which there is added finely pulverized tin to the graphite for facing the wax mould; the effect in the sulphate of copper bath is to cause a rapid deposition of copper by the substitution of copper for the tin, the latter being seized by the oxygen, while the copper is deposited upon the graphite. The film is after increased by the usual means. Knight's expeditious process consists in dusting fine iron filings on the wet graphite surface of the wax mould, and then pouring upon it a solution of sulphate of copper. Stirring with a brush expedites the contact, and a decomposition takes place; the acid leaves the copper and forms with the iron sulphate a solution which floats off, while the copper is freed and deposited in a pure metallic form upon the graphite. The black surface takes on a muddy tinge with marvelous rapidity. The electric-connection gripper is designed to hold and sustain the moulding pan and make an electric connection with the prepared conducting pan of the mould only, while the metallic pan itself is out of the current of electricity, and receives no deposit.

BACKING-UP.

The thin copper-plate, when removed from the wax mould, is just as minutely correct in the lines and points as was the wax mould, and the original page of type. But it is obvious that the copper sheet is no use to get a print from. You must have something as solid as the type itself before it can be reproduced on paper. So a basis of metal is affixed to the copper film, and this again is backed up with wood thick enough to make the whole type-high. To get this, a man melts some tinfoil in a shallow iron tray, which he places on the surface of molten lead, kept to that heat in square tanks over ordinary fires. The tinfoil sticks to the back of the copper, and on the back of this is poured melted type-metal, until a solid plate has been formed, the surface of which is the copper facsimile and the body white metal. The electro metal plate, copper colored and bright on its surface, has now to go to the

FINISHING ROOM.

Here are two departments. In one the plates are shaved and trimmed down to fit the wood blocks, which are made in the other department. Some of these operations are done by hand, but it is very interesting to see self-working machines planing the sheets of metal to precisely the required thinness with mathematical exactness. A pointed tool is set to a certain pitch, and the plate of metal is made to revolve in such a way that one continuous curl shaving falls until the whole surface (back) has been planed perfectly true. The wood blocks are treated in the same way, after being sawn into the required sizes by a number of circular saws. Another set of workmen fit and join the metal to the wood, trim the edges, and turn the blocks out type-high and ready for working on the printing press.

A WET BLACKLEADING PROCESS.

In Messrs. Harper's establishment in New York, an improved wet process of blackleading is adopted. The wax mould is laid face upward on the floor of an inclosed box, and a torrent of finely pulverized graphite suspended in water is poured upon it by means of a rotary pump, a hose, and a distributing nozzle which dashes the liquid equally over the whole surface of the mould. Superfluous graphite is then removed by copious washing, an extremely fine film of graphite adhering to the wax. This answers a triple purpose; it coats the mould with graphite, wets it ready for the bath, and expels air bubbles from the letters. This process prevents entirely the circulation of blacklead in the air, which has heretofore been so objectionable in the process of electrotyping.

plaited manner. This arrangement makes a porous carbon of high resistance, although each separate strand is extremely dense and homogeneous. From this results the fact that they burn away entirely, not disintegrating in the customary way with pressed and moulded carbons, thus avoiding a considerable annoyance from the dust. The heated part of these cords is confined within narrow limits, and embraced within the flame, thereby aiding total consumption and dissipation of the elements. The resistance of this carbon per foot is about 10 ohms cold; this necessitates the contacts being very near the extremities and close to the arc, which is also of high resistance, approximating from 15 to 20 ohms.

The lamps can be run either in series or in parallel circuit; as an instance of parallel running, they have been worked in seven parallels with three in series.

Those exhibited were working with a current of 2·27 amperes, measured by a Siemens electro-dynamometer with a potential of, it was said, 37 to 40 volts; the candle-power was considerably over 100, and it had been measured with a larger current to produce 250 candles per lamp.

The light was good, with a slight but not disagreeable tint, and the steadiness was up to the usual standard.

A few mechanical improvements that are about to be made in various details of the construction should render this lamp an electrical and commercial success. For street lighting alone there should be a large demand, the carbon costing very little relatively to moulded ones, and the amounts of each lamp in candle-power being highly suitable for that purpose, while they can run for some days without attention.—*Electrical Review.*

[Continued from SUPPLEMENT No. 488, page 7792.]

THE HYDRODYNAMIC RESEARCHES OF PROFESSOR BJERKNES.

By CONRAD W. COOKE.

WE shall now refer to the three classes of phenomena in detail, and in the order in which we have classified them:

1. The effect of the vibrating cylinder upon the fluid in which it is immersed may be investigated by the apparatus which we figured and described in connection with Professor Bjerknes' earlier experiments,* and

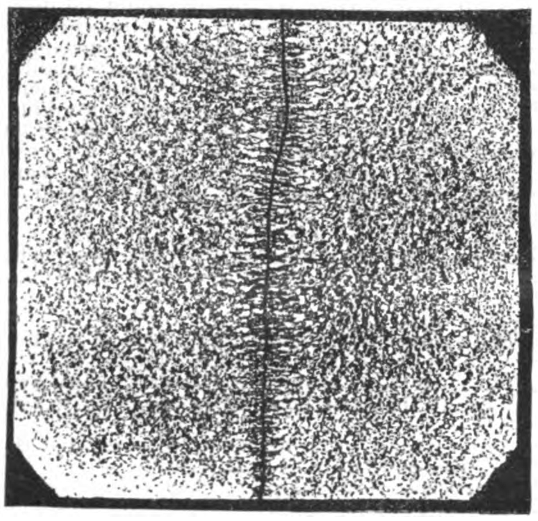
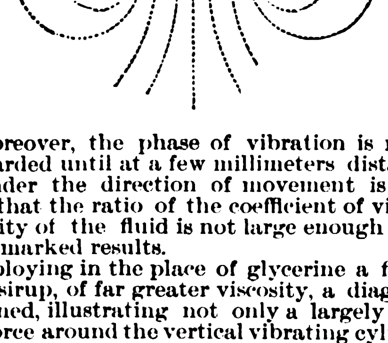


FIG. 6.

which consisted of a hollow metal cylinder with hemispherical ends supported upon a vertical fine elastic steel wire, rising from a firm stand, and surmounted by a camel's hair pencil, which, projecting out of the fluid in which the apparatus is immersed, can be made to record the direction and amplitude of the vibrations on the under side of a plate of glass or sheet of paper. When this apparatus is immersed in glycerine, and placed in different positions within the field of influence of a vibrating cylinder (such as that shown in Fig. 3), a diagram can be produced which is a graphic record of the directions and extent of the vibrations within that field of influence, but it will be found that in the case of glycerine the field of influence extends but a short distance from the vibrating cylinder, and that the motion communicated to the fluid by the vibrating cylinder, which at the surface of contact is very nearly equal to that of the cylinder itself, very rapidly falls off as the distance from the cylinder increases, and



that, moreover, the phase of vibration is more and more retarded until at a few millimeters distance from the cylinder the direction of movement is reversed; showing that the ratio of the coefficient of viscosity to the density of the fluid is not large enough to insure the most marked results.

By employing in the place of glycerine a fluid, such as maize sirup, of far greater viscosity, a diagram may be obtained, illustrating not only a largely extended field of force around the vertical vibrating cylinder, but the figure so produced is identical with that obtained by iron filings scattered over a glass plate and around a vertical wire, through which an electric current is passing (Fig. 1, see page 7791 *ante*). And in the same medium, by employing the horizontal vibrating cylinder shown in Fig. 5, in conjunction with the secondary apparatus, a figure is obtained which is identical with that produced by iron filings on a glass plate, below which, and parallel to its plane, is fixed a wire through which a current of electricity is being transmitted; see Fig. 6.

If two cylinders each circularly vibrating about their vertical axes, and of the form shown to the left of Fig. 3, be introduced into a viscous medium, such as maize sirup, and within the range of each other's field of vibration, figures may be produced with the recording apparatus which are identical with the filing figures produced upon a horizontal plate around two vertical wires conveying electric currents. If the two cylinders

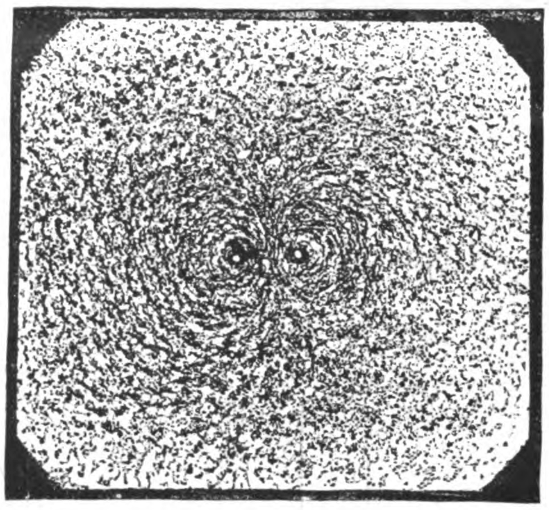
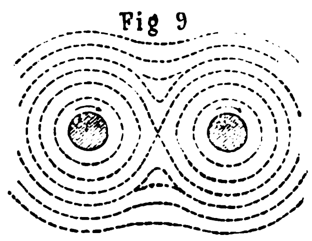


FIG. 8.

are moving in opposite phases, that is to say, if the one be rotating to the left while the other is moving to the right, the figure shown in Fig. 7 is produced; and if this figure be compared with Fig. 8, which is a reproduction of the filing figure produced on a horizontal plate of glass around two wires whose direction is parallel to the plane of the plate, and through which electric currents are being transmitted in opposite directions, it will be seen that the two figures are identical.

If now the two cylinders be similarly placed within the viscous medium, and they be circularly vibrated, but in the same phases, that is to say, both moving to the right or both moving to the left at the same time, then the recording apparatus will trace out a diagram similar to Fig. 9, and on comparing this figure with the filing figure, shown in Fig. 10, it will be seen to be identical in form with the arrangement of magnetic par-



ticles around a field of force produced by two parallel electric currents, moving in similar directions, but perpendicular to the plane on which the magnetic particles are scattered.

One of the most interesting of this series of Professor Bjerknes' experiments is the reproduction in a viscous medium of a field of vibration represented by a diagram which is identical with that obtained by iron filings around a magnet through which an electric current is being transmitted. Professor Bjerknes, reasoning that while a body pulsating within a viscous medium sets up in that medium *radial* lines of force, and a circularly vibrating body produces a field of *concentric* circles of force, combined the two and produced the diagram, Fig. 11, in which a spiral figure is drawn which is a sort of compromise between the radial lines of force and the concentric circles produced by a circularly vibrating body. Fig. 12 is the figure produced around the pole of a magnet through which an electric current is being transmitted, by iron filings scattered on a plate, the plane of which is perpendicular to the axis of the mag-

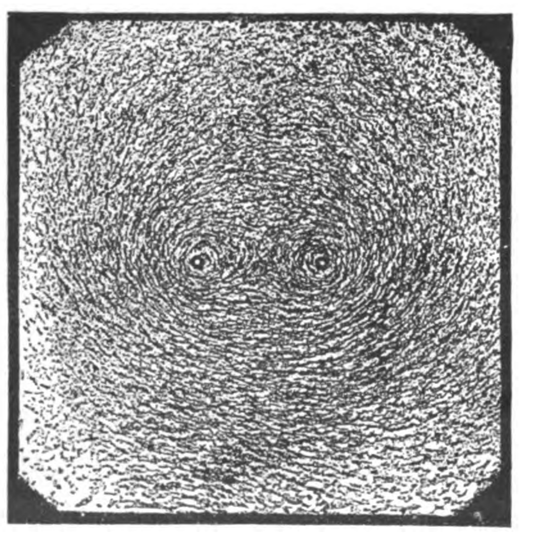
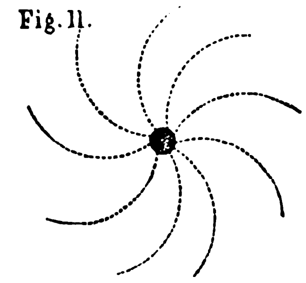


FIG. 10.

net, and to the direction of the electric current, and it will be seen that the figure drawn by Professor Bjerknes' apparatus is identical in form with it; thus giving another striking example of the very close analogy which exists between the effect of vibrating bodies in a viscous medium and magnetic and electric phenomena.

2. We will now consider the mutual effect produced by bodies circularly vibrating in the same viscous medium, and it will be seen that this class of phenomena bears a remarkably close analogy to the effects produced by electric currents transmitted through conductors, of which one or more are capable of moving under the influence of whatever dynamical forces may be called into action. These phenomena were investigated by Ampere in a research which has long become classical, and it will, in this place, be necessary only to refer to one figure connected with that research as explanatory of Professor Bjerknes' hydro-dynamic analogue of the mutual action of electric currents upon one another. If a wire, A (Fig. 13), through which an electric current is being transmitted in the direction of the arrow, be presented to the vertical side, *a*, of the light wire frame *a b c*, which is pivoted in the two mercury cups, *x* and *y*, so that the current in A and in *a* are parallel, and in the same direction, attraction will take place, and the frame, *a b c*, will follow the wire, A, if the latter displaced. If, on the other hand, the



wire, A, be be placed near to the opposite side of the frame, *c*, so that the two currents while parallel are in opposite directions, repulsion will ensue. If now a wire conveying an electric current be placed below the frame as at B, attraction will take place when the currents in the wires, B and *b*, are in the same direction, and the frame, *a b c*, will place itself in such a position that *b* becomes parallel to B; but if the currents in the two wires be opposite in direction, repulsion will take place, and the frame will rotate until its plane becomes perpendicular to B. Once more, if the wire conveying the current be presented to one side, *c*, of the movable frame, but in a plane perpendicular to the plane of the frame as at *d*, then a deflection of the frame will take place, and if the wire, *d*, be moved lower down, the deflection will become less and less, until a point, *d'*, is reached which is opposite the middle of the length of

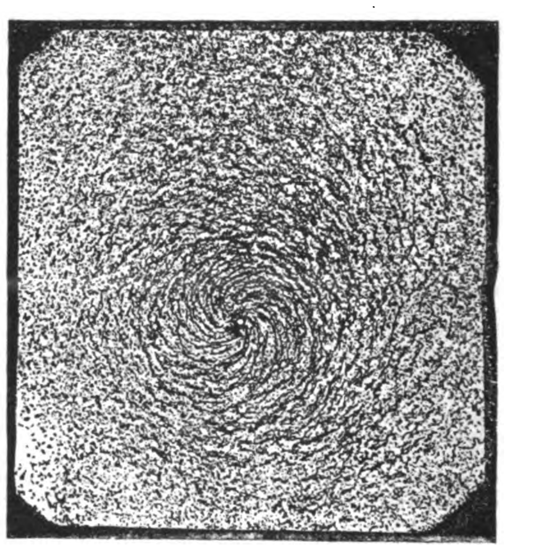
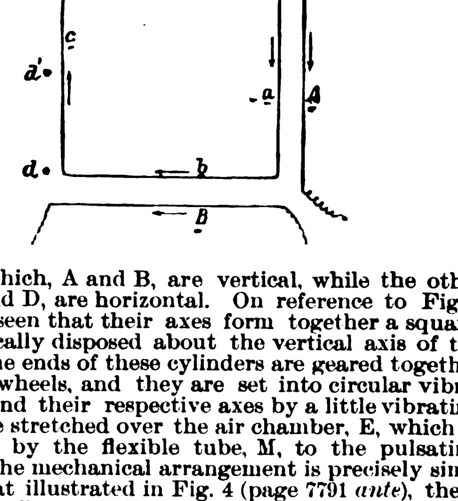


FIG. 12.

C; at this neutral point no deflection will take place, and if the wire be still further lowered, it will deflect the frame in the opposite direction, and this deflection will increase as the wire is lowered, until it reaches the point, *d''*, where the deflection will have reached its maximum, being equal to what it was when the wire was at *d*, and in an opposite direction.

All the above phenomena Professor Bjerknes has been able to reproduce hydrodynamically with remarkable accuracy, by means of the very beautiful apparatus shown in Fig. 5 (see page 7791 *ante*), and illustrated in the diagram, Fig. 13, so far as its essential parts are concerned. This apparatus consists of a light frame delicately poised between vertical axes on a rigid stand, F F, and carrying four cylinders, A, B, C, and D,



two of which, A and B, are vertical, while the other pair, C and D, are horizontal. On reference to Fig. 5 it will be seen that their axes form together a square, symmetrically disposed about the vertical axis of the frame. The ends of these cylinders are geared together by bevel wheels, and they are set into circular vibrations around their respective axes by a little vibrating membrane stretched over the air chamber, E, which is connected by the flexible tube, M, to the pulsating pump. The mechanical arrangement is precisely similar to that illustrated in Fig. 4 (page 7791 *ante*), there being a small connecting-rod attached to the center of the membrane in E, and taking hold of a crank-pin inside the slot shown in the cylinder C (Fig. 5). When all these cylinders are set into oscillation, they repre-

* See *Engineering*, vol. xxxiii., page 192.

sent a closed electrical circuit such as that illustrated in Fig. 13, and the eight arrows around the figure (Fig. 14) indicate the direction of that current.

If now the vertical oscillating cylinder (shown at A, Fig. 3, page 7791) be placed close and parallel to the vertical cylinder, A or B (Figs. 5 and 14), repulsion will take place when the two cylinders are rotating in the same phase, that is to say, when they are both moving to the right or to the left at the same time; but when the cylinders are oscillating in opposite phases, attraction will take place. These phenomena are illustrated in Fig. 15, the upper part of the figure marked R illustrating the repulsion between two cylinders vibrating in similar phases, and the lower part of the figure marked A shows the attraction effect of two cylinders vibrating in the opposite phases. The curved arrows indicate the direction of rotation at any given moment, and the straight arrows show the direction in which the cylinders tend to move through the medium. It will be observed that these phenomena are closely analogous to the action of electric currents upon one another, as illustrated in the diagram, Fig 13, although the phenomena of attraction and repulsion are inversed.

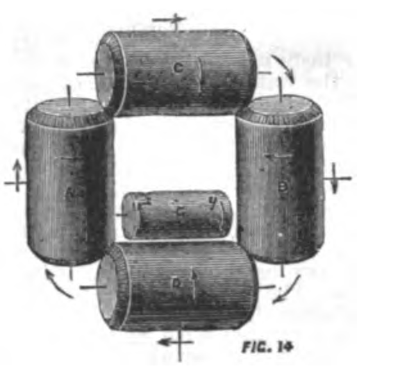
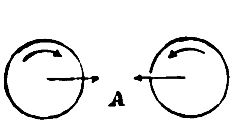


FIG. 14

If now we take the horizontal vibrating cylinder, G, Fig. 5, and place it close to the lower horizontal cylinder, D, as is shown in Fig. 5, and again in the diagram, Fig. 14, the whole system of vibrating cylinders, A, B C, and D, will turn until the axis of the cylinder, D, lies in the same plane as that of the cylinder, G, and is moving in the opposite phase; and this will be its position of stable equilibrium; but if the frame carrying the cylinders be turned through an angle of 180 deg., the two cylinders will again become parallel; this time, however, their phases of oscillation will be similar, and the apparatus will be in its position of unstable equilibrium, as may be shown by moving it slightly to the right or the left, when it will immediately turn until the cylinders again become parallel and are vibrating in opposite phases. In the position shown in the diagram, Fig. 14, the balance is in stable equilibrium when the cylinders are oscillating in the phase indicated by the arrows, D and y, and is in unstable equilibrium when oscillating in the phases indicated by the arrows, D and x. If the cylinder, G, be placed above D in such a position that its axis lies in a plane perpendicular to that of the axis of D (as is shown in Fig. 16), that is to say, in that position which is farthest from that in which the two axes of the cylinders lie in the same plane, then, if the two cylinders are oscillating in the phases shown by the arrows G, and D (Fig. 16), the axis of G will turn in the direction shown by the arrow, x, until parallelism between the cylinders is reached; and this corresponds very exactly with Ampere's experiment with two electric currents similarly disposed.

Fig. 15.



In the last mentioned series of experiments, Professor Bjerknes has produced the hydrodynamic analogues of attraction, repulsion, and rotation, by which what is called "action at a distance" is ordinarily made manifest in electro-dynamics, and in all cases has he demonstrated this by the use of circularly vibrating cylinders. He has, however, gone a step farther, for he has been able to reproduce phenomena analogous to the action of other electric currents upon one another, such as we have already described in connection with Fig. 13; as, for example, the effect upon the current in the upright wire, C (Fig. 13), of a current passing through a wire whose plane is perpendicular to that of C, when in the positions indicated in the positions d' and d'' as well as in positions intermediate between them. Fig. 17 shows the arrangement of the apparatus for producing the analogues of these phenomena. A, B, C, and D are the four cylinders shown in Fig. 5, and which together are free to turn around a vertical axis; G is the horizontally vibrating cylinder, and if it be placed near to but at the upper end of A, the whole being submerged in viscous fluid, the latter will swing round either forward or backward according to the mutual phases of A and G; if the phases are those indicated by the arrows in the figure, then A will move forward in a direction perpendicular to the plane of the paper; on lowering the position of G this deflective action will become smaller and smaller until it reaches a point, G, opposite the middle of the length of A, where it will disappear altogether; and on still further lowering the cylinder, G, the deflective action, becomes stronger and stronger, but this time in the opposite direction, until the point, G, is reached, at which it again reached a maximum; and on comparing these hydrodynamical phenomena with the electrical phenomena described in connection with Fig. 13, it will be seen that that they are inverse to one another.—*Engineering.*

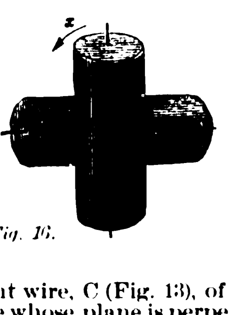


Fig. 16.

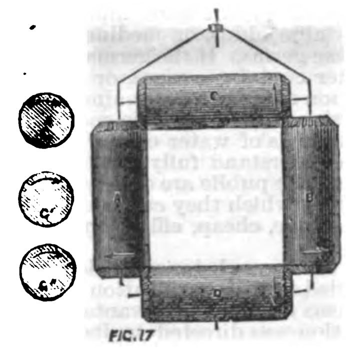


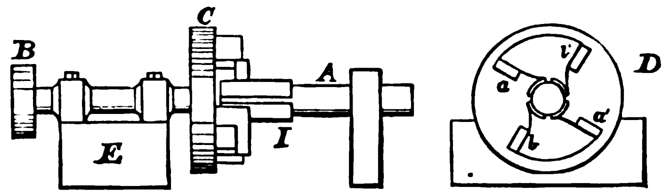
FIG. 17

ON THE PRODUCTION OF ALTERNATING CURRENTS BY MEANS OF A DIRECT CURRENT DYNAMO-ELECTRIC MACHINE.

By JOHN TROWBRIDGE and HAMMOND VINTON HAYES.

IT is often desirable to transform a direct current into an alternating one for the purpose of obtaining electricity of high tension by means of a Ruhmkorff coil, for studying the effects of stratifications in vacuum tubes, or for employing alternating currents in the study of magnetism. The best way is undoubtedly to employ an alternating dynamo-electric machine, as has been done by Spottiswoode. When, however, only a direct current machine is available, the following method can be employed:

The dynamo machine, if it is not a shunt wound machine, is shunted by a suitable resistance. We have employed for this purpose thin ribbon steel about 1·5 cm. broad and 0·01 mm. in thickness. The remaining portion of the current from the machine is conducted to two brass or copper segments, a, a', Fig. 2. This current is led to the primary coil for, for instance of a Ruhmkorff coil from two other segments, b, b'. These segments are fixed upon a cylindrical shaft, A, Fig. 1, which is stationary. A belt passing over the pulley, B, turns the wheel, C, upon the face, D, of which revolve four brushes which connect the adjoining segments. The brushes, a a, b b, are made adjustable, the two adjoining brushes being electrically connected, and a small stream of water plays upon the segments of the commutator. The character of the spark produced by a Ruhmkorff coil which is marked by alternating currents has been studied by Spottiswoode. Without condensers in the secondary circuit a bright yellow glow spans the distance between the two terminals of the coil, which partakes more of the character of a voltaic arc than of the ordinary discharge from a Ruhmkorff coil. The apparatus we used produced three thousand reversals a minute. This rate was too rapid for the best effects with a Ruhmkorff coil. It enabled us, however, to study the musical note produced in the cores of the electro-magnet by rapid reversals of the current in the electro-magnet, and also the heating effects which have been so often studied.



Jefferson Physical Laboratory.

—*Amer. Jour. Science.*

SOME PROPERTIES OF THE ETHER.

AT a recent meeting of the Royal Society, a model was presented, illustrating some properties of the ether, by Prof. G. F. FitzGerald, M.A., F.R.S. The model consisted of a series of wheels arranged at equal distances along parallel rows on axes fixed perpendicularly into a board. The wheels were connected together by India rubber bands, each wheel being so connected with its four neighbors. Under these circumstances it was shown that if any wheel was turned all the wheels turned simultaneously, and that, except for friction on the axes, etc., they would all turn equally. It was explained that the model only exhibited properties of the ether itself, and did not exhibit the connections of matter with ether. A region within which the bands did not slip represented a non-conducting region, and differences of elasticity of the bands represented differences of specific inductive capacity: slipping of the bands represented a conducting region, and complete absence of bands represented a perfectly conducting region. When bands were removed from a certain region and all around it a line of bands left, and all around outside this again a conducting region, then if a conducting line connected these regions, the wheels along this line might be turned in opposite directions, and when this is done all the non-conducting region is thrown into a state of stress by all the wheels not rotating equal amounts, in which the bands are tight on one side of a pair of wheels and loose on the opposite side. It was explained that this exhibited the polarization of the medium between two oppositely charged conductors, the direction of polarization being at right angles to these bands—*i. e.*, in the line joining the conductors—the medium in this state representing a charged Leyden jar, the two opposite electrifications being represented by the tight and loose bands, one conductor being bounded entirely by tight bands and the other by loose ones, and the electric displacement of Maxwell being represented by the difference between the two sides of a band. If the bands along any line between the two conductors slipped, all the energy of the medium was spent along this line in friction, and this is represented a discharge along the line. This energy was conveyed into the line of discharge by its side and not along its length in accordance with what Prof. Poynting has recently shown to be the case in all electric currents. If the resistance along the line of discharge were sufficiently small, the momentum of the wheels would carry them beyond their position of equilibrium, and the well-known phenomenon of an alternating discharge would be represented. This led to the observation that the magnetic displacement was represented by the angular velocity of rotation of the wheels and the self-induction by their momentum. It was remarked that the mechanical attraction between the two conductors was not represented, but it was explained that as this depends on the connection of matter with ether, it would require more complicated mechanism. It was, however, pointed out that by supposing the wheels slightly distorted by the stress, and by supposing a thread wound around them, and each end connected with the material of a conductor, a force would be produced drawing the conductors together, owing to the circumference of a distorted wheel being longer than of an undistorted one. This force would be proportional to the square of the distortion, a necessary condition not satisfied by ordinary stresses, and would be, if exerted between two infinite planes, independent of their distance apart, and so must represent a force varying inversely as the square of the distance. Returning to the electric currents, it was shown that by turning the wheels at any point of a conducting circuit the whole region was filled with turning wheels—*i. e.*, with magnetic displacement—and that, if a resistance were introduced at any point of the circuit, the energy would be transferred to that point through the medium, and enter by the side of the conductor. If two independent conducting circuits existed near one another, it was shown that the phenomena of induced currents were represented. It was explained that the mechanical force was not represented, as it depended upon the connection between matter and ether, but that it might be looked for as in some way depending on the centrifugal force arising from the rotations. The equations representing the energy of the model are of the same form as those of Maxwell representing the energy of the ether when limited by the consideration that the model was only in one plane. It was explained that a tridimensional model whose energy could be represented by the same equations as Maxwell's could not be constructed with India rubber bands, but might be constructed by means of wheels pumping fluid through pipes. This led to the observation that the propagation of waves by transverse vibrations could be illustrated by the model, and it was explained how a sudden turning of any set of wheels would start a wave-propagation whose direction of propagation was at right angles to the directions of magnetic displacement and of electric displacement, the former represented by the axes of rotation and the latter by the line joining the centers of a tight and loose band. It would be possible theoretically to construct a model illustrating the laws of reflection and refraction of light even at the surfaces of crystalline media, and to reproduce conical refraction. It was explained by twisting the medium the rotatory polarization of quartz might be represented, and that probably a mechanism might be introduced by which the rotation of other wheels or of something besides the wheels being altered by the rotation of the wheels, a reaction of the former on the latter would reproduce magnetic rotatory polarization. It was pointed out that both magnetic rotatory polarization and dispersion were due to a reaction of the medium during the wave-propagation, and not to a change of the medium independent of the wave-propagation. It was explained that it was not to be supposed that the ether was constructed of wheels and India rubber bands, nor even of wheels pumping fluid in pipes, but it was pointed out that some properties of the ether might be gathered from the model if it be assumed that the qualities of the ether represented by symbols obeying the laws of rotation for instance are really of the nature of rotation. If this be so, the ether must be such that any part of it can rotate as often as it likes, provided all the neighboring parts rotate equally, and the electrostatic stresses in the ether must be due to the difference of rotation of its parts. If the ether be a perfect liquid, it can only have such properties as represent rigidity by being in motion, and it was explained that many electrical phenomena might be illustrated by the polarization of the vortical motions in a vortex-sponge. Sir Wm. Thomson has pointed out that such a state of polarization as a single vortex region in the center of a cylindrical box will not of itself change unless it can spend its energy on the box, which is quite analogous to the fact that the energy of the polarization of the ether does not disappear unless it can produce heat or mechanical or other forms of energy. It was also pointed out that forces depending on small vortices vanished at small distances from them, and that hence forces depending on their polarization between two infinite planes would depend on the polarization and not on the distance between the planes, and so must be of the nature of forces varying inversely as the square of the distance. It was explained that the modes of polarization of vortices were sufficient to explain both electrical, magnetic, cohesional, and chemical forces. It was finally reiterated that the only possible way of giving anything of the nature of rigidity to a perfect liquid was by conferring motion on it, and that it seemed likely that any mechanical properties could be conveyed by suitably chosen motions. This was quite in accordance with Sir Wm. Thomson's suggestive address to Section A at Montreal.

THE HON. SIR WILLIAM R. GROVE, D.C.L., F.R.S.

WILLIAM ROBERT GROVE was born at Swansea in 1811. His father was a justice of the peace and Deputy Lieutenant for the county. He received his early education at Swansea Grammar-school, whence he passed to Darlington House, Bath, and afterward to Brazenose College, Oxford. It was originally intended by his parents that he should enter the Church; but for conscientious reasons he preferred to adopt the legal profession, and was called to the bar in 1823.

During an interval of forced leisure, occasioned by ill health, Mr. Grove was led to return to the favorite study of his youth—electricity. Original research was soon followed by important discoveries. In 1839 he communicated to the Academie des Sciences, through M. Becquerel, the first idea of the gas battery (afterward produced by him in 1841), viz., the fact that "if a positive electrode be immersed half in water and half in a tube of hydrogen, and a negative electrode in water and oxygen, the water ascends in the tubes, the galvanometer is deflected, and the water is decomposed and recomposed by galvanic action." Later on in the same year Mr. Grove discovered the nitric acid battery which bears his name, announcing it to the world in a communication to the Academie. In 1840 he was elected a member of the Royal Society. In the following year he laid before the Electrical Society a new and ingenious process for engraving daguerreotype pictures by means of electricity. From 1840 to 1847 Mr. Grove was Professor of Experimental Philosophy at the London Institution, and it was in a lecture delivered there in 1842, "On the Progress of Physical Science since the Opening of the London Institution," that he briefly and clearly communicated the theory of the "Correlation of Physical Forces." This lecture was afterward further enlarged and published in 1846, since which time it has passed through several editions. The position taken up, to quote Mr. Grove's own words, was "That the various affections of matter which constitute the main objects of experimental physics, viz., heat, light, electricity, magnetism, chemical affinity, and motion, are all correlative, or have a reciprocal dependence. That neither, taken abstractedly, can be said to be the essential or proximate cause of the others, but that either may, as a force, produce the others; thus heat may mediately produce electricity, electricity may produce heat; and so of the rest, each merging itself as the force it produces becomes developed; and that the same must hold good of other forces, it being an irresistible inference that a force cannot originate otherwise than by generation from some antecedent force or forces." In spite of a steadily increasing professional work, Mr. Grove still continued to apply himself to scientific research. In 1847 he received the medal of the Royal Society, for his Bakerian lecture on "Voltaic Ignition, and on the Decomposition of Water into its Constituent Gases by Heat." Passing over several papers on the gas pile, etc., he spent some time in examination of "the electro-chemical polarity of the gases," "the electricity of flame," and the construction of a flame pile. He also conducted several experiments in search of the conversion of electricity into motion. In 1866 he was President at the meeting of the British Association at Nottingham, when he delivered an address on the "Continuity of Natural Phenomena."

In the midst of all this activity in study and research, which entitle Sir William Grove to so high a position among "Leaders of Science," it is hardly credible that he should have yet been able to reach as high an eminence in his own profession. He became a Q.C. in 1853, has been a member of several Royal Commissions, was knighted in 1871 on his elevation to the judicial bench, as Justice of the Common Pleas, and, by the operation of the Judicature Act in 1875, was appointed a Judge in the High Court of Justice.—*Science Monthly.*

SIR WILLIAM R. GROVE.

PURIFICATION OF DRINKING WATER BY ALUM.*

By Profs. PETER T. AUSTEN, Ph.D., F.C.S., and FRANCIS A. WILBER, M.S.

THE many discoveries that have been made during the last few years in regard to the transmission of diseases by drinking-waters have caused attention to be directed to the methods of its examination and the processes for purifying it. Chemical analysis can establish the presence of albuminoid matter in water, and by its means we are able to state if the water under examination can become a suitable nidus, or medium, for the development of disease germs. If the germs are actually there, or if the water contains a virus, or ptomaine,† biological examination alone can determine.

While physicians and scientific men are experimenting on the methods of water examination, and are endeavoring to understand fully the meaning of the results obtained, the public are chiefly interested to have some method by which they can purify their drinking water in a simple, cheap, efficacious, and expeditious manner.

Running over the substances which have been suggested and tried for the purification of water, there is none that seems to offer the advantages of alum. Particular attention was directed to its use by Jeunet in 1865, in an article published in the *Moniteur Scientifique* (page 1,007). He found that 0·4 gramme of alum to a liter of water (23·3 grains to one gallon) rendered it drinkable, even when it was quite full of foreign matter. The time taken for this clarification was from seven to seventeen minutes.

Alum is a double sulphate of potash and aluminum, and in this case breaks into potassium sulphate, which remains in solution, and a basic aluminic sulphate. This basic sulphate of aluminum, the composition of which is undetermined, precipitates as a more or less gelatinous and flocculent mass, and carries down with it the foreign matters and humus bodies. The sulphuric acid set free in the formation of the basic aluminic sulphate attacks the earthy and alkaline carbonates which are always present, and forms with them sulphates, setting carbonic acid free. Aluminic sulphate acts like alum. Aluminic acetate and ferric acetate do not give such good results. Peligot, however, found that ferric chloride (sesquichloride of iron) acted well, and Scherer recommends the use of a neutral sulphate of iron.

In the last years an extensive use of alum has been made in the many processes of purifying water, sewage, etc. It is not improbable that aside from its effect in precipitating matter mechanically by envelopment with the precipitating basic aluminic sulphate, the alum exerts a distinct coagulative action on the albuminous substances in the water, rendering them insoluble, and thus causing their precipitation; perhaps the same or similar effect that alum produces in the tanning of leather. One of the most prominent applications of alum at present is in the Hyatt filter. By the addition of a minute amount of alum, water is rendered capable of a most perfect mechanical filtration.

The fact that alum is cheap, and can be obtained in quite a pure state at any drug store, places it within the reach of every one. Its sharp taste precludes the possibility of its being swallowed by mistake. But even should it be swallowed by mistake, no great harm would be likely to ensue, unless a large amount were taken. In medical treatment as high as 30 grains are given in a single dose, and this may be repeated four times per day. If it can be proved that alum not only clarifies a water, but also removes from it disease germs and ptomaines, its use will prove of incalculable value to the human race, for facts begin to indicate that a vast number of diseases are communicated through drinking-water.

The investigation of the effects of alum on drinking water falls under the several heads—

I. Clarification of the water by settling.
II. Clarification of the water by filtration.
III. Use of water clarified by alum in manufacturing.
IV. Removal of disease germs.
V. Removal of ptomaines.
VI. Removal of organic matter.

The investigation must needs be both chemical and biological. Only the first and part of the second cases have so far been examined.

I. THE EFFECT OF ALUM IN CLARIFYING WATER BY SETTLING.

It is evident that to obtain practical results in the clarification of water by alum, it must be added in such small amounts as to leave no unnecessary excess, and that neither taste nor physiological action should be imparted to the water. At the time of our experiments (January, 1885) the New Brunswick city water was quite turbid from clayey and other matters, so that we were able to obtain some very reliable results.

The amount of alum used in the experiments of Jeunet seems to be unnecessarily high, in case the water is to be drunk. Water was treated with the amount of alum recommended by Jeunet (23·3 grains to the gallon), but no perfect settling was obtained under six hours or more; in some cases not under twelve hours. The water thus treated had no perceptible taste of alum, but it gave a decided reaction for alumina when treated with ammonia, showing that the water contained a certain amount of free alum. While the amount is evidently too small to produce any physiological effect, there seems to be no necessity to use such an excess.

To determine the effect of alum as a precipitating agent, tall cylinders were filled with water and a solution of alum was added, the whole well mixed, and allowed to stand. It was found that in varying lengths of time, depending on the amount of alum used, a gelatinous precipitate settled out, and the water above it became perfectly clear. On adding a relatively large amount of alum, and mixing, the coagulation and separation of the precipitate is at once visible, the water appearing by careful examination to be filled with gelatinous particles. The amount of alum necessary for the precipitation of a water will, of course, depend on the amounts of impurity present, but in the present case, which may be taken as a typical one, we found that 0·02 gramme of alum to a liter of water (1·2 grains to a gallon) caused the separation and settling of the impurities, so that the supernatant water could be poured off. This amount of alum was shown by numerous experiments to be about the practical limit. The complete settling took place as a rule in not less, and usually more, than two days. It is evident that the amount of alum thus added is too slight to be perceptible to the taste, and can exert no physiological action. We were unable to detect the slightest taste or change in the water so treated.

Still smaller amounts of alum will produce a precipitate after longer standing. Sixty liters of the city water were treated with two grammes of alum (this was about 31 grains to 16 gallons) and allowed to stand. After forty-eight hours the precipitation seemed complete, and the water was perfectly clear, while the bottom of the vessel was covered with a brownish, slimy deposit. This substance was collected, dried, and analyzed. It gave—

Carbon	16·50 per cent.
Hydrogen	2·02 "
Nitrogen	0·77 "

It is evident from this analysis that a large amount of the organic matter has been removed from the water by the alum treatment.

On incineration, it yielded 59·28 per cent. of ash, which contained silica and alumina in relatively small amounts, oxide of iron in large amounts, and a considerable quantity of phosphoric acid.

To determine if there was free alum in the water, a sample of the clear water, filtered off from the precipitate produced by the alum, was made slightly alkaline with ammonia and warmed for some time. Only the merest traces of an alumina reaction could be obtained, and, in fact, in some cases, it was doubtful if a reaction was observable. To prove that no more matter could be precipitated by the addition of a greater amount of alum, samples of the clean filtered water were treated with more alum, but there was in no case any indication of further precipitation on standing.

We consider it, then, established that, by the addition of two grains of alum to the gallon, or half an ounce to one hundred gallons, water can be clarified by standing, and that neither taste nor physiological properties will be imparted to it by this treatment. By increasing the amount of alum, the time required for the separation and settling can be diminished, and *vie versa*, by diminishing the amount of alum added, a greater time will be required for the clarification.

This method is particularly adapted to the clarification of large volumes of water, where filtration is not practical. The cleared water can be racked off to as low a level as possible, after which the sediment should be washed out and the receptacle cleansed by a free use of water.

II. THE EFFECT OF ALUM IN CLARIFYING WATER BY FILTRATION.

In order to test the clarification of water by filtration after addition of alum, the New Brunswick city water was again made the subject of our experiments. It was found that the suspended clayey matters were so fine that the best varieties of filtering papers were unable to remove them. Even when several layers of heavy Schleicher and Schull paper were used, a very large portion of the suspended matters passed through. This, however, is not surprising, since it is well known that the mineral matters suspended in water are of a remarkable degree of fineness. Thus the water of the river Rhine, near Bonn, cannot be clarified by simple filtration, and takes four months to settle. The addition of certain chemicals aids the filtration of suspended matters in some cases, but it does not always entirely remove them. Calcium chloride and other salts are recommended as effective agents in aiding the removal of suspended matters, but in the case of New Brunswick water, at least, they have no apparent action. The following substances were found to have no effect in aiding the filtration of the water: sodium salts—chloride, carbonate, nitrate, acid carbonate, hydrogen phosphate, acid sulphite, ammonium phosphate, sulphate, biborate, tungstate, acetate; potassium salts—hydroxide, chloride, bromide, iodide, acetate, phos-

* From the advance sheets of the Annual Report of the State Geologist of New Jersey for 1884.

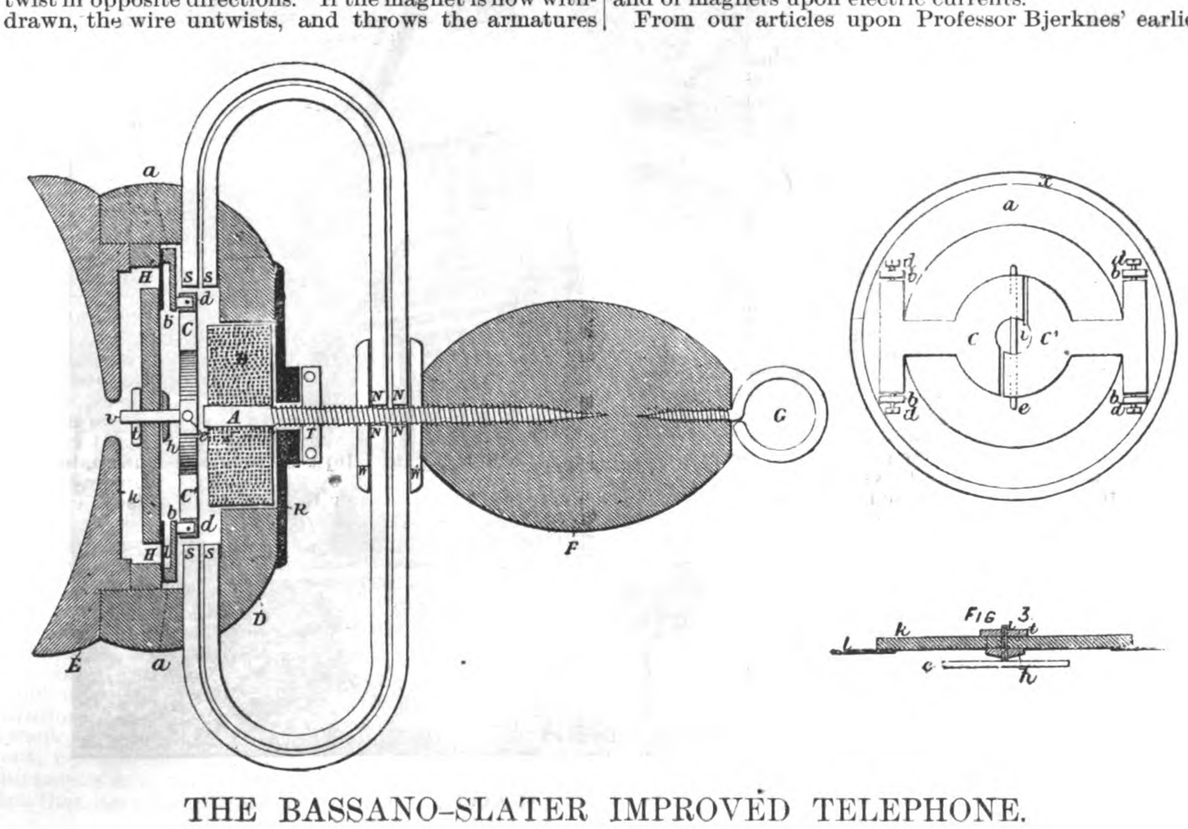
† Putrefaction alkaloid.

hension; and, therefore, that any change taking place in the mind and any corresponding change taking place in the brain are not really two changes, but one change. There is thus supposed to be only one stream of causation in which both motion and mind are simultaneously concerned; motion is supposed to be producing nothing but motion, mind-changes nothing but mind-changes. Both producing both simultaneously, neither could be what it is without the other, because without the other neither could be the cause which in fact it is. The use of mind to animals is thus explained, for intelligent volition is shown to be a true cause of bodily movement, seeing that the cerebration which it involves would not otherwise be possible. This monistic theory thus serves to terminate the otherwise interminable controversy on the freedom of the will; for the theory shows it to be merely a matter of terminology whether we speak of the mind or of the brain as the cause of bodily movement. That particular kind of physical activity which takes place in the brain could not take place without the occurrence of volition, and *vice versa*. All the requirements alike of the determinist and of the free-will hypotheses are thus satisfied by a synthesis which comprises them both in one. Mr. Romanes afterward reviewed the opinions of the late Professor Clifford upon this subject, and concluded by observing that if it were true that the voice of science must of necessity speak the language of agnosticism, at least let them see to it that the language was pure; let them not tolerate any barbarisms introduced from this side of aggressive dogma. So would they find that this new grammar of thought did not admit of any constructions radically opposed to more venerable ways of thinking, and that the often-quoted words of its earliest formulator applied with special force to its latest dialects—that if a little knowledge of physiology and a little knowledge of psychology incline men to atheism, a deeper knowledge of both, and still more a deeper thought upon their relations to one another, could only lead men back to some form of religion, which, if it be more vague, will also be more worthy than that of earlier days.

THE "BASSANO-SLATER" IMPROVED TELEPHONE.

The accompanying sketches show an improved form of telephone receiver by Messrs. G. H. Bassano, A. E. Slater, and F. T. Hollins, of Derby, England. The inventors have been so good as to place at our disposal a receiver constructed according to their patent, and we find that it gives excellent results, being both sufficiently loud and very distinct in its articulation; it is, in fact, a good practical instrument. The very many patents taken out for telephone receivers are, as a rule, conspicuous only for their want of novelty. So far as we are able to judge, this receiver has several points in which it differs from others, and is generally a novel and, we understand, most effective arrangement, but it being *sub judice* we express no opinion as to its bearing on existing patents. Fig. 1 is a section of the complete receiver; Fig. 2 a plan of an improved arrangement or bar armature; and Fig. 3 a section of a steel wire T-piece, carrying a disk of pine or other non-inductive material. Corresponding parts are indicated by the same letters. Now in Fig. 2, *a* is a brass rim having an outer ridge or collar, *x*, and four small ears or lugs, *b*, *b*, *b*, *b*. C, C', are two soft iron bar armatures fixed on center screws, *d*, *d*, *d*, *d*. These two bar armatures are kept in a state of tension by means of a small piece of thin steel wire, *e*, passing through a hole in the center of the two armatures and riveted, or otherwise secured, only just at the ends of the wire, so that the greater part of the wire, even where passing through the armatures, is free to twist or untwist, as will afterward be explained To the center of this small piece of wire is brazed a steel or iron pin, *i*, with a screw thread forming together a T-piece, shown in section, Fig. 3. The pin, *i*, carries a small brass washer, *h*, upon which rests a circular disk, *k*, of pine or other non-inductive material, to the outer edge of which is glued a circular rim, *l*, of thin leather, macintosh, or other air tight material, the disk being held at its center by a small brass nut, *t*. Taking the arrangement of Fig. 2, if a magnet is caused to approach the center of the bar armatures, C, C', they are pulled out of their normal position, and being centered at opposite points, and each firmly gripping the small piece of steel wire, *e*, which is squared just as its two ends, give the said wire a slight twist in opposite directions. If the magnet is now withdrawn, the wire untwists, and throws the armatures sharply back into their normal position. Now as the wire, *e*, carries the pin, *i*, and the disk of pine by its center, *k*, it follows that the latter, every time the armatures move, will also make a bodily movement backward or forward according as the bar armatures are attracted or released by the magnet. When, therefore, it is inclosed in a recess or air chamber, as in Fig. 1, a condensation and rarefaction of the air takes place in the recess formed by the cap, E, corresponding to the condensations and rarefactions of the air operating the electric current at the transmitter, and which alter or reverse the magnetism in the magnet of the receiver. It is obvious, say the inventors, that the effect all depends upon the torsion of the small piece of wire, *e*, of thin hardened steel, the pitch and loudness of the sound depending upon the velocity and amplitude of the vibration of the disk, *k*. The inventors have therefore taken four U-shaped steel magnets, and placing their four similar or north poles, N, N, N, N, between the two soft iron rings, W, W' (tapped to fit the thread on A), to polarize the soft iron screw, A; and the four south poles, S, S, S, S, to magnetize the two bar armatures, C, C', by magnetic induction. It is clear that a most intense magnetic field will be set up just at the end of the pole piece, A, and which causes the movement of the armatures to be extremely sharp when the magnetic field is altered by the electric current. The object of the thin ring of leather, *l* (which is fixed loosely so as not to impede the movement of the disk, *k*), is to make the movements of the pine disk air tight. It is not, however, essential, but improves the efficiency of the instrument. A brass ring, H, clamps the thin leather, and it is in its turn secured by the screwed cap, E.

The inventors hold that this receiver is not an infringement of the Bell receiver, not having a plate of iron or steel, but bar armatures, and the disk of wood vibrating not as tympan, but as free vibrator, more approximating to the wood tongue of Reis than to Bell's steel tympan. The other parts will be understood; the nut, T, is for the purpose of regulating the distance between the pole piece and the armatures by springing the magnets open.—*Electrical Review.*



THE BASSANO-SLATER IMPROVED TELEPHONE.

[Continued from Supplement No. 491, page 7841.]

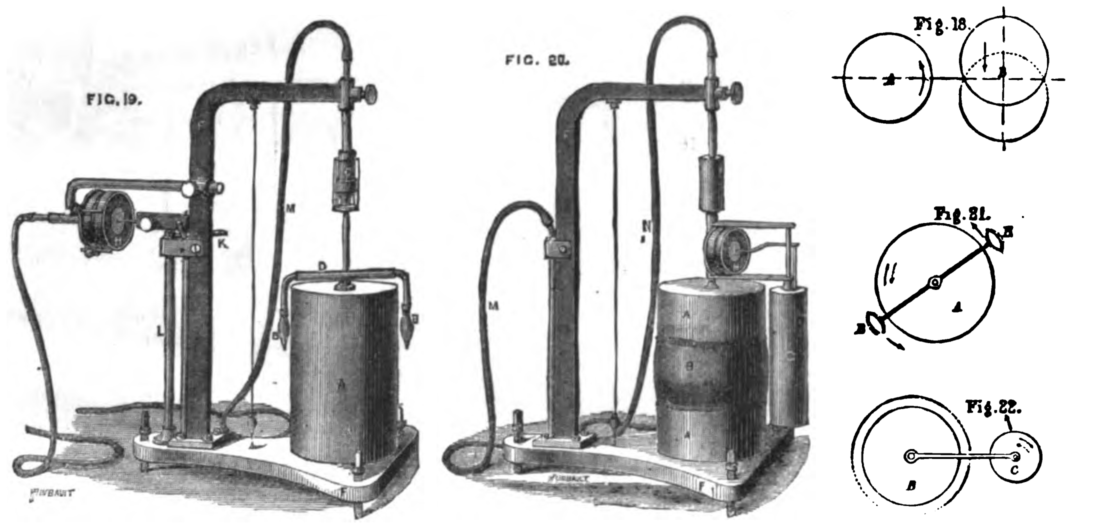
[Engineering.]

THE HYDRODYNAMIC RESEARCHES OF PROFESSOR BJERKNES.

By Conrad W. Cooke.

3. Having considered (1) the effect of circularly vibrating cylinders upon a viscous fluid in which they are immersed, and (2) the effect of one vibrating cylinder upon others vibrating in the same medium, we now have to examine (3) the effect of circularly vibrating cylinders upon pulsating and oscillating bodies similarly immersed; and here again we shall find that a remarkable analogy exists between hydrodynamic phenomena of this class and phenomena resulting from the mutual influence of electric currents upon magnets and of magnets upon electric currents.

From our articles upon Professor Bjerknes' earlier experiments,* it will be remembered that the hydrodynamic analogue of a magnet is a rectilinearly oscillating body, a vibrating sphere for instance, such as is shown at B, Fig. 8, and when mounted, as shown in that illustration (so as to be capable of turning around a vertical axis), the apparatus becomes the hydrodynamic analogue of a compass needle, or of the needle of a simple galvanometer. With reference to this figure we need hardly remind our readers that both the cylinder, A, and the sphere, B, are set into vibration by an alternating air current transmitted by an air-pump to the two parts of the apparatus respectively through the flexible tubes, M and N. If the circularly oscillating cylinder, A, be brought close to the vibrating sphere, B, both being immersed in the viscous medium, the sphere with its frame will rotate around its vertical axis until its axis of vibration lies in a plane perpendicular to that in which the axes of the two instruments both lie. The motions of their proximate surfaces are then in opposite directions, and the position, which is represented in Fig. 18, is one of stable equilibrium. If from this position the frame of B be turned through 180 deg., it will then be in a position of unstable equilibrium, as will be shown by moving it a little to the right or left, when it will immediately return to the position shown in Fig. 18. In this experiment again the hydrodynamic phenomena are inverse to their electro-magnetic analogues, and it is obvious, from what has already been said, that a very perfect hydrodynamic analogy to a galvanometer might by produced by constructing an apparatus in which a horizontally vibrating body, such as a vibrating sphere, is inclosed within the space formed by four circularly vibrating cylinders, such as is shown in Fig. 5 and illustrated in the diagram, Fig. 14.



PROF. BJERKNES' HYDRODYNAMIC RESEARCHES.

Fig. 19 is a view of an exceedingly apparatus designed by Mr. Vilhelm Bjerknes to illustrate the hydrodynamic phenomenon of the rotation of a pulsating body around a circularly vibrating body, which phenomenon is the hydrodynamic analogue of the rotation of a magnet around an electric current, for, as we have seen in all Professor Bjerknes' experiments, a pulsating or rectilinearly vibrating body is the analogue of a magnet, while a circularly oscillating body represents hydrodynamically an electric current.

Referring to Fig. 19, A is a cylinder which is made to oscillate around a vertical axis by means of the small pulsating drum, H, in connection with the air-pump, by means of a flexible tube, and communicating motion to A by a simple system of levers and rods, of which K and L are visible, while others are below the base of the stand, F F. B B are two little flat bags of flexible caoutchouc of lenticular form, and are attached by the tubular arm, D, to a vertical axis which terminates at its lower extremity in a needle point, resting upon an agate center exactly in the axis of the cylinder, A. The little caoutchouc bags, B B, are caused to expand and contract together by being connected with the pulsation pump by the flexible tube, M, through the air-trap, C. When this apparatus is immersed in glycerine and the pump is set to work, the pulsating bodies, B B, begin to rotate continuously around the cylinder, A, and if the phase of pulsation with respect to the phase of vibration of the cylinder be changed, the rotation will be in the opposite direction.

It is a curious fact that in glycerine or in fluids of smaller viscosity the phenomena illustrated by this apparatus are directly analogous to the corresponding electro-dynamic phenomena, thus forming a remarkable exception to the inverse nature of the analogies illustrated by this research; but it must be remembered that the viscosity of glycerine is not so high as that of several other fluids, and it is probable that this may account for the apparent anomaly; for when a fluid of higher viscosity, such as maize syrup, is employed (thus satisfying more completely the conditions required by theory), the rotation of B is in the normal direction, which is inverse to that of the rotation of a magnet around a current.

Just as in the above apparatus the hydro dynamic analogies of a magnet rotating around an electric current may be produced and studied, so with the apparatus shown in Fig. 20, which is the converse of that illustrated in Fig. 19, the hydrodynamic analogy of an electric current rotating around a magnet may be produced. In this apparatus the circularly vibrating cylinder is replaced by a pulsating cylinder, or, to speak more correctly, by a fixed cylinder, A, having a pulsating zone, B, around the middle of its length, and instead of the pulsating bodies (B B, Fig. 19) there is a circularly vibrating cylinder, C, set into motion by the vibrating drum, H, and free to turn around the vertical axis of the pulsating cylinder by mechanical devices similar to those described in connection with Fig. 19, the two essential parts of the apparatus being connected respectively to the pulsation pump by the flexible tubes, M and N. When this apparatus is set to work in glycerine or in maize sirup, the cylinder, C, rotates

* See Supplement, Nos. 488 and 491.

around B in a direction inverse to that of its electro-magnetic analogue, so that the apparent irregularity applies only to the case of the pulsating body rotating around the circularly vibrating cylinder. Figs. 21 and 22 are diagrams which will explain respectively the action of the apparatus illustrated in Fig. 19 and that of the instrument last described.

In following the long and very beautiful experimental researches of Professor Bjerknes and his son, two points cannot fail to strike the mind of either the experimental philosopher or the practical mechanician: the first is the extremely ingenious and varied devices by which an alternating (blow and suck) current of air is made to do duty in setting all the various parts of the different instruments into synchronous motion, whether that motion be rectilinear vibration, circular oscillation, pulsatory expansions and contractions, or a combination of several of them together; and the second point is that while such a motive power is theoretically nearly perfect for such delicate experiments, it becomes most severely handicapped in its practical application by the apparently overwhelming mechanical difficulties introduced by making joints and pivots, which, while offering no obstruction to the pulsatory current of air through them, should at the same time introduce no more friction or resistance to minute influences of motion than is offered by the needle point of a compass card. That such extraordinary success should have attended the exceedingly delicate experiments in which an alternating current of air is employed reflects the highest possible credit on Mr. Vilhelm Bjerknes, who devised the apparatus, and upon Mr. Andersen, the resident mechanician to the University of Christiania, who has carried out Mr. Bjerknes' designs with extraordinary perfection of workmanship and constructive ability.

But notwithstanding the great ingenuity displayed in the design, the remarkable skill exhibited in the construction of the apparatus, and the fact that friction and all other disturbing influences have in these instruments been reduced to the lowest possible amount, it must be obvious to any practical mechanician, who is able to appreciate the extremely delicate nature of the experiments, that retarding and disturbing influences, whether of weight or of friction, must in the case of air-driven instruments play great havoc with their sensitiveness, and render it impossible for them to exhibit or even detect many phenomena of the highest possible importance to the research—for, just as a galvanometer needle, heavy in itself, and involving considerable friction in its method of suspension, is unable to respond to certain currents of electricity transmitted through its coils, indicating an absence of current, when in reality comparatively strong currents are flowing around it, so it is equally clear that in the use of the apparatus which we have been describing, all the phenomena exhibited are reduced in their significance by disturbing and retarding influences, and many phenomena, slightly more delicate but equally important, must be lost altogether to demonstration. Thus, electric science, as well in her instrumental defects as in her phenomena, finds her hydrodyamic analogue in the researches of Professor Bjerknes and his son.

[Continued from SUPPLEMENT, No. 498, page 7958.]

[JOURNAL OF THE SOCIETY OF ARTS.]

ON THE CONVERSION OF HEAT INTO USEFUL WORK.*

By WILLIAM ANDERSON, M.Inst.C.E.

LECTURE II.

IN my first lecture, I dwelt briefly upon the laws of motion, the principles of work and energy, and the laws of impact. This evening we have to consider several other phenomena, the right understanding of which is necessary before a correct idea of the conversion of heat into useful work can be formed. The theories of oscillation and vibration, involving, as they do, sufficiently high mathematics, might alone occupy the whole of the time I have at my disposal. I must, therefore, deal very briefly with them, although they are so intimately involved in the immediate scope of these lectures. Oscillation or vibration, then, is motion propagated through the substance of a body by short excursions of the molecules of the body to and fro, either in direct lines or in closed curves. A familiar illustration of an oscillating motion is a pendulum; and it is also an instance of the mutual relations between kinetic and potential energies. The moving force is gravity. The bob of the pendulum falls from the highest point to which it has been raised to the lowest point, and in so doing the whole of the potential energy with which it had been endowed, just when allowed to drop, is converted gradually into kinetic energy, and this notwithstanding that its path is not free, but constrained by the rod of the pendulum; but this constraint, according to the second law of motion, does not interfere with the action of gravity. The kinetic energy with which the bob is endowed at its lowest point is competent to carry it again up to the same height as that from which it fell, and in doing so the energy is gradually changed till again it all becomes potential. Were it not for the friction of the attachment of the pendulum-rod, and the resistance of the air, the oscillation, once set going, would continue forever, and at a uniform speed, because the force causing it is constant. In clocks, where advantage is taken of this property of a pendulum, the retarding forces are counteracted by the escapement, a mechanical contrivance set in motion by a wound-up weight or spring, which gives the pendulum a little push during each oscillation.

Let A C, B C (Fig. 10), be the two extreme positions of a pendulum. The force acting on the bob is its weight, represented in magnitude and direction by the vertical line, B G. This force is resolved in the direction of the rod, B F, and at right angles to it, and therefore tangentially to the arc described, B H. Now, because B G is parallel to C E, and H G to C B, therefore the angle β is equal to the angle α. H B, which represents the magnitude and direction of the impelling force throughout the swing, is proportional to the sine of β, and therefore to the sine of α, and consequently to D B. Now if any elastic rod fixed at one end be pulled to one side, the resistance to deflection for moderate distances will be proportional to the amount of deflection or to the length D B, and therefore such a rod, if let go, will vibrate with the same speed as a pendulum; and the general equation for the maximum velocity attained applies to all vibrating bodies, namely—

$$v = \frac{\text{D B} \times 2\pi}{\text{T}}$$

Where T is the time of a complete vibration, and D B is half the amplitude of the swing.

Let us take the case of a pendulum beating seconds, its length L in feet will be—

$$\text{L} = \left(\frac{0{\cdot}5 \text{ second}}{0{\cdot}554}\right)^2 = 0{\cdot}8145 \text{ foot.}$$

The maximum velocity will be—

$$v \text{ ft.} = \frac{0{\cdot}25 \text{ ft.} \times 2 \times 3{\cdot}1416}{1 \text{ sec.}} = 1{\cdot}5708 \text{ feet per second.}$$

The versed sine D E is the height which the bob falls each half excursion.

$$h = 0{\cdot}8145 \text{ ft.} - \sqrt{0{\cdot}8145^2 - 0{\cdot}25^2} = 0{\cdot}0393 \text{ ft.}$$

Now, if our reasoning has been correct, we shall find that the potential energy of the bob equals its kinetic. Suppose the bob to weigh 1 lb., the potential energy, in

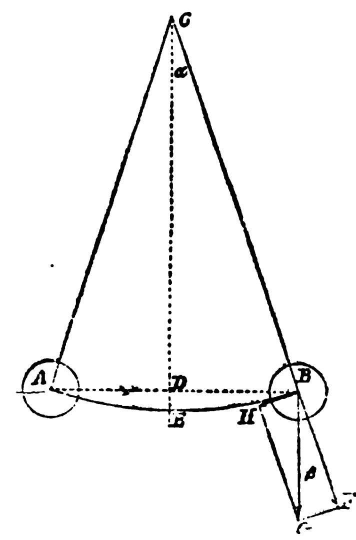


FIG. 10.

the positions A or B = 0·0393 ft. × 1 lb. = 0·0393 foot-pounds. The kinetic energy in the position E, where the velocity is a maximum, and = 1·5708 ft. per second.

$$\text{Kinetic energy} = \frac{1{\cdot}5708^2 \times 1 \text{ lb.}}{64{\cdot}4} = 0{\cdot}0383.$$

The two results are practically identical.

In watches, the pendulum is replaced by a wheel attached to one end of a spiral spring, the other end of the spring being fastened to the framing which supports the mechanism. When the wheel is turned a short distance, the spring is either wound up or unwound, and by that means brought into a state of tension, and then, being set free, the spring restores the wheel to its original position, and in doing so converts the potential energy imparted by the forcible compression or extension of the spring into kinetic energy, and this expends itself in carrying the wheel as much past the neutral point as it had been moved in the opposite direction at starting. This oscillating motion would also continue forever, were it not for the imperfect elasticity of the spring, the resistance of the air, and the friction of the journals; and, as in the case of the clock, these resistances have to be overcome by an escapement actuated by a wound-up spring, which gives the wheel a little push at each oscillation.

Vibrations may be propagated in many ways. Any elastic material may be set into longitudinal vibration. A wire stretched between two fixed points, if rubbed longitudinally, will be set into vibration. The action is of this nature: A portion of the wire rubbed is stretched a little more than the rest by the pull of friction; when the elasticity of the wire overcomes this pull, a portion of wire springs back, and, being elastic, returns beyond the neutral position as far as it was dragged from it. The motion is analogous to what we can see in the pendulum and balance; the elasticity of the material is the moving force. In obedience to the third law of motion, no part of a continuous bar can spring backward and forward without the neighboring sections participating in the movement, and so the oscillation travels along the bar according to well established laws; and because the wave of oscillation causes alternate compression and extension in the bar, it must also cause corresponding changes in its cross section—the bar will be reduced in diameter where extended, and increased where compressed. It is probably to this change of diameter, slight though it be, that we are indebted to the beneficial results of "jarring" anything which fits very tight into a hole when we want to get it out. The sudden alternation from compression to tension in highly elastic and brittle bodies, such as glass, is so intense that they may be fractured into thin slices through being brought into longitudinal vibration by vigorous rubbing.

The mode by which longitudinal vibrations are established and propagated may be very distinctly seen by fastening to some support one end of about a yard of India rubber pipe, and holding it out horizontally, but without stretching it much, with the hand; then, if the end near the hand is well wetted, and the fingers of the other hand rubbed lightly over it, the pulsations will be distinctly felt as they are formed by the alternate catching and releasing of the pipe by the fingers. The vibrations will be propagated along the pipe to the opposite end, and will become apparent as transverse vibrations which result from the sudden alterations of length, due to the pulsations jerking the pipe up and down.

I have here a brass tube fastened securely by its middle to a stout board. Opposite one end is hung a small glass ball; I rub my gloved hand, powdered with rosin, along the rod, you hear a musical note, and at the same time the ball is repelled with violence from the end of the rod. The note is between F sharp and G, corresponding to about 1,400 pulsations per second; therefore, although the excursion of each portion of the rod is but small, the velocity is very great, and hence the sharpness of the blow delivered to the ball.

All solid substances may be brought into transverse vibrations. Familiar illustrations of this are tuning forks, the sounding boards of musical instruments, and

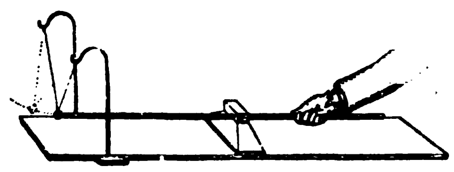


FIG. 11.

stretched strings. When these motions are sufficiently pronounced, they can be seen by the naked eye, but when very rapid and of small amplitude, they can be made to register themselves, so as to become visible, by mechanical means.

Waves are propagated through fluids and gases, such as water and air, much in the same way as along a rigid bar, that is to say, by alternate compression and extension, but the lines of compression and rarefaction extend all round the point from which the impulse is given, spheres of compression being surrounded by spheres of rarefaction, and consequently the impulse travels outward in every direction; and as the energy of motion is imparted to constantly increasing masses, so the velocity of motion is decreased, and the waves become more and more feeble as they recede from the point whence they started. Waves on the surface of a liquid are produced by a similar oscillation of the particles of the liquid, that is to say, each particle describes a curve of elliptical form, the plane being in the direction of motion of the waves, the long axis in deep liquid horizontal. The moving force is usually one acting on the surface, generally the action of the wind; the disturbance is propagated deeper and deeper, the energy of motion acquired at the surface is communicated to greater masses, and hence the motion becomes more feeble, the elliptic paths of the particles

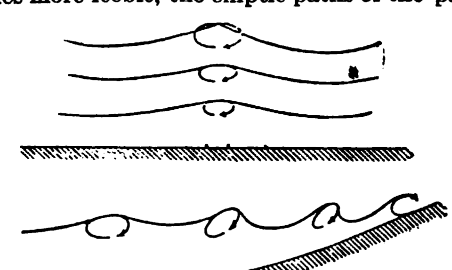


FIG. 12.

become flatter, and at last vanish altogether. In moderate depths, when the bottom is reached, there remains a simple to and fro movement. As water, for example, shoals toward the shore, the lower part of the orbits of the particles is retarded, hence the long axes of the ellipses become sloping, they approach more and more to the vertical, and at last the continuity of the ellipses is destroyed, and the wave breaks in a crest of foam on the beach. The action of the wind in creating waves is analogous to that of friction in producing pulsation in a solid rod, the friction of the air against the water which it slips over tends to move the particles along and heap them up; this heaping up goes on until the weight is more than the friction of the air can support, the mass of water falls, and like the pendulum falls as much below the mean level as it was raised above it. The elliptic motion is due to a combination of the vertical motion produced by gravity and the horizontal motion due to the wind.

Wave motion, like all other oscillating movements, once started would go on forever, were it not that the resistance of the air and friction of the particles of water among themselves tend gradually to bring the motion to rest. The movements which I have described may be plainly seen from any pier in deep water. Looking down on the waves, and observing some floating object, it will be seen to move a little backward and forward as well as up and down, while in shoal water the weeds growing on the bottom are seen to wave to and fro only.

If you watch the surface of the sea, you will notice an infinite series of waves existing at the same time, and being propagated in various directions. This is in accordance with the second law of motion, and you would expect consequently that, if the motion of two waves happened to be in the same direction, the motion of the water would be augmented, and, on the contrary, if the water happened to be in opposite directions it would be reduced, while, in the intermediate stages, there would be a resultant motion depending upon the magnitude and the direction of the other two. This effect is known by the name of "interference" of waves, and may best be studied on the surface of calm water, in which waves may be generated at pleasure. In a calm sea the long smooth rollers, intersected in various ways by minor waves, may also be watched with much profit. It is not alone in water that this interference takes place, but in all cases of vibration, whether in solids, liquids, or gases, the main vibrations are accompanied by minor ones. In musical instruments these minor vibrations are called harmonics or overtones, and to them is due the quality, tint, or *timbre* of the note. The difference in richness of the pure fundamental note and the one accompanied by its overtones is much like the difference between the sea on a very calm day and the sea when a breeze is sweeping over it. In the former case you see only the long, sleepy, oily-looking swell of previous disturbance, in the latter the same swell decorated and rendered brilliant by innumerable systems of wavelets superimposed on the majestic rollers of the swell and on each other. In the same way interference of pulses in the air are recognized by the dullest ear as "beats," that is to say, periods of comparative silence caused by the neutralizing coincidences of regions of compression and rarefaction in the sound wave.

* Lectures recently delivered before the Society of Arts, London.

As a consequence of the second law of motion, all wave motions are capable of being augmented by fresh impulses communicated synchronously, that is, timed so as to be always in the direction in which the particles are moving, or of being diminished and neutralized by the opposite course. The energy latent in wave motions is small compared to the apparent result produced. Thus, on the sea the friction on the surface of the water of a brisk breeze, having a velocity of thirty feet per second, is but one-tenth of an ounce per square foot, yet the constant and synchronous application of this slight force is capable of raising considerable waves. The power necessary to produce the volume of sound which emanates from a large organ is not more than that which one man working the bellows can easily supply, and yet the flood of sound fills a spacious building, and is even competent to affect it with a perceptible tremor. The lightest touch of a wetted finger on the edge of a tumbler will set it vibrating with exceeding rapidity, emitting a shrill note, while the slight pressure of a feather will instantly damp the vibrations of a piano string.

The last kind of vibration that I have to bring under your notice is that of a mysterious substance, which, for want of a better name, we call ether, which pervades all space and all bodies, whether solid, liquid, or aeriform. It is this ether which links us to the planetary world, for it is the medium by which light and heat are communicated to the earth from the sun and the other heavenly bodies. It must be of extreme tenuity, because it offers no appreciable resistance to the motion of the planets, and, as I have just said, permeates all substances. You may, at first, be disposed to hesitate at accepting a statement that solids can thus be permeated, but we have reason to believe that, looked at with the mind's eye, the densest solid is no better than a very porous piece of sponge. The evidence of the truth of what I have stated lies in the remarkable phenomena of the occlusion of gases in solids and liquids, that is to say, the power which solids and liquids possess of absorbing many times their own bulk of certain gases. Thus platinum, the densest of all substances, occludes as much as five times its own volume of hydrogen without change of bulk; the metal palladium, as much as 643 times its own volume of carbonic oxide. It is, in fact, upon this property that the manufacture of steel from wrought iron by the cementation process depends. In that process bars of wrought iron are packed with substances rich in carbon into iron boxes, and closely cemented in them; they are then exposed to a red heat for many days, during which carbon slowly penetrates right into the heart of the bars. Again, platinum and iron are, at a red heat, permeated by gases to a remarkable extent, that is to say, gases pass right through them. Liquids, again, absorb many gases readily. Rain water takes up 2½ per cent. of its bulk of atmospheric air, and the principle on which the manufacture of aerated drinks depends is that water can, by pressure, be made to hold many times its bulk of carbonic acid gas. At the atmospheric pressure water dissolves about its own volume of the gas, but as the pressure rises, and the gas is reduced in bulk, more gas is absorbed, and it is found that the weight of gas taken up is nearly in direct proportion to the pressure, a relation which the theory of the porosity of bodies would lead us to expect.

Our knowledge of molecular physics is still very limited; the subject is now occupying the attention of some of the most powerful minds of the age; it comes within the province of the chemist, the mathematician, and the physicist, and any theories put forth must satisfy the claims of each. Speaking broadly, I may say that the elementary substances are composed of atoms or particles incapable of further subdivision, and these atoms have each a definite weight, and probably a common specific heat, that is to say, each atom requires the same quantity of heat to raise its temperature one degree. Compound bodies are composed of molecules which are formed each of a definite number and arrangement of the atoms of the elements of which they are composed. Of the structure of the atoms and molecules little or nothing is known, though many bold and ingenious conjectures have been made, but long years will probably elapse before any fully satisfactory theory can be established. The atoms of simple substances, and the molecules of compound bodies, are not in permanent contact with each other. In solids they are in a state of oscillation due to their temperature; this oscillation is analogous to that of a pendulum or watch balance, the forces acting on the particles being mutual attraction and that force which causes the movement which we call heat. Molecular motion, like any other, may be communicated from one body to another, or propagated along the same body, as you saw in the experiment with the brass tube. A body in which the particles are oscillating more vigorously than in another body, if placed in contact with it, will gradually impart a portion of the motion of its own particles to those of the body it touches, and in consequence the motion of its own particles will be enfeebled, because the total kinetic energy of the two substances remains constant.

I have here a light framework from which are hung a number of heavy balls by strings of equal length. I set one ball swinging across the frame; the pull upon its string, due to the motion, sets the top bar of the frame moving synchronously, this motion is imparted to the points of suspension of the other balls, and you see that they all gradually get into swing, and as their swing increases, that of the ball which originated it decreases. This illustrates how heat vibrations are communicated from one body to another, and how the former must necessarily cool in heating that with which it is in contact.

A vibrating string, if it has light substances showered down on it, sets them in motion, but in so doing it has its own velocity reduced. A string vibrating between rigid supports will continue to sound longer than one attached to a sounding-board, because, in the latter case, much more motion is communicated to the air, the sound is much louder, and hence the motion of the string is more quickly damped. The same action takes place in the communication of heat from one body to another by conduction, or from the hotter portion of one body to a colder portion; the rise in temperature—that is, the increase in the amplitude of vibrations of the colder body—is accompanied by a fall in temperature of the hotter. When such increased motion is communicated, the particles make wider excursions, and generally cause the body to expand. At last a point is reached at which the bonds of cohesion have been so weakened by the separation of the particles that they escape from the influence of the other particles they were associated with, and become free to slide over each other, the consequence of which is that the solid substance becomes liquid. In both these states the violence of motion flings off, as it were, particles at the surface, in consequence of which most solid and liquid substances have a characteristic smell, and many of them, such as snow, ice, and sal ammoniac, evaporate with tolerable rapidity, even at very low temperatures. In the case of liquids, the particles in the mass of the substance are in equilibrium, and move indifferently in any direction; but when a free surface is reached, the outward movement has to take place against the force of gravity so soon as any particle tends to rise above the level of the rest, and hence the tendency of liquids to assume a horizontal free surface. Yet from this surface particles are occasionally projected and escape into the air, assuming the form of vapor; and this escape, as might be expected, is more frequent the more rapid the motion of the particles is, that is to say, the hotter the liquid becomes. In gases, the motion of the particles is similar to that in liquids, but more energetic. They move with great velocity in all directions, striking against each other and against the sides of containing vessels, and rebounding according to the laws of impact of elastic substances, which I have briefly explained. It is the continued bombardment of the sides of the containing vessels by particles extremely minute, inconceivably numerous, and gifted with a stupendous energy, due to their high velocity, which produces the phenomena of pressure and temperature of gases. Were the molecules or atoms perfectly elastic, and were there no friction or resisting medium of any kind, there would be no loss of energy, and hence a gas completely inclosed in a non-conducting vessel would never change its temperature. There is, however, one source of apparent loss of energy, and that is that the innumerable collisions among the particles tend to set up very minute vibrations in the substance of the atoms and molecules themselves, and this action would produce the same effect as in the collision of elastic bodies, where I have already shown that the internal vibrations rendered sensible to us in the form of sound are competent to bring the bodies to rest. In the case of gases, the internal molecular vibrations set up would probably not have the character of sensible heat. All gases are supposed to contain the same number of elastic molecules in the same volume, under similar conditions, hence their specific gravities are proportioned to their atomic weights, and their physical properties are also very much alike, that is to say, they obey the same laws of variation of volume and pressure with respect to heat. The space passed through by a particle of gas without collision is termed the free path. There is a difference in the nature and properties of gases in the three following conditions: When in contact with the liquids from which they have become disengaged; when completely separated from their liquids; and again when, at high temperatures, dissociation or a subdivision of the molecules takes place, so that when examining a gas, its condition requires to be defined. The evidence of the truth of the molecular theory of liquids and gases is, that they diffuse into each other, that is to say, two different liquids or two different gases in contact with each other will mix more or less rapidly, which proves that the particles are free to perform excursions of unlimited extent. Mathematical calculations based on these theories enable us to account for the laws relating to the pressure, temperature, and other properties of liquids and gases.

Although the heat and light bearing ether is of the nature of a gas, yet vibrations rendered evident as radiant light and heat do not take place in the direction in which the tangible effects seem to travel, but at right angles to them, like a wave traveling along a string, and these vibrations are extremely complex; they are made up, not only of vibrations of various wave lengths vibrating in the same plane, but of vibrations in planes at right angles and other angles to each other. The waves are of inconceivable minuteness and rapidity of motion, else they could not be expected to traverse solid substances. You are doubtless aware that by means of a transparent triangular prism rays of white light can be decomposed, that is to say, the effect of the form of the prism on a ray from a hot body is to separate the various complex vibrations into ones of definite wave lengths. The visible spectrum is bounded by red at one end and violet at the other, but beyond the red, invisible to human eyes, the heat rays spread out, and beyond the violet equally invisible the actinic or chemical rays. The length of a wave of the extreme red is 39,000 to one inch, and of the violet ray 64,631 to one inch. The velocity of light is 186,000 miles a second, hence the red waves strike the retina of the eye at the inconceivable rate of four hundred and sixty millions of millions of times each second. The analogy between the comparatively coarse motions of sound and those of radiant light and heat is very remarkable, and have, in fact, been the means of leading up to the now well-established undulatory theory. It is well known that musical sounds extend beyond the compass of the human ear, and that ears are not all alike in respect of their powers of hearing extreme notes at either end of the scale; some people, for instance, cannot hear the cry of a bat. The same thing applies to light; we cannot perceive the excessively rapid vibrations beyond the extreme violet of the spectrum, or the comparatively slow movement of the red end, but we can damp the too rapid vibrations by letting the dark rays fall on certain substances, such as sulphate of quinine, and then we are made conscious of fluorescence—light shining out of darkness. You must try and banish from your minds any idea that you

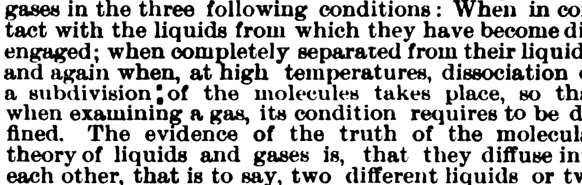


FIG. 13

may have that there is a substantial difference between rays of heat, of light, or of chemical action. The difference is only one of wave length, and it is due to the structure of our organs of senses that only certain of the vibrations produce the sensation of light, and some of heat, or some produce the impression of light to the eye and heat to the touch. In the case of the actinic rays their superior energy, due to the velocity of motion, may be the cause of their power in decomposing certain substances.

A string made to vibrate, as I have already stated, vibrates in a complex manner, the fundamental note is accompanied by overtones and harmonics; by damping the string in suitable places, the overtones may be extinguished and the fundamental note sounded alone. And so with light and heat. The vibrations in every conceivable plane may be reduced to vibrations in one plane only; this is termed polarization, and as we have seen that sound waves interfere with each other, so do the waves of heat and light. The iridescent colors seen in soap bubbles, and in thin films generally, are caused by the interference of certain wave lengths reflected from the two sides of the film abolishing certain colors, and destroying the usual whiteness of the light by giving prominence to the complementary colors.

The diathermancy of substances, that is, their transparency to heat, is so intimately connected with my subject, that I must devote some time to it. It is a matter of every day observation that substances are endowed with varied degrees of transparency, that is to say, that the undulations corresponding to visible rays make their way among the particles of some bodies, and are arrested in whole or in part by others. For example, glass, water, and air allow the luminous rays to pass with only slightly altered intensity. A certain diminution of energy, indeed, depending upon the thickness of the medium, takes place, as might be expected, from the vibrations having to pass through a crowd of vibrating particles of the substance through which the light is transmitted. Surrounding this monochord, I have placed a tin cylinder with several internal ledges or shelves. It is partially filled with fine

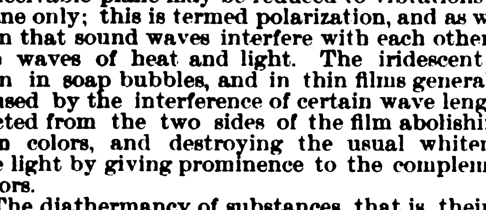


FIG. 14.

sawdust, and as I turn it, the sawdust is showered down upon the string. I now sound the note, and you hear its prolonged cadence gradually dying out. I sound it again, and, at the same time, turn the cylinder; the particles of sawdust, as they fall on the string, are set in motion, and the energy so imparted is deducted from the string, consequently you hear that the sound is quickly extinguished. This is analogous to the effect of radiant light and heat passing through substances, the particles of which are capable of responding to the vibration of the ether, and themselves consequently becoming hot at the expense of the radiant energy.

The experiment with the swinging balls will serve to illustrate this point. When the balls were arranged so as to have the same period of oscillation, you saw that they all got into swing. This would represent the case of an adiathermanous body, which will not transmit radiant heat, and, therefore, gets hot itself. But if I shorten one or two of the strings, and so give the balls a period of vibration which does not synchronize with that of the swinging ball, you observe that they remain quite unaffected; that is the case of a diathermanous substance, which does not get hot itself, but allows the heat rays to pass through.

In the case of light, some substances affect certain wave lengths only and arrest their movement altogether; we then have colored light such as is produced by colored glass, liquids, and gases. A very large number of substances, when they are of appreciable thickness, will not permit the waves to pass at all, and then we have opaque bodies.

The same rules apply to the heat waves, and what we know of light will lead us to expect that the heat wave will be more interfered with by some bodies than others, and that transparency to light need not be accompanied by transparency to heat, and so we find that transparent rock salt is also diathermanous, whereas glass and water very greatly damp the longer heat waves. Gases vary quite as much as liquids and solids in their effect on radiant heat. Atmospheric air, oxygen, hydrogen, and nitrogen scarcely produce any effect on heat waves, whereas olefiant gas and ammonia interfere with them to a very considerable extent.

The remarkable adiathermancy of water is taken advantage of by diamond cutters and engravers, to concentrate a powerful pencil of light on their work without the accompanying heat. Instead of using glass lenses, they use globular vessels filled with water, which act as water lenses, concentrating the light while they completely cut off the heat. I have seen a fire-screen formed by a sheet of water contrived to fall in front of the fire from a slit under the mantelpiece into a trough concealed by the fender.

Our knowledge of the diathermancy of the metals and other substances used in the arts is very limited. Melloni, from whose experiments most of our information is derived, operated mostly on substances more common in the laboratory than in everyday life, but we may safely say that all substances are more or less diathermanous, and that the thinner the substances are, the less the heat waves are interfered with.

We are now in a condition to explain many of the phenomena connected with heat.

First, we will take specific heat. It is a matter patent to our senses that there is a great difference in the physical properties of bodies. They differ in specific weight, in strength, in elasticity, in color, in hardness, and in many other more subtle points, hence we might expect that the atoms or molecules would not be set vibrating with equal facility. We have seen that a force of 10 lb. acting on a weight of 10 lb. will produce a definite velocity in a second of time; but if the force of 10 lb. acts on a weight of 20 lb., the velocity will be reduced to half, and so it is found that a pound of water, the molecules of which are endowed with energy competent to produce the sensation of 100° Fahr. of heat, if mixed with a pound of water the molecules of which are moving with less energy, and producing the sensation of 50°, the former will lose a portion of their motion while the cold water will gain; the momentum of the two pounds of molecules vibrating at a common velocity will remain the same as the sum of momenta of the respective pounds before mixture, in other words we shall have two pounds of water at 75°. But when the substances mixed together are different, the change of velocity of motion is not so simply arrived at, because not only are the weights of the particles of the two substances different, but the forces which unite them, and which oppose the change of motion, are also different. Thus, if 1 lb. of mercury at 100° be mixed with 1 lb. of water at 50°, the result will be a mixture at 53½° only, the reason being that the energy of the vibrations in mercury is only about 3⅓ per cent. of that of the molecules of water. This relation of the energy of the vibrations of various substances to water is called the specific heat of the substance. It has been determined with great care for most bodies, and always takes the form of a decimal fraction, water being unity, for it so happens that water requires more heat to raise it a given number of degrees than any other substance. The specific heat of mercury is 0·0333, that of iron 0·1138, that of alcohol 0·615, that of air 0·169, at constant volume. Specific heat in simple substances and in compound bodies of similar atomic composition is found to vary inversely as the atomic weight, that is to say, the product of the atomic weight into the specific heat is very nearly a constant quantity in the elements and compound bodies of the same order, the said product varying in value with each order.

I have stated that water has been constituted the standard to which specific heats are referred; it is time that I should now explain that the quantity of heat or energy of molecular vibrations which raises one pound of water one degree of Fahrenheit is called the British unit of heat, and because it is a fact that energy is indestructible, so heat, being a form of energy, is also indestructible, it cannot disappear or be lost; hence all calculations connected with heat are based upon the supposition that whatever changes of temperature take place, the total amount of heat units involved will remain unaltered in value, though, perhaps, greatly changed in form. By way of illustration, we will take a very convenient method of measuring very high temperatures. It consists in heating a ball of some refractory metal to the same temperature as that which it is desired to measure, and then, with proper precautions against loss of heat, plunging the ball into water. In order to use this apparatus it is only necessary to know the specific heat of the material of which the ball is composed, its weight, the weight of water into which the ball is plunged, and the increase of temperature in the water. Supposing that a ball of platinum weighing one pound had been heated white hot in a furnace, and then plunged into one pound of water at 50°, and that after a time the water had risen to 112°, a simple calculation will show that the ball must have been at a temperature of 2025·3°. The specific heat of platinum is 0·0324. Let us now make what Sir Frederick Bramwell calls a debtor and creditor account. Before the ball was quenched we had the following number of heat units:

In the platinum ball,	2025·3×0·0324×1 lb.	=	65·62
In the water	50° ×1 lb.	=	50
Total heat units........			115·62

After the ball was quenched, and had got to the same temperature as the water, we had—

In the water	112° × 1 lb.	=	112 units.
In the ball	112° × 0·0324 × 1 lb.	=	3·62 "
			115·62

You see the account balances, and it is on that expectation that the formula is based by which the temperature of the ball is calculated.

W = weight of water at temp. t being also that of the air.

W′ = weight of ball.

t' = temperature of ball before quenching.

t'' = temperature of water and ball after quenching.

S = specific heat of ball.

Units of heat in the ball = W′ S × (t'—t).

Units of heat after mixture = W (t''—t) + W′ S × (t'—t).

These two quantities are equal to each other, hence it is easy to work out that t', the temperature of the ball when plunged into the water, will be—

$$t' = \frac{(t'-t)\ (W + W'\ S)}{W'\ S} + t.$$

You will find later on that we shall make frequent reference to specific heat.

I have already explained how, when the energy of molecular vibration is increased in a solid, the molecules become emancipated from the rigid thralldom in which they were bound, and the solid becomes a liquid. If still more energy be communicated, the liquid becomes a gas.

Now, in the case of accelerated motion, we have seen that as long as the accelerating force acted, the motion of the body acted on continued to increase; but as soon as the accelerating force was diverted and ceased to act, the motion remained uniform, the effect produced by the force remains, according to the first law of motion, though the force has disappeared. So it is with heat motion imparted to a body. So long as the body heated retains its normal form and properties, we can observe the increase of temperature corresponding to an increase of molecular velocity; but as soon as destruction of form begins to takes place, the increase of heat no longer becomes sensible, the energy of the force is diverted to breaking up the structure of the body, and to keeping its molecules apart and free to slide over each other. When this has been completely accomplished, and not till then, additional energy imparted again produces an accelerating motion, and the liquid gets hotter and hotter, till at last a second boundary is reached, a second destruction of form takes place, and again the rise of temperature ceases till the whole liquid is transformed into a gas, after which acceleration can again take place and the gas further heated, whereby the energy of its molecules, already very high, is still further increased. The heat which apparently disappears during liquefaction and vaporization is said to be latent, which means no more than that heat, like many persons, cannot do two things at the same time. The work of pulling to pieces the structure of a solid or liquid cannot go on if the mercury in the bulb of a thermometer has to be expanded and made to rise at the same time.

If we wish to restore the substances to their original state, we must arrange matters so that the energy which is keeping the molecules of a body apart shall be diverted to heating some other body, in other words we must cool the vapor to make it return to the liquid form, and cool the liquid to make it become solid again.

I have spoken of degrees of temperature very often, and have assumed that you understand that the ordinary mercurial thermometer is a contrivance by which the expansion of mercury in a narrow glass tube enables us to measure changes of heat which affect our senses. The two fixed points in a thermometer scale are the melting point of ice and the boiling point of water, and the space between has been divided, in England, into 180°. Fahrenheit, however, to whom we owe our thermometer scale, had an idea that there was a zero point, a point beyond which temperature could not fall, and he fixed it at 32° below the freezing point of water. Fahrenheit was right in his idea, but quite wrong in the zero point he fixed. We have now better grounds upon which to arrive at what is termed the absolute zero of temperature. A perfect gas is found by experiment to expand or contract regularly in direct proportion to the alteration of temperature, and the rate of expansion is such that a volume of 1 at the freezing point becomes a volume of 1·3665 at the boiling point, a range of 180°, so that the volume has increased by $\frac{1}{491}$ part for each degree of rise of temperature. On cooling the gas, it is found to contract at the same rate, so that, supposing it could be cooled 492° below the freezing point, the gas would occupy no volume at all; and this point is called the absolute zero of temperature; it is 492° below the freezing point, or —460° on the Fahrenheit scale. To convert our ordinary degrees into absolute temperature, therefore, we have only to add 460°.

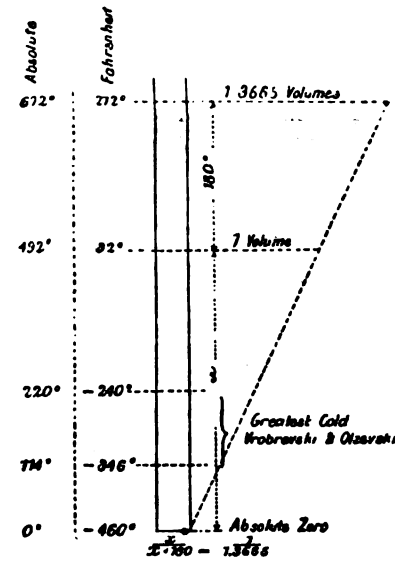


FIG. 15.

It may be asked whether it is possible that gas deprived of all sensible heat will cease to occupy space; the answer is that we cannot tell. The lowest temperature reached up to the present time has been attained by the Russian chemists Wrobrevski and Olsevski, and is 114° on the absolute scale. The absolute zero of temperature can be arrived at also by other means which it is beyond the scope of these lectures to explain.

THE ERODING POWER OF ICE.

By Prof. J. S. NEWBERRY.

THE geological history of our great and yet largely unexplored continent offers a most important and fascinating subject for observation and study. Many earnest men have devoted themselves to it, and they are making commendable, I may even say splendid, progress, but the impediments thrown in their way by hasty generalization and unwarranted statement are scarcely less than those which nature has opposed to their progress. We have too much closet geology, too much evolution of theory and system from inner consciousness, and too much dependence upon views seen through other people's eyes. What we want instead is *facts*, and more facts, and still more facts, in order that we may have more real knowledge.

No better illustration of the justice of these remarks can be given than are furnished by the heterodox notions which have been promulgated in reference to glaciers and the glacial period.

The most important heresies, as I deem them, which have been advanced in regard to this subject are: 1. The denial that there ever was a glacial period. 2. "If there was an ice period, it was a warm and not a cold one." 3. "That the phenomena usually ascribed to glacial action in the record of an ice period were generally caused by icebergs." 4. "That ice has little or no eroding power," and "that glaciers have never been important geological agents."

It has chanced to me to have opportunities of studying the record of an ice period and glacial action in different countries, viz., in the Alps of Switzerland, in the Sierra Nevada and Cascade Mountains of California, Oregon, and Washington, in the Wasatch and Rocky Mountain belts and the Canadian highlands, throughout New England, New York, the basin of the Great Lakes and the valley of the Mississippi. Over this wide field I have observed a variety of facts, all tending to prove, as it seems to me, the truth of the conclusion reached by the pioneers and masters in the study of glacial phenomena, and heretofore accepted by the best geologists of Europe and America, viz., that the glacial period was a reality, and that its record constitutes one of the most important and interesting chapter of geological history; second, that this was a cold and not a warm period; third, that ice has great though unmeasured and perhaps unmeasurable eroding power, and that in the regions they have occupied glaciers have been always important and often preponderating agents in effecting geological changes.

I have elsewhere discussed the first three of these propositions, and I now propose to say a few words in regard to the last.

The excavating action of the glaciers of the Alps early attracted the attention of Charpentier, Agassiz, Guyot, and others who were the pioneers in the study of glacial phenomena, and they described in detail and gave names—now everywhere adopted into the language of geology—to the characteristic inscriptions and the masses of debris which are the products of ice action. By later geologists, "*glacial striæ*," "*roches moutonnees*," and "*moraines*" have been discovered and described in various parts of both the northern and southern hemispheres, and the space given to these records in geological literature attests the potency ascribed to ice as an agent effecting changes on the earth's surface. All the most distinguished geologists of the Old World have conceded to moving masses of ice an important role in producing or modifying topography, and one eminent authority, Prof. Ramsay, late Director of the Geological Survey of the United Kingdom, has gone so far as to attribute the excavations of all lake-basins to this cause. In our own country witness has often been borne to the record of powerful erosive action produced by ice; and while the effect of this action has not been accurately measured, it has not until recently been denied.

Within the last few months, however, a number of American geologists have taken upon themselves to deny that ice possesses any eroding or excavating power. Examples of the utterences of this school may be found in Prof. J. D. Whitney's "Climate Changes," in papers by Prof J. W. Spencer on "The Old Outlet of Lake Erie,"* by Prof. W. M. Davis on the "Classification of Lake Basins," † and the "Erosive Action of Ice," ‡ and remarks on the same subject by Prof. J. P. Lesley.‖

No new facts or original observations are adduced by any of these writers to refute the prevailing opinion that ice is a powerful eroding agent, but they have for the most part contented themselves with the assumption of a judicial attitude and the delivery of a verdict, without a trial of the case.

As one of those who have had some opportunity of studying this question in the field, and one who has committed himself to a view opposite to that now become locally popular, I venture to submit a few facts and arguments which make it impossible for me to accept the recently promulgated views on ice erosion to which references has been made. These naturally arrange themselves under several heads, as follows:

I.—GLACIAL TOPOGRAPHY.

In the Alps the glaciers have done the characteristic work of *local ice streams;* have scoured and filed the bottom and sides of the valleys, forming *roches moutonnees* of all projecting points, and giving to these valleys a simpler and more open section than would be produced by water. Good examples of the contrasting action of ice and water in erosion are given in some of the views in Agassiz's "Etudes." The broad valley with planed sides, the work of ice, is cut at bottom by a deep and narrow channel formed by the flow of the stream which drains the diminished glacier.

In the mountains of Oregon a remarkable monotony of surface has been produced by ice action. The crest of the Cascades, crowned by the volcanic peaks, Mt. Jefferson, Mt. Hood, etc., has sides sloping east and west like the roof of a house. These slopes are planed down, and their asperities removed; everywhere showing the effects of a powerful grinding agent. Where a rough volcanic ledge once rose above the surface, only a remnant of it now remains in a *roche moutonnee* or a low ridge like a boat bottom, its top and sides smoothed over or beaded, as a plasterer beads a cornice, by the moving ice under which it once was deeply buried. From the great crater in the center of the group of snow peaks called the Three Sisters, the courses of ancient glaciers can be traced far down the mountain sides by the polished or deeply furrowed surfaces of the hard volcanic rock which composes the mass of the range. In the Sierra Nevada, the Wasatch, and the Rocky Mts. similar inscriptions are visible in innumerable localities. Slopes are ground off, the outlines of the mountains rounded, the valleys broadened, their sides and bottoms smoothed as they could only be by the removal of a vast amount of material.

In the Laurentian belt north of Lake Huron, Lake Ontario, and the St. Lawrence, where were formerly high mountains are now only low hills and rolling surfaces. Over hundreds of square miles the rock is mostly bare, consisting of strata of granite, slate, dolomite, diorite, etc., standing at high angles, but planed down, scratched, and ground by glaciers until their cut edges are like the boards in a floor.

In the interval between the Hudson and the Connecticut, layers of crystalline rock of similar character stand on edge, the arches so truncated by erosion that it is almost impossible to analyze the section. Here also the edges of the granite, slate or marble layers are ground down into a plane or rolling surface. Here, too, as in Rutland County, Vermont, and many places where the strike of the strata has been nearly in the line of the glacial movement, the softer beds, as slate and marble, are scooped out into ice-worn and glaciated valleys, the harder strata left in relief on either side. Where the whole face of the country has been ground off, and nothing is left to mark the original level, it is of course impossible to measure the amount of erosion produced by ice; but where we find broad, straight, glaciated troughs scooped out of the softer rocks in the line of glacial motion, we have evidence that ice has done most, if not all, of the erosion; and facts of this kind are sufficiently numerous and striking to furnish in themselves a refutation of the statement that ice has no eroding power.

Any one who has any knowledge of surface geology knows that the action of running water on topography

* 1 Proc. Amer. Philos. Soc., Vol. xix., p. 300.

† 2 Proc. Bost. Nat. Hist. Soc., Vol. xxi., p. 315.

‡ 3 Proc. Bost. Nat. Hist. Soc. Vol., xxii., p. 19.

‖ 4 Proc. Amer. Philos. Soc., Vol. xx., p. 95.