the seventh, the ratio being 8 : 15. When this disk is rotated rapidly, and wind is blown through a flat nozzle held with its opening radially at the edge, two notes are heard giving this exact interval. *If the vibration is slow, beats are heard: if the vibration be rapid, the beat-note is heard.* In order to compare these notes the more accurately with a true combinational tone, the same disk is pierced by three concentric rings of holes, one with 64, another with 120, giving the ratio 8 : 15, and another, with 8 holes only, corresponding to the number of beats between 120 and the octave of the 64 set (128), that is to say, to the upper beat-note of the interval 8 : 15. When air is blown through the rings of 64 and 120 holes in the rotating siren-disk, exactly the same notes and same beats or beat-notes are produced as by the wave-curve at the edge. Here there can surely be no partial tones present to complicate the phenomenon. For greater convenience in comparing several combinations, the wave-forms are cut upon cylindrical rims mounted upon one axis as in the first figure, a flat disk pierced with holes being added above for comparison. In every case slow rotation gives beats, and rapid rotation the beat-note exactly as König's theory requires.

It remains yet to be seen what answer Helmholtz and the mathematical acousticians will give to the challenge thrown down by König in this beautiful and ingenious piece of mechanism. Meantime we may mention that Mr. Bosanquet of Oxford has just been examining the very same question, though by different means. He finds that all König's higher beat-tones can be accounted for by the assumption that the terms of higher orders become important in the mechanism of the ear when the displacements are considerable, and that therefore "by transformation" in this sense the variations of maximum displacement in the resultant wave give rise to to-and-fro vibrations of simple form having the same frequency as these variations, and therefore evoke *in the ear* a note whose frequency is the same as the number of beats. He is also positive that such tones exist only in the ear, and are inaudible in resonators. Lastly, he has satisfied himself that in all the cases of beats between mistuned consonances in which the higher note is (nearly) 2, 3, 4, . . . &c., times as rapid as the lower, *the beat consists of variations of intensity of the* lower *of the two primary tones.*

S. P. T.

HYDRODYNAMIC ANALOGIES TO ELECTRICITY AND MAGNETISM

FROM a scientific and purely theoretical point of view there is no object in the whole of the Electrical Exhibition at Paris of greater interest than the remarkable collection of apparatus exhibited by Dr. C. A. Bjerknes of Christiania, and intended to show the fundamental phenomena of electricity and magnetism by the analogous ones of hydrodynamics. I will try to give a clear account of these experiments and the apparatus employed; but no description can convey any idea of the wonderful beauty of the actual experiments, whilst the mechanism itself is also of most exquisite construction. Every result which is thus shown by experiment had been previously predicted by Prof. Bjerknes as the result of his mathematical investigations.

It has long been known that if a tuning-fork be struck and held near to a light object like a balloon it attracts it. This is an old experiment, and the theory of it has been worked out more than once. Among others Sir William Thomson gave the theory in the *Philosophical Magazine* in 1867. In general words the explanation is that the air in the neighbourhood of the tuning-fork is rarefied by the agitation which it experiences. Consequently the pressure of the air is greater as the distance from the tuning-fork increases. Thus the pressure on the far side of the balloon is greater than that on the near side, and the balloon is attracted.

Dr. Bjerknes has followed out the theory of this action until he has succeeded in illustrating most of the fundamental phenomena of electricity and magnetism. He causes vibrations to take place in a trough of water about six inches deep. He uses a pair of cylinders fitted with pistons which are moved in and out by a gearing which regulates the length of stroke and also gives great rapidity. These cylinders simply act alternately as air-compressers and expanders, and they can be arranged so that both compress and both expand the air simultaneously, or in such a way that the one expands while the other compresses the air, and *vice versâ*. These cylinders are connected by thin india-rubber tubing and fine metal pipes to the various instruments. A very simple experiment consists in communicating pulsations to a pair of tambours, and observing their mutual actions. They consist each of a ring of metal faced at both sides with india-rubber and connected by a tube with the air-cylinders. One of them is held in the hand; the other is mounted in the water in a manner which leaves it free to move. It is then found that if the pulsations are of the same kind, *i.e.* if both expand and both contract simultaneously, there is attraction. But if one expands while the other contracts, and *vice versâ*, there is repulsion. In fact the phenomenon is the opposite of magnetical and electrical phenomena, for here like poles attract, and unlike poles repel.

Instead of having the pulsation of a drum we may use the oscillation of a sphere; and Dr. Bjerknes has mounted a beautiful piece of apparatus by which the compressions and expansions of air are used to cause a sphere to oscillate in the water. But in this case it must be noticed that opposite sides of the sphere are in opposite phases. In fact the sphere might be expected to act like a magnet; and so it does. If two oscillating spheres be brought near each other, then, if they are both moving to and from each other at the same time, there is attraction; but if one of them be turned round, so that both spheres move in the same direction in their oscillations, then there is repulsion. If one of these spheres be mounted so as to be free to move about a vertical axis, it is found that when a second oscillating sphere is brought near to it, the one which is free turns round its axis and sets itself so that both spheres in their oscillations are approaching each other or receding simultaneously. Two oscillating spheres, mounted at the extremities of an arm, with freedom to move, behave with respect to another oscillating sphere exactly like a magnet in the neighbourhood of another magnetic pole. I believe that these directive effects are perfectly new, both theoretically and experimentally. The professor mounts his rod with a sphere at each end in two ways: (1) so that the oscillations are along the arm, and (2) so that they are perpendicular. In all cases they behave as if each sphere was a little magnet with its axis lying along the direction of oscillation.

Dr. Bjerknes looks upon the water in his trough as being the analogue of Faraday's medium; and he looks upon these attractions and repulsions as being due, not to the action of one body on the other, but to the mutual action of one body and the water in contact with it. Viewed in this light, his first experiment is equivalent to saying that if a vibrating or oscillating body have its motions in the same direction as the water, the body moves away from the centre of disturbance, but if in the opposite direction, towards it. This idea gives us the analogy of dia- and para-magnetism. If, in the neighbourhood of a vibrating drum, we have a cork ball, retained under the water by a thread, the oscillations of the cork are greater than those of the water in contact with it, owing to its small mass, and are consequently *relatively* in the same direction. Accordingly we have repulsion,

corresponding to diamagnetism. If, on the other hand, we hang in the water a ball which is heavier than water, its oscillations are not so great as that of the water in its vicinity, owing to its mass, and consequently the oscillations of the ball relatively to the water are in the opposite direction to those of the water itself, and there is attraction, corresponding to paramagnetism. A rod of cork and another of metal are suspended horizontally by threads in the trough. A vibrating drum is brought near to them; the cork rod sets itself equatorially, and the metal rod axially.

If a pellet of iron be floated by a cork on water and two similar poles (*e.g.* both north) be brought to its vicinity, one above and the other below the pellet, the latter cannot remain exactly in the centre, but will be repelled to a certain distance, beyond which however there is the usual attraction. The reason is that when the pellet is nearly in the line joining the two poles the north pole of the pellet (according to our supposition) is further from this line than the south one. The angle of action is less; so that although the north pole is further away, the horizontal component of the north pole repulsion may be greater than that of the south pole attraction. Dr. Bjerknes reproduces this experiment by causing two drums to pulsate in concord, the one above the other. A pellet fixed to a wire, which is attached by threads to two pieces of cork, is brought between the drums, and it is found impossible to cause it to remain in the centre.

Dr. Bjerknes conceived further the beautiful idea of tracing out the conditions of the vibrations of the water when acted on by pulsating drums. For this purpose he mounted a sphere or cylinder on a thin spring and fixed a fine paint-brush to the top of it. This is put into the water. The vibrations are in most cases so small that they could not be detected, but by regulating the pulsations so as to be isochronous with the vibrations of the spring, a powerful vibration can be set up. When this is done a glass plate mounted on four springs is lowered so as to touch the paint-brush, and the direction of a hydrodynamic line of force is depicted. Thus the whole field is explored and different diagrams are obtained according to the nature of the pulsations. Using two drums pulsating concordantly, we get a figure exactly like that produced by iron filings in a field of two similar magnetic poles. If the pulsations are discordant it is like the figure with two dissimilar poles. Three pulsating drums give a figure identical with that produced by three magnetic poles. The professor had previously calculated that the effects ought to be identical, and I think the same might have been gathered from the formulæ in Sir William Thomson's "Mathematical Theory of Magnetism," but this only enhances the beauty of the experimental confirmation.

Physicists have been in the habit of looking upon magnetism as some kind of molecular rotation. According to the present view it is a rectilinear motion. Physicists have been accustomed to look upon the conception of an isolated magnetic pole as an impossibility, but here, while the oscillating sphere represents a magnetic molecule with north and south poles, the pulsating drum represents an isolated pole. These are new conceptions to the physicist, let us see whither they lead us. The professor shows that if a rectilinear oscillation constitutes magnetism, a circular oscillation must signify an electric current, the axis of oscillation being the direction of the current. According to this view what would be the action of a ring through which a current is passing? If the ring were horizontal the inner parts of the ring would all rise together and all fall together, they would vibrate and produce the same effect as the rectilinear vibrations of a magnet. This is the analogue of the Amperian currents.

To illustrate the condition of the magnetic field in the neighbourhood of electric currents, Dr. Bjerknes mounted two wooden cylinders on vertical axes, connecting them by link-work, which enabled him to vibrate them in the same or opposite ways. To produce enough friction he was forced to employ syrup in place of water. The figures which are produced on the glass plate are in every case the same as those which are produced by iron filings in the neighbourhood of electric currents, including the case of currents going in parallel and in opposite directions.

The theory is carried out a step further to explain the attraction and subsequent repulsion after contact of an electrified and a neutral substance and the passage of a spark. But it is extremely speculative, and is not as yet experimentally illustrated, and I think that at present it is better to pass it by.

I believe that the professor will exhibit his experiments and give some account of his mathematical investigations, which have occupied his time for five years, to the Académie des Sciences this afternoon. His results have not been published before. GEORGE FORBES

Paris, August 15

NOTES

JOHN DUNCAN, the Alford weaver-botanist, has at last passed away, and his dust now lies under the earth whose beautiful children he knew and loved so well. He expired a little after noon on the 9th instant, in his eighty-seventh year, and was buried on the 16th in the old churchyard at Alford, in a selected spot, where a monument will soon be raised to his memory by the free-will offerings of those who admired his high character and pure-minded enthusiasm for science. The poor old man has not lived long to enjoy the comforts lately provided for him, but it is pleasant to think that this aged and unselfish student of nature passed the last days of his long and silent life in comparative affluence, and that he now rests in no pauper's grave. His life was so recently sketched in these pages (NATURE, vol. xxiii. p. 269) that it is unnecessary here again to rehearse it. In December last, when it was ascertained that, after an unusually laborious life, winning his daily bread by weaving, carried on till beyond his eighty-fifth year, he had through failing strength been at last reluctantly forced to fall on the parish for bare support, an appeal was made in his favour by Mr. Jolly, H.M. Inspector of Schools, in the newspaper press throughout the country, and in our own columns. The response was speedy and ample, so that in a very short time a sum of 326*l.* was spontaneously sent for his relief, with every expression of admiration and regret from all parts of the land, and from most of our most eminent scientific men, whose kindly appreciation of his scientific labours was not unfrequently very aptly and memorably put. His pride and appreciation of all this kindness were genuine, deep, and child-like, and were expressed not seldom in piquant and touching terms; so that his numerous friends have the great satisfaction of thinking, that by their means, though he has departed sooner than was anticipated, they have helped to comfort the evening of his days. His constitution was of the healthiest type, and his tenacity of life remarkable in a frame so exhausted, and he only passed away when the last particle of the expiring taper was slowly consumed. As already told in NATURE (vol. xxiv. p. 6), the money raised in John Duncan's behoof has been vested in seven trustees, under a trust-deed executed during his life. By its provisions his valuable books on botany and other sciences are bequeathed to the parish library of Alford for the use of the district; and all remaining funds are to be safely invested and the interest to be devoted for all time to the foundation of certain prizes, to be called by his name, for the promotion of the study of natural science, especially botany, amongst the children in certain parishes in and round the Vale of Alford. A memoir of the old man is now being written by Mr. Jolly, and will be anticipated with interest.