What is the Ether?*

The History and Necessity of a Remarkable Conception

By Owen Ely

SINCE the time of Newton, physicists have seen the need of assuming an ether to explain "action at a distance," or the passage of electric and magnetic forces through empty space. Though these phenomena have been thoroughly studied through experimental research, comparatively little work has been done to deduce from the laws and facts at our disposal the real properties and conditions of the ether. The concepts of an ether have generally been so mystical and vague that scientists have shunned the task of correlating or confirming them. But more recently science has realized the importance of this realm of inquiry. Lorentz, Larmor, Thomson, Kelvin, Lodge, and others have sought some basis of experimentation and have attempted to build complete and consistent theories. Results are slowly accumulating, more definite hypotheses are being formulated, and perhaps a few more decades will give us a fairly complete knowledge of this substratum of nature.

The first important theory of the ether was developed by Green and others, in the early part of the nineteenth century. The ether was regarded as a kind of incompressible jelly, easily set a-quiver by the motions of the molecules and able to transmit this motion, through its vast bulk, to the ends of space. And yet, for any motions of matter other than the molecular, the ether was thought to act as a perfect fluid. This provision was necessary to limit the ether to transverse vibrations. Owing to the increasing demands which new discoveries in optics made upon the theory, it was abandoned.

One of the most prominent theories which have been brought forward, was that connected with Maxwell's electro-magnetic theory of light. The ether was assumed to be a turbulent fluid, the particles of which oscillate, revolve, or in some way change their condition, causing the rapidly alternating "polarizations" which Maxwell used, to explain his conception of the electro-magnetic wave. Sir William Thomson, in the *Philosophical Magazine* for June, 1853, gave the theoretical demonstration to prove that the reversing of an electric charge produces a "polarization," the same in kind as that which constitutes a light-wave. Later, Hertz actually proved the identity. But "polarization" is still little more than a name, and there is yet some discussion as to whether it involves any bodily displacement of the ether.

The ether having been regarded as a solid and a fluid, it remained to treat it as a gas. This was attempted by several, among them Mendeleef, the chemist. But the results did not seem very satisfactory. Evidently, the ether needed properties of each state of matter, solid, fluid and gaseous. Rigidity and elasticity of some sort were required, that light should travel in a straight path; the freedom of movement of a perfect fluid was necessary, since apparently there was no friction between matter and ether; and finally its inertness, its failure to affect matter of itself, pointed to a lack of cohesion or activity among its particles. For these reasons, apparently, modern physicists have generally ceased trying to picture ether in terms of matter, but rather are inclined to explain matter in terms of ether. Thus Prof. Osborne Reynolds, who has worked upon his theory for many years, regards the ether as a system of finely-packed grains of which it would take same 112.10^{11} to make up an inch, and whose mean free path is 4.10^{-11} of their diameter. These round, hard grains are piled up like billiard-balls through the universe, but here and there is a crack or separation, and this vacuum is matter! The encounters of the cracks make up the phenomena of the cosmos.

Larmor's concept seems somewhat similar, for he regards electrons as "nuclei of permanent ethereal strains in rapid motion." Kelvin and his school lay emphasis upon an explanation of the ether's perfect elasticity. Kelvin's famous theory of the ether makes its elasticity "due to rotational motion—intimate, fine-grained motion throughout the whole ethereal region—motion, not of the nature of locomotion, but circulation in closed curves, returning upon itself—vortex motion, of a kind far more finely grained than any waves of light or any atomic or even electronic structure. If the elasticity of any medium is to be explained kinetically, it follows, as a necessary consequence, that the speed of this internal motion must be comparable to the speed of wave propagation; that is to say, that the internal squirming circulation, to which every part of the ether is subject, must be carried on with a velocity of the same order of magnitude as the velocity of light."†

On this assumption, Sir Oliver Lodge calculates that the ether must possess 3.10^{14} kilowatt centuries per cubic millimeter, or "the energy of a million horsepower station working continuously for forty million years!" Kelvin's theory is based upon the principle of the gyroscope as applied to fluids, which thus imitate solids. Many experiments have been made to demonstrate the strange properties of liquids or flexible solids when in rapid motion. A silk cord moving swiftly over a pulley, has become rigid and viscous; and waves set up on the cord traveled with its velocity, thus standing still. This shows why "the speed of (the ether's) internal motion must be comparable to the speed of wave propagation." To show the elasticity of spinning bodies, Lord Kelvin made a spring balance out of gyrostats.* The "hardness" of fluids in motion is illustrated by a stream of water under strong pressure, which will resist blows from a sword.

Kelvin's gyroscopic theory, however, is useful only in providing a fluid ether with the elasticity of a solid. And does it not seem futile to evolve an ether from the properties of matter, when those properties in turn depend upon the ether? The action of the gyroscope involves the inertia of matter: yet Prof. J. J. Thomson and others are now inclined to explain inertia as an effect of the electromagnetic energy which a body carries about with it in the ether. But if inertia is not an "inherent" property of matter, but rather a phenomenon involving ether, why should it be used to endow the ether-particles? A second ether would be necessary to account for the inertia of the first. Indeed, it is so difficult to build up any hypothesis without the use of inertia and the laws of motion, that we may be compelled at last to resort to another ether. But since that is merely shifting the ultimate problem, we must do our best to gain a simpler theory.

Again, it is difficult to conceive how the particles, however "fine-grained" their gyroscopic motion, would avoid being in continual contact and collision, destroying the permanency of the system and producing a gaseous state. Motion in exact circles would be broken up and the gyroscopic principle no longer at work. At least it is difficult to explain how any kind of motion can be provided for the crowded particles of ether other than some irregular chaotic vibration like that of a gaseous molecule. The particle cannot be compared to the vibrating molecule in cohesive solids, nor to the revolving electron, for both must be held in their systematic orbits by forces acting through a medium. The difficulty of making the ether circulate about a fixed center, in order to make it gyroscopic and elastic, seems about as large as the original problem itself.

There are, perhaps, other ways of explaining the properties of rigidity and fluidity in the ether. If matter be regarded as merely a crack or strain in the ether, the latter need not be fluid, since there could be no such thing as "friction" between matter and ether. Then if the ether be thought of as quite densely packed, with particles in orderly rows, columns, and tiers, it might not be difficult to imagine how a single pulse of light emanating from a molecule should continue, like a missile having inertia, to follow the straight line upon which it was started. For light is made up of waves in several planes, which we may regard separately. Motion in one plane cannot pass into another, and if the tier of particles in which the wave started is not disturbed by passing matter, the wave would remain in one plane. But what prevents the wave from spreading about its plane, instead of holding a straight path? This, too, must be a result of the regular arrangement of the particles, so that the wave moves as a uniform interaction among the particles of several rows, confined to these rows alone, like a moving pendulum. Thus the simple pulse from a molecule in the Sun would reach our Earth practically unchanged. The size of an object, then, alters not because all the mingled pulses reach the eye diminished in size, but because the number of pulses entering the eye, undiminished, depends upon the square of the distance. Were the former the case, and if the light-wave spread out like a sound-wave as it emanated from a source, some change in the structure of wave would take place, and it would be difficult to explain the rectilinear propagation of light. The structure of the ether could scarcely be as perfect as pictured, but if the particles be of a very small order of size compared to the light-wave the result should be about the same. Only by this means, indeed, could we imagine the tubes, or parallel rows traversed by each wave, as stretching away from the source in

every direction. This description, crude as it is, may serve to show that the theory of the ether has not yet been exhaustively worked, while it points out some of the difficulties in an adequate explanation of the actual transverse wave in ether.

Having reviewed some of the general theories of the ether, it will be interesting to look into the methods which have been used to gain facts and figures in regard to the ether, and to see what tangible results have been reached.

A modern school of physicists have derived a value for the elasticity of the ether from the formula

$$V = \sqrt{\frac{K}{D}} \text{ or } K = V^2 D. \text{ The density of the ether has}$$

been calculated on the assumption that the electron is a differential portion of ether but of equal density. The linear dimension of the electron is about 10^{-12} or 10^{-13} millimeters, and if its mass is not an effect of its magnetic field, the various estimates based upon different experiments all yield the same result, about 10^{12} c.g.s. units. V^2 we know to be 9.10^{20} , so that $K = 10^{32}$, the figure generally agreed upon by some of the greatest scientists. The estimate is of little value, however, except as it may direct further inquiry. The structure of the electron must be investigated before its density can safely be used to indicate that of the ether.

Deductions have been made as to the structure of the ether from the computed velocities of the various wave-lengths of light in space. But they are of questionable value, for at present it is still a moot question whether or not the various waves have exactly the same velocity. However, it is an important line of research and will certainly yield us some knowledge of the ether. We are too accustomed to treat light as a whole, not as to particular wave-lengths. Lord Rayleigh has said: "We have no means of identifying a particular wave so as to determine its rate of progress. What we really do in most cases is to impress some peculiarity, it may be of intensity, or of polarization, upon a part of an otherwise continuous train of waves, and determine the velocity at which the peculiarity travels." Rayleigh used the formula

$$U = \frac{d(kV)}{dk} \text{ to express the possibility that } V, \text{ the}$$

velocity of a particular wave-length, may differ from U , the group velocity. Now the work of Nordmann on Algol has tended to show that red rays (about 0.68μ) were sixteen minutes ahead of the blue (about 0.43μ). Pritchard's estimate of Algol's parallax is 0.0556 second, or about 61 light-years. Dr. C. V. Burton, using these data and Rayleigh's formula (L. E. D. *Philosophical Magazine*, December, 1909) has set up equations representing the conditions of periodic motion in the ether, in order to show that the velocity of propagation is a function of the wave-length and that no absorption need occur in the ether. The laws of dispersion are applied to strings and by combination of these to three-dimensional space. The nature of the formulæ developed by him leads to the conclusion that "The system (of ether-particles) has a structure on a scale not infinitely minute compared with the wave-length. Though we may conceive the electro-magnetic vibration of the ether to be executed in a manner widely different from anything occurring in these simple mechanical models, we may yet attempt to form some idea of the coarseness of structure of the ether which could suffice to account for such dispersions as Nordmann and Tikhoff have thought to be indicated by their observations." The formula deduced by Dr. Burton from Rayleigh's equation is $U = V \infty (1 - \pi^2 b^2) 2\lambda^2$. When this is applied to the figures given by Nordmann and Tikhoff above, the result is only $1.7.10^{-3}$ centimeters and $3.1.10^{-3}$ centimeters, respectively, for b , "a linear magnitude which expresses the coarseness of structure of the ether." But the electron is said to be only 10^{-13} centimeters in diameter; and since the ether-particle should be of a lower order of size than the electron, this indicates that the observations are unreliable or the formulæ wrong. The fact that the two observations disagree in the ratio of nearly one to thirty has furnished an argument against the reality of dispersion. But if dispersion is proved to exist it must be attributed to the structure of the ether, since Lebedow has shown that it cannot be accounted for by the presence of any known substance in space (for example, hydrogen at low pressure), which would absorb light enough to make Sun and stars invisible.

In 1874 Clerk-Maxwell calculated the pressure of light to be about 1/23,000 of a dyne per square centi-

* Popular Astronomy.

† Lodge, *The Ether of Space* (1900), pp. 102-03.

* Address to Section A of British Association at Montreal, 1884.

meter for full sunlight; and a quarter of a century later Lebedow, Nicols, and Hull verified the theory, the two latter reaching a figure within one per cent of Maxwell's estimate. Lately Prof. Poynting has measured the backward thrust of the light-wave as it leaves its source. When we have worked out a definite picture of the electro-magnetic wave, this primary fact should be very useful in explaining its genesis and the relation of the electron to the ether surrounding it.

It has been assumed, during the above discussion, that no friction exists between matter and ether; but the question was by no means settled until recent years. Many experiments were tried during the past half century, but none were conclusive until Michelson made his famous experiment in 1887. This seemed at first to show that the ether is stagnant about the Earth, or that it does not rush by us and through us at the rate of the Earth's motion. Two half beams of light, one sent to and fro along the line of the ether drift, east and west, and the other across the line of drift, were reunited and should have shown a displacement in the bands of the spectrum of one part in a hundred million—the square of the ratio of the speed of the Earth to that of light. A change of one part in 4,000 millions could have been detected in the apparatus, but no change was seen. The explanation was first suggested by Prof. G. F. Fitzgerald, of Trinity

College, Dublin, and was later developed by Prof. H. A. Lorentz of Leiden. The cohesion of the materials in the apparatus by which the measurements were made, was probably due to electric charges in the atoms. The cohesion was then less great across the line of the Earth's motion than along it, for the reason that the charges become currents on account of the Earth's motion, and the attraction between the parallel currents is less than in the currents which follow each other in the same line of motion. Therefore, although the light-wave probably increased in velocity across the line of the Earth's motion, the stone slab across which it traveled increased in length proportionately.

An interesting and original experiment was undertaken by Sir Oliver Lodge to settle the question in a different way. Two large steel disks an inch apart were rotated at enormous speed while a beam of light was divided by a semi-transparent mirror and the two halves were sent in opposite directions around and between the disks until they met in a telescope. After eliminating the sources of error, it was found that the images were exactly coincident and that hence no ether had been caught up in the motion of the steel disks.

Perhaps nothing has contributed so much to the possible development of a theory of the ether as the electron theory, which has done so much to reduce

phenomena to the inter-play of the electro-static, magnetic, and inductive forces of charged atoms. These forces, together with matter, which may be simply their source in the ether, and gravitation, which is probably an electro-static effect, constitute the whole problem of the ether. The ultimate task is to explain them as the varieties of motion in the fundamental stuff.

To sum up, it is apparent that the problem of the ether, the greatest enigma of all time, cannot be solved by one group or generation or class of scientists. It claims the work of specialists in many fields. While each may see the task from his viewpoint alone, it is worthy of attack from many standpoints. To analyze and classify a nearly infinite variety of phenomena to reach the root-causes of nature, requires the genius of the investigator. To arrange the data in the most logical relationships requires the work of the theorists. To condense and reduce these relations to the simplest and most elegant form the brain of the mathematician is necessary. To appreciate the ultimate significance of those factors which the others use but as the material of their building, the philosopher is final critic. And to make the results of all the others of interest and value to the human race as a whole, the interpreter must picture them in simplest phrase and most apt illustration.

Do Fishes Hear?

A Summary of Recent Studies

By Dr. Wilhelm Roth

ALTHOUGH Saint Anthony of Padua preached to the fishes, this is no proof that the fishes heard him, for the holy man preached to many "deaf ears." Another ecclesiastical tradition, which has often been cited in evidence of the auditory power of fishes, has likewise failed to stand the test of critical investigation.

The famous old Benedictine cloister of Krems, in Austria, possesses a monumental fish pond, surrounded by stone balustrades and arcades, whose finny denizens have, from time immemorial, been summoned to their meals by acoustic signals—in the old days by beating a drum and in modern times by ringing a hand bell.

Dr. Alois Kreidl, who had previously expressed the opinion that, if the fishes really come in response to the ringing of a bell, they do so because they feel the vibration, not because they hear it, recently visited the monastery in company with Prof. Exner, the well-known Viennese physiologist. The investigators easily proved that the fishes did not hear the sound of the bell, but came to the feeding place only when they saw the attendant ring the bell and throw out the food, or when they felt the vibration communicated to the water by the man's footsteps on the stone run of the pond. When the two observers approached the feeding place in such a manner that the fishes could not see them, hid behind a column and there rang the bell, the fishes did not take the slightest notice of the sound, but when they came to the feeding place in the customary manner of the attendant, without ringing the bell, the fishes quickly swam to the spot. They dispersed immediately on finding that no food was forthcoming, and could not be recalled by ringing the bell.

A similar explanation can be given of many other

instances in which fishes are apparently attracted by the sound of the human voice, of bells attached to fishing nets, of drums, and of the clappers which the Japanese employ, in conjunction with torches, in fishing with cormorants. Kreidl and Exner found it impossible to elicit from goldfish any response to whistling, the peal of a large bell, and various other sounds generated in the air, or even to tones produced by drawing a violin bow over metals bars under water. Another experimenter obtained the same negative result with the ear-splitting noise of the toy known as a "cricket."

Even when the reflex irritability of the fishes was greatly increased by dosing them with strychnine, they responded only to sudden and violent sounds, like that of a pistol shot, which caused them to flee in terror. As Langes and Vulpien have found that a pigeon which has been deprived of its brain, and therefore of its sense of hearing, responds to a pistol shot, it appears probable that violent, explosive noises affect the nerves of touch or feeling by means of the concussion of the air, which is transmitted to fishes through the water.

In order to prove decisively whether the reaction, in the case of fishes, is accomplished by any true auditory sensation, or is caused entirely by mechanical stimulation of the tactile nerves, Kreidl experimented with fishes from which the labyrinths of both ears had been removed. These fishes reacted to very loud sounds in precisely the same manner as unaltered fishes, when both had been dosed with strychnine.

Hence there can be little doubt that in fishes the surface of the body has assumed the auditory function, and that a perception of vibrations by the tactile nerves takes the place of a true sense of hearing. It is natural to assume that in fishes the organs of the

so-called "lateral line," which are sensitive to the slightest change in pressure, correspond to the cochlea of higher vertebrates with its Corti's fibers, which parts are entirely absent from the ears of fishes.

We are not justified, however, in assuming that the ears of fishes play no part in the perception of vibrations produced by sound waves, for the otoliths of the labyrinth may serve in fishes, as they do in many other aquatic animals, for the perception of vibration, and may thus assist the organs of the lateral line of the body. It is probable, indeed, that the labyrinth of the ear is only a highly developed and specialized "lateral" organ, and, according to Bonnier, the perception of mechanical vibration is simply the initial stage of the sense of hearing. The difference between the two functions is that in the former the vibrations of pressure are perceived separately, while in the latter they are fused into a single tone, as the mosaic image formed on the retina is seen as a single picture.

Although the fishes that have been studied appear to possess no true sense of hearing, it is not impossible that the ears of some fishes have acquired some slight development. There are many fishes—about 80 species—which produce sounds. In the pairing season some fishes fill the water with noise, which can be heard plainly by an ear pressed to the ship's side. Whether these sounds are produced voluntarily (perhaps to attract the opposite sex) or not, is wholly unknown, but even if some of these musical fishes are found to be sensitive to sounds of moderate intensity, it will still remain probable that they perceive these sounds by a sense of vibration akin to the sense of touch, and do not really hear them.—Translated for the SCIENTIFIC AMERICAN SUPPLEMENT from Umschau.

The Transformation of Sea Water Into Fresh Water

THE belief was prevalent among the savants of the 17th and 18th centuries that a hermetically sealed earthen vessel dipped into the sea would fill itself with fresh water. At the present day it is difficult to say on what this belief was grounded. It surely could not have been evoked by experiment. In a similar sense Marsigli, the founder of oceanology, made in the year 1725 an experiment which effected the filtration of sea-water through a system of fifteen pots filled with washed garden-earth or sand and so placed as to let the water fall as if in a cascade. It is stated that the palate disclosed a definite diminution of the presence of salt. Similar assertions are everywhere current among seamen.

A scientific test of the endeavor to free salt from water was recently made by the French investigator Thoulet. His report which appears in the minutes of the Académie des Sciences of Paris states that the presence of salt can be reduced by filtration. Forty centimeters of the length of a glass tube, which was one meter long and was placed in a perpendicular position, was filled with sea-sand, and the rest of the tube was filled with sea-water; portions of the filtrate were examined at intervals of the experiment to ascertain its

density and chemical composition. The result was that in the initial stage of the experiment density as well as saline content were found to be moderately reduced; very soon thereafter both recovered their original value. The early decrease of value is explained by the mechanical attraction which every chemically neutral body exercises on the molecules of a substance in solution as soon as the body comes in contact with the solution. In nature, too, sand fails to effect the separation of salt. Through shipwrecked seamen it became known that relatively fresh water may be found on very low and barren coral reefs in the Pacific Ocean by digging to a trifling depth in the coral sand. It is not, however, as was supposed, sea-water freed from salt through the layers of sand, but is simply rain water that is retained by a sandy stratum and by it protected from admixture with the sea-water. Similar phenomena may be observed on the European coasts. They may be considered the key to the popular belief, now contradicted, that sea water can be sweetened by filtration through sand.

Mr. W. Rosenhain, a well-known English metallurgist, in a report of the Advisory Committee for Aeronautics, reviews the results of researches on the alloys of aluminium containing small quantities of

other metals so as to leave the density of the alloy very nearly as low as that of the pure metal and yet obtain the increased strength and hardness given to the alloy by such additions. A certain number of these alloys are already in industrial use, namely, those containing Cu, Ni, Zn, and Mg. The mechanical tests of the Cu-Al alloys containing 2.77 and 3.76 per cent of Cu are given, and also the tests of two Cu-Mn-Al alloys containing respectively 2 per cent of Cu and 2 per cent of Mn and 3 per cent of Cu with 1 per cent Mn. The elastic moduli of these latter alloys have been determined and are compared with wood. The elastic modulus of wood is of the order of one-sixth of these alloys. Some tests are given of Al-Ni alloys which appear very promising, but these are said by Guillet to easily corrode. Some details are also given of the Al-Zn alloys. One of the most interesting of the Al alloys is known as wolframium or wolframinium, which contains small quantities of Cu, Sn, Sb, and W. The alloys known as magnalium contain from 3 to 10 per cent Mg, and it is claimed that they are 2 to 2½ times as strong as pure Al. It is pointed out that there is a large field for possible improvement in the range of light alloys to be obtained by the addition of small proportions of heavier elements to Al.