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THE ETHER CONCEPT IN MODERN PHYSICS[1]

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I HAVE felt it would be safe to assume that the ether concept is a subject of interest to the workers in all scientific fields. As a matter of fact, it must be a matter of concern to all thinking people, since it has to do with some of the greatest of those forces of nature upon which depend the comfort, the happiness and, indeed, the very existence of the human race.

It is not here implied that a knowledge of this or, for that matter, of any physical theory is essential to man's existence; but it will be conceded, I think, that knowledge of this sort may contribute greatly to his comfort and happiness.

To have one's interest in this question aroused it would perhaps be sufficient to be reminded that the ether theory attempts among other things to explain the machinery by means of which heat and light are transmitted through regions devoid of ordinary matter —the radiant energy, for example, which comes to us from the sun across more than ninety millions of miles of empty space. It is, of course, this unbroken stream of energy which pouring upon the surface of the earth makes possible here all the varied forms of life, and the study of life, together with its conditions and environments, is directly or indirectly the ultimate objective of all branches of physical and biological science.

The first use of the ether concept is shrouded in the haze of the fragmentary records of antiquity. In more recent times, for which the records are more complete, it has had a strange and checkered history and for centuries in scientific discussions it has been a subject of bitter controversy.

The theory that space is filled by an all-pervading medium having properties unlike those of ordinary matter was for a time quite generally accepted. Later on, it was rejected and all but forgotten. It was afterwards revived and strengthened and brought

[1] Address of the president, forty-fourth annual meeting of the Iowa Academy of Science, Ames, Iowa, May 2, 1930.

to a high place in scientific thought—only once more to fall into serious question. At the present time it struggles for existence but it shows signs of surviving and gives promise of continuing for a long time to come. It is doubtful if man in his thinking can ever dispense with it altogether.

To be sure, there are scientists of to-day, as there always were in the generations past, who profess to have no need for the ether hypothesis; but curiously enough there is usually collateral evidence that these same philosophers make use of it in their thinking, however studiously they may avoid any reference to it in their speech.

The widely accepted pronouncement that "truth crushed to earth will rise again" carries with it, as a sort of corollary, the implication that in man's search for truth a recurring theory must have in it the elements, at least, of conformity to fact. The very circumstance of its return, after temporary overthrow, to a high place in scientific thought argues for some sort of relationship to truth.

The astounding history of the ether concept—of its rise and fall, its resurrection and its continuing power—is probably without parallel in the records of the scientific world.

I invite you to a brief consideration of the ether concept, directing your attention particularly to its rise and development, to some of its shortcomings and to its more important implications.

The writings of St. Thomas Aquinas, whom we may regard as the spokesman of the religio-scientific thinkers of the thirteenth century, indicate a general acceptance at that time of the Ptolemaic system of astronomy. This system was founded upon the assumption that as "man was the object of creation, so the earth was the center of the universe, and around it revolved concentric spheres of air, aether, and fire—'the flaming walls of the world'—which carried round the sun, stars and planets."[2]

This early history is mentioned partly in preparation for that which follows and partly to show that an ether concept was in use at this period. It should be noted, however, that this "aether" is not an all-pervading medium. It composes one of the concentric spheres and is, therefore, in form a spherical shell.

Two hundred years later, after the work of Copernicus and Galileo had overthrown the geocentric theory of the universe, and the hypothesis of the crystalline spheres as the carriers of celestial bodies had been abandoned, it became necessary to find a way to account for the motion of the planets.

The first conspicuous attempt to do this was made in the middle of the seventeenth century by Descartes in his celebrated vortex theory. This theory assumes that interplanetary spaces are occupied by a plenum which is filled with great vortices. In these plenum vortices the planets and their satellites are carried. The sun is at the center of an immense vortex which carries the planets, and each planet the center of another vortex accounting for the motion of the planet's satellites. Thus the plenum is formed into vortices of varying size and velocity, and it is assumed that a celestial body in any such vortex, being slower and less subject to centrifugal action, is forced toward the vortex center.

Descartes' theory is not considered comparable in importance with those of Ptolemy or Copernicus, largely perhaps because it apparently led to no new discoveries; but it was rated of considerable importance in philosophy because it constituted an attempt at a mechanical explanation of the universe. It is interesting to note that it survived for a century or more in advanced scientific thought and teaching, not alone in France, but in England and America as well. It is recorded that an English translation of Descartes' treatise was in use as a text-book in Yale College as late as 1743—long after the publication of Newton's work which pointed out the inconsistencies of the vortex theory.

As we have seen, the first important use of the ether concept was in an attempt to account for planetary motion and to explain the structure of the universe. It was next employed by Hooke and Huygens toward the end of the seventeenth century (1678) to explain the transmission of light. Descartes too, as a matter of fact, had held that light is a pressure transmitted through his plenum of space.

Thus we see that again the assumption is made that there is a non-material medium which fills all space, the medium this time being particularly characterized by the property that luminous bodies have the power to set up wave motion within it. This is the luminiferous ether, and under this ether theory light is a wave phenomenon.

Newton professed to be unable to accept the theory of the luminiferous ether on this basis, chiefly because he believed it failed to explain in a satisfactory way the fact that light travels in straight lines. He taught that straight line motion is natural to moving *bodies,* and it is easy to understand the appeal of the corpuscular theory to him on this score. He says in Query 29 of his "Opticks," "Are not the Rays of Light very small Bodies emitted from shining substances? For such Bodies will pass through uniform mediums in right Lines without bending into the Shadow which is the nature of the Rays of Light."

The seventeenth century witnessed a conflict between these two theories of light. "Newton from facts then known balanced the arguments for and against each

[2] Dampier-Whetham, "A History of Science," p. 96.

theory, and hesitatingly decided in favor of the emission theory, while on the continent his great contemporary Huygens advocated the wave theory."

Concerning this conflict S. P. Langley said:

> These two great men, then, each looked around in the darkness as far as his light carried him. All beyond that was chance to each; and fate willed that Newton, whose light shone farther than his rival's, found it extended just far enough to show the entrance to the wrong way. He reaches the conclusion that we all know; one not only wrong in regard to light but which bears pernicious results on the whole theory of heat, since light, being conceded to be material, radiant heat, if affiliated to light, must be regarded as material too; and Newton's influence is so permanent, that we shall see this strange conclusion drawn by the contemporaries of Herschel from his experiments made a hundred years later. It would seem then that the result of this unhappy corpuscular theory was more far-reaching than we commonly suppose.[3]

This comment of Langley's was written about forty years ago, at a time when the wave theory was quite universally accepted. Now it is thought by many that Newton in adopting the corpuscular theory of light denied the existence of the ether. But this is far from the truth, as his own writings unmistakably show. To illustrate, in offering an explanation under the corpuscular theory of the fact that a transparent body, a sheet of glass for example, can at the same time reflect and refract, he considers that the corpuscles are subject to "fits of easy reflection and easy transmission" communicated to these particles by undulations in an all-pervading ether. The ether at the surface of the body, agitated by the flying particles, is alternately compressed and rarefied, and a particle at the surface in a compression is thrown back, whereas in a rarefaction it passes through. Other references, particularly in the "Queries," are equally illuminating. The significant fact just here is that even Newton, the most distinguished opponent of the wave theory of light, found it necessary in his thinking to employ the ether concept.

It came about then, that notwithstanding the very able defense of the undulatory theory by Hooke, Huygens and others, and largely because of Newton's overpowering authority, the corpuscular hypothesis rose in power and for a long time remained in the ascendancy. Cajori states that "the only prominent writers of the eighteenth century who advocated the undulatory theory were Leonard Euler and Benjamin Franklin."[4]

At the beginning of the nineteenth century (1801), Thomas Young after a study of the colors of thin plates, the familiar soap-bubble colors, declared himself in favor of the wave theory for the following reasons. These colors are explained under other theories only with greatest difficulty and by the aid of most gratuitous assumptions, whereas "the minutest particulars of these phenomena are not only perfectly consistent with the [wave] theory . . . but . . . they are all the necessary consequences of that theory, without any auxiliary suppositions."[5]

Some years later (1815) Fresnel became strongly convinced of the truth of the wave theory, and deeply impressed by its power to explain transmission, he succeeded in accounting for rectilinear propagation on the wave theory basis, and also explained more fully two other troublesome matters, namely, diffraction and interference. As a result of the work of Young and Fresnel, there once more arose a bitter contest between the advocates of the opposing theories of light.

Just at the middle of the century (1850) came the experiments of Fizeau and Foucault and their so-called laboratory methods for measuring the velocity of light. These methods made it possible to put to the test the old controversy as to whether light travels faster or slower in a denser medium. The corpuscular theory demanded a faster, the wave theory a slower speed in the denser medium. The test was now made and showed that the velocity of light in water was only about three fourths that in air. This was strong evidence for the wave theory.

Foucault's experiment was by many regarded as a crucial test, and as a result the ether wave theory came into greater prominence and was, in fact, quite generally accepted.

In the meantime (about 1835) Faraday's researches, in a field apparently unrelated to light, had pointed to a need for a medium to explain electrostatic and magnetic effects. And a few years later (1863) in the process of developing a mathematical statement of Faraday's results Maxwell reached the conclusion that in such a medium as Faraday postulated it ought to be possible to establish electromagnetic waves. Furthermore, as soon as a numerical relationship could be established experimentally between electrostatic and magnetic units of measurement, the velocity of such waves was calculated and proved to be the same as that of light. This was an astounding discovery which excited the interest and admiration of the world.

Now it can easily be seen that if a luminiferous ether was necessary to account for the transmission of light, and an electromagnetic ether was needed in electrical theory, and if, furthermore, the velocity of

[3] F. Cajori, "A History of Physics," revised, p. 109.
[4] *Loc. cit.*, p. 110.
[5] "Classics of Science," *Science News Letter*, November 2, 1929, p. 273.

propagation of a disturbance proved to be the same in each the question would naturally arise whether the same medium might not answer both requirements. Maxwell concluded that light is an electromagnetic phenomenon and that light waves are in fact electromagnetic waves like those he had been studying, differing only in wave-length. This formulation of Maxwell's electromagnetic theory of light was regarded as one of the most brilliant generalizations in the history of science.

The production of long electromagnetic waves such as were first contemplated by Maxwell offered no appreciable difficulty, since suitable apparatus was available in almost any physics laboratory. But a detector or receiver for such waves by means of which their existence could be proved or demonstrated was a different matter. No one knew how to construct such a device, and as a consequence, verification of Maxwell's theory by experiment was for a time delayed.

Some years later (1888) Hertz succeeded in devising a receiver. As soon as he had done this he proceeded to a detailed study of the electromagnetic waves produced by his laboratory apparatus and verified the predictions of Maxwell's theory, showing that these waves were similar to light waves in many of their properties and were propagated with the same speed.

Supported by the results of Hertz's experiments, Maxwell's theory became firmly entrenched and the position of the ether concept, now greatly strengthened, seemed well-nigh impregnable.

Our discussion has now brought us near but not quite to the close of the nineteenth century. In those few remaining years discoveries were to be made which would have far-reaching effects on all branches of science. In 1895 Roentgen discovered the X-rays, and shortly thereafter came the announcement of radioactivity and the identification of the electron as one of the building-stones common to the atomic structures of all the elements.

These discoveries aroused the interest of the entire world and greatly stimulated scientific research in many fields. Their importance, so far as concerns our discussion, lies in the fact that they directed the attention of the scientific world to a closer study of the general subject of radiation.

The ether theory gave scant information as to the mechanism of the radiation process. It was a theory of transmission. It gave a good account of how the energy of light and radiant heat is carried through empty spaces and accounted for many of the phenomena characterizing transmission, but it did not explain the mechanism by means of which such energy is started on its way, and its explanation of the effects which accompany the absorption of this wave energy was hazy and at times wholly inadequate.

It now developed that certain phenomena of radiation and absorption could be explained on a satisfactory basis only on the assumption that radiation is a discontinuous process, that radiant energy is broken up into parts or parcels. And lo! there arose before the scientific world the specter of the corpuscular theory, the body of which had long since been laid away.

This time (1901) the theory was given the name of the quantum hypothesis, and it treated not of corpuscles but of quanta. It was a new theory, to be sure, but one which as it developed was to show a most striking resemblance to the corpuscular theory of a time more than two centuries past.

Now the X-rays were later found to be identical in character with light waves except as to wave-length. So also for the gamma rays, one of the radiations from radioactive bodies. These new forms of radiation fitted nicely into the ether wave series occupying regions in the wave scale hitherto vacant and unexplored. So also the new theory of atomic structures which gave a picture of the atom as consisting principally of wide open spaces really strengthened the ether theory by removing one of its great obstacles. It had been objected that the interpenetration of ether and matter was difficult to conceive, and so under the old theory of solid, closely packed atoms it was; but under the new theory of an open atomic structure this difficulty largely disappeared. These new discoveries, then, did but little if anything to impede the triumphant progress of the ether wave theory.

But the quantum theory, giving a more plausible explanation of radiation and absorption, constituted a real menace. I shall leave this consideration for the present, however, as we must now turn our attention to a different phase of the general question.

It was pointed out long ago that if this ether medium actually exists there ought to be an ether drift past the earth caused by the motion of the earth along its orbit. The effect here contemplated is analogous to the air drift one feels when traveling rapidly, in an open car for instance, through still air. Now if the earth moves through the ether without disturbing it there must be an ether drift, and light should be found to travel faster when moving with the ether than when it moves against, or across, the ether stream.

A little more than forty years ago (1887) an attempt was made by Michelson and Morley to detect or measure this effect. Elaborate preparations were made for this experiment and it was carried out with the greatest possible care. The experiment gave negative results and this was generally accepted as proving the absence of an ether drift. "The earth seemed to drag the ether with it."

Now it must be allowed that the negative result of the Michelson-Morley experiment is to be interpreted in one of three ways. The first of these possible interpretations is that there is no ether. The second is that there is an ether but no drift because the ether is dragged along with the earth. The third interpretation is that there is an ether and also an ether drift, but for some reason the drift was not detected in the experiment.

It is significant as showing the firm hold which the ether theory had on the minds of men that few, if any, accepted the results of this experiment as proving the non-existence of the ether and practically all explanations offered were based upon the second or third interpretation.

Sir Oliver Lodge attempted to demonstrate an ether drag between two massive steel plates revolving at enormous speeds, but was unsuccessful. Had this experiment succeeded, an explanation might have been possible under the second interpretation.

FitzGerald and others directed attention to the third interpretation and suggested inherent defects in the method, the apparatus or perhaps in both. A suggestion offered by FitzGerald was of far-reaching importance. He pointed out that if, as modern theory would indicate, matter is electrical in its nature, it may contract in the direction of motion as it moves through the electromagnetic ether. Such contraction, he explained, would under ordinary circumstances quite escape attention since any scale used to measure it would also be subject to the same effect, so that, in the direction of motion, the unit of length would be shortened.

Thus the various parts of the Michelson-Morley apparatus, although not showing it in any other way, might change in length, as they were placed alternately parallel and perpendicular to the direction of motion, to such an extent as to compensate for the effect it was expected the test might show. This suggested explanation, known as the FitzGerald contraction, was at first not altogether well received, no doubt largely because of its very novelty.

The justly famous Michelson-Morley experiment, it would seem, has thus far yielded results of doubtful significance. It has been repeated a number of times by Morley and Miller and by Miller and others in different localities, at different altitudes, with more elaborate equipment and under better conditions as to temperature control, always with results more or less open to question. However, it should here be recorded that Miller, in his report to the National Academy of Science last year, stated that he believes he has measured an ether drift, although he is not yet ready to pronounce it an established fact.

Just after the opening of the present century (1905) the scientific world was set to thinking about these and related matters in a new way. This was occasioned by the announcement of Einstein's special theory of relativity. This theory teaches that when such changes as the FitzGerald contraction take place in our standards we must, in the very nature of things, be totally unaware of them, since we move with them and suffer like changes ourselves, but they might be measurable to an observer having different motion. It follows logically that time and space are therefore not absolute concepts but are relative only, in any given case, to the observer.

Under this theory the negative results of the Michelson-Morley experiment are exactly what one would expect. Indeed, one of the two great postulates upon which this theory is founded states that the velocity of light is always the same whatever the apparatus used in its determination, whatever the circumstances under which the measurement is made.

It is sometimes asserted that Einstein's theory is founded upon the negative results of the Michelson-Morley experiment and that it denies the existence of the ether. These statements are only partially true and perhaps should not be regarded as serious objections to the relativity theory. It seems probable that if, perchance, the ether drift is at last demonstrated to be a fact, this or an equivalent theory will be reconstructed on a similar, or possibly quite different, basis, for the results which have come from the theory of relativity seem of themselves a sufficient justification of the theory.

As regards the other assertion, it may be pointed out that Einstein concedes that the ether concept can not at present be dispensed with even in this strange world which he has builded on the foundation of relativity.

Our attention turns now to a consideration of some of the more recent developments in the new physics. The quarter of a century which has elapsed since the advent of Einstein's special theory will long be celebrated in the story of scientific progress for the revolutionary changes which it has witnessed in the theories and methods of physical science. It is probably not too much to say that never in the history of man's intellectual advance has there been a similar period so filled with changing theory! These new theories have to do largely with the structure of matter and the nature of radiation, and to them all the subject of the ether concept is related in an important way.

It might easily be imagined that as the quantum theory advanced step by step, becoming apparently ever more firmly established, the ether wave theory must have become of lesser and lesser importance. But evidently such has not proved to be the case.

The quantum theory grew in power as it helped to solve the problems of emission and absorption, but it was unsatisfactory in explaining the phenomena of transmission. On the other hand, the wave theory gave a good account of transmission, and as a consequence being firmly entrenched in this field, was able in a large measure to withstand the onslaughts of the quantum hypothesis.

It will not be out of place to mention here one or two points of advantage possessed by the wave theory. The quantum theory does not give a satisfactory answer to the question: Why do all quanta, large and small, travel through empty space with the same velocity? It is understood that quanta vary greatly in size. The constant of this theory is a factor, h, which multiplied by the associated frequency in a given case gives the quantum energy. Hence the quantum of high frequency radiation is relatively large, while that of low frequency radiation is small.

It does seem strange that two radiators, the one hot and the other cold, throwing off, therefore, quanta of different size, should shoot them out into space with exactly equal velocities. Now there is nothing strange about equal velocities of waves in the ether. Ether wave velocities depend upon the ratio of what we may call the elasticity and mass properties, actually the electric and magnetic properties, of the ether, and upon these alone. Such velocities are therefore always the same regardless of wave-length. We have a somewhat analogous case in the passage of sound waves through the air. Under ordinary conditions, at least, long and short sound waves travel with the same speed.

In other cases the advantages of the wave theory are not so apparent. For example, the quantum theory gives no answer to the question: How large is a quantum? The wave theory, of course, is not called upon to answer this specific question, but is required to answer a closely related one which is almost equally difficult, as we shall see.

An examination of the star image formed by a one-hundred-inch reflecting telescope indicates that the quantum must reach all parts of the mirror. This means that a quantum must be large enough to cover a mirror more than eight feet in diameter. But if light from this same star falls directly upon a potassium film it will eject electrons. This means a quantum must be small enough to enter an atom. It is very difficult to reconcile these results.

Now if we try to explain such effects from the standpoint of the wave theory we also get into trouble. There is, of course, no difficulty in covering a one-hundred-inch mirror with an ether wave front but when we come to the effect upon the potassium film the matter is not so simple. Each electron thrown off from the film escapes with a definite speed and carries away a definite energy, the amount of which has been shown to depend upon the incident light alone. It varies with the wave-length of the incident light but is independent of its intensity. It is the same for feeble light as for strong.

This curious but apparently well-established fact that light of low intensity ejects electrons from the potassium film with the same velocity as that produced by light of the same quality but much higher intensity is called the "photoelectric paradox." The electrons ejected under high intensity radiation are more numerous but they travel with no greater speed.

To illustrate, when light from the star Sirius, fifty billion miles away, falls upon the potassium film, the electrons are actually ejected with greater speed or energy than they are when stimulated by exposure to the light from the sun. This effect does seem altogether paradoxical, since the sun's light is enormously more intense and, as already stated, the energy of the ejected electrons comes from the stimulating radiation. But the energy of the electron emitted does not depend upon the intensity of this radiation. It is determined by the frequency alone. Now Sirius is a bluer, that is, a hotter, star than the sun. Thus it comes about that notwithstanding its low intensity the light from the star, because of its higher frequency, can throw out electrons from potassium at the higher speed.

But how are these effects to be explained on the basis of the wave theory? Consider the spread, the extreme attenuation of the energy of this spherical wave front having a radius of fifty billion miles. How can it carry still, in a microscopic portion of its wave front, the energy requisite to this atomic explosion?

There are then certain phenomena well accounted for by the quantum hypothesis, others which are more readily explained by the wave theory and certain others which are not very well described by either.

This state of affairs has enabled the wave theory, in spite of its shortcomings, largely to hold its own in the face of the rising popularity of the quantum hypothesis. And so it has come about that with the passing years both these rival theories have continued in use.

In his fascinating book, "The Nature of the Physical World," published about a year ago, Eddington reminds us that "for at least fifteen years we have used classical laws and quantum laws alongside one another notwithstanding the irreconcilability of their conceptions."[6] And farther on by way of illustration he says:

> In my observatory there is a telescope which condenses the light of a star on a film of sodium in a photoelectric cell. I rely on the classical theory to conduct the light through the lens and focus it in the cell; then I switch on to the quantum theory to make the light fetch out electrons from the sodium film to be collected in an electrometer. If I happen to transpose the two theories, the quantum theory convinces me that the light will never get concentrated in the cell and the classical theory shows that it is powerless to extract the electrons if it does get in. I have no logical reason for not using the theories this way round; only experience teaches me that I must not.

He goes on to quote the famous saying of Sir William Bragg that "we use the classical theory on Mondays, Wednesdays and Fridays, and the quantum theory on Tuesdays, Thursdays and Saturdays," and then remarks, "Perhaps that ought to make us feel a little sympathetic towards the man whose philosophy of the universe takes one form on week-days and another form on Sunday."

It is the conviction of many, if not all, physicists that a rearrangement of our ideas of the physical world will come which will reconcile these two great theories. Some apparently believe it will come through a further development of the classical theory; others that it will come from the other side.

We turn now to a consideration of the ether concept in relation to the modern theories of atomic structure.

The atom, according to Bohr's theory, consists of a central nucleus of large mass and positive charge about which minute negative electrons revolve like satellites in a miniature solar system. These electrons are restricted to certain special orbits and the atom can neither radiate nor absorb energy while the electrons continue their orbital motions unchanged. According to Bohr, radiation or absorption is possible only when electrons jump from one orbit or "energy level" to another. The assumptions upon which this theoretical structure is based are founded upon a strange mixture of the classical theory, the quantum hypothesis and the general theory of relativity.

This picture of the atom was for a time remarkably successful, particularly in explaining such facts as the curious grouping of lines in the spectra of the elements. However, there are certain other matters, such as line intensities and particular line groupings, which it explained in a way not altogether satisfactory, if at all. It was recognized some time ago that this theory would have to be modified if not altogether replaced by a new theory of atomic structure.

[6] A. S. Eddington, "The Nature of the Physical World," p. 194.

A number of physicists have been active in this field of investigation. Outstanding among these are de Broglie, Heisenberg, Dirac and Schroedinger. In the past few years the theories proposed by these men have been repeatedly revised and extended until at the present time we have an entirely new picture of the atom.

Under the new theory of "wave mechanics" which has resulted, the electrons within the atom are believed to be accompanied by groups of waves, the extreme assumption being that an electron consists entirely of waves, that the wave group is, in fact, the electron. This is a theory which is apparently quite as good as Bohr's theory in its own field and appears to be capable of much greater extension.

A few years ago A. H. Compton discovered experimentally an effect which seemed to indicate that waves sometimes behave like particles, and Davisson and Germer proved that electrons reflected from a crystal of nickel are grouped in a manner to indicate that small particles in rapid motion behave somewhat like waves.

Also G. P. Thomson by passing a stream of cathode rays or swiftly moving electrons through a very thin metal film found that the metal scattered the electrons, the distribution of the scattered electrons being exactly that which would occur in the diffraction of waves like X-rays by the known crystal structure of the metal film.

Now it had been suggested by de Broglie that the reason the electron in the atom behaves in such a peculiar manner, seemingly following at one time the classical laws and at another the rules of the quantum theory, was that its real nature was more like that of a wave than a pårticle. It is easy to understand that the results of the experiments just described are in accord with de Broglie's hypothesis.

We must now consider how the phenomena just recounted are related to the ether hypothesis and determine what rôle the ether plays in the new wave mechanics.

You will understand that waves and wave groups are conspicuous features of this new theory. But waves in what?

It must strike the student of wave mechanics rather forcibly that while the discussion of these waves and their properties is quite free from hesitation and embarrassment any mention of the wave medium is made apparently with great reluctance and where possible is avoided altogether. Now a wave is a disturbance of the equilibrium of a medium. Without a medium there can be no waves, and to postulate waves is to postulate a medium in which such waves are formed and propagated.

The real explanation of this strange situation is found not in any disinclination on the part of the modern physicist to make use of the ether concept, which has been so freely employed in earlier science, but rather in the failure on the part of the ether to qualify in this particular field. For the medium required by the wave mechanics is a dispersive medium, that is, one in which waves of different length have different velocities. It is a necessary requirement that the shorter waves shall travel faster than the longer ones. Now in the ether all waves travel with the same speed. The ether, therefore, is unable to meet the requirements of this new theory.

For the first time, says G. P. Thomson, physics is faced with waves in empty space which do not fit into the ordinary series of ether vibrations.[7] These electron waves are of about the size of those in the X-ray spectrum, but of course they can not be X-ray waves, since these belong to the ether series and have the properties of ether waves.

To meet this difficulty the bold suggestion is made that we postulate an entirely new medium having the desired characteristics. Enters now the concept of the *subether*. Concerning this assumption Thomson says, "It is not a very attractive idea to have two ethers filling space, especially as the waves of protons, if they exist, would demand yet a third. Space is getting overcrowded."[8]

It is significant that the subether is proposed as an additional medium and not as a substitute for the ether of earlier theory. This can be interpreted only as meaning that regardless of the need for a dispersive medium we can not dispense with the luminiferous ether; that this medium is still necessary in our thinking to account for the propagation of all those forms of radiation heretofore classified as ether waves.

The universe is made up largely of open spaces. The stars and the island universes we see in the night sky are at almost inconceivable distances from the earth, and they are separated from each other by spaces equally great. Ordinary matter is constructed on the same plan. It is extremely porous. This is a fact which ordinarily escapes our attention; but if it were possible sufficiently to magnify its structure, modern theory teaches that so magnified its appearance would be much like that of the sky at night. We should see a multitude of material specks separated by great distances like those between the stars.

Across these spaces these specks of matter, stars and atoms, act upon each other. They are bound together by gravitation, by electrostatic and magnetic forces and by cohesion, and between them various forms of energy are incessantly streaming to and fro. Do these forces and energy streams extend through empty space? Or is there a medium for their transmission?

It may be difficult to conceive of a non-material, all-pervading medium which serves as a carrier of these forces; but it is even more difficult to imagine these interactions in a space which is absolutely void.

Newton said:

> That one body may act upon another at a distance, through a vacuum, without the mediation of anything else by and through which their action may be conveyed from one to another, is to me so great an absurdity that I believe no man, who has in philosophical matters a competent faculty for thinking, can ever fall into it.[9]

Sir Oliver Lodge says:

> Always look for the medium of communication: it may be an invisible thread, as in a conjuring trick; it may be the atmosphere, as when you whistle for a dog; it may be the ether, as when you beckon to a friend.[10]

Says Einstein:

> To deny the ether is ultimately to assume that empty space has no physical properties whatever. The fundamental facts of mechanics do not harmonize with this view . . . According to the general theory of relativity space without ether is unthinkable, for in such space there not only would be no propagation of light, but also no possibility of existence for standards of space and time.[11]

And finally, as regards the importance of the ether concept in modern physics we shall probably be inclined to agree with Eddington who expresses his views in the following words.

> We need an ether. The physical world is not to be analyzed into isolated particles of matter or electricity with featureless interspace. We have to attribute as much character to the interspace as to the particles, and in present-day physics quite an army of symbols is required to describe what is going on in the interspace. We postulate ether to bear the characters of the interspace as we postulate matter or electricity to bear the characters of the particles. . . . The ether itself is as much to the fore as ever it was, in our present scheme of the world.[12]

[7] SCIENCE, December 6, 1929, p. 545.
[8] *Ibid.*

[9] Quoted by Lodge, "Ether and Relativity," p. 79.
[10] *Loc. cit.*, p. 80.
[11] "Sidelights on Relativity," quoted by Lodge in "Ether and Reality," p. 123.
[12] A. S. Eddington, "Nature of the Physical World," pp. 31–32.