Encyclopaedia Britannica
Fourteenth Edition (1937), Volume 8, Pages 751-755

ETHER (in Physics).— Whether space is a mere geometrical abstraction, or whether it has definite physical properties which can be investigated, is a question which in one form or another has often been debated. As to the parts occupied by matter, that is by a substance which appeals to the senses, there has never been any serious doubt; almost the whole of science may be said to be an investigation of the properties of matter. But from time to time attention has been directed to the intervening portions of space from which sensible matter is absent; and this also has physical properties, of which the complete investigation has hardly begun.

These physical properties do not appeal directly to the senses, and are therefore comparatively obscure; but there is now no doubt of their existence, even among those who still prefer to use the term "space." But a space endowed with physical properties is more than a geometrical abstraction, and is most conveniently thought of as a substantial reality, to which therefore some other name is appropriate. The term used is unimportant, but long ago the term ether was invented; it was adopted by Isaac Newton, and is good enough for us. The term ether therefore con notes a genuine entity filling all space, without any break or cavity anywhere, the one omnipresent physical reality, of which there is a growing tendency to perceive that everything in the material universe consists; matter itself being in all probability one of its modifications.

Many attempts have been made to state the properties of such a substance in terms of material analogies, and all these attempts have shown signs of weakness and may be said to have failed. The properties of the ether are too fundamental to be stated in terms of something else.

There have been tendencies at different times to invent ethers or effluvia with special qualities to account for specific phenomena. These attempts were long ago discarded, and are now regarded as absurd. But that space has physical properties is a definite fact of experience, provided experience is extended to include inferences and deductions and is not limited to direct sensual perception. What we perceive directly

are length, breadth and height, modified here and there by a resistance or obstruction which we call matter, and combined with the element of time or duration, as exhibited and measured by the motion of matter, with speeds that can be directly apprehended.

But in addition to all that mass of common experience, the free unobstructed space is modified by the neighbourhood of matter; so that there exists everywhere a gravitational potential varying inversely with the distance from its appropriate portion of matter; the result of which is that matter tends to move from places of higher to places of lower potential, as if some force were driving the masses of matter together. Civil engineering— the erection of structures and the movement of great masses of material—is constantly concerned with this fact; and on this basis the whole of the older astronomy has been worked out in the most intricate detail.

Testimony of Optics.— The atoms of matter are not quiescent, even when a mass appears stationary, but are in a state of rapid quivering motion; and these motions are not independent of each other, but are interrelated and connected by additional and special disturbances which they communicate to the space or medium in which they occur. And about these supplementary disturbances our sense organ, the eye, has given us a mass of indirect information. These disturbances, though generated by matter, are not conveyed or transmitted by matter. They travel at a rate depending on innate properties of space; or rather, as we feel bound to say, on the physical properties of the substantial reality which fills space; thereby telling us something definite about those properties, though in a form difficult of apprehension and one which is not fully expressible in terms of any of the familiar properties of matter.

Thus the different masses of matter, even though separated by great distances, are not isolated or independent of each other. They are connected gravitationally, and they are connected optically. The energies of the earth, of which we constantly make use, are derived from the sun, and have travelled across the intervening 92,000,000 miles of empty space at a perfectly known and definite rate, with which rate matter has nothing to do. There may be uncertainty as to what exactly it is that is travelling; but the fact that it is travelling energy is certain. All that

matter does is to generate this radiant energy at one end and absorb it at the other. (*See* RADIATION RAYS; PHYSICS.)

Concerning the processes of generation and absorption a good deal is now known. Moreover not only is the speed of travel of the transmitted disturbance known, but also the fact that it is a periodic disturbance, expressible mathematically in exact analogy with a wave equation. Wherefore the disturbance may be spoken of without further hypothesis as ether "waves," the generic name for which is "radiation," a small range of this radiation being visible light.

Radiation is generated by some cataclysm or collision or other violent and sudden disturbance in the atoms of matter. When radiation encounters matter (unless it be merely reflected or passed on) it can throw the multitude of atoms into the con fused motion we call "heat," and produce other remarkable and chemical effects. Thus an ether is necessary for the purpose of transmitting what is called gravitational force between one piece of matter and another, and for the still more important and universal purpose of transmitting waves of radiation between one piece of matter and another, however distant they be.

Electric and Magnetic Properties.— In addition to those two functions, other properties have been discovered, notably the properties called electric and magnetic. Atoms of matter are electrically constituted, and accordingly tend to attract each other with a force which is the source of chemical affinity; with the result that molecules and other aggregates are formed, of which the structure is studied in the science of chemistry. Moreover the molecules themselves attract each other by a residual affinity, giving the familiar shape of crystals and other solids, the particles of which are held together in regular packing across ultra-microscopic intervals by what is called cohesion, for which likewise the ether must be held responsible. For, as Newton forcefully said in other words, it is absurd to imagine one piece of matter acting mechanically on another at a distance, whether that distance be large or small, without some intervening mechanism or connecting link. The continuous medium which fills space, therefore, is not only the vehicle of gravitation and light, but is also the instrument for cohesion and chemical affinity and for electric and magnetic attractions and repulsions. It must also be the vehicle for every kind of mechanical force, and for the elastic

connection between particles of matter, which are never in real contact with each other.

The intimate structure of the ether may ultimately be expressible and partially understood in terms of the phenomena of electricity and magnetism: for electric and magnetic influences are transmitted perfectly through vacuum, that is, across space empty of matter. They represent primarily properties of the ether, though they are only made manifest to our senses by means of matter. It was in terms of electricity and magnetism that Clerk Maxwell was able to explain the phenomenon of light. A close study of electro-magnetism, that is, of the interaction between electric and magnetic disturbances, showed that they must combine into a wave equation, the waves being transmitted at a rate calculable from purely electric and magnetic considerations. This velocity turned out to be the velocity of light; and so in 1865 the true theory of light was born.

Not that it is anything like complete. We know too little of the electric and magnetic properties of the ether to be able to picture exactly what is happening. What we do know is that light is an electro-magnetic phenomenon, and that it is entirely de pendent on the properties of the ether. The ether involves or possesses properties expressible by two fundamental constants; one of which regulates the force of attraction between two electrified bodies, and the other the force of attraction between two magnets. Neither constant by itself is as yet known. But the value of the constants multiplied together is known; it was discovered by Clerk Maxwell, and is the reciprocal of the square of the velocity of light. In other words, the combination of the electric and magnetic properties of the ether enables it to transmit waves at a rate equal to the inverse geometric mean of its two constants.

So far we have been dealing with things which have been known for some time. But the subject is so fundamental and important that a recapitulation in other terms seemed advisable. It now remains to deal with the later progress which has been made in investigating the properties of this extraordinary non-material but physical substance. Perhaps “substance” is hardly the right term, for, though exceedingly substantial in one sense, it makes no appeal to the senses and is therefore unlike any substance we know.

In the 9th Edition of the *Encyclopaedia Britannica* an attempt was made to estimate the elasticity and the density of the ether, on the strength of a certain hypothesis made by Lord Kelvin. In the 11th Edition (1.292) this estimate was repeated, and it was hinted that the hypothesis might be erroneous and the values obtained exceedingly wrong. Everything tends to confirm that conclusion. Strictly speaking the very terms elasticity and density, which are terms applicable to matter, may be inapplicable to the ether without redefinition; if used they must be understood in a formal sense. The properties of the ether are not likely to be expressible in terms of matter; but, as we have no better clue, we must proceed by analogy, and we may apologetically speak of the elasticity and density of the ether as representing things which, if it were matter, would be called by those names. What these terms really express we have not yet fathomed; but if, as is now regarded as very probable, atomic matter is a structure in ether, there is every reason for saying that the ether must in some sense be far denser than any known material substance. The only alternative contention— and it is an important one— is that the density which displays itself as inertia may be due to the organisation responsible for the very existence of matter, and that the unorganised general body of ether does not possess the attribute of inertia. The densest known matter, or matter of highest inertia, is found in some of the stars; the barely visible companion of Sirius having been found, on converging grounds of evidence, to be more than 1,000 times as dense as lead. Unless the above alternative contention turns out true, the density of ether must exceed even that startling amount; indeed there are sound arguments for regarding it as a million times denser. The fundamental substance is not likely to be filmy and unsubstantial.

Recent discoveries have represented the atom of matter as composed of minute electric charges, which fill hardly any of the space inside the atom, so that it is as porous as a solar system. (*See* ATOM.) The great bulk of an atom is occupied only by a few electrons; so that it is by no means impenetrable to particles, which if they fly through it at sufficient speed, may escape being entangled and absorbed. Matter therefore is comparatively a gossamer structure, subsisting in a very substantial medium. An estimate of the substantiality of the medium can be made from its magnetic energies, and it comes out almost incredibly

large. If it is right to express it in terms of material properties (which is doubtful) its inertia comes out as of the order of 1,000 tons per cubic millimetre. While as to the elasticity, that is still more enormous, since it is equal to the density multiplied by the square of the velocity of light.

These values are barely conceivable, being so much higher thananything of which we have sensual experience. But still they should be capable of being measured and expressed; so the ether is a physical substance, with properties which can in time be ascertained; and if the estimate above given of the source of the vast energies involved is wrong (as it is sure to be inadequately and incompletely worded) subsequent investigation can correct it. Meanwhile we may assume that there is some truth underlying these modes of expression, a truth which we cannot at present formulate any better.

The constants embodying the physical properties of the ether though so huge are not infinite: its properties are finite but very simple and perfect. It is perfectly transparent, it dissipates no energy; otherwise the stars and the spiral nebulae could not be seen at their gigantic distances across space. There is no friction between matter and ether, otherwise a portion of matter isolated from the rest would cool down, and the planets would not continue forever in their courses unperturbed. The ether has nothing of what we call in matter viscosity or fluid friction. There is no real heat in the ether, nor any sound. Nothing but one simple type of propagation by waves goes on in free space, and that with a definite unchangeable velocity which is known as the velocity of light, the one fundamental and so to say absolute velocity in the universe.

Possible Structure.— The question arises as to what that velocity can be due to. The most probable surmise or guess at present is that the ether is a perfectly incompressible continuous fluid, in a state of fine-grained vortex motion, circulating with that same enormous speed. For it has been partly, though as yet incompletely, shown that such a vortex fluid would transmit waves of the same general nature as light waves—*i.e.*, periodic disturbances across the line of propagation—and would transmit them at a rate of the same order of magnitude as the vortex or circulation speed. There remains indeed a question of stability to be safeguarded, but in these days of quanta (*see* QUANTUM THEORY) stability considerations are apt to be deferred. Thus it appears possible

that someday an extended hydrodynamics of a perfect fluid will explain all the physical properties of the material universe. *See* Lord Kelvin, "The Vortex Theory of Ether," *Phil. Mag.* (1887) and *Math. and Phys. Papers*, vol. iv. and passim; also G. F. FitzGerald, *Proc. Roy. Dub. Soc.* (1899), or *Collected Papers*, pp. 154, 238, 472.

This notion of a structure due to vortex circulation in a perfect fluid may be regarded by some as too material an idea, and it may have to be discarded; but it is the nearest approach that can be suggested to a pictorial image of the etheric constitution. Certainly no *structureless* fluid could transmit actual radiation. And certainly the ether is continuous and without viscosity or any dissipation of energy, and so in many respects is like an ideal fluid. More than that we cannot say, except speculatively, about its constitution.

Ether and Matter.— Meanwhile we must assume that the ether has a substantiality and a wave-conveying structure beyond our present clear imaginings, with parts of it modified in an un known way into electrons and protons; that of these the atoms of matter are built up; and that the whole of material activity consists in the interactions of these minute electric charges, connected as they are by their lines of force and by radiation.

These electric charges, and the aggregates which they have built up are subject to what we experience or recognise as loco motion. The ether itself is stationary. Whether it is really infinite in extent, or whether, though boundless like the surface of a sphere, it is nevertheless finite, are questions which we cannot at present answer. There is no doubt that it extends beyond the farthest visible stellar object, and for all practical purposes is infinite. There is very little doubt that matter is not an alien substance, but is essentially composed of it, being built up of the electrons and protons whose constitution has not yet been ascertained, but which must somehow be constituted of ether, perhaps in some sense analogous to that in which a knot in a piece of string is constructed of string, or a vortex in air is com posed of air, or the fibre of a muscle is still essentially flesh.

Einstein's Theory.— The theory of Relativity (*see* RELATIVITY) has led some people—not many of the leaders of thought— to doubt if the ether can really exist. It may be useful therefore to explain in what

way the equations connected with that theory are to be understood physically. Newton expressed the laws binding the planets and suns together in terms of a hypothetical force acting between them, the same kind of force as we experience when a weight is supported above the earth; which force may therefore be taken as a fact of experience. But though the force is a fact, it is not explained: any expression in terms of action at a distance is necessarily incomplete.

Einstein was led by considerations of relativity to formulate a law of gravitation, not in terms of force or of action at a distance, but in terms of something in space, that is, in the ether, which results in a tendency of bodies to approach each other. It might be called a warp in space, or it might be called by other names: the names do not matter. The thing that has to be expressed is that the presence of matter modifies its whole neighbourhood, causing a gravitational potential or virtual stress. And, until we know more about its intimate nature, the action of this modification is best expressed in terms of a differential equation which seeks to formulate abstractly, without physical hypothesis, the essence of what is really happening. None of the arguments which necessitate the existence of a medium are affected, but no name for it need be used, nor need the idea of a medium be introduced, for mathematical purposes. Mathematicians are quite able to work with abstract equations about quantities without physical implications or conceptions, as long as they remain purely mathematicians. They can reduce even geometry to arithmetic.

In a complete expression for the enlarged geometric "interval" between two points, the element of time must be introduced as well as the element of space, because they may be moving points. In other words geometry must be enlarged into kinematics, in order to express activities. The interval or line element between two neighbouring points may be expressed in polar co-ordinates r, θ, ϕ thus : $ds^2 = -dr^2 -(rd\theta)^2 -(r\sin\theta d\phi)^2 +c^2dt^2$, a mode of expression devised by Minkowski, an enthusiast for this kind of four-dimensional treatment, where the fundamental etheric velocity c is introduced as a coefficient able to turn time into imaginary space, $icdt$. The emphasis on c, as an absolute geometric constant, is perhaps the most remarkable part of the Einstein-Minkowski conception, as a preparation for the building erected upon it.

But Einstein took a further step, introducing the gravitation potential as something which would modify the motions of matter, and introduced it not only into the element of time (as Newton might have done if he had used that notation) but into the element of radial distance also; so that if the points are in the field of a mass of matter m the Minkowski equation is:—

$$ds^2 = -\gamma^{-1}(dr)^2 - (rd\theta)^2 - (r\sin\theta d\phi)^2 + \gamma c^2 dt^2$$

where $\gamma = 1 - 2P/c^2$, P being the gravitation potential at the place considered; which, if caused by a mass at a distance r, is $P = km/r$, with k as the Newtonian gravitation constant.

Here the coefficient γ occurs twice. If it occurred in the t term only it would be a mode of stating Newton's theory of astronomy, in differential instead of integral fashion; but this γ occurs in the r term also, as a result of the isotropy of the four fold medium contemplated in this gravitational theory. This equation when elaborated gives, strangely enough, the outstanding progression of the perihelion of Mercury, and it also gives the double deflection for a ray of light passing near the Sun (doubled because the co-efficient γ occurs twice), which has since been confirmed quantitatively by observation of stars near an eclipsed sun. It likewise gives the shift of the spectral lines emanating from any sufficiently massive body, which has now been confirmed beyond the reach of reasonable controversy by observations on light coming from the companion of Sirius, which Eddington has astonishingly proved to be by far the most compact and densest material body at present known to science, so that it is characterized by an excessively high gravitational potential.

The beauty of these results is overwhelming; but the idea that any mathematical scheme is more than a powerful method of exploration, and that a universe can be thus constructed in which physical explanations can be dispensed with, involves too simple and anthropomorphic a view of nature. The things calculated, and the things observed, however brilliantly accordant, cannot exhaust reality; an explanation is bound to be sought, and ultimately attained, in terms of the partially recognised but largely unexplored properties of the entity which fills space.

Locomotion of Matter.— The locomotion of matter is perhaps the commonest fact of experience, and it seems strange that it should be in need of explanation. But since an atom of matter is composed of electric charges, the locomotion of those charges has to be considered more in detail. An electric charge in motion constitutes an electric current, and the path of every electric current is surrounded by rings of magnetic force. This magnetic field confers inertia or momentum upon the moving charge; so that mechanical impulse is necessary to start it moving; and also to stop the motion. If not stopped it will continue to move uniformly in a straight line until it encounters some deflecting or retarding agency.

But though locomotion can thus be stated and worked out electromagnetically, that cannot be regarded as an ultimate explanation of so familiar and apparently simple a thing. Moving matter is known to have kinetic energy; and the familiar expression $\frac{1}{2}mv^2$ is the type of its measure. But when we come to analyse this expression there are difficulties about it, which hardly need elaborate theory to bring out and emphasise. For when we try to specify the velocity of a body, in order to calculate its energy, we find it difficult to say what that velocity really is: we can only specify it with reference to something else, commonly with reference to the earth. But the earth itself is moving. Hence $\frac{1}{2}mv^2$ does not give the absolute energy, but only the energy relative to the earth or other frame of reference, as Newton implicitly recognised. What the velocity of a body is in space we have no means at present of ascertaining, having no universal standard of reference; and accordingly the usual expressions, though practically useful, are by no means ultimately satisfactory. Nor can a statement in terms of electromagnetism be considered as ultimate.

The fact is that locomotion does not seem to be a property of the ether; it appears to be affected by one speed and one speed only, namely, what we may imagine to be the speed of its internal circulation and are familiar with as the velocity of light. Yet a modified particle of ether, like an electron, can move from one place to another. The analogy of a loose knot slipping along a string may be helpful.

An electron even at rest has intrinsic energy, *viz.*, its electro static energy of constitution, which can be expressed in various ways, and which, when expressed in terms of mass and speed, is $m_o c^2$, m_o being its

inertia at rest. Its static energy is thus expressible as equivalent to that of a particle of certain mass m_o or $2m_o$, moving with the speed c, the speed of light. To assist ideas, it might be thought of as a spinning motion; at any rate not locomotion.

When the particle is moved, the natural idea would be that this velocity c is increased, or that some addition is made to it. But according to the doctrine of relativity that is impossible: the velocity c is constant. The thing that changes is not c, but m. And the energy of a moving body is m_1c^2, where is m_1 *is* greater than m_o. As the speed of motion increases, m_1 increases too; until at high speeds it grows fast, and, as the speed of light is approached, tends to become infinite. The factor, or ratio between m_1 and m_o, is $c/\sqrt{(c^2-v^2)}$. So when an identified portion of ether is in locomotion, it is not the fundamental speed that is changed, but the amount of modified ether, or modification of ether associated with that identified moving portion. And what we observe as the kinetic energy of a body is really $(m_1- m_o)c^2$ or c^2dm. This is what we have hitherto recognized and called $\frac{1}{2}mv^2$, an expression which is only relative, and moreover is not exactly applicable to great velocities, such as we encounter in vacuum tubes and in radioactivity generally.

Short Summary of Present Knowledge.— To sum up our present position in more compact form, in order to put on record what may perhaps excite the interest or else the derision of posterity:—Assuming the Ether to be in some sense a substance, that is real and substantial, a genuine entity and not the mere emptiness which it superficially appears to be, the things that are known about it are these:—

(1) It is absolutely transparent and undispersive. In other words it quenches no light but transmits it undiminished in total intensity, though diluted by spreading, to and from the greatest distances known in astronomy. Moreover it transmits every kind of radiation at the same pace, whatever the wavelength, except in so far as it is interfered with by electricity or matter.

(2) It is absolutely devoid of viscosity. In other words it allows the motion of matter through it without any friction; it dissipates no energyand generates no heat. A serious attempt made at Liverpool (University College) from 1890 to 1897 to detect a mechanical grip or cling between ether and rapidly moving matter, failed (as was more than

half expected) to find any convective effect, even when the moving matter was strongly electrified or magnetised. (*Phil. Trans. Roy. Soc.*, 1893 and 1897.)

(3) Ether is the sole vehicle of radiation, that is of transverse disturbances periodic in space and time travelling at a definite and immense speed without any obvious destination, but it neither emits nor absorbs them. In other words it generates neither heat nor light; but it can receive these forms of energy from matter, and can convey and deliver them to other matter at a distance. Our sensory instrument, the eye, has long familiarised mankind with various practical aspects of this wonderful phenomenon.

(4) An electric field is another form of energy existing in the ether. For this we have no sense organ, and therefore know less about it, but its lines of force appear to be of the nature of strain. And probably the ether is the seat of all strain or potential energy. An electric field (like radiation) can only be originated by matter: its lines of force never terminate in ether, but they pass through ether along their whole extent. Insulating matter only modifies the lines, but conductors stop them.

(5) Another etheric form of energy is a magnetic field, which is certainly different from an electric field though somewhat similar. Magnetic lines of force are closed curves, and seem more intimately connected with the ether than with matter. But they interact with matter, and have thus displayed their existence by consequent attractions and repulsions.

(6) Electric and magnetic fields interact also with each other in free space, and thereby constitute radiation, in accordance with the Poynting formula that the flux of energy at every place is their vector product.

(7) Chemical affinity between atoms of matter is undoubtedly due to electric or magnetic attraction or both. And cohesion may be attributed to a residual chemical affinity between molecules. Thus the ether is indirectly responsible as a vehicle for all physical and chemical activity, and no one who believes in the ether has any doubt that it is responsible also for whatever is rep resented by the word “gravitation.” What other functions this universal medium may be found to possess, and whether life and mind can be in any way associated with those functions, must be left to posterity to find out. Our serious surmise is

that they are so associated, in a primary sense, and are temporarily manifested by secondary association with matter.

Steps Toward Further Knowledge.— Beyond definite knowledge, other guesses and working hypotheses have been made concerning the ether on the assumption that its properties can be partially expressed in terms of more or less familiar ideas. The property of inertia, so fundamentally possessed by matter, is doubtfully applicable to the ether. Even if matter turns out to be really modified ether, as many are beginning to expect, it is a question whether inertia arises as a result of the modification, or whether it is a property of the primitive substance which, by the materialisation, is individualised, localised and made manifest. If inertia can rightly be predicated of the ether itself, its value per unit bulk must be enormously greater than is exhibited by any kind of matter; for matter by its very constitution is certainly excessively porous, consisting as it does of minute particles far apart from each other in proportion to their size, whereas the ether must be as continuous as space itself. A molecular structure for the ether is not to be thought of, for its whole value as an explanation of facts depends on its continuity: separate particles with interspaces are appropriate to matter, but the whole problem of action at a distance would remain unsolved unless the particles are united into a coherent whole by something which has no gaps, and is responsible for cohesion, elastic rigidity and other proper ties of solids.

The fundamental units of measurement, the centimetre, gramme and second, have direct relation to matter, and it is doubtful if they are applicable to the continuous ether at all. If they are, then there are grounds for maintaining that the inertia of unit volume of ether is represented by a number of the order while, since it certainly transmits the polarisable and therefore transverse vibration of light, it must on that view have a quasi-rigidity comparable to the number 10^{33}.

This elastic quasi-rigidity can be attributed to a continuous perfect fluid provided, and only provided, it is in an excessively rapid and fine-grained state of vortex motion; and Lord Kelvin showed that such a rotational or turbulent fluid could transmit transverse waves at a speed of the same order as the circulation velocity. This velocity c is now regarded as one of the unalterable constants of nature: it is the one

definite measurement which has been made concerning the ether of space, and of itself is sufficient to show that space empty of matter is endowed with finite and measurable physical properties. We can measure the speed of light by aid of matter, because matter generates, absorbs, reflects, and otherwise interferes with it: we observe electricity and magnetism and every other manifestation of the ether by aid of matter; but unfortunately all the properties of ether itself, apart from matter, have hitherto proved completely elusive. None of our apparatus grips or gives us a foothold; so that some physicists claim that pragmatically the ether is a gratuitous hypothesis and need not really exist. It is quite true that physical calculations and discoveries can proceed without explicit reference to the ether, but when we come to philosophise and try to formulate the facts physically, it is clear that space must be endowed with physical properties and is therefore entitled to something more than a merely geometrical name. These properties are equally real inside matter, and radiation is everywhere conveyed by space: transparent material does not really convey light, it only allows the passage and reduces the speed.

So much for a transparent body, which must be an insulator because the electrons are tightly attached and not free to move. On the other hand, when the electronic constituents of matter are loose, not anchored to something heavier than themselves, the substance becomes a metallic conductor, and as such must be mainly opaque. A conducting film, or rarefied electric region, if it can transmit radiation at all can only do so in a peculiar manner. In an electrified region waves do not travel as in free space. Different wave lengths begin to be treated differently, for their speed is a function of wave length. An expression for their speed in that case is

$$v = \sqrt{(c^2 + b^2\lambda^2)}$$

where b^2 is proportional to the electrical concentration. It turns out that b is the smallest frequency which such waves can have under the given conditions. Strangely enough the energy of the radiation is apt to lag a little behind these curious waves, for it travels at a speed called the group velocity c^2/v; and this may be slow when b^2 is big. The amount of

energy is proportional to the frequency of vibration.

Interaction of Ether and Matter.— A part of space occupied by matter or electrical particles transmits radiation in a peculiar way. Treated in a statistical or average fashion, matter in which electric constituents are firmly attached to the atoms— so that it insulates when solid, and conducts chemically when liquid—has a refractive index μ which reduces the apparent velocity of light to c/μ; a simple consequence of wave theory which Foucault definitely verified; though the full explanation of such a reduced velocity is not simple. Maxwell's view of the dielectric constant, or specific inductive capacity of insulators, is that it must be nearly the same as μ^2. Transparent matter thus seems to load or increase the effective density of the ether by the amount μ^2-1, so that what is sometimes spoken of as bound ether—the portion appearing to cling to matter and move with it—is in such a substance μ^2-1/μ^2 of the whole: as Fresnel surmised and Fizeau experimentally verified by a successful experiment on the speed of light in moving water.

It must be admitted that this is only a superficial or tentative way of regarding the still partially unexplained reaction between matter and ether; for it must be understood that statistical or average forms of statement are never completely and finally satisfactory; they fill a gap in our knowledge for the time being, and are true as far as they go. The Lorentz transformation, used by Relativists, arrives at the same result without philosophising about it or explaining it.

Question of Reversibility.— Every star is emitting energy at the expense of its own material, so that matter is gradually turning into radiation and passing into an unlocalised form in the ether. It may be said that, without the restriction of the quantum, whereby only whole units of energy can be radiated, all the energy of matter would pass into the ether and become radiation. A good deal does. The question naturally arises whether this process is reversible or not; i.e., whether radiation can under any condition generate, in return, the fundamental ingredients of which matter is composed. This discovery has not yet been made. What we know of is that the jump of an electron generates radiation, of a frequency proportional to the energy of the jump; and that this same radiation, whenever absorbed, can cause another electron elsewhere to jump with the same energy. Hence the idea looks hopeful

that a reversible process may be involved generally, in the interchange of energy between ether and matter, not only in this ordinary electronic laboratory case, but in the more violent clashes in the stars, where matter appears to be destroyed. May it not perhaps in some distant region be reconstituted, with a consequent great gain of gravitational potential energy, so as to render the cosmos permanent, and reduce the useful law of dissipation of energy to comparative insignificance?

Concluding Remarks.— We have seen that when we try to look at even so apparently simple a thing as locomotion, absolutely, we have to admit that varying speed means varying amounts of ether-modification in the identified portion of matter we are attending to; for we can only express absolute energy in terms of an ether constant *c*, which at first sight would appear to have nothing to do with it. The same constant enters into the com position of velocities. It is as if the normal constitutional etheric circulation trended or drifted in one direction, so as to constitute perceptible or available energy, much as the energy of a river or a gale of wind is a directed fraction of random molecular motions.

The same idea may be expressed magnetically by calling attention to the magnetic field surrounding a moving charge. At high speeds the magnetic field is strong; more substance is involved in it: and the additional spin (if that is the right term, for magnetism is usually thought of as a kind of spin) accounts for the additional energy. Why it should appeal to us as locomotion, and what the real meaning of locomotion is, are not so clear. This is only an illustration of the difficulty we experience when we come to probe the simplest thing to its depths. We have grown accustomed to certain aspects of the universe given us by our senses, but we do not fundamentally understand them. And when we come to probe the meaning of things deeply enough, we find ourselves up against difficulties of conception, toward the elucidation of which our senses give hardly any aid. What we are used to is mechanical movement; but the effort to explain things ultimately in that way is not easy, and may turn out to be not possible.

Meanwhile we take refuge in expressing these things in terms of electricity and magnetism; which is a step toward an explanation, and is useful in bringing out the difficulties which underlie every ultimate and

absolute statement. The attempted absolute expression for static electric energy, mc^2, with the inertia m as the only variable, is a legitimate mathematical expression of actual facts. But the real meaning of c is, at present, a hypothesis: and what the real meaning of m is, must be regarded as still less known. Both these factors must have reference to the ether, and until we know more about the constitution of the ether we must be content to remain in a condition of provisional ignorance. We are led to regard the material universe as a substantial reality in various stages or varieties of internal activity. We may try to think of this activity as akin to a fine-grained vortex circulation in a continuous, incompressible, perfect fluid: beyond that we cannot at present go; nor are we clear about the exact meaning of these terms when applied to a medium of unknown constitution. When we understand the real and ultimate nature of electricity and magnetism we may hope to proceed further. Till then we must be content with proximate explanations and await the gradual illumination of further experience.

BIBLIOGRAPHY. — *See* T. Preston, *The Theory of Light* (1895, new edition ed. by A. W. Porter, 1928); J. Larmor, *Aether and Matter* (1900); J. Larmor ed., *Writings of George Francis Fitzgerald* (Dublin, 1902); E. T. Whitaker, *A History of the Theories of Ether and Electricity* (1910); O. Lodge, *Electrons* (1913); A. Einstein, *The Theory of Relativity* (1915-17); O. Lodge, *Ether and Reality* (1925); H. Buckley, *A Short History of Physics* (1927). *See* also the articles "Radiation" and "Quantum" in R. T. Glazebrook's *Dictionary of Applied Physics*, vol. iv. (O. J. L.)