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EDWARD to EXTRACT

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In the textile industry triethanolamine soaps are employed for many purposes, particularly in the preparation of mineral-oil emulsions for lubricating fibres and yarns. The ability of triethanolamine to combine with acids either to counteract the undesirable effects of acidic conditions or to produce new compounds results in applications which serve useful purposes in the manufacture of cosmetics, insecticides, metal-cutting oils, petroleum chemicals and cement-grinding aids.

BIBLIOGRAPHY.—Emil J. Fischer, *Trianthanolamin und andere Athanolamine*; C. B. Kremer, "Ethanolamines," *Journal of Chemical Education*, vol. 19, pp. 80–81 (1942); Carbide and Carbon Chemicals Company, *Synthetic Organic Chemicals*, 13th ed. (1952).

ETHER (IN CHEMISTRY), any member of a certain class of substances (of which the well-known anaesthetic, diethyl ether, commonly called "ether" or "aether," is one) composed of carbon, hydrogen and oxygen and having the general formula R.O.R.′, where R and R′ are alkyl or aryl groups (*see* CHEMISTRY: *Organic*). The term ether formerly included the esters (*q.v.*) of organic acids, such as acetic ether, now termed ethyl acetate. The true ethers are formed by elimination of one molecule of water from two molecules of the alcohols; the two hydrocarbon radicals are the same in simple ethers, and different in mixed ethers. They may be prepared by the action of concentrated sulphuric acid on the alcohols; alkyl sulphuric acids are first formed and yield ethers on being heated with alcohols. The process is rendered continuous by running an alcohol slowly into the heated reaction mixture of alcohol and sulphuric acid. Benzene sulphonic acid has been used in place of sulphuric acid (F. Krafft, 1893). A. W. Williamson explained the mechanism of this action in 1850; in 1851 and 1852 he prepared diethyl ether (*see* below) by the action of sodium ethoxide on ethyl iodide, and showed that all ethers possess the structural formula given above. They may also be prepared by heating the alkyl halides with silver oxide. Hydrogen halides convert them into alkyl halides. With chlorine they yield substitution products.

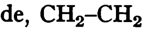
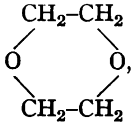
Dimethyl ether, $(CH_3)_2O$, first obtained by J. B. Dumas and E. Péligot, 1835, is best prepared by heating methyl alcohol and sulphuric acid to 140° C. and leading the evolved gas into sulphuric acid. The sulphuric acid solution is then allowed to drop slowly into an equal volume of water, so that the methyl ether is liberated (E. Erlenmeyer and A. Kriechbaumer, 1874). It is a pleasant-smelling inflammable gas, condensing to a liquid which boils at $-23.6°$ C. It is somewhat soluble in water and readily soluble in alcohol and concentrated sulphuric acid. It combines with hydrogen chloride to form a compound $(CH_3)_2O.HCl$. Methyl ethyl ether, $CH_3.O.C_2H_5$, prepared from methyl iodide and sodium ethoxide or from ethyl iodide and sodium methoxide, is a liquid boiling at 10.8° C. The homologous ethers are also liquids, with boiling points rising with increase of carbon content.

Diethyl ether, $(C_2H_5)_2O$, the ether of pharmacy, is a colourless, volatile, highly inflammable liquid, of specific gravity 0.736 at 0°, boiling point 35° C. and freezing point $-117.4°$ C., with a powerful characteristic odour and a hot, sweetish taste; it is soluble in ten parts of water and in all proportions in alcohol; it dissolves bromine, iodine and, in small quantities, sulphur and phosphorus, also the volatile oils, most fatty and resinous substances, pure rubber and certain vegetable alkaloids. Mixed with ethyl alcohol it is an important solvent for nitrocellulose. A mixture of the vapour with oxygen or air is violently explosive. The making of ether by the action of sulphuric acid on alcohol was known about the 13th century, and later Basil Valentine and Valerius Cordus described its preparation and properties. The name ether appears to have been applied to the drug only since the time of F. G. Frobenius, who in 1730 termed it *spiritus aethereus* or *vini vitriolatus*. It was considered to be a sulphur compound, hence its name sulphuric ether; this idea was proved to be erroneous by Valentin Rose about 1800. Ether is manufactured by the distillation of five parts of 90% alcohol with nine parts of concentrated sulphuric acid at a temperature of 127°–140° C., a constant stream of alcohol being caused to flow into the mixture during the operation. The distillate is purified by treatment with lime and calcium chloride and by subsequent distillation.

The presence of even small amounts of water or alcohol in ether can be shown by the continued evolution of hydrogen gas on treatment with metallic sodium. Chromic acid oxidizes ether to acetaldehyde, acetic acid and ethyl acetate, the proportions depending upon the experimental conditions. Ozone oxidizes it to a mixture in which acetaldehyde, hydrogen peroxide and organic peroxides have been identified. Peroxides are also formed in the presence of air under many conditions of storage. This action is inhibited by certain metals, notably copper. In contact with hydrogen iodide at 0° C. it forms ethyl iodide, and with water and a little sulphuric acid at 180° C. it yields alcohol. It forms crystalline compounds with bromine and with many metallic salts. Ether may be transported in iron drums, glass bottles or tin cans. Its principal use is in the manufacture of smokeless powder, in organic synthesis, as a solvent, in analytical chemistry and for medicinal purposes (*see* below). No flames or sparking electrical equipment may be used in connection with the industrial application of ether.

Absolute ether is ether from which water, alcohol and acidic impurities have been removed to the greatest practicable extent. It is prepared from the ether of commerce by washing with a saturated aqueous solution of calcium chloride, then treating with sodium until the evolution of hydrogen ceases, and finally distilling from the excess of sodium. It is used as a solvent in various organic syntheses. (*See* GRIGNARD REAGENTS.)

Diisopropyl ether, $(CH_3)_2CH.O.CH(CH_3)_2$, is a liquid boiling at 68° C. It is made from propylene, a by-product of the cracking process (*see* PETROLEUM). To some extent it has displaced diethyl ether as a solvent, and it finds some use in high-octane motor fuel.

Cyclic ethers, ethylene oxide, , boiling at 14° C., is used as a fumigant and also as a reagent in organic synthesis. Dioxane, , boils at 101° C. and is widely used as a solvent. (X.)

Medicinal Uses.—(*See* ANAESTHESIA AND ANAESTHETICS.) Ether was still the most widely used general anaesthetic at mid-20th century. This is because in ether anaesthesia the various stages are well demarcated and the ratio between toxic and therapeutic levels is relatively large. Ether depresses neither the respiration nor the circulation until high concentrations are present in the blood. It is frequently employed to augment other anaesthetics, such as nitrous oxide and cyclopropane. It is occasionally used rectally, after being mixed with oil, in prolonged and severe asthmatic attacks. Ether was used in the past for other medical purposes. Because its rapid evaporation causes intense cold, it was once used as a local anaesthesia, but it has largely been replaced by other, more effective agents.

When ether is taken internally, the effect is quite similar to that of ingested alcohol. In the 19th century ether parties were held because of this effect. These went out of fashion, and cases of acute etherism are rare. The ether addict is virtually unknown in the 20th century. (R. G. PE.)

ETHER (IN PHYSICS), a hypothetical substance filling all space, inclusive of those volumes occupied by ordinary matter, and serving to transmit those forces (gravitational, electric, magnetic) which one material object exerts on another located at a distance. During the 19th century the ether hypothesis was accepted by all competent authorities, although there was diversity of opinion as to the ether's properties. After 1900 the opposite opinion gained ground; namely, that the hypothesis is unnecessary for the explanation of any observed phenomena. A few physicists still hold to the older view that an ether must exist and that otherwise philosophical difficulties would arise in connection with the concept of action-at-a-distance. This radical change of attitude in regard to the ether was brought about by Albert Einstein, who showed that many of the properties formerly ascribed to the ether can equally well be ascribed to space and time.

Traditionally, space has been conceived as an unchangeable, passive constituent of the universe, neither affecting nor being affected by the dynamic changes occurring in the material parts of the universe. On this view, space is analogous to a moving-picture screen which remains unaltered even when the most violent scenes are projected upon it, and neither aids nor hinders the action, though its presence is necessary for the perception of the pictures. If space is unchangeable, in this sense, then it is necessary to assume the existence of a more active medium, occupying all space, and taking a dynamic part in the motions and other phenomena of the universe.

Twentieth century physicists agree with their predecessors on this point. In fact, there has been no discontinuity in the chain of reasoning, and the Einstein theory of space and time rests on foundations that were laid in the distant past. The present conception of a dynamic space-time continuum has evolved gradually out of the original conception of a pair of continua: passive space and dynamic ether.

The Development of the Ether Theory from Descartes through Huygens.—Many ancient philosophers stressed the necessity of postulating an invisible intangible substance which takes a causal part in the motions of the planets, etc. The name "aether" or "ether" is derived from their writings. Some writers postulated many ethers, each occupying its own region in space. The idea of a single, all-pervasive ether may have originated with René Descartes (1638). In any case, Descartes exercised a dominant influence on all later physical theories of the ether.

The characteristic feature of Descartes' cosmology was its rejection of action-at-a-distance. Force was communicated only by contact, from one particle of matter to its immediate neighbours. As the sun warms and illuminates the earth, it was therefore necessary to assume that the space between the earth and sun is filled by some form of matter—the imperceptible ether. Light and heat were considered to be pressure, transmitted instantaneously from the sun to the earth. A visible object is seen, according to this theory, because the ether transmits a pressure from it to the beholder's eyes. The ether is thus conceived as a sort of blind man's stick.

Descartes' theory of light was shortly challenged from two directions. Pierre de Fermat (in 1657) doubted that light is transmitted instantaneously, and this was confirmed (in 1675) by Ole Roemer, who showed that the eclipses of Jupiter's moons gave definite evidence of the time needed by light to travel from Jupiter to the earth (*see* VELOCITY OF LIGHT). Robert Hooke (1667) pointed out that Descartes had given no explanation of colour, and proposed the theory that light was an oscillatory motion of the ether, such that the particles of ether move back and forth in the same direction as that in which the light is being transmitted (longitudinal waves). Light of different colours is characterized by different rates of vibration (*see* OPTICS; SPECTROSCOPY).

Another investigator into the cause of colour was Sir Isaac Newton (1672). He became involved in a painful controversy with Hooke; perhaps because of this, or possibly because of uncertainty in his own mind, his writings on the ether problem are confused. Apparently Newton did not entirely reject the idea of an ether capable of longitudinal vibrations. These might even have something to do with light, but fundamentally he thought light consisted of streams of particles or corpuscles. These particles, emitted by the source of light and moving away from it at a high speed, might interact with the ether and set up waves, much like a ship moving over the sea. Moreover, their emission was in some way connected with the vibrations of the luminous flame or other source of light. It cannot be said, however, that Newton really developed a coherent theory of light; however important his contributions to optics are, the pages on which he outlines basic concepts show indecision and a reluctance to commit himself to any one hypothesis.

This is also apparent in his treatment of gravitation and the ether, but his famous inverse square law is susceptible to precise formulation without using the picturesque terms of the ether theory. Consequently, all consideration of the ether is brusquely postponed indefinitely. Descartes' principle that forces result only from the contact of one material particle on another is not definitely rejected, and many of Newton's followers considered that the ether transmitted the force of gravity; no detailed theory of this process was ever developed, however.

In 1690, Christiaan Huygens published an explanation of the double refraction of light by Iceland spar. He developed Hooke's theory of light as a form of longitudinal wave motion to the stage where it could give quantitative explanation of additional phenomena. Newton was justly critical of this theory, in that it did not account for all of the known optical phenomena associated with Iceland spar.

The 18th Century.—The following century was one of great scientific activity. Many discoveries were made in the field of electricity and magnetism. The ether—even a multitude of ethers—was invoked by many writers to explain the phenomena, but no general agreement was reached.

Newton's corpuscular theory of light dominated the writings on optics. Thomas Melvili and Gaspard de Courtivron (1752) advanced the hypothesis that the colour of light was determined by the velocity of the corpuscules. This was disproved by observing that the satellites of Jupiter did not change colour at the moment of eclipse: thus different colours must travel with the same velocity.

James Bradley discovered the aberration of light (*q.v.*) in 1725; this is the apparent displacement of the stars because of the motion of the earth in its orbit. It can be explained by the corpuscular theory and is analogous to the slanting path of a raindrop down the window of a moving car. It can also be explained by the wave theory, although not so picturesquely. However, since all stars show the same displacement it follows that the velocity of light must be independent of that of its source. This is easily understood if light is a series of waves in a stationary ether, but it is difficult to see how corpuscules emitted by a moving body can fail to share in that motion.

The mediocre success of the corpuscular theory of light left the wave theory with some adherents, notably Benjamin Franklin, Jean Bernoulli (the younger) and the mathematician Leonhard Euler. The latter epitomized the current state of the theory in the words "light is in the ether the same thing as sound in the air."

The Triumphal Period of the Ether Theory.—The phenomena of the colours of thin films (such as soap bubbles or oil on water) and of the colours seen when light is passed through fine-meshed screen or cloth, were known throughout the 18th century, but received little attention. The first triumph of the wave theory of light was Thomas Young's explanation, in 1800, of the effect of films on light. He reasoned that light may be reflected from both surfaces of the film. If the incident light consists of a single train of waves, the reflected light must consist of two trains moving through the same part of the ether. The one train will lag behind the other by a distance equal to twice the thickness of the film. Since the waves consist of alternate rarefactions and condensations, it may happen that the rarefactions of the reflected train coincide with the condensations of the other so that the two neutralize each other. The two trains are said to interfere destructively with each other. Whether or not this interference will occur depends on the spacing of the waves (their wave length) and on the thickness of the plate. If the colour of light is determined by its wave length, a thin film will not reflect light of some colours. Those colours which it does reflect are the only ones perceived by the eye. Young was able to develop this principle of interference into a complete quantitative account of the observed phenomena.

Young also endeavoured to apply his principle to the explanation of the coloured fringes which appear to surround fine fibres or wires—which is usually called diffraction. He was not successful, and this triumph was reserved for Augustin Fresnel (1815) who wrote several brilliant papers showing how the principle of interference when combined with Huygen's earlier theory explained this very complex set of phenomena.

The adherents of the corpuscular theory of light could not furnish any equally satisfactory explanation of diffraction, but the triumph of the ether theory was not yet complete. Newton's critique of the theory had been based on the phenomena of the double images seen through a crystal of Iceland spar. The phenomena had been investigated by others, and Etienne L. Malus

(1808) had shown that when light is reflected from a windowpane, it will not pass through a crystal if the latter is held in certain positions. (This basic discovery has been applied in the manufacture of sunglasses.) This polarization of light, which prevents it from passing through a crystal in one position, but enables it to pass when the crystal is turned through 90°, has no analogue in acoustic phenomena. This, in essence, is Newton's criticism of the wave theory in the form summarized by Euler. A beam of polarized light is characterized by two mutually perpendicular directions: its direction of propagation and its direction of polarization. The relation of the latter to a crystal determines whether or not the light will be transmitted.

The solution of this problem was suggested to Young by the discovery (made by François J. Arago in 1816) that two beams of light will not interfere if they are polarized at right angles to each other. Instead of assuming that the ether particles vibrate back and forth in the *same* direction as the waves are travelling, as is the case in sound, Young assumed that the direction of vibration is at *right angles* to the direction of the wave propagation. This theory of transverse waves was first published in the *Encyclopædia Britannica* article on CHROMATICS, written by Young in 1817. With its aid, Young and Fresnel were ultimately able to give a complete explanation of the phenomena of polarization. This completed the triumph of the wave theory over the corpuscular theory of light, but new problems immediately arose.

The Solid Ether.—Previous to Young's investigations, it had been tacitly assumed that the ether was a fluid, more tenuous than air. How else could the planets move through the ether without encountering a resistance that would have brought them to rest long ago? Now, a fluid cannot transmit transverse waves; such vibrations require a degree of rigidity not possessed even by liquids. Thus Young's hypothesis amounted to supposing that the ether is solid. It eliminated one objection to the wave theory of light, but only to replace it by another. George G. Stokes (1845) gave a partial explanation of the manner in which the planets move through the solid ether. He pointed out that sealing wax and similar compounds are rigid so far as rapidly changing forces are concerned, but flow like liquids under long continued forces. Compared with the very rapid vibrations of light waves, even the motions of the planets are slow.

However, Fresnel and his immediate followers found much to be done, and postponed this question. The theory of a vibrating solid had not been worked out, and presented many technical problems. These can only be mentioned although they occupied a full generation of mathematical physicists.

One guiding principle governed all their researches, and raised interesting problems. The ether was conceived to be qualitatively identical with elastic solids such as glass or steel. Thus the theoretical developments could be guided by experiments with tangible solids, as well as by optical experiments with the otherwise intangible ether. The ether was assumed to differ only quantitatively from ordinary solids. Thus, it was shown that in order to account for the very high velocity of light (as compared with the velocity of sound in, say, steel) its rigidity and density must both be enormously much greater than that of steel. Estimates of the density of the ether varied, but ran as high as 1,000 tons per cu.mm. This accentuated the paradox of an intangible solid through which the planets move without resistance.

Another problem is presented by the fact that an ordinary solid can and does transmit both longitudinal and transverse waves. An experimental search for two kinds of light waves was made, but only the transverse waves were found. This ultimately led to the abandonment of the principle of qualitative similarity, and the recognition that the ether must be qualitatively different from ordinary solid matter. Thus a first step toward the ultimate identification of the ether with space itself was taken in the early 19th century.

The Electromagnetic Theory.—In accordance with Descartes' views, not only light, but gravitational, electric and magnetic forces must be transmitted through an ether. In order to leave open the question of the number of ethers required, that ether which transmits light was often called the luminiferous ether. During the 18th century, the ether hypothesis was most often invoked to explain the electric and magnetic forces. Thus, Henry Cavendish, in 1771, wrote a paper entitled "An Attempt to Explain . . . Electricity by Means of an Elastic Fluid." Since writers on optics, electricity and magnetism usually concentrated on the problems of a single field, it is often not easy to determine whether they assumed that there were many ethers or only one. Occasionally a writer, such as Joseph Priestley, hinted at the next great development in the ether theory, which was the recognition that a single ether sufficed for the three groups of phenomena. The question of a gravitational ether remained in the limbo to which Newton had consigned it.

During the earlier phases of investigation, electric and magnetic quantities were measured in similar but quite independent units. The possibility of a single system of units was brought about by Hans Christian Oersted's discovery (1820) that an electric current produces a magnetic field, and Michael Faraday's discovery (1832) that a changing magnetic field produces an electromotive force. Two such complete systems of measurement were established, the one based on the original magnetic, the other on the electric system. Any quantity, such as electric current, could then be measured in either of two units. The ratio of the units of electric current was called c and was found to be equal to 3.1×10^{10} cm./sec. This constant became the centre of a remarkable development.

The experimental investigations initiated by the discoveries of Oersted and Faraday were supplemented by many theoretical investigations, and by 1854, William Thomson, Lord Kelvin was able to calculate the velocity with which telegraph signals were propagated along submarine cables. In doing so, he had to introduce constants whose values depended on the materials of which the wire and its insulating cover were made, the way in which it was supported, etc. Gustav R. Kirchhoff, in 1857, set himself a simpler problem, supposing the wire to be bare and suspended in free space. He was able to show that the velocity with which an electric signal would be propagated along such a wire is simply equal to $c = 3.1 \times 10^{10}$ cm./sec.

In itself, this is not surprising. The remarkable thing is that the velocity of light is also 3.1×10^{10} cm./sec., to within the limits of the accuracy of the measurements previous to that time. Kirchhoff recognized that this could not be a coincidence, and thus the way was opened for a unification of the optical and electromagnetic theories. (*See* VELOCITY OF LIGHT.)

However, light is not propagated along wires, and the question remained: are electromagnetic waves propagated through free space? If so, the identity of optical and electromagnetic phenomena can be considered as proven. This technical problem of proving that electromagnetic waves are transverse and can be propagated with the velocity of light through free space was solved by James Clerk Maxwell. He was able to show that longitudinal electromagnetic waves cannot travel through transparent substances or free space, thus establishing the superiority of the electromagnetic theory of light over those theories based on an ether qualitatively similar to ordinary elastic solids. Finally, he was able to show that all electromagnetic and optical phenomena could be explained by a single system of stresses in the ether, which obey quite different laws than do the elastic stresses in such substances as steel.

While the principle of qualitative similarity was thus no longer tenable in its simplest form, attempts were made to reconstruct it in a more complicated form. Thus Lord Kelvin (1887) suggested that the ether might be a fluid in rapid motion—filled with minute vortices. A similar theory had been suggested by Jean Bernoulli more than a century before. Such a vortex ether had some of the properties needed to support the Maxwell stresses.

The experimental verification of Maxwell's electromagnetic waves by Heinrich R. Hertz, and their application to wireless telegraphy by Guglielmo Marconi, are worthy of mention, although not strictly relevant to the ether theory. (*See* WIRELESS TELEGRAPHY.)

After Maxwell, there was no further mention of a plurality of ethers, and physicists were convinced that a single ether sufficed for the transmission of all known forces, including the gravitational. But a detailed ether theory of gravitation was not forthcoming.

The Ether Drag Experiments.—The manner in which solid objects move through the ether was the subject of much experimentation and more speculation. It has already been noted that this problem was especially acute during the period in which the ether was conceived to be a solid, but it continued to be studied for more than a century.

Young had pointed out that the observed aberration of light could most easily be fitted into the wave theory by supposing that the earth moves through the ether without disturbing it, or imparting any motion to it. However inexplicable such a state of affairs might be, it was at least simple.

It was also necessary to suppose that the ether permeated all matter, otherwise how could light be transmitted through transparent substances? Moreover, the density of the ether inside glass or water would have to be greater than in free space—otherwise the phenomenon of refraction could not be explained. Fresnel considered how a material object could move without setting the surrounding ether in motion, and yet allow the ether inside it to be denser than its surroundings. This is possible only if the ether inside the moving object also is in motion, but has a velocity which is less than that of the object itself. Ether flows into the front of the object and out at the rear in such a way that it is compressed while inside. The ratio of the ether's velocity to that of the object became known as the Fresnel drag coefficient, and can be calculated from the index of refraction of the object. This motion of the entrained ether affects the velocity with which light is transmitted. This was investigated experimentally by Armand H. Fizeau (1851) who measured the velocity of light in a stream of water. His results confirmed Fresnel's theory.

This relatively satisfactory solution of the problem was upset in 1887 by the famous Michelson-Morley experiment (*q.v.*). If the ether surrounding the earth does not share the earth's motion, then the velocity of light relative to the earth should depend on the direction of the ray. If the light is transmitted in the direction of the earth's motion, the earth will partially overtake it; hence in this direction light will seem to have a lower speed than in any other. In 1881 Albert A. Michelson had designed an experiment to test this conclusion, and with E. W. Morley's aid it was carried out. The result was negative: light appeared to travel in all directions with the same speed. It seemed necessary to suppose that the earth carried the ether with it, having imparted its full velocity at least to the ether in its immediate vicinity.

This was in direct contradiction with Young's explanation of aberration. Even worse, Sir Oliver Lodge soon after (1892) performed an experiment whose simplest interpretation was also in conflict with the idea of an ether set into motion by nearby matter. Lodge reasoned that, if the earth imparts its velocity to the ether, then the rotation of a heavy steel disk would set the ether into motion. This ether motion must in turn affect the propagation of light in a detectable manner. But on performing the experiment, Lodge was forced to conclude that the disk imparted less than 1/200 of its velocity to the surrounding ether. If the same fraction applied also to the motion of the earth, the Michelson-Morley experiment would have yielded a positive result.

The first attempt at a theoretical resolution of these conflicts ignored Lodge's experiment. Hendrik A. Lorentz recalled that Stokes had proposed an alternative to Young's explanation. Stokes (1845) showed that if the earth imparted its full motion to the ether in immediate contact with its surface, and if the surrounding ether moved in a certain way, then the phenomenon of aberration could still be explained. Lorentz pointed out that Stokes' theory reconciled the two experimental results, but that the kind of motion required of the ether was impossible unless the ether was very compressible. Max Planck (1899) examined this suggestion in detail, assuming that the earth carried along an atmosphere of ether in the same way it carries along an atmosphere of air. The difficulty of conceiving an ether which is at once very compressible and very rigid could be avoided as already suggested by Stokes (*see* above).

However, even this explanation did not survive experimental test, for it predicted that the velocity of the ether at a height above the earth would be different than immediately at the earth's surface. Michelson made a direct comparison of the velocity of light at a height of about 50 ft. with that a few feet beneath the earth's surface, and found no difference. The Michelson-Morley experiment was repeated from a balloon and the same negative result was found.

Many variants of these experiments were performed without clarifying the paradoxical situation. The Michelson-Morley experiment was also repeated with increased precision. In 1925–26, D. C. Miller repeated it both near sea level and on Mt. Wilson (6,000 ft. altitude). He believed that his experiments showed a small velocity of the ether relative to the earth, but it is possible that he overestimated the accuracy of his results. At the same time and place, R. J. Kennedy also repeated the experiment, without detecting any relative motion of the earth and the ether. Miller's results attracted considerable public attention, and he endeavoured to draw various conclusions from them. It should be remarked that his theories failed to account either for aberration or for the result of Lodge's experiment.

It will be recalled that this and the experiments on aberration are most readily explained by assuming the ether to be stationary and not set into motion by nearby matter. George Francis FitzGerald (1892) suggested that the Michelson-Morley experiment might also be consistent with this hypothesis, although at first glance it contradicts it flatly. The simple theory of the experiment assumes that the apparatus is constructed of perfectly rigid material and does not change its shape when rotated from one position into another. He suggested that motion through the ether might cause solid objects to contract in the direction of motion, and that this contraction might be of just the proper amount to bring about the negative result of the experiment.

This contraction hypothesis has an unpleasant *ad hoc* character; it was relieved of this onus by the investigations of Lorentz (1905), who showed that it was almost a logical consequence of Maxwell's electrodynamic equations. When these are supplemented by a very simple postulate, they predict that an object moving through the stationary ether will contract by just the necessary amount to explain the negative result of the Michelson-Morley experiment. In addition, they predict that a moving clock will run slow.

In view of these theoretical and experimental results, it became customary to speak of "a conspiracy of natural laws" to prevent any observation of motion relative to the ether.

The Principle of the Relativity of Motion.—It remained only to recognize that this interplay of natural laws was not accidental, but itself the consequence of a more general law. In 1905, Einstein recognized this more general law as the principle of the relativity of motion. In its most general form, this reads as follows:

> The motion of a single object cannot be observed experimentally; only changes in the spacial relations of two or more material objects can be observed.

A restricted form of this principle had been accepted as valid since the time of Newton, and is even common knowledge among the general public. Most people have been in a railway car drawn up beside another in a station, and have experienced momentary confusion when one of the two began to move. Only by glancing at a building or some other third object is it possible to be certain which train has started.

One consequence of the old principle of qualitative similarity was that the ether could serve as such a third material object, despite its intangibility. The negative results of the many modifications of the Michelson-Morley experiment indicated that the ether was not a material object in the sense of the principle of relativity.

However, the many lines of evidence for an all-pervasive something which takes part in the dynamic processes of the universe remained valid. While it was not immediately recognized that space itself has some of the properties formerly ascribed to the ether, Einstein immediately recognized that an acceptance of the principle of relativity in its most general form had implications for all natural laws, including those of geometry.

To understand this, it is necessary to make a brief review of the development of geometric theory. This began in earliest history, and there is every reason to believe that at first geometry bore the same relation to the practical affairs of the architect and engineer as, say, the theory of electricity does today. Even in the highly academic writings of Euclid (300 B.C.) there is internal evidence of this mundane origin. Later writers, puzzled by the remarkable logical rigour of Euclid's theorems, advanced the idea that the concepts of space and time are a congenital part of human reason. The denial of any of the "self-evident" axioms of geometry would, according to this view, result in demonstrable contradictions.

This *a priori* position of geometry was rendered untenable by the investigations of Nikolai Lobachevski (1826) who showed that it was possible to construct logical systems analogous to Euclidean geometry, based on sets of axioms which are incompatible with the "true" axioms of geometry.

At first, these non-Euclidean geometries were merely mathematical curiosities, but they gradually forced a return to the older conception of geometry. The decision as to the "true" axioms was not a matter of pure logic, nor were all of the axioms of geometry "self-evident" (*see* Geometry). Perhaps it was Einstein who first clearly formulated the view that the axioms of geometry are generalizations based on experiments with solid objects, and as such, are subject to reformulation in the light of more refined experiment.

In the same way, geometrical concepts are abstractions from reality, just as are the concepts of electrical theory, etc. The primary concept of Euclidean geometry is that of a rigid body, which can be moved without changing its shape. It was from this point of view that Einstein approached the Lorentz-FitzGerald contraction hypothesis, and recognized its implications for geometry. A less obvious concept of Euclidean geometry is that of a signal which can be transmitted instantaneously from one place to another. A study of the ether drag experiments led Einstein to the hypothesis that no signal could be transmitted with a velocity greater than that of light. This necessitated other revisions of geometry and also of the theory of time. Ultimately, it was possible to construct a single theory which embraced all of geometry, kinematics, mechanics and electromagnetic theory.

The achievement was similar to that of Maxwell, who had welded the previously separate theories of electricity and magnetism into a single logical unit. Perhaps not surprisingly, Maxwell's electromagnetic theory was the only one of the four that could be included in Einstein's system without critical revision.

Einstein's Theory of Gravitation.—It has repeatedly been noted above that the theory of gravitation had resisted all efforts to make it an integral part of the theories whose development has been traced. Neither had any major contribution to our knowledge of gravitation been made since Newton's time. The necessity for a revision of the Newtonian theory was now acute: for it implied that the gravitational forces were transmitted instantaneously. This was a flat contradiction to Einstein's 1905 hypothesis of a maximum signal velocity. While this was at once apparent, it was not until 1916 that Einstein constructed a detailed theory which embraced gravitational as well as electromagnetic forces.

It is characteristic of the force of gravity that it produces the same acceleration in all objects, large or small, light or heavy. This has been embodied in the apocryphal tale of Galileo Galilei and the leaning tower of Pisa. It was the subject of Evangelista Torricelli's famous experiment showing that a feather and a coin fall side by side in a vacuum. Einstein generalized it into the proposition that it is impossible to distinguish between an acceleration and a gravitational field. With the advance of aviation, this principle has become part of ordinary language, and it is common to hear such statements as, "The pilot weighs half a ton as he pulls his plane out of a power dive." Einstein's principle of equivalence asserts that this is neither metaphor nor exaggeration. The theory of gravitation is part of geometry and kinematics.

The actual incorporation of this principle into the theory of space-time required abstract logical reasoning of considerable complexity. The basic mathematical investigations were already complete, however, They had been begun by Karl F. Gauss (1821–1848) and carried through by Georg F. Riemann (1854). It is no disparagement of Einstein's achievement to emphasize the continuity of his work with that of his predecessors. They had been tentatively developing the idea that the properties of space are somehow determined by its material content of planets, houses, men. It was a major advance to assert definitely that the local properties of both space and time are direct consequences of the existence of nearby matter, and that, in turn, these properties have a causal influence on the motions of that matter. The development of this assertion into a detailed scientific theory was an even greater step.

This theory of gravitation has been confirmed experimentally. For a long time, a certain small irregularity in the motion of the planet Mercury (the precession of its perihelion) had defied explanation. The modified theory accounted perfectly for it.

Furthermore, the new theory predicted that light rays would be curved when passing close to a large object such as the sun. This has been confirmed by observations of the stars seen near the sun during a total eclipse. (*See* Space-Time; Relativity.)

The Photon Theory.—It might be satisfactory to some if this partial account of man's attempt to understand the universe could be closed with an implication of success and completion. The successes of the project are obvious, but it is not yet completed.

The history of the ether theory is essentially that of the rise of the wave theory of light and the decline of the rival corpuscular theory. Even while the former was being completed, new experimental discoveries gave the corpuscular theory a new vitality. The discovery of the photoelectric effect by Philipp von Lenard (1904) and of the change of wave length of X-rays on scattering (Arthur H. Compton, 1923) unexpectedly disclosed new properties of light. Had these been known at the time of Fresnel, it is doubtful whether the wave theory of light could ever have won adherents.

It was Einstein who pointed out that these newly discovered properties could easily be explained by the corpuscular theory, but would be very difficult to reconcile with the wave theory.

Detailed theories were developed by Erwin Schroedinger, Werner Heisenberg and Paul A. M. Dirac (1925) but have no direct bearing on the ether theory and therefore do not come into the present considerations. (*See* Quantum Mechanics.) It is certain that they, also, are only the first stage of a further evolution of physical theory.

See E. T. Whittaker, *History of the Theories of the Aether and Electricity*, 2 vol., 2nd ed. (London, 1951; New York, 1952).

See also Electricity; Electric Waves; Radio; Light; Relativity; Quantum Mechanics. (C. Et.)

ETHEREGE, SIR GEORGE (*c.* 1635–1691), English dramatist and poet, was probably born about 1634–35, but practically nothing is known of his life except for a short period. Knowledge of his ancestry and early history is only derived from some chancery papers in the record office, from which it is gathered that his grandfather lived at Maidenhead and that he spelled his name as it is here spelled. He may have been educated at Cambridge, have studied law at one of the inns of court, and have lived some part of his early life abroad. In 1664 he was living in London, apparently quite unknown, when his first comedy, *Love in a Tub*, was produced at the Duke's theatre. This play marks the beginning of the specifically restoration comedy. It is partly in rhymed heroic verse, but the comedy scenes, with their play of wit, and their introduction of the "war of the sexes" theme, strike a new note in the history of the English drama. With the production of this play, Etherege leaped into fame. Thereafter he was one of the outstanding figures in the circle of