Einstein's and other Unitary Field Theories: An Explanation for the General Reader.

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I.

THE announcement of the publication of Einstein's new theory has aroused great interest even among those who do not usually follow the advances of science. Unfortunately, this interest has been accompanied by a feeling that the new theory, like Einstein's earlier ones, is a mysterious mixture of metaphysics and mathematics, so obscure and paradoxical that the average man cannot possibly acquire any notion of what it is all about. Indeed, a French author declared that " when two German professors meet, and each can understand what he says himself, but cannot understand the other, they are said to be talking Metaphysics. If, however, the subject of discussion is so profound that they are unable to understand not only each other, but even themselves, it is called the Higher Metaphysics. Now Einstein's Theory belongs to the Higher Metaphysics."

The purpose of the present article is to dispel such views. By going back to the work of Newton and Maxwell we can trace the general nature of the ideas that have been uppermost in Einstein's mind. It will be shown how the desire for unification of apparently different physical phenomena was the guiding force in each case. Other attempts at unification of gravitation and electromagnetism will be explained and contrasted with Einstein's. It is hoped that, by simple considerations concerning the meridians and parallels of longitude on the earth's surface, readers without any mathematical knowledge may be able to grasp the general nature of the principles underlying the new geometries.

NEWTON AND GRAVITATION.

When Newton (1642–1727) started to consider the subject of planetary motions, he found in existence fairly accurate knowledge of the facts, but only the wildest speculations as to the underlying causes. Thus Kepler (1571–1630), by analysing the astronomical observations of Tycho Brahe (1546–1601), had found three laws of planetary motion. One of these was that the orbits were ellipses with the sun in the focus. Kepler even guessed that universal gravitation might have something to do with these laws, but he also considered them as partly due to a magnetic force set up by the sun's rotation. Descartes (1596–1650) thought that space was filled with vortices of ether, and the planets were dragged round by these vortices like sand particles in a whirlwind.

It was Newton's magnificent combination of physical intuition and mathematical power that enabled him to sweep aside these vague ideas, and to set up what we may call a unitary theory, which explained on a single basis effects hitherto believed to be due to more than one source. He showed that gravitation alone, acting between every two particles of the universe with a force proportional to the product of the masses divided by the square of the distance between them, was sufficient to account for all the phenomena of planetary motion. It is interesting to notice that at first Newton's theory of gravitation appeared to be disproved by the observed facts concerning the moon and the earth. This caused Newton to put aside his ideas for several years. When a more accurate set of observations was available the theory was vindicated. Its substantial correctness is conclusively proved every year by the truth, to a very close approximation, of the astronomical predictions of the *Nautical Almanac*.

MAXWELL AND ELECTROMAGNETISM.

We now come to the twin sciences of electricity and magnetism. The investigation of their mutual relationship was due to several investigators, among whom Faraday (1791–1867) takes a prominent place. Then came Maxwell (1831–1879), who, in what are now well known as " Maxwell's Electromagnetic Equations ", gave mathematical form to Faraday's ideas and extended them. Maxwell's theories, which united electromagnetism and light, were criticised at the time, and even Lord Kelvin was of opinion that " up to the present the so-called Electromagnetic Theory of Light does not seem to have accomplished much ". One term in Maxwell's equations (representing what is called a displacement current) seemed to owe its origin to an illegitimate union of mathematics and metaphysics. Worst of all, there seemed no experimental verification of the consequences of the equations. This was not forthcoming until after Maxwell's death, and was due to Hertz (1857–1894). The electric waves the existence of which was implied by Maxwell's equations were actually produced, and they may now be received every night by the millions who listen to radio concerts.

EINSTEIN'S SPECIAL THEORY (1905).

Long after Maxwell's equations had been firmly established for a fixed system, there was grave doubt as to how they should be extended to a moving one. In order to explain the results of the famous Michelson-Morley experiment, FitzGerald and Lorentz introduced the remarkable hypothesis of a contraction caused by motion. Einstein (1879–) showed that the phenomena could be accounted for on the basis of the hypothesis that the velocity of light and all other electromagnetic phenomena would be exactly the same for two observers who were moving with uniform velocity relative to each other. This was based on the measurement of time by light signals, an idea which seemed fantastic in those days, but an equivalent idea, the fixing of time by electromagnetic signals sent out by radio from Daventry or Paris, has now become a commonplace in many households.

Those who scoffed at the idea of time being anything but an absolute quantity must now see that it is at least possible that the clocks regulated by the radio signals from the Eiffel Tower, based upon observations at the Paris Observatory, might not agree exactly with those sent out from Daventry and based on observations at Greenwich. This discrepancy, conceivable in any case, would become more so if France and the Eiffel Tower were moving away from Daventry with enormous velocity. But the contraction of rods and the slowing down of clocks, to which so much attention has been directed, are (as pointed out by Eddington) only apparent. Nothing really happens, except that each observer is unable to get an accurate idea of what length and time really are in the other system. The only accurate way to take measurements in a system is to travel with it, and if this is impracticable, as in the case of an electron moving with a speed which is an appreciable fraction of that of light, our measurements of both space and time concerning the electron are slightly different from what they would have been if we could have travelled with it. These slight differences are related to each other. This is what we mean when we say that space and time form a four-dimensional continuum.

There is no need to try to imagine a fourth dimension, but calculations, to be accurate in the case of high velocities, must deal with time as well as with the three dimensions of space. In this sense the theory united space with time, and so was a unitary one. It also united electricity more closely with magnetism, for it showed that what appears to be a purely magnetic field in one system will appear to be a purely electric field in another system moving relative to the first. Moreover, it united mass (inertia) and energy, showing that one can be transformed into the other. This has since been confirmed in the case of the helium atom, the mass of which is slightly less than the sum of the masses of the nucleus and the electrons which compose it. The discrepancy is made up by the potential energy stored up when the electrons and nucleus are packed closely together.

In spite of this discussion of mass and energy, we can say broadly that Einstein's Special Theory was fundamentally an electromagnetic one, having no connexion with gravitation. Its experimental basis was a slender one, and even such as it is, it has been called in question by Miller, who claims to have obtained, at great distances above sea-level, evidence of the ether-drag of which Michelson and Morley, at about sea-level, found no trace. (In spite of the elaborate precautions against error that Miller took, there is a general disposition to reject his results.) Perhaps the chief service rendered to science by the Special Theory was the help it gave in arriving at the general one, with which we will now deal.

PHYSICAL BASIS OF EINSTEIN'S GENERAL THEORY (1915).

In the dynamics of Newton, the same number, the *mass*, appears to measure three entirely different properties, namely, the quantity of matter, the inertia (or difficulty of setting it in motion), and the weight (the force exerted on it by the earth). Is this merely a marvellous coincidence? Einstein thought not, and inferred that inertia and weight are probably two aspects of the same phenomenon, due to something in the nature of space (or rather of space-time). Again, everyone knows the queer feeling of falling when a lift starts to descend, or of heaviness when a descending lift is coming to rest. Weight, in fact, seems to alter when in a system, like a lift, which can be accelerated.

This suggests a connexion with relative motion, which, for uniform velocity, was considered in the Special Theory. These considerations led Einstein to seek hypotheses concerning space and time which would incorporate the results of his former theory and at the same time account for inertia and gravitation. In other words, he was led to seek a new geometry.

ABSTRACT AND PHYSICAL GEOMETRY.

How can there be a new geometry? Most of us had it fixed in our minds that geometry was a fixed and unalterable science. Did not Euclid, starting with axioms that were self-evident truths, reach conclusions which will stand for all time and, moreover, can be verified by sufficiently careful drawing? This is certainly what we gathered from Blank and Dash's "Geometry for Schools", but it rests upon a confusion of ideas.

First of all, there are two distinct kinds of geometry, abstract and physical. The first starts with certain *undefined* terms, such as point, straight line, and plane, and makes certain *unproved* statements, called axioms (or postulates), about them. Then we deduce consequences from these definitions and axioms, which constitute abstract geometry. The whole structure is purely a sort of building game, in which the definitions and axioms, taken more or less at random, furnish the bricks, and we see what we can build with them. There is no necessary connexion with the physical world, and so it is meaningless to inquire whether the axioms are true or self-evident. To vary the metaphor, they are the rules of the game, and may be changed at will if we want to construct a new game. Euclid's geometry in its ideal form, when it reasons entirely from the definitions and axioms (an ideal not realised in any school geometry), is one system of abstract geometry. But so long as the science is only an abstract one, we are at liberty to start with a set of axioms quite different from those of Euclid. We shall see later that by studying the properties of a sphere we can build up a system called Riemannian geometry, of which Einstein makes great use.

We now come to physical geometry, the science that deals with the results of the draughtsman, the surveyor, and the architect, and expresses the properties of rulers, set-squares, plumb-lines, and other physical objects. Of course, Poincaré was right when he asserted that we can assume any system of geometry we like (and no doubt most of us prefer the simplest, namely, Euclidean), and then explain any observed physical phenomenon, however strange, by attributing it to some physical force. However, Einstein preferred to proceed otherwise, and exercised his free choice of an abstract geometry in such a way as to sacrifice some of the simplicity in the geometry to gain as much as possible in the physics. For example, in his theory there is no need of a gravitational force to make a planet move in its orbit, for this orbit is as natural in his geometry as is a straight line in the geometry of Euclid and Newton. This is what is meant by 'the geometrisation of physics', and we may define physical geometry as that one of the many possible systems of abstract geometry which is most successful in giving a simple account of physical phenomena. The experience of draughtsmen and others shows that Euclidean geometry works very well indeed in ordinary terrestrial affairs, so physical geometry cannot differ very much from Euclidean.

The Origin of Adaptations.[1]

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BY an adaptation is meant nothing more than a character of an organism, which has enabled a species to survive itself as such, or to survive until it is transformed into another species. It is survival that gives the measure of the value of the adaptation. Survival can only occur if the whole organism is adapted to the environment to an extent that suffices. Organism and environment must be thought of as a unity, as interlocked and fitted closely to form that harmony which is Nature and life. Organic evolution is a phase—the crowning phase, may be—of cosmic evolution. The biological environment determines survival no less than the physical, and adaptation to both must be sufficient. The environment is not fixed, but must be thought of as in a condition of perpetual flux and change. This is true especially of the biological environment, for species once common may practically disappear, and years later may reappear abundantly with devastating effect on other organisms.

The general physical conditions under which organisms live have been well discussed by L. J. Henderson in his book "The Fitness of the Environment" (1913). Henderson discusses the unique properties of water, carbonic acid, hydrogen, and oxygen, and shows how they are specially fitted for the purposes of organic life. "There are no other compounds which share more than a small part of the qualities of fitness of water and carbonic acid; no other elements which share those of carbon, hydrogen, and oxygen." "None of the characteristics of these substances is known to be unfit or seriously inferior to the same characteristics in any other substance." "The fitness of the environment is one part of a reciprocal relationship of which the fitness of the organism is the other."

Darwin's answer to the question, how does the adaptation of organism to environment come to be, was based on three factors—heredity, variation, selection. In ultimate analysis the fact of heredity depends on the cellular structure of organisms and the phenomenon of cell division. When a living cell divides, its most essential substance, the germ plasm, separates into two portions which are almost equal. But we cannot so easily obtain an insight into the problem of variation. For simplicity's sake, consider first the formation of a germ cell from its mother cell in an organism which is developing parthenogenetically. The researches of the colloid chemist have given us the picture. In imagination enlarge the germ mother-cell until you see the two phases; the liquid, the mass of molecular aggregates varied in size and shape; until you see the long, complex chains of atoms, building up the heavy molecules which form the aggregates; until you see the solar systems in miniature of protons and electrons which are the atoms—a seething, churning mass, active with the activity of cosmic forces, receiving matter and energy constantly from the surrounding medium, and giving them back. The preparations for cell-division begin; the molecular aggregates arrange themselves in new patterns; the separation of the cell into two parts ensues. Is it a matter for surprise that the partition of pattern and of substance is not always, perhaps is never, exact? We cannot wonder that germ cells thus produced differ in small respects among themselves. A few molecules more or less, a few atoms more or less, a few electrons even more or less, may mean large changes in the offspring into which the germ cell grows. We are, I think, safe in concluding that lack of equality in the partition of the hereditary material is one important cause of variation. If we think on similar lines of sexual development, where instead of one we have two germ cells uniting to form the zygote from which the offspring is developed, the probability of variation between parent and offspring, and between different offspring of the same parent, is obviously much increased.

Weismann was the first to draw a clear and sharp distinction between true hereditary characters and modifications of the body or soma, produced by the direct action of physical changes in the environment, and to develop the conception of the continuity of the germ-plasm. The germ-plasm is the transmitter, in unbroken continuity from generation to generation, of hereditary qualities. The body or soma is its temporary guardian, perishing when the work of transmission has been done. Blastogenic characters, as Weismann called the true hereditary characters, reappear in exactly the same form in the offspring as they show in the parent, provided both parent and offspring have grown up in the normal environment. Few now question that the nucleus is the essential organ of the germ cell which is engaged in the transmission of hereditary characters. Few

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[1] Extracted from the Hooker Lecture, delivered before the Linnean Society of London on Mar. 14.