Gravitation and Light.

As I said last week (p. 334), and also in the December *Phil. Mag.* (p. 737), the refractivity $\mu-1$, necessary at every point of a gravitational field to produce the Einstein deflection, is the ratio of the energy of a constant-mass particle fallen there from infinity to the energy of the same particle moving with the speed of light; but it is not permissible to say that the solar gravitational field acts like a lens, for it has no focal length. If the sun were backed by a nebula or any luminous area, the light grazing the rim all round would be brought to a focus at a place seventeen times the distance of Neptune, while light from any larger circle would focus still further off in proportion to the area of the circle. So from a uniformly luminous area there would result a focal line of constant brightness. The moon is, unfortunately, impotent to make an annular eclipse interesting.

For an extended solar atmosphere to produce the deflection, its density would have to vary with the inverse distance, which seems unlikely; but this is just the way in which an æther tension ought to vary in order to cause gravitation—as Newton knew. The extra æther-tension factor, μ^2-1 , would be twice the refractivity.

Possibly the concluding sentence in the *Phil. Mag.* article above referred to is not expressed with sufficient clearness. Permit me to explain my points thus:—

(1) The quasi-elasticity of æther—the property which enables it to transmit light and to effect electrical discharge—is probably due to exceedingly fine-grained constitutional vorticity with high-speed circulation, as argued in my book “The Ether of Space.” Consequently it would have facility for gyrostatic action, yielding a perpendicular result to an acting force.

(2) That a gravitational force acting obliquely on light would probably be unable to alter speed, but, through the co-operation of its transverse and longitudinal components, it might be expected to produce an extra dose of deflection—assuming light to be subject to gravitation, as Newton surmised. So that by the time a beam of light coming from infinity had arrived at its nearest point to the sun, it would already have been deflected as much as an ordinary heavy particle would be deflected along its whole course.

I am aware that these are only suggestions for working out.

Einstein's equations, based on the impossibility of observing motion through æther, seem powerful instruments for extracting results; just as more familiar equations, based on the impossibility of “perpetual motion,” have proved themselves effective; but neither set of equations explains, nor attempts to explain, the mechanism of the consequences they deduce. Dynamics have served us so well in the past that it must be still legitimate to try, wherever possible, to apply well-established principles to new phenomena.

OLIVER J. LODGE.

Edgbaston, Birmingham, November 30.

The Displacement of Light Rays Passing near the Sun.

THE part of the earth's atmosphere within the conical shadow of the moon during a total solar eclipse may be regarded as approximately a right circular cylinder, the area of the base of which depends on the length of the shadow. Observations have shown that there are temperature and pressure gradients in this cylinder. The latter gradient at the surface of the earth is usually slight, but the temperature gradient may be considerable, so that, assuming that there is equilibrium, we have, roughly speaking, a cylinder of air the density of which decreases outwards

in all directions perpendicular to its axis. When we remember that the light from stars at small angular distances from the sun's centre makes small angles with the axis of this cylinder, it is easy to see that a very small density gradient would be sufficient to account for the displacements that were observed in the total solar eclipse of the present year.

Suppose the cylinder to be made up of two parts, an inner and an outer, the common boundary being a coaxial cylinder, and let a ray of light in the outer portion inclined at a small angle α to the axis fall on the boundary, the deviation δ is given by

$$\cos \alpha = \mu \cos (\alpha + \delta),$$

where μ is the index of refraction for rays passing from the outer portion to the inner.

Since δ is very small in comparison with α , we have, approximately,

$$\delta = \frac{\mu-1}{\mu \tan \alpha} = \frac{\mu-1}{\tan \alpha} \text{ very nearly,}$$

since μ does not differ much from unity.

If $\alpha = 30'$ and $\delta = 1.7''$, we get

$$\mu = 1 + \delta \tan \alpha,$$

δ being expressed in circular measure.

Thus $\mu = 1.00000007$, and for small values of α it is clear that δ is inversely proportional to the angular distance of the star from the centre of the sun's disc.

If we take μ_1 , the absolute index of refraction of the outer portion, to be 1.0003, μ_2 , the absolute index of refraction of the inner portion, will be 1.00030007, and consequently

$$\frac{\mu_2-1}{\mu_1-1} = 1.0002,$$

which will be the ratio of the density of the air in the inside portion to the density of the air in the outside portion. On the assumption that there is no gradient of pressure, this would imply a difference of temperature of about $1/180^\circ \text{C.}$, a very small amount when it is remembered that the lowering of temperature at the surface of the earth during an eclipse may be as much as 5°C.

In the actual case the path of a ray will be a curve, but the above remarks will serve to show that the density gradient would probably be sufficient to produce the observed effect. It is clear, too, that the displacement in the actual case will be inversely proportional to the angular distance of the star from the sun's centre, and that it will depend on local conditions, so that the amount of displacement will be different for different places.

I think it is quite likely that if the refraction of the atmosphere of the earth due to density changes during an eclipse could be accurately obtained and allowed for, it would be found that there is no Einstein effect at all.

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EINSTEIN'S RELATIVITY THEORY OF GRAVITATION.

I.

THE results of the Solar Eclipse Expeditions announced at the joint meeting of the Royal Society and Royal Astronomical Society on November 6 brought for the first time to the notice of the general public the consummation of Einstein's new theory of gravitation. The theory was already in being before the war; it is one of the few pieces of pure scientific knowledge which have not been set aside in the emergency; pre-

parations for this expedition were in progress before the war had ceased.

Before attempting to understand the theory which, if we are to believe the daily Press, has dimmed the fame of Newton, it may be worth while to recall what it was that he did. It was not so much that he, first among men, used the differential calculus. That claim was disputed by Leibniz. Nor did he first conceive the exact relations of inertia and force. Of these, Galileo certainly had an inkling. Kepler, long before, had a vague suspicion of a universal gravitation, and the law of the inverse square had, at any rate, been mooted by Hooke before the "Principia" saw the light. The outstanding feature of Newton's work was that it drew together so many loose threads. It unified phenomena so diverse as the planetary motions, exactly described by Kepler, the everyday facts of falling bodies, the rise and fall of the tides, the top-like motion of the earth's axis, besides many minor irregularities in lunar and planetary motions. With all these drawn into such a simple scheme as the three laws of motion combined with the compact law of the inverse square, it is no wonder that flights of speculation ceased for a time. The universe seemed simple and satisfying. For a century at least there was little to do but formal development of Newton's dynamics. In the mid-eighteenth century Maupertuis hinted at a new physical doctrine. He was not content to think of the universe as a great clock the wheels of which turned inevitably and irrevocably according to a fixed rule. Surely there must be some purpose, some divine economy in all its motions. So he propounded a principle of least action. But it soon appeared that this was only Newton's laws in a new guise; and so the eighteenth century closed.

The nineteenth saw great changes. When it closed, the age of electricity had come. Men were peering into the secrets of the atom. Space was no longer a mighty vacuum in the cold emptiness of which rolled the planets. It was filled in every part with restless energy. Æther, not matter, was the last reality. Mass and matter were electrical at bottom. A great problem was set for the present generation: to reconcile one with the other the new laws of electricity and the classical dynamics of Newton. At this point the principle of least action began to assume greater importance; for the old and the new schemes of the universe had this in common, that in each of them the time average of the difference between the kinetic and the potential energies appears to be a minimum.

One of the main difficulties encountered by the electrical theory of matter has been the obstinate refusal of gravitation to come within its scope. Quietly obeying the law of the inverse square, it heeded not the bustle and excitement of the new physics of the atom, but remained, independent and inevitable, a constant challenge to rash claimants to the key of the universe. The electrical theory seemed on the way to explain every property of matter yet known, except the one most universal of them all. It could trace to

its origins the difference between copper and glass, but not the common fact of their weight; and now the æther began silently to steal away.

One matter that has seriously troubled men in Newton's picture of the universe is its failure to accord with the philosophic doctrine of the relativity of space and time. The vital quantity in dynamics is the acceleration, the change of motion of a body. This does not mean that Newton assumed the existence of some ultimate framework in space relative to which the actual velocity of a body can be uniquely specified, for no difference is made to his laws if any arbitrary constant velocity is added to the velocity of every particle of matter at all time. The serious matter is that the laws cannot possibly have the same simplicity of form relative to two frameworks of which one is in rotation or non-uniform motion relative to the other. It seems, for instance, that if Newton were right, the term "fixed direction" in space means something, but "fixed position" means nothing. It seems as if the two must stand or fall together. And yet the physical relations certainly make a distinction. Why this should be so has not yet been made known to us. Whatever new theory we adopt must take account of the fact.

It was with some feeling of relief that men hailed the advent of the æther as a substitute for empty space, though we may note in passing that some philosophers—Comte, for example—have held that the concept of an æther, infinite and intangible, is as illogical as that of an absolute space. But, jumping at the notion, physicists proposed to measure all velocities and rotations relative to it. Alas! the æther refused to disclose the measurements. Explanations were soon forthcoming to account for its reluctance; but these were so far-reaching that they explained away the æther itself in the sense in which it was commonly understood. At any rate, they proved that this creature of the scientific imagination was not one, but many. It quite failed to satisfy the cravings for a permanent standard against which motion might be measured. The problem was left exactly where it was before. This was pre-war relativity, summarised by Einstein in 1905. The physicists complained loudly that he was taking away their æther.

Let it not be thought, however, that the results of the hypothesis then advanced were purely negative. They showed quite clearly that many current ideas must be modified, and in what direction this must be done. Most notably it emphasised the fact that inertia is not a fundamental and invariable property of matter; rather it must be supposed that it is consequent upon the property of energy. And, again, energy is a relative term. One absolute quantity alone remained; one only stood independent of the taste or fancy of the observer, and that was "action." While the æther and the associated system of measurement could be selected as any one of a legion, the principle of least action was satisfied in each of them, and the magnitude of the action was the same in all.

But, still, gravitation had to be left out; and the question from which Einstein began the great advance now consummated in success was this. If energy and inertia are inseparable, may not gravitation, too, be rooted in energy? If the energy in a beam of light has momentum, may it not also have weight?

The mere thought was revolutionary, crude though it be. For if at all possible it means reconsidering the hypothesis of the constancy and universality of the velocity of light. This hypothesis was essential to the yet infant principle of relativity. But if called in question, if the velocity of light is only approximately constant because of our ordinary ways of measuring, the principle of relativity, general as it is, becomes itself an approximation. But to what? It can only be to something more general still. Is it possible to maintain anything at all of the principle with that essential limitation removed?

Here was exactly the point at which philosophers had criticised the original work of Einstein. For the physicist it did too much. For the philosopher it was not nearly drastic enough. He asked for an out-and-out relativity of space and time. He would have it that there is no ultimate criterion of the equality of space intervals or time intervals, save complete coincidence. All that is asked is that the order in which an observer perceives occurrences to happen and objects to be arranged shall not be disturbed. Subject to this, any way of measuring will do. The globe may be mapped on a Mercator projection, a gnomonic, a stereographic, or any other projection; but no one can say that one is a truer map than another. Each is a safe guide to the mariner or the aviator. So there are many ways of mapping out the sequences of events in space and time, all of which are equally true pictures and equally faithful servants.

This, then, was the mathematical problem presented to Einstein and solved. The pure mathematics required was already in existence. An absolute differential calculus, the theory of differential invariants, was already known. In pages of pure mathematics that the majority must always take as read, Riemann, Christoffel, Ricci, and Levi-Civita supplied him with the necessary machinery. It remained out of their equations and expressions to select some which had the nearest kinship to those of mathematical physics and to see what could be done with them. E. CUNNINGHAM.

DISCOVERY OF A MINOAN PALACE AT MALIA, IN CRETE.

DISCOVERIES of great importance have been made during the course of excavations carried out this year in Crete by M. Joseph Hatzidakis, at a site one kilometre from the shore, near the village of Malia, about twenty miles east of Candia.

The site of a palace of the Middle Minoan epoch has been uncovered, and numerous objects found. The containing walls of the palace, the lower courses of which consist of *poros* stone, can all

be traced, the dimensions of the building being 110 metres in length and 80 metres in width. The interior walls, which are of bricks and rubble, are 2'30 metres in thickness, and the floor of the palace is composed of a layer of white earth upon which is a stratum of chalk and sand with a top surface of red chalk paste. The outside of the containing walls was covered with a white chalk wash.

The palace was destroyed by fire shortly after the end of the Middle Minoan epoch, and probably suffered from the depredations of looters for a considerable time after its destruction. In consequence, few objects of value, and nothing intact, have so far been discovered. A very large number of small fragments of gold leaf, however, have been found. For many years past similar fragments have been found by the peasants from time to time, and the site became known as "Chryso-lakkos," "The ditch of gold." Capt. Spratt early last century noted the prevalence of such gold fragments on this site. The fragments are derived in all probability from some large bone or wooden objects which were decorated with gold leaf. Bronze was rare, only a dagger blade, a brooch, and a band having been found.

The fields between the shore and the palace show traces of walls, and in one case a complete house, all of the same date as the palace, and clearly belonging to the town in which the palace was situated. The site of a necropolis was found near the shore, where one grave containing pottery of the same date as the palace was opened.

Minoan pictographic or graphic signs were found cut on various stone blocks in the palace. The double-axe occurred on a large tetragonal pillar, which was of the type found at Knossos, but twice the size. A six-rayed star of a known type also occurred; a similar star with a spray at the end of one of the rays represents a sign not hitherto known.

The pottery so far discovered is disappointing, no complete or even well-preserved pieces having been found. The best fragments, mostly of cups of the Middle Minoan periods, were found in what appears to have been a shrine.

Three kilometres to the west of the palace a number of graves of the third Late Minoan or Mycenaean period were found. One of these graves was opened, and was found to contain five rectangular "larnakes," in each of which was a skeleton.

The importance of the site lies in the fact that this is the only example hitherto found of a palace of the Middle Minoan epoch without an overlying building of later date. The Middle Minoan parts of the palaces of Phæstos and Knossos are overbuilt with walls of the Late Minoan periods, and the plans and details of the Middle Minoan palaces at these places cannot, in consequence, be definitely ascertained. The existence of a city and necropolis of the same date as the palace increases the importance of the site. The Late Minoan city is clearly to be found some distance away. The excavations will be continued, and promise important results.