ment démonstratif de l'installation nouvelle de 50,000 chevaux en cours de montage à la Milwaukee Electric Railway and Lighting Co. destinée à alimenter une centrale de 200,000 kw." At home pulverised coal has recently been applied at the Hammersmith Central Electrical Station.

The advent of a new process in connection with coal dust has resulted in a considerable step forward being made towards the reduction in the extent of the equipment necessary in the preparation and conveyance of coal dust for combustion. This process is that by which the finely divided coal dust is intimately mixed with oil to form what is inaccurately termed a "colloidal" fuel, for *colloidal* it is not. In this process the coal is ground in oil, a mixture resulting which is sufficiently stable for all practical purposes, especially so when the proportion of solid fuel contained therein exceeds 50 per cent.; mixtures of equal quantities of oil and coal have been used after standing three months in barrels without any difficulty having been experienced in regard to sediment.

In the case of the so-called "colloidal" fuel, unless the amount of moisture is very excessive, the coal can be used without having to resort to drying preliminary to crushing, which means a curtailment in the equipment required as compared with the use of simple pulverised fuel. It has a further advantage in respect of transportation and of handling, in that it is a semi-liquid, and can be treated as an oil fuel, after due allowance for its greater viscosity. It is not liable to spontaneous combustion, and is burnt in the same manner as if it were "straight" oil.

The field for the use of "colloidal" fuel is great. The fuel can be employed wherever oil is applicable as a steam raiser. Its wide application will result in a vast saving in the consumption of oil, and its manufacture allows of the useful employment of low-grade coals and of coals deficient, for other purposes, in volatile constituents.

Remarks on Gravitational Relativity.[1]

By Sir Oliver Lodge, F.R.S.

IV.

WHEN we come to the more general theory, which attends to the acceleration and not merely the velocity of the observer, I find myself in disaccord on some points with many eminent exponents, chiefly in connection with their abolition of the idea of "force," and the consequent replacement of gravitation by a modified geometry; as if the earth's natural motion was in a hypocycloidal sort of spiral, and was not under compulsion by any deflecting force.

A revolt against "force" as a real objective entity was led by that great mathematician and physicist, Prof. Tait of Edinburgh. In the first instance he rebelled against the practice, adopted by text-books of the period, of using the term "accelerative force" instead of "acceleration," and making a muddle of the laws of motion by formulating what they called Law 3 thus:—"When pressure communicates motion to a body the accelerative force varies as the ratio of the pressure to the mass." Then he objected to some of the pedagogic arrow-heads sprinkled on mechanical diagrams, especially the arrow-head representing centrifugal force; since it is obvious that no such force acts on the revolving body. Ultimately Tait or his disciples (W. K. Clifford too, if I remember right, also Mach and Kirchhoff) were prepared to abandon the term force altogether, and to substitute space-rate of change of energy, or time-rate of change of momentum, or mass multiplied by acceleration, as a more real equivalent. Tait even denounced the idea of balanced forces, saying that only their effects were balanced ("Ency. Brit.," 9th ed., art. "Mechanics," §§ 285–300); as if two opposing forces were each producing their proper amount of acceleration, or of momentum, but in opposite directions. Though how this kind of statement could include the production of scalar quantities, like work and energy, is not apparent. The whole idea of "cause" came into disrepute.

Now mass-acceleration truly is a measure of the force which produces it, but that does not mean identity. Reformers spoke sometimes as if they meant identity, and desired to get rid of the term force altogether because it had been so misused. After a lecture by Prof. Tait to the British Association on "Force" (at Glasgow, in the year 1876), Sir Frederick Bramwell amusingly said that in the North of Britain the term meant a waterfall, while in London it meant the police, and that really, after the lecture, he himself scarcely knew exactly what it did mean! In that lecture Tait had dealt pugnaciously with some misuses of the term by Prof. Tyndall and other scientific people; for it is not so long ago that the words *vis* and *Kraft* were used with but little modification or caution for the quite different conception of Energy. "The Persistence of Force" was a phrase frequently employed in philosophic writings. Indeed, an accurate nomenclature has scarcely yet penetrated into common usage; and the result is an unnecessary vagueness about the term, typified by Sir F. Bramwell's more than half serious confession. Centrifugal force, for example, can be treated correctly enough by equating it to the product of inertia and rate of change of velocity, but that does not do away with the force: the force is exerted by the revolving body against its constraints. The word is misleading if thought of, in what was no doubt its original intention, as a radial fly-away tendency; it should connote only

[1] Continued from p. 785.

© 1921 Nature Publishing Group

an outward radial pressure, due to kinetic reaction against the normal component of acceleration. It is the necessary correlative of the centripetal force which must be acting on any revolving body. Centrifugal force is not acting on the revolving body, and, strictly speaking, should never be so thought of, or so depicted: it is the pressure or reaction exerted by the body on the groove or rail or æther, or whatever it may be that guides and deflects it.

Part of the mistake, if I may call it so, connected with the denial of physical reality to the directly apprehended thing called force, is the identifying of a thing with its measure. Because two things are equivalent it does not follow that they are identical. There is room for both; and force may be measured statically as well as kinetically. It is only unbalanced force that produces acceleration and calls out kinetic reaction. Acceleration is often prevented by an equal opposite force, but that does not abolish the force. Whether balanced or unbalanced, force is real enough. If Galileo had been put on the rack, the assurance of an Inquisitor that he was only suffering from balanced accelerations would have been no relief. It will be said that force is only one end of a stress, and that attention to the stress is the illuminating thing. That is perfectly true; but as a fact of experience we came across force before we understood about stress, and there are states of stress which we still are not able to understand, because they occur in the æther, and only display themselves by their "ends"—that is, by the pair of equal opposite forces in which they terminate—called in old phrase "action and reaction."

The weight of a book, or a stone, or an apple is a force acting on it; this force is due no doubt in the last resort to a stress in the ætheric medium, but we experience it as a force when we resist it muscularly; and though we may measure it by the mass-acceleration of the body when allowed to drop, it acts equally when the body is resting on a table or hanging from a twig; only then the reasoned and hypothetical æther stress is counteracted by an obvious stress in the material support. The stress can be measured by resting the body on a spring, or hanging it from a piece of elastic; and the strain so caused is surely an undoubted reality, about which it would be extremely artificial and confusing to postulate any kind of acceleration. Some day we may be able to dive into deeper constitutional secrets, and explain all stresses and strains kinetically in terms of the gyrostatic rigidity and elasticity of æther; but that time is not yet. Meanwhile the objects here used in illustration are in static equilibrium, are obeying the first law of motion and moving with uniform velocity, so long as the forces acting on them are equal and opposite and therefore balanced.

But an unbalanced force can always be equated to the kinetic reaction or mass-acceleration of the body acted on; and in dynamics unbalanced forces are those which demand attention. All the rest is the statics of strain. D'Alembert's principle rather tended to tempt us to contemplate spurious forces, for supposed convenience, so as to reduce kinetics to statics when writing down equations—for there must be equilibrium among the internal forces acting within the confines of any closed system—and a flagrant elementary example of the kind of thing thus led up to was the ordinary text-book treatment of centrifugal force.

Elementary Repetition.

If a governor ball or conical pendulum is depicted on paper, the only arrows that ought to be drawn on it are those representing the tension in the string and the weight of the body. But such a diagram looks unfinished; nothing could rest like that; the two forces are evidently not in equilibrium; they clearly have a resultant. The unpardonable, or at least the confusing, thing is for a teacher to draw an arrow indicating a force equal and opposite to that resultant in order to make the diagram look comfortable and static. The fact is that no third force acts on the body; the body itself reacts, its mass-acceleration is equal to the resultant force; and that is the proper fact to express in an equation; you cannot express it in a diagram. The diagram can be completed only by motion, and it ought not to look as if equilibrium were attained by any part of the system. The system as a whole is in equilibrium, or the internal stresses balance, directly the kinetic reaction is taken into account, not otherwise. Centrifugal force, as the term is often employed to signify a force acting on the revolving body, is a fiction.

Yet centrifugal force is a reality; it is essential to the equality of action and reaction. There ought to be no objection to the term or idea when properly applied. But it does not act on the revolving body at all. In every instance the real centrifugal force acts, not on the revolving body, but on whatever fixed centre is responsible for holding it in its orbit; or on the constraint, such as rails or groove or ætherial medium, which is directly effective in guiding and deflecting it. The centrifugal force of the moon acts, not on the moon, but on the earth. It is part of the cause of the tides. No doubt it is primarily exerted on the ætherial medium in contact with each lunar particle, and is thus transmitted to the earth at the other end of the gravitational stress.

To finish this trivial pedagogic discussion of centrifugal force in its true, as distinguished from its usual artificial, sense, and the confusion about which body the force really acts on, we may as well point out that the same sort of trifling difficulty—caused by there being always two bodies bounding a stress,[2] while we are liable to concentrate attention on one—is responsible for that simple old puzzle about the horse and the cart. If the cart pulls back as hard as the horse pulls forward, why does it move? Every good student, sooner or later, asks himself or his teacher this question. The correspondence columns of the *Engineer* at one time exhibited persistent misconception about this elementary matter among quite a large number of readers, and some text-book writers have been bothered by it. The confusion is caused entirely by the tacit assumption that both forces must act on the cart. Not so; one acts on the cart and one on the horse. Two forces and two bodies, one force acting on each. The difficulty disappears. The horse must get a grip of the ground to enable him to exert his force on the cart, true; and the cart exerts its reaction on the horse entirely be-

[2] The fact that an advancing wave-front may simulate a body, for this purpose, is of high interest.

© 1921 Nature Publishing Group

cause of, and in proportion to, its mass-acceleration, until friction and other obvious extras have to be taken into account.

The Principle of Equivalence.

In returning from this, I hope pardonable, elementary digression to more general considerations, let me quote and amplify a sentence from a sort of summary which will appear in the *Fortnightly Review* for September:—

> To ignore or deny or supersede the gravitational stress, merely because we do not yet understand the particular configuration of the æther which is responsible for it and which renders it possible, is to blind our eyes dangerously to dynamical reality, and to rest satisfied with a mere geometrical specification of the motion as if it were a peculiarity of space.

The "principle of equivalence" formulated by Einstein claims that the inertia reaction of a revolving body, to the centripetal force responsible for the curvature of its path, is of the same character as what we call the force of gravity, due to the neighbourhood of a large mass; that this inertia reaction is indistinguishable from weight; and, generally, that no distinction can be drawn between an artificial field of force, such as that representing the effect of a carefully defined revolution round a centre, and what we are accustomed to think of as a real field of force, such as that surrounding the earth.

We are told that by referring motion to rotating axes it is possible to abolish revolution and to replace it by a centrifugal force acting outwards on the body, thereby enabling the body to be treated as if in static equilibrium. We do this when we draw a static diagram of a revolving body, say a conical pendulum or pair of governor balls, and when a spurious and non-existent force is supplied, to represent the inertia reaction, and to balance the centripetal-force component which in reality is curving the path. I called this "unpardonable" in an elementary text-book, and also wrong as a philosophic representation of fact, but as a mathematical device it seems to be permissible; at any rate, it is quite consistent with the principle of relativity. In fact, it is part of the foundation of Einstein's principle of equivalence.

Now it is true that the most careful experimentation (first Newton, and now Eötvös) has shown that weight and inertia are accurately proportional. So it is possible to balance weight precisely by inertia reaction, and, for calculation purposes, to treat centrifugal force as if it were an artificial kind of gravity, obedient to the same laws. But this can only be done with due caution and limitation, for it does not represent reality, and the laws are not in all respects the same.

We are also told that, by choosing accelerated axes as our frame of reference, weight can be abolished too. Passengers in an unsupported, and therefore freely falling, enclosure, such as a cage or lift, would experience no force of gravity; for nothing would require any support, and nothing would tend to move out of its place as defined by the walls of the room, which constitutes the passenger's natural frame of reference.

We are told still further that the behaviour of things inside an enclosure or cage in free space, dragged along by a hook with an acceleration of 32 ft. per sec. per sec., would be indistinguishable from the behaviour of things inside a stationary or equilibrated cage slung by the same hook above the earth. These examples are instructive, for in many respects the behaviour would be just the same. But such illustrations must not be pressed to philosophic extremes, as if there were really no discrimination. For one of the two cages, after the lapse of about a year, would attain the velocity of light; and surely something noticeable must happen then, even if only the invisibility of the floor. Moreover, force is not really evaded; for *something* must be dragging at the hook—something quite gratuitous—whereas the influence of the neighbourhood of the earth is a manifest *vera causa*, however little we may as yet understand about its ætherial mechanism. It must not be supposed that we have no criterion for what is *true* in all these cases; we need not allow that we have no means of discrimination, and that we are really subject to all the uncertainties and ignorances about absolute truth which tend to be grafted on to us by the doctrine of relativity in general and by the principle of equivalence in particular.

The fact is that the passengers-in-a-lift argument, like others that we encounter round about this subject, is of very limited application. It can be well used to illustrate certain non-obvious and interesting facts, but innumerable considerations contradict the idea that the force of gravity is really nothing else than a fanciful name for the mass-acceleration which can be written in equations as equivalent to it. After all, distinction is quite feasible between the reaction of a heavy body on the earth to its centripetal diurnal acceleration, and any corresponding fraction of the force of gravitation. The two do not even act in the same direction, save at the equator; and at the poles one vanishes. What is true is that the resultant between the pressure of the ground on a stone or man, and the real weight of the stone or man, is an unbalanced force which causes that stone or man to rotate round the earth once a day, and (if we allow for complete weight) round the sun once a year. Attachment to the earth has nothing to do with astronomical motions of our human body; for we are not attached. Each of us, and each loose pebble, is as much a planet as the earth, and nearly as much a satellite as the moon.

To say—if anyone does—that the force exerted by a gravitational field, such as might be due to a heavy mass at the centre of a wheel, is indistinguishable from any other constraint needed to curb the inertia reaction of a particle attached to the rim of the wheel when it is revolving, is false. For the way the force is applied is not the same, and the law of force is different. The one increases with distance from centre, the other diminishes with the inverse square.

© 1921 Nature Publishing Group

To reduce the field of the earth locally to zero by means of a falling elevator or "lift" is feasible for observers inside the lift, so long as it is small. But if, in an extensive falling chamber, gravity is to be imitated or neutralised exactly, its parts must fall in different directions, or with different accelerations, or both.

The elimination or avoidance of the idea of absolute rotation, through imitating or replacing centrifugal reaction by the influence of the stars, or by an imaginary distribution of attracting matter in distant space, round the earth or other rotating body, is preposterous, and cannot be seriously contemplated.

I know that the mathematical physicists who allow themselves to assist their exposition by employing illustrations of this kind must be well aware of the limitations attending their use; but I do not think that philosophers always are, and they may not always attend to the cautionary language employed by careful expounders. In fact, the so-called "principle of equivalence," like other popular wordings of extreme relativity, is liable to lead an incautious exponent to go beyond what is legitimate or necessary, and to land him in paradox. Yet if not pushed to absurd extremes, and if the wording is carefully guarded, the principle of equivalence is useful enough; for it is true that any effect on bodies produced by their weight can be imitated by whirling them on a revolving table. Mechanically the principle is used in industrial separators of various kinds, and in any operation requiring an enhanced value of gravity; and the principle extends to optic and electric effects also.

Reference to Mercury's Orbit again.

The theory of relativity, though originally suggested by electrical theory, was developed without further reference to that theory, and reduces an orbit to a mere spatial relation determined by the central body. But it should be clear that, unless an æther is admitted, the gravitational potential or potentials essential to the theory must represent an action-at-a-distance of the central body on space. In the third article (NATURE, August 18, p. 784), when discussing the orbit of Mercury, I did not seek to explain how it was that an extra small perturbation was necessitated by the principle of relativity; because no question about it has arisen, and because it has been done, so far as reasonably possible, at least for the bending of light, by Prof. Eddington, in chap. vi. of his book "Space, Time, etc."; while the equations are in chap. v. of his "Report" to the Physical Society of London; or, in another form, in Cunningham's "Relativity," second edition. The theory for a planetary orbit is similar to the light-path theory; but it is difficult to put the gist of it into ordinary language. Suffice it to say (1) that Newton showed, in the "Principia" (Book 1., sect. ix.), that the inverse square law is the only one to give an exact elliptic orbit, and that the slightest interference with that law would bring about a specified revolution of the orbit in its own plane, *i.e.* an apsidal progression; or, in vaguer words, would prevent the same orbit from being retraced or repeated by the planet. And (2) that the Relativity theory, virtually though not explicitly, does interfere with the exact law of inverse square, especially for a near planet. For in the ordinary equation for orbital revolution in general,

$$\frac{d^2}{d\theta^2}\left(\frac{1}{r}\right)+\frac{1}{r}=\frac{Pr^2}{h^2}$$

(with P as the acceleration at distance r from the central body M, and $\frac{1}{2}h$ as the constant rate of sweeping areas), the right-hand side is constant only for an inverse square law, $P=GM/r^2$. But relativity adds to the right-hand side, which ordinarily would be GM/h^2, another term, namely $3GM/c^2r^2$; and this small term is the one responsible for the departure from an exact conic-section orbit. The discrepancy thus introduced turns out to be right for Mercury, and insignificant for other planets; while it does not interfere with their eccentricities. Moreover, the same term is responsible for the bending of a ray of light. So the double success is very striking, and the jubilation entirely justified.

To sum up this portion.

Force is essentially a human conception derived from our muscular sense; and, from the psychological point of view, is as basic as motion, and more directly apprehended than matter. Unforced motion is straight and uniform,[3] not varying or curvilinear, and acceleration is not a fundamental property of matter, nor a diversion of empty space, but is always the result of pressure exerted upon a mass by other bodies, or in the last resort by the circumambient medium.

To geometrise physics, even if legitimate for convenience of calculation, is ultimately to complicate it. Directly the operation becomes complicated it becomes needless, or even obstructive. The new facts can be accepted, and the relativity equations can be used, but a physical explanation can still be looked for, and our knowledge of the universe will not be complete until it is found. We cannot be for ever satisfied with a blindfold mathematical method of arriving at results. We can utilise the clues so given, and admire the ingenuity which has provided them, but that is not the end; it is only the beginning. The explanation is still to seek, and when we really know the properties of the æther we shall perceive why it is that things happen as they do.

CONCLUSION.

The relativity method, by aid of its differential geometrical analysis, seeks to interpret all that is directly experienced through our senses as a manifestation of the peculiarities of space. Matter and all its functions are thus reduced to a kind of subjective space-time geometry, and everything absolute has disappeared from the physical world.

An alternative view of what may be the outcome

[3] Straightness means that no reason for deflection in any direction can be assigned; and the absence of any accelerating or retarding cause yields uniformity.

© 1921 Nature Publishing Group

of the method—a view taken in these articles, though it is not likely to be immediately acceptable to fully assured relativists—is to regard the theory of relativity as an indirect attempt, not unlike the principle of Least Action, to treat all material phenomena as developments or manifestations of unknown essential features in one universal medium; thus restoring a kind of absoluteness to motion, and therefore presumably to space and time. From that point of view the comprehensive scope of the method, with its infinitesimal continuity of treatment, is hopeful and encouraging; and the highly abstract and symbolic modes of representation, which now seem inevitable in its more advanced developments, are the tribute to our ignorance of the kind of dynamics appropriate to a substance the properties of which must be more fundamental than any we are likely as yet to have encountered among its sensory derivatives, electricity and matter.

The Edinburgh Meeting of the British Association.

By PROF. J. H. ASHWORTH, F.R.S.

PROGRAMME OF THE SECTIONS.

THE Journal for the Edinburgh meeting of the British Association, now in the hands of the printers, shows the completed plans for the business of the various sections. In particular, attention may be directed to the careful arrangements for the joint discussions. "The Age of the Earth" is to be the subject of a discussion, by the conjoined sections of physics, geology, zoology, and botany, to take place in the Natural History Lecture Theatre, Old College—the largest theatre in the University, with accommodation for an audience of more than 400. The discussion will be opened by Lord Rayleigh, and other speakers will be Prof. Sollas, Prof. Eddington, Prof. J. W. Gregory, and Prof. Lindemann.

Sections A and B will take part in a discussion on the structure of molecules, to be opened by Dr. Langmuir, of New York. He will be followed by Prof. Smithells, Prof. W. L. Bragg, Prof. Partington, Prof. Rankine, and others.

Chemists and physiologists will find common ground in the discussion on "Oxidations and Oxidative Mechanisms in Living Organisms," to which Prof. Gowland Hopkins will contribute the opening paper.

The sections on geology and engineering are to discuss the various aspects of the proposed mid-Scotland canal. The geology of the suggested route will be explained by Mr. M. Macgregor and Mr. C. H. Dinham, of H.M. Geological Survey.

"The Origin of the Scottish People" is to be the subject of discussion opened by Sir Arthur Keith before the joint sections of geography and anthropology. Prof. T. H. Bryce, Lord Abercromby, Prof. R. Weymouth Reid, Prof. Jehu, Prof. W. J. Watson, and Dr. Tocher are to take part in this discussion.

The sections of geography and education will combine for discussion on the teaching of geography, which will be opened by Mr. G. G. Chisholm, and it is hoped that Sir Richard Gregory, Sir Halford Mackinder, Prof. J. W. Gregory, Prof. Patrick Geddes, Dr. Rudmose Brown, Mr. W. H. Barker, Mr. T. S. Muir, and others will put forward their views on this subject.

The sections of zoology and psychology are to discuss "Instinctive Behaviour." Dr. Drever will open for the psychologists, and he will be followed by Prof. Goodrich, Prof. J. Arthur Thomson, and others.

A joint meeting of the sections of economics, psychology, and education will be held to discuss "Vocational Training and Tests."

The discussion following the presidential address in Section K, in which Section C is to take part, on the early history of plants, with special reference to the Rhynie fossil plants, promises to be an outstanding feature. These plants, representative of the earliest known land flora, had an organisation different from that of any living land plants, and their investigation by Dr. Kidston and Prof. Lang has thrown much light on the evolution of land floras. In addition to the president of Section K (Dr. D. H. Scott), Dr. Kidston, Prof. Lang, Dr. Horne, Prof. Bower, and Dr. Lotsy will take part in the discussion. There is to be an extensive demonstration by Dr. Kidston in the Botanical Laboratory, Royal Botanic Garden, of sections of these Rhynie plants.

As indicated in a previous notice, the presidential addresses in other sections are to be followed by discussions, and in several cases should lead to interesting debates, for instance, on "The Principles by which Wages are Determined," on "The Place of Music in a Liberal Education," and (at the Conference of Delegates of Corresponding Societies) on "Science and Citizenship."

There are other discussions planned which, though nominally forming part of the programme of one section only, will attract interested members from other sections. Among these may be mentioned discussions on "An Imperial School of Anthropology for the Training of Civil Servants and Administrators in the Dependencies of the Empire," on "Heavy Muscular Work," on "Size and Form," on "Extramural Education," and on "University Reform."

There are to be, as usual, many communications giving the results of recent investigations, and there will be exhibitions of apparatus and specimens and demonstrations of methods.

Nearly all the sections have arranged excursions to places of special interest to their members. The local secretaries of the sections of chemistry, geology, engineering, and botany have been par-

© 1921 Nature Publishing Group