

character. This renders the existence of charged material particles possible without requiring an immense mass-horizon as in Einstein's cosmology.

At first the *non-integrability of the transference of distances* (*Streckenübertragung*) aroused much antipathy. Does not this mean that two measuring-rods which coincide at one position in the universe no longer need to coincide in the event of a subsequent encounter? Or that two clocks which set out from one world-position with the same period will possess different periods should they happen to encounter at a subsequent position in space? Such a behaviour of "atomic clocks" obviously stands in opposition to the fact that atoms emit spectral lines of a definite frequency, independently of their past history. Neither does a measuring-rod at rest in a static field experience a congruent transference from moment to moment.

What is the cause of this discrepancy between the idea of congruent transfer and the behaviour of measuring-rods and clocks? I differentiate between the determination of a magnitude in Nature by "persistence" (*Beharrung*) and by "adjustment" (*Einstellung*). I shall make the difference clear by the following illustration: We can give to the axis of a rotating top any arbitrary direction in space. This arbitrary original direction then determines for all time the direction of the axis of the top when left to itself, by means of a *tendency of persistence* which operates from moment to moment; the axis experiences at every instant a parallel displacement. The exact opposite is the case for a magnetic needle in a magnetic field. Its direction is determined at each instant independently of the condition of the system at other instants by the fact that, in virtue of its constitution, the system *adjusts* itself in an unequivocally determined manner to the field in which it is situated. *A priori* we have no ground for assuming as integrable a transfer which results purely from the tendency of persistence. Even if that is the case, as, for instance, for the rotation of the top in Euclidean space, we should find that two tops which start out from the same

point with the same axial positions and encounter again after the lapse of a very long time would show arbitrary deviations of their axial positions, for they can never be completely isolated from every influence. Thus, although, for example, Maxwell's equations demand the conservational equation $de/dt=0$ for the charge e of an electron, we are unable to understand from this fact why an electron, even after an indefinitely long time, always possesses an unaltered charge, and why the same charge e is associated with all electrons. This circumstance shows that the charge is not determined by persistence, but by adjustment, and that there can exist only *one* state of equilibrium of the negative electricity, to which the corpuscle adjusts itself afresh at every instant. For the same reason we can conclude the same thing for the spectral lines of atoms. The one thing common to atoms emitting the same frequency is their constitution, and not the agreement of their frequencies on the occasion of an encounter in the distant past. Similarly, the length of a measuring-rod is obviously determined by adjustment, for I could not give *this* measuring-rod in *this* field-position any other length arbitrarily (say double or treble length) in place of the length which it now possesses, in the manner in which I can at will predetermine its direction. The theoretical possibility of a determination of length by adjustment is given as a consequence of the *world-curvature*, which arises from the metrical field according to a complicated mathematical law. As a result of its constitution, the measuring-rod assumes a length which possesses this or that value, *in relation to the radius of curvature of the field*. In point of fact, and taking the laws of Nature indicated above as a basis, it can be made plausible that measuring-rods and clocks adjust themselves exactly *in this way*, although this assumption—which, in the neighbourhood of large masses, involves the displacement of spectral lines towards the red upheld by Einstein—does not appear anything like so conclusive in our theory as it does in that of Einstein.

The Relativity of Time.

By PROF. A. S. EDDINGTON, F.R.S.

THE philosopher discusses the significance of time; the astronomer measures time. The astronomer goes confidently about his business and does not think of asking the philosopher what exactly is this thing he is supposed to be measuring; nor does the philosopher always stop to consider whether time in his speculations is identical with the time which the world humbly accepts from the astronomer. In these circumstances it is not surprising that some confusion should have arisen.

In many globular clusters there are stars which oscillate in intrinsic brightness; let us select two such stars from different clusters and invite all

the astronomers in the universe to measure the true interval of time between the moments of maximum light of the two stars. They must, of course, make whatever measurements and calculations they consider necessary to allow for the finite velocity of light. It may easily happen that the astronomers on Arcturus report that the two maxima were simultaneous; whereas those on the earth report an interval of *ten years* between the same two maxima. There is here no question of observational error; the recognised terrestrial method necessarily gives a discordant result when used on Arcturus, owing to its different motion.

Our first impulse is to blame the astronomers.

Evidently they are not giving us the true time-interval; and now that they are informed of the discordance they ought to give up their out-of-date procedure. But the astronomers reply: "Tell us, then, how we ought to find this 'true time.' By what characteristics are we to recognise it?" No answer has been given. Michelson and others sought in vain for an answer; for if our velocity through the æther could be defined, it would single out one universal system of time-measurement which might reasonably (if somewhat arbitrarily) be called true. Meanwhile the phrase *true time* is a "meaningless noise." It is idle to contest with those who hold that the thing exists and ought to be regarded. "Who would give a bird the lie, though he cry 'Cuckoo' never so?"

The direction of Northampton measured by astronomers at Cambridge is due west; measured by astronomers at Greenwich it is north-west. It is no use to tell them that they must adopt a different plan, and find a "true direction" of Northampton which does not show these discordances. They reply: "We are perfectly aware that there must be discordances, as you call them; but that is in the nature of a relative property like direction; as for this true direction which shall be the same from all stations, we have no idea what you are talking about."

The time determined by astronomers and in general use is thus a fictitious time, or, in the usual phrase, it is *relative* to terrestrial observers. Similarly it has been found that extension in space is also relative. When the Copernican theory led to the abandonment of the geocentric view of the universe, the revolution did not go far enough; it was thought that we could pass to the heliocentric outlook by merely allowing for what in pure geometry would be called a change of origin. Actually a more profound transformation is necessary. For example, the Michelson-Morley experiment is a terrestrial experiment, but its theory is treated from a heliocentric point of view; that is to say, account is taken of the varying orbital motion of the earth; it furnishes a proof of the famous FitzGerald contraction, and much ingenuity has been spent on an electrical explanation of this curious property of matter. Einstein's theory waves this aside with the remark: "Of course, your results appear strange when you describe the apparatus in terms of a space and time which do not belong to it. Your electromagnetic discussion is no doubt valid, but it is leading you away from the root of the matter; the immediate explanation lies in the difference between the heliocentric and geocentric space and time systems."

It was shown by Minkowski that all these fictitious spaces and times can be united in a single continuum of four dimensions. The question is often raised whether this four-dimensional spacetime is real, or merely a mathematical construction; perhaps it is sufficient to reply that it can at any rate not be less real than the fictitious space

and time which it supplants. Terrestrial observers divide the four-dimensional world into a series of sections or thin sheets (representing space) piled in an order which signifies time; in other words, the enduring universe is analysed into a succession of instantaneous states. But this division is purely geometrical. The physical structure of the enduring world is not laminated in this way; and there is nothing to prevent another observer drawing his geometrical sections in a different direction. In fact, he will do so if his motion differs from ours.

Now it may seem that we have been paying too much deference to the astronomers: "After all, they did not discover time. Time is something of which we are immediately conscious." I venture to differ and to suggest that (subject to certain reservations) time as now understood *was* discovered by an astronomer—Römer. By our sense of vision it appears to us that we are present at events far distant from us, so that they seem to occur in instants of which we are immediately conscious. Römer's discovery of the finite velocity of light has forced us to abandon that view; we still like to think of *world-wide* instants, but the location of distant events among them is a matter of hypothetical calculation, not of perception. Since Römer, time has become a mathematical construction devised to give the least disturbance to the old illusion that the instants in our consciousness are world-wide.

Without using any external senses, we are conscious of the flight of time. This, however, is not a succession of world-wide states, but a succession of events at one place—not a pile of sheets, but a chain of points. Common-sense demands that this time-succession should be essentially different from the space-succession of points along a line. The preservation of a fundamental distinction between timelike succession and spacelike succession is essential in any acceptable theory. Thus in the four-dimensional world we recognise that there are two types of ordered succession of events which have no common measure; type A is like the succession of instants in our minds, and type B is the relation of order along a line in space. Proceeding from the instant "here-now," I can divide the regions of the world into two zones, according as they are reached by a succession of type A (my absolute past and future), or of type B (my absolute "elsewhere"). This scheme of structure is very different from the supposed laminated structure of the older view. Since we believe that this distinction of types A and B corresponds to something in the actual structure of the world, it is likely to determine the various natural phenomena that are observed. Thus it determines the propagation of light, since it is found that the line of a light-pulse is always on the boundary between the two zones above-mentioned. More important still, a particle of matter is a structure which can occupy a chain of points only of type A. Since we are limited by our material bodies, it must be this type of succession which we immediately experience; we are aware

of the existence of the other type only by deduction from the indications of our external senses.

Objection is sometimes raised to the extravagantly important part taken by light-signals and light-propagation in Einstein's discussion of space and time. But Einstein did not invent a space and time depending on light-signals; he pointed out that the space and time already in general use depended on light-signals and equivalent processes, and proceeded to show the consequences of this. Turning from fictitious space and time to the absolute four-dimensional world, we still find the velocity of light playing a very prominent part. It is scarcely necessary to offer any excuse for this. Whether the substratum of phenomena is called *aether* or *world* or *space-time*, one requirement of its structure is that it should propagate light with this velocity.

The resolution of the four-dimensional continuum into a succession of instantaneous spaces is not dictated by anything in the structure of the continuum. Nevertheless, it is convenient, and corresponds approximately to our practical outlook on the world; and it is rarely necessary to go back to the undivided world. We have to go back to the undivided world when a comparison is made between the phenomena experienced by observers with different motions, who make the resolution in different directions. Moreover, a world-wide resolution into a space and time with the familiar properties is possible only when the continuum satisfies certain conditions. Are these conditions rigorously satisfied? They are not; that is Einstein's second great discovery. It is no more possible to divide the universe in this way than to divide the whole sky into squares. We have

tried to make the division, and it has failed; and to cover up the consequences of the failure we have introduced an almost supernatural agency—gravitation. When we cease to strive after this impossibility—a mode of division which there was never any adequate reason for believing to be possible—gravitation as a separate agency becomes unnecessary. Our concern here is with the bearing of this result on time. Time is now not merely relative, but local. The relative time for an observer is a construction extended by astronomers throughout the universe according to mathematical rules; but these rules break down in a region disturbed by the proximity of heavy matter, and cannot be fulfilled accurately. We can preserve our time-partitions only by making up fresh rules as we require them. The local time for a particular observer is always definite, and is the physical representation of the flight of instants of which he is immediately aware; the extended mesh-work of co-ordinates radiating from this is drawn so as to conform roughly to certain rules—so as not to violate too grossly certain requirements which the untutored mind thought necessary at one time. Subject to this, time is merely one of four co-ordinates, and its exact definition is arbitrary.

To sum up, world-wide time is a mathematical system of location of events according to rules which on examination can only be regarded as arbitrary; it has not any structural—and still less any metaphysical—significance. Local time, which for animate beings corresponds to the immediate time-sense, is a type of linear succession of events distinct from a pure spacelike succession; and this distinction is fully recognised in the relativity theory of the world.

Theory and Experiment in Relativity.¹

By DR. NORMAN CAMPBELL.

"SPACE" and "time" are the conceptions of theory, not of laws. They are neither necessary nor useful in the statement of the results of any experiment. The experimental concepts with which, like all theoretical ideas, they are connected are such magnitudes as length, area, volume, angle, period (of a system), or time-interval. The numerical laws of experimental geometry involve two or more "spatial" magnitudes and no other magnitudes; for example, the area of a rectangle is proportional to the product of the lengths of its sides. There are no laws relating "temporal" magnitudes only.

Relativity neither adds to nor subtracts from the collection of spatial and temporal laws. The laws which it explains all involve magnitudes that are not spatial or temporal. And this is fortunate. For the subject has been so completely

examined that it is very improbable that any proposed new laws could be true. If relativity predicted anything inconsistent with firmly established experiment, NATURE would not devote a special number to discussing it.

It may be objected that relativity does predict new and strange laws; it predicts that the velocity of light in a region remote from material bodies is always the same; and it predicts unfamiliar experiences of observers travelling at great speeds or in the neighbourhood of concentrated mass. But, it may be replied, the measurement of the velocity of light does not involve only spatial and temporal magnitudes; we do not measure that velocity as we do the velocity of a material body; an element of theory is always involved. Again, we do *not* observe any disturbance of geometrical laws in the neighbourhood of the densest bodies we know. And as for Prof. Eddington's observers in aeroplanes travelling with half the velocity of light, no two human

¹ Since it is impossible to make a short article on a large subject anything but a summary, perhaps I may be permitted to refer any reader who is interested to my "Physics: The Elements" for a fuller discussion of many of the questions raised.