the higher chromosphere. Mr. Bridges, of the *Melbourne Herald*, was also attached to the British party as a volunteer, and a cinema camera of his was used with one of Mr. Merfield's parabolic gratings to get a timed series of photographs of the spectrum at the second and third contact. This instrument was worked by Capt. Akkersdyk, who was in command at the Fort and who helped the British expedition by every means that lay in his power. The photographs illustrating this article were taken by Mr. Bridges.

The choice of Benkulen as the site for most of the expeditions was based upon careful observations on cloudiness at eclipse time in previous years. These were made under the direction of Dr. Braak of Lembang, and they proved a useful guide to the visiting astronomers. It should be added that the facilities at Benkulen, and the friendly help given freely on every side, showed how luckily the choice of a site had been made.

The season—the rainy season—was not at all promising, and for the month preceding the eclipse the numbers of fine and cloudy days were about equal. The day of the eclipse itself was cloudy most of the morning, but the sun cleared up for first contact. Thin cloud gathered between first and second contact, but cleared away shortly before totality. Five minutes after the end of totality, the sun was in cloud for the British station.

The corona was intermediate in type, resembling that of the 1900 eclipse in India. There were several very striking prominences on the limb, and the black moon, ringed with bright red prominences and surrounded by the pearl grey corona with its long irregular rays, made a wonderful picture, well worth travelling thousands of miles to see.

Space, Time, and the Universe.[1]

By J. H. Jeans, Sec. R.S.

Some of us may remember the story of the children who played truant in order to explore the regions where the rainbow ends. After travelling all day, up hill and down dale, they had to admit failure of the most thoroughgoing kind—the rainbow was, to all appearances, no nearer than when they started. Really scientific children might have thought of estimating their rate of approach to the rainbow by measuring the angle it subtended. If they had measured it in the morning it would have been $42° 23'$; it would have been $42° 23'$ at noon, and again at night it would still be precisely $42° 23'$. If they had done this they must have felt that they were the victims of extreme bad luck, for they had clearly seen the rainbow in front of the nearest hill when they started out; could there be some sort of conspiracy on the part of rainbows, hills, and indeed the whole scheme of Nature, to prevent their getting close up to that rainbow?

In the year 1905 the world of physicists was engaged in a pastime which was, in many respects, very similar to that of chasing rainbows. They believed light to travel through an ether with a speed of 300,000 km. a second. If the solar system were travelling through this ether at a speed of, say, 1000 km. a second, it would partially overtake light travelling in the same direction, so that this light ought to appear to travel at only 299,000 km. a second. On the other hand, light travelling in the opposite direction ought to appear to travel with a velocity of 301,000 km. a second. This suggested an obvious means of discovering both the speed and direction of the earth's voyage through the ether—indeed, it was every bit as obvious as the children's plan for exploring the foot of the rainbow. Experiments were designed to utilise this principle and were tried time after time, not in one form only but in many. Time after time experiment gave the answer that the velocity of the earth through the ether was zero, or at least, to put it in another form, which was at that time thought to mean precisely the same thing, the velocity of light relative to the earth was the same in all directions. No doubt it was conceivable that on the occasion of the first experiment the earth really might have happened to be at rest in the ether, but it was quite inconceivable that this should be the case every time; indeed, the earth's orbital motion alone required a variation of some 30 km. a second, and all the experiments were capable of detecting far smaller variations than this.

At first glance it looked as though the earth must be carrying its own private ether about with it, and I suppose this view would have prevailed had it not been for the astronomers, who were ready with an aberration-constant which at once, and, I think, irrevocably, dismissed the possibility of an ether being dragged about with us. Incidentally, this episode provides an often overlooked instance of the services of astronomy to the other sciences and to the growth of knowledge in general. The physicists on Jupiter may still believe that a luminiferous ether exists which follows Jupiter about wherever it goes; the reason is that there are no astronomers on Jupiter to put them right, their permanent blanket of clouds not encouraging this profession.

I forget the end of the story of the rainbow quest, but am prepared to provide an entirely unauthoritative ending. After the children had got completely tired in their bodies and still more completely bewildered in their wits, they rested for a long time, until they encountered a magician. He was not in the least the conventional magician, ponderous of speech and with a long white beard; indeed, he was a young man of twenty-seven, extraordinarily simple and unassuming in all that he said. What he said in brief was this: "I can tell you what is the matter. You have started to chase the rainbow on the supposition that it is a material arch; in actual fact it is all in your own eyes. Gretchen sees one rainbow and Hans sees a quite different one. But if Hans walks up to where Gretchen is standing, he simply changes his rainbow for hers; you don't get any nearer to a rainbow by walking this distance because there isn't really anything for you to get any nearer to. The angle you have been measuring must always stay at $42° 23'$; it is fixed there by the

[1] Presidential address delivered before the Royal Astronomical Society on February 12, on the award of the gold medal of the Society to Prof. Albert Einstein for his researches on relativity and the theory of gravitation.

unalterable laws of Nature, and children cannot alter these by walking about." As the children were tired, and the young magician had perhaps expressed himself in rather unfamiliar ways, they did not at first quite understand what he meant. But then another magician, whose name was Minkowski, came along, and he made it all seem much simpler; he said it was quite true that each child carried its own rainbow about with it, but that behind the subjective vision of the rainbow was an objective reality consisting of a shower of raindrops. These raindrops were the same for everybody, but out of the whole lot each person's eye selected, or rather the sunshine selected for each person's eye, a small group of drops which appeared to him to form a bright arch. If all space were filled with children standing in different spots, then the aggregate of all the raindrops seen in all the children's eyes would constitute the reality behind the whole phenomenon, a shower of rain. When the second magician put things in this way the children began to understand; they saw that the first magician, whose name was Einstein, had been right.

I doubt if the Royal Astronomical Society has ever had its medallist introduced to it in so disrespectful a way before, but my little parable may remind you of the way in which our present medallist made his entry into the scientific world, and also of the way in which the scientific world made their entry into the changed universe in which science moves to-day. Time and space, as separate entities, the time and space we wrote about and thought about previous to 1905, have gone, or, as Minkowski puts it, have become shadows, while only the product of the two remains as the framework in which all material phenomena take place. Time and space separately may mean something to us subjectively, but Nature knows nothing of them until they have been multiplied together into a four-dimensional space-time continuum; it is in this that she has set her laws. If I have seemed to treat Einstein's great early work too lightly, I would plead, first, that it has already suffered enough serious exposition, and, secondly, that only really great work permits of being treated lightly, and that it is well to take a chance when it offers itself. But let not the lightness of treatment be thought to imply lightness of esteem for the work. By his single 1905 paper, Einstein started a revolution in scientific thought to which as yet we can see no end, to which, indeed, we can scarcely yet imagine any end. Had he written only that one paper, his position as one of the great figures of science would, in my opinion, have been secure. He would, perhaps, not have been awarded the gold medal of our Society, but that would be because he had not yet become an astronomer.

If the magicians had given the right explanation of the rainbow, then everything the children saw in the rainbow ought to admit of explanation in terms of the ultimate reality provided by the shower of rain. Obviously there would have been something radically wrong if Gretchen had seen a circular rainbow while Hans, standing by her side, had seen a square one; something wrong, too, if Gretchen had said that the colours ran from red to blue as you passed inwards, while Hans said they ran from blue to red. In the same way, if Einstein and Minkowski were right about time and space, there must have been something radically wrong when Isaac Newton had said that every particle in the universe attracted every other particle with a force that varied as the inverse square of the distance, and again when he had said that the path of a planet about the sun was an endlessly repeated ellipse. When the last of these statements, for example, is expressed in terms of the four-dimensional framework which Einstein and Minkowski regarded as the ultimate objective reality, it is found to make sheer nonsense, to be inconsistent with itself. Viewed in that framework, an endlessly repeated ellipse becomes a sort of helical curve, a spiral staircase climbing up into eternity, the projection of which on one particular cross-section is the single ellipse in question. View it at any angle you like and it is still a helical curve, but project it on some other cross-section and you will find that the radius vector relative to the sun no longer describes an endlessly repeated ellipse. In brief, the Newtonian law of gravitation could not be true because it could not be expressed in terms of the ultimate four-dimensional reality in such a way as to be true for more than one person at a time.

When Einstein had this brought to his notice he at once became an astronomer. His task, rather a heavy one for the first piece of work of a young apprentice to astronomy, was to find out what was the matter with Newton's law of gravitation and to put it right. Of course, in a sense, there was not very much wrong: Halley's comet had come back when it was expected, and Jupiter's satellites could be seen every night exactly as the pictures in the "Nautical Almanac" predicted that they ought to be seen if Newton had been right, and all the planets seemed actually to be describing endlessly repeated ellipses except that Mercury wandered very, very slightly from its proper place. Yet, in another sense, there must be everything wrong with a law that did not fit properly into the four-dimensional reality, or at least there was as much wrong as the difference between truth and error, which the true man of science regards as the biggest magnitude with which he ever has to deal. And, just as Kepler, starting from the established error of 8′ in the observed position of Mars had set out "to construct a new theory that will explain the motions of all the planets," so Einstein set to work to construct a new theory which was incidentally to explain the motion of the planets but was destined also to change our whole interpretation of the fundamental significance of these motions.

Every astronomer is familiar with this part of Einstein's work. By 1915 he had found the modification needed in Newton's view of gravitation, and had shown that the orbit of a planet, instead of being the impossible endlessly repeated ellipse, was an ellipse which kept slowly turning round in its own plane. He had also found that the theoretically predicted rate of turning for Mercury was exactly the 43″ a century by which Leverrier had found that the planet's perihelion advanced over and beyond the advance caused by the pull of the other planets. He announced two further physical consequences of his theory. Rays of light passing through a gravitational field ought to be bent by a calculable amount, 0·745″ for light which has just grazed the sun's limb; and spectral lines emanating from atoms in a gravitational field ought to be displaced towards the red, the displacement of lines from the solar photosphere being that corresponding to a velocity of 0·634 km. a second, or, say, 0·008 Å.U. at the cyanogen band, $\lambda 3883$. Newton had queried in his "Optics" whether rays of light would bend in obedience to gravitational force, but Einstein was the first since Newton to make any definite physical predictions arising out of a theory of gravitation.

Our two British expeditions put the first of these predictions to the test at the 1919 eclipse, and, as we know, brought back the news that the prediction was amply verified. The testing of the second prediction was a more difficult matter, not so much because the small displacement of 0·008 Å.U. was difficult to measure, as because it was masked by bigger displacements of unknown amount. Even to-day the problem can scarcely be said to be solved with absolute finality so far as solar light is concerned, although probably Evershed, St. John, and others have done all that it is possible to do. But the prediction which it was found almost impossible to test by the light of our sun has been tested by the light of one of the faintest of stars. Sirius has, as companion, a smaller and far fainter star which describes an orbit round it. Its effect on the motion of Sirius shows its mass to be 0·85 times that of the sun, and its distance is for all practical purposes the same as that of Sirius. The amount of light it emits is so small that Seares had calculated its radius to be only about 20,000 km. or one thirty-fifth of the radius of our sun. Now Einstein's theory predicts a shift proportional to M/r, so that whereas the predicted shift in the solar spectrum corresponds to a velocity of only 0·634 km. a second, the light from the companion to Sirius ought to show a shift corresponding to a velocity of 20 km. a second, something like a third of an angstrom. Here then was a shift the magnitude of which was suitable for measurement. The measurement was undertaken at Mount Wilson, and the observed shift was found to agree almost exactly with that predicted by theory. This experiment not only established the validity of Einstein's theory of the gravitational displacement of spectral lines, but also showed its usefulness as an instrument to be utilised by the practical astronomer in his everyday work.

The ultimate importance of Einstein's work was not, however, that it gave astronomers new tools for the measurement of stellar diameters, or for the prediction of the position of Mercury; it was not even that it gave the true law of gravitation; it was that it gave a new conception of the meaning of gravitation and of gravitational force. Strictly speaking, Einstein did not amend Newton's law of force; he abolished it. He put something else of a quite different nature in its place, something which was consistent with itself when looked at in the four-dimensional continuum and agreed with the observed facts of Nature, including the then untested bending and reddening of light. At first he had tried to amend Newton's law to fit the continuum, but he soon found it was a case of amending the continuum so as to fit Newton's law. Or rather, since a perfect fit was impossible, this being the cause of all the trouble, he amended the continuum so as to fit Newton's law in the only region where it could fit, namely, at infinity, and then found that the misfit for nearer distances gave just the needed $43''$ a century for Mercury's orbit. Just as completely as, some three centuries earlier, the kinematical explanation of cycles and epicycles had crumbled to nothing in the hands of Kepler and Newton, so now the dynamical explanation of a gravitational force crumbled in the hands of Einstein. The story of this part of Einstein's work has been so often told and is so familiar to all astronomers that you will scarcely wish to linger over it. It opened up a path into entirely new scientific territory along which Weyl and others have advanced, attempting, so far as can at present be seen with success, to extend Einstein's fundamental conceptions so as to explain the "forces" of electromagnetism in terms of a still further generalisation of the geometry of the continuum. If they have succeeded, the mechanism of the whole universe is transformed; dynamics disappears from science and the laws of Nature are those of geometry alone.

We need scarcely spend time over the threadbare and rather meaningless question of whether Einstein has performed the feat of "abolishing the ether." So much depends on what we mean by "ether." As soon as the term is defined, the question as to whether or not that particular ether exists almost answers itself—generally in the negative. The luminiferous ether of Kelvin, Maxwell, and Faraday, largely as the result of Einstein's new outlook on the universe, may be described as dead; it is no longer a serious scientific hypothesis, but merely an item in the unscientific jargon of popular expositions of "wireless."

Let us take a glimpse at the new universe into which Einstein's work has led us. Until the seventeenth century the majority of men believed that terrestrial life was the prime reason for the existence of the myriads of stars that lighted the firmament; they had indeed been created just a few days before man so as to be ready to minister to his pleasure on his arrival. In the twentieth century the majority of men believe that there is a sort of flow of time which is regulated by our consciousness. We live now in the year 1926, and therefore speak of 1925 as dead and past; 1927 is not yet born, but will spring into life for us just as soon as we need it, which will be when we reach the end of 1926. So the traveller journeying west through Devon might suppose that Somerset had fallen out of existence at the moment he left it, and that Cornwall was waiting only for his arrival to come into existence. Foolish, perhaps, when expressed in terms of space, and yet our everyday belief in respect of time.

Einstein's theory eliminates the supposed essential difference between space and time; what is one man's space is another man's time. Not only so, but what is the past in time for one man is the future for another man. According to the view thrust upon us by the theory of relativity, the space-time landscape does not spring into life in front of us and die behind us; it is unalterably there. Existence becomes a picture rather than a drama, and the year 1927 has the same sort of existence as the county of Cornwall. Probably no one would regard this as a final statement of the matter; it goes as far as the theory of relativity carries us, but the theory of relativity is concerned only with inanimate Nature; it takes no cognisance of life or consciousness. It is for us to go further if we can.

Does the theory, however, leave room for us to go further? Does it leave room for life and consciousness, and for the attributes, such as free-will, which we attach to them?

The materialistic philosophy of a generation ago used to insist that the picture which science then presented of the universe left no room for such things. That picture has no doubt been torn to shreds, but what about the new picture? Does this look with any more favour on our instinctive belief that we can guide our actions and make the universe in some small degree different by our presence? Or are we mere passive spectators, carried—in a train the speed of which we cannot regulate and the course of which we cannot alter by an inch—out of a Devon with which we can do nothing except gaze at it through a window, into a Cornwall which is already in existence and has been unalterably created by other hands than ours? To this last question the answer of the theory of relativity would seem to be in the affirmative, but relativity is not the whole of natural science; it is not even the whole of Einstein's work. His contributions to science fall into two columns which, unhappily, are parallel and show no signs of meeting. The first column contains his contributions to the theory of relativity, the red-letter years being 1905 and 1915; the second column contains his contributions to the theory of quanta, the red-letter years being 1905 and 1916. It is not yet altogether clear which of these columns will figure most prominently in the history of present-day science when this is finally written in its proper perspective. But it already seems possible that the second column of Einstein's work may contain the needed antidote to the determinism and automatism to which the first column, if it stood by itself, would seem to condemn us.

This room contains, let us say, a thousand atoms of uranium. The chances are that after five million years only 999 of these will be left, the other one having been transformed into an atom of lead, eight atoms of helium and about 10^{-27} grams of radiation or heat. One of the thousand atoms is fated to be transformed in this way, but what determines which particular atom it is to be? Are we tempted to conjecture that it will be that one that gets most knocked about in the interval, or that gets into the hottest places, or what not? If so, we are wrong; for if blows or heat could disintegrate the one atom they could also disintegrate the other 999, and yet every physicist is firmly convinced that no possible treatment can retard or expedite the disintegration of the uranium atoms in the least degree. Once every five million years fate knocks at the door of one atom and it breaks up. Why fate chooses this interval, why she selects one particular atom rather than its fellow, we simply do not know; we seem to be beyond the domain of what have heretofore been called natural laws.

Now let us think of a more familiar, although more complicated, phenomenon. The hot filament of an electric light bulb receives energy from a dynamo and discharges it as radiation. Inside that filament millions of atoms are jumping up and down between different energy levels, and Einstein has investigated what may be called the statistics of their jumping about. Most of the knocks now are just those of ordinary radiation. The temperature radiation of the filament knocks some atoms up and some down; double the stream of radiation and the atoms will be knocked up and down twice as frequently. But this is not the whole story; if it were, the emission of light from the filament would not be what exact experiment shows it to be. Einstein finds that to explain the observed stream of radiation from the filament, fate must be invoked here also. Some atoms are knocked down from the high energy level to the lower because the stream of radiation pushes them down, but others stumble down by processes analogous to those by which the uranium atom disintegrates. They stumble, if you like, of their own clumsiness, or, if you like, because fate beckons them down. Put it anyhow you like, and you will almost certainly be wrong; Einstein has shown that it happens, and beyond this we know nothing.

It is, however, clear that we may be in the presence of something here which is quite beyond the inflexible cause and effect of the older mechanics, and possibly equally beyond the precreated tangle of events of the theory of relativity. A single instance will perhaps suggest how far beyond. The lines of the hydrogen spectrum result from the falling down of the atoms of hydrogen from one energy level to another, and in the determination of the wave-lengths represented by these lines, the future of the atom enters as an equal partner with the past, although, as we have seen, the future of an individual atom can no longer be regarded as a consequence of its past in the sense in which an effect is the consequence of the cause. We are here in unfamiliar regions of thought where our minds get frozen and refuse to operate. But one thing at least seems possible. It seems as though the deadly inevitability of cause and effect has ended, and we are in the presence of new possibilities of freedom which as yet we do not understand. Einstein's work on relativity changed the universe from a drama into a picture. It seems possible, as Weyl first suggested, that his work on quanta may have provided the clue which is destined to change it back again into a drama—no longer a drama in which all the parts have been written and the gestures prearranged before the curtain went up, but a drama in which all the actors choose their actions as the play proceeds—in fact, not a staged drama, but life.

No doubt the great mass of the universe must always follow a predestined path; nothing but predetermined forces can bind the cluster of the Pleiades or loose the bands of Orion or guide the Bear with its train, but there is now, for the first time since Newton, room in the universe for something besides predestined forces. No doubt this is only a possibility, only a conjecture if you like. We do not understand quantum phenomena well enough to go beyond conjectures. Perhaps a hope is dawning that some quite recent investigations of an abstruse mathematical nature are going to provide an answer to the puzzle, but if so it seems probable that the answer will not be in terms of ordinary time and space, and so will come from outside the regions surveyed by the theory of relativity. In any event it seems that there must be room for much in the universe about which relativity knows nothing. Perhaps the two columns of Einstein's work, which never clash because they never meet, provide a true symbolical picture of the universe which he has done so much towards elucidating.