The following figures represent the most striking phases, as nearly as may be at intervals of five minutes.

Fig. 1 shows how the streak extended from the cometary head so as to form a long wavy tail, and represents also the streak at its greatest length. As indicated in the sketch, there was a central portion much more brilliant than the rest, running from the head into the body of the streak.

In Fig. 2 the streak is seen when it had more the appearance of a rainbow than of a comet; and it was very noticeable that one side—that towards the north—was much brighter than the other.

Fig. 3 shows how the "head" began to shrivel up—shortening the streak. The glimmering appearance of the "shrivelling" put me very much in mind of the motion of the air over a "hot heap" (of slag); the tail end began to broaden out somewhat.

In Fig. 4 the streak has taken a very pronounced arrow-headed shape, and, as if to complete the resemblance, the

NORTH.

FIG. 1.

FIG. 2.

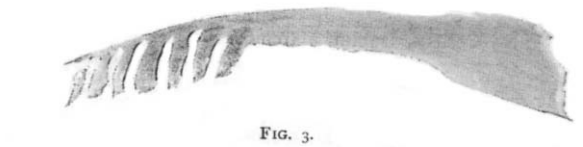


FIG. 3.

FIG. 4.

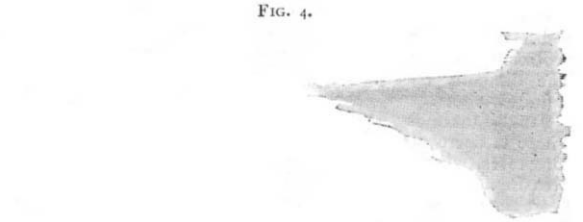


FIG 5.

SOUTH.

shimmering part took the form of the feathering; whereas in the preceding figure it had more the appearance of comb-teeth. The more brilliant parts are indicated by darker shading.

In Fig. 5 the streak has considerably shortened and broadened out in the west, where it soon afterwards mingled with faint auroral rays which had come round from the northern horizon.

I may say, in general, that the appearances were singularly noticeable and brilliant. The sky was very clear at the time, and every star was visible through the most brilliant parts of the streak. During the time the streak was visible there was a faint display of aurora on the northern horizon, which, as I have already said, worked round to the west and caught the last of the streak.

JAS. G. RICHMOND.

Muirkirk, N.B.

THE AGE OF THE EARTH.[1]

ILL-HEALTH has hitherto prevented my making the comments which seemed called for by Lord Kelvin's friendly article of March 7, in reply to my communication of January 3. Perhaps I may be allowed not merely to restrict my remarks to this article, but to deal more generally with the subject, in the hope of clearing away the misapprehensions which exist between modern geologists and palæontologists, who are no longer uniformitarians, and physicists who are represented by Lord Kelvin.

The arguments as to the age of life on the earth are based on considerations of (1) geology and palæontology; (2) tidal retardation and shape of the earth; (3) the cooling of the earth from an initially hot condition; (4) the age of the sun.

(1) From geology. The leading geologists declare that the great thickness of sedimentary rocks created since the Lower Cambrian, which are almost the oldest fossiliferous rocks, can only have been produced during many millions of years.

It is difficult to get geologists to give even wide limits for the age of the Lower Cambrian.[2] Their calculations are based not upon the rate of accumulation of sediment in one of our quiet oceans, but upon the rate of degradation in valleys where the rate is greatest at the present time. They make this declaration, thinking that for the last thirty-three years it has been authoritatively declared by physicists that such an estimate is absurdly great. I have no doubt that they have done their best to keep this estimate as low as possible, for they have a great interest in making geological theory agree with physics. Some physicists tell them that the flaw in the geologists' reasoning consists in their not taking into account the much greater tidal actions of the past. When tides rose and fell many hundreds of feet, and swept over tens or hundreds of miles of foreshore, there must undoubtedly have been a more rapid formation of sedimentary rock than anything of which we now have experience. The geologists' answer is:—We acknowledge that all nature's actions were on the whole, possibly, more intense in the past. We know from Prof. Darwin's development of Prof. Purser's theory that the moon was undoubtedly nearer the earth in palæozoic times, and the tide influence was therefore greater. But there seems to be no method of even approximately calculating how much greater the tidal influence was. Whilst one great astronomical authority speaks of tides of 500 feet deep in palæozoic times, Prof. Darwin himself thinks that two or three times as great as at present may be an excessive estimate. There is a good deal of geological evidence for much smaller seas than at present, and even if tidal influence were greater the actual tides may have been much smaller than now. Of positive evidence in our favour, we have the fact that numerous examples exist of palæozoic rocks which are identical in almost every physical way with tertiary rocks, and it is difficult to believe that they can have been deposited under very different conditions. Again, nearly all the old sedimentary rocks were laid down near coasts where tidal action would be most violent. Yet even low down in the Cambrian we find the remains of creatures

[1] In this paper free use has been made of many suggestions from Prof. Fitzgerald.

[2] Their data are of this nature:—Of fossiliferous rocks successively formed the total thickness may be taken as not less than 80,000 feet. Over the areas of the basin drained by many rivers the rate of denudation is known with sufficient accuracy for approximate calculation. Of the basin of the Mississippi a thickness of one foot of rock is removed in 6000 years; the Ganges, 2358; the Hoang Ho, 1464; the Rhone, 1528; the Danube, 6846; the Po, 729; the Nith, 4723 (Sir A. Geikie, Geol. Soc. of Glasgow, 1868). I have heard that Prof. Sollas demands less time than other geologists; but since this paper was written, I have seen (NATURE, April 4) that even he does not care to put the age of the Lower Cambrian at much less than 17 million years.

which still have attached to them delicate antennæ. In sandstones we find most delicate ripple marks and the marks of rain-drops. But over and above all this, denudation along coast-lines can hardly be regarded as of much importance compared with subaerial denudation (Sir A. Geikie, *Trans.* Geol. Soc. of Glasgow, 1868). Was there more rain? and did it fall more suddenly? Did the wind blow more strongly? Were atmospheric actions more vigorous in the past? There is no great reason for believing that they were. As Prof. G. Darwin observes, fossil trees do not seem to have been built more strongly than modern trees, and this gives some evidence as to the relative violence of aerial forces.

All the geological evidence points to rates of denudation and deposition in the past which may, on the average, have been greater than the average rate at present, but which were not on the average greater than the greatest rates at present.

The palæontologist now comes in. A study of fossils shows that there has been a gradual development, sometimes more quickly perhaps, and sometimes more slowly, but on the whole a continuous development of animal life in the past. We believe from all our study of nature that the development has been continuous. As more and more strata are studied, many of the apparent discontinuities are being converted into continuities. Now even in the lower parts of the Cambrian, *Brachiopoda* are found. Biologists tell us that in all probability these were gradually developed from creatures like worms; their structures are sufficiently complex for us to know that the time taken to develop the Brachiopod from the worm may have been as great as the age of known fossiliferous rocks. There are many rocks, evidently sedimentary, enormously older than the Cambrian, and when laid down there was certainly water on the earth, and hence it was neither too hot nor too cold for animal life. In these lower formations there are conglomerates containing pieces of still older rocks. Although in pre-Cambrian strata traces of animal remains are said to occur, we may say that the palæontological record is almost lost below the Cambrian, most of the earlier rocks having been subjected to great metamorphic action. If we keep to our principle of continuity in nature's actions, we see that the first beginning of life must have taken place at a date many times earlier than the very earliest geological record.

But the most experienced geologists and palæontologists state that they are satisfied with a few hundred million years as the possible age of life or the existence of water on the earth.

2. The considerations drawn from tidal retardation are as follows:—

(α) The shape of the earth now is the same as its shape when it solidified. (β) The shape of a liquid earth tells us its rate of revolution on its axis, therefore we know the rate of revolution of the earth on its axis when it solidified. (γ) Assuming that we know, with a fair amount of accuracy, the rate at which the length of the day is altering, we know the date of the earth's solidification, and certainly this is later than 1000 million years ago.

When I referred to the fallacy in this argument, I did not know that it had already been pointed out by the Rev. M. H. Close and Mr. Clarence King and Prof. George Darwin. It lies in the fact that (α) is certainly wrong. A solid body like the earth will, under the action of great forces, alter its shape in time. Such alteration is continually going on. Again (γ) is very doubtful.

(3) I now come to the considerations from the cooling of the earth. Lord Kelvin proved that, if the earth was once at a uniform temperature of 7000° F. or 3870° C., of material the heat properties of which are the same as the average of three rocks experimented upon at Edinburgh —these remaining constant throughout—and if the rate of increase of temperature downwards in the crust is now 1 Centigrade degree for every 90 feet, 100 million years have elapsed since cooling began; but there is a possible maximum of 400 millions.

In the article on this subject, published in NATURE, January 3, 1895, I showed that, if we assume greater conductivity in the interior than at the surface, we increase this limit of age. I took a number of examples, which could be worked mathematically. I did not pretend that any one of these represented the actual state of the earth. They merely proved that there were *possible* internal conditions which might give enormously greater ages than physicists had been inclined to allow. Of my various results, I did not give one as more correct than another, although some may have seemed more probable than others. It was not my object to obtain a correct estimate. Indeed I tried to show that it was impossible for a physicist to obtain such an estimate, as there were all kinds of possible assumptions which led to many different answers.

The validity of my reasoning in no degree rests upon the accuracy of R. Weber's results as quoted by me. Indeed, I only discovered these results when writing to Prof. Tait. In NATURE, February 7, p. 341, I have shown the extent to which the possible limit of the earth's age is increased if k and c increase with temperature and k/c remains constant. But I published this as an interesting mathematical result, and was careful to add—"It must be understood that my conclusions are really independent of whether R. Weber's results are correct or not." It is comparatively unimportant, but R. Weber has published another set of results which confirm those which I quoted. The results, published on March 7 for the first time, differ so utterly from the two previous sets, that I venture to think there may be mistakes in transcribing. However that may be, I am not concerned either to support or refute them.

I mentioned the possible great quasi-conductivity due to the interior of the earth being a honey-combed mass containing liquid, and to the possible greater conduction due to the presence of iron and other metals. Almost anything is possible as to the present internal state of the earth. Dr. Ramsay seems to think that there must be great quantities of sulphides inside, and these would probably be much better conductors than the surface rocks.

Prof. Schuster, in discussing the diurnal variation of terrestrial magnetism (*Phil. Trans.* 1889, p. 467), comes to the conclusion that the *electric* conductivity of the earth must be considerably greater inside than at the surface.

In all probability there are no great masses of liquid inside the earth *at the present time*, but it is quite possible that until recent times convection in such masses may have been conveying heat from the very inner earth towards its surface, and the latent heat given out by such masses of liquid as they solidified would be another potent factor. Some distinguished geologists say that the excessive folding which has occurred on the earth's surface cannot be accounted for by the current assumption of physicists, which involves the result that, practically, no cooling has yet taken place below the depth of 120 miles: my assumption is that cooling has taken place to much greater depths.

All these things, like the numbers published by R. Weber, support the argument if they are correct, but they do not in any way destroy it if they are wrong. I was not looking for a *probable* age of the earth from the point of view of mere physics. I wished to show that the physics' higher limit was greater than a few hundred of millions of years.

Mr. Clarence King's paper appears somewhat inconclusive. He assumes, possibly rightly, that the earth's crust may have the properties of *Diabase*; experiment has

shown what is the rate of increase of the melting temperature with increase of pressure of this rock: Laplace's hypothetical law of increase of density downwards in the earth cannot be very wrong, and from this a law of increase of pressure downwards may be formulated. From these data Mr. King finds what are the temperatures at various depths, which if exceeded would mean liquidity. A liquid layer inside the earth's crust being assumed to be impossible, Mr. King, trying all sorts of Kelvin solutions of a solid earth of uniform conductivity and uniform temperature, initially finds a maximum age of 25 million years, the initial temperature being not greater than 2000° C.! Furthermore, higher initial temperatures are not possible!

Now it is evident that if we take any probable law of temperature of convective equilibrium at the beginning and assume that there may be greater conductivity inside than on the surface rocks, Mr. King's ingenious test for liquidity will not bar us from almost any great age.

(4) There remain, lastly, considerations drawn from the age of the sun. On the assumption that all the energy possessed by the sun was that due to the mutual gravitation of its parts, and that the sun is now of uniform density, Helmholtz found that the sun may have in the past radiated as much as 22 million times his present annual loss. Langley found that the sun's present rate of radiation was under-estimated, and the statement of Prof. Newcomb may be taken as that of Helmholtz, corrected. Newcomb says ("Popular Astronomy," p. 523): "If we take the doctrine of the sun's contraction as furnishing the complete explanation of the solar heat during the whole period of the sun's existence, we can readily compute . . . It is thus found that if the sun had, in the beginning, filled all space, the amount of heat generated by his contraction to his present volume would have been sufficient to last 18 million years at his present rate of radiation."

Lord Kelvin pointed out (pp. 364–65, vol. i. "Pop. Lectures") that Helmholtz had assumed a sun of uniform density, whereas the sun's density must increase very much towards his centre, and as a result of calculation on the assumption that only half of the original energy was available (p. 374), that the radiation was greater in the past, and that the original collisions occurred practically simultaneously, he says: "We may therefore accept as the lowest estimate for the sun's initial heat 10,000,000 times a year's supply at present rate, but 50,000,000 or 100,000,000 as possible, in consequence of the sun's greater density in his central parts." And again (p. 375): "It seems therefore, on the whole, most probable that the sun has not illuminated the earth for 100,000,000 years, and almost certain that he has not done so for 500,000,000 years. This last number, then, is Lord Kelvin's higher limit. After six years, in 1868, Lord Kelvin returned to the question, and he says (p. 53, vol. ii. "Pop. Lect. and Addresses"): "The estimates here are necessarily very vague, but yet vague as they are, I do not know that it is possible, upon any reasonable estimate, founded on known properties of matter, to say that we can believe the sun has really illuminated the earth for five hundred million years."

In his R.I. address of 1887 Lord Kelvin gave no higher limit. I think that, on his specified assumptions in giving these large numbers, he has been very generous; for, taking Mr. Homer Lane's determination of the internal density of the sun, I find that the Helmholtz total energy need only be multiplied by about $2\frac{1}{2}$. If, however, instead of taking, as Mr. H. Lane did, 1·4 as the ratio of specific heat, we take a less number, and there is no reason why we should not, we find much greater densities towards the centre, and a much greater total energy and age. Still, I think that it is only when we escape from the above assumptions that we can see our way to increase the higher limits which have been quoted.

To justify the Helmholtz hypothesis of mere mutual attraction, initially, between the portions of matter which form the sun, Lord Kelvin ("Pop. Lect.," vol. i., pp. 411–3) dwells upon the great improbability that any parts of the sun possessed much initial velocity. He shows that if two bodies, A and B, came together to form the sun, when the bodies were still far apart before collision, the motion of the centre of B relatively to A, must have been directed with great exactness to pass nearly through the centre of A (as the sun has a comparatively small moment of momentum), and this was very improbable if the bodies had initial velocities. But this argument is only satisfactory when the bodies coming together are two in number. For example, let us imagine in early times a sun of half the mass of the present one, but of many times its diameter. It is possible that its radiant energy was supplied by meteors. If the meteor feeding was in excess, the sun became larger in volume. If there was too little meteor feeding, the sun became smaller. Even if there was a very excessive supply for a short time, say by the incoming of a huge meteor, we need not assume excessive radiation in consequence. Such meteors may have come from stellar space with great initial velocities, and may have possessed before collision many times the kinetic energy which a mere solar system meteor of the same mass would possess.[1] If there were many such meteors, their paths might be enormously out of line with one another and with the centre of the sun, and yet we need not imagine them to alter much the moment of momentum of the sun about its axis. If we look for the *probable* age of the sun as deduced from mere physics, we ought to take Helmholtz' condition of mere mutual attraction, the Helmholtz calculation being corrected of course for greater internal density; but if we look for a higher limit to the age of the sun, it is difficult to see why we may not multiply Lord Kelvin's total energy and age of 500 million years.

Again, the ages determined by Von Helmholtz, Prof. Newcomb, and Lord Kelvin, are given on the uniformitarian assumption that the sun has been radiating energy always at his present rate. If we may imagine that for long periods the sun radiated at a smaller rate, whether because his mass was smaller, or because of his atmosphere, we again have an increase to the calculated age. Prof. Newcomb seems to have noticed this, and to meet the objection (p. 525, "Popular Astronomy") he says, "that a diminution of the solar heat by less than one-fourth of its amount would probably make our earth so cold, that all the water on its surface would freeze, while an increase by much more than one-half would probably boil the water all away." On account of this exigency, indeed, he reduces his previous estimate in the ratio of nine to five. This statement ought to have the careful consideration of men who know more about astronomical physics than I do. It means that if the earth were now $15\frac{1}{2}$ per cent. further away from the sun, there would be no water and no life, only ice; and if we were 18·4 per cent. nearer the sun, there would be again no water and no life, only steam. It becomes an important question, is there no life, is there no water on the planet Venus which has twice our solar radiation? Is all its water in its atmosphere as steam? Again, Mars has only 40 per cent. of our solar radiation; is there no life, no water, only ice upon Mars? I have no right to speak on such a subject, but I understood that the atmosphere of Venus was much like that of our own planet, and that the water of Mars is not all ice, for his polar

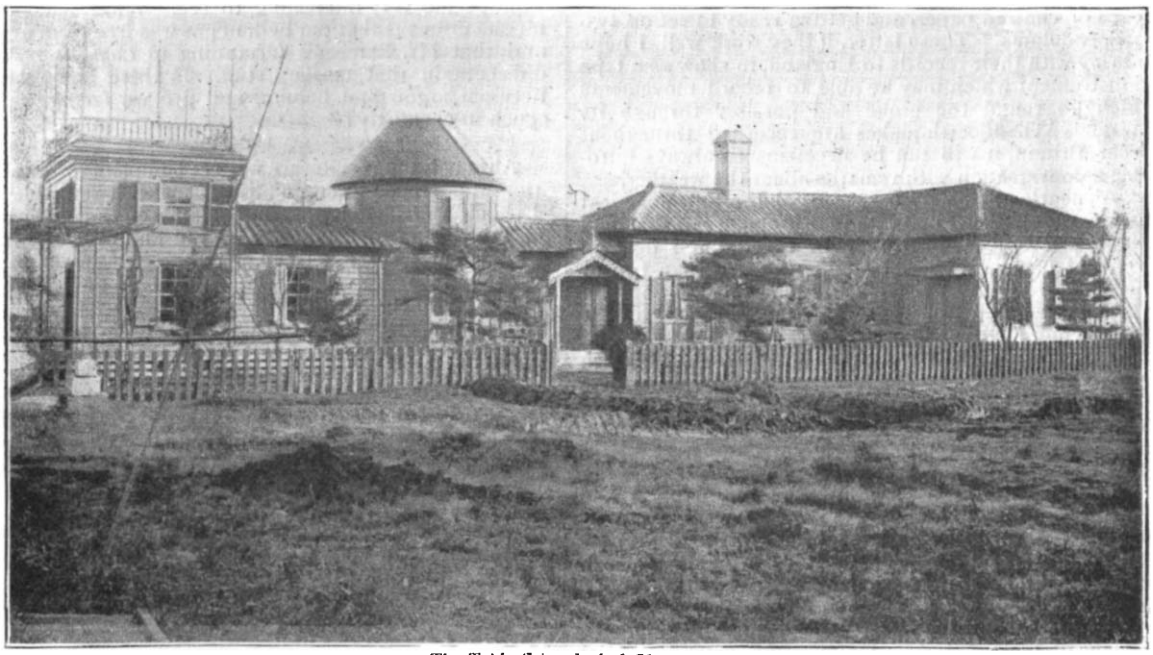
[1] The velocities of stars are probably much less than the possible velocities of smaller bodies.

snow-caps are seen to melt in summer. True, they may be solid carbonic acid, but I have recently read that the green colour of vegetation had been observed to appear and disappear regularly on the planet. If there is little water on the surface of Mars, I should imagine that this is rather due to its having soaked into the crust, which is probably colder underground than ours. Prof. Newcomb has evidently not thought of Mars in this connection, for elsewhere he says: "If there are any astronomers on Mars . . ." On this question I venture to quote Lord Kelvin, who said, in 1887 ("Pop. Lect.," vol. i. p. 376), that "the intensity of the solar radiation to the earth is $6\frac{1}{2}$ per cent. greater in January than in July; and neither at the equator nor in the northern or southern hemispheres has this difference been discovered by experience or general observation of any kind." It is difficult to imagine that if the effect of $6\frac{1}{2}$ per cent. cannot be detected, 25 per cent. should convert all the water to ice and destroy all life.

Even if a small diminution of the solar radiation produced a very cold climate on our present earth, we must remember that the earth's atmosphere may have been very different in the past; the earth may have been very greatly blanketed, and the surface may have been actually warmer, although there was much less solar radiation. That the atmosphere is far more important in this connection than the amount of solar radiation, is evident if we consider Langley's determination that in the tropics, if there were no atmosphere, the temperature of the surface of the earth would be $-200°$ C. Any addition to the quantity of air in our present atmosphere means an increase of the temperature of the rocky surface. But in the past, not only may there have been more atmosphere, but there may have been a very different kind of atmosphere. Again, we must consider a possible great amelioration of climate due to the earth's internal heat. It could not occur by mere conduction, but it is quite possible that for many millions of years there was great blanketing by clouds of watery vapour, and that underneath these blankets half the surface of the globe may have been a lake, or a number of lakes, of melted lava, which may have carried large amounts of heat convectively from considerable depths, this heat again being carried about convectively by the earth's atmosphere, keeping the solid parts of the earth's surface in a fit state for the existence of low forms of animal life. It is possible that at the present time the surface of Jupiter, which receives a very small intensity of solar radiation, may have solid parts surrounding watery lakes and oceans capable of supporting life because of the existence of many lakes of melted lava.

To sum up, we can find no published record of any lower maximum age of life on the earth as calculated by physicists (I leave out the estimates based upon the assumption of uniform density in the sun, and also that of Mr. Clarence King) than 400 million years. From the three physical arguments, Lord Kelvin's higher limits are 1000, 400, and 500 million years. I have shown that we have reasons for believing that the age, from all three, may be very considerably under-estimated. It is to be observed that if we exclude everything but the arguments from mere physics, the *probable* age of life on the earth is much less than any of the above estimates; but if the palæontologists have good reasons for demanding much greater times, I see nothing from the physicist's point of view which denies them four times the greatest of these estimates.

JOHN PERRY.



The Tokio Seismological Observatory.

THE SEISMOLOGICAL OBSERVATORY DESTROYED AT TOKIO.

THE destruction by fire of the Seismological Observatory and Library, at Tokio, Japan, has already been referred to in these columns (p. 533). The valuable work which Prof. Milne has accomplished during his long stay in Japan is well known to our readers; and it is to be hoped that means for its continuance will be fully provided. By the kindness of Japanese friends, Prof. Milne has been able to make observations in a temporary home since the fire, and it will not be for lack of enthusiasm and activity if a new observatory is not soon in working order. We print below extracts from Prof. Milne's