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JOURNAL OF

THE TRANSACTIONS

OF

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EDITED BY THE HONORARY SECRETARY,
CAPTAIN F. W. H. PETRIE, F.G.S., &c.

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THE AGE OF THE EARTH AS AN ABODE FITTED FOR LIFE. By the RIGHT HON. LORD KELVIN, G.C.V.O.

§ 1. The age of the earth as an abode fitted for Life is certainly a subject which largely interests mankind in general. For geology it is of vital and fundamental importance—as important as the date of the battle of Hastings is for English History—yet it was very little thought of by geologists of thirty or forty years ago; how little is illustrated by a statement,* which I will now read, given originally from the presidential chair of the Geological Society by Professor Huxley in 1869, when for a second time, after a seven years' interval, he was president of the Society.

" I do not suppose that at the present day any geologist would be found . . . . to deny that the rapidity of the rotation of the earth *may* be diminishing, that the sun *may* be waxing dim, or that the earth itself *may* be cooling. Most of us, I suspect, are Gallios, 'who care for none of these things,' being of opinion that, true or fictitious, they have made no practical difference to the earth, during the period of which a record is preserved in stratified deposits."

§ 2. I believe the explanation of how it was possible for Professor Huxley to say that he and other geologists did not care for things on which the age of life on the earth essentially depends, is because he did not know that there was valid foundation for any estimates worth considering as to absolute magnitudes. If science did not allow us to give any estimate whatever as to whether 10,000,000 or 10,000,000,000 years is the age of this earth as an abode fitted for life, then I think Professor Huxley would have been perfectly right in saying that geologists should not trouble themselves about it, and biologists should go on in their own way, not enquiring into things utterly beyond the power of human

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* In the printed quotations the italics are mine in every case, not so the capitals in the quotation from Page's Text-book.

understanding and scientific investigation. This would have left geology much in the same position as that in which English history would be if it were impossible to ascertain whether the battle of Hastings took place 800 years ago, or 800 thousand years ago, or 800 million years ago. If it were absolutely impossible to find out which of these periods is more probable than the other, then I agree we might be Gallios as to the date of the Norman Conquest. But a change took place just about the time to which I refer, and from then till now geologists have not considered the question of absolute dates in their science as outside the scope of their investigations.

§ 3. I may be allowed to read a few extracts to indicate how geological thought was expressed in respect of this subject, in various largely used popular text books, and in scientific writings which were new in 1868, or not too old to be forgotten. I have several short extracts to read and I hope you will not find them tedious.

The first is three lines from Darwin's *Origin of Species*, 1859 Edition, p. 287.

" In all probability a far longer period than 300,000,000 years has elapsed since the latter part of the secondary period."

Here is another still more important sentence, which I read to you from the same book :—

" He who can read Sir Charles Lyell's grand work on the Principles of Geology, which the future historian will recognise as having produced a revolution in natural science, yet does not admit how *incomprehensibly vast* have been the past periods of time, *may at once close this volume.*"

I shall next read a short statement from Page's *Advanced Students' Text Book of Geology*, published in 1859 :—

" Again where the FORCE seems unequal to the result, the student should never lose sight of the element TIME : *an element to which we can set no bounds in the past,* any more than we know of its limit in the future."

" It will be seen from this hasty indication that there are two great schools of geological causation—the one ascribing every result to the ordinary operations of Nature, combined with the element of *unlimited time,* the other appealing to agents that operated during the earlier epochs of the world with greater intensity, and also for the most part over wider areas. *The former belief is certainly more in accordance with the spirit of right philosophy,* though it must be confessed that many problems in geology seem to find their solution only through the admission of the latter hypothesis."

§ 4. I have several other statements which I think you may hear with some interest. Dr. Samuel Haughton, of Trinity

College, Dublin, in his *Manual of Geology*, published in 1865, p. 82, says :—

"The infinite time of the geologists is in the past ; and *most of their speculations regarding this subject seem to imply the absolute infinity of time*, as if the human imagination was unable to grasp the period of time requisite for the formation of a few inches of sand or feet of mud, and its subsequent consolidation into rock." (This delicate satire is certainly not overstrained.)

"Professor Thomson has made an attempt to calculate the length of time during which the sun can have gone on burning at the present rate, and has come to the following conclusion : 'It seems, 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. As for the future, we may say with equal certainty, that the inhabitants of the earth cannot continue to enjoy the light and heat essential to their life for many million years longer, unless new sources, now unknown to us are prepared in the great storehouse of creation.'"

I said that in the sixties and I repeat it now; but with charming logic it is held to be inconsistent with a later state-ment that the sun has not been shining 60,000,000 years; and that both that and this are stultified by a still closer estimate which says that probably the sun has not been shining for 30,000,000 years! And so my efforts to find some limit or estimate for Geological Time have been referred to and put before the public, even in London daily and weekly papers, to show how exceedingly wild are the wanderings of physicists, and how mutually contradictory are their conclusions, as to the length of time which has actually passed since the early geological epochs to the present date.

Dr. Haughton further goes on—

"*This result* (100 to 500 million years) of Professor Thomson's, *although very liberal in the allowance of time, has offended geologists, because, having been accustomed to deal with time as an infinite quantity at their disposal, they feel naturally embarrassment and alarm at any attempt of the science of Physics to place a limit upon their speculations.* It is quite possible that even a hundred million of years may be greatly in excess of the actual time during which the sun's heat has remained constant."

§ 5. Dr. Haughton admitted so much with a candid open mind; but he went on to express his own belief (in 1865) thus :

"Although I have spoken somewhat disrespectfully of the geological calculus in my lecture, yet I believe that the time during which organic life has existed on the earth is practically infinite, because it can be shown to be so great as to be inconceivable by beings of our limited intelligence."

Where is inconceivableness in 10,000,000,000 ? There is nothing inconceivable in the number of persons in this room, or in London. We get up to millions quickly. Is there any-

thing inconceivable in 30,000,000 as the population of England, or in 38,000,000 as the population of Great Britain and Ireland, or in 352,704,863 as the population of the British Empire? Not at all. It is just as conceivable as half a million years or 500 millions.

§ 6. The following statement is from Professor Jukes's *Students' Manual of Geology* :—

"The time required for such a slow process to effect such enormous results must of course be taken to be inconceivably great. The word 'inconceivably' is not here used in a vague but in a literal sense, to indicate that the lapse of time required for the denudation that has produced the present surfaces of some of the older rocks, is vast beyond any idea of time which the human mind is capable of conceiving."

" Mr. Darwin, in his admirably reasoned book on the origin of species, so full of information and suggestion on all geological subjects, estimates the time required for the denudation of the rocks of the Weald of Kent, or the erosion of space between the ranges of chalk hills, known as the North and South Downs, at *three hundred millions of years*. The grounds for forming this estimate are of course of the vaguest description. It may be possible, perhaps, that the estimate is a hundred times too great, and that the real time elapsed did not exceed three million years, but, on the other hand, it is just as likely that the time which actually elapsed since the first commencement of the erosion till it was nearly as complete as it now is, was really a hundred times greater than his estimate, or thirty thousand millions of years."

§ 7. Thus Jukes allowed estimates of anything from 3 millions to 30,000 millions as the time which actually passed during the denudation of the Weald. On the other hand Professor Phillips in his Rede lecture to the University of Cambridge (1860), decidedly prefers one inch per annum to Darwin's one inch per century as the rate of erosion ; and says that most observers would consider even the one inch per annum too small for all but the most invincible coasts ! He thus, on purely geological grounds, reduces Darwin's estimate of the time to less than one one-hundredth. And, reckoning the actual thicknesses of all the known geological strata of the earth, he finds 96 million years as a possible estimate for the antiquity of the base of the stratified rocks ; but he gives reasons for supposing that this may be an over-estimate, and he finds that from stratigraphical evidence alone, we may regard the antiquity of life on the earth as possibly between 38 millions and 96 millions of years. Quite lately a very careful estimate of the antiquity of strata containing remains of life on the earth, has been given by Professor Sollas, of Oxford, calculated according to stratigraphical principles which had been pointed out

by Mr. Alfred Wallace. Here it is* :—" So far as I can at present see, the lapse of time since the beginning of the Cambrian system is probably less than 17,000,000 years, even when computed on an assumption of uniformity, which to me seems contradicted by the most salient facts of geology. Whatever additional time the calculations made on physical data can afford us, may go to the account of pre-Cambrian deposits, of which at present we know too little to serve for an independent estimate."

§ 8. In one of the evening Conversaziones of the British Association during its meeting at Dundee in 1867 I had a conversation on geological time with the late Sir Andrew Ramsay, almost every word of which remains stamped on my mind to this day. We had been hearing a brilliant and suggestive lecture by Professor (now Sir Archibald) Geikie on the geological history of the actions by which the existing scenery of Scotland was produced. I asked Ramsay how long a time he allowed for that history. He answered that he could suggest no limit to it. I said, " You don't suppose things have been going on always as they are now? You don't suppose geological history has run through 1,000,000,000 years?" "Certainly I do." "10,000,000,000 years?" "Yes." " The sun is a finite body. You can tell how many tons it is. Do you think it has been shining on for a million million years?" "I am as incapable of estimating and understanding the reasons which you physicists have for limiting geological time as you are incapable of understanding the geological reasons for our unlimited estimates." I answered, " You can understand physicists' reasoning perfectly if you give your mind to it." I ventured also to say that physicists were not wholly incapable of appreciating geological difficulties; and so the matter ended, and we had a friendly agreement to temporarily differ.

§ 9. In fact, from about the beginning of the century till that time (1867), geologists had been nurtured in a philosophy originating with the Huttonian system: much of it substantially very good philosophy, but some of it essentially unsound and misleading : witness this, from Playfair, the eloquent and able expounder of Hutton :—

" How often these vicissitudes of decay and renovation have been repeated is not for us to determine ; they constitute a series of which as .the author of this theory has remarked, we neither see the beginning nor'

* " The Age of the Earth," *Nature*, April 4th, 1895.

the end; a circumstance that accords well with what is known concerning other parts of the economy of the world. In the continuation of the different species of animals and vegetables that inhabit the earth, we discern neither a beginning nor an end; in the planetary motions where geometry has carried the eye so far both into the future and the past we discover no mark either of the commencement or the termination of the present order."

§ 10. Led by Hutton and Playfair, Lyell taught the doctrine of eternity and uniformity in geology; and to explain plutonic action and underground heat, invented a thermo-electric "perpetual" motion on which, in the year 1862, in my paper on the "Secular Cooling of the Earth,"* published in the *Transactions of the Royal Society of Edinburgh*, I commented as follows :—

"To suppose, as Lyell, adopting the chemical hypothesis, has done,† that the substances, combining together, may be again separated electro-lytically by thermo-electric currents, due to the heat generated by their combination, and thus the chemical action and its heat continued in an endless cycle, violates the principles of natural philosophy in exactly the same manner, and to the same degree, as to believe that a clock constructed with a self-winding movement may fulfil the expectations of its ingenious inventor by going for ever."

It was only by sheer force of reason that geologists have been compelled to think otherwise, and to see that there was a definite beginning, and to look forward to a definite end, of this world as an abode fitted for life.

§ 11. It is curious that English philosophers and writers should not have noticed how Newton treated the astronomical problem. Playfair, in what I have read to you, speaks of the planetary system as being absolutely eternal, and unchangeable : having had no beginning and showing no signs of progress towards an end. He assumes also that the sun is to go on shining for ever, and that the earth is to go on revolving round it for ever. He quite overlooked Laplace's nebular theory; and he overlooked Newton's counterblast to the planetary "perpetual motion." Newton, commenting on his own *First Law of Motion*, says, in his terse Latin, which I will endeavour to translate, " But the greater bodies of planets and comets moving in spaces less resisting, keep their motions longer." That is a strong counterblast against any idea of eternity in the planetary system.

§ 12. I shall now, without further preface, explain, and I

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* Reprinted in Thomson and Tait, *Treatise on Natural Philosophy*, 1st and 2nd Editions, Appendix D (g).

† *Principles of Geology*, chap. xxxi, ed. 1853.

hope briefly, so as not to wear out your patience, some of the arguments that I brought forward between 1862 and 1869, to show strict limitations to the possible age of the earth as an abode fitted for life.

Kant* pointed out in the middle of last century, what had not previously been discovered by mathematicians or physical astronomers, that the frictional resistance against tidal currents on the earth's surface must cause a diminution of the earth's rotational speed. This really great discovery in Natural Philosophy seems to have attracted very little attention,—indeed to have passed quite unnoticed,—among mathematicians, and astronomers, and naturalists, until about 1840, when the doctrine of energy began to be taken to heart. In 1866, Delaunay suggested that tidal retardation of the earth's rotation was probably the cause of an outstanding acceleration of the moon's mean motion reckoned according to the earth's rotation as a timekeeper found by Adams in 1853 by correcting a calculation of Laplace which had seemed to prove the earth's rotational speed to be uniform.† Adopting Delaunay's suggestion as true, Adams, in conjunction with Professor Tait and myself, estimated the diminution of the earth's rotational speed to be such that the earth as a timekeeper, in the course of a century, would get 22 seconds behind a thoroughly perfect watch or clock rated to agree with it at the beginning of the century. According to this rate of retardation the earth, 7,200 million years ago, would have been rotating twice as fast as now: and the centrifugal force in the equatorial regions would have been four times as great as its present amount, which is $\frac{1}{289}$ of gravity. At present the radius of the equatorial sea-level exceeds the polar semi-diameter by $21\frac{1}{2}$ kilometres, which is, as nearly as the most careful cal-

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* In an essay first published in the Kœnigsberg Nachrichten, 1754, Nos. 23, 24 ; having been written with reference to the offer of a prize by the Berlin Academy of Sciences in 1754. Here is the title-page, in full, as it appears in vol. vi of Kant's Collected Works, Leipzig, 1839 :— Untersuchung der Frage : Ob die Erde in ihrer Umdrehung um die Achse, wodurch sie die Abwechselung des Tages und der Nacht hervorbringt, einige Veränderung seit den ersten Zeiten ihres Ursprunges erlitten habe, welches die Ursache davon sei, und woraus man sich ihrer versichern könne ? welche von der Königlichen Akademie Der Wissenschaften zu Berlin zum Preise aufgegeben worden, 1754.

† *Treatise on Natural Philosophy* (Thomson and Tait) § 830, ed. 1, 1867, and later editions ; also *Popular Lectures and Addresses*, vol. ii (Kelvin). *Geological Time* being a reprint of an article communicated to the Glasgow Geological Society February 27th, 1868.

culations in the theory of the earth's figure can tell us, just
what the excess of equatorial radius of the surface of the
sea all round would be if the whole material of the earth
were at present liquid and in equilibrium under the in-
fluence of gravity and centrifugal force with the present
rotational speed, and ¼ of what it would be if the rotational
speed were twice as great. Hence, if the rotational speed
had been twice as great as its present amount when con-
solidation from approximately the figure of fluid equilibrium
took place, and if the solid earth, remaining absolutely rigid,
had been gradually slowed down in the course of millions
of years to its present speed of rotation, the water would
have settled into two circular oceans round the two poles : and
the equator, dry all round, would be 64·5 kilometres above
the level of the polar sea bottoms. This is on the sup-
position of absolute rigidity of the earth after primitive
consolidation. There would, in reality, have been some
degree of yielding to the gravitational tendency to level the
great gentle slope up from each pole to equator. But if the
earth, at the time of primitive consolidation, had been rota-
ting twice as fast as at present, or even 20 per cent. faster
than at present, traces of its present figure must have been
left in a great preponderance of land, and probably no sea
at all, in the equatorial regions. Taking into account all
uncertainties, whether in respect to Adams' estimate of the
rate of frictional retardation of the earth's rotatory speed,
or to the conditions as to rigidity of the earth once consoli-
dated, we may safely conclude that the earth was certainly
not solid 5,000 million years ago, and was probably not solid
1,000 million years ago.*

§ 13. A second argument for limitation of the earth's age,
which was really my own first argument, is founded on the
consideration of underground heat. To explain a first rough
and ready estimate of it I shall read one short statement.
It is from a very short paper that I communicated to the
Royal Society of Edinburgh on the 18th December, 1865,

* "The fact that the continents are arranged along meridians, rather
than in an equatorial belt, affords some degree of proof that the consoli-
dation of the earth took place at a time when the diurnal rotation differed
but little from its present value. It is probable that the date of consoli-
dation is considerably more recent than a thousand million years ago."
Thomson and Tait. *Treatise on Natural Philosophy*, 2nd Edition, 1883,
§ 830.

entitled, "The Doctrine of Uniformity in Geology briefly refuted."

"The 'Doctrine of Uniformity' in Geology, as held by many of the most eminent of British Geologists, assumes that the earth's surface and upper crust have been nearly as they are at present in temperature, and other physical qualities, during millions of millions of years. But *the heat which we know, by observation, to be now conducted out of the earth yearly* is so great, that if this action had been going on with any approach to uniformity for 20,000 million years, the amount of heat lost out of the earth would have been about as much as would heat, by 100° Cent., a quantity of ordinary surface rock of 100 times the earth's bulk. This would be more than enough to melt a mass of surface rock equal in bulk to the whole earth. No hypothesis as to chemical action, internal fluidity, effects of pressure at great depth, or possible character of substances in the interior of the earth, possessing the smallest vestige of probability, can justify the supposition that the earth's upper crust has remained nearly as it is, while from the whole, or from any part, of the earth, so great a quantity of heat has been lost."

§ 14. The sixteen words which I have emphasized in reading this statement to you (italics in the reprint) indicate the matter-of-fact foundation for the conclusion asserted. This conclusion suffices to sweep away the whole system of geological and biological speculation demanding an "inconceivably" great vista of past time, or even a few thousand million years, for the history of life on the earth, and approximate uniformity of plutonic action throughout that time; which, as we have seen, was very generally prevalent thirty years ago among British Geologists and Biologists; and which, I must say, some of our chiefs of the present day have not yet abandoned. Witness the Presidents of the Geological and Zoological Sections of the British Association at its meetings of 1893 (Nottingham), and of 1896 (Liverpool).

Mr. Teall : Presidential Address to the Geological Section, 1892. "The good old British ship ' Uniformity,' built by Hutton and refitted by Lyell, has won so many glorious victories in the past, and appears still to be in such excellent fighting trim, that I see no reason why she should haul down her colours either to 'Catastrophe' or 'Evolution.' Instead, therefore, of acceding to the request to ' hurry up' we make a demand for more time."

Professor Poulton : Presidential Address to the Zoological Section, 1896. " Our argument does not deal with the time required for the origin of life, or for the development of the lowest beings with which we are acquainted from the first formed beings, of which we know nothing. Both these processes may have required an immensity of time ; but as we know nothing whatever about them and have as yet no prospect of acquiring any information, we are compelled to confine ourselves to as much of the process of evolution as we can infer from the structure of living and fossil forms—that is, as regards animals, to the development of the simplest into the most complex Protozoa, the evolution of the

Metazoa from the Protozoa, and the branching of the former into its numerous Phyla, with all their Classes, Orders, Families, Genera, and Species. But we shall find that this is quite enough to necessitate *a very large increase in the time estimated by the geologist.*"

§ 15. In my own short paper from which I have read you a sentence, the rate at which heat is at the present time lost from the earth by conduction outwards through the upper crust, as proved by observations of underground temperature in different parts of the world, and by measurement of the thermal conductivity of surface rocks and strata, sufficed to utterly refute the Doctrine of Uniformity as taught by Hutton, Lyell, and their followers; which was the sole object of that paper.

§ 16. In an earlier communication to the Royal Society of Edinburgh,* I had considered the cooling of the earth due to this loss of heat; and by tracing backwards the process of cooling had formed a definite estimate of the greatest and least number of million years which can possibly have passed since the surface of the earth was everywhere red hot. I expressed my conclusion in the following statement† :—

"We are very ignorant as to the effects of high temperatures in altering the conductivities and specific heats and melting temperatures of rocks, and as to their latent heat of fusion. We must, therefore allow very wide limits in such an estimate as I have attempted to make ; but I think we may with much probability say that the consolidation cannot have taken place less than 20 million years ago, or we should now have more underground heat than we actually have; nor more than 400 million years ago, or we should now have less underground heat than we actually have. That is to say, I conclude that Leibnitz's epoch of emergence of the *consistentior status* [the consolidation of the earth from red hot or white hot molten matter] was probably between those dates."

§ 17. During the 35 years which have passed since I gave this wide-ranged estimate, experimental investigation has supplied much of the knowledge then wanting regarding the thermal properties of rocks to form a closer estimate of the time which has passed since the consolidation of the earth, and we have now good reason for judging that it was more than 20 and less than 40 million years ago ; and probably much nearer 20 than 40.

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* *On the Secular Cooling of the Earth, Trans. Roy. Soc., Edinburgh*, vol. xxiii, April 28th, 1862, reprinted in Thomson and Tait, vol. iii, pp. 468–485, and *Math. and Phys. Papers*, Art. XCIV, pp. 295–311.
† *On the Secular Cooling of the Earth, Math. and Phys. Papers*, vol. iii, § 11 of Art. XCIV.

§ 18. Twelve years ago, in a laboratory established by Mr. Clarence King in connection with the United States Geological Survey, a very important series of experimental researches on the physical properties of rocks at high temperatures was commenced by Dr. Carl Barus, for the purpose of supplying trustworthy data for geological theory. Mr. Clarence King, in an article published in the *American Journal of Science*,* used data thus supplied, to estimate the age of the earth more definitely than was possible for me to do in 1862, with the very meagre information then available as to the specific heats, thermal conductivities, and temperatures of fusion, of rocks. I had taken 7,000° F. (3,871° C.) as a high estimate of the temperature of melting rock. Even then I might have taken something between 1,000° C. and 2,000° C. as more probable, but I was most anxious not to *under-estimate* the age of the earth, and so I founded my primary calculation on the 7,000° F. for the temperature of melting rock. We know now from the experiments of Carl Barus† that diabase, a typical basalt of very primitive character, melts between 1100° C. and 1170°, and is thoroughly liquid at 1200°. The correction from 3871° C. to 1200° or 1/3·22 of that value, for the temperature of solidification, would, with no other change of assumptions, reduce my estimate of 100 million to 1/(3·22)² of its amount, or a little less than 10 million years; but the effect of pressure on the temperature of solidification must also be taken into account, and Mr. Clarence King, after a careful scrutiny of all the data given him for this purpose by Dr. Barus, concludes that without further experimental data "we have no warrant for extending the earth's age beyond 24 millions of years."

§ 19. By an elaborate piece of mathematical book-keeping I have worked out the problem of the conduction of heat outwards from the earth, with specific heat increasing up to the melting point as found by Rücker and Roberts-Austen and by Barus, but with the conductivity assumed constant; and, by taking into account the augmentation of melting temperature with pressure in a somewhat more complete manner than that adopted by Mr. Clarence King, I am not led to differ much from his estimate of 24 million years. But, until we know something more than we know at present as to the probable diminution of thermal conductivity with

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* *On the Age of the Earth*, vol. xlv, January, 1893.
† *Phil. Mag.*, 1893, first half-year, pp. 186, 187, 301–305.

increasing temperature, which would shorten the time since
consolidation, it would be quite inadvisable to publish any
closer estimate.

§ 20. All these reckonings of the history of underground
heat, the details of which I am sure you do not wish me to
put before you at present, are founded on the very sure
assumption that the material of our present solid earth all
round its surface was at one time a white hot liquid.   The
earth is at present losing heat from its surface all round
from year to year and century to century.   We may dismiss
as utterly untenable any supposition such as that a few
thousand or a few million years of the present regime in
this respect was preceded by a few thousand or a few
million years of heating from without.   History, guided
by science, is bound to find, if possible, an antecedent
condition preceding every known state of affairs, whether
of dead matter or of living creatures.   Unless the earth was
created solid and hot out of nothing, the regime of con-
tinued loss of heat must have been preceded by molten
matter all round the surface. ∗

§ 21. I have given strong reasons* for believing that
immediately before solidification at the surface, the interior
was solid close up to the surface : except comparatively small
portions of lava or melted rock among the solid masses of
denser solid rock which had sunk through the liquid, and
possibly a somewhat large space around the centre occupied
by platinum, gold, silver, lead, copper, iron and other dense
metals, still remaining liquid under very high pressure.

§ 22. I wish now to speak to you of depths below the
great surface of liquid lava bounding the earth before
consolidation ; and of mountain heights and ocean depths
formed probably a few years after a first emergence of
solid rock from the liquid surface (see § 24, below), which
must have been quickly followed by complete consolida-
tion all round the globe.   But I must first ask you to ex-
cuse my giving you all my depths, heights, and distances,
in terms of the kilometre, being about six-tenths of that
very inconvenient measure the English statute mile, which,
with all the other monstrosities of our British metrical
system, will, let us hope, not long survive the legislation of
our present Parliamentary session destined to honour the

* *On the Secular Cooling of the Earth,* vol. iii, *Math. and Phys. Papers,*
§§ 19-33.

sixty years' Jubilee of Queen Victoria's reign by legalising the French metrical system for the United Kingdom.

§ 23. To prepare for considering consolidation at the surface let us go back to a time (probably not more than twenty years earlier as we shall presently see—§ 24) when the solid nucleus was covered with liquid lava to a depth of several kilometres; to fix our ideas let us say 40 kilometres (or 4 million centimetres). At this depth in lava, if of specific gravity 2·5, the hydrostatic pressure is 10 tons weight (10 million grammes) per square centimetre, or ten thousand atmospheres approximately. According to the laboratory experiments of Clarence King and Carl Barus* on Diabase, and the thermodynamic theory† of my brother, the late Professor James Thomson, the melting temperature of diabase is 1170° C. at ordinary atmospheric pressure, and would be 1420° under the pressure of ten thousand atmospheres, if the rise of temperature with pressure followed the law of simple proportion up to so high a pressure.

§ 24. The temperature of our 40 kilometres deep lava ocean of melted diabase may therefore be taken as but little less than 1420° from surface to bottom. Its surface would radiate heat out into space at some such rate as 2 (gramme-water) thermal units Centigrade per square centimetre per second.‡ Thus, in a year (31½ million seconds) 63 million thermal units would be lost per square centimetre from the surface. This is, according to Carl Barus, very nearly equal to the latent heat of fusion abandoned by a million cubic centimetres of melted diabase in solidifying into the glassy condition (pitch-stone) which is assumed when the freezing takes place in the course of a few minutes. But, as found by Sir James Hall in his Edinburgh experiments§ of 100 years ago, when more than a few minutes is taken for the freezing, the solid formed is not a glass but a heterogeneous crystalline solid of rough fracture; and if a

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* *Phil. Mag.*, 1893, first half-year, p. 306.

† *Trans. Roy. Soc., Edinburgh*, Jan. 2, 1849 ; *Cambridge and Dublin Mathematical Journal*, Nov. 1850. Reprinted in *Math. and Phys. Papers* (Kelvin), vol. i, p. 156.

‡ This is a very rough estimate which I have formed from consideration of J. T. Bottomley's accurate determinations in absolute measure of thermal radiation at temperatures up to 920° C. from platinum wire and from polished and blackened surfaces of various kinds in receivers of air-pumps exhausted down to one ten-millionth of the atmospheric pressure. *Phil. Trans. Roy. Soc.*, 1887 and 1893.

§ *Trans. Roy. Soc., Edinburgh*

few hours or days, or any longer time, is taken, the solid formed has the well known rough crystalline structure of basaltic rocks found in all parts of the world. Now Carl Barus finds that basaltic diabase is 14 per cent. denser than melted diabase, and 10 per cent. denser than the glass produced by quick freezing of the liquid. He gives no data, nor do Rücker and Roberts-Austen, who have also experimented on the thermodynamic properties of melted basalt, give any data, as to the latent heat evolved in the consolidation of liquid lava into rock of basaltic quality. Guessing it as three times the latent heat of fusion of the diabase pitch-stone, I estimate a million cubic centimetres of liquid frozen per square centimetre per centimetre per three years. This would diminish the depth of the liquid at the rate of a million centimetres per three years, or 40 kilometres in twelve years.

§ 25. Let us now consider in what manner this diminution of depth of the lava ocean must have proceeded, by the freezing of portions of it; all having been at temperatures very little below the assumed 1420° melting temperature of the bottom, when the depth was 40 kilometres. The loss of heat from the white-hot surface (temperatures from 1420° to perhaps 1380° in different parts) at our assumed rate of 2 (gramme-water Centigrade) thermal units per sq. cm. per sec. produces very rapid cooling of the liquid within a few centimetres of the surface (thermal capacity ·36 per gramme, according to Barus) and in consequence great downward rushes of this cooled liquid, and upwards of hot liquid, spreading out horizontally in all directions when it reaches the surface. When the sinking liquid gets within perhaps 20 or 10 or 5 kilometres of the bottom, its temperature* becomes the freezing point as raised by the increased pressure; or, perhaps more correctly stated, a temperature at which some of its ingredients crystallise out of it. Hence, beginning a few kilometres above the bottom, we have a snow shower of solidified lava or of crystalline flakes, or prisms, or granules of felspar, mica, hornblende, quartz, and other ingredients: each little crystal gaining mass and falling somewhat faster than the descending liquid around it, till it

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* The temperature of the sinking liquid rock rises in virtue of the increasing pressure: but much less than does the freezing point of the liquid or of some of its ingredients. (See Kelvin, *Math. and Phys. Papers*, vol. iii, pp. 69, 70.)

reaches the bottom. This process goes on until, by the heaping of granules and crystals on the bottom, our lava ocean becomes silted up to the surface

PROBABLE ORIGIN OF GRANITE.   (§§ 26, 27.)

§ 26. Upon the suppositions we have hitherto made we have, at the stage now reached, all round the earth at the same time a red hot or white hot surface of solid granules or crystals with interstices filled by the mother liquor still liquid, but ready to freeze with the slightest cooling. The thermal conductivity of this heterogeneous mass, even before the freezing of the liquid part, is probably nearly the same as that of ordinary solid granite or basalt at a red heat, which is almost certainly* somewhat less than the thermal conductivity of igneous rocks at ordinary temperatures. If you wish to see for yourselves how quickly it would cool when wholly solidified take a large macadamising stone, and heat it red hot in an ordinary coal fire. Take it out with a pair of tongs and leave it on the hearth, or on a stone slab at a distance from the fire, and you will see that in a minute or two, or perhaps in less than a minute, it cools to below red heat.

§ 27. Half an hour† after solidification reached up to the surface in any part of the earth, the mother liquor among the granules must have frozen to a depth of several centimetres below the surface and must have cemented together the granules and crystals, and so formed a crust of primeval granite, comparatively cool at its upper surface, and red hot to white hot, but still all solid, a little distance down; becoming thicker and thicker very rapidly at first; and after a few weeks certainly cold enough at its outer surface to be touched by the hand.

PROBABLE ORIGIN OF BASALTIC ROCK.   (§§ 28, 29.)

§ 28. We have hitherto left, without much consideration, the mother liquor among the crystalline granules at all depths below the bottom of our shoaling lava ocean. It was probably this interstitial mother liquor that was destined to form the basaltic rock of future geological time. What-

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* *Proc. R.S.*, May 30, 1895.

† Witness the rapid cooling of lava running red hot or white hot from a volcano, and after a few days or weeks presenting a black hard crust strong enough and cool enough to be walked over with impunity.

ever be the shapes and sizes of the solid granules when first falling to the bottom, they must have lain in loose heaps with a somewhat large proportion of space occupied by liquid among them. But, at considerable distances down in the heap, the weight of the superincumbent granules must tend to crush corners and edges into fine powder. If the snow shower had taken place in air we may feel pretty sure (even with the slight knowledge which we have of the hardnesses of the crystals of felspar, mica and hornblende, and of the solid granules of quartz) that, at a depth of 10 kilometres, enough of matter from the corners and edges of the granules of different kinds, would have been crushed into powder of various degrees of fineness, to leave an exceedingly small proportionate volume of air in the interstices between the solid fragments. But in reality the effective weight of each solid particle, buoyed as it was by hydrostatic pressure of a liquid less dense than itself by not more than 20 or 15 or 10 per cent., cannot have been more than from about $\frac{1}{5}$th to $\frac{1}{10}$th of its weight in air, and therefore the same degree of crushing effect as would have been experienced at 10 kilometres with air in the interstices, must have been experienced only at depths of from 50 to 100 kilometres below the bottom of the lava ocean.

§ 29. A result of this tremendous crushing together of the solid granules must have been to press out the liquid from among them, as water from a sponge, and cause it to pass upwards through the less and less closely packed heaps of solid particles, and out into the lava ocean above the heap. But, on account of the great resistance against the liquid permeating upwards 30 or 40 kilometres through interstices among the solid granules, this process must have gone on somewhat slowly ; and, during all the time of the shoaling of the lava ocean, there may have been a considerable proportion of the whole volume occupied by the mother liquor among the solid granules, down to even as low as 50 or 100 kilometres below the top of the heap, or bottom of the ocean, at each instant. When consolidation reached the surface, the oozing upwards of the mother liquor must have been still going on to some degree. Thus, probably for a few years after the first consolidation at the surface, not probably for as long as one hundred years, the settlement of the solid structure by mere mechanical crushing of the corners and edges of solid granules, may have continued to cause the oozing upwards of mother liquor to the surface through

cracks in the first formed granite crust and through fresh cracks in basaltic crust subsequently formed above it.

LEIBNITZ'S CONSISTENTIOR STATUS.

§ 30. When this oozing everywhere through fine cracks in the surface ceases, we have reached Leibnitz's *consistentior status;* beginning with the surface cool and permanently solid and the temperature increasing to 1150° C. at 25 or 50 or 100 metres below the surface.

PROBABLE ORIGIN OF CONTINENTS AND OCEAN DEPTHS OF THE EARTH (§§ 31–37.)

§ 31. If the shoaling of the lava ocean up to the surface had taken place everywhere at the same time, the whole surface of the consistent solid would be the dead level of the liquid lava all round, just before its depth became zero. On this supposition there seems no possibility that our present-day continents could have risen to their present heights, and that the surface of the solid in its other parts could have sunk down to their present ocean depths, during the twenty or twenty-five million years which may have passed since the *consistentior status* began or during any time however long. Rejecting the extremely improbable hypothesis that the conti nents were built up of meteoric matter tossed from without, upon the already solidified earth, we have no other possible alternative than that they are due to heterogeneousness in different parts of the liquid which constituted the earth before its solidification. The hydrostatic equilibrium of the rotating liquid involved only homogeneousness in respect to density over every level surface (that is to say, surface perpendicular to the resultant of gravity and centrifugal force): it required no homogeneousness in respect to chemical composition. Considering the almost certain truth that the earth was built up of meteorites falling together, we may follow in imagination the whole process of shrinking from gaseous nebula to liquid lava and metals, and solidification of liquid from central regions outwards, without finding any thorough mixing up of different ingredients, coming together from different directions of space—any mixing up so thorough as to produce even approximately chemical homogeneousness throughout every layer of equal density. Thus we have no difficulty in understanding how even the gaseous nebula, which at one time constituted the matter of our present earth, had in itself a

heterogeneousness from which followed by dynamical neces-
sity Europe, Asia, Africa, America, Australia, Greenland and
the Antarctic Continent, and the Pacific, Atlantic, Indian and
Arctic Ocean depths, as we know them at present.

§ 32. We may reasonably believe that a very slight degree
of chemical heterogeneousness could cause great differences
in the heaviness of the snow shower of granules and crystals
on different regions of the bottom of the lava ocean when
still 50 or 100 kilometres deep. Thus we can quite see how
it may have shoaled much more rapidly in some places than
in others. It is also interesting to consider that the solid
granules, falling on the bottom, may have been largely
disturbed, blown as it were into ridges (like rippled sand in
the bed of a flowing stream, or like dry sand blown into
sand-hills by wind) by the eastward horizontal motion
which liquid descending in the equatorial regions must
acquire, relatively to the bottom, in virtue of the earth's
rotation. It is indeed not improbable that this influence
may have been largely effective in producing the general
configuration of the great ridges of the Andes and Rocky
Mountains and of the West Coasts of Europe and Africa. It
seems, however, certain that the main determining cause of
the continents and ocean-depths was chemical differences,
perhaps very slight differences, of the material in different
parts of the great lava ocean before consolidation.

§ 33. To fix our ideas let us now suppose that over some
great areas such as those which have since become Asia,
Europe, Africa, Australia, and America, the lava ocean had
silted up to its surface, while in other parts there still were
depths ranging down to 40 kilometres at the deepest. In
a very short time, say about twelve years according to our
former estimate (§ 24) the whole lava ocean becomes silted
up to its surface.

§ 34. We have not time enough at present to think out all
the complicated actions, hydrostatic and thermodynamic,
which must accompany, and follow after, the cooling of the
lava ocean surrounding our ideal primitive continent. By
a hurried view however of the affair we see that in virtue
of, let us say 15 per cent. shrinkage by freezing, the level
of the liquid must, at its greatest supposed depth, sink six
kilometres relatively to the continents : and thus the liquid
must recede from them ; and their bounding coast-lines must
become enlarged. And just as water runs out of a sand-
bank, drying when the sea recedes from it on a falling

tide, so rivulets of the mother liquor must run out from
the edges of the continents into the receding lava ocean.
But, unlike sandbanks of incoherent sand permeated by
water remaining liquid, our uncovered banks of white-hot
solid crystals, with interstices full of the mother liquor, will,
within a few hours of being uncovered, become crusted into
hard rock by cooling at the surface, and freezing of the
liquor, at a temperature somewhat lower than the melting
temperatures of any of the crystals previously formed. The
thickness of the wholly solidified crust grows at first with
extreme rapidity, so that in the course of three or four days
it may come to be as much as a mètre. At the end of a
year it may be as much as 10 metres; with a surface,
almost, or quite, cool enough for some kinds of vegetation.
In the course of the first few weeks the *régime* of conduction
of heat outwards becomes such that the thickness of the
wholly solid crust, as long as it remains undisturbed,
increases as the square root of the time; so that in 100 years
it becomes 10 times, in 25 million years 5,000 times, as thick
as it was at the end of one year; thus, from one year to
25 million years after the time of surface freezing, the
thickness of the wholly solid crust might grow from 10
metres to 50 kilometres. These definite numbers are given
merely as an illustration; but it is probable they are not
enormously far from the truth in respect to what has
happened under some of the least disturbed parts of the
earth's surface.

§ 35. We have now reached the condition described above
in § 30, with only this difference, that instead of the upper
surface of the whole solidified crust being level we have
in virtue of the assumptions of §§ 33, 34, inequalities of
6 kilometres from highest to lowest levels, or as much more
than 6 kilometres as we please to assume it.

§ 36. There must still be a small, but important, proportion
of mother liquor in the interstices between the closely packed
uncooled crystals below the wholly solidified crust. This
liquor, differing in chemical constitution from the crystals, has
its freezing point somewhat lower, perhaps very largely lower,
than the lowest of their melting points. But, when we con-
sider the mode of formation (§ 25) of the crystals from the
mother liquor, we must regard it as still always a solvent
ready to dissolve, and to redeposit, portions of the crystalline
matter, when slight variations of temperature or pressure
tend to cause such actions. Now as the specific gravity of

the liquor is less, by something like 15 per cent., than the specific gravity of the solid crystals, it must *tend* to find its way upwards, and will actually do so, however slowly, until stopped by the already solidified impermeable crust, or until itself becomes solid on account of loss of heat by conduction outwards. If the upper crust were everywhere continuous and perfectly rigid the mother liquor must, inevitably, if sufficient time be given, find its way to the highest places of the lower boundary of the crust, and there form gigantic pockets of liquid lava tending to break the crust above it and burst up through it.

§ 37. But in reality the upper crust cannot have been infinitely strong; and, judging alone from what we know of properties of matter, we should expect gigantic cracks to occur from time to time in the upper crust tending to shrink as it cools and prevented from lateral shrinkage by the non-shrinking uncooled solid below it. When any such crack extends downwards as far as a pocket of mother liquor underlying the wholly solidified crust, we should have an outburst of trap rock or of volcanic lava just such as have been discovered by geologists in great abundance in many parts of the world. We might even have comparatively small portions of high plateaus of the primitive solid earth raised still higher by outbursts of the mother liquor squeezed out from below them in virtue of the pressure of large surrounding portions of the superincumbent crust. In any such action, due to purely gravitational energy, the centre of gravity of all the material concerned must sink, although portions of the matter may be raised to greater heights; but we must leave these large questions of geological dynamics, having been only brought to think of them at all just now by our consideration of the earth, antecedent to life upon it.

§ 38. The temperature to which the earth's surface cooled within a few years after the solidification reached it, must have been, as it is now, such that the temperature at which heat radiated into space during the night exceeds that received from the sun during the day, by the small difference due to heat conducted outwards from within.* One year

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* Suppose for example the cooling and thickening of the upper crust has proceeded so far, that at the surface and therefore approximately for a few decimetres below the surface, the rate of augmentation of temperature downwards is one degree per centimetre. Taking as a rough average ·005 c.g.s. as the thermal conductivity of the surface rock, we should have for the heat conducted outwards ·005 of a gramme water

after the freezing of the granitic interstitial mother liquor at the earth's surface in any locality, the average temperature at the surface might be warmer, by 60° or 80° Cent., than if the whole interior had the same average temperature as the surface. To fix our ideas, let us suppose, at the end of one year, the surface to be 80° warmer than it would be with no underground heat : then at the end of 100 years it would be 8° warmer, and at the end of 10,000 years it would be ·8 of a degree warmer, and at the end of 25 million years it would be ·016 of a degree warmer, than if there were no underground heat.

§ 39. When the surface of the earth was still white-hot liquid all round, at a temperature fallen to about 1200° Cent., there must have been hot gases and vapour of water above it in all parts, and possibly vapours of some of the more volatile of the present known terrestrial solids and liquids, such as zinc, mercury, sulphur, phosphorus. The very rapid cooling which followed instantly on the solidification at the surface must have caused a rapid downpour of all the vapours other than water, if any there were; and a little later, rain of water out of the air, as the temperature of the surface cooled from red heat to such moderate temperatures as 40° and 20° and 10° Cent., above the average due to sun heat and radiation into the ether around the earth. What that primitive atmosphere was, and how much rain of water fell on the earth in the course of the first century after consolidation, we cannot tell for certain; but Natural History and Natural Philosophy give us some foundation for endeavours to discover much towards answering the great questions,

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thermal unit centigrade per sq. cm. per sec. (Kelvin, *Math. and Phys. Papers*, vol. III, p. 226). Hence if (*ibid.* p. 223) we take $\frac{1}{8000}$ as the radiational emissivity of rock and atmosphere of gases and watery vapour above it radiating heat into the surrounding vacuous space (ether), we find $8000 \times \cdot005$, or 40 degrees Cent. as the excess of the mean surface temperature above what it would be if no heat were conducted from within outwards. The present augmentation of temperature downwards may be taken as 1 degree Cent. per 27 metres as a rough average derived from observations in all parts of the earth where underground temperature has been observed. (See British Association Reports, from 1868 to 1895. The very valuable work of this Committee has been carried on for these twenty-seven years with great skill, perseverance, and success, by Professor Everett, and he promises a continuation of his reports from time to time.) This with the same data for conductivity and radiational emissivity as in the preceding calculation makes 40°/2700 or 0·0148° Cent. per centimetre as the amount by which the average temperature of the earth's surface is at present kept up by underground heat.

—Whence came our present atmosphere of nitrogen, oxygen, and carbonic acid? Whence came our present oceans and lakes of salt and fresh water? How near an approximation to present conditions was realised in the first hundred centuries after consolidation of the surface?

§ 40. We may consider it as quite certain that nitrogen gas, carbonic acid gas, and steam, escaped abundantly in bubbles from the mother liquor of granite, before the primitive consolidation of the surface, and from the mother liquor squeezed up from below in subsequent eruptions of basaltic rock; because all, or nearly all, specimens of granite and basaltic rock, which have been tested by chemists in respect to this question,* have been found to contain, condensed in minute cavities within them, large quantities of nitrogen, carbonic acid, and water. It seems that in no specimen of granite or basalt tested has chemically free oxygen been discovered, while in many, chemically free hydrogen has been found; and either native iron or magnetic oxide of iron in those which do not contain hydrogen. From this it might seem probable that there was no free oxygen in the primitive atmosphere, and that if there was free hydrogen, it was due to the decomposition of steam by iron or magnetic oxide of iron. Going back to still earlier conditions we might judge that, probably, among the dissolved gases of the hot nebula which became the earth, the oxygen all fell into combination with hydrogen and other metallic vapours in the cooling of the nebula, and that although it is known to be the most abundant material of all the chemical elements constituting the earth, none of it was left out of combination with other elements to give free oxygen in our primitive atmosphere.

§ 41. It is however possible, although it might seem not probable, that there was free oxygen in the primitive atmosphere. With or without free oxygen, however, *but with sunlight*, we may regard the earth as fitted for vegetable life as now known in some species, wherever water moistened the newly solidified rocky crust cooled down below the temperature of 80° or 70° of our present Centigrade thermometric scale, a year or two after solidification of the primitive lava had come up to the surface. The thick tough velvety coating of living vegetable matter, covering the rocky slopes under hot

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* See for example Tilden, *Proc. R.S.*, February 4th, 1897. "On the Gases enclosed in Crystalline Rocks and Minerals."

water flowing direct out of the earth at Banff (Canada),* lives without help from any ingredients of the atmosphere above it, and takes from the water and from carbonic acid or carbonates, dissolved in it, the hydrogen and carbon needed for its own growth by the dynamical power of sunlight; thus leaving free oxygen in the water to pass ultimately into the air. Similar vegetation is found abundantly on the terraces of the Mammoth hot springs and on the beds of the hot water streams flowing from the Geysers in the Yellowstone National Park of the United States. This vegetation, consisting of confervæ, all grows under flowing water at various temperatures, some said to be as high as $74°$ Cent. We cannot doubt but that some such confervæ, if sown or planted in a rivulet or pool of warm water in the early years of the first century of the solid earth's history, and if favoured with sunlight, would have lived, and grown, and multiplied, and would have made a beginning of oxygen in the air, if there had been none of it before their contributions. Before the end of the century, if sun-heat, and sunlight, and rainfall, were suitable, the whole earth not under water must have been fitted for all kinds of land plants which do not require much or any oxygen in the air, and which can find, or make, place and soil for their roots on the rocks on which they grow; and the lakes or oceans formed by that time must have been quite fitted for the life of many or all of the species of water plants living on the earth at the present time. The moderate warming, both of land and water, by underground heat, towards the end of the century, would probably be favourable rather than adverse to vegetation, and there can be no doubt but that if abundance of seeds of all species of the present day had been scattered over the earth at that time, an important proportion of them would have lived and multiplied by natural selection of the places where they could best thrive.

§ 42. But if there was no free oxygen in the primitive atmosphere or primitive water, several thousands, possibly hundreds of thousands, of years must pass before oxygen enough for supporting animal life, as we now know it, was produced. Even if the average activity of vegetable growth on land and in water over the whole earth was, in those early times, as great in respect to evolution of

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* Rocky Mountains Park of Canada, on the Canadian Pacific Railway.

oxygen as that of a Hessian forest, as estimated by Liebig[*] 50 years ago, or of a cultivated English hayfield of the present day, a very improbable supposition, and if there were no decay (*eremacausis*, or gradual recombination with oxygen) of the plants or of portions such as leaves falling from plants, the rate of evolution of oxygen, reckoned as three times the weight of the wood or the dry hay produced, would be only about 6 tons per English acre per annum or $1\frac{1}{2}$ tons per square metre per thousand years. At this rate it would take only 1533 years, and therefore in reality a much longer time would almost certainly be required, to produce the 2·3 tons of oxygen which we have at present resting on every square metre of the earth's surface, land and sea.[†] But probably quite a moderate number of hundred thousand years may have sufficed. It is interesting at all events to remark that, at any time, the total amount of combustible material on the earth, in the form of living plants or their remains left dead, must have been just so much that to burn it all would take either the whole oxygen of the atmosphere, or the excess of oxygen in the atmosphere at the time, above that, if any, which there was in the beginning. This we can safely say, because we almost certainly neglect nothing considerable in comparison with what we assert when we say that the free oxygen of the earth's atmosphere is augmented only by vegetation liberating it from carbonic acid and water, in virtue of the power of sunlight, and is diminished only by virtual burning[‡] of the vegetable matter thus produced. But it seems improbable that the average of the whole earth—dry land and sea-bottom,—contains at present coal, or wood, or oil, or fuel of any kind originating in vegetation, to so great an amount as ·767 of a ton per square metre of surface; which is the amount at the rate of one ton of fuel to three tons of oxygen, that would be required to produce the 2·3 tons of

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[*] Liebig, "Chemistry in its application to Agriculture and Physiology," English, 2nd ed., edited by Playfair, 1842.

[†] In our present atmosphere, in average conditions of barometer and thermometer we have, resting on each square metre of the earth's surface, ten tons total weight, of which 7·7 is nitrogen and 2·3 is oxygen.

[‡] This "virtual burning" includes eremacausis of decay of vegetable matter, if there is any eremacausis of decay without the intervention of microbes or other animals. It also includes the combination of a portion of the food with inhaled oxygen in the regular animal economy of provision for heat and power.

oxygen per square metre of surface, which our present atmosphere contains. Hence it seems probable that the earth's primitive atmosphere must have contained free oxygen.

§ 43. Whatever may have been the true history of our atmosphere it seems certain that if sunlight was ready, the earth was ready, both for vegetable and animal life, if not within a century, at all events within a few hundred centuries after the rocky consolidation of its surface. But was the sun ready? The well founded dynamical theory of the sun's heat carefully worked out and discussed by Helmholtz, Newcomb, and myself,* says NO if the consolidation of the earth took place as long ago as 50 million years; the solid earth must in that case have waited 20 or 30 million years for the sun to be anything nearly as warm as he is at present. If the consolidation of the earth was finished 20 or 25 million years ago, the sun was probably ready,— though probably not then quite so warm as at present, yet warm enough to support some kind of vegetable and animal life on the earth.

§ 44. My task has been rigorously confined to what, humanly speaking, we may call the fortuitous concourse of atoms, in the preparation of the earth as an abode fitted for life, except in so far as I have referred to vegetation, as possibly having been concerned in the preparation of an atmosphere suitable for animal life as we now have it. Mathematics and dynamics fail us when we contemplate the earth, fitted for life but lifeless, and try to imagine the commencement of life upon it. This certainly did not take place by any action of chemistry, or electricity, or crystalline grouping of molecules under the influence of force, or by any possible kind of fortuitous concourse of atoms. We must pause, face to face with the mystery and miracle of the creation of living creatures.

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* See *Popular Lectures and Addresses*, vol. 1, pp. 376–429, particularly page 397.

The LORD CHANCELLOR (Earl HALSBURY, F.R.S.)—As we have been dealing so lavishly with millions of years, you will not grudge me half a minute to return thanks to Lord Kelvin, and those authors who have taken part in the work of the session.

I am afraid, interesting as have been some of his communi-cations, the subject is of such vastness that, although he has put before us some most valuable propositions, any one of which might form the subject of a most interesting debate and opening up, as he has a whole fountain of learning and science at every turn of his Address, they have been so numerous, that some present may have failed to appreciate them. My own impression at present is (I have not had the opportunity of studying more deeply what my noble friend has said), that he has criticised with great power a number of gentlemen who seem to adopt the principle that if the facts do not accord with the theories, so much the worse for the facts. (Applause and laughter.) I think, under these circumstances, you will agree that we are all deeply indebted to Lord Kelvin for what he has said. Perhaps we are more deeply indebted to him than we appreciate for the moment ; for it will be on record here that a gentleman of Lord Kelvin's eminence, learning, and wonderful power of investigating nature has been here delivering an address to a Society of this character the prin-cipal function of which, I believe, is to show that there is nothing inconsistent between Revelation and Science, and to show, as he has done, that many of the theories at all events, which are supposed to conflict with that proposition, are utterly without foundation. (Applause.)

Sir J. FAYRER, Bart., K.C.S.I., F.R.S.—It gives me much pleasure, as it is a great honour, to be permitted to second the vote of thanks that has been proposed by the noble Lord who has just sat down.

It would be as presumptuous in me, as it would be unnecessary, if I were to try to add anything to what has just been said ; but still I should like to remark, from the Victoria Institute point of view—of which I happen now to be a very old member—how very gratifying it is to this Institute that it should have been addressed by the most distinguished leading man of science of the present day. (Applause.) I think this, and many other things that have

occurred of late years, go far to remove any of the false impressions set abroad about the nature, object, and purposes of this Institute. I feel that it is also an endorsement of what we were told long, long ago by Bishop Butler, that we had a perfect right to the due use of our reason—reason being the one only faculty with which the Almighty has endowed us, by which we can understand anything at all, even Revelation itself. Therefore I think, with such an example from such a man, the Victoria Institute may well go on prosecuting the investigations it has been conducting, in my judgment so well, during many past years.

I beg to second the vote of thanks that has just been proposed to Lord Kelvin for his very admirable and interesting Address (applause), and those authors who have taken part in the work of the session.

The resolution was carried by acclamation.

Sir SIDNEY G. A. SHIPPARD, G.C.M.G.—Before we separate I will ask you to join in what I am sure we shall all regard with pleasure, and that is a vote of thanks to our venerable President, who has, at great inconvenience to himself, come forward to indicate once more his great devotion to science and his deep interest in this Institute by presiding upon this occasion. We have in Sir Gabriel Stokes one of the greatest lights of the present day, and I rejoice to see him here, and I hope for many years he will be spared to prosecute his labours and to preside over this Institute. (Applause.)

Captain E. W. CREAK, R.N., F.R.S.—I have the great pleasure of seconding this resolution, and am sure you will all accord your thanks with acclamation.

Carried *nem. con.*

The PRESIDENT (Sir G. GABRIEL STOKES, Bart., F.R.S.).—I thank you much for the great kindness with which you have spoken of myself. It affords me much satisfaction to find that I have been successful in persuading my old friend Lord Kelvin to give the Address on this occasion, to which we have just listened with so much interest.

The meeting is now concluded, and with it the present session, and I hope that next session we shall again resume our labours.

LORD KELVIN ON DESIGN IN NATURE.

In his Presidential Address before the British Association in
1871, Lord Kelvin thus referred to the Argument in favour of
Design in Nature (Paley's) :—" I feel profoundly convinced that
the argument of design has been too much lost sight of in recent
zoological speculations. Reaction against frivolities of teleology
such as are to be found in the notes of learned commentators on
Paley's *Natural Theology*, has, I believe, had a temporary effect
in turning attention from the solid and irrefragable argument so
well put forward in that excellent old book. But overpoweringly
strong proofs of intelligent and benevolent design lie all round
us ; and if ever perplexities, whether metaphysical or scientific,
turn us away from them for a time, they come back upon us
with irresistible force, showing to us through nature the influence
of a free will, and teaching us that all living beings depend on
one ever-acting Creator and Ruler."—ED.