ON THE

PROBABLE ORIGIN AND AGE

OF

THE SUN.

BY

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Oct 29. 1877.

THE total annual amount of radiation from the whole surface of the sun is 8340×10^{30} foot-pounds. To maintain the present rate of radiation it would require the combustion of about 1500 lbs. of coal per hour on every square foot of the sun's surface; and were the sun composed of that material it would all be consumed in less than 5000 years. The opinion that the sun's heat is maintained by combustion cannot be entertained for a single moment. Mr. Lockyer has suggested that the elements of the sun are, owing to its excessive temperature, in a state of dissociation, and some have supposed that this fact might help to explain the duration of the sun's heat. But it must be obvious that, even supposing we were to make the most extravagant estimate of the chemical affinities of these elements, the amount of heat derived from their combination could at most give us only a few thousand years additional heat. Under every conceivable supposition the combustion theory must be abandoned.

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It is now generally held by physicists that the enormous store of heat possessed by the sun could only have been derived from gravitation. For example, a pound of coal falling into the sun from an infinite distance would produce by its concussion more than 6000 times the amount of heat that would be generated by its combustion. It would, in fact, amount to upwards of 65,000,000,000 foot-pounds—an amount of energy sufficient to raise 1000 tons to a height of $5\frac{1}{2}$ miles.

Calculating machine work

There are two forms in which the gravitation theory has been presented: the first, the meteoric theory, propounded by Dr. Meyer; and the second, the contraction theory, advocated by Helmholtz. The meteoric theory of the sun's heat has now been pretty generally abandoned for the contraction theory advanced by Helmholtz. Suppose, with Helmholtz, that the sun originally existed as a nebulous mass, filling the entire space presently occupied by the solar system, and extending into space indefinitely beyond the

outermost planet. The total amount of work in foot-pounds performed by gravitation in the condensation of this mass to an orb of the sun's present size can be found by means of the following formula given by Helmholtz :—

$$\text{Work of condensation} = \frac{3}{5} \cdot \frac{r^2 M^2}{Rm} \cdot g.$$

M is the mass of the sun, m the mass of the earth, R the sun's radius, and r the earth's radius. Taking—

$$M = 4230 \times 10^{27} \text{ lbs.}, \; m = 11{,}920 \times 10^{21} \text{ lbs.},$$
$$R = 2{,}328{,}500{,}000 \text{ feet, and } r = 20{,}889{,}272 \text{ feet},$$

we have then, for the total amount of work performed by gravitation in foot-pounds,

$$\frac{3}{5} \cdot \frac{(20{,}889{,}272{\cdot}5)^2 \times (4230 \times 10^{27})^2}{2{,}328{,}500{,}000 \times 11{,}920 \times 10^{21}}$$
$$= 168{,}790 \times 10^{36} \text{ foot-pounds.}$$

The amount of heat thus produced by gravitation would suffice for 20,237,500 years.

The conclusions are based upon the assumption that the density of the sun is uniform throughout. But it is highly probable that the sun's density increases towards the centre, in which case the amount of work performed by gravitation would be something more than the above.

At this point, in reference to the age of our globe, Geology and Physics are generally supposed to come into direct antagonism. For if it be true, as physicists maintain, that gravitation is the only possible source from which the sun could have derived its store of energy, then the sun could not have maintained our globe at its present temperature for more than about 20 millions of years. "On the very highest computation which can be permitted," says Prof. Tait, "it cannot have supplied the earth, even at the present rate, for more than about fifteen or twenty million years."* The limit to the age of the sun's heat must have limited the age of the habitable globe. All the geological history of the globe would necessarily be comprehended within this period. If the sun derived its heat from the condensation of its mass, then it could not possibly be more than about twenty million years since the beginning of the Laurentian period. But twenty million years would be considered by most geologists to represent only a comparatively small portion of the time which must have elapsed since organic life began on our globe.

Here come conclusions which seem to me non sequiter

* Recent Advances in Physical Science, p. 175.

It is true that the views which formerly prevailed amongst geologists, in regard to the almost unlimited extent of geological time, have of late undergone very considerable modifications; but there are few geologists, I presume, who would be willing to admit that the above period is sufficient to comprehend the entire history of stratified rocks.

It is the facts of denudation which most forcibly impress the mind with a sense of immense duration, and show most convincingly the great antiquity of the earth.

We know unquestionably that many of the greatest changes undergone by the earth's crust were produced, not by convulsions and cataclysms of nature, but by those ordinary agencies that we see at work every day around us, such as rain, snow, frost, ice, chemical action, &c. Valleys have not been produced by violent dislocations, nor the hills by upheavals, but both have been carved out of the solid rock by the silent and gentle agency of chemical action, frost, rain, ice, and running water. In short, the rocky face of our globe has been moulded into hill and dale, and ultimately worn down to the sea-level by means of these apparently trifling agents, not merely once or twice, but probably dozens of times over during past ages. Now when we reflect that with such extreme slowness do these agents perform their work that we might, if we could, watch their operations from year to year, and from century to century, without being able to perceive that they make any sensible impression, we are necessitated to conclude that geological periods must be enormous. The utter inadequacy of a period of 20 million years for the age of our earth is demonstrable from the enormous thickness of rock which is known to have been removed off certain areas by denudation. I shall now briefly refer to a few of the many facts which might be adduced on this point.

One plain and obvious method of showing the great extent to which the general surface of the country has been lowered by denudation is furnished, as is well known, by the way in which the inequalities of surface produced by faults or dislocations have been effaced. It is quite common to meet with faults where the strata on the one side have been depressed several hundreds—and in some cases thousands—of feet below that on the other, but we seldom find any indications of such on the surface, the inequalities on the surface having been all removed by denudation. But in order to effect this a mass of rock must have been removed equal in thickness to the extent of the dislocation. The following are a few examples of large faults :—

The great Irwell fault, described by Prof. Hull,* which stretches from the Mersey west of Stockport to the north of Bolton, has a throw of upwards of 3000 feet.

Some remarkable faults have been found by Prof. Ramsay in North Wales. For example, near Snowdon, and about a mile E.S.E. of Beddgelert, there is a fault with a downthrow of 5000 feet; and in the Berwyn Hills, between Bryn-mawr and Post-gwyn, there is one of 5000 feet. In the Aran Range there is a great fault, designated the Bala fault, with a downthrow of 7000 feet. Again, between Aran Mowddwy and Careg Aderyn the displacement of the strata amounts to no less than from 10,000 to 11,000 feet.† Here we have evidence that a mass of rock, varying from 1 mile to 2 miles in vertical thickness, must have been denuded in many places from the surface of the country in North Wales.

The fault which passes along the east side of the Pentlands is estimated to have a throw of upwards of 3000 feet.‡ Along the flank of the Grampians a great fault runs from the North Sea at Stonehaven to the estuary of the Clyde, throwing the Old Red Sandstone on end sometimes for a distance of 2 miles from the line of dislocation. The amount of the displacement, Prof. Geikie‖ concludes, must be in some places not less than 5000 feet, as indicated by the position of occasional outlyers of conglomerate on the Highland side of the fault.

The great fault crossing Scotland from near Dunbar to the Ayrshire coast, and which separates the Silurians of the South of Scotland from the Old Red Sandstone and Carboniferous tracts of the North, has been found, by Mr. B. N. Peach, of the Geological Survey,§ to have in some places a throw of fully 15,000 feet. This great dislocation is older than the Carboniferous period, as is shown by the entire absence of any Old Red Sandstone on the south side of the fault, and by the occurrence of the Carboniferous Limestone and Coal-measures lying directly on the Silurian rocks. We obtain here some idea of the enormous amount of denudation which must have taken place during a comparatively limited geological epoch. So vast a thickness of Old Red Sandstone could not, as Mr. Peach remarks, "have ended originally where the fault now is, but must have swept southwards over the Lower Silurian uplands. Yet these thousands of feet of sandstones, conglomerates, lavas, and

* Mem. Geol. Survey of Lancashire, 1862.
† Mem. Geol. Survey of Great Britain, vol. iii.
‡ Memoir to Sheet 32, Geol. Survey Map of Scotland.
‖ Nature, vol. xiii., p. 390.
§ Explanation to Sheet 15, Geol. Survey Map of Scotland.

tuffs were so completely removed from the south side of the fault previous to the deposition of the Carboniferous Limestone series and the Coal-measures that not a fragment of them is anywhere to be seen between these latter formations and the old Silurian floor." This enormous thickness of nearly 3 miles of Old Red Sandstone must have been denuded away during the period which intervened between the deposition of the Lower Old Red Sandstone and the accumulation of the Carboniferous Limestone.

Near Tipperary, in the south of Ireland, there is a dislocation of the strata of not less than 4000 feet,* which brings down the Coal-measures against the Silurian rocks. Here 1000 feet of Old Red Sandstone, 3000 feet of Carboniferous Limestone, and 800 feet of Coal-measures have been removed by denudation off the Silurian rocks. Not only has this immense thickness of beds been carried away, but the Silurian itself on which they rested has been eaten down in some places into deep valleys several hundreds of feet below the surface on which the Old Red Sandstone rested.

Faults to a similar extent abound on the Continent and in America, but they have not been so minutely examined as in this country. In the Valley of Thessolon, to the north of Lake Huron, there is a dislocation of the strata to the extent of 9000 feet.†

In front of the Chilowee Mountains there is a vertical displacement of the strata of more than 10,000 feet.‡ Prof. H. D. Rogers found in the Appalachian coal-fields faults ranging from 5000 feet to more than 10,000 feet of displacement.

There are other modes than the foregoing by means of which geologists are enabled to measure the thickness of strata which may have been removed in places off the present surface of the country, into the details of which I need not here enter. But I may give a few examples of the enormous extent to which the country, in some places, has been found to have been lowered by denudation.

Prof. Geikie has shown‖ that the Pentlands must at one time have been covered with upwards of a mile in thickness of Carboniferous rocks which have all been removed by denudation.

In the Bristol coal-fields, between the River Avon and the Mendips, Prof. Ramsay has shown§ that about 9000 feet of

* Jukes's and Geikie's Manual of Geology, p. 441.
† Geology of Canada, 1863, p. 61.
‡ Safford's Geology of Tennessee, p. 309.
‖ Mem. to Sheet 32, Geol. Survey of Scotland.
§ "Denudation of South Wales." Memoirs of Geol. Survey, vol. i.

Carboniferous strata have been removed by denudation from the present surface.

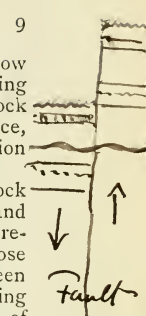
Between Bendrick Rock and Garth Hill, South Glamorganshire, a mass of Carboniferous and Old Red Sandstone, of upwards of 9000 feet, has been removed. At the Vale of Towy, Caermarthenshire, about 6000 feet of Silurian and 5000 feet of Old Red Sandstone—in all about 11,000 vertical feet—have been swept away. Between Llandovery and Aberaeron a mass of about 12,000 vertical feet of the Silurian series has been removed by denudation. Between Ebwy and the Forest of Dean, a distance of upwards of 20 miles, a thickness of rock varying from 5000 to 10,000 feet has been abstracted.

Prof. Hull found* on the northern flanks of the Pendle Range, Lancashire, the Permian beds resting on the denuded edges of the Millstone Grit, and these were again observed resting on the Upper Coal-measures south of the Wigan coal-field. Now, from the known thickness of the Carboniferous series in this part of Lancashire, he was enabled to calculate approximately the quantity of Carboniferous strata which must have been carried away between the period of the Millstone Grit and the deposition of the Permian beds, and found that it actually amounted to no less than 9,900 feet. He also found in the Vale of Clitheroe, and at the base of the Pendle Range, that the Coal-measures, the whole of the Millstone grit, the Yoredale series, and part of the Carboniferous Limestone, amounting in all to nearly 20,000 feet, had been swept away—an amount of denudation which, as Prof. Hull remarks, cannot fail to impress us with some idea of the prodigious lapse of time necessary for its accomplishment.

In the Nova Scotia coal-fields one or two miles in thickness of strata have been removed in some places.†

It may be observed that, enormous as is the amount of denudation indicated by the foregoing figures, these figures do not represent in most cases the actual thickness of rock removed from the surface. We are necessitated to conclude that a mass of rock equal to the thickness stated must have been removed, but we are in most cases left in uncertainty as to the total thickness which has actually been carried away. In the case of a fault, for example, with a displacement of (say) one mile, where no indication of it is seen at the surface of the ground, we know that on one side of the fault a thickness of rock equal to one

* Quart. Journ. Geol. Soc., vol. xxiv., p. 323.
† Lyell's Student's Manual, chap. 23.



mile must have been denuded, but we do not know how much more than that may have been removed. For anything which we know to the contrary hundreds of feet of rock may have been removed before the dislocation took place, and as many more hundreds after all indications of dislocation had been effaced at the surface.

But it must be observed that the total quantity of rock which has been removed from the *present* surface of the land is evidently small in proportion to the total quantity removed during the past history of our globe. For those thousands and thousands of feet of rock which have been denuded were formed out of the waste of previously existing rocks, just as these had been formed out of the waste of yet older rock-masses. In short, as a general rule, the rocks of one epoch have been formed out of those of preceding periods, and go themselves to form those of subsequent epochs.

In many of the cases of enormous denudation to which we have referred, the erosion has been effected during a limited geological epoch. We have, for example, seen that upwards of a mile in thickness of Carboniferous rock has been denuded in the area of the Pentlands. But the Pentlands themselves, it can be proved, existed as hills, in much their present form, before the Carboniferous rocks were laid down over them; and as they are of Lower Old Red Sandstone age, and have been formed by denudation, they must consequently have been carved out of the solid rock between the period of the Old Red Sandstone and the beginning of the Carboniferous age. This affords us some conception of the immense lapse of time represented by the Middle and Upper Old Red Sandstone periods.

Again, in the case of the great fault separating the Silurians of the south of Scotland from the Old Red Sandstone tracts lying to the north, a thickness of the latter strata of probably more than a mile, as we have seen, must have been removed from the ground to the south of the fault before the commencement of the Carboniferous period. And again, in the case of the Lancashire coal-fields, to which reference has been made, nearly two miles in thickness of strata had been removed in the interval which elapsed between the Millstone Grit and the Permian periods.

As we are enabled, from geological evidence, to form some rough estimate of the extent to which the country in various places has been lowered by sub-aërial denudation during a given epoch, it is evident that we should have a means of arriving at some idea of the length of that epoch, did we

know the probable rate at which the denudation took place. If we had a means of forming even the roughest estimate of the probable average rate of sub-aërial denudation during past ages, we should be enabled thereby to assign approximately an inferior limit to the age of the stratified rocks. We could then tell, at least, whether the amount of sub-aërial denudation known to have been effected during past geological ages could have been accomplished within 20 million years or not, and this is about all with which we are at present concerned. And if it can be proved that a period of 20 millions of years is much too short to account for the amount of denudation known to have taken place, then it is certain that the gravitation theory cannot explain the origin and source of the sun's heat.

A very simple and obvious method of determining the present mean rate of sub-aërial denudation was pointed out several years ago,* viz., that the rate of denudation must be equal to the rate at which the materials are carried off the land into the sea. But the rate at which the materials are thus abstracted is measured by the rate at which sediment is carried down by our rivers. Consequently, in order to determine the present rate of sub-aërial denudation, we have only to ascertain the quantity of sediment annually carried down by the river systems.

Very accurate measurements have been made of the quantity of sediment carried down into the Gulf of Mexico by the River Mississippi, and it is found to amount to 7,474,000,000 cubic feet. The area drained by the river is 1,224,000 square miles. Now 7,474,000,000 cubic feet removed from 1,224,000 square miles of surface is equal to 1-4566th of a foot off the surface per annum, or 1 foot in 4566 years. The specific gravity of the sediment is taken at 1·9, and that of the rock at 2·5; consequently the amount removed is equal to 1 foot of rock in about 6000 years. For many reasons there are few rivers better adapted for affording us a fair average of the rate of sub-aërial denudation than the Mississippi. In reference to the above I may here quote the words of Sir Charles Lyell:—"There seems," he says, "no danger of our over-rating the mean rate of waste by selecting the Mississippi as our example, for that river drains a country equal to more than half the continent of Europe, extends through 20 degrees of latitude, and therefore through regions enjoying a great variety of climate, and some of its tributaries descend from mountains of great height. The

* Phil. Mag., May, 1868; Feb., 1867. Climate and Time, chap. 20. See also Trans. Geol. Soc. of Glasgow, vol. iii.

Mississippi is also more likely to afford us a fair test of ordinary denudation, because, unlike the St. Lawrence and its tributaries, there are no great lakes in which the fluviatile sediment is thrown down and arrested on its way to the sea." *

Rough estimates have been made of the sediment carried down by some eight or ten European rivers; and although those estimates cannot be depended upon as being anything like accurate, still they show that it is extremely probable that the European continent is being denuded at about the same rate as the American.

I think we may safely assume, without the risk of any great error, that the average rate of sub-aërial denudation during past geological ages did not differ much from the present. The rate at which a country is lowered by sub-aërial denudation is determined† not so much by the character of its rocks as by the sedimentary carrying power of its river systems. And this again depends mainly upon the amount of rain-fall, the slope of the ground, and the character of the soil and vegetation covering the surface of the country. And in respect of these we have no reason to believe that the present is materially different from the past. No doubt the average rain-fall during some past epochs might have been greater than at present, but there is just as little reason to doubt that during other epochs it might have been less than now. We may therefore conclude that about one foot of rock removed from the general surface of the country in 6000 years may be regarded as not very far from the average rate of denudation during past ages.

But some of the cases we have given of great denudation refer to comparatively small areas, and others to beds which form anticlinal axes, and which, as is well known, denude more rapidly than either synclinal or horizontal beds. We shall therefore—to prevent the possibility of over-estimating the length of time necessary to effect the required amount of denudation—assume the rate to have been double the above, or equal to one foot in 3000 years.

To lower the country one mile by denudation would therefore require, according to the above rate, about 15 million years; but we have seen that a thickness of rock more than equal to that must have been swept away since the Carboniferous period. For even during the Carboniferous period itself more than a mile in thickness of strata in many places was removed. Again, there can be no doubt whatever that

* Student's Manual of Geology, p. 91 (second edition).

† *See* Climate and Time, p. 334.

the amount of rock removed during the Old Red Sandstone period was much greater than one mile; for we know perfectly well that over large tracts of country nearly a mile in thickness of rock was carried away between the period of the Lower Old Red Sandstone and the Carboniferous epoch. Further, all geological facts go to show that the time represented by the Lower Old Red Sandstone itself must have been enormous.

Now, three miles of rock removed since the commencement of the Old Red Sandstone period (which in all probability is an under-estimate) would give us 45 million years.

Again, going further back, we find the lapse of time represented by the Silurian period to be even more striking than that of the Old Red Sandstone. The uncomformities in the Silurian series indicate that many thousands of feet of these strata were denuded before overlying members of the same great formations were deposited. And again, this immense formation was formed in the ocean by the slow denudation of pre-existing Cambrian continents, just as these had been built up out of the ruins of the still prior Laurentian land. And even here we do not reach the end of the series, for the very Laurentians themselves resulted from the denudation not of the primary rocks of the globe, but of previously existing sedimentary and probably igneous rocks of which, perhaps, no recognisable portion now remains.

Few familiar with the facts of geology will consider it too much to assume that the time which had elapsed prior to the Old Red Sandstone was equal to the time which has elapsed since that period. But if we make this assumption, this will give us at least 90 million years as the age of the stratified rocks.

That the foregoing is not an over-estimate of the probable amount of rock removed by sub-aërial denudation during past geological ages will appear further evident from the following considerations:—The mountain ridges of our globe, in most cases, as is well known, have been formed by sub-aërial denudation: they have been carved out of the solid block. They stand two thousand, four thousand, or five thousand feet high, as the case may be, simply because two thousand, four thousand, or five thousand feet of rock have been denuded from the surrounding country. The mountains are high simply because the country has been lowered. But it must be observed that the height which the mountains reach above the surrounding country does not measure the full extent to which the country has been lowered by denudation, because the mountains themselves have also been lowered.

The height of the mountains represents merely the extent to which the country has been lowered. In the formation of a mountain by denudation, say 3000 feet in height, probably more than 6000 feet of strata may have been removed from the surrounding country. The very fact of a mountain standing above the surrounding country exposes it the more to denudation, and it is certainly not an exaggerated assumption to suppose that whilst the general surface of the country was being lowered 6000 feet by denudation, the mountain itself was at least lowered by 3000 feet.

The very common existence of mountains two or three thousand feet in height, formed by sub-aërial denudation, proves that at least one mile must have been worn off the general surface of the country. It does not, of course, follow that the general surface ever stood at an elevation of one mile above the sea-level, since denudation would take place as the land gradually rose. We know that the land was once under the sea, for it was there that it was formed. It is built up out of the materials resulting from the carving out into hill and dale, through countless ages, of a previously existing land, just as this latter had resulted from the destruction of a still older land, and so on in like manner back into the unknown past.

It has now been proved, by the foregoing very simple and obvious method, that the age of the earth must be far more than 20 or 30 million years. This method, it is true, does not enable us to determine with anything like accuracy the actual age of the globe, but it enables us to determine with absolute certainty that it must be far greater than 20 million years. We have not sufficient data to determine how many years have elapsed since life began on the globe, for we do not know the total amount of rock removed by denudation; but we have data perfectly sufficient to show that it began far more than twice 20 million years ago.

But if the present order of things has been existing for more than 20 million years, then the sun must have been illuminating our globe for that period, and, if so, then there must have been some other source than that of gravitation from which the sun derived its energy, for gravitation, as we have seen, could only have supplied the present rate of radiation for about one-half that period.

It is perfectly true, as has been stated, that the length of time that the sun could, by its radiation, have kept the earth in a state fit for animal and vegetable life, must have been limited by the store of energy in the form of heat which it possessed. But it does not follow as a necessary conse-

quence, as is generally supposed, that this store of energy must have been limited to the amount obtained from gravity in the condensation of the sun's mass. The utmost that any physicist is warranted in affirming is simply that it is impossible for him to *conceive* of any other source. His *inability*, however, to conceive of another source cannot be accepted as a proof that there *is* no other source. But the physical argument that the age of our earth must be limited by the amount of heat which could have been received from gravity is in reality based upon this assumption—that, because no other source can be conceived of, there is no other source.

If the earth has condensed more is another Conceivable Source of heat.

It is perfectly obvious, then, that this mere negative evidence against the possibility of the age of our habitable globe being more than 20 or 30 million years is of no weight whatever when pitted against the positive evidence here advanced, that its age must be far greater.

Now, in proving that the antiquity of our habitable globe must be far greater than 20 or 30 million years, we prove that there must have been some other source in addition to gravity from which the sun derived his store of energy; *and this is the point which I have been endeavouring to reach by this somewhat lengthy discussion.*

Are we really under any necessity of assuming that the sun's heat was wholly, or even mainly, derived from the condensation of his mass by gravity? According to Helmholtz's theory of the origin of the sun's heat by condensation, it is assumed that the matter composing the sun, when it existed in space as a nebulous mass, was not originally possessed of temperature, but that the temperature was given to it as the mass became condensed under the force of gravitation. It is supposed that the heat given out was simply the heat of condensation. But it is quite conceivable that the nebulous mass might have been possessed of an original store of heat previous to condensation.

It is quite possible that the very reason why it existed in such a rarefied or gaseous condition was its excessive temperature, and that condensation only began to take place when the mass began to cool down. It seems far more probable that this should have been the case than that the mass existed in so rarefied a condition without temperature. For why should the particles have existed in this separate form when devoid of the repulsive energy of heat, seeing that, in virtue of gravitation, they had such a tendency to approach one another?

It will not do to begin with the assumption of a cold nebulous mass, for, the moment that the mass existed as

such, condensation—under the influence of the mutual attraction of its particles—would commence. We must therefore assume either that the mass was created at the moment condensation began, or that, prior to this moment, it existed under some other form. There are few, I think, who would be willing to adopt the former alternative. If we adopt the latter we must then ask the question, In what condition did this mass exist prior to the commencement of condensation? The answer to this question would naturally be that it existed in a condition of excessive temperature, the repulsive force of heat preventing the particles approaching one another. In short, the excessive temperature was the very cause of the nebulous condition.

But if the mass was originally in a heated condition, then in condensing it would have to part not only with the heat of condensation, but also with the heat which it originally possessed.

It is therefore evident that if we admit that the nebulous mass was in a state of incandescence prior to condensation, it will really be difficult to fix any limit either to the age of the sun or to the amount of heat which it may have originally possessed. The 20 million years' heat obtained by condensation may in such a case be but a small fraction of the total quantity possessed by the mass.

The question now arises—By what means could the nebulous mass have become incandescent? From what source could the heat have been obtained? The dynamical theory of heat affords, as was shown several years ago,* an easy answer to this question. The answer is that *the energy in the form of heat possessed by the mass may have been derived from Motion in Space.* Two bodies, each one-half the mass of the sun, moving directly towards each other with a velocity of 476 miles per second, would by their concussion generate in a *single moment* 50 million years' heat. For two bodies of that mass, moving with a velocity of 476 miles per second, would possess 4149×10^{38} foot-pounds of kinetic energy, and this converted into heat by the stoppage of their motion would give out an amount of heat which would cover the present rate of the sun's radiation for a period of 50 million years.

Why may not the sun have been composed of two such bodies? And why may not the original store of heat possessed by him have all been derived from the concussion of these two bodies? Two such bodies coming into collision with that velocity would be dissipated into vapour and converted into a nebulous mass by such an inconceivable amount of heat as would thus be generated; and when

* Phil. Mag. for May, 1868.

condensation on cooling took place, a spherical mass like that of the sun would result. It is perfectly true that two such bodies could never attain the required amount of velocity by their mutual gravitation towards each other. But there is no necessity whatever for supposing that their velocities were derived from their mutual attraction alone: they might have been approaching each other with the required velocity wholly independent of gravitation.

We know nothing whatever regarding the absolute motion of bodies in Space; and, beyond the limited sphere of our observation, we know nothing even of their relative motions. There may be bodies moving in relation to our system with inconceivable velocity. For anything that we know to the contrary, were one of these bodies to strike our earth the shock might be sufficient to generate an amount of heat that would dissipate the earth into vapour, though the striking body might not be heavier than a cannon-ball. There is, however, nothing very extraordinary in the velocity which we have found would be required to generate the 50 million years' heat in the case of the two supposed bodies. A comet having an orbit extending to the path of the planet Neptune, approaching so near the sun as to almost graze his surface in passing, would have a velocity of about 390 miles per second, which is within 86 miles of that required.

It must be borne in mind, however, that the 476 miles per second is the velocity at the moment of collision; but more than one-half of this would be derived from the mutual attraction of the two bodies in their approach to each other. Suppose, for simplicity of calculation, each body to be equal in volume to the sun, and of course one-half the density, the amount of velocity which they would acquire by their mutual attraction would be 274 miles per second. Consequently we have to assume an original or projected velocity of only 202 miles per second. And if the original velocity was 676 per second, the total amount of heat generated would suffice for 200 million years at the present rate of radiation.

On former occasions* I expressed it as my opinion that the total quantity of heat possessed by the sun could not probably exceed 100 million years' heat. But if we admit that the heat was derived from Motion in Space, there really does not seem any reason why it may not be double that amount.

It will be asked—Where did the two bodies get their motion? It may as well, however, be asked—Where did

* Phil. Mag., May, 1868. Climate and Time, chap. 21.

they get their existence? It is just as easy to conceive that they always existed in motion as to conceive that they always existed at rest. In fact, this is the only way in which energy can remain in a body without dissipation into Space. Under other forms a certain amount of the energy is constantly being transformed into heat which never can be re-transformed back again, but is dissipated into Space as radiant heat. But a body moving in void stellar space will, unless a collision takes place, retain its energy in the form of motion untransformed for ever.

It will perhaps be urged as an objection that we have no experience of bodies moving in space with velocities approaching to anything like 400 or 600 miles per second. A little consideration will, however, show that this is an objection which can hardly be admitted, as we are not in a position to be able to perceive bodies moving with such velocities. No body moving at the rate of 400 miles per second could remain as a member of our solar system. Beyond our system, the only bodies visible to us are the nebulæ and fixed stars, and they are visible because they are luminous. But the fixed stars are beyond doubt suns similar to our own; and if we assume that the energy in the form of heat and light possessed by our sun has been derived from Motion in Space, we are hardly warranted in denying that the light and heat possessed by the stars were derived from another source. It is true that the motion of the stars in relation to one another, or in relation to our system (and this is the only motion known to us), is but trifling in comparison to what we even witness in our solar system. But this is what we ought, *à priori*, to expect; for if their light and heat were derived from Motion in Space, like that of our sun, then, like the sun, they must have lost their motion. In fact, *they are suns, and visible because they have lost their motion.* Had not the masses of which these suns were composed lost their motion they would have been non-luminous, and of course totally invisible to us. In short, we only see in stellar space those bodies which, by coming into collision, have lost their motion, for it is the lost motion which renders them luminous and visible.*

That's pure assertion. Grand assertion, and you get any results you please with mathematical certainty.

* When the foregoing theory of the origin of the sun's heat was advanced, in 1868, I was not aware that a paper on the "Physical Constitution of the Sun and Stars" had been read before the Royal Society by Mr. G. Johnstone Stoney, in which he suggested that the heat possessed by the stars may have been derived from collisions with one another. "If two stars," he says, should be brought by their proper motion very close, one of three things would happen:—Either they would pass quite clear of one another, in which case they would recede to the same immense distance asunder from which they had come; or they would become so entangled with one another as to emerge

The formation of a sun by collision is an event that would not be likely to escape observation if it occurred within the limits of visibility in space. But such an event must be of very rare occurrence, or the number of stars visible would be far greater than it is. The number of stars registered down to the seventh magnitude, inclusive, is—according to Herschel—somewhere between 12,000 and 15,000, and this is all that can possibly be seen by the naked eye. Now, if we suppose each of them to shine like our sun for (say) 100 million years, then one formed in every 7000 or 8000 years would maintain the present number undiminished. But this is the number included in both hemispheres, so that the occurrence of an event of such unparalleled splendour and magnificence as the formation of a star or rather nebula—for this would be the form first assumed—is what can only be expected to be seen on our hemisphere once in about 15,000 years.

The absence of any historical record of such an event having ever occurred can therefore be no evidence whatever against the theory.

There is reasoning in this but too many ifs for my taste. So it was with Sir William's paper. Given [illegible] assumed [illegible] two others; then by [illegible] grinding, come results: Croll's & Sir W.'s & they differ because [illegible] got different grist; if one sun is cooling then X. If two have met than Y.

Note on Sir William Thomson's Arguments for the Age of the Earth.

Sir William Thomson has endeavoured to prove the recent age of the earth by three well-known arguments of a purely physical nature:—The first is based on the age of the sun's heat; the second, on the tidal retardation of the earth's rotation; and the third, on the secular cooling of the earth.

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from the frightful conflagration which would ensue, as one star; or, thirdly, they would brush against one another, but not to the extent of preventing the stars from getting clear again." In the latter case he considers a double star is formed. Mr. Stoney's paper, though read in 1867, was not published till 1869.

Mr. Herbert Spencer, in his "First Principles" (pp. 532 to 535), has also directed attention to the fact that the stars distributed through space must tend, under the influence of gravity, to concentrate and become locally aggregated. Separate aggregations will be drawn towards one another, and ultimately coalesce. The result will be that the heat evolved by such collisions taking place under the enormous velocities acquired by gravity must have the effect of dissipating the matter of which they are composed into the gaseous state.

Both Mr. Stoney and Mr. Spencer consider the motions of the cosmic masses to be due wholly to gravity, but, as we have seen, gravity alone cannot account for the enormous amount of energy originally possessed by the sun.

Argument from the Age of the Sun's Heat.—It will be obvious that, if what has already been advanced in regard to the origin of the sun's heat be correct, it will follow that the argument for the recent age of the earth, based upon the assumption that the sun could have derived its store of heat only from the condensation of its mass, must be wholly abandoned, and that, in so far as this argument is concerned, there is no known limit to the amount of heat which the sun may have possessed, or to the time during which it may have illuminated the earth.

Argument from Tidal Retardation.—It is well known that, owing to tidal retardation, the rate of the earth's rotation is slowly diminishing; and it is therefore evident that if we go back for many millions of years, we reach a period when the earth must have been rotating much faster than now. Sir William's argument is,* that had the earth solidified several hundred millions of years ago, the flattening at the Poles and the bulging at the Equator would have been much greater than we find them to be. Therefore, because the earth is so little flattened, it must have been rotating, when it became solid, at very nearly the same rate as at present. And as the rate of rotation is becoming slower and slower, it cannot be so many millions of years back since solidification took place. A few years ago I ventured to point out† what appeared to be a very obvious objection to this argument, viz., that the influence of sub-aërial denudation in altering the form of the earth had been entirely overlooked. It has been proved, as we have seen, that the rocky surface of our globe is being lowered, on an average, by sub-aërial denudation, at the rate of about 1 foot in 6000 years. It follows as a consequence, from the loss of centrifugal force resulting from the retardation of the earth's rotation occasioned by the friction of the tidal wave, that the sea-level must be slowly sinking at the Equator and rising at the Poles. This, of course, tends to protect the polar regions and expose equatorial regions to sub-aërial denudation. Now it is perfectly obvious that unless the sea-level at the Equator has, in consequence of tidal retardation, been sinking during past ages at a greater rate than 1 foot in 6000 years, it is physically impossible the form of our globe could have been very much different from what it is at present, whatever may have been its form when it consolidated, because sub-aërial denudation would have lowered the Equator as rapidly as the sea sank.

* Trans. Geol. Soc. of Glasgow, vol. iii., p. 1.
† Nature, August 21, 1872. Climate and Time, p. 335.

But in equatorial regions the rate of denudation is no doubt much greater than 1 foot in 6000 years, because there the rainfall is greater than in the temperate regions. It has been shown that the rate at which a country is being lowered by subaërial denudation is mainly determined not so much by the character of its rocks as by the sediment-carrying power of its river systems. Consequently, other things being equal, the greater the rainfall the greater will be the rate of denudation. We know that the basin of the Ganges, for example, is being lowered by denudation at the rate of about 1 foot in 2300 years; and this is probably not very far from the average rate at which the equatorial regions are being denuded. It is therefore evident that sub-aërial denudation is lowering the Equator as rapidly as the sea-level is sinking from loss of rotation, and that consequently we cannot infer from the present form of our globe what was its form when it solidified. In as far as tidal retardation can show to the contrary, its form, when solidification took place, may have been as oblate as that of the planet Jupiter. There is another circumstance which must be taken into account. The lowering of the Equator, by the transference of materials from the Equator to the higher latitudes, must tend to increase the rate of rotation, or, more properly, it must tend to lessen the rate of tidal retardation.

The argument may be shown to be inconclusive from another consideration. The question as to whether the earth's axis of rotation could ever have changed to such an extent as to have affected the climate of the Poles is at present exciting a good deal of attention. The subject has recently been investigated with great care by Professor Haughton,* Mr. George Darwin,† the Rev. J. F. Twisden,‡ and others, and the general result arrived at may be expressed in the words of Mr. G. Darwin :—"If the earth be quite rigid no re-distribution of matter in new continents could ever have caused the deviation of the Pole from its present position to exceed the limit of about 3°."

Mr. Darwin has shown that, in order to produce a displacement of the Pole to the extent of only 1° 46′, an area equal to one-twentieth of the entire surface of the globe would have to be elevated to the height of two miles. The entire continent of Europe elevated two miles would not deflect the Pole much over half a degree. Assuming the

* Proc. Roy. Soc., vol. xxvi., p. 51.
† Proc. Roy. Soc., vol. xxv., p. 328.
‡ Paper read before the Geological Society, February 21st, 1877.

mean elevation of the continents of Europe and Asia to be 1000 feet, Prof. Houghton calculates that their removal would displace the Pole only 199·4 miles.

It may now be admitted as settled that if the earth be perfectly rigid the climate of our globe could never possibly have been affected by any change in the axis of rotation. But it is maintained that if the earth can yield as a whole, so as to adapt its form to a new axis of rotation, the effects may be cumulative, and that a displacement of the Pole as much as 10° or 15° is possible.*

But then if the earth be able to adapt its form to a *change in the axis of rotation*, there is no reason why it may not be able to adapt its form to a *change in the rate of rotation*, and, if so, the flattening at the Poles and the bulging at the Equator would diminish as the rate of rotation diminished, even supposing there were no denudation going on.

Argument from the Secular Cooling of the Earth.—The earth, like the sun, is a body in the process of cooling, and it is evident that if we go back sufficiently far we shall reach a period when it was in a molten condition. Calculating by means of Fourier's mathematical theory of the conductivity of heat, Sir William Thomson has endeavoured to determine how many years must have elapsed since solidification of the earth's crust may have taken place. This argument is undoubtedly the most reliable of the three. Nevertheless, the data on the subject are yet very imperfect, so that no definite and trustworthy result can be arrived at by this means as to the actual age of the earth. In fact this is obvious from the very wide limits assigned by him within which solidification probably took place. "We must," quoting Sir William's own words on the subject, "allow very wide limits on such an estimate as I have attempted to make;

* A displacement of the Pole of less than 15° or 20° would be of very little service in accounting for the warm climate of Greenland during the Miocene and other periods. But a displacement to that extent, even supposing we admit the earth to be yielding, demands a condition of things which few geologists would be willing to grant. When it becomes generally recognised to what an enormous extent the temperature of the Arctic regions is dependent upon ocean currents, the difficulties in understanding how those regions have once enjoyed a temperate climate will disappear. Were the ice removed from Greenland that region would at present enjoy a warm summer, suitable for plant and animal life. It is the presence of ice rather than a positive deficiency of heat that makes Greenland so cold and barren (*see* Climate and Time, Chap. IV.). An increase in the quantity of heat conveyed by ocean-currents, merely sufficient to prevent the accumulation of ice, would completely transform the climate of the Arctic lands. And such an increase would take place during an Inter-glacial period when the eccentricity of the earth's orbit was at a high value and the winter solstice in perihelion.

but I think we may, with much probability, say that the consolidation cannot have taken place less than 20,000,000 years ago, or we should have more underground heat than we actually have,—nor more than 400,000,000 years ago, or we should not have so much as the least observed underground increment of temperature. That is to say, I conclude that Leibnitz's epoch of 'emergence' of the 'consistentur status' was probably within these dates."*

* Trans. Roy. Soc. of Edinburgh, vol. xxiii., p. 161.

That gives a wide limit. I think it was in this paper that Sir W. asserted that the crust forming on the molten mass would sink to the centre. But in every solid that freezes, the crust floats from ice to iron. Even Sir W. T. great as he is does facts in filling his mill and so it is best to let Cambridge in thinking of such problems.

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above all authority is not to be accepted at human hands.