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THE AGE OF THE SUN'S HEAT

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THE second great law of thermodynamics involves a certain principle of irreversible action in Nature. It is thus shown that, although mechanical energy is indestructible, there is a universal tendency to its dissipation, which produces gradual augmentation and diffusion of heat, cessation of motion, and exhaustion of potential energy through the material universe.1. The result would inevitably be a state of universal rest and death, if the universe were finite and left to obey existing laws. But it is impossible to conceive a limit to the extent of matter in the universe; and therefore science points rather to an endless progress, through an endless space, of action involving the transformation of potential energy into palpable motion and thence into heat, than to a single finite mechanism, running down like a clock, and stopping forever. It is also impossible to conceive either the beginning or the continuance of life, without an overruling creative power; and, therefore, no conclusions of dynamical science regarding the future condition of the earth can be held to give dispiriting views as to the destiny of the race of intelligent beings by which it is at present inhabited. The object proposed in the present article is an application of these general principles to the discovery of probable limits to the periods of time, past and future, during which the sun can be reckoned on as a source of heat and light. The subject will be discussed under three heads:

I. The secular cooling of the sun.
II. The present temperature of the sun.
III. The origin and total amount of the sun's heat.

I. THE SECULAR COOLING OF THE SUN.- How much the sun is actually cooled from year to year, if at all, we have no means of ascertaining, or scarcely even of estimating in the roughest manner. In the first place we do not know that he is losing heat at all. For it is quite certain that some heat is generated in his atmosphere by the influx of meteoric matter; and it is possible that the amount of heat so generated from year to year is sufficient to compensate the loss by radiation. It is, however, also possible that the sun is now an incandescent liquid mass, radiating away heat, either primitively created in his substance, or, what seems far more probable, generated by the falling in of meteors in past times, with no sensible compensation by a continuance of meteoric action. It has been shown 2. that, if the former supposition were true, the meteors by which the sun's heat would have been produced during the last 2,000 or 3,000 years must have been all that time much within the earth's distance from the sun, and must therefore have approached the central body in very gradual spirals; because, if enough of matter to produce the supposed thermal effect fell in from space outside the earth's orbit, the length of the year would have been very sensibly shortened by the additions to the sun's mass which must have been made. The quantity of matter annually falling in must, on that supposition, have amounted to 1/47 of the earth's mass, or to 1/15000000 of the sun's; and therefore it would be necessary to suppose" the "zodiacal light" to amount to at least 1/5000 of the sun's mass, to account in the same way for a future supply of 3,000 years' sun-heat. When these conclusions were first published it was pointed out that disturbances in the motions of visible planets " should be looked for, as affording us means for estimating the possible amount of matter in the zodiacal light; and it was conjectured that it could not be nearly enough to give a supply of 30,000 years' heat at the present rate. These anticipations have been to some extent fulfilled in Le Verrier's great researches on the motion of the planet Mercury, which have recently given evidence of a sensible influence attributable to matter circulating, as a great number of small planets, within his orbit round the sun. But the amount of matter thus indicated is very small; and, therefore, if the meteoric influx taking place at present is enough to produce any appreciable portion of the heat radiated away, it must be supposed to come from matter circulating round the sun, within very short distances of his surface. The density of this meteoric cloud would have to be supposed so great that comets could scarcely have escaped as comets actually have escaped, showing no discoverable effects of resistance, after passing his surface within a distance equal to 1/8 of his radius. All things considered, there seems little probability in the hypothesis that solar radiation is at present compensated, to any appreciable degree, by heat generated by meteors falling in; and, as it can be shown that no chemical theory is tenable, 3. it must be concluded as most probable that the sun is at present merely an incandescent liquid mass cooling. How much he cools from year to year becomes therefore a question of very serious import, but it is one which we are at present quite unable to answer. It is true we have data on which we might plausibly found a probable estimate, and from which we might deduce, with at first sight seemingly well-founded confidence, limits, not very wide, within which the present true rate of the sun's cooling must lie. For we know, from the independent but concordant investigations of Herschel and Pouillet, that the sun radiates every year from his whole surface about 6 x 10^{30} (six million million million million million) times as much heat as is sufficient to raise the temperature of one pound of water by 1^0C. We also have exce1lent reason for believing that the sun's substance is very much like the earth's. Stokes's principles of solar and stellar chemistry have been for many years explained in the University of Glasgow, and it has been taught as a first result that sodium does certainly exist in the sun's atmosphere, and in the atmospheres of many of the stars, but that it is not discoverable in others. The recent application of these principles in the splendid researches of Bunsen and Kirchhof (who made an independent discovery of Stokes's theory) has demonstrated with equal certainty that there are iron and manganese, and several of our other known metals, in the sun. The specific heat of each of these substances is less than the specific heat of water, which indeed exceeds that of every other known terrestrial body, solid or liquid. It might, therefore, at first sight seem probable that the mean specific heat 4. of the sun's whole substance is less, and very certain that it can not be much greater, than that of water. If it were equal to the specific heat of water we should only have to divide the preceding number (6 x 10^{30}), de- rived from Herschel's and Pouillet's observations, by the number of pounds (4.3 x 10^{30}) in the sun's mass, to find 1.4^0 C. for the present annual rate of cooling. It might therefore seem probable that the sun cools more, and almost certain that he does not cool less, than a centigrade degree and four tenths annually. But, if this estimate were .well founded, it would be equally just to assume that the sun's expansibility 5. with heat does not differ greatly from that of some average terrestrial body. If, for instance, it- were the same as that of solid glass, which is about 1/40000 on bulk, or 1/120000 on diameter, per 1^0 C. (and for most terrestrial liquids, especially at high temperatures, the expansibility is much more), and if the specific heat were the same as that of liquid water, there would be in 860 years a contraction of one per cent on the sun's diameter, which could scarcely have escaped detection by astronomical observation. There is, however, a far stronger reason than this for believing that no such amount of contraction could have taken place, and therefore for suspecting that the physical circumstances of the sun's mass render the condition of the substances of which it is composed, as to expansibility and specific heat, very different from that of the same substances when experimented on in our terrestrial laboratories. Mutual gravitation between the different parts of the sun's contracting mass must do an amount of work, which can not be calculated with certainty, only be- cause the law of the sun's interior density is not known. The amount of work performed on a contraction of one tenth per cent of the diameter, if the density remained uniform throughout the interior, would, as Helmholtz showed, be equal to 20,000 times the mechanical equivalent of the amount of heat which Pouillet estimated to be radiated ,. from the sun in a year. But in reality the sun's density must increase very much toward his centre, and probably in varying proportions, as the temperature becomes lower and the whole mass contracts. We can not, therefore, say whether the work actually done by mutual gravitation during a contraction of one tenth per cent of the diameter would be more or less than the equivalent of 20,000 years' heat; but we may regard it as most probably not many times more or less than this amount. Now, it is in the highest degree improbable that mechanical energy can in any case increase in a body contracting in virtue of cooling. It is certain that it really does diminish very notably in every case hitherto experimented on. It must be supposed, therefore, that the sun always radiates away in heat something more than the Joule-equivalent of the work done on his contracting mass, by mutual gravitation of its parts. Hence, in contracting by one tenth per cent in his diameter, or three tenths per cent in his bulk, the sun must give out something either more, or not greatly less, than 20,000 years' heat; and thus, even without historical evidence as to the constancy of his diameter, it seems safe to conclude that no such contraction as that calculated above (one per cent in 860 years) can have taken place in reality. It seems, on the contrary, probable that, at the present rate of radiation, a contraction of one tenth per cent in the sun's diameter could not take place in much less than 20,000. years, and scarcely possible that it could take place in less than 8,600 years. If, then, the .mean specific heat of the sun's mass, in its actual condition, is not more than ten times that of water, the expansibility in volume must be less than 1/4000 per 100^0 C. (that is to say, less than 1/10 of that of solid glass), which seems Improbable. But although from this consideration we are led to regard it as possible that the sun's specific heat is considerably more than ten times that of water (and, therefore, that his mass cools considerably less than 100^0 C. in 700 years, a conclusion which, indeed, we could scarcely avoid on simply geological grounds), the physical principles we now rest on fall to give us any reason for supposing that the sun's specific heat is more than 10,000 times that of water, because we can not say that his expansibility in volume is probably more than 1/400 per 1^0 C. , And there IS, on other grounds, very' strong reason for believing that the specific heat is really much less than 10,000. For it is almost certain that the sun's mean temperature is even now as high as 14,0000 C,; and the greatest quantity of heat that we can explain, with any probability, to have been by natural causes ever acquired by the sun (as we shall see in the third part of this article), could not have raised his mass at any time to this temperature, unless his specific heat were less than 10,000 times that of water. We may therefore consider it as rendered highly probable that the sun's specific heat is more than ten times, and less than 10,000 times, that of liquid water. From this it would follow with certainty that his temperature sinks 100^0 C. in some time from 700 years to 700,000 years. What, then, are we to think of such geological estimates as 300,000,000 years for the "denudation of the Weald "? Whether is it more probable that the physical conditions of the sun's matter differ 1,000 times more than dynamics compel us to suppose they differ from those of matter in our laboratories; or that a stormy sea, with possibly Channel tides of extreme violence, should encroach on a chalk cliff 1,000 times more rapidly than Mr. Darwin's estimate of one inch per century?

II. THE PRESENT TEMPERATURE OF THE SUN,

-At his surface the sun's temperature can not, as we have many reasons for believing, be incomparably higher than temperatures attainable artificially in our terrestrial laboratories, Among other reasons it may be mentioned that the sun radiates out heat from every square foot of his surface at only about 7,000 horse power.[6] Coal, burning at a rate of a little less than a pound per two seconds, would generate the same amount; and it is estimated (Rankine, "Prime Movers," p. 285, edition 1852) that, in the furnaces of locomotive engines, coal burns at from one pound in thirty seconds to one pound in ninety seconds per square foot of grate-bars. Hence heat is radiated from the sun at a rate not more than from fifteen to forty-five times as high as that at which heat is generated on the grate-bars of a locomotive furnace, per equal areas. The interior temperature of the sun is probably far higher than that at his surface, because direct conduction can play no sensible part in the transference of heat between the inner and outer portions of his mass, and there must be an approximate convective equilibrium of heat throughout the whole, if the whole is fluid. That is to say, the temperatures, at different distances from the centre, must be approximately those which any portion of the substance, if carried from the centre to the surface, would acquire by expansion without loss or gain of heat.

III. THE ORIGIN AND TOTAL AMOUNT OF THE SUN'S HEAT.

-The sun being, for reasons referred to above, assumed to be an incandescent liquid now losing heat, the question naturally occurs, How did this heat originate? It is certain that it can not have existed in the sun through an infinity of past time, since, as long as it has so existed, it must have been suffering dissipation, and the finiteness of the sun precludes the supposition of an infinite primitive store of heat in his body. The sun must, therefore, either have been created as an active source of heat at some time of not immeasurable , antiquity, by an overruling decree; or the heat which he has already radiated away, and that which he still possesses, must have been acquired by a natural process, following permanently established laws. Without pronouncing the former supposition to be

essentially incredible, we may safely say that it is in the highest degree improbable, if we can show the latter to be not contradictory to known physical laws. And we do show this and more, by merely pointing to certain actions going on before us at present, which, if sufficiently abundant at some past time, must have given the sun heat enough to account for all we know of his past radiation and present temperature, It is not necessary at present to enter at length on details regarding the meteoric theory, which appears to have been first proposed in a definite form by Mayer, and afterward independently by Waterston; or regarding the modified hypothesis of meteoric vortices, which the writer of the present article showed to be necessary, in order that the length of the year, as known for the last 2,000 years, may not have been sensibly disturbed by the accessions which the sun's mass must have had during that period, if the heat radiated away has been always compensated by heat generated by meteoric influx, For reasons mentioned in the first part of the present article, we may now believe that all theories of complete, or nearly complete, contemporaneous meteoric compensation must be rejected; but we may still hold that "meteoric action … is … not only proved to exist as a cause of solar heat, but it is the only one of all conceivable causes which we know to exist from independent evidence." 7.
The form of meteoric theory which now seems most probable, and which was first discussed on true thermodynamic principles by Helmholtz, 8. consists in supposing the sun and his heat to have originated in a coalition of smaller bodies, falling together by mutual gravitation, and generating, as they must do according to the great law demonstrated by Joule, an exact equivalent of heat for the motion lost in collision. That some form of the meteoric theory is certainly the true and complete explanation of solar heat can scarcely be doubted, when the following reasons are considered:

1. No other natural explanation, except by chemical action, can be conceived,

2. The chemical theory is quite insufficient, because the most energetic chemical action we know, taking place between substances amounting to the whole sun's mass, would only generate about 3,000 years' heat. 9.

3. There is no difficulty in accounting for 20,000,000 years' heat by the meteoric theory.

It would extend this article to too great a length, and would require something of mathematical calculation, to explain fully the principles on which this last estimate is founded. It is enough to say that bodies, all much smaller than the sun, falling together from a state of relative rest, at mutual distances all large in comparison with their diameters, and forming a globe of uniform density equal in mass and diameter to the sun, would generate an amount of heat which, accurately calculated according to Joule's principles and experimental results, is found to be just 20,000,000 times Pouillet's estimate of the annual amount of solar radiation. The sun's density must, in all probability, increase very much toward his centre, and therefore a considerably greater amount of heat than that must be supposed to have been generated if his whole mass was formed by the coalition of comparatively small bodies. On the other hand, we do not know how much heat may have been dissipated by resistance and minor impacts before the final conglomeration; but there is reason to believe that even the most rapid conglomeration that we can conceive to have probably taken place could only leave the finished globe with about half the entire heat due to the amount of potential energy of mutual gravitation exhausted. We may, therefore, accept, as a lowest estimate for the sun's initial heat, 10,000,000 times a year's supply at the present rate, but 50,000,000 or 100,000,000 as possible, In consequence of the sun's greater density in his central parts. The considerations adduced above, in this paper, regarding the sun's possible specific heat, rate of cooling, and superficial temperature, render it probable that he must have been very sensibly warmer 1,000,000 years ago than now; and, consequently, if he has existed as a luminary for 10,000,000 or 20,000,000 years, he must have radiated away considerably more than the corresponding number of times the present yearly amount of loss. It seems, therefore, on the whole most probable that the sun has not illuminated the earth for 100,000,000 years, and almost certain that he has not done so for 500,000,000 years. As for the future, we may say, with equal certainty, that inhabitants of the earth can not continue to enjoy the light and heat essential to their life for many million years longer unless sources now unknown to us are prepared in the great storehouse of creation.

1. See "On a Universal Tendency in Nature to the Dissipation of Mechanical Energy," "Proceedings of the Royal Society of Edinburgh," April 19, 1852; or the "Philosophical Magazine," October, 1852; also "Mathematical and Physical Papers," vol. i, art. 59.

2. "On the Mechanical Energies of the Solar System," "Transactions of the Royal Society of Edinburgh," April, 1854, and "Philosophical Magazine," December, 1854.

3. "Mechanical Energies of the Solar System."

4. The" specific heat " of a homogeneous body is the quantity of heat that a unit of its substance must acquire or must part with, to rise or .to fall by 1° in temperature. The main specific heat of a heterogeneous mass, or of a mass of homogeneous substance, under different pressures in different parts, is the quantity of heat which the whole body takes or gives in rising or in falling 1° in temperature, divided by the' number of units in its mass. The expression, "mean specific heat" of the sun, in the text, signifies the total amount of heat actually radiated away from the sun, divided by his mass, during any time in which the average temperature of his mass sinks by 1°, whatever physical or chemical changes any part of his substance may experience.

5. The "expansibility in volume," or the" cubical expansibility," of a body, is an expression technically used to denote the proportion which the increase or diminution of its bulk, accompanying a rise or fall of 1^0 in its temperature, bears to its whole bulk at some stated temperature. The expression, "the sun's expansibility," used in the text, may be taken as signifying the ratio which the actual contraction, during a lowering of his mean temperature by 1^0C., bears to his present volume.

6. One horse power in mechanics is a technical expression (following Watt's estimate) used to denote a rate of working in which energy is involved at the rate of 33,000 foot pounds per minute. This, according to Joule's determination of the dynamical value of heat, would, if spent wholly in heat, be sufficient to raise the temperature of 23 3/4 pounds of water by 1^0 C. per minute.

7. Mechanical Energies of the Solar System." Note, p. 351.

8. Popular lecture delivered on February 7, 1854, at Konigsberg, on the occasion of Kant commemoration.

9. "Mechanical Energies of the Solar System." Note, p. 351.