Wolves, Mares, and Foals

WHEN in The Asturias in 1885, I was told of a very curious case of animal instinct, which may be worth recording. Wolves are by no means unfrequent in The Asturias, and often attack the young foals which are sent up to pasturage with the mares in the mountains. The experienced danger seems to have begotten a precautionary instinct of a very intelligent kind. It is said that, on an alarm of wolves, the mares and foals congregate for mutual protection and common defence. The mares form themselves into a sort of cordon, heads outwards, surrounding a space inclosing the young foals, and are ready for attacking with their fore-feet the wolves on their approach.

My informant gave me a graphic account of such an attack, of which he was an eye-witness for nearly an hour, and described to me how the wolves circled round and round the defenders, first at some distance, then gradually approaching nearer and nearer, seeking an opening into the inclosure, till at last they came within striking distance, and he saw one wolf rolled over dead by a blow from the fore-foot of one of the mares.

The fore-foot is not commonly used for defence by any equine species; but it is obvious that the more powerful hind-leg blow would be of little service against the spring of a wolf from behind, without the directing eye to guide the stroke. What a long experience must this mutual protection have been the result of! We can scarcely understand it, without councils of war having been held, the dangers discussed, and signals for concerted action arranged; but now all this instinct may merely be the inheritance of the experience of former generations.

Benthall, Kenley, Surrey, January 6 GEORGE MAW

THE SUN'S HEAT[1]

FROM human history we know that for several thousand years the Sun has been giving heat and light to the earth as at present; possibly with some considerable fluctuations, and possibly with some not very small progressive variation. The records of agriculture, and the natural history of plants and animals within the time of human history, abound with evidence that there has been no exceedingly great change in the intensity of the Sun's heat and light within the last 3000 years; but for all that, there may have been variations of quite as much as 5 or 10 per cent., as we may judge from considering that the intensity of the solar radiation to the earth is 6½ per cent. greater in January than in July; and neither at the equator nor in the northern or southern hemispheres has this difference been discovered by experience or general observation of any kind. But as for the mere age of the Sun, irrespective of the question of uniformity, we have proof of something vastly more than 3000 years in geological history, with its irrefragable evidence of continuity of life on the earth in time past for tens of thousands, and probably for millions of years.

Here, then, we have a splendid subject for contemplation and research in natural philosophy, or physics, the science of dead matter. The sun, a mere piece of matter of the moderate dimensions which we know it to have, bounded all round by cold ether, has been doing work at the rate of four hundred and seventy-six thousand million million million horse-power for 3000 years, and at possibly more, and certainly not much less than that for a few million years. How is this to be explained? Natural philosophy cannot evade the question, and no physicist who is not engaged in trying to answer it can have any other justification than that his whole working time is occupied with work on some other subject or subjects of his province by which he has more hope of being able to advance science.

I suppose I may assume that every person present knows as an established result of scientific inquiry that the sun is not a burning fire, and is merely a fluid mass cooling, with some little accession of fresh energy by meteors occasionally falling in, of very small account in comparison with the whole energy of heat which he gives out from year to year. You are also perfectly familiar with Helmholtz's form of the meteoric theory, and accept it as having the highest degree of scientific probability that can be assigned to any assumption regarding actions of prehistoric times. You understand, then, that the essential principle of the explanation is this: at some period of time, long past, the sun's initial heat was generated by the collision of pieces of matter gravitationally attracted together from distant space to build up his present mass; and shrinkage due to cooling gives, through the work done by the mutual gravitation of all parts of the shrinking mass, the vast thermal capacity in virtue of which the cooling has been, and continues to be, so slow. I assume that you have not been misled by any of your teachers who may have told you, or by any of your books in which you may have read, that the sun is becoming hotter because a gaseous mass, shrinking because it is becoming colder, becomes hotter because it shrinks.

An essential detail of Helmholtz's theory of solar heat is that the sun must be fluid, because even though given at any moment hot enough from the surface to any depth, however great, inwards, to be brilliantly incandescent, the conduction of heat from within through solid matter of even the highest conducting quality known to us would not suffice to maintain the incandescence of the surface for more than a few hours, after which all would be darkness. Observation confirms this conclusion so far as the outward appearance of the sun is concerned, but does not suffice to disprove the idea which prevailed till thirty or forty years ago that the sun is a solid nucleus inclosed in a sheet of violently agitated flame. In reality, the matter of the outer shell of the sun, from which the heat is radiated outwards, must in cooling become denser, and so becoming unstable in its high position, must fall down, and hotter fluid from within must rush up to take its place. The tremendous currents thus continually produced in this great mass of flaming fluid constitute the province of the newly-developed science of solar physics, which, with its marvellous instrument of research—the spectroscope—is yearly and daily giving us more and more knowledge of the actual motions of the different ingredients, and of the splendid and all-important resulting phenomena.

Now, to form some idea of the amount of the heat which is being continually carried up to the sun's surface and radiated out into space, and of the dynamical relations between it and the solar gravitation, let us first divide that prodigious number (476×10^{21}) of horse-power by the number ($6{\cdot}1 \times 10^{18}$) of square metres in the sun's surface, and we find 78,000 horse-power as the mechanical value of the radiation per square metre. Imagine, then, the engines of eight ironclads applied to do all their available work of, say, 10,000 horse-power each, in perpetuity driving one small paddle in a fluid contained in a square metre vat. The same heat will be given out from the square metre surface of the fluid as is given out from every square metre of the sun's surface.

But now to pass from a practically impossible combination of engines and a physically impossible paddle and fluid and containing vessel, towards a more practical combination of matter for producing the same effect: still keep the ideal vat and paddle and fluid, but place the vat on the surface of a cool, solid, homogeneous globe of the same size ($\cdot 697 \times 10^9$ metres radius) as the sun, and of density (1·4) equal to the sun's density. Instead of using steam-power, let the paddle be driven by a weight descending in a pit excavated below the vat. As the simplest possible mechanism, take a long vertical shaft, with the paddle mounted on the top of it so as to turn horizontally. Let the weight be a nut working on a screw-thread on the vertical shaft, with guides to prevent the nut from turning—the screw and the guides being all absolutely

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[1] Lecture on "The Probable Origin, the Total Amount, and the Possible Duration, of the Sun's Heat," delivered by Sir William Thomson, F.R.S., at the Royal Institution, on Friday, the 21st inst.

frictionless. Let the pit be a metre square at its upper end, and let it be excavated quite down to the sun's centre, everywhere of square horizontal section, and tapering uniformly to a point at the centre. Let the weight be simply the excavated matter of the sun's mass, with merely a little clearance space between it and the four sides of the pit, and a kilometre or so cut off the lower pointed end to allow space for its descent. The mass of this weight is 326×10^6 tons. Its heaviness, three-quarters of the heaviness of an equal mass at the sun's surface, is 244×10^6 tons solar surface-heaviness. Now a horse-power is 270 metre-tons, terrestrial surface-heaviness, per hour; or 10 metre-tons, solar surface-heaviness, per hour. To do 78,000 horse-power, or 780,000 metre-tons, solar surface-heaviness, per hour, our weight must therefore descend at the rate of 1 metre in 313 hours, or about 28 metres per year.

To advance another step, still through impracticable mechanism, towards the practical method by which the sun's heat is produced, let the thread of the screw be of uniformly decreasing steepness from the surface downwards, so that the velocity of the weight, as it is allowed to descend by the turning of the screw, shall be in simple proportion to distance from the sun's centre. This will involve a uniform condensation of the material of the weight; but a condensation so exceedingly small in the course even of tens of thousands of years, that, whatever be the supposed character, metal or stone, of the weight, the elastic reaction against the condensation will be utterly imperceptible in comparison with the gravitational forces with which we are concerned. The work done per metre of descent of the top end of the weight will be just four-fifths of what it was when the thread of the screw was uniform. Thus, to do the 78,000 horse-power of work, the top end of the weight must descend at the rate of 35 metres per year: or 70 kilometres, which is one one-hundredth per cent. (1/10,000) of the sun's radius, per 2000 years.

Now let the whole surface of our cool solid sun be divided into squares, for example as nearly as may be of 1 square metre area each, and let the whole mass of the sun be divided into long inverted pyramids or pointed rods, each 700,000 kilometres long, with their points meeting at the centre. Let each be mounted on a screw, as already described for the long tapering weight which we first considered; and let the paddle at the top end of each screw-shaft revolve in a fluid, not now confined to a vat, but covering the whole surface of the sun to a depth of a few metres or kilometres. Arrange the viscosity of the fluid and the size of each paddle so as to let the paddle turn just so fast as to allow the top end of each pointed rod to descend at the rate of 35 metres per year. The whole fluid will, by the work which the paddles do in it, be made incandescent, and it will give out heat and light to just about the same amount as is actually done by the sun. If the fluid be a few thousand kilometres deep over the paddles, it would be impossible, by any of the appliances of solar physics, to see the difference between our model mechanical sun and the true sun.

Now, to do away with the last vestige of impracticable mechanism, in which the heavinesses of all parts of each long rod are supported on the thread of an ideal screw cut on a vertical shaft of ideal matter, absolutely hard and absolutely frictionless: first, go back a step to our supposition of just one such rod and screw working in a single pit excavated down to the centre of the sun, and let us suppose all the rest of the sun's mass to be rigid and absolutely impervious to heat. Warm up the matter of the pyramidal rod to such a temperature that its material melts and experiences enough of Sir Humphrey Davy's "repulsive motion" to keep it balanced as a fluid, without either sinking or rising from the position in which it was held by the thread of the screw. When the matter is thus held up without the screw, take away the screw or let it melt in its place. We should thus have a pit from the sun's surface to his centre, of a square metre area at the surface, full of incandescent fluid, which we may suppose to be of the actual ingredients of the solar substance. This fluid, having at the first instant the temperature with which the paddle left it, would at the first instant continue radiating heat just as it did when the paddle was kept moving; but it would quickly become much cooler at its surface, and to a distance of a few metres down. Convection-currents, with their irregular whirls, would carry the cooled fluid down from the surface, and bring up hotter fluid from below, but this mixing could not go on through a depth of very many metres to a sufficient degree to keep up anything approaching to the high temperature maintained by the paddle; and after a few hours or days, solidification would commence at the surface. If the solidified matter floats on the fluid at the same temperature below it, the crust would simply thicken as ice on a lake thickens in frosty weather; but if, as is more probable, solid matter, of such ingredients as the sun is composed of, sinks in the liquid when both are at the melting temperature of the substance, thin films of the upper crust would fall in, and continue falling in, until, for several metres downwards, the whole mass of mixed solid and fluid becomes stiff enough (like the stiffness of paste or of mortar) to prevent the frozen film from falling down from the surface. The surface film would then quickly thicken, and in the course of a few hours or days become less than red-hot on its upper surface. The whole pit full of fluid would go on cooling with extreme slowness until, after possibly about a million million million years or so, it would be all at the same temperature as the space to which its upper end radiates.

Now, let precisely what we have been considering be done for every one of our pyramidal rods, with, however, in the first place, thin partitions of matter impervious to heat separating every pit from its four surrounding neighbours. Precisely the same series of events as we have been considering will take place in every one of the pits.

Suppose the whole complex mass to be rotating at the rate of once round in 25 days.

Now at the instant when the paddle stops let all the partitions be annulled, so that there shall be perfect freedom for convection-currents to flow unresisted in any direction, except so far as resisted by the viscosity of the fluid, and leave the piece of matter, which we may now call the Sun, to himself. He will immediately begin showing all the phenomena known in solar physics. Of course the observer might have to wait a few years for sunspots, and a few quarter-centuries to discover periods of sunspots, but they would, I think I may say probably, all be there just as they are; because I think we may feel that it is most probable that all these actions are due to the sun's own mass and not to external influences of any kind. It is, however, quite possible, and indeed many who know most of the subject think it probable, that some of the chief phenomena due to sunspots arise from influxes of meteoric matter circling round the sun. The energy of chemical combination is as nothing compared with the gravitational energy of shrinkage, to which the sun's activity is almost wholly due, but chemical combinations and dissociations may, as urged by Lockyer, be thoroughly potent determining influences on some of the features of non-uniformity of the brightness in the grand phenomena of sunspots, hydrogen flames, and corona, which make the province of solar physics. But these are questions belonging to a very splendid branch of solar science with which we are not occupied this evening.

What concerns us at present may be summarised in two propositions:—

(1) Gigantic convection-currents throughout the sun's liquid mass are continually maintained by fluid, slightly

cooled by radiation, falling down from the surface, and hotter fluid rushing up to take its place.

(2) The work done in any time by the mutual gravitation of all the parts of the fluid, as it shrinks in virtue of the lowering of its temperature, is but little less than (so little less than, that we may regard it as practically equal to[1]) the dynamical equivalent of the heat that is radiated from the sun in the same time.

The rate of shrinkage corresponding to the present rate of solar radiation has been proved to us, by the consideration of our dynamical model, to be 35 metres on the radius per year, or one ten-thousandth of its own length on the radius per two thousand years. Hence, if the solar radiation has been about the same as at present for two hundred thousand years, his radius must have been greater by 1 per cent. two hundred thousand years ago than at present. If we wish to carry our calculations much farther back or forward than two hundred thousand years, we must reckon by differences of the reciprocal of the sun's radius, and not by differences simply of the radius, to take into account the change of density (which, for example, would be 3 per cent. for 1 per cent. change of the radius). Thus the rule, easily worked out according to the principles illustrated by our mechanical model, is this:—

Equal differences of the reciprocal of the radius correspond to equal quantities of heat radiated away from million of years to million of years.

Take two examples:—

(1) If in past time there has been as much as fifteen million times the heat radiated from the sun as is at present radiated out in one year, the solar radius must have been four times as great as at present.

(2) If the sun's effective thermal capacity can be maintained by shrinkage till twenty million times the present year's amount of heat is radiated away, the sun's radius must be half what it is now. But it is to be remarked that the density which this would imply, being 11·2 times the density of water, or just about the density of lead, is probably too great to allow the free shrinkage as of a cooling gas to be still continued without obstruction through overcrowding of the molecules. It seems, therefore, most probable that we cannot for the future reckon on more of solar radiation than, if so much as, twenty million times the amount at present radiated out in a year. It is also to be remarked that the greatly diminished radiating surface, at a much lower temperature, would give out annually much less heat than the sun in his present condition gives. The same considerations led Newcomb to the conclusion "that it is hardly likely that the sun can continue to give sufficient heat to support life on the earth (such life as we now are acquainted with, at least) for ten million years from the present time."

In all our calculations hitherto we have for simplicity taken the density as uniform throughout, and equal to the true mean density of the sun, being about 1·4 times the density of water, or about a fourth of the earth's mean density. In reality the density in the upper parts of the sun's mass must be something less than this, and something considerably more than this in the central parts, because of the pressure in the interior increasing to something enormously great at the centre. If we knew the distribution of interior density we could easily modify our calculations accordingly, but it does not seem probable that the correction could, with any probable assumption as to the greatness of the density throughout a considerable proportion of the sun's interior, add more than a few million years to the past of solar heat, and what could be added to the past must be taken from the future.

In our calculations we have taken Pouillet's number for the total activity of solar radiation, which practically agrees with Herschel's. Forbes[1] showed the necessity for correcting the mode of allowing for atmospheric absorption used by his two predecessors in estimating the total amount of solar radiation, and he was thus led to a number 1·6 times theirs. Forty years later Langley,[2] in an excellently worked out consideration of the whole question of absorption by our atmosphere, of radiant heat of all wave-lengths, accepts and confirms Forbes's reasoning, and by fresh observations in very favourable circumstances on Mount Whitney, 15,000 feet above the sea-level, finds a number a little greater still than Forbes (1·7, instead of Forbes's 1·6, times Pouillet's number). Thus Langley's number expressing the quantity of heat radiated per second of time from each square centimetre of the sun's surface corresponds to 133,000 horse-power per square metre, instead of the 78,000 horse-power which we have taken, and diminishes each of our times in the ratio of 1 to 1·7. Thus, instead of Helmholtz's twenty million years, which was founded on Pouillet's estimate, we have only twelve millons, and similarly with all our other time reckonings based on Pouillet's results. In the circumstances, and taking fully into account all possibilities of greater density in the sun's interior, and of greater or less activity of radiation in past ages, it would, I think, be exceedingly rash to assume as probable anything more than twenty million years of the sun's light in the past history of the earth, or to reckon on more than five or six million years of sunlight for time to come.

But now we come to the most interesting part of our subject—the early history of the sun. Five or ten million years ago he may have been about double his present diameter and an eighth of his present mean density, or ·175 of the density of water; but we cannot, with any probability of argument or speculation, go on continuously much beyond that. We cannot, however, help asking the question, What was the condition of the sun's matter before it came together and became hot? It may have been two cool solid masses, which collided with the velocity due to their mutual gravitation; or, but with enormously less of probability, it may have been two masses colliding with velocities considerably greater than the velocities due to mutual gravitation. This last supposition implies that, calling the two bodies A and B for brevity, the motion of the centre of inertia of B relatively to A, must, when the distances between them was great, have been directed with great exactness to pass through the centre of inertia of A; such great exactness that the rotational momentum after collision was of proper amount to let the sun have his present rotational period when shrunk to his present dimensions. This exceedingly exact aiming of the one body at the other, so to speak, is, on the dry theory of probability, exceedingly improbable. On the other hand, there is certainty that the two bodies A and B at rest in space if left to themselves, undisturbed by other bodies and only influenced by their mutual gravitation, shall collide with direct impact, and therefore with no motion of their centre of inertia, and no rotational momentum of the compound body after the collision. Thus we see that the dry probability of collision between two of a vast number of mutually attracting bodies widely scattered through space is much greater if the bodies be all given at rest, than if they be given moving in any random directions and with any velocities considerable in comparison with the velocities which they would acquire in falling from rest into collision. In this connection it is most interesting to know from stellar astronomy, aided so splendidly as it has recently been by the spectroscope, that the relative motions of the visible stars and our sun are generally very small in comparison with the velocity (612 kilometres per second) a body would acquire

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[1] "On the Age of the Sun's Heat," by Sir William Thomson (*Macmillan's Magazine*, March 1862); and Thomson and Tait's "Natural Philosophy," 2nd edition, vol. i. part ii., Appendix E.

[1] *Edin. New Phil. Journal*, xxxvi. 1844.

[2] "On the Selective Absorption of Solar Energy," *American Journal of Science*, vol. xxv., March 1883.

in falling into the sun, and are comparable with the moderate little velocity (29·5 kilometres per second) of the earth in her orbit round the sun.

To fix the ideas, think of two cool solid globes, each of the same mean density as the earth, and of half the sun's diameter, given at rest, or nearly at rest, at a distance asunder equal to twice the earth's distance from the sun. They will fall together and collide in half a year. The collision will last for a few hours, in the course of which they will be transformed into a violently agitated incandescent fluid mass, with about eighteen million (according to the Pouillet-Helmholtz reckoning, of twenty million) years' heat ready made in it, and swelled out by this heat to possibly one and a half times, or two, or three, or four times, the sun's present diameter. If instead of being at rest initially they had had a transverse relative velocity of 1·42 kilometres per second, they would just escape collision, and would revolve in equal ellipses in a period of one year round the centre of inertia, just grazing one another's surfaces every time they come round to the nearest points of their orbits.

If the initial transverse component of relative velocity be less than, but not much less than, 1·42 kilometres per second, there will be a violent grazing collision, and two bright suns, solid globes bathed in flaming fluid, will come into existence in the course of a few hours, and will commence revolving round their common centre of inertia in long elliptic orbits in a period of a little less than a year. The *quasi*-tidal interaction will diminish the eccentricities of their orbits; and if continued long enough will cause the two to revolve in circular orbits round their centre of inertia with a distance between their surfaces equal to 644 of the diameter of each.

If the initial transverse component relative velocity of the two bodies were just 68 metres per second, the moment of momentum, the same before and after collision, would be just equal to that of the solar system, of which seventeen-eighteenths is Jupiter's and one-eighteenth the sun's: the other bodies of the system being not worth considering in the account. Fragments of superficially-melted solid, or splashes of fluid, sent flying away from the main compound mass could not possibly by tidal action or other resistance get into the actual orbits of the planets, whose evolution requires some finer if more complex fore-ordination than merely the existence of two masses undisturbed by any other matter in space.

I shall only say in conclusion:—Assuming the sun's mass to be composed of portions which were far asunder before it was hot, the immediate antecedent to its incandescence must have been either two bodies with details differing only in proportion and densities from the cases we have been now considering as examples; or it must have been some number more than two—some finite number—at the most the number of atoms in the sun's present mass, which is a finite number as easily understood and imagined as number 3 or number 123. The immediate antecedent to incandescence may have been the whole constituents in the extreme condition of subdivision—that is to say, in the condition of separate atoms; or it may have been any smaller number of groups of atoms making up minute crystals or groups of crystals—snowflakes of matter, as it were; or it may have been lumps of matter like this macadamising stone; or like this stone, which you might mistake for a macadamising stone, and which was actually travelling through space till it fell on the earth at Possil, in the neighbourhood of Glasgow, on April 5, 1804; or like this—which was found in the Desert of Atacama in South America, and is believed to have fallen there from the sky—a fragment made up of iron and stone, which looks as if it has solidified from a mixture of gravel and melted iron in a place where there was very little of heaviness; or this splendidly crystallised piece of iron, a slab cut out of the celebrated aërolite of Lenarto, in Hungary;[1] or this wonderfully shaped specimen, a model of the Middlesburgh meteorite, kindly given me by Prof. A. S. Herschel, with corrugations showing how its melted matter has been scoured off from the front part of its surface in its final rush through the earth's atmosphere when it was seen to fall on March 14, 1881, at 3.35 p.m.

For the theory of the sun it is indifferent which of these varieties of configurations of matter may have been the immediate antecedent of his incandescence, but I can never think of these material antecedents without remembering a question put to me thirty years ago by the late Bishop Ewing, Bishop of Argyll and the Isles: "Do you imagine that piece of matter to have been as it is from the beginning; to have been created as it is, or to have been as it is through all time till it fell on the earth?" I had told him that I believed the sun to be built up of stones, but he would not be satisfied till he knew or could imagine, what kind of stones. I could not but agree with him in feeling it impossible to imagine that any one of these meteorites before you has been as it is through all time, or that the materials of the sun were like this for all time before they came together and became hot. Surely this stone has an eventful history, but I shall not tax your patience longer to-night by trying to trace it conjecturally. I shall only say that we cannot but agree with the common opinion which regards meteorites as fragments broken from larger masses, but we cannot be satisfied without trying to imagine what were the antecedents of those masses.

PROTOPLASM[2]

It is a natural and beneficial result of the present energetic pursuit of biological science that every now and again some thinker comes forward to show us where we stand, and to what our thoughts are impelling us. Subordinate to the universal eminence and influence of a Linnæus or a Darwin, the critics of a decade exert no small effect on contemporary investigation by suggesting new modes of viewing or expressing things; and even though the originality is not always happy, and the generalisations are sometimes unfortunate, it is nevertheless a healthy sign that specialists of reputation, led to view matters with a severely critical eye as their work progresses, occasionally turn round and warn us that it would be as well to take stock of the facts, and see what are the chances of solving some large problem. Moreover, it has to be borne in mind that as various branches reach a certain stage their results need overhauling by specialists in other departments, and it becomes a question who is to prepare the problems of biology, for instance, so that the mathematician or the physicist may criticise them.

As much on this account as for his own contributions to the store of facts, we must welcome Dr. Berthold's clever "Studies" as an earnest and important attempt to contribute to a knowledge of the mechanics of life. Of course it is always a difficulty to decide how far a specialist may be expected to take an accurate view of a large problem to the direct solution of which his own researches can contribute but little; but experience has shown that more is to be looked for from the deep insight obtained by close investigation than from the few brilliant suggestions scattered through volumes of merely clever thinking. In the present case, the moderate tone of the book, and the easy earnestness of the writer, should at least insure careful reading of the 324 pages of text in which Dr. Berthold expresses his bold ideas; and whether the conclusions stand or fall, the reader will be amply repaid by the observations collected and the criticisms on several questions now agitating the minds of botanists.

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[1] The three aërolites now exhibited belong to the Hunterian Museum of the University of Glasgow, and have been kindly lent me for this evening by the Curator, Dr. Young.

[2] "Studien über Protoplasmamechanik." By Dr. G. Berthold, Professor of Botany in the University of Göttingen. (Leipzig: Arthur Felix, 1886.)