# REMARKS ON SIR ROBERT BALL'S PAPER (READ AT THE HOBART MEETING OF THE AUSTRALASIAN SCIENCE ASSOCIATION), ENTITLED: "THE ASTRONOMICAL EXPLANATION OF A GLACIAL PERIOD."

By A. B. Biggs.

Of the many interesting papers that were read in the Astronomical Section of the recent Science Congress, by far the most interesting to me, and probably to the majority of those who listened to it, was that with which we were favoured by Sir Robert Ball, and which was read by His Excellency, Sir Robert Hamilton.

In the paper referred to, Sir John Herschel is accused by the author of having made, in his "Outlines of Astronomy," "a curiously erroneous statement:" that "Herschel wrote down hastily a statement which was quite wrong," and that Croll and others had been misled by Herschel's mistake.

It was startling to me to find two men of such eminence in Astronomical Science at variance with reference to a comparatively simple astronomical fact. Sir Robert Ball announces, as the object of his paper, "to indicate clearly the character of the error . . . and to substitute for it the correct mathematical theory." So that he is very emphatic upon the subject of the supposed mistake.

I did not feel myself in a position to criticise the paper at its reading, even had I the temerity to attempt it. I needed to study it at leisure before venturing on so bold a step. The receipt of a copy from the General Secretary of the association has put me in a position to look into the matter more closely.

The purport of Sir Robert Ball's paper is to show that the successive periods of glaciation, alternating with periods of genial or tropical temperature, which geologists infer from the indications of the rocks and strata, are a necessary corollary from astronomical data. It will be well then, as a preliminary, to state as concisely and clearly as I possibly can what are the conditions of the problem, which I take to be the following, every one of which is essential to the conclusion arrived at:—

1. That the earth's orbit is not a circle, but an ellipse, the sun's position in relation thereto being, not in the centre, but in one of the foci of the curve; consequently there are two opposite points at which respectively the earth is nearest to,

and farthest from the sun (Perihelion and Aphelion), these points being reached at the beginning of January and the beginning of July.

2. That a bisection of the orbit by a line through the sun's centre in any direction but that of coincidence with the major axis of the ellipse will cut the orbit into two unequal divisions, of which that which comprises the perihelion will receive the greater intensity of heat, in accordance with the law of inverse squares of distance.

3. Nevertheless, as the earth's angular velocity is in the same ratio of inverse squares of distance, the *total amount* of heat received in the one division of the orbit (and of the year), will exactly equal that received in the other division. Further, the year's supply will be equal in the two hemispheres.

4. That owing to the disturbing attraction of the planets (Venus and Jupiter principally), a slow variation is produced in the length of the minor axis of the earth's orbit, the major axis remaining constant. This amounts to saying that the eccentricity varies. This variation oscillates within certain limits, and occupies an enormously long period.

5. As a further effect from planetary perturbation, the direction of the major axis undergoes a slow progressive change, making a complete revolution in about 110,000 years.

6. That the moon's attractive force upon the earth's equatorial protuberance causes a gyration of the polar axis in a circle of 47 degrees in diameter, and the consequent revolution of the line of the equinoxes in the comparatively short period of 25,000 years.

7. The movement described above (6), known as the "precession of the equinoxes," and the revolution of the major axis of the orbit (5) being in opposite directions, it follows that they will recur to the same relative positions in the shorter period of 21,000 years.

8. The elementary fact of the inclination of the polar axis to the plane of the orbit at an angle of $66\frac{1}{2}$ degrees must be takent into account. Upon this, and this only, depends the relative distribution of the total yearly supply of heat between the summer and winter seasons of the year in either hemisphere. This is shown by mathematical formulæ to be in the ratio of 63 to 37 nearly, *which ratio remains constant under all circumstances.*

There is still one other condition, as laid down by Sir Robert Ball, equally essential, but which I will postpone for the present, and will proceed to discuss the bearing which the foregoing postulates have upon the problem.

It must be evident that, at enormously long intervals (as we judge of time), the combined effects of the conditions above enumerated must be at a maximum as regards the relative *intensity* (as distinguished from *total amount*) of summer and winter heat. This will be when the eccentricity of the orbit is at its maximum, and the relative movements indicated in Nos. 6 and 7 have brought the line of the equinoxes at *right angles* with the major axis, thus cutting the orbit into its shortest possible perihelion, and longest aphelion divisions. That hemisphere, then, which has the perihelion summer will have its summer portion of heat (see No. 3) concentrated into a short and intensely hot summer; whilst its winter portion will be spread over a long, cold winter. At the same time the reverse of this will prevail in the other hemisphere. These conditions will alternate between the two hemispheres in the mid interval of 10,500 years.

I must now add, as No. 9, a further condition as laid down by Sir Robert Ball, which is, that "the sunbeams in the brief and fiercely hot summer of the glacial period *fail to melt as much ice as had been accumulated during the preceding winter*." If this statement is correct, it must be admitted, I think, that the theory is established beyond question. If, on the other hand, it be not correct, and that the intensity of summer heat compensates the prolonged coldness of the winter (and this is the only point that is not quite clear to my mind), the theory breaks down utterly, even though all the other conditions remain intact.

The point on which Sir John Herschel is challenged by Sir Robert Ball is contained in the concluding sentence of condition 8. Sir Robert Ball puts the case as against Herschel thus (I cannot well shorten the quotation):—

"Suppose that the total heat received from the sun on one hemisphere of the earth during the course of a twelvemonth be represented by 100, we proceed to consider how these parts are shared between the seasons. I mean by 'summer' in the Northern Hemisphere the interval from the vernal equinox to the autumnal, and by 'winter' the interval from the autumnal equinox to the vernal. With this understanding 63 parts of heat are received on each hemisphere during its summer, and the remaining 37 parts during the winter. . . . Herschel's erroneous statement was to the effect that *the heat was equally distributed, so that* 50 *parts were received in summer and* 50 *parts in winter*." (All italics are mine unless otherwise indicated.)

Now, the question is:—Is this just what Sir John Herschel said or meant to say? The passage on which Sir Robert Ball founds his charge can be only that on page 333 of the

5th edition of Herschel's "Outlines of Astronomy," which runs thus:—

"Supposing the eccentricity of the earth's orbit were very much greater than it actually is, the position of its perihelion remaining the same, it is evident that the character of the seasons in the two hemispheres would be strongly contrasted. In the Northern we should have a short but very mild winter, with a long but very cool summer,—that is, an approach to perpetual spring; while the Southern Hemisphere would be inconvenienced and might be rendered uninhabitable by the fierce extremes caused by concentrating half *the* annual supply of heat into a summer of very short duration, and spreading the other half over a long and dreary winter, sharpened into an intolerable intensity of frost when at its climax by the much greater remoteness of the sun." (Mark, "*the* annual supply," not *its*, etc.)

It must be admitted that, on a cursory reading, and taking it apart from its context, the above passage would appear to bear only the construction which Sir Robert Ball puts upon it. But is it fair, so to take it, or to take any man's utterances? Herschel has just been taking great pains to make clear the fact that (dividing the year and the orbit each into its—at present—two unequal portions by the equinoctial diameter of the orbit), though the earth is nearer the sun during the (northern) winter portion of the year than during the summer portion, and is consequently receiving a greater intensity of heat (according to the law of inverse squares of the distance), the earth's angular velocity being in the same ratio, the shortness of the season exactly compensates the intensity of radiation. He sums up the case thus:—

"The momentary supply of heat received by *the earth* in every point of its orbit varies exactly as the momentary increase of its longitude, from which it obviously follows that equal amounts of heat are received from the sun in whatever part of the ellipse those angles are situated. Supposing the orbit, then, to be divided into two segments by any straight line drawn through the sun, since equal angles in longitude (180 deg.) are described on either side of this line, the amount of heat received will be equal. In passing, then, from either equinox to the other, the *whole earth* receives equal amount of heat," etc.

Now take this quotation in connection with that to which Sir Robert Ball takes exception, as quoted above, and I think Herschel's meaning will be apparent, although in this case it must be admitted that he has failed to express himself with his accustomed preciseness. His statement is that "the hemisphere would be inconvenienced . . by concentrating half *the*" (not *its*) "annual supply of heat into a summer of short duration," etc., which is of course apportioned between the summer of one hemisphere and winter of the other alternately, and he can only be referring to that portion of this "supply" which pertains to the summer or winter of either hemisphere. That he could have meant nothing else is still more evident from a further quotation (page 230), in which he admits the unequal distribution of heat between summer and winter:—"Whenever, then, the sun remains more than 12 hours above the horizon of any place, and less beneath, the general temperature of that place will be above the average; when the reverse, below;" that is, the summer and winter portions of the year respectively.

The extent of the inequality of the distribution of the annual supply of heat between the summer and winter portions of the year in either hemisphere depends (as I have said) wholly and solely upon the inclination of the earth's axis, and no one could be more cognisant of this fact than Sir John Herschel. Assuming extreme conditions, the inclination of the axis, instead of being some 66½ deg., might have been zero, that is, coincident with the plane of the ecliptic, in which case the distribution of summer and winter heat (the yearly total), in either hemisphere (employing Sir Robert Ball's formula), would be as 818 to 182. On the other hand, the inclination might have been 90 deg., that is vertical, when there would have been no inequality, and the distinction of summer and winter would vanish. The inclination being actually between these two extremes (that is, 66½ deg.), the relative summer and winter heat supplies must lie between the aforesaid ratios, and is no doubt correctly stated by Sir Robert Ball as 63 to 37.

Of the geological aspect of the question I do not deem myself competent to speak; but, admitting the deductions of geologists as to the alternations of extreme heat and cold in the geological history of the earth, and the correctness of Sir Robert Ball's dictum with regard to the inefficiency of the extreme summer hear to dissipate the glacial effects of the preceding winter's cold (No. 9), the theory discussed by Sir Robert Ball is, I think, the only one yet propounded that will bear investigation.