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FORMATION OF EARTH: ITS AGE, ORIGIN AND PRESENT TEMPERATURE

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Abstract: We follow the Big Bang Model of the Universe The earth at the time of its formation is assumed to be a spherical mass of plasma with temperature as high as the temperature of the interior of the Sun. The cooling is similar to the cooling of a hot sphere. The geo-thermal gradient has been mathematically worked out and is found fairly in good agreement. Following a scheme provided by Lord Kelvin some 150 years ago, readings for 'Time' and 'Temperature' of Earth from the start of its formation to date are taken arbitrarily right from the first day of the epoch. An independent treatment on the lines of Newton's law of cooling graphically reveals facts such as mode of cooling, the age of Earth and its present temperature. From the intensity of cooling, it is shown Earth as a part of Solar Nebula.
Keywords: Big Bang, Cooling Constant, Geothermal Gradient, Newton's Law of Cooling, Solar Nebula.

INTRODUCTION

Our treatment in this Paper is exclusively classical and historical and we have not considered a situation in which the Universe starting from a primeval atom where one has to deal with the Planck time (5.39…..x 10^{-44}sec) and the Planck temperature (1.416….x10^{32}K) in which the quantum gravitational effects are more relevant. We start from the time when Earth was in a molten state and became a part of the Solar system. The Earth at the time of its formation as mentioned must have been in a state of plasma with temperature of about 2×10^7 °C [7] equivalent to the present temperature of the interior of the Sun. The present state of the Earth is as a result of cooling of this sphere of plasma since the time of its birth. To start with, we need some mathematics to work out the geothermal gradient and subsequently get an equation for cooling. We need the following constants

Constants:

Age of Earth = 4.6 Billion (4.6×10^9) years = 1.45×10^{17} second

Radius of Earth, $r_e = 6.4 \times 10^6$ meter

Mass of Earth, $m_e = 5.98 \times 10^{24}$ kg

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Average density of material of Earth, $\rho = 5500\ \mathrm{kg\ m^{-3}}$

Surface area of Earth = $5.101 \times 10^{14}\ \mathrm{m^2}$

[4]Quantity of heat lost across the surface of Earth by conduction per second, $Q = 2.7 \times 10^{13}\ \mathrm{J\ s^{-1}}$

[6]Specific heat of material of Earth, $s = 837\ \mathrm{J\ kg^{-1}{}^\circ C^{-1}}$

[13]Thermal diffusivity, $h^2 = K\, s^{-1}\, \rho^{-1} = 2 \times 10^{-7}\ \mathrm{m^2 s^{-1}}$

Thermal conductivity of material of Earth, $K = 0.9206\ \mathrm{W\ m^{-1}{}^\circ C^{-1}}$ (Worked out from the above value of constants).

Geothermal gradient:

The gradual cooling can be compared with the cooling of a hot sphere[1]

The wave equation in polar coordinates is the Laplace's equation,

$$\frac{\partial^2 w}{\partial r^2} + \frac{2}{r}\frac{\partial w}{\partial r} + \frac{1}{r^2 \sin^2\theta}\frac{\partial}{\partial \theta}\left(\sin\theta \frac{\partial w}{\partial \theta}\right) + \frac{1}{r^2 \sin^2\theta}\frac{\partial^2 w}{\partial \phi^2} - \frac{1}{C^2}\frac{\partial^2 w}{\partial t^2} = 0 \qquad (1)$$

where the wave function W is a product of the type

$$W = R(r)\, \Theta(\theta)\, \Phi(\varphi)\, T(t) \qquad (2)$$

The quantity T is of the form

$$a\, e^{-k^2 h^2 t}$$

where a and k are constants and h^2 is the diffusivity. A solution which depends on r and t is of the type

$$\frac{1}{r} \sin\ k r\, e^{-k^2 h^2 t}$$

and is ideal for the present problem of the spherical Earth. There is uniform and continuous flow of heat radially outward from the center. If θ is the temperature, the Fourier equation of heat conduction is,

$$\frac{\partial \theta}{\partial t} = h^2 \nabla^2 \theta \qquad (3)$$

.Where $h^2 = K s^{-1} \rho^{-1}$ is the diffusivity.

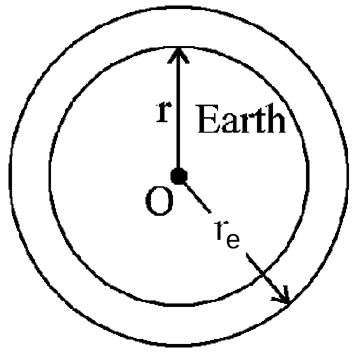
Equation (3) holds good if K, s and ρ are independent of temperature, θ whereas in reality they are not constants but vary slowly with temperature. As there are no sources of heat continuously distributed within a certain volume of the sphere, an additional term, $\frac{Q}{s\rho}$ where $Q \equiv Q(x, y, z, t)$ is a function denoting the strength of the sources, will appear. Equation (3) then becomes non-homogeneous. That is

$$\frac{\partial \theta}{\partial t} = h^2 \nabla^2 \theta + b^2 \tag{4}$$

where $b^2 = \frac{Q}{s\rho}$. The particular integral which must be added to the solution of equaton (3) is $-\frac{b^2 r^2}{6h^2}$.

Let the temperature θ be equal to a constant value θ_0 throughout the Earth and let the boundary r = a = r_e where r_e is the radius of the Earth (Fig. 1) is suddenly maintained at a temperature, θ_1 since the formation of the Earth at t=0 a to a sufficiently long time T, the condition at the surface is satisfied by writing

Fig. 1



$$\theta = \theta 1 + \frac{b^2}{6h^2}(r_e^2 - r^2) + \frac{1}{r}\sum_{m=1}^{\infty} D_m \sin\left(\frac{m\pi r}{r_e}\right) e^{-\left(\frac{m^2\pi^2 h^2 rt}{r_e^2}\right)} \tag{5}$$

where the constant D_m is obtained by Fourier rule from the expansion of

$\theta_0 - \theta_1 - \left[\frac{b^2}{6h^2}\left(r_e^2 - r^2\right)\right]$ in a sine series, thus

$$D_m = (-)^m \left[\frac{2r_e^3 b^2}{h^2 m^3 \pi^3} + \frac{2r_e\,(\theta_1 - \theta_0)}{m\pi}\right] \tag{6}$$

where m is an integer.

After initially long time approaching the present age of the Earth, we may set the time t to infinity so that the temperature assumes the value

$$\theta = \theta_1 + \frac{b^2}{6h^2}\left(r_e^2 - r^2\right) \tag{7}$$

and the temperature gradient is given by

$$\frac{\partial \theta}{\partial r} = -\left(\frac{b^2}{3h^2}\right) r \tag{8}$$

where $$b^2 = \frac{Q}{s\rho} \text{ and } h^2 = \frac{K}{s\rho} \tag{9}$$

From equation (7), the temperature further tends to θ_1 on the surface of the Earth where $r = r_e$ is the radius. As one goes to the interior from the surface, we have to consider the thermal gradient or more correctly the geothermal gradient given by equation (8). The negative sign indicates that there is a fall of temperature with increasing r towards the surface of the Earth. Let us now work out the value of this geothermal gradient under different conditions. Ignoring the negative sign and combining with equation (9), we have

$$\frac{\partial\theta}{\partial r} = \left(\frac{b^2}{3h^2}\right)r = \left(\frac{Q}{3K}\right)r \tag{10}$$

[This equation (10), $\frac{\partial\theta}{\partial r} = \left(\frac{Q}{3K}\right) r$ is a first order partial differential equation appearing to be very simple but will really confuse any law-abiding physicist. The trouble arises when units are substituted for quantities on the right of the equation. A close look will show that the equation is actually the Fourier equation for thermal conductivity with the lhs the temperature gradient, Q the rate of conduction per unit area even though there is no mention of area anywhere and K the coefficient of thermal conductivity. The multiple r appearing on the right requires clarification for which we actually assign units for quantities on the right. As Q is the rate of conduction per unit area, its unit is Joules per second per m^2 or Watt per m^2; Unit of K is $\frac{W}{m℃}$ and r is in meter. Thus the ultimate unit on the right becomes $\left(\frac{\frac{W}{m^2}}{\frac{W}{m℃}}\right)m \rightarrow$ ℃ and when one looks at the lhs $\frac{\partial\theta}{\partial r}$ the unit is $\frac{℃}{m}$. Thus the dimensions are not matching which is really surprising as dimensional analysis is a basic tool to check the correctness of an equation. Before we work out the values of geothermal gradient under different conditions, this anomaly requires clarification. The clarification lies with Norman Robert Campbell[3] in his book on Foundations of Science has extensively dealt with "Dimensions of Temperature". Some of the points by the author, is shown below in italics:

"Temperature is the magnitude ....which all physicists *find it most difficult to deal. The choice of the numerals which are to represent temperatures is certainly independent of the choice of the system of measurement of any other magnitude......... "Temperature is a derived or defined no-dimensional magnitude....... Thermodynamic temperature has dimensions which are completely indeterminate; there is no reason for assigning one dimension rather than another; accordingly since experimental temperature approaches more nearly to no dimensions than to any other, it is probably best to regard it also of no dimensions".*

As a further support of the above, Dimensional Analysis in Wikipedia, the free encyclopedia of "Google" proposed since May 2014, some definitions given under Mathematical examples have given the following in Italics:

"*Physicists do not recognize Temperature as a fundamental definition of physical quantity since it essentially expresses the energy per particle per degree of freedom which can be expressed in terms of energy (or mass, length and time)*"

Thus the temperature on the rhs is dimensionless and just a value for which one can legitimately assign unit of $\frac{℃}{m}$. for the quantity appearing on lhs. of the equation (10)].

Considering the quantity of heat lost by conduction across unit area per second and substituting the values, we have

$$\frac{\partial\theta}{\partial r} = \left(\frac{2.7 \times 10^{13}}{3 \times 0.9206 \times 5.101 \times 10^{14}}\right) r = 0.01916\ r$$

Thus, for a km depth from the surface, we put r = 1000 m and therefore

$$\frac{\partial\theta}{\partial r} = 19.16\ \frac{℃}{km} \approx 19.2\ \frac{℃}{km}$$

This thermal gradient agrees very well with the value of 19 $\frac{℃}{km}$[9]. However, we shall work out its value from all angles. The discrepancies can be accounted for the fact that there is a variation of specific heat with temperature and the change of density from 5500 kg m^{-3} to 9500 kg m^{-3} from mantle to core of the Earth [8] These variations affect the conductivity. Assuming the diffusivity to be constant within limits and taking the mean value of the density from mantle to core, we have the conductivity as 1.255 $Wm^{-1}℃^{-1}$ and hence

$$\frac{\partial\theta}{\partial r} = \left(\frac{2.7 \times 10^{13}}{3 \times 1.255 \times 5.101 \times 10^{14}}\right) r = 0.014006\ r$$

Thus, for a km depth, we have the thermal gradient,

$$\frac{\partial\theta}{\partial r} = 14.06\ \frac{℃}{km} \approx 14.1\ \frac{℃}{km}$$

This is in perfect agreement with the value of 14 $\frac{℃}{km}$ [5]

Apart from variations in density with temperature, the particular temperature variations are also due to the nature of material constituting the earth's crust. Most of the crust consists of solid granite $\left(\text{density, } 2650\ \frac{kg}{m^3}\right)$ floating over a layer of basalt $\left(\text{density, } 3000\ \frac{kg}{m^3}\right)$.

These values of density do not differ much and the hotter layers inside consist mainly of basalt and taking that density into consideration and assuming there is no much variation of specific heat, the conductivity works out to be 0.5022 $\frac{W}{m°C}$ and the resulting thermal gradient for a km depth from the surface is,

$$\frac{\partial\theta}{\partial r} = 35.1\,\frac{°C}{km}$$

This is in perfect agreement with the value of 36 $\frac{°C}{km}$ [14]. The value, however, is slightly greater than 30 $\frac{°C}{km}$ [2], a value obtained by deep mining operations. Elementary books on Physics, for example, the one by Stolberg and Hill [14] have given the value of thermal conductivity as 1.675 $\frac{W}{m°C}$ with which the thermal gradient works out to be

$$10.5\,\frac{°C}{km}$$

To summarize, various values of geothermal gradient are given below

$$10.5\,\frac{°C}{km}$$

14.1 ″

19.2 ″

35.1 ″

Values of thermal gradient vary because of non-uniformity of the Earth's crust. Large differences are probably due to very low values of thermal conductivity of the order of 0.15$\frac{W}{m°C}$ such as that of brick made from Earth's soil and of conductivity 0.13$\frac{W}{m°C}$. Values of thermal gradient in such cases exceed even 100$\frac{°C}{km}$. The rate of increase is greater near a source of heat such as an active volcanic center and also affected by the thermal conductivity of rocks at a particular locality.

Due to the high temperature of the sphere of plasma at the time of formation of the Earth, no thermal equilibrium between the sphere and the convective cloud which is the present atmosphere could be expected. The cooling must have taken place in different ways. One must be by the rotation and revolution of the Earth. The other must be due to conduction from the interior of the Earth with a variable thermal gradient which is the most prominent and responsible for the cooling. After sufficient cooling, there is no much difference of temperature between the sphere of plasma and the convective cloud in its immediate neighborhood and hence one can legitimately apply Newton's Law of Cooling as a first approximation.

Readings for Time and Temperature:

We want to list out the temperature at various times of cooling of the Earth. Hence we can legitimately take the temperature $2 \text{x} 10^7$°C mentioned in the beginning as a starting temperature. As values of thermal gradient obtained differ considerably from each other, one cannot take an average. The value, $14\frac{°C^{[5]}}{km}$ may be taken as standard as it is from a modern encyclopedia. Thus the temperature of the inner core of the Earth has a theoretical value

$$0.014 \times 6.4 \times 10^6 = 0.09 \times 10^6 \approx 10^5 \text{ °C}$$

We can assume the fall of temperature taking place from 2×10^7 °C at the time of formation of the Earth to 10^5 °C over a period of time corresponding to the present age of Earth. Now, in order to find out the fall of temperature over a period of time, we follow the scheme provided by Sir William Thomson (Lord Kelvin)[10] and Peter Guthrie Tait in their classical book on "Principles of Mechanics and Dynamics", Dover Edition, 1962. In the Appendix D on 'Secular Cooling of Earth' under serial (r) on page 478, is quoted here in Italics and in brackets:

"*[……… (r) Whenever the amount of such effects is at any one time, it would go on diminishing according to the inverse proportion of the square roots of the times from the initial epoch.*

Thus, if at 10,000 years we have	2^0	*per foot of increment below ground.*
At 40,000 years we should have	1^0	*per foot*
At 160,000 " " " " " " " " " " " " "	$\left(\frac{1}{2}\right)^0$	*per foot*
At 4000,000 " " " " " " " " " " " "	$\left(\frac{1}{10}\right)^0$	*per foot*
At 100,000,000 " " " " " " " " " "	$\left(\frac{1}{50}\right)^0$	*per foot]"*

As events correct to a second in the Big Bang are uncertain, let us have a look at Fig. 2[12] which gives the Big Bang model of the universe that appeared in the 'Independent' newspaper in Great Britain on Friday the 24th April 1992. From the figure it is seen that a temperature of 10^9 degree corresponds to 3 minutes after the Big Bang. As the diagram is not as per scale and as a reasonable approximation, the starting time for our purpose can be taken as the very first day (86400 second) after the initial epoch and the corresponding temperature as (2×10^7) °C. Following the method given by Lord Kelvin mentioned above, various readings for time and temperature are shown in Table -1. In order to facilitate plotting a graph later, the readings for time are shown as multiples of 10^{13} and readings for temperature as multiples of 10^3.

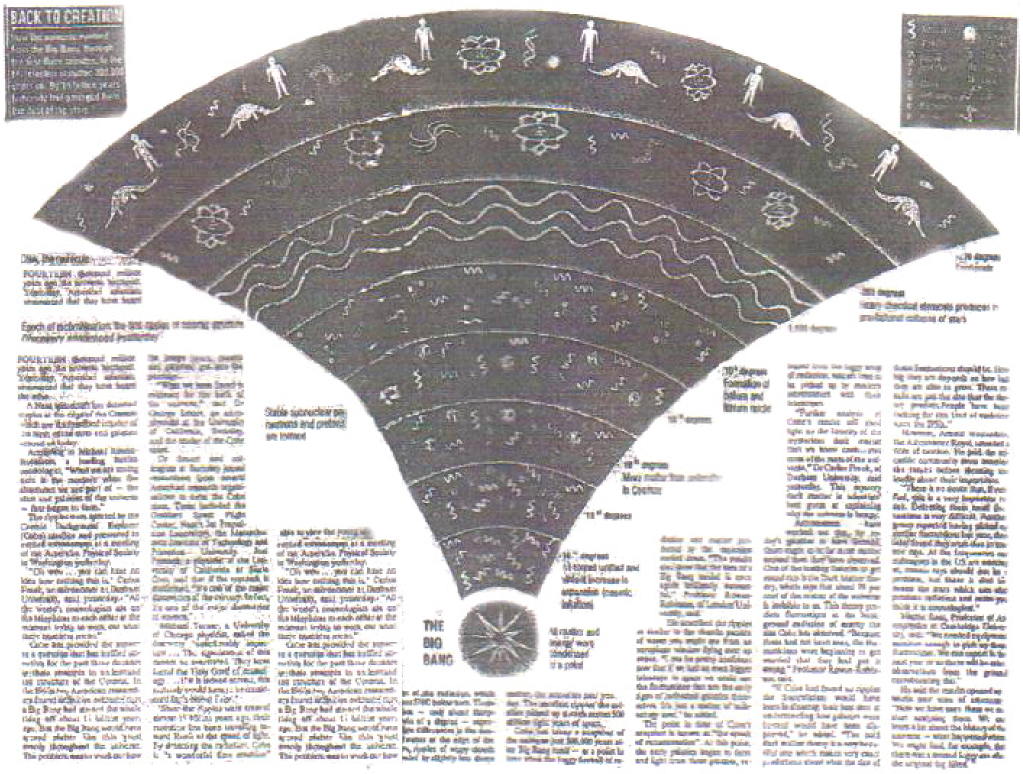


Fig. 2[12] The Big Bang Model of Universe depicting how the universe began

Table-1

No.	Time in seconds × 10^{13}	Temperature in °C × 10^3
1	0.00000000864 (1st day of the Big Bang)	20000
2	0.00000003456	10000
3	0.00000013824	5000
4	0.00000055296	2500
5	0.00000221184	1250
6	0.00000884736	625

7	0.00003538944	312.5
8	0.00014155776	156
9	0.00056623104	78
10	0.002265	39
11	0.00906	19.5
12	0.03624	9.77
13	0.14496	4.885
14	0.57984	2.44
15	2.31936	1.22
16	9.27744	0.61
17	37.10976	0.305
18	148.43904	0.153
19	593.7562	0.076
20	2375.025	0.038
21	9500.099	0.019

In the above table, we have taken the starting time arbitrarily as the very first day of the epoch. Few seconds or even few days in a duration of 10^{17} seconds which is the order of the age of Earth do not matter as our focus is on getting a cooling curve. In order to get the readings for 'time' and 'temperature' and strictly following Kelvin's scheme, brings out a temperature under serial No. 21 as 19°C which appears to be close to the real value of present temperature of Earth.

It should be noted that the temperature 10^5 °C is just a theoretical value and the difference $(\theta - \theta_1)$ is not much different from θ.

<u>Newton's Law of Cooling and the Cooling Curve:</u>.

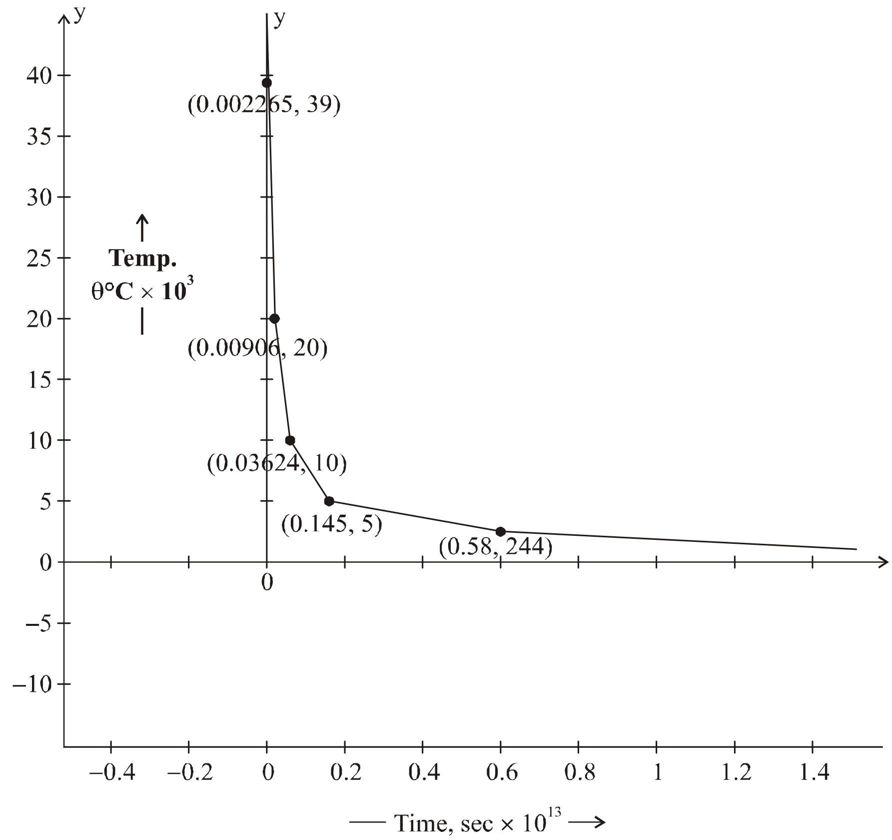
A simple form of equation (5) for temperature, θ at any time t is given by

$$\theta = \theta_1 + (\theta_0 - \theta_1)\, e^{-\lambda t} \qquad (11)$$

This is akin to Newton's Law of Cooling where λ is the cooling constant.The negative sign for λ indicates a fall of temperature with time. It should be noted that the reciprocal of λ has dimensions of time. From the above equation, we have

$$\frac{d\theta}{dt} = -\lambda\,(\theta - \theta_1) \qquad (12)$$

Now, in order to find the age of Earth graphically, we must try to get a cooling curve by plotting 'time' versus 'temperature' .From Table 1 plot a graph of time (x-axis) versus temperature (y-axis) and the nature of graph is as shown in Graph 1. It is a computerized plotting and hence only few points appear in the curve as other points both in the x and y-axis appear to lean on their respective axes and hence are not visible. It is found from the table



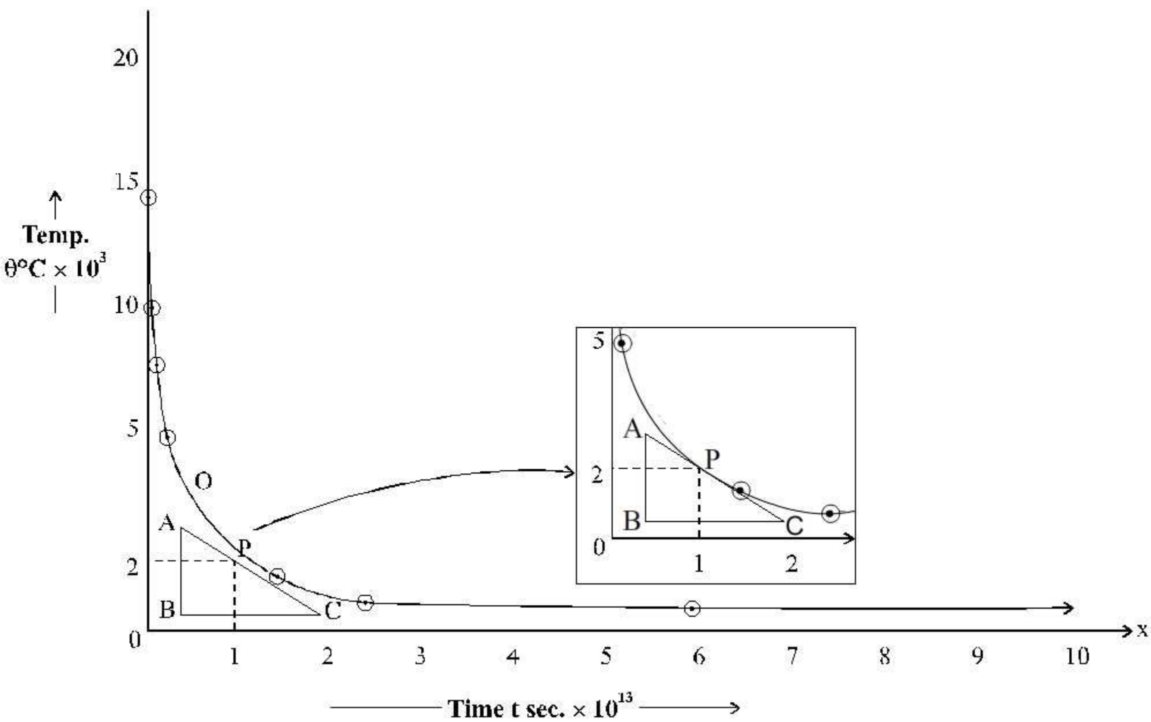
Graph 1

that the readings with serial numbers 11 to16 lie near the origin and may form a curve. But in order to get a smooth curve we need more readings for which a separate table is prepared with intermediate readings which lie mid-way between the readings and the same is shown in Table 2 where the intermediate readings are shown with asterisk. It is found that the intermediate readings with asterisk also follow the scheme given by Lord Kelvin.

With the same scale a separate graph is plotted and the same is shown in Graph2.The curve so obtained is the 'cooling curve' obeying Newton's Law of Cooling and the same can be very well applied as sufficient cooling has already taken place. It is to be noted that the lower part of the curve asymptotically approaches the present temperature of the Earth.

Table 2

No.	Time in seconds × 10^{13}	Temperature in °C × 10^{3}
11	0.00906	19.53
*11 (a)	0.02265	14.67
12	0.03624	9.8
*12 (a)	0.09062	7.34
13	0.145	4.88
*13 (a)	0.3625	3.66
14	0.58	2.44
*14 (a)	1.45	1.83
15	2.32	1.22
*15 (a)	5.8	0.915
16	9.277	0.61



Graph 2

Slope of graph at the point P = $\dfrac{AB}{BC} = \dfrac{d\theta}{dt} = \dfrac{2.1\times 10^{3}}{1.5\times 10^{13}} = 1.4\times 10^{-10}$

$= -\lambda\,(\theta - \theta_1) = -\lambda\,[10^5 - (2\times 10^7)\,]$

$= -\lambda\,(-1.99\times 10^7) = (1.99\times 10^7)\,\lambda$

$\therefore\ \lambda = \dfrac{\frac{d\theta}{dt}}{1.99\times 10^{7}} = \dfrac{1.4}{1.99}\times 10^{-17}$ per second

$\therefore\ \dfrac{1}{\lambda} = \dfrac{1.99}{1.4} = 10^{17} = 1.42\times 10^{17}$ second = Age of Earth (4.5) billion years)

The rate of cooling can be found from the graph by carefully taking the slope of the tangent exactly at the curved portion, say at point P. It is found from the graph that

$$AB = d\theta = 2.1\times 10^{3}$$

$$BC = dt = 1.5\times 10^{13}$$

$$\therefore\ \frac{d\theta}{dt} = \frac{2.1}{1.5}\times 10^{-10} = 1.4\times 10^{-10}$$

From equation (12), $\frac{d\theta}{dt} = -\lambda(\theta - \theta_1) = -\lambda[10^5 - (2x10^7)] = -\lambda(-1.99x10^7) = 1.99x10^7\lambda$

$$\therefore\ \lambda = [\frac{\frac{d\theta}{dt}}{1.99x10^7}] = \frac{1.4}{1.99}\ x\ 10^{-17}$$

$$\therefore\ \frac{1}{\lambda} = \frac{1.99}{1.4}\times 10^{17} = 1.42\times 10^{17}\ \text{second.}$$

which is the age of the Earth.

The cooling constant, $\left(\dfrac{m^2\pi^2h^2t}{r_e^2}\right)$ for m = 1 obtained from equation (5) also gives the value of age of Earth as 200×10^{17} second. The discrepancy is large due to the uncertain value of diffusivity, h^2. Values tally only for higher values of h^2 and the value of age of Earth obtained by graph is more reliable.

The graphically obtained value 1.42×10^{17} second (4.5 billion years) as the age of Earth is in perfect agreement with the accepted value 1.45×10^{17} second (4.6 billion years).

The 'cooling curve' obtained in Graph 2 is peculiar in the sense that it represents a transition from plasma state to molten state and subsequent solidification of the Earth. The curve can rightly be called a 'Transition Curve'. The point P in the curve where the slope has been taken may be called a 'Transition Point'. The temperature corresponding to this point is about 2000 °C when the molten metals start solidifying. The time corresponding to this temperature is about 1.2×10^{13} second (380000 years). In geological time scale, this corresponds to 'Quaternary period' of the Cenozoic era and the same is in agreement.

We may also find the global surface temperature from the Table 1. Let the last reading No. 21 follow the time 1.42 x 10^{13} second obtained by us from the graph 2. In order to get the corresponding reading for the temperature, we have to do a small arithmetic so as to follow the rule of Lord Kelvin.

Divide 14200 by the previous reading 9500 and we get a figure 1.4947. The corresponding reading for temperature is obtained by dividing the previous temperature 0.019 by the square root of 1.4947. That is, $\frac{0.019}{\sqrt{1.4947}} = \frac{0.019}{1.223} = 0.0155$. Let us make a Table 3 below:

Table 3

No.	Time in seconds x 10^{13}	Temp. in ℃ x 10^3
21	9500.099	0.019
22	14200	0.0155

It is understood that In the above calculation the multiple 10^{13} and 10^3 for time and temperature respectively are maintained. The Table shows that the global surface temperature is 15.5℃ and is in perfect agreement with the temperature of 15℃ obtained by NASA and reported from all sources.

Earth, a part of Solar Nebula:

At this stage it is of great interest for us to find out the total radiation given out by Earth in its process of cooling between the past and the present. We proceed as follows:

$$\Delta Q = -m_e \, s \, \Delta\theta$$

Minus sign indicating a process of cooling

$$\therefore \; Q = -m_e \, s \int_{\theta_1}^{\theta} d\theta = -m_e \, s \, [\theta - \theta_1] = -5.98 \text{ x } 10^{24} \text{ x } 837 \text{ x } [10^5 - 2x10^7]$$

$$\therefore \; Q = -5.98 \text{ x } 10^{24} \text{ x } 837 \text{ x } [-1.99 \text{ x} 10^7]$$

$$= 9.96 \text{ x } 10^{34} \text{ Joule}$$

where we have substituted the value for specific heat of material of Earth from the list of constants given in the beginning of this paper. Divide this by our already obtained value of age of Earth so as to get the radiant energy per unit time. That is,

$$\frac{Q}{t} = \frac{9.96x10^{34}}{1.42x10^{17}} = 7.014 \text{ x } 10^{17} \ \frac{J}{s} \text{ or Watt}$$

Dividing this by the surface area of Earth, we get the intensity of radiation (more appropriately the intensity of cooling) as

$$\frac{7.014x10^{17}}{5.101x10^{14}} = 1375\,\frac{W}{m^2}$$

But, this is almost exactly equal to the Solar Constant $1370\,\frac{W}{m^2}$ [11]

This perfect coincidence is a confirmation that Earth was formed by accretion from the Solar Nebula. The Earth is now sufficiently cooled after radiation as mentioned above

For the interaction of solar radiation, the solidification of Earth and the final stage of formation of atmosphere have to take place. That happened some 3.8 billion years ($3.8x10^9$years = $1.2x10^{17}$second) ago with the formation of the hydrosphere and evidence of life.

CONCLUSION

It can be seen, although not shown in the paper, that the temperatures obtained by following a method suggested by Lord Kelvin are very much in accordance with the geological time scale. The method adopted is unique in showing the Earth as a part of Solar Nebula which is an authentic confirmation of Big Bang theory.

After the formation of the solid Earth and being made habitable, the natural Greenhouse Effect, its magnitude and enhanced Greenhouse Effect, etc. are not considered in the paper.

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