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AN ASTRONOMICAL ASPECT OF THE EVOLUTION OF THE EARTH.

By J. K. E. Halm, Ph.D., F.R.A.S.

(Presidential Address, Session 1934-1935.)

Among the problems of the evolution of celestial bodies which confront the physicist the evolution of our own planet is the one which perhaps appeals most strongly to the human interest on account of its important bearing on investigations into the origin of life. Whatever our views on this question may be, we agree that the existence and development of organic life is conditioned by physical factors, such as temperature, pressure, humidity and chemical composition of the atmosphere and many others which, within comparatively narrow limits, must combine in a manner favourable to the growth of living organisms. A study of *biological* evolution must therefore always be closely associated with a study of *physical* evolution.

Now for the latter, obviously two courses in opposite directions are open. Either we may try to trace the development of the Earth from an earlier stage to the present, or we may take the opposite course of tracing the course of events in the backward direction from the present to an earlier stage. The former is the procedure adopted by the astro-physicist who studies the evolution of the celestial bodies from their earliest evidence of existence to the end of their career as luminous bodies. The latter course is taken by the geologist who endeavours to obtain a picture of past stages in the earth's evolution from the evidence of the relics of these stages in the present formations of its surface layers.

The obvious difficulty of research along either of these lines lies in the fact that between the span of time within which the astrophysicist can investigate and that which is at the disposal of the geophysicist there lies a tremendous gap within which no data of observation are available by which theoretical research might be guided. Even if the astronomer has succeeded in finding a satisfactory theory for representing the evolution of a star within the limits of the time interval at his disposal, is he safe in extrapolating his formulae over the thousands of millions of years, during which his result cannot be checked by observation? Obviously the acceptance of his conclusions depends on the success with which he can represent the observed facts at the other end, *i.e.*, within the domain of the geologist. Naturally the same remarks apply to an extrapolation by the geologist in the backward direction. Perhaps the following simple demonstration may illustrate my argument.

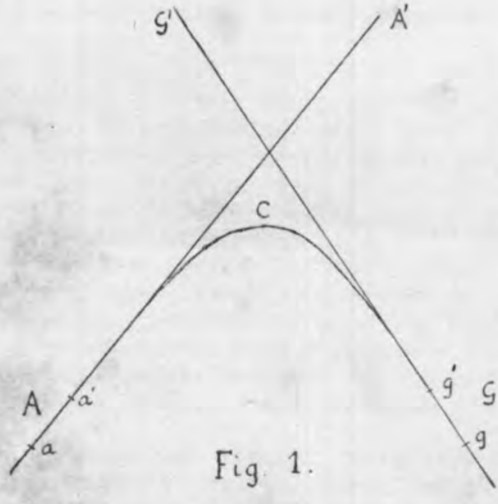


Fig. 1.

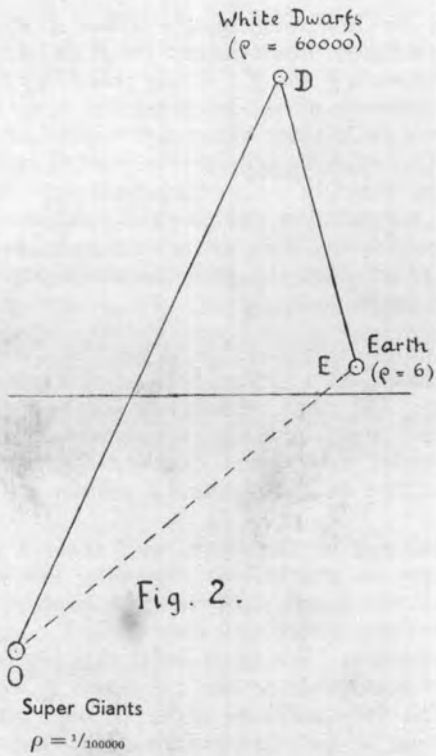
Suppose a certain event, say the track of a meteor through space, takes place along the curve of a hyperbola. Two observers, A and G, are stationed at points of the opposite branches AC and GC and at considerable distances from C. As you know, at such points the curvature of the hyperbola may be so small that, taken over the short distances aa′ and gg′, it may be undistinguishable from a straight line. We suppose the range of observations for A to be between a and a′, and for G between g and g′. Being guided by their observations only, both observers would independently come to the conclusion that the event took place along a straight line, for observer A in the direction of AA′, and for observer G in the direction G′G Evidently the error in their conclusions can only be discovered by mutual consultation which will convince them that the assumed straight line laws are wrong and have to be modified to such an extent that the path calculated at A passes through G and *vice versa.*

This simple demonstration shows the danger of extending any theory based on a limited field of observation much beyond these limits. The slight difference between the curve of the hyperbola and a straight line, apparently negligible within the short path under observation, causes a most profound disparity between the true and the assumed path.

The geologist is, therefore, well advised not to place too much reliance on conclusions regarding the evolution of our planet which are based solely on the properties of matter as he observes them under the very limited conditions accessible to his observations. We must insist that his conclusions, when extrapolated backwards to the *star*-stage of our planet, are in harmony with the conditions under which matter exists at that stage according to the observations of the astronomer.

These general reflections bring me to one of the cardinal assumptions on which the evolution of the Earth has been based. In all the theories hitherto propounded, however divergent they may be in other respects, it has been accepted, as an unassailable basic conception, that the Earth, by cooling from the high temperature state as a star to the low temperature as a planet, has been *shrinking,* which means that its density has been *increasing.* I do not think that this postulate has ever been challenged. It seems to be so convincingly supported by the general behaviour of matter to expand by heating and to contract by cooling (and by the fact that in the star-stage, in which undoubtedly the Earth had once been in the dim past, matter is found to be in an attenuated gaseous condition) that geologists have accepted the theory of a *shrinking* Earth as an unchallengeable axiom.

But if we examine this axiom in the light of our modern knowledge of star evolution, it appears not only doubtful but indeed inacceptable.



Let us briefly examine the knowledge we have gained regarding the densities of celestial bodies at different stages of evolution. In the diagram (Fig. 2) let progression along the *horizontal* line from left to right represent progression in the *age* of the star, and let progression along the *vertical* line from bottom to top indicate increase in its mean density ρ (referred to water as unit).

The earliest stage in its career as a luminous body (Super-Giants) is marked by the point *O*, the latest stage (White Dwarfs) by the point *D*.

The line connecting *O* with *D* is meant to indicate in a general way the increase in the mean density during the star's evolution. You notice the enormous difference in density between *O* and *D*. While at *O* the density is so small that 1 cubic inch of matter would weigh only about the 6,000th part of a gramme, the same volume of matter at *D* would turn the scales at about 1 million grammes or 1 ton. The average weight of the matter of which our planet is composed is about 90 grms. per cubic inch, and the position on the diagram corresponding with this density is marked at E.

You notice at once the striking divergence between the views of the geologist and the astronomer. The geologist traces the development of our planet along OE, i.e., along the path indicating a continuous *increase* in the density.

The astronomer, on the other hand, would be inclined to prescribe a course first from O to D and then from D to E, *i.e., increase* of density and corresponding *contraction* in the first stage, and *decrease* of density and corresponding *expansion* in the second stage. Since the *geological* history of the Earth comprises an epoch during which the planet has moved along the path DE, the astronomer must come to the inevitable conclusion that *during geological time the Earth has been in a state of progressive expansion.*

Of course such considerations can do no more than describe the general trend of events as evidenced by observed facts, without explaining *why* evolution should have proceeded on these lines. Deeper insight into the underlying causes can only be gained by a more rigorous investigation of the problem on thermodynamical lines.

Fortunately the problem is not quite so formidable as it may appear at first sight. Let us define the star as a spherical agglomeration of matter held together by its own gravitational attractions. Let us suppose the boundary of the globe to be fixed by a spherical surface S, the *photosphere* in the case of a star and the solid and liquid surface in the case of a planet and let this surface be enclosed by an atmosphere. (Fig. 3.)

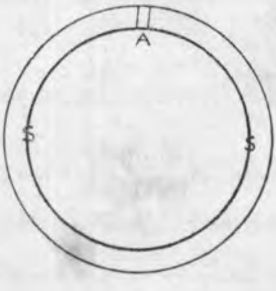


Fig. 3.

Let further the temperature at the surface be denoted by T_s being expressed on the absolute scale (freezing point of water at 273 degrees Cent.). At any point A we consider a small volume v of atmosphere containing a unit of mass (1 gr.) at temperature T_s and acted upon by a pressure p.

We know from thermodynamics that if a small quantity of energy dQ in the form of heat is introduced into the element this heat will be used partially to raise the temperature T_s by an amount dT_s and partially to perform work by increasing the volume by an amount dv. The amount of heat required in raising the temperature is $c_v dT_s$ where c_v is known as the specific heat at constant volume. The amount of work done in expanding the volume against the pressure, is expressed by pdv. Hence the fundamental equation between Q, T_s and v is given by

$$dQ = c_v\,dT_s + pdv. \tag{1}$$

Since $$d(pv) = pdv + vdp,$$

we have also $$dQ = \left[\, c_v + \frac{d(pv)}{dT_s}\right] dT_s - vdp. \tag{2}$$

The bracketed term is known as the specific heat at constant pressure and may be denoted by c_p. Hence

$$\frac{d(pv)}{dT_s} = c_p - c_v,$$

and since in gases the specific heats are independent of the variables, T, v and p:

$$pv = (c_p - c_v)T_s, \tag{3}$$

which will be recognised as the well-known thermodynamical relation between p, v, T_s valid for gases (the law of Boyle and Charles).

Reverting to equation (2) and dividing by c_pT_s we find:

$$\frac{dQ}{c_pT_s} = \frac{dT_s}{T_s} - \left(1 - {c_v}/{c_p}\right)\frac{dp}{p},$$

or denoting the ratio between the specific heats c_p/c_v by γ and remembering that

$$\frac{dT_s}{T_s} = dlnT_s\,; \qquad \frac{dp}{p} = dlnp,$$

(ln meaning the natural or Napierian logarithm):

$$\frac{dQ}{c_pT_s} = dlnT_s - \frac{\gamma-1}{\gamma}dlnp = dlnS, \text{ say.}$$

Finally by integration we get:

$$T_s/p^{\frac{\gamma-1}{\gamma}} = S. \tag{4}$$

We had defined dQ as the amount of heat-energy received by the atmospheric element at A. Now what happens is this: The element receives an amount dQ_1 from the surface and communicates a certain amount dQ_2 to the overlying atmosphere and space, so that

$$dQ = dQ_1 - dQ_2.$$

There is a tendency to reach a state of thermal equilibrium in which $dQ_1 = dQ_2$ and hence $dQ = o$. In this case S would have the same value for all times. I prefer, however, to leave this question in abeyance for the present, and to look upon S as a quantity which may vary.

Now, with regard to the pressure p we know that it must be in accordance with the hydrodynamical equation:

$$p = g.m \tag{5}$$

where g is the constant of gravitation at the surface and m is the mass of the atmosphere resting on unit surface (1 sq. cm.).

Substituting (5) into (4) we have

$$T_s \Big/ (gm)^{\frac{\gamma - 1}{\gamma}} = S. \tag{6}$$

This equation applies to the state of the star at a moment t, say. At another time t', we have a similar equation:

$$T'_s \Big/ (g'm')^{\frac{\gamma - 1}{\gamma}} = S',$$

and hence

$$\left(T_s / T'_s\right)\left(\frac{g'm'}{gm}\right)^{\frac{\gamma - 1}{\gamma}} = S / S'. \tag{7}$$

But

$$g = \frac{GM}{r^2}; \qquad g' = \frac{G.M}{r'^2},$$

where G is the universal constant of gravitation, and M the total mass of the star, which is the same at both instants. Hence

$$g' / g = \left(r / r'\right)^2 \tag{8}$$

Further, the total mass of the atmosphere, M_s, is

$$M_s = 4\pi r^2 m \quad \text{and} \quad M'_s = 4\pi r'^2 m'$$

and hence

$$\frac{m'}{m} = \frac{M_s'}{M_s}\left(\frac{r}{r'}\right)^2.$$

Consequently

$$\frac{g'm'}{gm} = \frac{M'_s}{M_s} \left(r/_{r'}\right)^4$$

Further, the total mass of the star is expressed by

$$M = {}^4/_3\pi\rho_m r^3,$$

and therefore

$$\left(r/_{r'}\right)^3 = \frac{\rho'_m}{\rho_m}; \qquad \left(r/_{r'}\right)^4 = \left(\frac{\rho'_m}{\rho_m}\right)^{4/3}$$

$$\left(\frac{g'm'}{gm}\right) = \frac{M'_s}{M_s} \left(\frac{\rho'_m}{\rho_m}\right)^{4/3} \tag{9}$$

Substituting (9) into (7), we obtain:

$$\left(T_s/_{T'_s}\right)\left(\frac{\rho'_m}{\rho_m}\right)^{\frac{4(\gamma-1)}{3\gamma}} = S/_{S'}\left(M_s/_{M'_s}\right)^{\frac{\gamma-1}{\gamma}} \tag{10}$$

This relation is obviously satisfied if at any moment

$$T_s/\rho_m^{\frac{4(\gamma-1)}{3\gamma}} = cS.M_s^{\frac{\gamma-1}{\gamma}}, \tag{11}$$

where c is a constant.

As regards the ratio of the specific heats we know that for our own atmosphere $\gamma = 1.4$. In the absence of direct evidence an assumption as regards its value on stars in general has to be made. As a result of investigations of various problems of stellar evolution upon which I cannot enter here, I have come to the conclusion that $\gamma = 1{\cdot}4$ leads in all cases to the best agreement between theory and observation. We shall see presently that its choice in the problem before us, is likewise justified.

Hence equation (11) may now be written:

$$T_s/(\rho_m)^{8/21} = c.(S.M_s^{2/7}) = C, \text{ say.} \tag{12}$$

This equation has been derived under the most general conditions. It will be readily seen that if we had assumed the state of equilibrium which is characterised by a steady flow of heat energy through the atmospheric element with the effect that at any moment equal amounts of heat enter and leave the element ($dQ = o$), then S would have the same value at all instants. And if, in addition, we had assumed that the total mass of the atmosphere M_s had remained constant, then C would appear as a constant throughout the whole lifetime of the star. I prefer, however, to treat the problem from its most general aspect, to calculate the values of C [equation (12)] for stars (including the planets) for which the surface temperatures T_s and the mean densities ρ_m are known, and to derive conclusions as regards the course of stellar evolution from a study of the character of C in different phases of star development.

Most of the material which could be used for calculating C from equation (12) has been taken from data exhibited in Tables 17 and 18 of Sir Arthur Eddington's book on "The Internal Constitution of the Stars." In those tables we find the temperatures T_s, the absolute bolometric magnitudes and the masses for the components of 15 Binary Stars whose parallaxes and masses are known with sufficient accuracy. The data for the companion to Sirius are mentioned separately on p. 171 l.c. From the given data the mean densities ρ_m can be calculated and thus we find the values of log C from equation (12) for every component on the list. The data for the mean surface temperatures of the planets have been collected from various sources, chiefly from Dr. Spencer Jones' General Astronomy. Being based on observations of a most delicate nature, their accuracy cannot be vouchsafed, but I think that the errors can be safely assumed to be well within 10 per cent. of the values adopted. The planet Mercury had to be excluded for obvious reasons. Its mass and consequently the density derived from it, is extremely uncertain. Further it is highly problematic to define a *mean* surface-temperature on a planet, half of which shews perpetually a temperature of about $+400°$ C. and the other half a temperature not far from absolute zero. The result for Venus has to be accepted with some reserve. The planetary emission on the dark side points to a temperature of $-25°$ C. or 248° abs. It has been found that the part due to planetary emission on the bright side indicates a temperature not much higher. As a compromise I have accepted a mean temperature of $-20°$ C. or 253° abs. For Mars I have adopted the mean of the extreme temperatures $+10°$ and $-80°$ given by Dr. Spencer Jones. The temperatures for Jupiter and Saturn are derived from the observations of their water cell transmissions. For Jupiter Adams gives $-180°$ F. or 155° abs.; for Saturn Coblentz quotes 163° to 123° abs.

In the following table I show the values of log. C derived from these data in accordance with equation (12) and also the logs. of the observed masses M (in terms of the Sun's mass), the surface temperatures T_s and the mean densities ρ_m

BINARY STARS.

*	Log. M.	Log. T_s	Log. ρ_m	Log. C.
Capella b	+ 0.62	3.72	— 2.61	4.71
f	+ 0.52	3.87	— 1.45	4.42
Sirius b	+ 0.39	4.02	— 0.22	4.11
α Cent. b	+ 0.06	3.70	— 0.34	3.83
f	— 0.01	3.57	— 0.77	3.86
Sun	0.00	3.76	+ 0.15	3.71
Kruger 60 b ..	— 0.57	3.49	+ 0.95	3.13
f ..	— 0.80	3.49	+ 2.23	2.64
ϵ Hyd. b	+ 0.56	3.74	— 2.18	4.57
f	+ 0.36	3.74	— 1.48	4.30
β Aur. b	+ 0.38	4.02	— 1.13	4.45
f	+ 0.37	4.02	— 1.14	4.45
Procyon b	+ 0.05	3.83	— 0.52	4.03
δ Equul. b ..	0.00	3.83	+ 0.34	3.70
f ..	0.00	3.83	+ 0.40	3.68
η Cass. b	— 0.14	3.79	+ 0.29	3.68
f	— 0.39	3.58	+ 0.57	3.36
ζ Herc. b	+ 0.04	3.76	— 0.82	4.07
f	— 0.29	3.70	+ 0.52	3.50
70 Oph. b	+ 0.02	3.64	— 0.27	3.74
f	— 0.11	3.59	+ 0.14	3.54
ξ Bootis b ..	— 0.21	3.69	+ 0.03	3.68
f	— 0.33	3.59	+ 0.25	3.49
85 Peg. b	— 0.21	3.76	+ 0.49	3.57
f	— 0.51	3.51	+ 0.32	3.38
μ Herc. b ..	— 0.34	3.49	+ 0.61	3.26
f	— 0.38	3.49	+ 0.87	3.16
o Erid. f	— 0.70	3.46	+ 1.25	2.99

WHITE DWARFS.

*	Log. M.	Log. T_s	Log. ρ_m	Log. C
Sirius B	— 0.07	3.90	4.78	2.09
o_2 Erid. B ..	— 0.68	4.04	4.76	2.23

PLANETS.

	Log. M.	Log. T_s	Log. ρ_m	Log. C.
Venus	— 5.62	2.40	0.67	2.15
Earth	— 5.51	2.46	0.76	2.17
Moon	— 7.42	2.36	0.53	2.16
Mars	— 6.49	2.38	0.60	2.15
Jup.	— 3.02	2.19	0.11	2.15
Sat.	— 3.54	2.15	— 0.15	2.21

These figures reveal a most important feature in the behaviour of log. *C*. While in the Binary Stars there appears a distinct correlation between this quantity and the masses, we notice within the wide range of masses from the White Dwarfs to the planets a remarkable constancy. We see this even more clearly when the stars are arranged in small groups according to their masses.

BINARY STARS.

Log M.	*Log. C.*	*No. of Stars.*
0.57	4.57	3
0.38	4.33	4
0.04	3.95	4
—0.04	3.68	6
—0.26	3.56	4
—0.40	3.29	4
—0.69	2.92	3

WHITE DWARFS AND PLANETS.

Log. M.	*Log. C.*	*No.*
—0.38	2.16	2
—5.27	2.16	6

The annexed diagram (Fig. 4) in which the log. *C* have been plotted as ordinates against the log *M* (*M* expressed in units of the Sun's mass) as abscissae shows not only the

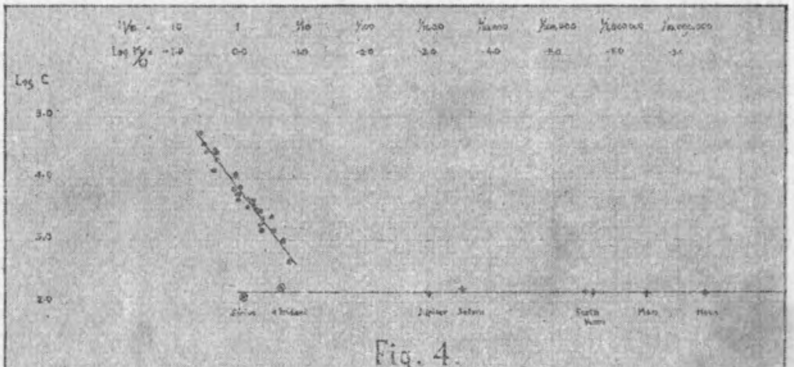


Fig. 4.

striking feature referred to, but it indicates also a lack of continuity between the two groups. Evidently there occurs an abrupt change of conditions when the stars reach the White Dwarf stage.

For our present purpose we are naturally more concerned with the evolution subsequent to the White Dwarf stage. We note down as the principal result of our enquiry that this phase of evolution is characterised by the fact that C has the *constant* value 145 (log. $145 = 2.16$). The fundamental equation on which the problem of the evolution of our planet must be based is therefore:

$$T_s \Big/ \rho_m^{\;0\cdot38} = 145 \qquad (13)$$

where T_s is the mean temperature at the surface expressed on the absolute scale, and ρ_m is the mean density. This equation applies not only to the Earth, but to all the planets *irrespective of their mass.*

To understand the meaning of this uniformity, we have to pry a little more deeply into the question of the constitution of matter. To explain generally the properties of matter we have to assume that it consists of an agglomeration of minute corpuscles called atoms. Until about half a century ago the universally accepted picture of an atom was that of an elastic spherical ball of a definite and invariable diameter. On this assumption the density of a body is obviously defined by the number of balls contained in a unit of volume. In a gas the mutual distances between the atoms are assumed to be large in comparison with their diameters, and hence the density is small, but capable of being increased by compressing the gas through external pressure. Naturally, however, this compression can be continued only to a certain point when the balls are approached to one another so closely that they resist further compression. This maximum density, or minimum volume, is determined solely by the diameter of the atom and for a given diameter is the same for bodies of large and small masses. Hence the condition that all celestial bodies from the White Dwarf stage down to the smallest planets satisfy the same equation (13) implies that all these bodies must have reached the highest possible degree of density, *i.e.,* a state in which the atoms are packed as closely as possible. For in this state the left hand side of the equation (13) depends on the behaviour of the single atoms only, but not on the number of atoms (mass) collected in the body. Such bodies must shew the characteristic properties associated with a state of high rigidity. That the Earth is actually in this condition is borne out by such facts as the effect of the tides, the propagation of seismic waves and the variation of latitude. It is also supported by the following consideration.

It can be shewn that if σ represents the diameter of a single atom, μ its mass and ρ the density (*i.e.,* the mass of all the atoms contained in 1 c.cm.), the condition of closest packing is satisfied if

$$\frac{\sigma^3 \rho}{\sqrt{2}\cdot\mu} = 1$$

Now it is generally assumed that the inner core of the Earth consists chiefly of iron and that the density in that part of the interior is about 8. Since the mass of an atom of iron is 9.3×10^{-23} gm., we find from the above formula

$$\sigma = 2.6 \times 10^{-8} \text{ cm.}$$

This agrees well with the results of direct determinations of the sizes of molecules for a number of gases and vapours given by Sir J. Jeans in "The Dynamical Theory of Gases" (p. 340) the mean value of which is 3.1×10^{-8}. Also, on the supposition that the atoms in metals in the solid state are approximately in the state of closest packing, I find values for σ ranging between 2.6 and 3.1×10^{-8}.

Now, it is obvious that if the old conception of the atom as an elastic sphere of *invariable* size were correct, and if the atoms inside our planet are in the state of closest packing, then the mean density of the Earth ($\rho = 6$) should represent the maximum mean density which any celestial body would be capable of attaining. But we find that in the White Dwarfs the mean density is not 6, but 60,000. Clearly, then, the assumption of a definite and invariable size of the atom is untenable. In the White Dwarf the "diameter" of the atom is less than 1/20th that of an atom in our planet.

The variability in the sizes of the molecules and atoms, which is so glaringly demonstrated in the case of the stars, is a phenomenon already noticeable on a minor scale within the range of physical experiments. It was noticed that a certain physical constant, known as the co-efficient of viscosity, did not behave in accordance with the assumption of the elastic sphere theory. The diameters of the molecules which satisfied the observed phenomenon shewed an appreciable decrease with increasing temperature. In the adjoined table I shew in a somewhat condensed form the values which are given by Jeans (l.c. p. 256). They refer to the diameters of the molecules of air at different temperatures.

Temp.	*Diameter.*
0° C.	2.86×10^{-8}
55	2.78
104	2.74
542	2.60
988	2.55
1213	2.44

On the basis of these and similar observations Clerk Maxwell saw reason for abandoning the conception of elastic spheres and for formulating his well-known theory in which the molecules are supposed to be point centres of force repelling each other according to the inverse 5th power of the distance. We see at once the essential difference between the two conceptions. In the older theory the closest approach between two atoms (or molecules) is invariably the diameter of the atom, inrrespective of the velocity (temperature) with which they approach. In Maxwell's theory, the velocity of approach plays an important part. The higher the velocity, the further each atom will be carried into the other's field of force, before the centres reach their shortest distance apart. The "diameter" is replaced by the "shortest possible distance" between two centres. At high temperatures this distance is shorter and consequently the density at closest packing is greater than at low temperatures. This is exactly the phenomenon which we observe when comparing the density of the extremely hot White Dwarf with that of the much cooler planet.

We have now reached a very definite conclusion with regard to the evolution of a star. We have found that for every star there comes a moment when its life as an active gaseous body comes to an end. For reasons, the meaning of which we have not yet grasped, it is turned abruptly into a *rigid* body, the *rigor mortis* of star life has set in. And similarly to our own case, this "death" may occur at widely different ages. Some stars may live to a ripe old age. I consider o Eridani B one of these old veterans. Others, like Sirius B, are fated to die in the vigour of manhood, and still others, like the planets, scarcely survive their exit from the maternal womb.

Once this *rigor mortis* has set in, the further fate of these star corpses is clearly defined by the condition expressed in equation (13). As the corpse grows colder, the atoms of which its bulk is composed require more and more elbow room. The star *expands,* and the ratio between cooling and expansion is strictly regulated in accordance with equation (13).

The rate of cooling obviously depends on the amount of heat energy which is abandoned into the surrounding space. A body which abandons its heat without receiving compensation by an influx of energy from an external source, is bound to cool more rapidly than a body which enjoys the benefit of such an influx. Consequently the former body will expand more rapidly than the latter. We thus understand why the densities of the planets decrease so conspicuously with their distances from the sun. We also find a reasonable explanation for the considerable difference in the densities of the Earth and its satellite, the former being enveloped by a heat preserving atmosphere while the latter is exposed to free radiation into space. I need not emphasise the beneficial qualities of a warm winter coat.

As the outcome of this somewhat lengthy, but necessary, discourse on stellar evolution, I shall now propound in the following brief satement the cardinal thesis which I wish to advocate in this address:

For many millions of years the Earth has been in the condition of a slowly cooling and expanding rigid body. During this time there has been a definite and unalterable relation between the mean surface temperature, T_s and the mean density, ρ_m which is expressed by the equation

$$T_s = 145 \times \rho_m{}^{0.38}$$

You notice that by this statement I put myself into opposition to current views on the past history of the Earth, which are based on the assumption of a *shrinking* globe. But I have endeavoured to convince you that the above statement is the inevitable conclusion which our present knowledge of stellar evolution forces us to accept. I wish also to emphasise that this statement is not merely the result of the theoretical views which I have developed, but it is based on the *observed* fact, so clearly evidenced in the diagram of Fig. 4, that equation (13) is valid throughout the whole range from the White Dwarfs to the coolest planets of our system.

We have now come so far to say that *if* the Earth is *cooling* it will *expand*. The next question will be: Is our planet progressively cooling and at what rate does such cooling take place? The only way in which the interior can lose heat energy is through conduction, and to maintain a flow from the interior to the surface the temperature of the interior layers must shew a gradient from higher to lower temperature in this direction. Such a gradient, of a very variable amount, has been observed. On the average, a mean gradient amounting to 35° C. for every 1,000 metres has been accepted. Knowing the conductivity of the surface crust we find that the heat received at the surface from the interior per sq. cm. amounts to 1.5×10^{-4} calories per minute, which is less than the 1/10,000th part of the energy received by a vertical sun. Infinitesimal as this amount may appear, if the total loss to the interior by conduction is calculated for the interval of 1,000 million years, which the geologist claims to be the time elapsed since the earliest records of geological formations, we find that the heat lost would be sufficient to raise the temperature of a globe of iron, the size of the Earth, by about 600—700°. Since it is highly probable that the rate of cooling was more rapid in the past, the figures may be easily doubled or even trebled. We have seen, in the case of the air quoted above, that an increase in the temperature of 1200° has diminished the effective size of the molecules from 2.86 to 2.44×10^{-8}. This corresponds with a change of density in the ratio 1 : 1.61, and with a change in the surface temperature in the ratio 1 : 1.17 [equation (13)]. Suppose we adopt these figures for the Earth, as representing the changes in T_s and ρ_m during geological time. If we take the present values:

$$T_s = 287^\circ; \ \rho_m = 5.67; \ \text{Radius} = 6371 \text{ km.}$$

the corresponding values at the beginning of geological time would be

$T_s = 336^\circ$ C	$\rho_m = 9.13$	Radius: 5430 km.
Increase: 49° C.	Increase: 3.46.	Decrease: 941 km.

Hence the mean surface temperature would have been 63° C. instead of 14°, as at present, and the radius would be less by 941 km., *i.e.,* about 100 times the height of Mount Everest.

You see from these figures what enormous changes in the conditions of temperature, density and size of a planet are caused by even such moderate changes in the effective "diameters" of the atoms as are indicated within the narrow range of our physical experiments. Even so minute a change as 5 per cent. in the diameter would cause a change of 14° C. in the mean surface temperature and of over 300 km. in the radius of our planet.

Without unduly stressing the reliability of these figures, we are justified in asserting that expansion must have played an important, indeed the prepondorating, rôle in the geological transformations of the surface of our planet.

So far attempts, on the whole unsuccessful, have been made to explain these transformations by the presence of forces acting along the surface, *i.e.,* at right angles to the radius. As an instance I may refer to the remarkable and fascinating suggestion regarding the formation of the continents made recently by the German geologist Wegener, a suggestion which has been, and still is, in the foreground of scientific interest and controversy.

If you look at the map of the world, it cannot escape your notice that the outline of the eastern coast of South America shows a striking similarity to that of the western coast of Africa, so much so that by bringing the two continents together they might be roughly joined like the adjacent blocks of a jig-saw puzzle. This remarkable fact suggested to Wegener the idea that at some remote time all the continents may have been joined together into one great block to which he gave the name *Pangea,* but that through some obscure agency this block was split into separate flakes which for some reason began to drift apart. These flakes constitute our present continents.

Although appearances are strongly in favour of Wegener's suggestion, scientists have been sceptical for the simple reason that no adequate physical forces could be suggested which would cause not only the splitting of the original block but also the drifts of the flakes across the globe. Wegener's conception of their motions is indeed highly problematic. In the light of his theory the continents behave very much like derelicts tossed about without guidance. At one time they are assumed to float southwards bringing the arctic regions into the vicinity of the equator and South Africa and Australia near the South Pole, and thus the tropical climate in high northern latitudes and the ice-age in the Southern Hemisphere are accounted for. At other times their excursion is towards the north, causing an ice-age in Northern America and Europe. But although his ideas about the drifts of the continents are built on an uncertain scientific basis, Wegener's fundamental conception of their formation from a coherent block is so strongly supported by their present configurations that it cannot be lightly rejected.

There is, of course, no difficulty in explaining the splitting of the Earth's crust by the expansion of the internal core on which it rests. With ever increasing pressure from the inside the strain on the crust will increase until a point is reached when the bubble will burst, the cracks being along lines where least resistance is offered to the onslaught of the expanding forces.

The interesting question is the further journey of the continental flakes after separation. Suppose $a_1a_2a_3$ is a section through a slab of the crust at a moment when a break occurs at a_2. The separated flakes a_1a_2 and a_2a_3 are now pushed outwards by the expanding core underneath along the radii CC' and CC'' respectively, the intervening gap being filled in by the waters of the oceans. They now appear as two separate flakes, $a'_1a'_2$ and $a'_2a'_3$, each one retaining its original area, but " floating " on the surface of a larger globe.

On this simple principle we may now test Wegener's theory. Let us first try to find how far we may succeed in reconstructing Wegener's original block. For this purpose we cut out the individual continents and try our game of jig-saw puzzle. Disregarding minor coastal frills in the form of small islands and peninsulas (even blocks like the British Isles play a very small rôle in this gigantic transfer) we find that Africa is joined to Eurasia by a comparatively slight northward shift, practically obliterating the Mediterranean and Red Seas.

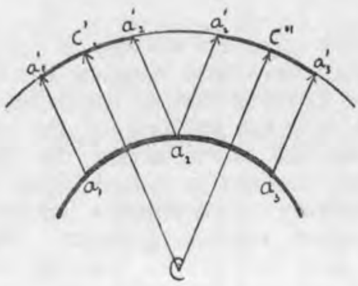


Fig. 5.

On the other hand, in the case of the two Americas a tremendous movement towards the East accompanied by a slight mutual approach and floating movement will bring all the four continents into satisfactory alignment. The remaining small gap in the arctic is very neatly filled up by Greenland. It will be admitted that the liberties I have taken in regard to the coast lines in order to effect the satisfactory coherence shown in Fig. 6 are not big enough to invalidate a decisive verdict in favour of Wegener's theory. Granting now that many millions of years ago the continents were blocked together as shown in Fig. 6, my contention is that their separation into the isolated positions which they occupy at present has been caused by the expansion of the globe. Forces in the radial direction acting on an extended slice spread over the surface must give rise to *tensile* forces tending to separate contingent parts along lines which mark the direction of least resistance to the onslaught of the expanding forces. I have marked these lines in Fig. 6, the major break by the line studded with round dots, and several minor subsidiary splits marked by lines studded with crosses. The principal split having occurred roughly along a meridian, the separation of the two Americas from the block (Eurasia-Africa) will have been in an east-west direction. But while the Atlantic gap has been widening, separation along the subsidiary breaks has likewise advanced. Take the split between North and

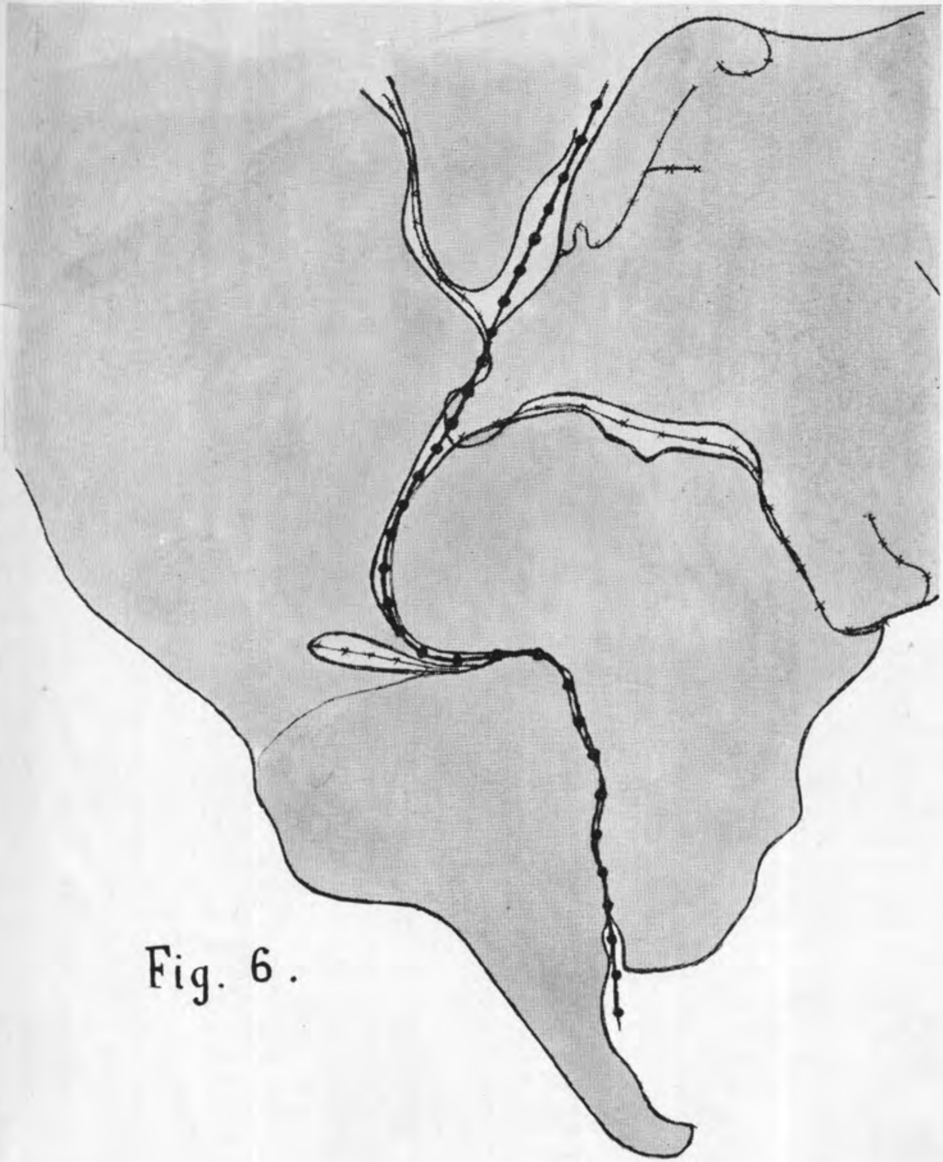


Fig. 6.

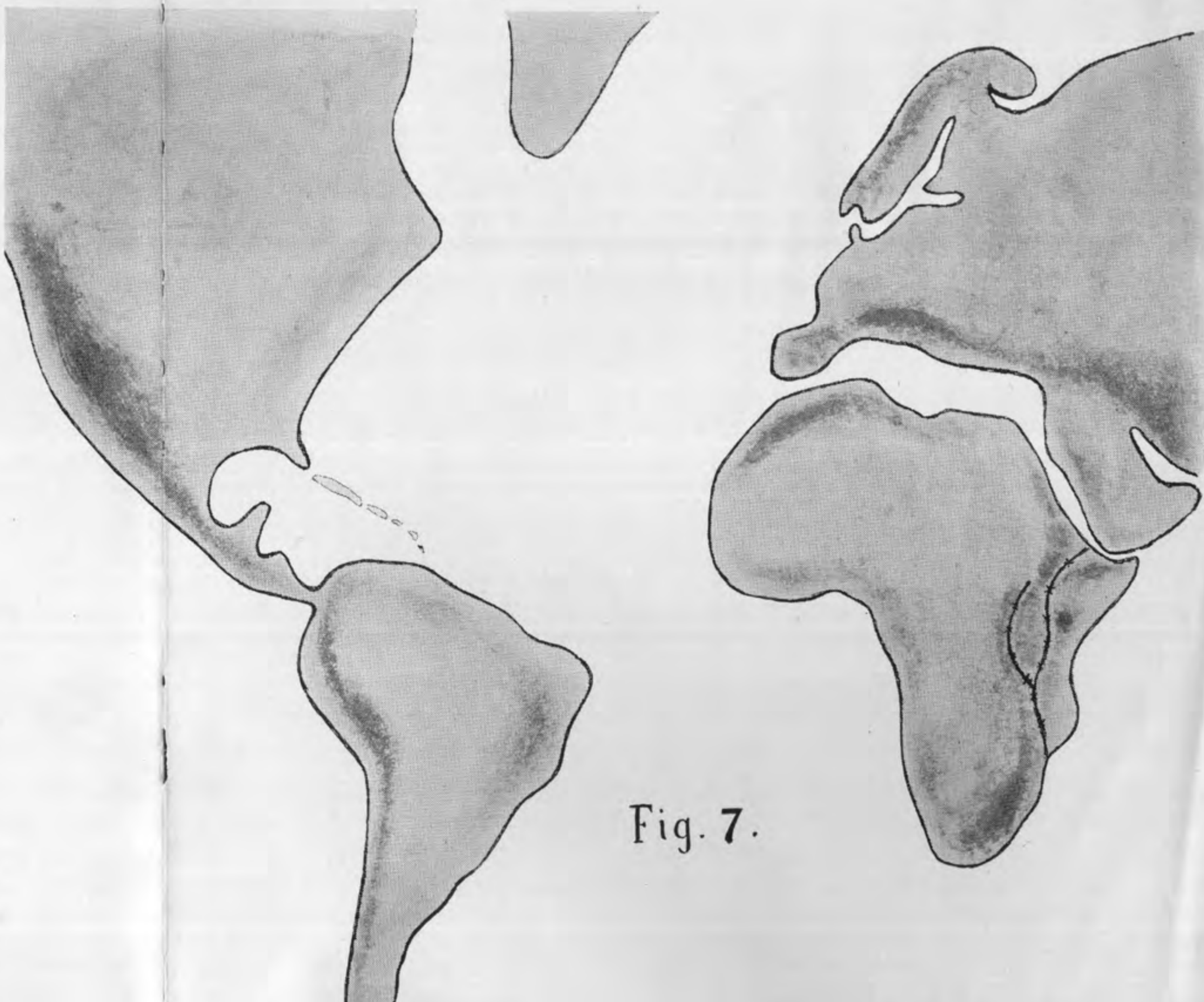


Fig. 7.

South America which, being arrested by the heavy barrier of mountains on the west coast, will allow only of a separation on the eastern side. The eastern contour will resemble that of a mouth in a fit of yawning, the jaws being hinged in the neck occupied at present by Mexico, which has become more and more elongated. There is no difficulty in understanding the present position and shape of the two continents as the natural result of the action of an expanding globe (see Fig. 7).

The formation of the Mediterranean gap, the peninsular character of Arabia and Scandinavia, the detachment of Australia and Polynesia from the Asiatic continent, and in its turn the separation of New Zealand from Australia, the splitting of the British Isles from the European continent, and of Japan from Asia, all these are features for which the cause can be attributed to the continued action of expanding forces. We find evidence of these tearing forces and the incipient process of splitting even in comparatively recent epochs of the Earth's history. The Great Rift in East Africa, a gigantic tear in the garment of Mother Earth, stretching from the Red Sea to Portugese East Africa is doubtless the precursor to a complete detachment of this slice and to its formation into an island.

From the present width of the Atlantic gap a rough estimate can be formed of the average rate at which expansion has been proceeding. I find that the radius of the Earth has increased in the ratio 3 : 4 which means an increase of about 1,600 km. or 1,000 miles. Now, geologists tell us that the time covered by geological records is of the order 10^9 years. Accepting this as the time elapsed since the continents began their separation we conclude that our planet has expanded at the rate of 1.6 mm. per annum, *i.e.,* about the thickness of a penny-piece. During the whole Christian era this would have amounted to only 10 feet, or less than the height of an ordinary room. An arc of a meridian of, say, 60° measured on any of the continents at the early epoch would now measure only 45°, the decrease per century being 0.005 seconds of arc. We are obviously dealing with changes which, enormous as they may appear in their accumulation during geological time, are yet immeasurably small within the short time during which scientific investigation is available.

So far the expansion we have been dealing with was supposed to be distributed *uniformly* over the globe; it affected continents and sea floors in a like manner. The very fact, however, that there are conspicuous differences in the level of the surface crust and that these differences are subject to considerable fluctuations appears to point to local differences in the rate of expansion. We may therefore ask: if at any point the level of the surface is raised, is this due to an abnormal expansion of the mass underneath this particular point by an increase of the volume at which the atoms are most closely packed? Obviously in such a process of local expansion the *mass* involved remains *unaltered.* If it can be shewn that observations confirm this conclusion, a most valuable proof in support of the expansion theory has been established.

The attracting mass underneath any point can be found by means of observations of the period of swing of a pendulum. This period t depends on the length of the swinging arm, l, and the force of gravitation at the point, g.

The formula connecting these quantities is the well-known equation:

$$t = 2\pi\sqrt{l/g}$$

or

$$g = \frac{4\pi^2.l}{t^2}$$

If the pendulum is used at another station, we have

$$g_0 = \frac{4\pi^2.l}{t_0^2}$$

l being the same, but g and t being different. Hence

$$g/g_0 = \left(t_0/t\right)^2$$

If further M and M_0 are the attracting masses and r and r_0 the distances from the Earth's centre, we find

$$M/M_0 = \left[\frac{r.t_0}{r_0.t}\right]^2$$

The right hand side being known by observation, we find the ratio M/M_0.

Now, according to the theory here advanced, we should find $M = M_0$, *i.e.,* M should have the same value at all points. This is exactly the result to which gravity measurements all over the globe have led, and which is known as the principle of *Isostacy.* It means that if observations with the same pendulum are made at two points *A* and *B*, situated at sea level and at the top of a mountain respectively, the values of *M* at *A* and *B* are the same. Moreover, if *B* would be raised still further, the value of *M* would not be altered. The presence of the mountain has no effect on the gravitational force acting on the pendulum.

It must be understood, however, that perfect isostacy is only possible if the formation of the mountain is solely due to *radial* expansion. If there is a transfer of matter from *B* to *A along the surface,* departures from the isostatic condition must be expected. In the piling up of mountain ranges such surface transfers of matter are bound to occur and must lead to disturbances of the isostatic equilibrium.

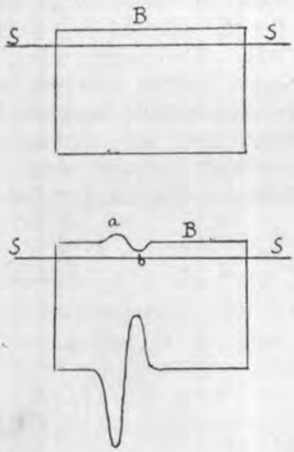


Fig. 8.

This explanation of the phenomenon of Isostacy differs essentially from the accepted view based on the assumption that the continents represent blocks of matter floating in a magma of slightly greater density. According to a fundamental hydrostatic law the mass of magma displaced equals the mass of the floating block. The condition of isostacy is certainly satisfied in the case of a square block (1) Fig. 8, the mass underneath any point on *B* being the same as underneath any point on *S*. But suppose the surface of the block (2) shewing an elevation (mountain) at *a* and a depression (valley) at *b*. In order to ensure isostacy we have to add to the immersed portion underneath *a* about 8 times the mass of the mountain as a "compensation" and to deduct a similar amount at *b*. Every change in the contour of the top surface would require an eightfold change in the opposite direction in the contour of the bottom surface, a most complicated and, I venture to say, impossible picture of the working of Nature.

Let us now proceed a step further and examine to what conclusions the theory of an expanding Earth will lead with regard to the formation of mountains and crustal movements in general.

If a sphere expands the curvature of its surface becomes more and more flattened. Obviously the *liquid* constituents of the surface, the oceans, will adapt themselves instantaneously to the altered conditions of gravitational equilibrium. But in the case of the solid crust we cannot expect a ready response. Take in Fig. 9 *ab* as the section through the crust of a continent supposed, for the sake of simplicity, to have the shape of a circular scull cap. Obviously when transferred to *a′b′* the cap will no longer fit the swelled head. All along its outward journey gravitation will be busy to adapt its surface to the changing conditions of curvature, probably for a considerable time without success until a point is reached when the strain becomes too great for the cohesive forces and the roof collapses.

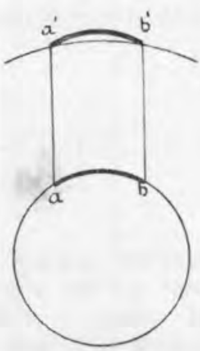


Fig. 9

Fig. 10.

To study the kinds of deformation which are to be expected, Mr. Miller, of the Royal Observatory, has assisted me in moulding a number of spherical caps of stiff jelly of various sizes and thicknesses. Placing these moulds on a table and allowing them to settle down, they appeared in the deformed conditions shown in the vertical sections of Fig. 10.

In all cases we found a central depression and a ring of elevated material concentric with the margin of the cap. Further, viewed from above, splits were noticed in many places along the margins.

It is certainly most remarkable that the standard pattern of the topography of a continent should shew exactly the two kinds of deformation noticed in the above experiments. The marginal splits correspond with the innumerable inlets and fjords dotted along the coast-lines, and the parallelism between the big mountain ranges and the coast-lines is undoubtedly the most prominent feature on the oreographic map of the world. To convey a general impression of this notable process of mountain building, I have shaded in the positions of the more prominent mountain ranges in the diagram shewing the present positions of the continents (Fig. 7).

Taking all the evidence collectively, I think it will be admitted that the single conception of the Earth as an *expanding* body has based Wegener's fascinating theory on a sound physical principle and has opened new vistas of approach towards the solution of the many problems which the history of our planet lays before us.

So far I have not touched upon the one problem which more than any other has agitated the thoughts of scientists, viz., the *climate* of our planet in the past ages. The problem seems to bristle with insuperable difficulties. There is undoubted evidence that at one time the arctic regions were under the spell of a tropical climate. At the same time, however, the presence of the remains of glaciers warns us of the existence of ice in extensive regions near the equator. At other epochs, again, the reverse conditions seem to have prevailed. These quasi-periodic fluctuations lent seemingly strong support to the conclusion that their cause must be sought for in an external agency, the Sun, exerting a varying influence on the heat supply to the northern and southern hemispheres, sometimes associating high temperature in the north with low temperature in the south and *vice versa*. It is now generally admitted that the numerous attempts which have been made to explain the climatic changes of the past by a varying action of the Sun's radiation have failed. The causes must be sought for in the planet itself.

We see at once from the fundamental equation (13) that on an expanding planet the temperature of the surface must decrease with age. If T_1 and T_2 denote the surface temperatures at epochs 1 and 2, ρ_1 and ρ_2 the corresponding densities, and r_1 and r_2 the radii, we have

$$T_1/T_2 = \left[\rho_1/\rho_2\right]^{0.38} = \left(r_2/r_1\right)^{1.14} \qquad (14)$$

For instance, if epoch 2 denotes the present moment ($T_2 = 287°$; $\rho_2 = 5.67$; $r_2 = 6{,}371$ km.) we find for the time when the radius was 0.9 of its present value:

$$T_1 = 324° \;(51° \text{ C.});\; \rho_1 = 7.78;\; r_1 = 5{,}734 \text{ km.}$$

Such a change in the surface temperature would be more than sufficient to cause a tropical climate in the arctic regions, while the equatorial belt would then probably be far too hot for the sustenance of organic life.

But this simple conclusion, while it helps us to understand the high temperature conditions in the arctic, appears to be in serious conflict with other evidence. Geological records point conclusively to the fact that even in the earliest stages of geological history glaciers must have existed, apparently pointing to conditions of intense cold at times when according to the above formula the temperature should have been extremely high. The hasty conclusion has been drawn that these relics of ancient glaciers point to the repeated existence of "ice ages," *i.e.*, to conditions under which extensive portions of the surface had been enveloped in a shrould of ice and snow. I confess that I cannot see the force of this argument. Take our present conditions. We know that the snow-clad mountains of the Alps and the Himalayas are of comparatively recent origin; they have arisen out of plains at one time submerged in the sea. And we feel likewise confident that the space of their existence will be limited. Suppose in a hundred million years a geologist would examine the remnants of these once mighty giants and would discover traces of their ancient glaciers which have escaped the tooth of Time. He would find these traces spread over the wide area from Europe to Asia, including probably East Africa (Kilimanjaro). Would he be right in concluding that the presence of glaciers spread over so wide an area proved the existence of an "ice age" in our days? This is exactly our position with regard to the evidence of the remnants of glaciers of the remote past.

What objection can be raised against the assumption that these glaciers were once situated on the slopes of mountains stretching their summits beyond the snow line? The question is: What order of mountain heights are required to satisfy this condition. This question, however, can be answered with a fair amount of certainty. We know that the lower strata of the atmosphere are in a condition of thermal equilibrium which is brought about mainly by convection. In such an atmosphere the temperature decreases uniformly with the height above the surface. For air, which contains water vapour in the condition of a gas (*i.e.,* below the saturation limit), the temperature decreases 10° C. for every kilometre. The liberation of latent heat through condensation reduces this figure to 6° C. Provided we know the surface temperature, we may calculate the height at which the temperature is 0° C. (*i.e.,* freezing point of water), *i.e.,* the so-called snow line. Naturally a permanent deposit of ice is possible only on those portions of a mountain which extend beyond this snow line.

Now, as we have seen, equation (14) enables us to calculate for any value of r the surface temperature T, and by means of the gradient we find readily the height of the snow line. The adjoined table gives gives all the desired information.

	Temperature at Surface.		*Height of Snow Line.*	
Radius.	° *Cent.*	° *Fahr.*	*A*	*B*
5734 km.	50.6	123.1	6.83 km.	4.10 km.
5798	46.6	115.9	6.43	3.86
5861	42.6	108.7	6.01	3.61
5925	38.7	101.7	5.58	3.35
5989	35.0	95.0	5.15	3.09
6053	31.3	88.3	4.71	2.82
6116	27.7	81.9	4.25	2.55
6180	24.1	75.5	3.78	2.27
6244	20.7	69.3	3.31	1.99
6307	17.3	63.1	2.82	1.70
6371	14.0	57.2	2.33	1.40

The height of the snow line is given for the two gradients 6° (column A) and 10° (column B). The gradient is known to increase considerably with the temperature and is proportional to the force of gravitation. We may assume that for the present day conditions the column A, but for the remote conditions the column B, give the best indication of the height of the snow line.

It is evident from the table, that even when the average temperature was as high as 123° Fahr. mountains of the height of the Alps and Himalayas would be covered with eternal snow, and since the amount of water-vapour carried upwards from the highly heated lower strata would be considerably greater than under present conditions, the deposits of ice, and consequently the depth of the glaciers, would be correspondingly enhanced.

I am therefore inclined to think that the remnants of the glaciers whose origin we trace back to the earliest stages of geological history, were originally situated on the highly elevated slopes of mountains extending beyond the snow line.

That mountains should be rather ephemeral phenomena, having their ups and downs in often repeated succession, is a conclusion to which the basic idea of an expanding Earth would naturally lead. For, although expansion has been mainly progressive, it cannot be supposed to have been absolutely uniform. There must have been times when the continental crust expanded more freely than the adjoining bed of the ocean, and a continental elevation over sea level was the result. At some other times the reverse has taken place. We need not be surprised, therefore, to find evidence of glaciers at low levels which have originated at high elevations. The intimate connection between "ice-ages" and mountain building is also evidenced by the observed fact that "cold climates nearly always exist during or immediately following the times when the earth is undergoing most marked mountain making" ("The Evolution of the Earth and its Inhabitants," Yale University Press, 1919; p. 58).

The general conclusion in regard to the past climate of the Earth may thus be summarised: the *mean* surface temperature underwent a slow progressive change from hot towards cold in accordance with the fundamental equation (13) applied to an *expanding* planet. To an increase in the radius by 1 per cent corresponds a decrease in temperature of 3.7° C. or 6.6° F. This simple relation, however, applies only to the normal surface at sea level. Differences in the altitudes of stations whose records are available will shew themselves as pronounced departures from the normal. Both causes, expansion on the one hand and topographic position on the other, have produced combined effects which it is difficult, if not impossible, to analyse. The undoubted fact, however, that the arctic regions once showed evidence of a tropical climate can only be explained on the basis of the expansion theory, while the existence of glaciers in the remote epochs does not contradict it when the observed close association between mountain-building and glaciation is taken into account.

There is still one more question to which I would like to draw your attention, perhaps to many of you the most important of all. How does an expanding Earth account for the particular mode of evolution of organic life? You know that Mother Earth has preserved some meagre and disjointed records of the kinds of plants and animals which were developed and were able to exist on her surface during subsequent epochs. Geologists assure us that they have succeeded in digging into her archives as far back as 1,000 million years ago. The records shew evidence that the first traces of organic life were of the lowest order; they also point to the conclusion that these low forms of life existed in water only. During a long period the exclusively marine character is maintained. There is yet in those early days no evidence of a fauna or flora capable of existing on dry land. Next comes the appearance of animals of an amphibious nature, the first indication of the possibility of life under dryland conditions. The ever growing preponderance of these conditions is initiated by a great development of insect life and of fernlike plants: the so-called *carboniferous* age. Henceforth the evolution of *land* life takes the lead, passing through successive stages of reptiles, birds and mammals to the present pinnacle of organic development, the advent of *man*. Undoubtedly the trend of evolution is from sea-forms to dryland-forms.

Let us now examine the relation between sea and dry land on an expanding globe. At present the average depth of the ocean is estimated at 3,800 m. and the average elevation of the continents above sea level at 800 m., which gives a distance of 4,600 m. between sea floor and continental surface. Going back to the time when the radius of the Earth was, say 0.9 of its present value, the surface of the globe is reduced in the ratio 0.81 : 1, and hence for the same quantity of water the depth of the oceans is $3{,}800/0.81 = 4{,}691$, *i.e.,* the average continent, instead of being 800 m. above sea level, would be submerged 91 m. below sea level. Hence on the expanding Earth there must have been a time when the whole surface was covered by the waters of the oceans. Gradually the continents emerged and the seas receded, *i.e.,* we find exactly

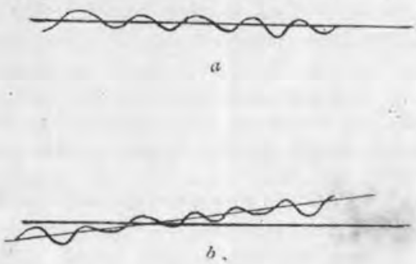


Fig. 11.

the physical conditions under which biological evolution could proceed along the lines indicated. The essential difference between the current views (stationary Earth) and the views expressed in this address (expanding Earth) may be represented graphically in the manner shewn in Fig. 11. Taking the surface of the oceans as standard of reference and representing it by the straight line, the continental surface would describe a sequence of undulations marking the succeeding upheavals and subsidences of the crust. The surface fluctuations on the *stationary* Earth would be of the character shown in Fig. 11 *a*, a succession of emergences and submergences repeating themselves in a quasi-periodic sequence throughout geological history. On the *expanding* Earth, Fig. 11 *b*, the same kind of fluctuations are noticed, but they are not rhythmical to the line of sea-level, but to a line slightly inclined in such a manner that in the early epochs the whole undulation took place under sea, while at the present time the continental surface will always remain above the water line.

I think you will realise the difficulty of accounting for any *progress* of biological evolution on the basis of physical conditions supposed to revert periodically to their *initial* state as they are supposed to do in Fig. 11 *a*.

Conclusion.

The main object of this address has been to examine the problem of the evolution of our planet from the astrophysical point of view. The chief result of the investigation is the establishment of a relationship between the surface temperatures and the densities, expressed in equation (13), which appears to be satisfied with remarkable accuracy throughout the whole range from the White Dwarfs to the coolest planets. This fundamental "equation of evolution" forms the basis for all the discussions embodied in this paper. As a direct result we find that, if evolution proceeds in the direction from White Dwarfs towards Saturn, the Earth must be looked upon as an *expanding* body. I have endeavoured to show how far we succeed in explaining some of the outstanding features in the development of the Earth on the basis of this single postulate. The establishment of the equation of evolution and the resulting conception of expansion are results which, so far as I am aware, are now announced for the first time. Whatever the merits or defects of these new ideas may be, I have deemed the offer of a first publication in the Journal of the Society a fitting expression of my gratitude for many tokens of friendship from its members.

ON THE THEORY OF AN "EXPANDING UNIVERSE."

By J. K. E. HALM, Ph.D., F.R.A.S.

The conception of an *expanding Universe* is based on the observation that certain lines in the spectrum of distant clusters are displaced towards the less refrangible side and that this displacement increases in proportion to the distance of the cluster. Since we are accustomed to interpret displacements of spectral lines by motion in the line of sight, the inference has been drawn that the Universe *in toto* must recede from us. The essential condition on which alone this conclusion could be warranted is that, in absence of motion in the line of sight, the wavelength of a monochromatic ray remains unaltered whatever the distance between source and receiver may be. Before accepting the reality of the enormous velocities with which we shall have to endow the distant members of the Cosmos, if the observed displacements are really due to motions, we are justified in demanding a convincing proof of the correctness of the assumption that the wavelength of the ray remains unaltered however long its journey through space may be.

From the most general dynamical aspect a wave represents a system in which the motion repeats itself in all respects at certain intervals of time which may be denoted by i. If T denotes the kinetic energy at any moment, V its potential energy, and if T_m and V_m signify the average values of these quantities taken over the interval of recurrence, i, any small disturbance affecting the system will produce changes δT_m, δV_m and δi which must satisfy Hamilton's fundamental equation. In a recurrent system this equation has the form

$$2\delta(T_m i) = i\delta(T_m + V_m) = i\delta E,$$

or

$$\delta T_m - \delta V_m = -2T_m \frac{\delta i}{i} \qquad (1)$$

E representing the total energy. (See Routh, Advanced Rigid Dynamics, 4th Edition, Art. 461.)

In addition, the law of the conservation of energy supplies the equation:

$$\delta E = \delta(T_m + V_m) = 0 \qquad (2)$$

Consequently the second equation (1) assumes the form:

$$\delta T_m = -\delta V_m = -T_m \frac{\delta i}{i} \qquad (3)$$

Dynamics thus supplies two equations for three variables. A unique solution, therefore, is possible only when a third equation can be established. This equation must necessarily be of a purely *empirical* character, *i.e.,* it must be framed in such a manner that it satisfies the results of observation. Thus, while equation (2) establishes the constancy of the *sum of the two energies,* $(T_m + V_m)$ on the basis of a general dynamical principle, viz. the conservation of energy, we are not permitted *a priori* to conclude that these energies are individually constant, *i.e.,* $\delta T_m = o$ *and* $\delta V_m = o$. Theoretically, the energies of a wave on its journey through space may be subject to changes δT_m *and* δV_m, provided that equation (2) is always satisfied, i.e., the wave may undergo *adiabatic* transformations. It may expand or contract or remain stationary. Its *observed* behaviour alone can decide on these alternative possibilities.

The most general form in which the third equation can be framed is to consider T_m as some function of the time t and write:

$$T_m = f(t)\,; \qquad \frac{\delta T_m}{\delta t} = \frac{\delta f}{\delta t}\,; \qquad \frac{\delta V_m}{\delta t} = -\frac{\delta T_m}{\delta t} = -\frac{\delta f}{\delta t} \tag{4}$$

But from equation (3) we find by integration:

$$T_m i = h, \tag{5}$$

where h is a constant. Considering that i has been defined as the time interval of one complete recurrence, $1/i$ represents the number of recurrences in unit time, *i.e.,* the frequency of the oscillations which is usually denoted by ν. Hence

$$\frac{\delta T_m}{\delta t} = h.\frac{\delta \nu}{\delta t} = \frac{\delta f}{\delta t} \tag{6}$$

Denoting by ν_0 and f_0 the values at the moment when the ray leaves the cluster and by ν and f the values at the time of arrival in the spectroscope we write

$$\nu - \nu_0 = \frac{1}{h}[f - f_0] \tag{7}$$

This equation refers to a state of relative rest in the line of sight. If the cluster moves with a radial velocity, v, the difference in the frequency is expressed by

$$\nu - \nu_0 = \frac{1}{h}[f - f_0] - \frac{\nu_0}{c}.v, \tag{8}$$

where c represents the velocity of light.

Let us now assume that the potential energy increases progressively, *i.e.,* that the wave *expands adiabatically,* and that this expansion is proportional to the time. Obviously in this case

$$f - f_0 = -\alpha(t - t_0),$$

where a is supposed to be an extremely small quantity. Since the distance r between cluster and star is:

$$r = c(t-t_0),$$
$$f-f_0 = -\frac{a}{c}.r,$$

and equation (8) becomes:

$$\nu-\nu_0 = -\frac{a}{ch}.r - \frac{\nu_0}{c}.v. \qquad (9)$$

The theory of the *Expansion of the Universe* represents the special case $a = o$, i.e.,

$$\nu-\nu_0 = -\frac{\nu_0}{c}.v.$$

The observed shift of the lines is attributed entirely to motions in the line of sight.

The theory of an *adiabatic expansion of the wave* attributes the observed progressive decrease in the frequency with the distance r to this expansion. The displacements due to velocity appear in the character of *accidental* errors, *i.e.*, plus and minus alike.

As pointed out, from the dynamical point of view both assumptions are possible. The choice lies between a theory which so far has entangled the mind in a maze of abstruse speculations without offering a definite hope of solution, and, on the other hand, an assumption which leads directly to a self-evident explanation of the observed phenomena.

NEW COMETS IN 1935.

By H. E. Wood, M.Sc., F.R.A.S.

For many years past, amateur astronomers in South Africa have been very successful in discovering new comets. One has only to recall the names of Reid, C. J. Taylor, Skjellerup, Blathwayt, Ensor, Houghton and Forbes, all of which are attached to recent comets. With the exception of Messrs. Ensor and Houghton, who are both variable star observers, these amateur astronomers made a practice of " sweeping " for comets. The late Mr. Reid in this way discovered as many as seven comets and Mr. Forbes, who is no doubt bewailing the undoubted present scarcity of comets, has already four comets standing to his credit. Astronomers who discover comets by searching for them really deserve all the credit for their discoveries, for the work demands keen observation not only in the evening but also in the quiet hours before the dawn, and unlimited patience. In the case of the comet known as 1932*b* (Houghton-Ensor) it might be said that the comet obligingly discovered itself by moving through the field of the variable star T Apodis just at the time when Mr. Houghton in Cape Town and Mr. Ensor in Pretoria were about to make their observations of the brightness of this variable.

In the present year of 1935 three cometary discoveries have been made up to the time of writing (27th August) and it is rather curious that all of them have been made by professional astronomers. The first two discoveries were made by members of the staff of the Union Observatory, Johannesburg, and the third by Professor van Biesbroeck, of the Yerkes Observatory. It may be of interest to relate the circumstances of the discovery of the two comets found at the Union Observatory.

On the evening of 7th January, 1935, the Franklin-Adams Star Camera was used by Mr. E. L. Johnson to obtain photographs of the two adjacent regions 0h 45m,—52°, and 1h 15m, —52°, for the purpose of filling some of the few remaining gaps in the series of star charts of the Southern Hemisphere. The first region was given an exposure of 30 minutes and then the photographing of the following region was begun, but clouds stopped the exposure after 22½ minutes. The plates were developed and examined on the next morning, when an unmistakable short hazy trail was easily seen on the first plate. The two plates had a very wide overlap and, by good fortune, the image was situated on the region common to the two plates. The second plate showed a similar trail almost but not exactly on the same spot. The discovery of a new comet was thus both made and confirmed practically at the same time. Had the trail not fallen on the overlapping portion of the two plates, it would have been necessary to photograph the region again on the following night in order to secure confirmatory evidence of its reality. It is not an uncommon experience to find curious hazy trails, frequently resembling cometary images, on astronomical negatives and, for this reason, the evidence of one plate alone is never accepted. However, on this occasion everything was fortunate: two plates both showed the trail so that it was proved to be genuine and not a "false object"; secondly, the plates were taken at different times so that the direction and magnitude of the motion of the comet was known. As the next two nights were clear, the three necessary positions for the calculation of a preliminary orbit were early obtained and from the observations of 7th, 8th and 9th January the following first rough orbit was computed:—

$$
\begin{aligned}
T &= 1935 \text{ February } 24.8794 \\
\omega &= 17^\circ\ 24'\ 9'' \\
\Omega &= 93\ \ 14\ \ 6 \\
i &= 64\ \ 33\ \ 6 \\
q &= 0.8097
\end{aligned}
$$

The comet moved rapidly Northwards at the rate of about one degree a day and soon came within reach of Northern observatories. It was always a faint object and when it was most favourably placed, at the end of February, it was hardly brighter than the 9th magnitude. It was observed until 11th April, when it had reached the high declination of 68° North. Thus it was observed over an arc of 120°. The most recent orbit is the following elliptic orbit by Dr. M. Davidson:—

$$
\begin{aligned}
T &= 1935 \text{ February } 26.46532 \\
\omega &= 18^\circ\ 23'\ 0''.8 \\
\Omega &= 91\ \ 32\ \ 1.6 \\
i &= 65\ \ 25\ \ 48.7 \\
e &= 0.\ 991489 \\
q &= 0.\ 811191 \\
a &= 95.3109 \\
P &= 930 \text{ years}
\end{aligned}
$$

The discovery of the second comet of the year, by Mr. C. Jackson, was made in the course of his routine plan for the observation of minor planets. Mr. Jackson photographs zones of the sky near the Ecliptic and takes the plates of each region near the time when it is opposite the Sun. The procedure is to secure two photographs of the same region on the same evening. When the plates are developed, washed and dried, they are examined in the Zeiss Stereocomparator. A minor planet which happens to be in the region photographed does not occupy exactly the same position on the two plates, because its orbital motion has carried it on during the interval. So it is easily detected in the Zeiss instrument because the image jumps to and fro when the " Blink " attachment is used.

On two plates which Mr. Jackson exposed on the night of 3rd June, 1935, he found a moving image, which had a greater motion than that of a normal minor planet, and which was nebulous in appearance. The object was so very faint (13th magnitude) that further observations were desirable to confirm its cometary nature. After three observations had been obtained an attempt to compute an orbit was made, and it was soon found that the distance of the body from the Sun was over *4* astronomical units and that the body had made its nearest approach to the Sun about ten months previously at a distance of $3\frac{1}{3}$ units. This was rather unusual, as the normal telescopic comet is generally at about one unit of distance from the Sun or the Earth when it is first observed. It was also found that the object was decidedly not moving in an ellipse and that the motion was apparently hyperbolic. Owing to these unusual features, when the cable was sent to Copenhagen announcing the discovery, the body observed was described as an "Object," leaving it for further observations to decide whether it was a true comet or not. Later observations have been made at Harvard Observatory and it has been decided that it is a comet, so that it has now received the designation 1935*b* (Jackson).

In the most recent computations by Dr. M. Davidson, he finds that the observations are best represented by the following hyperbolic orbit:—

$$
\begin{aligned}
T &= 1934 \text{ September } 8.29040 \\
\omega &= 124^\circ\ 34'\ 21'' \\
\Omega &= 73\ \ 17\ \ 4 \\
i &= 142\ \ 0\ \ 12 \\
q &= 3.49478 \\
e &= 1.01046
\end{aligned}
$$

From this description of the circumstances of the discovery of these two comets it is to be inferred that the comets really discovered themselves, and that the professional astronomers have not been trespassing upon the preserves of the amateur comet searchers.

INTERNATIONAL ASTRONOMICAL CO-OPERATION.

Astronomy is a science which requires international co-operation for various reasons. The number of astronomers is small, while the amount of work to be done is large. It is therefore important to share out the work so as to avoid unnecessary duplication. At the same time a certain minimum amount of duplication is necessary to co-ordinate the results obtained at different observatories. Again attention has to be paid to geographical distribution. Observers in the southern hemisphere have access to a part of the sky which cannot be observed from the northern hemisphere. To avoid errors, it is sometimes essential to have observations covering the whole sky. In this connection one problem of the greatest importance at the present time may be mentioned—the rotation of the galaxy. This fundamental discovery is largely based on observations of the radial velocities of distant stars in the northern sky. There is great difficulty in disentangling the phenomenon from other effects if observations from only a portion of the galaxy are available. The certainty with which the phenomenon can be detected would be enormously increased if observations were made of the radial velocities of B type stars in the southern hemisphere. It is hoped that when the new Radcliffe Observatory at Pretoria is in operation these highly desirable data will be secured.

The distribution of observations in longitude, though less fundamental, is important in connection with phenomena changing from hour to hour, such as solar activity and sudden changes in the brightness of stars.

It is not the intention of this article to give an historical account of the development of astronomical co-operation—for that the reader is referred to an address of Prof. F. J. M. Stratton to the Royal Astronomical Society, printed in the Monthly Notices of that Society for Feb. 1934. Many of the astronomical societies which are to be found in different countries have a membership scattered throughout the world, and some journals such as the Astrophysical Journal have had editors in several countries. At the present time there are two important international associations of astronomers—the Astronomische Gesellschaft and the International Astronomical Union. The former was founded in 1863 at Heidelberg and has its headquarters in Germany. It generally meets at intervals of two years, alternate meetings being held in Germany and outside Germany. This year a meeting took place at Berne, in Switzerland, while the meeting in 1937 will take place at Breslau. The Astronomische Gesellschaft is largely concerned with the older branches of astronomy. Under its auspices a great catalogue of stars was observed about fifty years ago, and these stars are now being re-observed.

One important piece of work is the circulation of astronomical news concerning the discovery of comets, new stars, etc. The first scheme was drawn up as early as 1832, when the King of Denmark awarded a medal for the discovery of a comet. At present telegrams covering important discoveries are sent from the Observatory at Copenhagen to subscribers throughout the world. The Royal Observatory at Cape Town acts as a centre for South Africa.

The World War brought to an end many of the arrangements for international co-operation in astronomy as in other branches of science. Soon after the war was over, leading men of science from the allied countries met at Brussels to set in motion again the wheels of international co-operation, and as a result the International Research Council was founded. Under its auspices unions were set up to deal with the various sciences. The International Astronomical Union which was thus formed has held meetings as follows:—Rome 1922, Cambridge (England) 1925, Leiden 1928, Cambridge (U.S.A.) 1932, Paris 1935. It has been agreed to hold the meeting of 1938 at Stockholm.

The reports prepared by the presidents of the various commissions for the meeting at Paris this year contain a vast amount of valuable information, including summaries of work done or projected at the principal observatories and surveys of the present position in the chief fields of research. It is not possible here to go into details, but those interested should read the report of the proceedings given in *The Observatory* for September. The meetings were specially useful to astronomers from remote parts of the world in enabling them to get into personal touch with fellow-workers, and it is probable that private conversations were more effective than public discussions. The various excursions brought the astronomers together privately, while the visits to the observatories at Paris and Meudon enabled visiting astronomers to view the instruments and examine the methods of their French colleagues.

At the Paris meeting there were present about 300 astronomers representing 30 nations. Two astronomers from South Africa were present. It is to be regretted that South Africa withdrew from the Union a few years ago for financial reasons, and it is to be hoped that it will soon join again.

J. J.

REVIEW.

"The Dimensions and Structure of the Galaxy," by J. S. Plaskett. (The Clarendon Press, Oxford; 2/-.)

Since the days of the elder Herschel, speculations and theories on the structure and dimensions of the Universe in general and the Galaxy in particular have become more and more the province of the professional astronomer. Consequently it is not surprising to find the Dominion Astronomer of Canada devoting the time allotted to him for this year's Halley Lecture to a discussion of the Galaxy's size and form.

Dr. Plaskett regards the problem of attempting to determine "the dimensions and structure of the galactic system" as "the fundamental astronomical problem of the present time." He regards it, too, as a problem of extraordinary difficulty.

In his lecture Dr. Plaskett describes the methods by which the problem can be grappled. He then proceeds to construct a number of alternative models of the Galaxy. After explaining the effect of absorption which may dim the light of distant stars, and the distribution of the globular clusters, Dr. Plaskett discusses the probable distance of the Sun from the geometrical centre of the Galaxy. This he gives as 10,000 parsecs (32,500 light years). A note of caution, however, is sounded. This value, says the doctor, is somewhat uncertain "on account of incompleteness in the observational data and doubts of the validity of some assumptions." He then proceeds to check this distance of 10,000 parsecs by considering the rotation of the Galaxy: "the distance to the centre being obtained dynamically from the constants of rotation."

This independent check again gives a value of 10,000 parsecs. From this value Dr. Plaskett calculates the dimensions of the Galaxy as a whole. Its major diameter, he concludes, is "not greater than 40,000 parsecs."

Comparison with extra-galactic systems follows. A beautiful similarity between the Andromeda system and our own is found. "It seems legitimate to think that the Galaxy may be a great nebula, probably of spiral form, about ten times the average diameter of extra-galactic nebulae, but only slightly larger than the Andromeda Nebula, which it appears to resemble in essential details."

The Galaxy which Dr. Plaskett finally visualises is a single dynamical unit but of complex structure. In the main, however, it consists of a great flattened disc of stars. This disc is irregularly distributed in groups or clusters but with a general underlying field of stars. The whole arrangement is probably spiral, as in the Andromeda Nebula. The *effective* diameter of the disc is 30,000 parsecs and its thickness from 1,000 to 2,000 parsecs—except at its centre, where there is probably a great spheroidal bulge 5,000 parsecs or more in thickness. The component members of this disc are moving in nearly circular orbits about the centre of mass.

Dr. Plaskett is careful to point out that the picture of the Universe he has drawn must not be regarded as a finished portrait. It is at best a tentative and preliminary sketch. "All that can safely be said at present," he concludes, "is that the concept developed has a certain unity, completeness, and probability, and it can only be hoped that it makes a useful introduction to more complete knowledge."

In its printed form the lecture is illustrated with several useful plates and diagrams.

OBITUARY.

James Hudson.

We regret to have to record the death of one of our old members, Mr. James Hudson, who passed away on the 18th April. Mr. Hudson was keenly interested in Astronomy, and possessed several fine Astronomical telescopes. His hobbies included the study of the microscope and its revelations, and the writer recalls many interesting evenings spent in his company, both at the telescope and the microscope. Mr. Hudson was a man of very decided views, and took nothing for granted, always seeking to get at the real nature of anything he was investigating. His death is a great loss to those who had the privilege of knowing him, and enjoying his kindly hospitality. He was always ready to lend a helping hand to anyone in a difficulty, either practical or theoretical, and his searching criticism was always helpful. His passing has left a blank in the lives of his many friends, who will always remember with gratitude his many sterling qualities.

E. J. S.

ASTRONOMICAL SOCIETY OF SOUTH AFRICA.

Session 1934-1935.

Annual Report of the Council.

In presenting its Annual Report, the Council records a year of steady progress. The roll of the Society now includes 128 members and associates, 5 honorary members and 2 members emeriti.

The Council has met four times during the year, those members who are eligible under Article VI (iii) of the Constitution being represented by alternates.

The Council regrets to record the loss through death of one of our honorary members, Professor W. de Sitter,; one Johannesburg member, T. B. Blathwayt; one Natal member, D. L. Forbes; and two Cape members, H. W. Crowther and J. Hudson. Owing to delay in publishing the last issue of the Journal, it was possible to include therein obituaries of the first three, to be found on p.p. 165-167.

As not sufficient support was given to the newly formed Mathematical Section, it was decided that regular meetings of the Section be discontinued for the present, and that occasional meetings be held by arrangement with the Cape Centre.

During the year Vol. III No. 4 of the Society's Journal has been published. In addition, two circulars, reprints of the monthly notes of astronomical phenomena appearing in the "Cape Times," were printed and posted to each member. These circulars were greatly appreciated by members, but owing to lack of funds it is found impossible to continue to publish them until the financial difficulties are overcome.

A communication was received from the City Council informing us that the right of way to the Herschel Monument, Claremont (10 feet wide from Obelisk Road to the Herschel Reserve) has now been registered.

The Council has much pleasure in recording the award to the President, Dr. J. K. E. Halm, of the King's Silver Jubilee Medal, in recognition of the services rendered to science by the Society during the King's reign.

The work of observing sections has been steadily continued throughout the year. The Council expresses its appreciation of the painstaking labour that directors and members of observing sections are devoting to the fulfilment of one of the objects of the Society, and would urge all who can to become active members of observing sections.

STATEMENT OF INCOME AND EXPENDITURE FOR YEAR ENDED 30th JUNE, 1935.

Income.	£	s.	d.	Expenditure.	£	s.	d.
To Balance 30/6/34 ..	£12	12	3	By Printing Journal:			
„ Contributions:				Vol. 3, No. 4 ..	£27	13	11
Cape Centre	28	4	1	„ Prntg. & Stationery	13	1	1
J'burg Centre ..	15	0	0	„ Typing	2	5	0
„ Donations:				„ Postages	2	9	0
H. E. Houghton	5	0	0	„ Printing Constitution	12	5	0
Cape Centre	5	0	0	„ Bank Charges		5	1
„ Sale of Sun Dial ..	0	9	3	„ Balance carried forward	8	6	6
	£66	5	7		£66	5	7

Examined and found correct:
E. J. STEER.
21st July, 1935.

W. H. SMITH,
Hon. Treasurer.
30th June, 1935.

REPORTS OF SECTIONS.

For the Year ended 30th June, 1935.

COMET SECTION.

We regret the death of our very ardent worker, Mr. T. B. Blathwayt, B.A., at Johannesburg. He was a great help to the Section in many ways and spent many hours in the work. As an experienced searcher, his place will be very difficult to fill. We appeal to the younger members of the Society to join the Section and try to carry on his valuable work.

Comet 1935*a* (Johnson). Owing to the present dearth of new comets the discovery at the Union Observatory by Mr. E. L. Johnson of a comet was an outstanding event. It was discovered on a photographic plate on 8th January, 1935. At discovery it was magnitude 10 and was moving North. It was well seen in the Northern Hemisphere, as it passed within 8½ degrees of the North Pole in May.

The following orbit is by the Rev. M. Davidson:—

T.1935. February 26.47492 U.T.
ω 18° 23′ 50″.5
Ω 91 32 0.5
i 65 25 56.0
e 0.991037
q 0. 811129
a 90.4975
Period 861 years.

Comet 1935*b* (Jackson). News of another comet discovery has just come to hand. It was discovered on 19th June, 1935, by Mr. C. Jackson at the Union Observatory. It is magnitude 13 and promises to be a comet of exceptional interest owing to its unusual orbit.

We heartily congratulate Mr. Johnson and Mr. Jackson on their discoveries.

Of returning comets: Comets Reinmuth 1928 I. and Schwassmann-Wachmann (2) 1929 I. have already been seen. Seven more comets are predicted to return during the latter part of 1935 so that there is promise of a busier time for observers.

A. F. I. Forbes,
Director.

VARIABLE STAR SECTION.

In presenting his Annual Report, your Director is pleased to be able to record a very successful year.

4,403 observations were received during the session, divided between the members of the Section as follows:—

H. E. Houghton, F.R.A.S.	2,405	observations of	89 variables.
G. E. Ensor	1,362	„ „	120 „
R. P. de Kock	595	„ „	39 „
Revd. S. Solberg	41	„ „	13 „

Mr. Houghton's contribution is a particularly fine effort, and is more than half of the total number received.

Mr. de Kock is to be commended for a number of early morning observations. These are especially useful when a star is near maximum, but in any case they provide material for more complete light curves, and add to our knowledge of the regular and other peculiarities of these stars.

Mr. D. C. Burrell, of Lambert's Bay, C.P., is joining the Section. We trust that he will soon be sending in regular contributions.

Since this is your Director's last report, he wishes to place on record his sincere appreciation of Mr. Houghton's invaluable assistance during practically the whole period of his term of office.

Your Director's thanks are also due to the Union Astronomer, Harvard College Observatory, and the New Zealand Astronomical Society for circulars and other publications received, and to Mr. R. P. de Kock and other members of the Section from whom regular reports have been received.

Notes.

Nova Pictoris.—This star, discovered by our member, Mr. Watson, in May 1925, has now been under observation for over 10 years. Its present magnitude is about 9; its decrease in brightness has been very slow for some years.

RS Ophiuchi.—A supposed Nova, which brightened again a year or so ago. This star has been under close observation, and seems to have returned to its normal faint magnitude of about 11.3.

RY Sagittarii.—This irregular variable has remained between magnitudes 8.8 and 7.2 during the year under review. There was a tendency to become brighter at the end of June, 1934, but it does not yet seem to have attained its former maximum brightness of about mag. 6.5.

S Apodis.—This irregular variable, which was at normal maximum of 10.1 in July 1934, began to decline in August, and remained invisible through our telescopes from the end of October to the middle of April 1935. It has now nearly regained its normal maximum brightness.

A number of bright stars which show small irregular changes are under observation (e.g., R.Dor, Y Hya, RR Car, V Hya, AD Cen, SU Sgr, Y Pav and 1 Car) and it is hoped that some definite periods may be discovered.

G. E. Ensor,
Director.

ZODIACAL LIGHT SECTION.

The year has mostly been occupied in preparatory work. It was felt that if the work of the Section was to appeal to members and be a success it would be necessary to have some means whereby the work could be co-ordinated. It was also felt that some simple and convenient method of recording the observations should be used. To this end, charts of the Zodiac have been prepared, printed and sent to members for the purpose of recording thereon their observations. These charts are intended to be returned yearly to the Director for the annual report of the Section.

About three months ago a few charts were sent out, but as the Zodiacal Light has not been very apparent in the evening sky we cannot expect to report this year.

From what we have seen so far we are very much encouraged to note that the charts will be of great value in revealing the position and the nature of the changes that occur in the light.

We appeal to members situated in country places, away from the lights of a town, to join the Section. They will find the work very interesting and not very arduous. The Director will send charts to those who signify their willingness to take a part in the work. It is particularly desired that we should have observers widely distributed throughout Southern Africa.

The Director has much pleasure in acknowledging his indebtedness to Mr. R. Watson for substantial help received in the preparation of the charts.

A. F. I. Forbes,
Director.

A FRAGMENT.

. . . . I fain would tell
You how one night it thus befell:—

One evening, in a pensive mood
Nearby my telescope I stood,
To rest awhile from efforts spent
With ranging eye and instrument
Amongst the crowded hosts that span
The glowing firmament—
For one, perchance, of those few shy
Mysterious strangers of the sky,
That in extended pathways trace
Ellipses to the Sun's embrace,
Or, routed from a further deep
To hyperbolic orbits keep;
As forward on their paths they move
They may most interesting prove;
For often as they nearer come
The brimming goblet of the Sun
Whose overflowing warming rays
Bestow them brighter better days.
They turn from years of weary plodding
To rich fruitions quicker nodding,
Where, tense with pride of brightness won,
They revel in the richer Sun
And in an ecstasy of glory—
The mantling of heavenly story—
They airily unloose their tresses
Of misty magic flowing graces,
And cast them on the beaming bright
And speeding radial breeze of light.

'Tis then we see upon the sky
That magic beam of mystery
The "portent" disc that spelt the fates
Of ancient Princes, Kings and States,
And brought much woe and great disaster—
The product of our "Adamaster";
But now we spurn such wintry notion,
And see the concave of devotion:—
A happy shape in golden dress
The urging of the Sun's caress.

The Autumn set was in the year,
Though Summer yet was lingering here;
The threatening clouds which day had reared,
Folded their wings and disappeared;
The spent yet furtive falling breeze,
That rustled gently through the trees,
Had scarcely breath enough to play
A dancing leaflet's sporting lay,
The last faint gleam of twilight threw
Up short and shorter, then withdrew;
The twittering sparrows near their nest
With a smothered "twit" had gone to rest;
The lights of houses one by one
Blinked out; and as the glowing span
Of glory twinkled o'er the land
There came a hush, so still,
Scarcely a sound
Broke the still quietness, all around.

A. F. I. F.

CAPE CENTRE.

Twenty-first Annual Report, 1934-1935.

Your Committee, in presenting this, the Twenty-first Annual Report of the Centre, have to record its continued activity.

MEMBERSHIP.

Five additions have been made to the roll of membership during the year. Two members have been lost through death, while six members have resigned. The total membership is now 98, consisting of 87 members, 2 members emeriti, and 9 associates.

MEETINGS.

During the session there have been nine ordinary meetings, all of which were held in the Mountain Club Room at 38, Strand Street. No observational meeting was held owing to the difficulty of obtaining the use of a suitable telescope.

ADDRESSES AND PAPERS.

Addresses and papers presented at the meetings included the following:—

"The Surveyor's Debt to the Astronomer": Mr. W. Whittingdale.

"Double Stars": Dr. J. Jackson, M.A., F.R.A.S.

"Early Astronomical References in the Archives": Mr. C. Graham Botha, M.A.

"The Stars of the Evening Sky, December-January": Mr. H. W. Schonegevel.
"The Globular Clusters": Mr. D. C. Alletson, B.A.
"New Stars": Mr. H. E. Houghton, F.R.A.S.
"An Amateur's Brief Survey of the Heavens": Mr. J. Simenhoff.
"Some Observatories of the British Isles": Mr. Arthur W. Long, F.R.A.S.
"The Moon": Capt. D. Cameron-Swan, F.R.A.S., F.R.P.S., F.S.A.(Scot.).

Articles in the Press.

Articles detailing astronomical phenomena, together with charts and diagrams of the sky, have been published monthly in the "Cape Times." Astronomical notes have also appeared in "Grocott's Daily Mail," Grahamstown, and articles in Afrikaans in "Die Burger." All of these were contributed by members of the Centre and were greatly appreciated by members and the public.

Cape Centre Telescopic Fund.

A fund was established at the beginning of the year for the purpose of procuring an observing instrument at some future date for the use of members of the Centre. The position of the fund is at present as follows:—

Contributed by Cape Centre		£5	0	0
"	" Capt. D. Cameron-Swan ..		10	6
"	" C. L. O'B. Dutton ..		10	0
"	" A. Menzies		10	0
"	" Miss C. Orpen		10	0
"	" Mrs. C. E. Shepherd ..		10	6
"	" Mr. W. Andrews		10	6
"	" Mrs. E. A. Borlase		10	0
		£8	11	6

Committee of Cape Centre.

Chairman: D. C. Alletson.
Vice-Chairman: Miss C. Orpen.
Hon. Secretary: A. Menzies.
Hon. Treasurer: J. B. G. Turner.
Librarian: W. Andrews.
Auditor: E. J. Steer.
Committee: Messrs. D. G. McIntyre, A. W. Long, H. C. Davies, R. Watson, C. E. Peers.

FINANCIAL STATEMENT FOR THE YEAR ENDED 30th JUNE, 1935.

Receipts.	£ s. d.	Payments.	£ s. d.
Credit Balance at 30th June, 1934	10 16 11	Contributions under Article IX of Constitution	28 4 1
Subscriptions:		Donation to Society ..	5 0 0
Arrears £10 15 3		Rent of Meeting Room	7 10 0
Current Year 42 10 0		Rent of P.O. Box	1 5 0
In Advance .. 3 3 0	56 8 3	Subscription to Astronomical Socy. of Pacific	1 2 3
Commission on Cheques	0 2 6	Typewriting & Stationery	4 6 0
Donations to Telescope Fund	3 11 6	"Cape Times" & Postage to Country Members	4 7 6
		Secretary's Expenses ..	2 0 2
		Treasurer's Expenses ..	0 15 0
		Bank Charges	1 11 8
		Cape of Good Hope Savings Bank Society for Telescope Fund	8 11 6
		Credit Balance	6 6 0
	£70 19 2		£70 19 2

Audited and found correct:

E. J. STEER,
Auditor.

RODNEY R. PRATT,
Hon. Treasurer.

8th July, 1935.

NATAL CENTRE.

Annual Report, 1934-1935.

The Thirteenth Session of our Society has been one of much encouragement, though it has not presented any very dramatic features.

The improvements mentioned in the last Report have been completed; the lecture room is now furnished with chairs, lantern, screen, and blackboard, and the floor has been covered. The new stairs did not, unfortunately, prove irresistible to the attacks of white ants, and it has been necessary to replace the lowest steps with concrete. This has been carried out by the Natal Technical College Council, to whom we are grateful for all their interest in our work.

The entries in the visitors' book show that a larger number of the public have availed themselves of our invitations to come to the Observatory and the attendances at our monthly meetings have been rather larger than in recent years.

We have to record the death of one of our foundation members, David Lamont Forbes, who put in several years of useful work as Secretary and as Chairman. We sent a wreath to his cremation and a letter of condolence to his bereaved family.

Since the installation of the electric light we have been disappointed to find that the Corporation insists on our paying the charge of 7s. 6d. per month, against which we have protested in vain. We hope, however, that a request we have sent for a grant-in-aid from the Council, which request has been backed up by Councillor S. K. Elgie, will bring us relief during the coming year.

During the year we have had lectures as follows:—

Capt. C. S. Hewlett, F.R.G.S., "Solectrics"; 2 lectures.
Mr. I. L. Green: "The Atom."
Mr. H. J. Roadknight: "The Equatorial Telescope."
Mr. H. L. Buzzard: "Some Observations on the Heavenly Bodies."
Mr. J. Bennett Mumford: "James Bradley and his Times."
Rev. C. E. Wilkinson, M.Sc.: "Radiation"; 2 lectures.
Mr. H. J. S. Ball: "Globular Clusters."

In March we had an open evening when Mr. A. de Charmoy gave a talk on "The Inspiration of Astronomy," Mr. Bell a talk on the "Moon," Mr. Roadknight on "Jupiter," and Mr. J. Bennett Mumford on "Double Stars."

The year can be looked back on with the satisfaction that we have continued to provide a little in the way of instruction and elevation to the community.

REVENUE AND EXPENDITURE ACCOUNT FOR TWELVE MONTHS ENDED 31st MAY, 1935.

Receipts.	£	s.	d.	Payments.	£	s.	d.
1st June, 1934:				By Caretaker, Technical College	0	10	6
To Balance	7	6	0	„ Stamps and Stationery	1	1	0
31st May, 1935:				„ Sweeping	1	5	0
To Subscriptions	14	6	6	„ Advertising	5	1	0
„ Donations	8	17	0	„ Refreshments	1	0	0
„ Collections	1	6	6	„ Lights, etc.	9	4	4
				„ Electric Light	3	12	6
				„ Bank Charges	0	12	0
				„ Wreath	1	1	0
				„ Balance	8	8	8
	£31	16	0		£31	16	0

Examined and found correct:
W. J. WOOD,
Hon. Examiner.

J. BENNETT MUMFORD,
Chairman.

ASTRONOMICAL SOCIETY OF SOUTH AFRICA.

OFFICERS AND COUNCIL, 1934-35.

President: J. Jackson, M.A., D.Sc., F.R.A.S.

Vice-Presidents: J. K. E. Halm, Ph.D.; A. Pilling, B.A.; J. Willis.

Hon. Secretary: A. Menzies, Royal Observatory, Cape of Good Hope.

Hon. Treasurer: W. H. Smith, Arum Villa, Plumstead, C.P.

Members of Council: H. E. Wood, M.Sc., F.R.A.S.; A. W. Long, F.R.A.S.; A. W Robinson; C. E. Peers; D. C. Alletson, B.A.; J. B. Mumford.

Alternate Members of Council: D. G. McIntyre, F.R.A.S.; W. G. Andrews; J. B. G. Turner.

Hon. Editor: J. Jackson, M.A., D.Sc., F.R.A.S., Royal Observatory, Cape of Good Hope.

Hon. Librarian: W. G. Andrews, "Tircreevan," Clifton Road, Mowbray.

Hon. Auditor: E. J. Steer.

DIRECTORS OF OBSERVING SECTIONS.

Comet: A. F. I. Forbes, M.I.A., "Blairythan," Main Road, Hermanus, C.P.

Zodiacal Light: A. F. I. Forbes, M.I.A.

Variable Stars: H. E. Houghton, F.R.A.S., High Commissioner's Office, Cape Town.

The Society acknowledges the receipt of publications, etc., from the following:—

University Observatory, Babelsberg, Berlin; Harvard College Observatory; Lick Observatory; University Observatory, Kasan; Union Observatory, Johannesburg; British Astronomical Association, Glasgow Branch of the British Astronomical Association, Sydney Branch of the British Astronomical Association; New Zealand Astronomical Society; Argentine Astronomical Society; Argentine Association of Friends of Astronomy; Antwerp Astronomical Society; Dr. L. J. Comrie; Yale Observatory; University Observatory, Bonn; Vereinigung von Freunden der Astronomie und Kosmischen Physik; Radcliffe Observatory; Astronomical Society of Tasmania.