on a wave function, all attempts to do so leading to divergent integrals. Under these circumstances, one does not really have a representation of the IHLG at all.

Physicists have constructed a method for handling the divergent integrals, the renormalization method, which is successful in many cases in leading to well-defined physical results that can be compared with experiment. However, the method can be considered only as a stopgap, since it does not follow logically from established physical laws. A satisfactory solution of the problem, if it is to conform to accepted basic laws of quantum mechanics, really must lead to a representation of the IHLG, and the renormalization technique does not do this.

Since the difficulties arise entirely from the integration of the infinitesimal operators, one can avoid them by short-circuiting the integration process, not using at all the infinitesimal operators, and dealing only with those integrals that are needed for comparison with experiment. A great deal of work has been done on these lines in recent years. However, it is unlikely that such work can lead to a complete theory. A process of integration seems to be an essential feature of dynamical theory.

It appears that the most hopeful prospect is to try to get representations of the IHLG in some more general way, still working from the infinitesimal operators and using a process of integration for the finite ones. There are several places where one might try to generalize the method that has been followed here. For example, one might depart from the local character of the energy density, or the local commutation relations for the basic field quantities. If all such attempts fail, one would have to consider altering the fundamental laws of quantum mechanics, which would involve finding some new general principle to replace the present use of representations of the IHLG.

SUMMARY

A quantum field theory in agreement with special relativity can be built up from the infinitesimal operators of translation and rotation. These operators are expressible in terms of a momentum density and an energy density. The momentum density is determined by the geometrical properties of the fields concerned. The energy density has to satisfy commutation relations for which certain conditions hold, given by Eqs. (15), (25), and (26).

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Geophysical Consequences of Dirac's Hypothesis

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SECTION 1

QUITE a revolution is going on at present concerning basic ideas of geophysics, geology, and paleoclimatology. Numerous authors have contributed to the new revolutionary picture of our Earth and its history that is now developing. Some of the contributions are newly detected empirical facts, others are new interpretations of things long known, and some of the ideas of the new theory have been conceived independently by several different authors. Among those who have contributed to the new ideas are Binge, Brill, Carey, Dicke, Egyed, Ewing, Fisher, Gamow, ter Haar, Heezen, Ivanenko, Jordan, Kirillow, Neumann, Sagitov, Teller, and Tharp.

This new understanding of the development of the earth is closely related to a generalization of the physical theory of gravitation. This started from Dirac's idea (1937) that the "constant" of gravitation, $\kappa = 8\pi G/c^2$, might in reality be a variable quantity. The generalization of Einstein's theory of gravitation that is generated by assuming κ to be a scalar field variable has been explored mathematically by the author since 1943. It was studied also by Einstein and Bergmann, Thiry, Dicke, and in connection with the author's work by Ludwig, Cl. Mueller, Heckmann, Fricke, Gressmann, Schuecking, Ehlers, Kundt, Pauli, Fierz, Just, Figueras, and Brill.

This generalized theory of gravitation, based on Dirac's hypothesis that κ is diminishing with time, approximately inversely proportional to the age of the universe, is meaningful in cosmology and astronomy, in connection with double stars, origin of the planetary system and astrophysical age determinations. It may become possible to test it in the near future with precision measurements, especially making use of satellites.

But the most conspicuous consequences of this theory, based on Dirac's hypothesis, are those concerning our Earth. That is the subject of this paper. In Secs. 3 to 5 are reviewed ideas presented earlier.[1] I shall try to show that modern knowledge of the earth gives what may be called proof of the correctness of Dirac's hypothesis.

SECTION 2

The generalization of Einstein's theory of gravitation is based on replacing the variational principle

$$\delta \int \left(R - \frac{\kappa}{2c^2} F_{kl}F^{kl} - \frac{\kappa}{c^2} L \right) d\tau = 0 ,$$
$$d\tau = (-g)^{1/2} dx_1 dx_2 dx_3 dx_4 , \qquad (1)$$

by

$$\delta \int \left(\frac{R}{\kappa} - \zeta \frac{\kappa^{|j} \kappa|_j}{\kappa^3} - \frac{1}{2c^2} F_{kl}F^{kl} - \frac{1}{c^2} L \right) d\tau = 0 , \qquad (2)$$

in which ζ is a dimensionless constant, perhaps of the order of 10, and $\kappa|_j$ is the gradient of the scalar κ. In my first papers, I preferred another variation principle which in the case of purely gravitational vacuum fields becomes equivalent with (2) on replacing κ by κ^{-1}. Discussions with Lichnerowicz, Fierz, and Pauli have convinced me that (2) is the correct principle: This form was mentioned in the second edition of my book, *Schwerkraft und Weltall*, published in 1955.

The Largange equations corresponding to (2) are

$$R - \zeta \left(2 \frac{\kappa^{|j}{}_{||j}}{\kappa} - 3 \frac{\kappa^{|j} \kappa|_j}{\kappa^2} \right) = 0 ; \qquad (3)$$

$$\begin{aligned} R_{kl} - \tfrac{1}{2} g_{kl} R - \frac{\kappa|_k||_l}{\kappa} - (\zeta - 2) \frac{\kappa|_k \kappa|_l}{\kappa^2} \\ + \tfrac{1}{2} g_{kl} \left(2 \frac{\kappa^{|j}{}_{||j}}{\kappa} + (\zeta - 4) \frac{\kappa^{|j} \kappa|_j}{\kappa^2} \right) \\ = \frac{\kappa}{c^2} (E_{kl} + T_{kl}) , \end{aligned} \qquad (4)$$

$$F^{kl}{}_{||l} = 0 \qquad (5)$$

and the field equations for matter, expressed with wave functions. In (4) we have the matter tensor T_{kl} and the electromagnetic energy tensor E_{kl}. The notation used in $\kappa|_k||_l$ means covariant differentiation.

In a pure gravitational vacuum without matter or electrical charge and current, the field equations lead to the divergence relations

$$\vartheta^l_{k|l} = 0 , \qquad (6)$$

in which (as kindly computed by Demmig),

$$\begin{aligned} \kappa \vartheta^l_k = {} & (\sqrt{-g}\, g^{jm})|_k (\delta^l_j \Gamma^h_{mh} - \Gamma^l_{jm}) \\ & + \sqrt{-g}\, \delta^l_k g^{jm} (\Gamma^i_{jm} \Gamma^h_{ih} - \Gamma^l_{ji} \Gamma^i_{mh}) \\ & - 2\sqrt{-g} \left\{ \frac{\kappa^{|l}{}_{||l}}{\kappa} + (\zeta - 2) \frac{\kappa^{|l} \kappa|_k}{\kappa^2} \right\} \\ & + \sqrt{-g} \left\{ \frac{\kappa^{|j}{}_{||j}}{\kappa} + (\zeta - 4) \frac{\kappa^{|j} \kappa|_j}{\kappa^2} \right\} \delta^l_k \\ & + A^{li}_k \frac{\kappa|_i}{\kappa} ; \end{aligned} \qquad (7)$$

$$\begin{aligned} A^{li}_k & = 6\sqrt{-g}\, g^{m|j} \delta^l_k g^{i|h} g_{mj|h} \\ & = \sqrt{-g} \begin{vmatrix} \delta^l_k & \delta^i_k & \delta^j_k \\ g^{ml} & g^{mi} & g^{mj} \\ \Gamma^l_{mj} & \Gamma^i_{mj} & \Gamma^j_{mj} \end{vmatrix} \end{aligned} \qquad (8)$$

Equation (6) shows that a flow of energy comes into the Earth from outside when the gravitational potential energy of the earth is decreasing because of the decrease of κ.

SECTION 3

It is well known that there are deep narrow rifts in the bottom of the oceans in which relatively rapid processes of transformation are going on, as partly shown by isostatic anomalies. It has been shown, through the work of Ewing, Heezen, and Tharp, that the rifts are part of a world-wide system, as shown by the dotted line in Fig. 1. The strait of Gibraltar is part of this system, this rift going near Spain and France, and through the northwestern part of Germany to Scandinavia. Ivanenko and Sagitov have discussed the extension of these rifts through Siberia. It seems that this rift is clearly to be found especially in the vicinity of Lake Baikal.

The whole system of rifts directly shows that the earth has undergone expansion, not contraction as has been generally believed by geophysicists for more than a century. The recent or former tearing apart caused by this expansion may be seen especially clearly in those parts of the system that lie on land, running through Iceland, and also in northwestern Germany, and also in east Africa.

This expansion must be regarded as the governing cause of the existence of oceans and continents. This view is supported by the following considerations:

I. Seismic evidence, combined with isostasy and petrographical studies, shows the sialic material of the continents to be different in density, and in

[1] P. Jordan, Abh.Akad.Wiss Lit. (Mainz) p. 769 (1959), and Naturwiss. 48, 417 (1961).

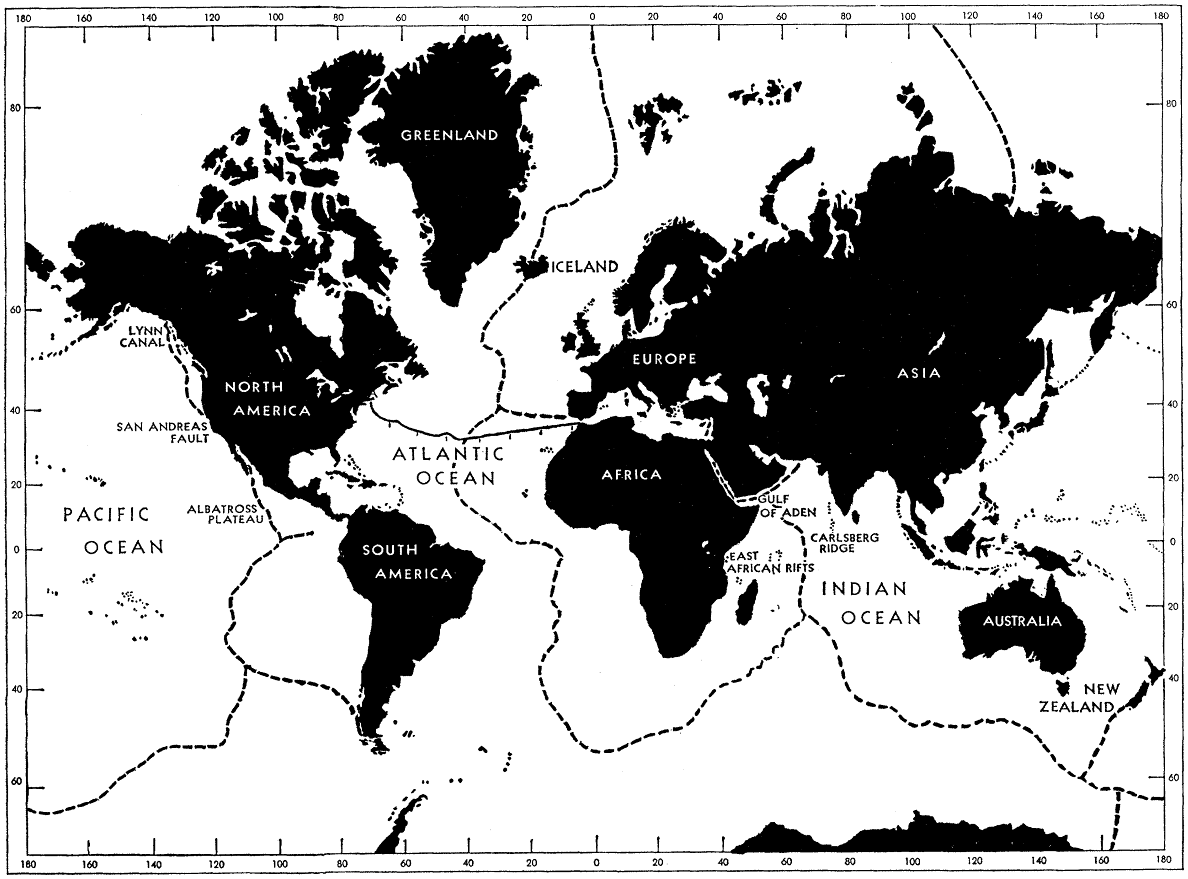

FIG. 1. The system of rifts (Ewing, Heezen, Tharpe).

chemical composition from the more dense sima material of the ocean bottom, below relatively thin layers of ocean sediments.

II. There exist two distinct and well-defined hypsographic levels, as shown in Fig. 2; that of the bottom of all oceans, and that of the surface of the continents. The continents must naturally not be defined by the coast lines, but in such a way that they include the continental shelves, where the sea is shallow. Nearly everywhere these shelves are limited by a steep continental slope, which divides them from the deep sea. Thus the continents as a whole form a layer, around those parts of the earth that are not covered by the ocean basins, which has a uniform thickness to a high degree.

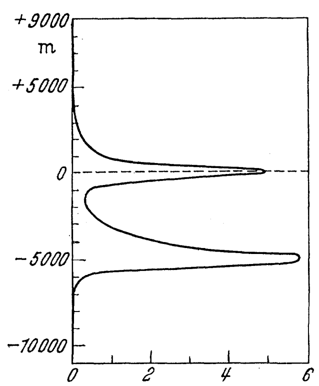

FIG. 2. Frequency of altitudes (Wegener, Bucher).

III. It follows from I and II that any transformation of continental areas to oceanic ones (by "absinken" as it is called in German) or the opposite change, called "growth of continents," is impossible.

IV. Paleontological evidence suggests that Africa and South America in former times were joined together in a huge continent, called "Gondwana," as shown in Fig. 3, which indicates, according to Carey, how well the contental slopes of the two continents fit together. The idea that these two continents were formed by separation from a single land mass was originally put forward by Wegener, on the basis of the much less accurate fitting of the coast lines.

V. If we accept the conclusion that the separation

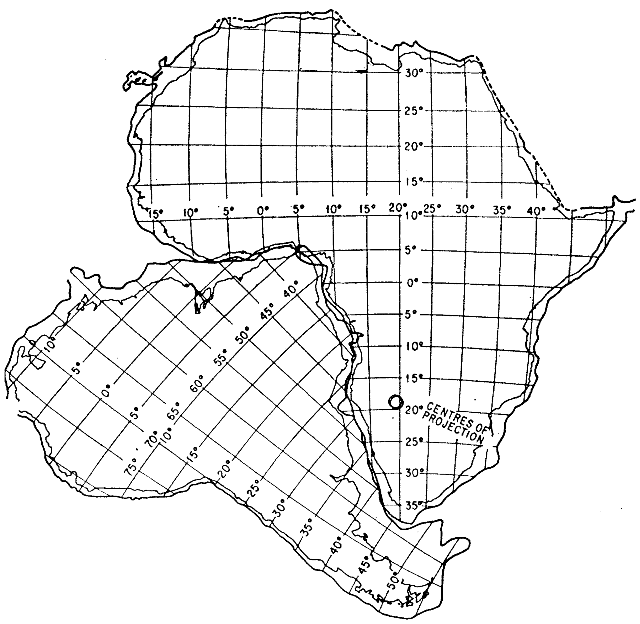

FIG. 3. Map showing fit between South America and Africa.

of Africa and South America occurred during geological times, then it follows that this must be a consequence of expansion. The same interpretation is applied to the other oceans, since there is no justification for invoking different principles of origin for different parts of the system of oceans.

In his pioneer work, Wegener believed in the idea of continental drift, and did not consider the possibility of expansion. The idea of drift has been generally discarded after Jeffreys showed that the forces necessary to cause such drift would be far greater than those arising from Wegener's view as to the physical cause of the supposed drift.

Some geophysicists believe in slow convection currents in the mantle of the earth, but this view does not explain the uniformity of thickness of the continents. On the expansion theory this observational fact is accounted for naturally in this way: During the formation of the earth the sialic material formed a closed layer of uniform thickness covering the whole sphere, then by expansion this outer layer has been torn into several parts, and these have preserved their original thickness, and their original total area.

VI. Kirillow has shown that the present continents do fit together on a sphere whose surface area is equal to the total area of the continents.

Heezen has concluded that the facts of paleomagnetism are in good accord with the expansion theory. Efforts have been made to account for these facts by assuming migration of the poles, but assuming that the magnetic and rotational poles were always near each other. However this view does not lead to a definite result for the supposed path of migration of the north pole.

Moreover the advocates of the migration view have not been able thus far to show mechanical causes adequate for the production of the supposed migrations, despite many efforts to do so. I am therefore inclined to think that the idea of such migrations must be discarded.

VII. Two more lines of evidence favor the expansion theory: (A) The area of land not covered by water has been found to increase during the last three billion years. The modern study of the period from 3 down to 0.5 billion years ago, has shown that only small "shields" were free from water in the early stages. The increase of the water free areas has been called the growth of continents. For the interval from 0.5 billion years ago to the present, Egyed has shown from the best existing geological maps that this growth has continued from the Cambrian to the Recent, leading to the present situation that the coast lines are near to the continental slope.

(B) The phenomenon of island arcs has been analyzed empirically and theoretically but it finds satisfactory explanation only on the basis of the expansion theory.

SECTION 4

The theory of expansion, associated with decreasing κ, also provides, according to Binge, a basis for understanding volcanoes and intrusions. The intrusions may be regarded as volcanoes that were unable to break through to the surface, but only pressed magmatic material into higher levels from below.

Many geophysicists believe that these phenomena are to be explained by local melting of magmatic material resulting from local concentrations of radioactive material. However, Rittman in his study of volcanism, saw that the explosive character of these processes offers the chief difficulty of interpretation. The very large amount of volcanic and intrusive activity in all continents and in all geological ages shows that a widespread instability exists in the deeper layers of the crust.

Binge explains these facts on the basis of Dirac's hypothesis. The bysmaliths, the intrusions that displace upward a great cone of magmatic material, show that the reacting material underwent an increase in volume, it must have undergone a phase transformation from a high pressure phase to a low pressure phase of lower density. He interprets the known facts of volcanism on the assumption that a considerable part of the material in the deeper layers is now still present in the form of high pressure phases, which have in the meantime been rendered unstable by the diminution of pressure resulting from the decrease of κ, and associated increase of the radius of the earth.

As a result of Baldwin's work it is coming to be believed that the Moon has no appreciable volcanic activity, but rather that the craters are the result of meteoric impacts. Our knowledge of the conditions on Mars is quite incomplete. It appears that there also, two hypsographic levels exist, but have a much smaller difference in altitude than on the Earth; and the relative area of the "continental" or high level is greater. The continental areas are divided by numerous cracks, giving rise to the markings formerly called "canals." There seems to exist no volcanic action and no processes of mountain formation.

On the expansion theory, the essential difference between Earth and Mars is that on Mars the outer, continental layer, is considerably thinner than that of the earth, and thus during expansion would be torn into many small pieces, whereas on Earth the continents were too strong by virtue of their thickness and remained in a few large pieces. These great continents were bent during the expansion, giving rise to formation of mountain chains. And then, the resulting local difference of pressure resulted in explosive phase transformations producing volcanic activity.

SECTION 5

The idea of pole migrations has also been applied to paleoclimatology, especially to the Permo-Carboniferous and Devonian glaciations. The Permo-Carboniferous glaciation left its traces in many places in a certain belt near the equator, which requires that the poles would have to have migrated along the present equator to fit the view that glaciations occur only in polar regions.

Potonié has given a precise description of the paleoclimatic data of the Carboniferous era. From it, the author has inferred that the earth must have been covered with clouds during this era. The humid climate of this age was astonishingly uniform, nearly independent of the seasons as well as of geographic latitude. From Spitzbergen through the equatorial zone to the Antarctic temperatures of 10 to 12 °C remained practically constant. The vegetation contained only plants adapted to conditions of permanent shadow. In consequence of the low temperature, the earth was nearly on the verge of a world-wide glaciation, which actually began with the next geological era, the Permian. In this way we can understand, especially if the equatorial cloud layers were thicker than elsewhere, how a maximal glaciation could occur in the equatorial belt. As Binge remarks this is not more paradoxical than the fact that today the stratosphere has a lower temperature above the equator than above the poles.

Also during the Devonian, before the Carboniferous era, glaciations were known to have occurred; they too were, according to our arguments, of a totally different character from those of the Pleistocene.

This new picture of paleozoic climatology is in accord with what is to be expected on the basis of Dirac's decreasing gravitational constant. During the history of the planetary system, the planetary orbital radii must have been inversely proportional to κ. Taken together with the astrophysical luminosity formula

$$\mathfrak{L} \approx M^{11/2} R^{-1/2} \kappa^{15/2}, \tag{9}$$

this leads to a proportionality of the solar constant with about κ^{10}. During the Carboniferous era therefore the solar constant may have been 2 or 3 times greater than to-day, so that the conditions of the atmosphere of the earth during that era may have been similar to those of Venus today, Venus being constantly enveloped in clouds.

The Pleistocene glaciation seems also to be understandable on these views. If κ is decreasing now at the rate of 10^{-8} or 10^{-9} per year, then proportionality of the solar constant S with κ^{10} means that during the last 10^6 years, S has decreased one to ten percent. This could have as a consequence that during the last 10^6 years, but not before, climatic periods with relatively cold summers, according to the Milankovitch curve, could have allowed glaciation in the polar regions. During the Tertiary the solar constant would have been still too great for such effects.

In conclusion, I think that our present knowledge of the earth, interpreted in the ways indicated, makes the correctness of Dirac's hypothesis an established fact, including also the puzzling circumstance that during the formation of the Earth, κ must have been quite considerably greater than it is now. This circumstance (emphasized by Teller in personal discussions) is perhaps a confirmation of the author's ideas about the formation of stars from Amburzumian's pre-stellar matter.[2]

[2] P. Jordan, *Recent Developments in General Relativity* (Pergamon Press, New York, 1962), p. 289.