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FEATURED ARTICLES

- COMPARISON OF MEASUREMENTS OF SOVIET AND AMERICAN SATELLITES
- SOME CALCULATIONS OF THE THERMAL HISTORY OF THE MOON
- THE NATURE OF THE EARTH'S THIRD RADIATION BELT

RELATIONSHIP BETWEEN THE RESULTS OF MEASUREMENTS BY CHARGED-PARTICLE TRAPS ON THE SOVIET COSMIC ROCKETS AND MAGNETIC-FIELD MEASUREMENTS ON THE AMERICAN SATELLITE "EXPLORER VI" AND ROCKET "PIONEER V". The following article by K. I. Gringauz and S. M. Rytov was translated from Doklady Akademii Nauk SSSR, Vol. 135, No. 1, pp 48-51, Nov., 1960.

In the description of the results obtained in 1959 in the vicinity of the Earth with the help of three electrode traps for charged particles placed on the Soviet cosmic rockets [1], it was indicated that at distances of 55,000 to 75,000 km from the Earth's surface, electron currents with densities of $\sim 10^8$ el$\cdot$cm$^{-2}\cdot$sec^{-1} and energies $\gtrsim 200$ ev had been detected. This made it possible to conclude that an outermost belt of charged particles surrounding the Earth exists [2,3], located beyond the radiation zones [4-7]. It was supposed that the boundaries of this belt lie along the force lines of the geomagnetic field [2,3].

In 1960, preliminary results were published of measurements of the geomagnetic field performed by the satellite "Explorer VI" (launched in the USA on August 7, 1959, with an apogee of 48,800 km, a revolution period of 12.45 min*, and orbit in a plane inclined by an angle of 47° with respect to the plane of the geographic equator) [8], and by the cosmic rocket "Pioneer V" (launched on March 11, 1960) [9,10]. These measurements showed that at distances from the

*Official data are: Perigee, 251 km; Apogee, 42,408 km; Inclination to equator, 46.9°; Period, 12½ hours.

center of the Earth less than 5-6 Earth radii R_E, there was a good agreement between the measured values of the geomagnetic field and the theoretical values calculated from its values at the Earth's surface and the eccentric dipole model according to [11].

At great distances from the Earth, systematic large-scale deviations from the theoretical values of the field were recorded; these deviations were observed all the time -- both in magnetically perturbed and in magnetically quiet days -- although they changed somewhat in time. The authors of papers [8-10] came to the conclusion that the perturbations in question detected by Explorer VI in the geomagnetic field are due to a permanent system of electric currents. This system of currents should be localized in a certain way and lie beyond the limits of the radiation zones, possibly in a toroidal region surrounding the Earth. In order to determine the characteristics of this current system, a hypothetical model of it was examined. This model consisted of a current flowing through a circular cylinder whose center lay on the geomagnetic equator, and having the same current density for every section. The total magnetic field resulting from the geomagnetic field and the magnetic field of the current ring was calculated. These calculations were compared with the measured values in order to verify whether the model chosen for the current ring was appropriate, and in order to determine the parameters of the current system fitting in the best way the experimental data.

The measurements carried out on Pioneer V, which passed through another part of the region under consideration than the Explorer VI and intersected the supposed current system, showed that at distances from the center of the Earth of 5-7 R_E, lower values of the geomagnetic fields were observed, as with Explorer VI. On the other hand, at distances larger than 13 R_E, values higher than those given by the theoretical law $1/R^3$ were detected. These results confirmed the idea of the existence of a "current ring" causing permanent perturbations of the geomagnetic field at geocentric distances $>5R_E$.

The results of the calculation of the parameters of the ring current, based on the model shown above, were the following.

a) For Explorer VI, $R_0 = 60{,}000$ km, $I = 5 \cdot 10^6$ amp, $a = 3R_E$ (or less), where R_0 is the distance from the center of the Earth to the center of the circular section of the cylinder, I is the total current intensity, a is the radius of the cylinder.

b) For Pioneer V, $R_0 = 50{,}000$ km, $I = 5 \cdot 10^6$ amp, $a = 3R_E$.

In [10] it was noted that no agreement can be obtained between the experimental data and the results of the calculation based on the current model mentioned above for $a < 3R_E$.

A comparison of the above preliminary results of measurement of the geomagnetic field by Explorer VI and Pioneer V, with published data [1-3] concerning the outmost belt of charged particles (discovered by means of charged-particle traps by Soviet cosmic rockets, and containing electrons with energies $200 \text{ ev} < E < {}^{\sim}10^4 \text{ ev}$) undoubtedly presents a great interest.

As can be seen from Fig. 3 of [3], the Soviet rockets cut the geomagnetic equator at a height of about 60,000 km from the surface of the Earth, i.e., just in the zone where the center of the current ring is located, and whose existence follows from the data of American magnetic measurements. As can be seen from Fig. 4 of [1], the center of the region in which currents of electrons with $E > 200$ ev were discovered (flight of the second cosmic rocket of September 9, 1959) lies at a height of ~60,000 - 65,000 km from the surface of the Earth (i.e., near the center of the section of the current ring, according to the data of Explorer VI). The density maximum of the electron currents lies in a region about 20,000 km wide (at heights of 55,000 - 75,000 km), and the extension of the whole region in which electron currents were detected was ~ 40,000 km, a value very close to the diameter of the section of the current ring $2a \cong 6 R_E$ calculated in [10].

The current density (of the electron flow), according to the data of experiments with charged-particle traps, becomes greater at shorter and shorter distances from the center of the region where they exist, and drops to zero at the boundaries of the existence region, whereas it was taken as constant along the section of a current ring in [10]. However, [10] clearly indicates that such a model of a current ring was taken only in order to simplify the calculation. The mean current density in the current ring calculated according to [10] is about $4 \cdot 10^{-13}$ amp/cm^2, whereas the density of the electron flow in the maximum of the outermost belt of charged particles is, according to [1-3], about $2 \cdot 10^8$ el/cm$^2 \cdot$ sec $= 3.2 \cdot 10^{-11}$ amp/cm^2.

However, one should keep in view the fact that by means of the traps of the experiments reported in [1], the density of the whole electron flow with $E > 200$ ev could be determined, whereas the changes of the geomagnetic field could be given only by the component of this current perpendicular to the lines of force of the geomagnetic field. Such a component must exist because of the well-known phenomenon of charged-particle drifting in a nonuniform magnetic field (see, e.g., [12]).

In order to be able to evaluate the drift current density and the current in a trap, we shall consider the geomagnetic field as the field of a dipole, and suppose that the distribution of electrons according to their velocities is a Maxwell distribution. This assumption is certainly conventional. The Maxwell distribution will be introduced only as some effective distribution, i.e., as one which gives in a trap the same currents as that observed in fact.

Under the assumptions mentioned, the general formulas for the drift in a nonuniform magnetic field [12] give the following expression for the density of the drift current in the plane of the magnetic equator:

$$j_{dr} = \frac{6c\theta N}{BR} = \frac{6c\theta NR^2}{B_o R^3{}_E},$$

where c is the velocity of light, θ and N are the energy temperature and the concentration of the electrons; R_E is the radius of the Earth, B_o is the field at the surface of the Earth; B is the field R from the dipole. Naturally, positive ions also carry a contribution to the drift current (at thermal equilibrium the expression given above should be doubled), but, as will be seen in the following, taking into account this insufficiently determined addition does not play any role in further considerations.

Under the same assumptions, the current density in a trap intersecting electrons with kinetic energies (along the normal to the surface of the trap collector) lower than ev, is

$$j_1 = eN\sqrt{\frac{\theta}{2\pi m}}\, e^{-x}, \quad x = \frac{eV}{\theta},$$

where e and m are the charge and mass of the electron. Dividing j_{dr} by j_1, and expressing θ through the parameter x, we obtain

$$\frac{j_{dr}}{j_1} = \frac{6cR^2}{B_o R^3{}_E}\sqrt{2\pi\frac{m}{e}V}\,\frac{e^x}{\sqrt{x}}\,.$$

Taking $R = 10R_E$ ($R_E = 6.4 \cdot 10^8$), $B_o = 0.5$ gauss, $eV = 200$ ev, and substituting the values of the other constants, we obtain

$$\frac{j_{dr}}{j_1} = 1.55 \cdot 10^{-6}\frac{e^x}{\sqrt{x}}\,.$$

The observed ratio of the current densities (of the order of 10^{-2}) corresponds to $x \cong 9.5$, i.e., $\theta \cong 21$ ev, or $230{,}000^o$ abs, if the root $x \sim 10^{-7}$, which corresponds to an exceedingly high temperature, is neglected. Let us note that for such values of x the quantity x depends very weakly (logarithmically) upon the ratio of the currents, the distance from the dipole, and the potential of the grid of the trap.

Using the value obtained for Θ, it is possible to calculate from the formula for j_1, or (which is even simpler), from the formula for j_{dr}, the value of the electron concentration N. For $j_{dr} = 4 \cdot 10^{-13}$ amp/cm^2 $= 1.2 \cdot 10^{-3}$ CGSE, we get $N \cong 600$ el/cm^3.

The evaluation made shows that within the frame of the rough assumptions made (dipole field and Maxwell distribution of electron velocities), it is possible to get a reasonable agreement between the intensity of the electron flow measured by the charged-particle traps in the outermost belt discovered by the Soviet cosmic rockets, and the intensities of the perturbation of the geomagnetic field observed in the same region in the American experiments. In addition, if the electron distribution according to their velocities is actually close to a Maxwell distribution, a decrease of the potential of the grid V should produce a significant increase of the current in the traps, since a trap with V = 200 v works, as can be seen from the value obtained for $\Theta \cong 21$ ev, on the tail of the effective Maxwell distribution. In a further study of the outermost belt of charged particles, it will be extremely important to find out which is the energy spectrum of the electrons (e.g., simultaneously using traps with different values of V).

The considerations reported above provide some grounds for believing that the results of the measurements made with three electrode traps on the Soviet cosmic rockets and with magnetometers on Explorer VI and Pioneer V are in good agreement with each other. Thus, these investigations, independent of one another, and carried out with different methods, apparently support and supplement each other, and prove that the current ring discovered in the magnetic experiments is nothing else than the drift current produced by the nonuniformity of the geomagnetic field in the outermost belt of charged particles permanently present at heights of about 60,000 km. Further direct investigations of this belt will make it possible to determine more accurately its properties, in particular its variations in time and space, and also the energy spectrum of the electrons producing the effects discovered by the Soviet and American experiments.

LITERATURE CITED

1. K. I. Gringauz, V. V. Bezrykikh, V. D. Ozerov, and R. E. Rybchinskii, Doklady Akad. Nauk SSSR 131, 1301 (1960) [Soviet Physics - Doklady, Vol. 5, p. 361].

2. K. I. Gringauz, V. G. Kurt, V. I. Moroz, and I. S. Shklovskii, Doklady Akad. Nauk SSSR 132, 1062 (1960).

3. K. I. Gringauz, V. G. Kurt, V. I. Moroz, and I. S. Shklovskii, Astron. Zhur. 37, 716 (1960) [Soviet Astronomy - AJ, Vol. 3, p. 680].

4. S. N. Vernov et al., Doklady Akad. Nauk SSSR 125, 304 (1959) [Soviet Physics - Doklady, Vol. 4, p. 338].

5. J. Van Allen and L. A. Frank, Nature, Febr. 14, (1959).

6. S. N. Vernov et al., Doklady Akad. Nauk SSSR 130, 517 (1960) [Soviet Physics - Doklady, Vol. 5, p. 95].

7. J. Van Allen, C. E. McIlwoun, and C. H. Ludwig, J. Geophys. Res. 64, 271 (1959).

8. C. P. Sonett et al., Phys. Rev. Letters 4, 161 (1960).

9. P. J. Coleman, Jr. et al., J. Geophys. Res. 65, 1856 (1960).

10. E. J. Smith et al., J. Geophys. Res. 65, No. 6 (1958).

11. E. H. Vestine, J. Geophys. Res. 58, 127 (1953).

12. L. Spitzer, Physics of Completely Ionized Gases [in Russian] (Moscow, 1957), Chap. 1.

(Soviet Physics Doklady, May-June, 1961)

SOME CALCULATIONS OF THE THERMAL HISTORY OF THE MOON. The following article by B. Yu. Levin and S. V. Maeva was translated from Doklady Akademii Nauk SSSR, Vol. 133, No. 1, pp 44-47, July, 1960.

In calculations of the thermal history of the Moon, as well as in analogous calculations for the Earth, one must examine the various models of these bodies, i.e., the simplified schemes of their structure and evolution. In the calculations carried out below, the authors have striven to picture the evolution of the Moon as strictly as possible as having developed through an accumulation of cold solids.

1. Initial data. As a consequence of the smallness of the Moon's mass, the heating by the impacts of the bodies which formed it, as well as the raising of the temperature of the core as a result of its compression by the accumulating exterior layers, was, in contrast to Earth, negligibly small. Therefore, an initial temperature distribution, which had been established at the moment of practical completion of the Moon's growth, was determined by use of the fact that the central portions had formed and begun to accumulate radiogenic heat before the peripheral portions. The "initial" temperature distributions used were calculated for two alternative contents of radioactive elements (see below) in the supposition that formation of the Moon took 0.23 10^9 years and proceeded according to the rule obtained by V. S. Safronov [1] for Earth. The temperature of the surface was assumed at all times equal to 0°, which corresponds approximately to the conditions on the equatorial zone of the Moon.

The mean content of radioactive elements in the Moon was taken the same as in meteorites. The analyses of meteorites carried out by various authors in recent years, although giving values which differ by orders of magnitude for the content of U and Th, nonetheless indicate a general tendency towards reduction. Therefore, along with calculations based upon the mean content of the anticline [2], which we denote as version C, calculations are also presented for version $C_{\frac{1}{2}}$, in which the contents of U and Th are taken smaller by a half with the same content of K. Version C contains (in g/g): U-$5.2 \cdot 10^{-8}$, Th-$21 \cdot 10^{-8}$ and K-$0.7 \cdot 10^{-3}$; version $C_{\frac{1}{2}}$ contains (in g/g): U-$2.6 \cdot 10^{-8}$, Th-$10.5 \cdot 10^{-8}$ and K-$0.7 \cdot 10^{-3}$. In version $C_{\frac{1}{2}}$ the content is very close to that assumed by A. P. Vinogradov [3]. MacDonald [4] assumes a still smaller (twofold) content of U and Th; he bases this on results of analyses of meteorites carried out by a neutron-activation method which gives systematically smaller values than the other methods. The age of the Moon reckoned from the beginning of its formation is taken to be $5 \cdot 10^9$ years.

The thermal conductivity was taken in the form of a sum of the molecular and radiation thermal conductivities $\lambda = A/T + {}^{16}/_{3}\, n^2 \sigma T^3/_{\epsilon}$, where T is the absolute temperature; σ, the Stefan-Boltzman constant; n, the index of refraction (n^2 was taken equal to 3); and ϵ the coefficient of absorption (we took $\epsilon = 10$ cm^{-1} and $\epsilon = 40$ cm^{-1}). The constant A was determined from the condition that 0°C, where the radiation thermal conductivity is unimportant, $\lambda = 1.2 \cdot 10^{-2}$ cal/cm sec · deg (dunite). The heat capacity was taken equal to 0.2 cal/g · deg.

The calculations referred to below were carried out on a hydrointegrator of V. S. Luk'yanov's design in the Mintransstra Central Scientific Institute of Construction.

2. Calculations of the heating up of the Moon. The Moon was considered homogeneous in density ($\rho = 3.3$ g/cm^3) with a uniform distribution of radioactive elements. The calculation was started from the moment of practical completion of the Moon's growth, i.e., from the time $t = 0.23 \cdot 10^9$ years (the time t is reckoned from the beginning of formation of the Moon). For both versions of the radioactive element content (C and $C_{\frac{1}{2}}$ one obtains melting of material starting from the center. Petrous material, consisting of various minerals, melts gradually in a certain temperature interval. It was assumed that melting of lunar material proceeds in a 200-degree interval and is completely ended when the melting temperature of dunite is reached. For the latter, the melting curve was taken according to Wolf [5], i.e., the dependence on pressure p was taken according to the formula $t_L = s_o + ap + bp$. The constants $s_o = 1250°$, a = 0.005, and b = $-0.020 \cdot 10^{-6}$ were obtained from measurements at relatively low pressures. According to this formula one finds that the melting temperature of dunite (and according to the assumptions indicated above, also the temperature of the initial melting) in the center of the Moon is 190 degrees higher than on the surface.

The heat of fusion was taken equal to 100 cal/g. Its absorption was considered to proceed uniformly in the assumed melting interval. Melting of the material in the center began at time $t = 0.5 \cdot 10^9$ years in version C and at time $t = 0.7 \cdot 10^9$ years in version $C_{\frac{1}{2}}$. We note that melting in the center is obtained even for a still smaller content of radioactive elements but it begins still later [4].

3. Qualitative picture of the processes going on during melting. Since the pressure in the core of the room is small, melting of its material implies not only a transition from a crystalline to an amorphous state but also a transition to a liquid fluid state. In the course of warming up, the lowest melting-point materials and eutectics must have been the first to melt. As a rule, they are less dense and, in addition, the melting itself decreases their density. Therefore the molten materials must have tended to move upwards, seeping between particles which had remained solid, while these solid, more dense, particles must have tended to move downward, squeezing the molten materials upwards. A differentiation in density and in chemical composition was obtained. (Moreover, large-scale vertical displacements must have occurred, along with which coarse-sized materials must have acquired somewhat different densities because of fluctuations of composition and structure of the solids which were accumulated). Insofar as the temperature gradient was several times greater than adiabatic, the vertical displacements of material implied the transfer of a tremendous amount of heat, equivalent to a certain degree to a substantial increase of thermal conductivity.

Oxides of the radioactive elements constitute alloying additions which lower the melting temperature of siliceous material [3]. Therefore, they get into the lightweight melds and are carried to the surface with them. In the course of heating up the Moon, this process must have abetted the undermelting of the external solid crust and lessened the heating of the internal regions of the Moon in which the content of radioactive elements was decreased. In the central portions of the Moon, on account of gravitational differentiation, an iron core grew containing altogether very little of the radioactive elements.

Idealizing the further course of the heating up of the Moon, we assume that the undermelting of the external solid crust has continued up to such time as when it became so thin that all of the heat generated in the core was able to pass through it. If one ascribes to the external layer a constant thermal conductivity independent of temperature, then its thickness D can be calculated from the condition that the heat flux through the surface $4\pi R^2 \lambda(-\partial T/\partial r)$ is equal to the generated heat $4/3\,\pi R^3 H(t)$ [$H(t)$ is the generation of heat per unit volume]. Neglecting the generation of heat within the confines of the considered layer, one can take $-\partial T/\partial r = T_1/D$. By means of the obtained curves of the distribution of temperature with depth one can find approximately the moment of maximum melting t_m, and then, knowing $H(t_m)$, find D. With $\lambda = 0.4^{-2}$ for version $C_{\frac{1}{2}}$, $t_m \approx 1.3 \cdot 10^9$, $D \approx 40$ km, and for version C, $t \approx 0.9 \cdot 10^9$, $D \approx 20$ km.

Such thin solid shells, more dense than the underlying molten material, cannot exist. This calculation shows that at a certain stage of undermelting of the external crust, breaks must have formed in it, on account of inhomogeneities of structure and density, and the pieces which were formed would have sunk and melted, being subjected thereby to the same differentiation as the residual material of the Moon. The exposed molten material, solidifying, also sank, and in its place new lava outpourings arrived. How and when this process stopped in the further cooling of the Moon depends essentially on the degree and character of the differentiation of the lunar material. The very transition from heating and melting to cooling and freezing was related to both the decrease in the overall amount of radioactive elements on account of their decay and to their being carried to the surface in the course of the differentiation of the core.

4. Calculations of the cooling of the Moon. In spite of the uncertainty introduced in the stage of development described above, one can estimate from calculations of the Moon's cooling the present temperature distribution in its core. With 3 to $3\frac{1}{2}$ billion years elapsed after the transition from heating to cooling, the effect of the "initial" (for this calculation) temperature distribution is washed out to a considerable degree and the present temperature distribution depends basically on the distribution of radioactive elements and also on the thermal conductivity.

Calculations of cooling were carried out for the following stratified model of the Moon: The Moon is assumed divided into an iron core (radius 685 km), comprising $^1/_7$ of the overall mass, a jacket and skin. The content of radioactive elements in the nucleus was taken the same as that in iron meteorites according to A. G. Starkova [2], namely (in g/g): U $0.5 \cdot 10^{-8}$, Th $2 \cdot 10^{-8}$, K - 0. In the jacket it was taken similar to that in dunite, namely: U $1.2 \cdot 10^{-8}$, Th $5.2 \cdot 10^{-8}$, K $6 \cdot 10^{-5}$. In the skin it was taken similar to that in a mixture of $^1/_3$ (by volume) granite and $^2/_3$ basalt, namely: U $1.6 \cdot 10^{-6}$, Th $6.6 \cdot 10^{-6}$, K $3 \cdot 10^{-2}$.

The thickness derived for the skin, enriched in radioactive elements, is equal to 17 km for version C and 10 km for version $C_{\frac{1}{2}}$.

For a provisional "initial" temperature distribution, the melting curve for iron at high pressure [6], was used in the core while an initial melting curve obtained in the following way was used in the jacket (the presence of a thin skin was not taken into account). Although the same content of radioactive elements was assumed for the entire jacket, it is supposed that this was somewhat differentiated, the more dense refractory minerals being concentrated below. Therefore, the temperature of initial melting was taken to be 200 degrees below the melting point of dunite at the surface but 100 degrees below it at the boundary of the core. It was assumed that the overall melting proceeds in a temperature interval of 100 degrees. Such a temperature distribution was assumed for the time $t = 1.5 \cdot 10^9$ years after the calculation of cooling was begun.

In this model it was found that the external layers cool quickly while the lower parts of the jacket are heated and partially melt (cf. Fig. 1). The cooling is gradually spreading deeper and at the present time the thickness of the solid crust amounts to 500-700 km. The lower strata of the jacket have continued to be slowly heated up to the present, however, not reaching complete melting. If the radiant heat conductivity plays a moderate role ($\epsilon = 40$, the solid curves), then the iron core also is partially melted (not by more than 15%); if, however, the radiant thermal conductivity is large ($\epsilon = 10$, the dashed curves) then it cools off by approximately 50 degrees.

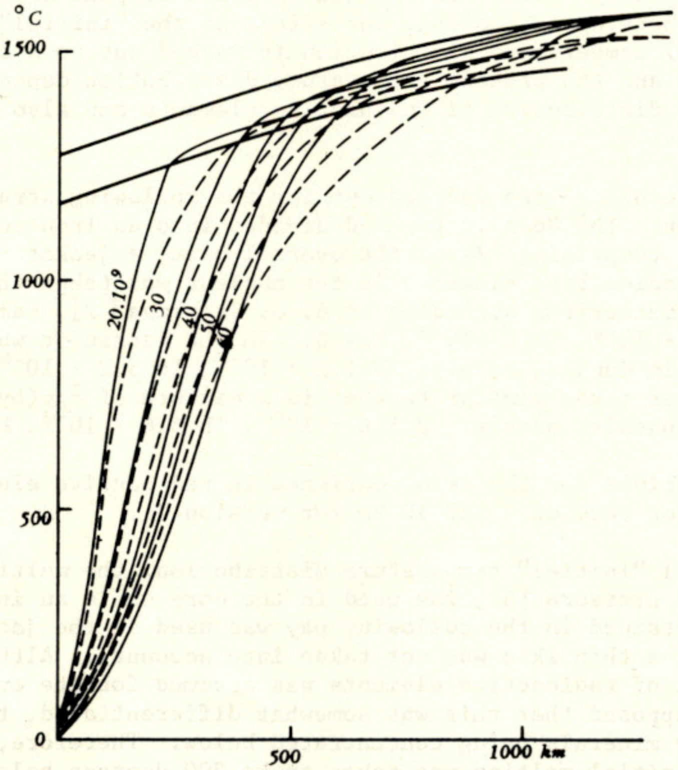

Figure 1

The stratification models for the versions C and $C_{\frac{1}{2}}$ which we examined differ only in the thickness of the skin and, therefore, the temperature distributions in the inside obtained from them are practically identical. Only at the surface is the temperature gradient, and along with it also the heat flux, in version C greater than in version $C_{\frac{1}{2}}$ by 15 to 20%. These fluxes amount to $0.2\text{-}0.25 \cdot 10^{-6}$ cal/cm^2 · sec. The calculation for the case of a surface temperature of -150°C, which corresponds to the polar regions of the Moon, gave a present heat flux 12% greater and a present thickness of the solid external crust 70 km greater than the calculation for the 0°C surface. The temperature increase of the insides, with respect to the "initial" temperature which we assume, obtained during the calculation shows that for the given content and distribution of radioactive elements such an "initial" temperature distribution could not have taken place. The lower portions of the jacket would have had to remain partially molten. In order to get cooling, however, i.e., a solid condition of the entire jacket and core of the Moon, it is sufficient to slightly lower the assumed content of radioactive elements in the jacket, even if only in its lower portions, which is very likely. Insofar as the provisional "initial" temperature distribution expresses itself only slightly in the temperature distribution at the present moment, which depends in the main on the content of radioactive elements, and insofar as the content assumed in our calculations can be considered maximal, one deduces that the Moon is at present solid to a depth of not less than 500-700 km. Under conditions of almost complete gravitational differentiation, one cannot expect the existence in the interior of the Moon of light molten masses which would be able to erupt and gush out through this crust.

LITERATURE CITED

1. V. S. Safronov, Izvest. Akad. Nauk SSSR, Ser. Geofiz., No. 1, 139 (1959).
2. A. G. Starkova, Meteoritika No. 13, 19 (1955).
3. A. P. Vinogradov, Chemical Evolution of the Earth [in Russian] (1959).
4. Macdonald, J. Geophys. Res. <u>64</u>, No. 11 (1959).
5. B. Gutenberg, Internal Structure of the Earth [in Russian] (1949).
6. V. N. Zharkov, Izvest. Akad. Nauk SSSR, Ser. Geofiz., No. 3, 465 (1959).

(<u>Soviet Physics Doklady</u>, January-February, 1961)

THE NATURE OF THE EARTH'S THIRD RADIATION BELT. This article by I. S. Shklovskii, V. I. Moroz, and V. G. Kurt, which was abstracted in SIN, June 1961, is reproduced in its entirety in the following translation from Astronomicheskii Zhurnal, Vol. 37, No. 5, pp. 931-934, Sept-Oct, 1960.

A third and outermost terrestrial radiation belt has been detected (beyond the first two belts); this third belt, consisting mainly of electrons with $E > 200$ ev, has been detected by means of computations based on current measurements made with ion detectors [1]. At $R = 50{,}000$ km, the electron flux is $N < 2 \cdot 10^{7} cm^{-2} \cdot sec^{-1}$, while in the region between 55,000 and 75,000 km, $N \approx 2 \cdot 10^{8} cm^{-2} \cdot sec^{-1}$. This radiation belt is formed by interaction between the permanent weak corpuscular "solar wind" flux and the Earth's magnetic field; this leads to a redistribution of energy from the protons to the electrons. The energy density of the Earth's magnetic field is in accord with the value of the charged-particle flux. The third belt is characteristic of magnetically quiet days. Favorable consideration is given to the premise that the concentration of interplanetary plasma does not exceed the concentration in the solar wind, i.e., ~ 1 cm^{-3}.

Computations based on current measurements made with ion detectors which were installed in Soviet space rockets have led to the detection of a third terrestrial radiation belt in the outermost position [1]. This belt is primarily composed of relatively soft electrons having energies $E > 200$ ev. In the region of the so-called "second" radiation belt, up to a distance of about 50,000 km from the center of the Earth, the flux of electrons with $E > 200$ ev is $N < 2 \cdot 10^{7} cm^{-2} \cdot sec^{-1}$. In the zone $55{,}000 < R < 75{,}000$ km, $N \sim 2 \cdot 10^{8} cm^{-2} \cdot sec^{-1}$. Thus, as has been shown in [1], the second belt must consist mainly of electrons with fairly high energies (about a hundred kilovolts). These electrons move in the Earth's magnetic "trap".

Naturally, the question arises - what is the nature of the electrons which produce the Earth's third (outermost) radiation belt? In this connection, we must first of all point out that solar activity was insignificant and magnetic disturbances were weak at the time of both the January and September Soviet space rocket flights. However, there is presently serious basis for thinking that even during periods of low activity the Sun appears to be a source of constant though relatively weak corpuscular radiation. Following other authors, we shall call this phenomenon the "solar wind".

Biermann's initial estimates of the energy flux in the "solar wind", made by analyzing the acceleration in several types of comet tails [2], were obviously high. The introduction of magnetic hydrodynamics (which Biermann did not do) permits significant lowering of the "solar wind" flux estimates obtained by analyzing the acceleration in comet tails [3]. However, reliable quantitative analyses have not yet been made. It should be noted that this problem is a very complex one. See [4] for details concerning the "solar wind". Since our experiment with ion detectors was carried out during a period of magnetic calm (K-index ~ 0 or 1), the corpuscular field in the vicinity of the Earth should have been primarily due to the "solar wind". Therefore, analysis of the results obtained with the aid of these ion detectors leads to direct determination of the basic characteristics of the "solar wind" as it exists in space in the vicinity of the Earth.

At great distances from the Earth, all detectors registered positively-charged corpuscular fluxes of intensities up to $2 \cdot 10^{8} \text{cm}^{-2} \cdot \text{sec}^{-1}$. This result was obtained during the flight of two space rockets. The energy of these corpuscules, as determined by the experimental conditions, exceeded 15 ev in any case. It is evidently much higher than this value, which was determined by the value of the maximum detector potential with respect to the rocket body. Furthermore, at these distances no case was observed where all the detectors showed simultaneous negative current. Individual detectors showed negative current at times, but this is explained by photoeffect with the second grid [5]. Since the detectors were so positioned on the body of the rocket that at least one of them had to be in the shade at any given moment, only the simultaneous indication of positive currents by all counters could indicate the presence of fluxes of fast electrons. Consequently, we can assert that fast electron fluxes ($E > 200$ ev, which was the potential of the anti-photoelectron grid) with $N > 2 \cdot 10^{7} \text{cm}^{-2} \cdot \text{sec}^{-1}$ were not found in this "remote" zone. Why are they observed in the annular zone of $55{,}000 < R <$ $< 75{,}000$ km? Let us examine the weak corpuscular flux and its "frozen-in" magnetic field moving at a sufficiently great distance from the Earth. Since the velocity of such a flux is several hundred kilometers per second, the kinetic energy of the protons generating this flux is $\sim 10^{8}$ ev, while the kinetic energy of the electrons is very small, ~ 1 ev.

When such a (weak) flux encounters the Earth's magnetic field, it evidently cannot penetrate the latter sufficiently deeply. The penetration depth can be determined from the simple relationship $H^{2}(R)/8\pi \sim \epsilon$, where ϵ is the energy density of the corpuscular flux. In addition, a significant process of energy redistribution from the proton component of the flux to the electron component must occur in the peripheral region of the Earth's magnetic field. The mechanism of this process might perhaps be a plausible modification of the scheme proposed fairly recently by Veksler [6]. As a result of such a redistribution, the electron energy in the flux approaches the energy of the protons, and becomes $\sim 10^2-10^3$ ev. It is precisely for this reason that electrons of relatively high energy will be found in a shell of some thickness surrounding the Earth, while there will be few or no such electrons outside the shell. If we assume, per the results of the detector measurements, that the average flux value of positively charged particles at a distance from the Earth's magnetic field is $\sim 1-2 \cdot 10^8$ $cm^{-2} \cdot sec^{-1}$, while the particle velocity is 500-1000 km/sec, we shall find that the concentration of solar corpuscules undisturbed by the Earth's magnetic field is $\sim 2\ cm^{-3}$, and their kinetic energy density is $\sim 5 \cdot 10^{-9}$ to $2 \cdot 10^{-8}$ erg/cm^3. Such a value of energy density for the Earth's magnetic field occurs at a distance of ~50,000 to 70,000 km. Fast electrons were observed at precisely such a distance during the flight of the second Soviet space rocket. Consequently, two independently measured quantities - the distance of the third radiation belt on one hand, and the flux magnitude of positively charged corpuscles outside the Earth's magnetic field on the other hand - are in good agreement with one another. If the electrons of the corpuscular flux accelerated in the zone of the third radiation belt did not accumulate there, but instead spread out into interplanetary space, then the flux would decrease relatively slowly with distance, such as with R^{-2}. In actual fact, it is 5-10 times smaller at $R \sim 75,000$ than at $R \sim 60,000$ km. This indicates that the accelerated electrons are detained within the region mentioned above for some time, moving in a magnetic field which has already lost its regularity to a considerable degree because of the disturbing action of corpuscular fluxes. Moving in such a field, the electrons will be degraded to relatively low levels only in the region of very high geomagnetic latitudes (75-85°). There they can cause specific geomagnetic phenomena (ionospheric and magnetic disturbances, aurora) of a local character. Since the "solar wind" evidently appears to be a permanent phenomenon independent of solar activity phases, the above-mentioned high-latitude geophysical phenomena should also be of a permanent character. As is known, these particular geomagnetic and ionospheric disturbances are observed in geomagnetic latitudes higher than those of the auroral zone [7,8].

We can draw an important astrophysical conclusion from the fact that high-energy electron fluxes are absent from interplanetary space ($R > 100,000$ km) at the time when fluxes of positively charged particles are observed. If interplanetary space contained a stationary plasma with a density not less than that of the corpuscular flux density, instability would occur during the motion of the latter. In this case, electron plasma vibrations of rapidly increasing wave amplitude would arise in the flux. The period of amplitude increase in the plasma vibrations by a factor of <u>e</u> would be $1/f_{II}$, where f_{II} is the plasma ion frequency. For $n_i \sim 1 - 10^2\ cm^{-3}$, $1/f_i$ is $\sim 10^{-3} - 10^{-2}$ sec. This process of collective interaction between the plasma components would very quickly cause the electron energies in the corpuscular flux to become equal to the proton energies. Not only the interaction of the corpuscular flux with the inhomogeneous magnetic field, but also interactions of the flux with the stationary plasma and with itself lead to energy redistribution between electrons and protons in the flux. From the fact that in interplanetary space ($R \geq 100,000$ km) the ion detectors did not register high-energy electron flux, while they did register positively charged corpuscular fluxes, it follows that the stationary interplanetary plasma concentration does not exceed the corpuscular concentration of the "solar wind", i.e., about one particle per cm^3. From this we immediately come to the conclusion that the ionized gas in interplanetary space exists only in the form of corpuscular fluxes, and that for practical purposes there is no stationary plasma present there. Evidently the corpuscular fluxes, with their "frozen-in" magnetic fields, "sweep up" the interplanetary gas from the inner portions of the Solar System.

On the basis of available experimental material, it is possible to conclude that the third radiation belt represents a formation characteristic of magnetically calm periods of small solar activity. During periods of strong solar activity, when sufficiently powerful corpuscular fluxes invade the Earth's atmosphere, one can expect the third belt (as well as the second) to be greatly deformed and to have its basic characteristics significantly altered. Therefore, there is great interest in investigations made with ion detectors aboard space rockets during periods of high-level solar activity.

LITERATURE CITED

1. K. I. Gringauz, V. G. Kurt, V. I. Moroz, and I. S. Shklovskii, Doklady Akad. Nauk SSSR 132, 1062 (1960).

2. L. Biermann, Observatory 77, 898, 109 (1957).

3. H. Alfven, Tellus 7, 50 (1955).

4. E. R. Mustel', Astron. Zhur. 37, 396 (1960) [Soviet Astronomy - AJ, Vol. 4, p. 380].

5. K. I. Gringauz et al., Doklady Akad. Nauk SSSR 131, 1301 (1960) [Soviet Physics - Doklady, Vol. 5, p. 361].

6. V. I. Veksler, Doklady Akad. Nauk SSSR 118, 263 (1958) [Soviet Physics - Doklady, Vol. 3, p. 84].

7. A. N. Nikol'skii, The Physics of Solar Corpuscular Fluxes and Their Effect on the Earth's Upper Atmosphere [in Russian] (Izd. AN SSSR, Moscow, 1957) p. 144.

8. K. Lassen, Nature 184, 1375 (1959).

9. F. D. Kan, Third Conference on Cosmic Gas Dynamics [Russian translation] (IL, Moscow, 1960) Vol. IV.

10. E. N. Parker, Phys. Rev. 112, 1429 (1958).

(Soviet Astronomy, March-April, 1961)

A NON-ROTATING VENUS? Recent Soviet and American observations of Venus strengthened the view that there may be no day-night sequence on that planet.

Although the results are not conclusive, they would mean that, like Mercury, one side of Venus is continuously roasted in scalding sunlight, whereas the other side is forever frigid. Since Venus is enveloped in clouds, the nature of its rotation has been unknown.

The Soviet observations consisted of radio studies at the Lebedev Institute in Moscow. Their measurements disclosed temperature differences between the light and dark sides of the planet so radical that they implied an extremely slow- or non-existent transition from day to night.

The Soviet results were backed up by American observations consisting of radar signals bounced off the planet by the Jet Propulsion Laboratory in California. The radar experiment was based on the fact that if the planet is turning on its axis at a rate comparable to that of the Earth, one edge would be moving away from the signals at considerable speed and the other edge would be coming towards them. Due to the Doppler effect, the reflected signals would vary in frequency from one edge of the planet to the other. The observed broadening is reported to have been no more than about two cycles per second, suggesting little or no rotation.

The Soviet experiment was based on the fact that a heated substance emits radiation at characteristic radio frequencies, thus permitting temperature studies by radiotelescope. Measurements made by this method are usually consistent with those obtained by optical observations and infra-red emissions. However, because of its clouds, Venus presents many problems.

Radio observations made by the Harvard College Observatory have obtained a Venus temperature of 600° F at 21 centimeter wavelengths. Similar temperatures have been obtained by the Naval Research Laboratory on 3 and 10 centimeter wavelengths.

Scientists at the Lincoln Laboratory of the Massachusetts Institute of Technology have suggested that the surface of Venus may be at room temperature. The radio emissions, they say, could be accounted for by a densely ionized portion of the planet's atmosphere. Such intense ionization of the Venus atmosphere would make it difficult, if not impossible, for a space vehicle on that planet to communicate with the Earth.

It should be pointed out that these results are contradictory to earlier radar measurements made by the Soviets, SIN, June 1961. The earlier measurements determined the planet's period of rotation to be either 9 or 11 days.

We can only hope that future investigation of the planet Venus will yield more consistent results and clear up some of the mystery. (New York Times, June 15, 1961)

TWO MORE NATURAL EARTH SATELLITES. A Polish astronomer, Dr. K. Kordylewski of Cracow Observatory, has discovered two faint, cloudlike objects circling the Earth in the lunar orbit. The find, if confirmed by other astronomers, would mean discovery of the first natural satellites of the Earth other than the Moon.

From the information disclosed, however, it appears that the two objects are almost certainly not solid bodies, but swarms of meteoric material caught in a pocket of low gravitational field strength of the Earth-Moon system, according to Dr. Kenneth L. Franklin of the American Museum - Hayden Planetarium.

The pocket in which the material is trapped is sixty degrees ahead of the Moon. Another such pocket exists sixty degrees behind the Moon in a similar orientation. It is believed that the trailing pocket may also contain satellites. (New York Times, June 23, 1961)

53 SIGNALS FROM SPACE STILL UNIDENTIFIED. British and Soviet scientists were still unable today to identify positively certain signals from outer space as those of the Soviet Venus probe launched February 12.

Working with Sir Bernard Lovell, Director of the Jodrell Bank Radio Observatory, which is trying to trace the probe, are Prof. Alla Masevitch, the woman director of the Soviet tracking stations, and Dr. Jouli Khodarev, an expert on the Venus rocket.

Sir Bernard described the unidentified signals as "extremely short bursts" and said the longest received so far had lasted about fifty seconds.

"I am not prepared to guess at the moment whether these signals come from the Venus rocket," he said.

The Soviet rocket was to have reached the vicinity of Venus about three weeks ago. Radio communications with the probe ended on March 2, but Jodrell Bank has picked up signals on the same wavelength since May 17th. (New York Times, June 12, 1961)

53 SOVIETS, BRITISH FAIL TO CONTACT VENUS PROBE. Final attempts to contact the Soviet Venus probe have ended in failure. After much confusion as to whether the probe had malfunctioned or was deliberately turned off until it passed near the planet (SIN, June 1961), Soviet Prof. Alla Masewitch and Dr. Jouli Khodrev travelled to Jodrell Bank June 9-16 to assist in the tracking. This seemed to be an indication that the Russians are as much in the dark concerning the fate of the probe as the rest of the world. (Aviation Week, June 26, 1961)

49 SOVIETS PROPOSE NEW LUNAR TV SATELLITE. Soviet Scientist N. Varvarov has proposed a satellite equipped with television cameras to photograph the entire surface of the Moon from a circumlunar-polar orbit at an altitude of about 120 miles..

It would take 308 of these 2 hour - 7.5 min orbits to complete the mission, but if the satellite were equipped with small rockets to change the plane of each orbit, the job could be done in no more than eight hours.

20 NEW SOVIET SPACE CHIEF. Konstantin N. Rudnev will succeed Lt. General Mikhail V. Krunichev, who died recently, as chairman of the recently established Soviet State Committee for the Coordination of Scientific Research, the top missile and space post in the USSR (SIN, May 1961 p. 6). Rudnev was formerly chairman of the Council of Ministers for Defense Technology.

50 THRUST OF VOSTOK CARRIER. It is estimated that the carrier vehicle that injected Vostok into orbit with passenger Gagarin developed between 1.3 and 1.8 million pounds of thrust. (Missiles and Rockets, June 12, 1961)

54 SOVIET WOMAN IN SPACE IMMINENT. Government scientists are predicting that the Russians are preparing to put a woman into space probably in the near future. The prediction is based on reports from tracking stations that women's voices are being picked up from launching sites. The reports go on to predict that the space capsule will carry two men along with the woman astronaut. (Washington Daily News, May 20, 1961)