for $e^2 = \frac{1}{2}$ $a = 9c$ $i = 0$

The perturbations of the elements $i^{(L)}$, $\omega^{(L)}$, $\Omega^{(L)}$ increase strongly when $e \to 1$. More detailed formulas will be published in the future.

—*Received January 24, 1961*

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3 Subbotin, M. F., *A Course in Celestial Mechanics* (Moscow-Leningrad, 1937), Vol. 2, p. 323.

Reviewer's Comment

The article treats the motion of an artificial satellite around the spherical earth under the influence of the moon and the sun. Since the coupling effects among the oblateness of the earth and the attraction of the moon and of the sun are neglected, the problem is similar to the lunar theory.

However, in contrast with the lunar theory, expansion of the disturbing function in powers of the eccentricity of the satellite is inefficient or impossible due to a possible large value of the eccentricity. The article avoids this difficulty by carrying out integration with a method of "integration by parts," the eccentric anomaly of the satellite being the variable of integration, and the true anomaly of the moon or the sun, the variable of differentiation. This may be the point of the present article.

The lunar or solar perturbations on the satellite motion are evaluated with the orbital plane of the moon or the ecliptic as the reference plane, respectively, so that Ω, i, and ω should be distinguished in the two cases, and, moreover, when both the lunar and solar perturbations are combined, transformations to a common reference plane are necessary.

Since the main source of perturbations is the oblateness of the earth, the reference plane should be the equatorial plane of the earth even if perturbations due to the oblateness and the attractions of the moon and of the sun are evaluated separately. This may constitute a weakness of the theory.

The article takes into account the influence of the moon through the fourth harmonic of the disturbing function. To preserve the order of the accuracy of the theory, the main perturbation of the moon's coordinates due to the solar attraction should be considered.

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Dosimetric Measurements on the Second Soviet Spaceship Satellite

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1 Introduction

In order to insure the safety of astronauts, a detailed knowledge of the physical properties of cosmic space is indispensable. Study of cosmic radiation, including the following forms of radiation, is of particular importance:

1) Charged particle flux (protons with energies $E_p > 10^8$ ev, in particular), penetrating into the solar system from the galaxy, which is isotropic in space and nearly uniform in time. This form of radiation which, in its narrow sense, constitutes cosmic rays, has been known for a long time and has been comparatively well studied. The cosmic ray intensity in interplanetary space during the years of maximum solar activity constitutes 2 to 2.5 particles$\cdot$cm$^{-2}\cdot$sec^{-1} (1).[1] As the solar activity decreases, the intensity of cosmic rays is doubled (2).

2) Charged particles (protons with energies of about 10^8 ev) and γ quanta, whose appearance is linked with chromospheric flares on the sun. Most of these flares are observed during the maximum period of the 11-year cycle of solar activity. During the last years, several flares were observed after which an increase in the proton flux of 10^3 and higher took place in the near-earth space (3).

3) Radiation originating from the earth's radiation belts. At present the existence of two such fundamental radiation belts has been established (4).[2] The outer belt is at a distance of 13,000 to 50,000 km from the earth in the equatorial plane. It consists basically of electrons with mean energy of the order of 10^5 ev. According to measurements on cosmic rockets, the maximum radiation intensity in the outer belt corresponds to the power of a dose to 10 r/hr (under an average substance layer exceeding 1 g$\cdot$cm^{-2} thickness) (5). The processes linked with chromospheric flares in the sun have a substantial influence on the intensity and position of the outer radiation belt (5). The inner radiation belt is situated at distances from 600 to 4500 km from the surface of the earth (in the magnetic equator plane), and it contains, besides electrons, protons with energies of the order of 10^8 ev. The radiation intensity in this belt is also high; it reaches 10 r/hr for the dose power under 1 g$\cdot$cm^{-2} substance layer (5, 6).[3]

The existence of the forementioned types of radiation, which may present a serious danger for biological objects under specific conditions, requires the carrying out of dosimetric control aboard spacecraft. This requirement becomes particularly obvious if one considers possible rapid variations in intensity of either form of cosmic radiation caused by solar processes.

The second Soviet spaceship satellite was launched on August 19, 1960. Its orbit plane was inclined at an angle of

Translated from *Iskusstvennye Sputniki Zemli* (*Artificial Earth Satellites*) (1961), no. 9, pp. 71–77. Translated by Andre L. Brichant for NASA Technical Information Agency.

[1] Numbers in parentheses indicate References at end of paper.

[2,3] See Editor's Note.

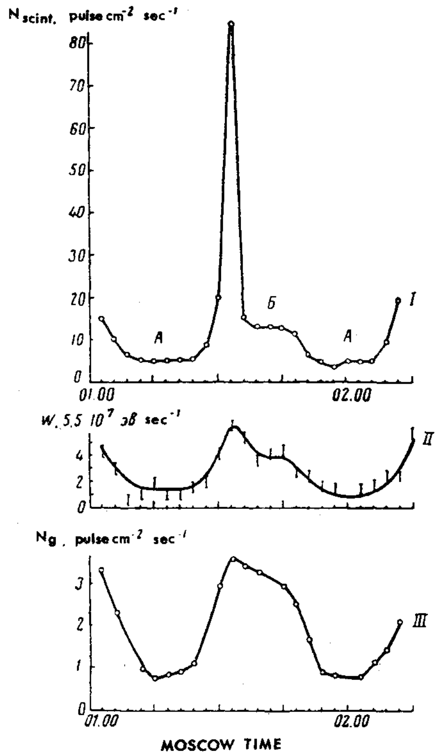

Fig. 1 I—intensity registered by the inside scintillation counter with a kev threshold; II—energy liberated in the NaI crystal per time unit; III—intensity registered by the STS-5 gas-discharge counter

65° to the equator plane, and its average altitude above ground was about 320 km.

Two scintillation and two gas-discharge counters were installed aboard the spaceship (7). One of the scintillation counters was installed outside the instrument compartment and was designed for the registration of soft electrons (with energies $E_e \geqslant 30$ kev), while the remaining counters were placed inside the spacecraft near the capsule with test animals. All information obtained during August 19–20, 1960, by the radiometric apparatus was entered into the memory device and then telemetered to the earth.

2 Experimental Results

Readings of counters placed inside the spaceship for one portion of its trajectory are plotted in Fig. 1. They refer to the gas-discharge counter STS-5 and the scintillator counter (NaI crystal), which registered γ quanta, charged particles (with a 25 kev counting threshold), and the aggregate energy liberation of ionizing radiations in the crystal.

The change in counter readings (about fourfold) during the spaceship's transition from the equatorial region (portion A), to higher latitudes (B) is explained by the latitude effect of cosmic rays. At the same time, the intensity registered by the counter STS-5 increased from 0.8 to 3.2 r/cm$^2\cdot$sec, the energy liberation on the crystal increased from $5.5\cdot10^7$ to 2.2 10^8 ev sec^{-1} and the intensity registered by the scintillator increased from 3.5 to 13 pulse$\cdot$cm$^{-2}\cdot$sec^{-1}. The sharp increase in the scintillator's counting rate over portion B (at 0130–0140 hr), attended by a certain increase in the energy liberation in the crystal and an insignificant increase of the counter's STS-5 counting rate may be explained by spaceship's passing through the lower region of the outer radiation belt (its protuberance, or "tongue," as the author puts it). At electron deceleration in the craft's casing, x-ray radiation appears which is registered quite effectively by the scintillation counter (near 100%). The effective x-ray registration by the counter STS-5 is low (less than 1%). For this reason, the increase in the counting rate in it is small.

The analysis of the outer scintillator counter's readings led to the conclusions that radiation in the belts is anistropic and that the energy flux under a $2\cdot10^{-3}$ g$\cdot$cm^{-2} substance layer is about 10^{10} ev cm$^{-2}\cdot$sec^{-1}.

3 Absorbed Dose

The absorbed dose inside the ship may be determined without a detailed examination of the composition and emission

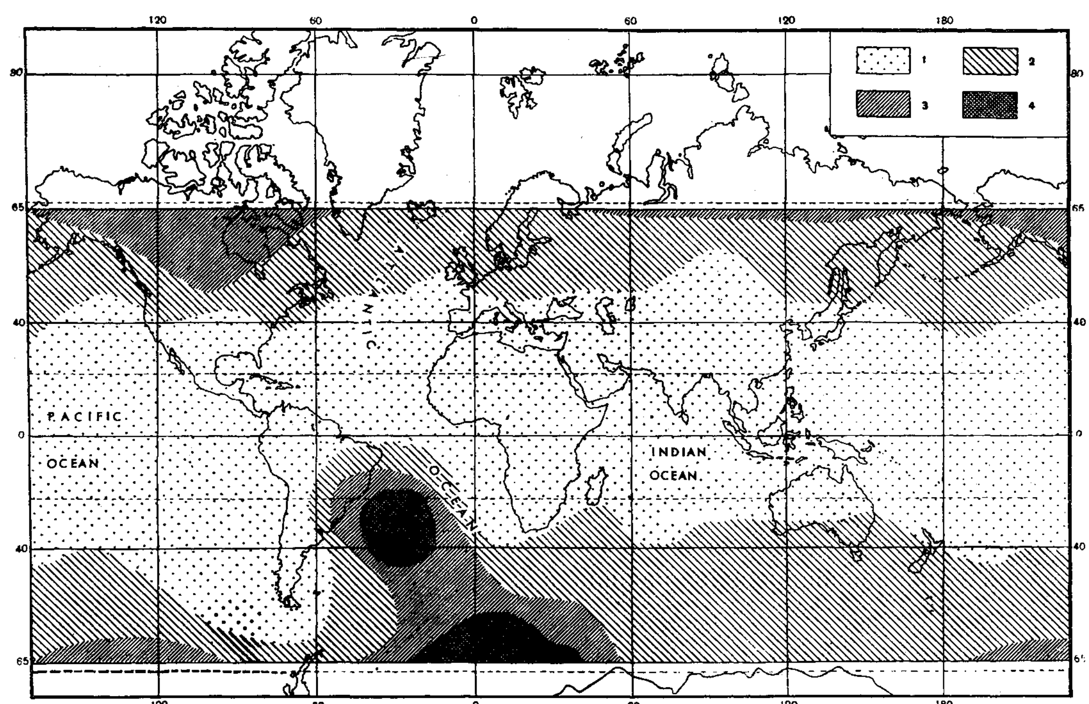

Fig. 2 Distribution of the power of absorbed dose at altitudes of the order of 320 km over the earth's surface according to measurements aboard the second Soviet spaceship satellite: 1) from 3 to 10 mrad per day; 2) from 10 to 20 mrad per day; 3) from 20 to 30 mrad per day; 4) from 30 to 50 mrad per day

spectrum by dividing the energy liberation in the crystal of sodium iodide by the crystal's weight (36.4 g). At the same time, the errors will be much lower as the radiation hardens, i.e., the edge effects in the crystal are less. The average dose absorbed during the flight of the second spaceship satellite and determined in this manner constituted as an average 7 mrad per day.

At the same time, the dose obtained over a single orbit around the earth varied from 0.35 to 0.70 mrad per day, which is explained by latitude and longitude effects of cosmic rays and by the specific pattern of radiation distribution at the given altitude (Fig. 2).

4 Composition of Cosmic Radiation

The flux of primary charged particles in the region of the equator must constitute about 0.05 particles$\cdot$cm$^{-2}\cdot$sec^{-1} (8).[4] As was already noted in Sec. 2, the gas-discharged counter registered in the equatorial region 0.8 particles$\cdot$cm$^{-2}\cdot$sec^{-1}. At the same time, the rate of the scintillation counter reached 3.5 pulse$\cdot$cm$^{-2}\cdot$sec^{-1}. Hence, we may conclude that the radiation registered in the equatorial region during the current experiment was basically of secondary origin and that photon radiation predominates in its composition. Its source might have been the earth's atmosphere or the spaceship's body.

Let N_e be the flux of charged particles and N_γ that of γ quanta inside the spaceship satellite. The counting rate of the scintillation counter will then be (upon reduction to 1 cm^2):

$$n = \epsilon_e \cdot N_e + \epsilon_\gamma \cdot N_\gamma \quad [1]$$

where ϵ_e and ϵ_γ are the effectiveness of charged particle and γ-quanta registration. The energy W liberated in the crystal (cm^2/sec) is

$$W = \epsilon_e w_e N_e + \epsilon_\gamma w_\gamma N_\gamma \quad [2]$$

where w_e and w_γ are the mean energy liberated by one charged particle and by one γ-quantum, respectively.

Hence, considering $\epsilon_e = 1$, we shall obtain

$$w_e = \frac{W}{N_e} - \left(\frac{n}{N_e} - 1\right) w_\gamma \quad [3]$$

The flux of charged particles N_e may be determined by the counting rate of the gas discharge counter m:

$$m = N_e + \eta_\gamma \cdot N_\gamma \quad [4]$$

where η_γ is the counter's STS-5 effectiveness with respect to the γ radiation. (Effectiveness with regard to charged particles is 100%.) Since in our case $N_\gamma \cdot \eta_\gamma \ll N_e$, we may consider $m \approx N_e$.

Assuming now that all the energy liberated in the NaI crystal is dependent upon the charged component, we have $w_e = W/N_e$, which in our case (see Sec. 2) leads to[5]

$$w_e = \frac{8 \cdot 10 \text{ ev cm}^{-2} \text{ sec}^{-2}}{0.8 \text{ cm}^{-2} \text{ sec}^{-1}} = 10^7 \text{ ev}$$

This is the upper limit for the mean energy liberation by a single charged particle. For the relativistic proton the mean energy loss in the crystal of sodium iodide is $0.8 \cdot 10^7$ ev.

[4] To my knowledge this is about an order of magnitude too low. Perhaps the original manuscript has this flux expressed as 0.05 particle/cm^2$\cdot$sec$\cdot$ster.—Reviewer.

[5] It appears that there are wrong numbers in the numerator, but it is difficult to correct, since the author does not give the area of the crystal. It should read:

$$W_e = \frac{5.5 \times 10^7 \text{ ev sec}^{-1}}{A(\text{cm}^2 \text{ area crystal?}) \times 0.8 \text{ cm}^2 \text{ sec}^{-1}}$$

—Reviewer.

If we assume that counter-registered charged particles are relativistic, we may find the upper limit for the energy liberated by one quantum w_γ. From [1] and [3], we have

$$w_\gamma = \frac{W - N_e W_e}{n - N_e} \approx 6 \cdot 10^5 \text{ ev}$$

Thus the radiation registered in the region of the geomagnetic equator consists of charged particles with an ionization near minimum and γ quanta with energy not higher than $6 \cdot 10^5$ ev. Since readings of all counters vary with latitude increase to about the same degree (see Sec. 2), this conclusion may be extended also to those polar regions in which the effect of radiation belts is not felt.

5 Radiation Belts

Analysis of the readings of the second spaceship satellite's various pickups permitted determination of the disposition of radiation belts at an altitude of about 320 km above the earth's surface.

The path of the second spaceship satellite crossed sectors of the outer radiation belt in the regions of Siberia, North America, at the extreme south of the Pacific Ocean, and at the south of Indian Ocean.

The boundary of the outer radiation belt coincides rather well with the 70° magnetic inclination line on the low-latitude side of the northern hemisphere and with the 66° line in the southern hemisphere. The outer radiation belt is bounded on the high-latitude side by the line of polar aurora maximum recurrence.

The counting rate of the scintillation counter sharply increased on entering the area of the outer radiation. The scintillation counter's peak indicated in Fig. 1 corresponds to an 85-pulse$\cdot$cm$^{-2}\cdot$sec^{-1} intensity. The maximum intensity registered by this counter at the spaceship's crossing of the radiation belt reached 570 pulse$\cdot$cm$^{-2}\cdot$sec^{-1}.

Knowing the counting rate accretion Δn and that of energy liberation in the crystal per time unit ΔW on entering the radiation belt, one may determine the mean energy liberated in the crystal for one quantum $w_\gamma = \Delta W/\Delta n$. This gives $w_\gamma = 2.5 \cdot 10^5$ ev for the case considered in Sec. 2. The mean value of w_γ for the second spaceship's flight time constituted $2.0 \cdot 10^5$ ev.

The fact that a harder brehmsstrahlung spectrum was found in the outer radiation belt as compared with that obtained in other works (4,5) may be explained by a greater thickness of matter surrounding the counters in the second spaceship satellite (7).

Knowing the energy W_1 under the layer of $2 \cdot 10^{-3}$ g$\cdot$cm^{-2} (see Sec. 2), the electron intensity in the outer radiation belt may be estimated. Assuming the mean energy of electrons as $E_{cp} \approx 2 \cdot 10^5$ ev, we shall obtain

$$N = \frac{W_1}{E_{cp}} = \frac{10^{10} \text{ ev}\cdot\text{cm}^{-2}\cdot\text{sec}^{-1}}{2 \cdot 10^5 \text{ eV}} \approx 5 \cdot 10^4 \text{ particles cm}^{-2} \text{ sec}^{-1}$$

Near the Brazilian coastline, the second spaceship was entering a region of higher radiation intensity in which protons were present. The presence of protons in the composition of the radiation provided the basis for considering this region to be a part of the inner radiation belt. The power of the dose registered above this region exceeded 50 mrad per day which is seven times higher than the average of the dose power (see Fig. 2).

6 Components of the Aggregate Dose

To estimate the biological effectiveness of the absorbed dose described in Sec. 3, we must know the relative contribution to that dose by the various forms of radiation.

As was shown in the foregoing, the following forms took part in the creation of the aggregate absorbed dose: 1) charged particles of cosmic origin (primary as well as secondary); 2) accompanying γ-radiation particles; 3) γ brehmsstrahlung created by electrons from the radiation belts; and 4) protons of the inner radiation belt. The relative contribution of these forms of radiation to the aggregate energy liberation and, consequently, to the absorbed dose is characterized by the following magnitudes: charged particles of cosmic origin—80%; all forms of γ radiation —15%; protons from the inner radiation belt—5%.

The relative biological effectiveness (RBE) for the γ radiation in the interval observed by us does not exceed 1. For the protons of the inner belt (their energy is of the order of hundreds of Mev), the RBE is not higher than 10. As for charged particles of cosmic origin, it is difficult to draw any conclusion with regard to their RBE at present. At any rate, it is well known (9) that the RBE is estimated at 7 for the primary cosmic particles. Since mesons, electrons, and positrons may be present in the composition of the secondary cosmic radiation, the RBE will be less than 7 for that component. But, despite that, if one takes 7 for the RBE of cosmic charged particles, the biological equivalent of the absorbed dose's power registered on the second spaceship satellite will amount to $\sim$40 mRem per day, and, allowing for the NaI crystal's texture variations, to 50 mRem per day. This is only three times more than the maximum permissible daily dose of outer radiation at lengthy operation under the effect of ionizing radiations (10).[6]

[6] This sentence is confusing, but I cannot correct it, since I am not familiar with Ref. 10—Reviewer.

7 Conclusion

The power of the absorbed dose, measured on the second Soviet spaceship satellite, constituted 7 mrad per day. Under certain assumptions concerning the RBE of cosmic radiation charged particles, this would correspond to 50 mRem per day. Such a dose may be considered relatively safe for long flights along trajectories similar to those of the second Soviet spaceship satellite during the quiet sun period. (It is assumed that the astronaut will have the same protection as that which surrounds the radiometric apparatus aboard the second spaceship satellite.) Chromospheric flares may increase the power of the dose substantially.

—Submitted April 3, 1961

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Editor's Note

This translation was reviewed by Professor Roger L. Arnoldy, School of Physics, University of Minnesota. The reviewer is of the opinion that, although the ostensible purpose of the paper is to arrive at the relative biological effectiveness of the radiation inside the second Soviet spaceship, not much is added to our knowledge, since the dosage depends on the shielding of the spacecraft which was not discussed. Nevertheless, Professor Arnoldy recommended publication because the paper contains cosmic ray and trapped radiation measurements that can be used in a study of these radiations.

The reviewer notes that recent measurements with detectors aboard the Explorer XII earth satellite (1) gave the flux of low energy electrons to be much lower than those inferred from previous data. The Explorer XII detectors and those aboard Explorer VI indicate (2) that electrons up to 5 Mev are present in the outer zone, and that the average energy of the radiation is greater than 100 kev.

Regarding radiation originating from the earth's radiation belts, an addition (3) to the author's Ref. 4 is suggested. Also, Ref. 5 (of which Professor Arnoldy is one of the authors) should be deleted in the context observed at the reviewer's footnote 3 in the text, since the reference did not quote an r/hr dosage for the inner zone.

—IGOR JURKEVICH

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