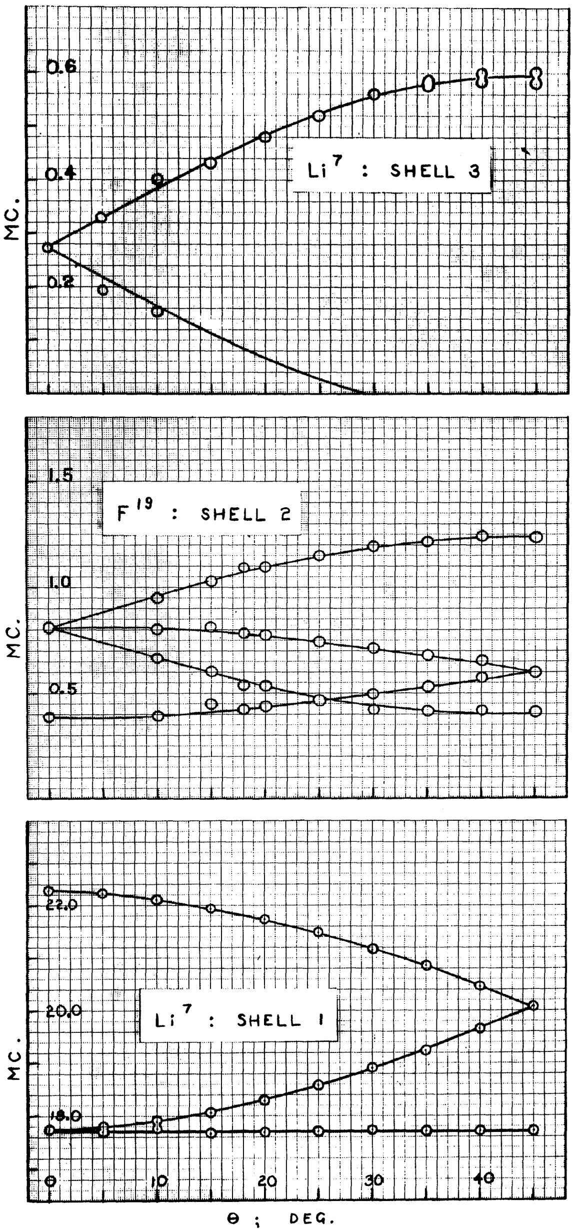

FIG. 1. Variation of double-resonance spectra as a function of the angle θ between H and the [100] axis in the (010) plane. Splitting in shell 3 is due to slight elevation of H out of this plane.

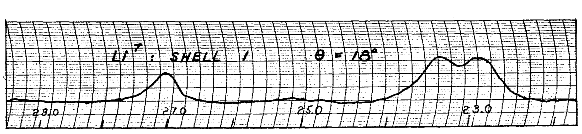

FIG. 2. Portion of double-resonance spectrum due to the first shell, demonstrating the extraordinary line width.

sumption that the width of each of the 19 partially resolved components was predominantly the hyperfine interaction of the F^{19} nuclei of shell 2. As a contrast, the dipolar interaction shows a remarkable persistence. This fact alone made portions of the outer shell spectra observable, their E_{α}^{S} being very much smaller.

It was expected that the lack of axial symmetry of φ about α-n axis would be much stronger in the more closely packed LiF cyrstal than in KCl. No evidence of this appeared either as a quadrupole splitting of shell 1 and shell 3 lines, or as an additional θ-dependence of shell 2 lines. Appreciable axial asymmetry would cause the intersecting low-frequency traces in Fig. 1 to be different at 0° and 45°, instead of being practically equal. Work in progress on the intermediate alkali halides may clarify this point.

It is a pleasure to thank my colleagues F. Adrian, B. S. Gourary and C. K. Jen for many informative discussions.

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"RADIATION BELT" AND TRAPPED COSMIC-RAY ALBEDO*

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The existence of a belt of unidentified ionizing radiation observed by the Explorer satellites[1] has led to speculations concerning the nature and source of this radiation. In a recent Letter Dessler[2] suggests that the radiation is related to auroral particles and is accelerated by hydromagnetic waves. This suggestion runs into several difficulties: (i) Hydromagnetic waves traveling along lines of force are probably the accelerating agent for auroral protons,[3] but only in the auroral zone (60°-70° magnetic latitude), where both waves and particles are trapped and can exchange energy.[4] (ii) Waves probably do not propagate perpendicular to the lines of force because of the strong reduction in conductivity due to a large neutral atom component in the exosphere.[4] (iii) In any case such waves could not accelerate particles very effectively at the equator and at the same time keep the particles trapped. (iv) The relative constancy of the observed radiation belt is difficult to reconcile with auroral phenomena, or indeed any solar corpuscular activity, and suggests instead a constant source for at least part of the radiation. (The observations certainly do not exclude a 27-day recurrence; furthermore auroral radiation might somehow diffuse to the equator.)

We have therefore been tempted to apply some earlier work[5] on cosmic-ray albedo, and particularly on albedo trapped in the geomagnetic field, to see how far it accounts for the satellite observations. Irrespective of such observations, however, the existence of trapped albedo is a necessary consequence of the impact of primary cosmic rays on the earth. Calculations (previously unpublished) were therefore started in connection with cosmic-ray experiments planned for the Farside Rocket (a 4000-mile Air Force rocket eventually fired in the Pacific in November, 1957).

The trapping of charged particles in the geomagnetic field, their diffusion, and eventual leakage has been studied in great detail for low-energy (~20 kev) solar corpuscular radiation. The azimuthal drift of these trapped protons leads to a Störmer ring current which is responsible for magnetic storms.[4] A fraction of the particles is accelerated to auroral energies (~500 kev) by hydromagnetic waves.[3]

We can apply similar considerations to trapped cosmic-ray albedo. We first assume (and justify it below) that the particles have a radius of curvature

$$\rho = (pc/e)\,(1/300\,B) \ll B/\mathrm{grad}\,B = r/3, \qquad (1)$$

so that their magnetic moment $\mu = \frac{1}{2} m v_\perp{}^2/B$ is a constant of the motion, and that therefore[6]

$$\sin^2\alpha/B = \sin^2\alpha_0/B_0 = \mathrm{constant}. \qquad (2)$$

B_0 and α_0 refer to the field and the particle's pitch angle in the equatorial plane. If the line of force intersects a given altitude level at latitude λ, then the range of pitch angles of particles which stay trapped above this level is

$$\pi/2 \geq \alpha_0 \geq \alpha_c = \sin^{-1}[\cos^3\lambda\,(1+3\sin^2\lambda)^{-\frac{1}{4}}]. \qquad (3)$$

We can now calculate the mean lifetime in the trapping region, as well as the leakage into the lower atmosphere where the particles are assumed to die. We also calculate the pitch angle distribution $n(\alpha_0)\,d\alpha_0$ giving the concentration of particles per cm^3 in $d\alpha_0$ at α_0. Let

$$(\Delta\alpha)^2 = Dt, \qquad (4)$$

where D is a diffusion coefficient in pitch angle. Assume an isotropic source function

$$q(\alpha_0) = Q\sin\alpha_0\,. \qquad (5)$$

Then we can set up a (steady-state) diffusion equation in α:

$$\partial n/\partial t = \mathrm{div}\,j + q = 0\,. \qquad (6)$$

Here

$$j = D\,\partial n/\partial\alpha, \text{ and } \mathrm{div}\,j = \frac{\partial}{\partial\alpha}\left(D\frac{\partial n}{\partial\alpha}\right) = D\frac{\partial^2 n}{\partial\alpha^2}. \qquad (7)$$

We finally have

$$D\,\partial^2 n/\partial\alpha^2 + Q\sin\alpha = 0. \qquad (8)$$

Introducing the boundary conditions

$$\partial n/\partial\alpha = 0 \text{ at } \alpha = \frac{\pi}{2};\ n(\alpha_c) = 0, \qquad (9)$$

and integrating, we find the pitch angle distribution at the equator (see Fig. 1):

$$n(\alpha_0) = (\sin\alpha_0 - \sin\alpha_c)\ Q/D. \qquad (10)$$

The rate of leakage of particles is $j(\alpha_c) = Q\cos\alpha_c$ and this equals the total production rate. The total concentration of particles N (per cm^3) is given by

$$N = 2\int_{\alpha_c}^{\pi/2} n(\alpha)\,d\alpha$$

$$= 2\,[\cos\alpha_c - (\sin\alpha_c)\,(\pi/2 - \alpha_c)]\,Q/D, \qquad (11)$$

and the mean lifetime T is determined as

$$T = N/Q = 2\,[\cos\alpha_c - \sin\alpha_c\,(\pi/2 - \alpha_c)]/D. \qquad (12)$$

The function in square brackets in (12) increases from 0 at $\lambda = 0$ to 1.0 at $\lambda = 90°$. Its variation can generally be neglected in relation to D and Q; it can be taken ~ 0.1.

In the simple derivation above we have neglected the variation of D due to a difference in atmospheric density along the particle's trajectory. Since $\alpha_0 = \alpha_c$ corresponds to particles reaching the lowest point of reflection, they will be most affected by the higher density. Its effect on $n(\alpha_0)$ is indicated in Fig. 1 by the dashed curve. Magnetic bremsstrahlung loss and catastrophic removal of particles are discussed elsewhere[7] and shown to be small.

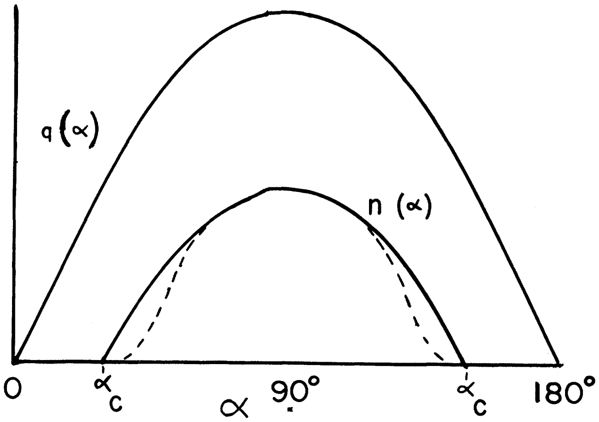

FIG. 1. The assumed isotropic source function $q(\alpha_0)$ and the resultant angular distribution of trapped particles $n(\alpha_0)$ plotted against the particles' pitch angle when they cross the plane of the magnetic equator. Note the absence of particles with $\alpha_0 < \alpha_C$ due to escape from the trapping field. The dashed curve indicates the effect on $n(\alpha_0)$ of the variation of atmospheric density with altitude.

The diffusion coefficient D used above has been evaluated for the mixture of atoms and ions present in the exosphere, using the theory for scattering of relativistic particles under screened and unscreened conditions.[7] Appropriate mean values for the inner exosphere and outer exosphere (where hydrogen predominates) are

$$D_{in} = 20\, cd/\gamma^2; \quad D_{out} = 10\, cd/\gamma^2, \qquad (13)$$

where d is the density in g/cm^3, and $\gamma^2 = (1-\beta^2)^{-1}$. The transition altitude (~1000 km) should therefore show itself as a sharp increase in N, assuming other quantities in (11) to be constant. If Q is independent of d (or if its dependence is known), then the increase of N with altitude can be used to derive the variation of density with altitude, thereby the scale height, and hence the kinetic temperature of the base of the exosphere.

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*Supported by the Air Force Office of Scientific Research.

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[2] A. J. Dessler, Phys. Rev. Lett. 1, 68 (1958).

[3] S. F. Singer, Bull. Am. Phys. Soc. Ser. II, 3, 40 (1958).

[4] S. F. Singer, Trans. Am. Geophys. Union 38, 175 (1957); a more detailed paper has been submitted to J. Geophys. Research.

[5] See S. F. Singer, in Progress in Elementary Particle and Cosmic-Ray Physics (Interscience Publishers, New York, 1958), Vol. 4, pp. 263-8; as well as earlier work by H. Griem and S. F. Singer, Phys. Rev. 99, 608, (1955).

[6] H. Alfvén, Cosmical Electrodynamics (Oxford University Press, Oxford, 1950).

[7] A more detailed account of this work is being submitted to the Journal of Geophysical Research.

CORRELATION OF COSMIC-RAY INTENSITY AND SOLAR ACTIVITY

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The present International Geophysical Year was chosen to include the most likely period of maximum activity of the sun. It is probably too early to tell whether or not the maximum of the current cycle has yet been reached, but it is already certain that the yearly average of the Zurich sunspot numbers for 1957 is much higher than ever before observed.[1] It is therefore of interest to see what has been the effect on cosmic rays.

In analyzing the data for long periods of time from the Carnegie Institution ionization chambers, Forbush[2] in 1954 found an inverse relationship between solar activity, as measured by Zurich sunspot numbers, and cosmic-ray intensity. Also Neher and Forbush[3] showed in 1952 that there was a good correlation for at least a few weeks between the ionization due to cosmic rays at balloon altitudes at geomagnetic latitude 56°N, the ionization at ground level at Cheltenham and Huancayo, and the neutron intensity at Sacramento Peak, New Mexico, and Climax, Colorado.

It is the purpose of this letter to point out the following relations: (a) The yearly averages of the ionization data at Huancayo correlate very well with the average value of the ionization measured at 90 000 ft, or 15 g cm^{-2} at Thule, Greenland. These latter values were made over about a 2-3 week period during the month of August of the particular year.[4] (b) There is also a very good anti-correlation with solar activity