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MOMENTUM SPECTRUM OF THE VAN ALLEN RADIATION

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If charged particles are injected at a certain point in a variable magnetic field, which has a number of scattering centers, the energy of the particles will increase (by "magnetic pumping") and at the same time the particles will diffuse away from the point of injection. A study of this process[1] shows that near the point of injection the momentum spectrum of the charged particles is $N = \text{const}\, p^{-n}$, with $n = 2 - \varphi$. Here φ is a small negative number (usually $-1 < \varphi < 0$) depending in an insensitive way on the properties of the scattering centers. In this way it is possible to explain the remarkable fact that the momentum spectrum of cosmic radiation obeys a power law, $N = \text{const}\, p^{-n}$, with n approximately constant ($=2.6$) from 10^{10} to 10^{19} ev/c.

It is of interest to see whether the Van Allen radiation can be explained by the same mechanism, which according to the description above is responsible for the acceleration of cosmic radiation. If this is true we should expect that the spectrum of the Van Allen radiation should obey the same power law as cosmic radiation.

The spectrum has recently been measured by Freden and White[2] who have plotted it as a function of the energy. If instead we plot it as a function of the momentum, we obtain the graph shown in Fig. 1. The straight line in the figure represents $N = \text{const}\, p^{-n}$, with $n = 2.6$ (obtained from measurements of cosmic radiation).

The fact that the measured points fall close to a straight line which has the same slope as for cosmic radiation, indicates that the theory may

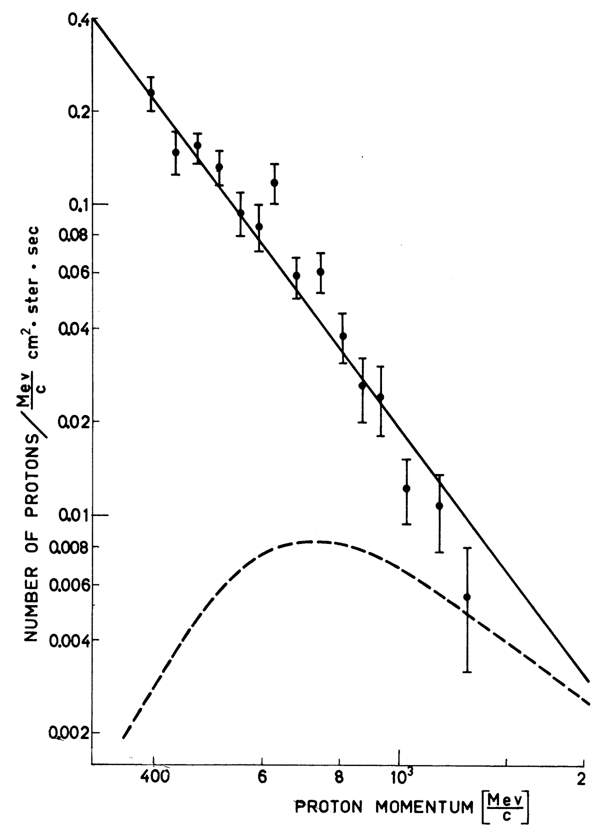

FIG. 1. Observational spectrum according to Freden and White, plotted with proton momentum as abscissa. Full line: $N = N_0 p^{-n}$ with $n = 2.6$ in agreement with cosmic-ray spectrum. Dashed line: Theoretically predicted spectrum [according to (1)] at some distance from the maximum of the Van Allen belt.

explain even the origin of the Van Allen radiation. This means that the particles are accelerated by variations in the earth's magnetic field. At the same time they diffuse away from the region of injection which defines the location of the maximum intensity.

The existence of two belts of radiation indicates that particles are injected in two different regions. It is natural to assume that the inner belt derives from the injection of particles from the ionosphere, possibly with some connection with the equatorial electro-jet.

The theory predicts that at a distance x from that line of force which passes through the point of injection, the spectrum should be

$$N = \frac{\text{const}}{p^{2-\varphi}} \exp\left(-\frac{x^2}{\kappa p^{1-\varphi}}\right), \qquad (1)$$

where κ is a constant.

Applying this to the Van Allen radiation, we should expect a spectrum as shown by the dashed curve in Fig. 1 with a cutoff at a momentum which depends on the distance from the point of injection. A reasonable measure of this distance would be the distance in the equatorial plane from that shell of magnetic field lines, at which the injection takes place. This prediction could be checked by future observations. For a more refined comparison the homogeneous field which is used in the model of the theory should be replaced by the earth's dipole field.

[1]H. Alfvén, Tellus 6, 232 (1954); 11, 106 (1959); Max Planck Festschrift 1958, p. 83.

[2]S. C. Freden and R. S. White, Phys. Rev. Letters 3, 9 (1959).

OPTICAL PUMPING IN CRYSTALS

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An estimate was made of the expected population change in the ground state of a crystal due to optical pumping. Kastler's original pumping scheme[1] assumed that the ground state and an optically excited state are characterized by J values and have fairly pure m_J sublevels. Also, one needs a crystal with relatively long relaxation time T_1, as is the case for an S ground state.

Thus, Series and Taylor[2] have suggested optical pumping of Eu^{++} in CaF_2 or $SrCl_2$ and the observation of possible changes of magnetic-resonance absorption. The free Eu^{++} ion has intense lines in the 2300-2500 A region[3] ascribed to electric dipole transitions between the $4f^6 5d$ configuration and the $4f^7$ ground state $^8S_{7/2}$, presumably corresponding to the 3200 A and 2480 A bands in aqueous $EuCl_2$ solution observed by Butement[4] and the 3380 A band observed in a CaF_2:Eu^{++} crystal by Series and Taylor. Although correlation between the observed absorption spectrum and specific excited states is conjectural, we shall consider, as an example, optical pumping of the transition $J=7/2$ to $J=7/2$ between the ground state and the $^8P_{7/2}$ excited state.[5] One knows the transition probabilities KBI (B = coefficient of absorption and $K = 7/84,\ 12/84, \ldots$[6]) between a ground-state sublevel m_1 and an excited sublevel $m_2 = m_1 + 1$ due to irradiation with circularly polarized light of intensity I. Likewise known is the relative distribution of spontaneous emission from m_2 to $m_1 = m_2 - 1$, m_2, $m_2 + 1$. If one assumes a common relaxation time T_1 between all ground-state sublevels, and one writes the rate of change of sublevel populations due to both pumping and relaxation, one obtains in the steady state for the ground-state populations[7]:

$$N_m - N_{m-1} = (N_m - N_{m-1})_0 + pBIT_1 N, \qquad (1)$$

where $(N_m - N_{m-1})_0$ is the Boltzmann equilibrium population difference, N is the paramagnetic-ion concentration, and p is a pumping coefficient listed in Table I. Similar orders of magnitude may be expected for transitions to the other optical states ($J = 5/2, 9/2$).

Series and Taylor estimate the oscillator strength of the 3380 A band in the CaF_2:Eu^{++} crystal comparable to Butement's values[4]