Radiation Belt

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Since Professor Singer gave a general picture on the radiation belts, I shall only give a brief remark on the effects of magnetic disturbances on the radiation belts, especially on the *E-3*. Although this problem might be regarded as a special one, the very nature of the radiation belts would be implied here.

A statistical study of this phenomenon has been presented by Yoshida, Matuura and Nagata[1] in this Conference. Adding an experimental evidence obtained by Winckler[2], I dare to draw the following crude picture.

(1) The decrease of the intensity of electrons with energies greater than 1 MeV takes place in association with the main phase.

(2) The increase of the intensity of electrons with energies smaller than 1 MeV in the same period seems to be inferred from the X-rays observed by Winckler[3].

(3) The increase of the electron intensity in a wide energy range occurs preferentially near the equator when the magnetic field shows a rapid variation[4].

The above features are shown schematically in Fig. 1 and may be accounted for in terms of the following three causes.

(a) The intensity decrease with decreasing magnetic field strength (3 cases) is suggested by Yoshida *et al.*[1], and this explanation seems to be agreed by everybody.

(b) The acceleration of electrons is caused by the rapid variation of the magnetic field; accordingly, the energy of an electron increases with time.

(c) The albedo neutrons produced by solar protons, suggested by Singer[4], cannot be ruled out, because the intensity increases thus far observed are all associated with polar-cap blackouts.

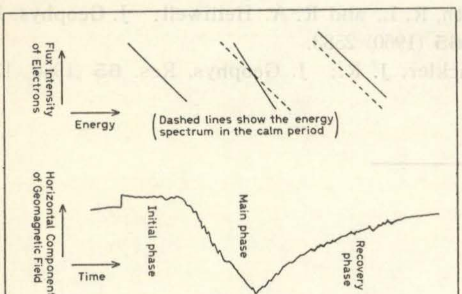

Fig. 1. Variation of the energy spectrum of electrons due to the magnetic storm.

Since the situation is clear about (a), and (c) has been just discussed by Singer, I shall restrict myself to (b). Although the increase is attributed to the solar electrons, by Yoshida *et al.*[1], because it seems to have started right after the solar flare having occurred towards the end of the preceding magnetic storm, one may also speculate, naively looking at the magnetogram, that the increase is associated with the rapid variation of the magnetic field. This magnetic disturbance seems to be responsible for the acceleration of electrons, consequently the increase of their intensity, as discussed by many people in this Conference.

Before going farther, I would like to add a remark that the acceleration and the trapping do not necessarily exclude each other, as has so far been disputed. The trapping of a particle in a region of higher magnetic field strength seems to be possible in association with the acceleration. The trapping occurs when a particle drifts from one magnetic line of force to another. Looking from the particle, the field strength, H, increases as the trapping proceeds towards a region of high H. Then the momentum of the particle, p, may increase satisfying the betatron acceleration condition $p^2 \propto H$. The energy of an electron in the Chapman belt where $H \simeq 10^2\gamma$ and $E=1\sim10$ keV may increase to $10\sim100$ keV in the *E-3* belt where $H \simeq 10^3\gamma$. However, details of the trapping mechanism remain to be studied more carefully.

The acceleration may be caused by the magnetic pumping; for the sake of concreteness, I refer to the acceleration rate predicted by the gyro-relaxation mechanism,

$$a \simeq 10^{-1} A^2 \omega_s,$$

where A is the relative amplitude of the varying field and ω_s the frequency of scattering of a particle by magnetic irregularity. For $A \simeq 10^{-1}$ and $\omega_s \simeq 10^{-2}\,\text{sec}^{-1}$, the characteristic time for acceleration is estimated as about a day. This seems to explain the gain of relativistic energy about a day after the rapid magnetic disturbance begins, in accordance with (3). The acceleration to non-relativistic energy, as expected in (2), should take place earlier.

The acceleration hypothesis appears to be consistent with Simpson's observation[5] that the intensity increase begins near the equator, as described in (3), because the increase of pitch angles takes place in association with the increase of the transverse energy.

Finally, a brief comment will be made concerning the non-adiabaticity. In defining the adiabatically invariant quantity, one cannot simply take $p^2 \sin^2\theta / H$ but should take the invariant integral $J = \oint p dq$.[6] This deviates from the conventional one by ΔJ, so that the invariance of J does not always lead to the mirror reflection at a definite position. This implies that the turning point is displaced according to $\Delta J/J$; if the energy of a particle changes, the so-called non-adiabaticity results in the drift of a particle from one magnetic line of force to another. If the energy change is negligible, the displacement of the turning point may be only an effect of interest. The displacement depends on the phase of the gyrating motion and is predictable if one follows the trajectory of a particle. Actually, however, a weak perturbation may cause phase changes, so that the value of $\Delta J/J$ may distribute at random. After n oscillations the particle may be lost from the mirror trapping, provided

$$n(\Delta J/J)^2 \simeq 1.$$

According to our rough estimate[6], $\Delta J/J \simeq \rho/R$, where ρ is the gyration radius and R the radius of curvature of a magnetic line of force. For a proton of about 100 MeV in the inner belt, therefore, the trapping time against the non-adiabaticity is estimated to be of the order of a month. Although I cannot give any quantitative result, I hope this would make clear the effect of the so-called non-adiabaticity.

References

1) S. Yoshida, N. Matuura and T. Nagata: This conference, RB II-2-6.
2) J. R. Winckler: RB II-2-1.
3) Professor Simpson pointed out in his private conversation that the electrons responsible for the intensity increase could be interpreted as due to protons. He also remarked that the increase coincides with a rapid magnetic disturbance.
4) S. F. Singer: This conference, RB II-2-4.
5) J. A. Simpson, C. Y. Fan and P. Meyer: This conference, RB II-2-11.
6) S. Fukui, S. Hayakawa, H. Nishimura and H. Obayashi: This conference, RB II-2-8.

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The study of radiation belts substantially adds to the knowledge we are able to acquire, of the properties of cosmic space in the intermediate vicinity of the earth.

At present one can consider it an established fact that the inner radiation belt is evolved by the decay of neutrons from the atmosphere affected by cosmic-ray bombardment. The compositions of the radiations, the energy spectrum of protons and the great permanency of the inner radiation belt are well consistent with the neutron hypothesis.

Mention, however, should be made of one observation that has yet to be accounted for.