Sonett, C.P.: In answer to Dungey's question: The work of Gardner, *et al.* has shown the possibility primarily of proton acceleration in a collisionless shock in a binary plasma. However they have also obtained solutions where the rôle of protons and electrons are reversed as to heating. Which case or whether both happen in the exosphere is not known. The evidence of Pioneers I and IV would suggest that the collisionless shocks which exist at times do accelerate electrons.

Gold, T.: The electric field necessarily associated with ionospheric and magnetospheric motions, (as discussed in J.G.R., Motions in the Magnetosphere) are large enough to destroy the stability of current rings due to low energy particle. I would therefore suppose that this effect would dominate for the destruction of the ring current if this is due to kilovolt or tens of kilovolt particles. I am not sure I would agree that "trapped particles" are responsible since the quality of trapping for low energy particles is so very poor. Why does Professor Singer not consider this loss mechanism for the recovery phase?

Singer: It is quite necessary to establish first of all to what extent magnetospheric motions exist, granted that they are possible.

Next one must establish the removal time scale which they would lead to if they were the only loss mechanism of the main phase particles. Then this time must be compared with other removal time scales (*e.g.* charge exchange) to see if it is shorter. As far as I know this has not been carried out by any one.

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INTERNATIONAL CONFERENCE ON COSMIC RAYS AND THE EARTH STORM Part I

I-3-P2. Theory of Magnetic Storms

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It was pointed out several years ago that the geomagnetic storm phenomenon should be regarded as a hydromagnetic deformation of the geomagnetic field (Parker, 1956)[1]. The observed distortions of the field are the result of stresses produced by the enhanced solar corpuscular radiation, or solar wind, and by the heated gases contained within the field. The observed geomagnetic storm consists of rapid and large amplitude fluctuations (with periods from a fraction of a second to an hour) superimposed on a general increase of the horizontal component of the field at low and middle latitudes (the initial phase), followed by a general decrease (the main phase).

It now is generally assumed that the onset of the enhanced solar wind, or corpuscular radiation, is in the form of a shock wave. The general shape of the boundary of the quiet-day geomagnetic field has been investigated theoretically (see for instance Beard, 1961[2]; Hurley, 1961[3]) and it has been shown (Dessler, *et al.*, 1960[4]) that the observed rise time of the sudden commencement of the geomagnetic storm can be explained as the result of the shock wave sweeping past the geomagnetic field in interplanetary space. The initial phase appears to be a general compression of the field as the result of the increased impact pressure of the enhanced solar wind behind the shock (Chapman and Ferraro, 1932[5]; Parker, 1958[6]). The rapid fluctuations of the active phase of the storm probably result from a combination of irregularities in the solar wind and the general instability of the field—wind interface (Parker, 1958).[6]

The main phase of the geomagnetic storm represents an outward expansion of the field, so that it cannot be the result merely of increased impact pressure of the enhanced solar wind. Its origin must lie elsewhere. Singer (1957)[7], modifying an earlier suggestion by Alfvén (1950)[8], proposed that the main phase is the result of energetic charged particles trapped in the geomagnetic field. The stresses exerted by the particle motions lead to a number of distortions (Dessler and Parker, 1959)[9]. The individual cyclotron motion is responsible for a diamagnetic effect, which increases the field everywhere outside the region of the particles. Diamagnetic repulsion and the centrifugal force of the particle motion along the curved geomagnetic lines of force both contribute an outward force which decreases the field everywhere inward from the region of the particles. The outward force dominates the diamagnetic effect so that there results a reduction ΔB of the horizontal component B of the order of magnitude of $\Delta B/B \sim E/E_m$, where E_m is the total kinetic energy of the trapped particles and $E_m \cong 8\times10^{17}$ joules is the total energy of the geomagnetic dipole field outside the surface of Earth. Thus a main phase decrease $\Delta B \sim 10^{-2}B$ for a large storm is the result of some $10^{15}-10^{16}$ joules of trapped particles. Observation suggests that the bulk of the particles are principally protons with energies of the order of kilovolts. Presumably the particles are in the general vicinity of 3—5 Earth's radii, since the tip of such a belt of particles would account for the reduction of vertical intensity at the surface of Earth in latitudes 55—67°. The relaxation of the main phase, with a characteristic time of the order of a day, follows to a large extent as the result of charge exchange with the neutral hydrogen in the region 3—5 Earth's radii.

Somewhat similar ideas of the main phase were proposed by Akasofu (1960)[10] though for some reason he associates the main phase with the Van Allen particles. His calculations neglected an important term in the current density, which has been corrected in a more recent paper with Chapman (Akasofu and Chapman, 1961)[11] where the effects of trapped particles of several hundred kev between 5 and 8 Earth's radii are discussed.

It was originally suggested (Singer, 1957[7]; Dessler and Parker, 1959[9]) that the trapped protons were injected by the solar wind, merely retaining a portion of their initial 10^3 km/sec velocity. The suggestion now appears dubious, and it is proposed (Dessler, Hanson and Parker, 1961)[12] that the protons are heated to their kilovolt temperatures through the dissipation of shock waves generated by the enhanced solar wind during the active phase of the storm. The heating by shock dissipation is presumably similar to shock heating of the solar corona.

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Discussion

Singer, S. F.: Could you explain why you assume that the shock wave dissipates its energy on the acceleration of protons? Why are not electrons accelerated as discussed by Gardner *et al.* (of NYU group) (in Proc. 2nd International Conference on Peaceful Uses of Atomic Energy, 31,230, 1958)?

Parker, E. N.: The proportion of the energy going into electrons as opposed to protons is a function of the Mach mumber (see paper by C. S. Morawetz, July issue of Physics of Fluids, 1961). My remark that the protons receive most of the heating was based on the general consideration that a shock of velocity v may impart motions to the particles of the order of v. On this basis we expect the protons to receive most of the energy because of their greater mass.

Dungey, J. W.: The formulation in terms of $p_{//}$ and $p_{\perp}$, used by fusion theorists, is convenient for the ring-current problem with axial symmetry, the equation in the equatorial plane is integrable.

If Prof. Parker's system is correct (100/cc at 1 kev) this is encouraging for mirror machines.

Slutz, R. J.: Prof. Singer has emphasized his viewpoint of the difficulty of explaining a negative kick before the sudden commencement from simple geomagnetic field compression. Could Prof. Parker give his views on this point?

Parker: I agree with Prof. Singer that the negative kick is a phenomenon which has not yet found suitable explanation. I think that Prof. Singer mentioned the negative kick to illustrate the complexity of the many different facts at the magnetic storm problem and to emphasize that the basic and idealized mechanisms currently under discussion need considerable extension before the theory will be complete.

Kellogg, P. J.: I would like to ask Dr. Parker how he reconciles his statement that the energy of the outer Van Allen zone is too small to produce appreciable magnetic effects with Dessler's published remark that fluxes measured by the Minnesota and Iowa groups are impossibly large because they would produce a larger magnetic effect than is observed.

Parker: We don't believe the Minnesota results.

JOURNAL OF THE PHYSICAL SOCIETY OF JAPAN Vol. 17, SUPPLEMENT A-I, 1962
INTERNATIONAL CONFERENCE ON COSMIC RAYS AND THE EARTH STORM Part I

I-3-P3. Particle Precipitations and Geomagnetic Storms*

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It has been known for many years that solar corpuscles streaming out from the sun produce various electromagnetic disturbances in the earth's upper atmosphere. In particular, an intense solar flare produces not only a plasma cloud, which is responsible for a geomagnetic storm, but also very high energy particles known as solar cosmic rays. These energetic particles are mostly protons with energies from 10 to 1000 Mev. They penetrate into the polar ionosphere causing polar cap absorption. It is also known that energetic electrons are precipitated into the auroral zone during the storm.

It is evident that the earth's upper atmosphere is exposed to particles with a very wide energy spectrum. The behavior of particles in the geomagnetic field differs considerably depending on their energies. This information may be used to explore the geomagnetic field during magnetic storms.

One of the important basic problems in the theory of geomagnetic storms is to find whether those particles entering into the geomagnetic field behave like single particles or like a conductive plasma. As shown in Fig. 1, for a typical energy versus density spectrum of solar flare particles, there is a certain critical density below which the electromagnetic interaction becomes negligible and the motion of the particles will then be nearly independent of each other. This limit of the so-called Störmer particles, occurs in the energy range of 10 to 100 Mev. Particles with energies less than this must be regarded as a conductive plasma rather

* No manuscript has been received and the preprint is reprinted.