plasma is found. However, the experimental data are still too crude to check the presumed pressure balance quantitatively.

During the active life of Explorer X, a sudden commencement was recorded on the earth. Simultaneously Explorer X recorded an increase in the strength of the magnetic field, in the proton flux, and in the mean energy of the individual protons. Presumably the sudden commencement was due to the arrival of a shock front initiated by a solar flare that had occurred about 29 hours earlier. From the transit time, one finds a value of $1.5\times10^{8}\,\mathrm{cm\cdot sec^{-1}}$ for the velocity of this shock front. Behind the front, one would expect to find a plasma moving with a velocity somewhat smaller than that of the front, but of the same order of magnitude. Protons with velocity of the order of $1.5\times10^{8}\,\mathrm{cm\cdot sec^{-1}}$ have energies of the order of 10,000 ev. On the other hand, the protons detected by the plasma probe had energies of the order of 1,000 ev. Moreover, while the existence of a second group of protons with energies of the order of 10,000 ev could not be ruled out, it is certain that the recorded protons were not the low-energy tail of a broad distribution peaked at about 10,000 ev. The theoretical interpretation of this result is still unclear.

Magnetic Effect

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I shall attempt to describe how we think the magnetic effects in the earth storm arise. These consist of the reverse impulse, the increase known as the sudden commencement, its continuation as the initial phase of the storm for an hour or so, after which a much larger diminution in field occurs during some hours, followed by a slow recovery to normal over a period of days.

If an electric field exists in the space surrounding the earth, Alfvén's electric field theory of storms describes how certain features of the ring-current, polar electrojets, and the aurora might arise. An electric field has not yet been detected by space experiments. If such an electric field is small, as many workers believe, the Chapman-Ferraro theory of the initial phase of magnetic storms which first appeared about 30 years ago remains basic in our approach in the theory of magnetic storms. According to this theory a solar emission produces a solar stream which overtakes the earth on its afternoon side, and then envelops the earth's magnetic field to form a magnetosphere some earth-radii in size.

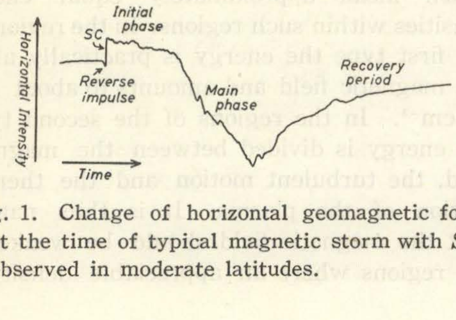

Fig. 1. Change of horizontal geomagnetic force at the time of typical magnetic storm with SC* observed in moderate latitudes.

In the case of the preliminary reverse impulse, it seems likely that due to stronger compression of the earth's field on the sunward side there will arise magnetic field gradients in the equatorial plane directed towards the sun, somewhat sunward of the dawn and evening half-planes. These will create driving forces in the direction $\boldsymbol{B}\times\mathrm{grad}\,B$ displacing and separating protons and electrons in a radial direction. In the process of charge equalization, which takes place along field lines of the geomagnetic field there will be a transient dumping of accelerated protons and electrons into the polar caps. Thus in Fig. 2, it is easy to imagine charges distributed in four sequences from the left: plus, minus, plus and minus, which will drive the Hall currents of the reverse impulse current pattern in the lower F and higher E-region. The current-pattern of Fig. 2 appears more quickly near the earth than does the hydromagnetic wave responding to the continuing compression of the magnetosphere on the sunward side; this arrives at ground level some 10 seconds or more later, first in polar regions and later on the night side. Continued compression of the field for a half hour or more results in the initial phase.

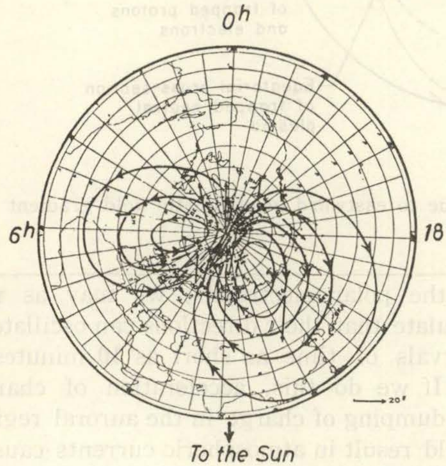

Fig. 2. Distribution of the equivalent current-arrows and current-system for the preliminary reverse impulse of SC^* at 06h 25m UT on May 29, 1933 (after Nagata and Abe).

In the case of the main phase an addition of protons or electrons suitably accelerated seems required, leading to a ring current flowing from east to west around the earth at an elevation of a few earth-radii. According to Parker and Dessler an enhanced supply of accelerated protons trapped in the magnetosphere is caused by the heating action of shock waves proceeding from the solar stream. The effects are more pronounced at night. Singer argues that electrons are more easily accelerated and therefore may be presumed the more likely contributor to the ring current. The recovery phase of the storm is supposed due to loss of protons by ion exchange with atomic hydrogen in the lower exosphere, or in the case of electrons by the scattering action of electric fields in the outer magnetosphere. Since both accelerated protons and electrons are surely present both processes leading to decay of the ring current may be contemplated.

In the case of the polar electrojets accelerating and dumping mechanisms are required in order to provide localized meridional electric fields to drive the Hall currents of the electrojets. Prior to this conference such mechanisms were relatively unknown, but three proposed at this meeting may be operative, and it may be that one may work. In addition to shock waves mentioned for the main phase, Hines and his colleagues, and in another related sense Dungey as well, propose a hydromagnetic model. Hines proposes that the solar stream communicates a magnetospheric circulation of plasma flowing in the equatorial plane from sun to earth just inside the magnetosphere and returning just outside the outer Van Allen radiation belt. The $\boldsymbol{v} \times \boldsymbol{B}$ fields, where $\boldsymbol{v}$ is the velocity and $\boldsymbol{B}$ the magnetic field leads to communication of electric fields into auroral regions to drive the polar electrojets. The flow pattern is shown in Fig. 3, and may contribute also to a ring current field, and auroral and ionospheric motions. Such a model has much intuitive appeal, but should of course be independently checked using a particle physics approach, in view of difficulty with boundary value aspects in such problems. Other theories of the polar electrojets were offered by Kern and Chamberlain, and might produce

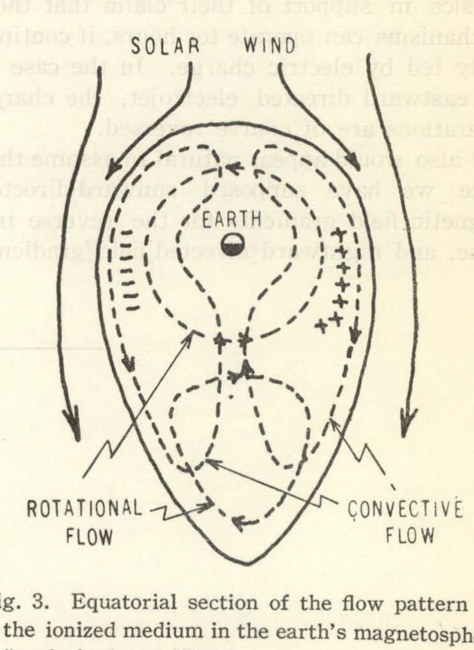

Fig. 3. Equatorial section of the flow pattern of the ionized medium in the earth's magnetosphere (by Axford and Hines).

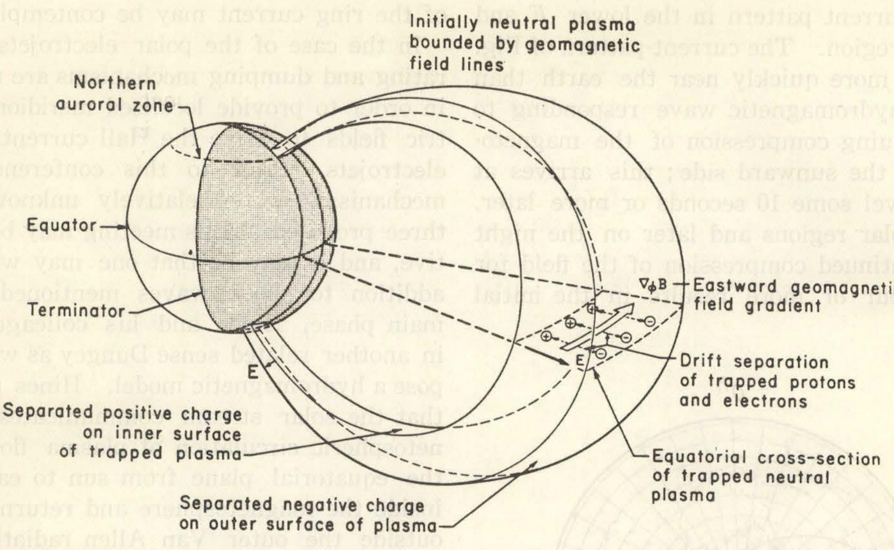

Fig. 4. Charge separation in the outer atmosphere due to eastward geomagnetic field gradient (after Kern).

aurora, auroral motions and ionospheric effects. In Fig. 4, field gradients in the equatorial plane produced by action of the solar stream on the magnetosphere are imagined by Kern to give charge separations and transient acceleration and dumping of particles. I think all will agree that it is obvious that this is an acceleration mechanism which can operate on a transient basis. Chamberlain and Kern have used both plasma and particle physics in support of their claim that their mechanisms can operate for hours, if continuously fed by electric charge. In the case of the eastward directed electrojet, the charge separations are of course reversed.

It also would appear natural to assume that since we have supposed sunward-directed magnetic field gradients for the reverse impulse, and nightward directed field gradients for the polar electrojets, we may as well postulate that their directions can oscillate at intervals of time as short as 10 minutes or so. If we do this, acceleration of charges and dumping of charge in the auroral regions should result in atmospheric currents causing the noise level that so dominates the magnetograms of polar stations. Oscillatory winds in the *E*-region may also contribute magnetic effects communicated both to ground level and the exosphere.

In the case of micropulsations Professor Kato showed that disturbances in the exosphere might be propagated across the geomagnetic field lines in low and middle latitudes to give the continuous pulsations (*pc*), and as transverse waves into the auroral zone to give the damped trains of larger waves (*pt*).