I-3. Theories of Magnetic Storms and Aurorae

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Sept. 5	15 : 30 – 17 : 30	from I–3–1 to I–3–7
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I-3-1. Solar-Stream Distortion of the Geomagnetic Field as a Mechanism for Producing Polar Auroras and Electrojets

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A mechanism for charge separation in the geomagnetically trapped radiation is described which may account for some observed phenomena associated with the polar aurora and the electrojet current systems. Separation of surfaces of constant number density and surfaces of constant integral invariant may occur within the trapped radiation as a result of distortion of the geomagnetic field by solor streams. Drift separation of protons and electrons will follow, and for irregular distributions of plasma number density, electric fields will arise. A direct consequence of such polarization of the geomagnetically trapped radiation will be the polar-electrojet current systems.

The polar auroras arise where energetic particles are discharged from regions of excess charge within the geomagnetically trapped radiation. A model for the discharge of such auroral particles is briefly discussed.

Distortion of the geomagnetic field by ionized solar streams has been considered by many authors in relation to the occurrence of polar-electrojet current systems and auroras. The magnetic-storm theories of *Chapman* and *Ferraro* (1931[1], 1932, 1940) and *Martyn* (1951)[2] require such distortion. Modification of the geomagnetic field by diamagnetic trapped-particle moments and current systems has been proposed by *Dessler* and *Parker* (1959)[3], *Akasofu* (1960)[4], and others. *Martyn* (1951)[2] considered the possible effects of polarization of a ring current based on the Chapman-Ferraro magnetic-storm theory. The present paper suggests that charge separation may arise in the geomagnetically trapped radiation as a result of eastward- or westward-directed components of the geomagnetic field gradient parallel to surfaces of constant plasma density. Gradients of this kind may result from solar-stream interaction with the geomagnetic field, as suggested earlier by *Chamberlain, Kern* and *Vestine* (1960)[5], *Kern* (1961)[6], and *Vestine* (1960)[7].

The discharge of protons or electrons to the atmosphere provides a mechanism for producing polar auroras and electrojets. A simple model is proposed for such discharge of particles from region of excess charge within the trapped radiation, and the effects of this excess charge on the particle motions are outlined. Observations relating to the theory are briefly discussed.

Charge separation can arise due to the opposite directions of adiabatic drift for protons and electrons. Proton-drift motion due to a magnetic field gradient is given by $\boldsymbol{v} = (\mu/eB^2)\boldsymbol{B} \times \nabla_1 B$, where μ is the proton diamagnetic moment, e is the proton charge, $\boldsymbol{B}$ is the magnetic field, and $\nabla_1 B$ is the transverse component of the magnetic field gradient. A similar expression applies for an electron, but the direction of drift is opposite to that of a proton, owing to the opposite sign of the electric charge. In a plasma with an irregular number density, this type of adiabatic drift leads to charge separation, with associated electric fields. The electrostatic potential energy associated with charge separation is supplied by changes in the transverse kinetic energies of trapped particles. *Chamberlain* (1961)[8] has shown that the transverse kinetic energy of a particle changes at a rate given by the scalar product of the drift velocity and the electric force due to charge separation.

If polar-electrojet current systems are ascribed to Hall conduction caused by meridional electric fields in the E-region (*Baker* and *Martyn*, 1953[9]; *Chamberlain, Kern* and *Vestine*, 1960[5]; *Akasofu*, private communication), eastward-directed electrojets in the ionosphere are associated with poleward-directed electric fields. The westward-directed electrojets are associated with equatorward-directed electric fields. The drift directions produced by eastward-directed magnetic field gradients are such as to produce poleward-directed electric fields, while westward-directed magnetic gradients produce equatorward-directed electric fields in the trapped radiation incident in auroral regions. Eastward-directed electrojets may therefore be associated with eastward-directed magnetic field gradients, and westward-directed electrojets with westward-directed gradients.

The extent in longitude of such meridional electric fields would correspond to the extent of the eastward- or westward-directed magnetic field gradients where irregularities in plasma density exist to allow the development of polarization. Electrojets would develop where sufficient trapped radiation, polarized and precipitated by charge separation, penetrates the ionosphere.

Mirror-point lowering is associated with electric field components parallel to the magnetic field $\boldsymbol{B}$. Such components arise from excess charge on field lines. The invariance of the particle magnetic moments for a system in which the electric field has a constant direction over a single particle orbit dictates that mirror points will be raised for particles which undergo a net decrease in kinetic energy. Particles accelerated parallel to the magnetic field $\boldsymbol{B}$ by electric fields will move to lower mirror points. Such electric fields are associated here with excess, or net, charge in a magnetic flux tube resulting from charge separation in a plasma density irregularity.

To estimate the effects of charge separation on particle motion, an electric-field model is defined along $\boldsymbol{B}$ by $E_2 = (\mu_l/e)\nabla_2 B$, where μ_l is the smallest magnetic moment of particles with the same charge as that of the excess charge in an auroral flux tube, e is the charge of a particle, and $\nabla_2 B$ is the parallel component of the geomagnetic field gradient. Particle accelerations parallel to $\boldsymbol{B}$ are governed by the equation $\ddot{z} = (1/m)(eE_2 - \mu\nabla_2 B)$, where m is the particle mass and μ is the magnetic moment of any particle of same sign as the charge excess. In this equation, z is taken as downward along $\boldsymbol{B}$, and eE_2 is taken as accelerating the particles toward the atmosphere. Note that $-\mu\nabla_2 B$ is the magnetic force on the spiraling particle acting along $\boldsymbol{B}$ toward the equatorial plane. The equation of motion can be written $\ddot{z} = (1/m)(\mu_l - \mu)\nabla_2 B$, so that the particle motion in the presence of the electric field is the same as if no electric field were present and the particle magnetic moments were diminished by μ_l. Particles of the opposite sign move as though their magnetic moments were increased by μ_l. Mirror-point lowering follows for particles of the same sign as the charge excess, while mirror points are raised for particles of opposite sign.

The above electric-field model allows particles with the magnetic moment μ_l, which are of the same sign as the charge excess, to move freely along $\boldsymbol{B}$. It is plausible for such a field to develop, since, if μ_l is finite, discharge of excess charge in a flux tube requires a finite electric field along $\boldsymbol{B}$. The electric-field model is that field which enables particles with the moment μ_l to move in the same manner as thermal particles.

The neutralization of excess charge by thermal particles from the atmosphere can be studied by noticing that for these particles $\mu=0$. Such particles must have a charge opposite to that of the excess charge in the flux tube. It follows from the equation of motion given earlier that the motion of thermal particles will be the same as though they had moments equal to μ_l and were mirrored in the atmosphere. If, say, 6-Kev electrons are discharged into the atmosphere by an electric field, the time required for thermal protons to travel from the atmosphere to the equatorial plane will be about $\sqrt{M/m}$ times the travel time for an electron of this energy, which is mirroring in the atmosphere in the absence of an electric field ($\sim$1 sec). Here M/m is the ratio of the proton mass to the electron mass. It follows that the time scales for proton neutralization of electron excesses are long($\sim$40 sec) and electron discharge to the atmosphere can be anticipated. The opposite conclusion is drawn for electron neutralization of proton excesses. *Chamberlain* (1961)[8] estimates the lifetime of proton excesses to be about 1 sec. It can be seen that the process of electron neutralization of proton excesses provides an auroral mechanism based on an electron flux, up magnetic field lines, that is in equilibrium with proton separation from a neutral plasma.

If the region of geomagnetically trapped particles has a fairly sharp outer boundary connected along $\boldsymbol{B}$ to the auroral zone, the observations of *Davis* (1960)[10] suggest that west of (or prior to) local magnetic midnight, an excess-electron region forms on the outer boundary. After midnight, a proton excess appears to form on the boundary.

The charge-separation mechanism outlined above produces sheet beams of charged particles from extended plasma density irregularities. Such charge-density distributions would be maintained in the trapped radiation (*Kern* and *Vestine*, 1961)[11]. Beams of charged particles are subject to electrodynamic instabilities as demonstrated both experimentally and theoretically (*Kyhl* and *Webster*, 1956[12]; *Pierce*, 1956[13]; and *Webster*, 1957[14]). Such considerations can be applied to auroral morphology with the result that the sequences of auroral forms can be ascribed to variations in velocity and flux density of incident particles (*Kern* and *Vestine*, 1961)[11].

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Discussion

Martyn, D. F.: Is your polarization field (in the equatorial plane) radial or tangential?

Kern, J. W.: In the equatorial plane the polarization field will be perpendicular to surface of constant trapped plasma density. In general, this will be nearly radial.

Campbell, W. H.: It dosen't seem that your model is consistent with the appearance, in the auroral zone, of a proton maximum before midnight and of an electron maximum after midnight. Can you explain this point?

Kern: This kind of maximum can occur at a single station owing to the latitude motion of protons resulting from the drift motion described. I believe that the model is consistent with the observations of Rees and Reid at College, Alaska, in this respect.

Singer, S. F.: I don't quite understand your model.

1) Do you inject a neutral stream into the geomagnetic field, *i.e.* ions and electrons moving with the same velocity, same direction?

2) Or are they trapped particles (such as are thought to produce ring current)? But thus you would hardly expect space charge regions since the exosphere plasma would neutralize such charges.

Kern: In answer to (1), the present treatment applies to trapped plasma. Point (2), that low energy plasma will neutralize separated charge, can be dealt with by noting that the mobility of even low energy particles is negligible across the magnetic field. If such particles travel along field lines, they can be seen to contribute to atmospheric currents. As mentioned in the text, electrons will still be discharged into the atmosphere.