Auroral Phenomena

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We have still much to learn about magnetic storms, but still more about the aurora. Its light comes mainly from ionospheric atoms and molecules, especially from those of oxygen and nitrogen. They are excited and ionized by primary particles, mainly electrons but also protons and perhaps other nucleons, which descend along the lines of geomagnetic force and enter the ionosphere. The electron energies may range perhaps up to 100 kev, though the average may be about 20 kev. The protons during their descent may capture electrons from ionospheric particles, to become swiftly moving hydrogen atoms. These reveal their presence by Doppler-displaced lines of hydrogen in the auroral spectrum.

Birkeland and Störmer proposed that the primary particles are all of one sign of charge, and come directly from the sun under the influence only of the geomagnetic field. This deflects some of them with unaltered energy to the higher latitudes, and to the night side of the earth, there producing the observed aurora.

Following Lindemann, we now consider the primary particles to come to the earth from the sun in the form of neutral ionized gas, mainly hydrogen. The particles may spend some time in the radiation belts before entering the atmosphere. An alternative view is that the primary particles belong to the ionized atmospheric background of the radiation belts, and are energized by the impact of the solar neutral ionized stream or cloud upon the geomagnetic field. Theories of such acceleration of background particles have been proposed, for example, by Dungey, by Dessler, Hanson and Parker, and by Axford and Hines. Dessler and Parker attribute the acceleration to shock waves coming from the solar gas. Dungey associates it with the arrival of southward magnetic fields transported from the sun to the earth by the solar streams and clouds. In combination with the geomagnetic field, two neutral points are produced, and an electric field resembling that associated with the *DS* system of polar ionospheric currents. Lines of magnetic force from the neutral point on the sunward side of the earth meet the ionosphere along two curves, whose shape and location are not yet determined. He hopes to examine whether they can be identified with the two auroral zones.

Axford and Hines infer a large-scale convection of charged particles in the magnetosphere, associated with an electric field corresponding with, and causing, the *DS* ionospheric current system, and with the entry of energized background particles into the auroral ionosphere. They suggest a driving mechanism for the primary magnetospheric convection, but claim that their conclusions would follow from almost any of the other mechanisms that have been proposed to drive the *DS* current system.

Still earlier, Alfvén assigned an important rôle in auroral and magnetic storm theory to the presence of an *electric* field associated with the polarization of the solar gas by a large-scale *magnetic* field pervading it. He infers that many of the solar particles enter the atmosphere and produce the aurora, under the combined influence of the electric field and the geomagnetic field.

Chamberlain attaches importance to the electric field set up when a portion of ionized gas captured in the magnetosphere separates by westward proton drift and eastward electron drift.

Akasofu and I have not attempted to explain the source of the primary auroral particles. Proceeding from the observed existence of energetic particles in the magnetosphere, we have attributed the thinness of diffuse auroral arcs to the presence of neutral lines in the geomagnetic equatorial plane, mainly on the night side of the earth. These lines we associate with reversal of the earth's field in the equatorial plane, by the field of

the ring current that produces the *Dst* field during the main phase. Near one of the neutral lines (the one of type X) the pitch angles of the charged particles in the magnetosphere are scattered. This provides a continuing supply of particles able to penetrate the atmosphere to auroral levels. We offer a simple explanation of the occurrence of multiple auroral arcs, as due to more than one minimum in the total magnetospheric field, arising from irregular distribution of the ring current and of the energetic particles that produce this current.

We propose an additional hypothesis to explain the second phase of active auroral displays, when the auroral light sources have the form of rayed, folded, moving curtains, of thickness about ten times less than that of the diffuse auroral forms. We suppose that intermittently an eastward electric field arises along the neutral line. This energizes electrons of the radiation belt and of the atmospheric background. It produces an unstable wavy electric current flow along the neutral line(s). The wavy form and motion of these lines are transmitted along the magnetic lines of force and thus repeat the form and motion in the auroral arcs.

Doubts have been cast on the possibility or likelihood of *reversals* of the field by the ring current. We shall examine whether strips of low field intensity in the equatorial plane can fulfil the rôle in our theory that we attribute to neutral lines associated with reversals of the field.

Transmission of Hydromagnetic Wave to the Earth

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Basic characteristics of hydromagnetic waves, which have been clarified by theoretical studies, are summarized. Descriptions are given on the process of transmission of hydromagnetic disturbances to the earth's surface, which are generated by impacts of the solar plasma wind at the interface between geomagnetic cavity and interplanetary space. Finally some problems for future study and some possible experiments by satellite are briefly discussed.

§1. Disturbance phenomena and hydromagnetic waves

The surface of the earth and its near surroundings, by which we mean generally the space including the ionosphere and its outward extension, are protected against the direct invasion of solar plasma wind by the earth's own magnetic field. Of course, it is believed that the polar region and its neighbour are always open to such direct invasion. But we know that there is a number of observed phenomena, which cannot be understood only by such direct injection of plasma particles. The examples of such cases are clearly demonstrated by the following geomagnetic disturbances.

(i) *ssc*: sudden commencement of geomagnetic storm,

(ii) *si*: sudden impulse,

(iii) pulse: disturbance of rectangular shape,

(iv) *pc*: quasi-sinusoidal oscillations with period of the order of seconds and minutes,

(v) *pt*: pulsation trains with period of 1~2 minutes,

(vi) geomagnetic effect by nuclear explosions in Johnston and Argus experiments.

When a uniform and steady solar wind is coming to the surface of geomagnetic cavity, the interface between the wind and the cavity will be stable, as studied by Dessler[1]. But if the flow of this solar wind varies in time or involves irregularities of some finite dimensions, then certain hydromagnetic dis-