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 disturbances will be generated and transmitted downward into the exosphere and the ionosphere of the earth. It is believed that the hydromagnetic theory is a useful tool to understand the phenomena, which are supposed to take place in such cases as described above.

The present paper will be confined mainly to the description of the theoretical side of hydromagnetic problems, which is largely supported by the papers of Kato *et al.*[2] and Dessler[1] presented at this symposium. However, it is necessary to remark here that disturbances generated far above the earth's surface are not only transmitted by means of the hydromagnetic waves, but also by the convection of charged particles, that is, protons and electrons. In this latter case, the protons and the electrons may come directly from the sun through interplanetary space, and sometimes may come from the so-called Van Allen belt and from the equatorial ring current in the outer exosphere. The disturbance effects caused by such charged particles are quite different from those by hydromagnetic waves, and are very important for interpreting various disturbance phenomena in geomagnetism and in the ionosphere, aurorae, VLF emissions and so forth.

§ 2. General theoretical features of hydromagnetic waves

Hydromagnetic waves can take place at frequencies (ω) lower than the gyro-frequency (ω_i) of ions involved, and waves with periods shorter than 1 sec. are improbable in the exosphere. Under the condition of $\omega \ll \omega_i$, the waves have in general three modes, provided that the magnetic pressure is much greater than the gas pressure.

(i) Extraordinary (X) mode, known as Alfvén wave, which propagates along lines of magnetic force and oscillates transversally (mainly azimuthally).

(ii) Ordinary (O) mode, known as modified Alfvén wave, which propagates isotropically and oscillates longitudinally (mainly meridionally).

(iii) Retarded sound wave, which propagates along lines of magnetic force and oscillates longitudinally.

The former two modes couple with each other in general and are independent of the third mode, which will be put aside in this paper. If a disturbance occurs in a source with a finite dimension, both the X and O modes can reach the point on the magnetic line of force which passes through the source, while in other directions only the O mode can travel. Therefore the transmitted disturbance is in general strong at places on the magnetic line connected with the source.

Next we have to consider about the factors, which affect the efficient transmission of disturbance energy.

(i) Absorption due to Joule heat dissipation; this effect is significant in the ionospheric region.

(ii) Absorption due to phase mixing process by proton cyclotron resonance; this effect will become serious for short period oscillations, say, of the order of second, travelling in the outer exosphere, and so governs the minimum period observable at the ground surface.

(iii) Partial or total reflection; this effect is serious for O mode waves propagating perpendicularly to the lines of magnetic force in the inner exosphere.

These effects act as something like attenuator and filter, so that they are very important for understanding energy spectrum, latitude effect and so forth.

§ 3. Transmission of disturbances

As a convention let us divide the exosphere into three regions, that is, (i) outermost exosphere ($14r_0 \sim 10r_0$), (ii) outer exosphere ($10r_0 \sim 5r_0$) and (iii) inner exosphere ($<5r_0$), where r_0 denotes the earth's radius.

(i) Outermost exosphere: this is an intensely disturbed region, and there is no ordered field here. Magnetic pressure is comparable to gas kinetic pressure. In this region hydromagnetic waves will have much more complicated characters than those described in the last section. This is the place of birth of strong disturbances. The minimum and maximum periods were given as about 1 and 300 seconds by Tamao[2], who estimated the minimum scale of field inhomogeneity as ca. 10^7 cm and the dimension of the outermost exosphere as ca. $4r_0$. These values cover most of observed periods of usual *pc* pulsations during daytime.

(ii) Outer exosphere: this is a weakly disturbed region, and there is almost ordered field here. The solar energetic particles will be trapped, ring current may flow and by its diamagnetic effect there is a gross deviation of the field from a dipole magnet. Short period oscillations, say, of the order of one second, are absorbed by phase mixing process.

(iii) Inner exosphere: there is an ordered field of a dipole magnet. The *O* mode of isotropic propagation is totally reflected at a height, which depends upon the frequency of the wave. Longer period oscillations are reflected at higher altitudes, and their energy is transferred to *X* mode and reaches the ionosphere, propagating along lines of magnetic force. Hence long period disturbances predominate in high-latitude zone. The transmission of disturbance from sunlit side to dark side will be possible by the *O* mode of isotropic propagation. In this case it is probable that for longer period oscillations it is easier to go round to the dark side. Ray theoretical treatment has been given on this problem by Dessler[1].

(iv) Ionosphere: Joule dissipation cannot be ignored, especially for waves with periods shorter than 20 seconds in the *E* layer. The disturbances, which concentrate at places of higher latitudes by *X* mode, will be transported to lower latitudes by diffusion. A part of the current vortex locally generated by hydromagnetic oscillation in high latitude will leak out to lower latitude, and this leakage current will cause a magnetic disturbance there.

(v) Below the ionosphere, the disturbance is observed by induction.

§ 4. Future problems

There are some other points of importance to remark.

(i) Interpretation of *pt*. The *pt* pulsations occur during night, most frequently around midnight. It is interpreted that *pc* and *ssc* occur at sunlit side of the earth and then hydromagnetically reach the sunlit and dark sides. But the problem of *pt* is obviously different. One may assume that the origination of *pt* disturbances lies in the region containing high-energy trapped particles or ring current, but the problem still remains on something like trigger mechanism of such disturbance in the dark hemisphere.

(ii) Heating of the ionosphere. The effect of the heating of the ionosphere by Joule dissipation of hydromagnetic disturbances has been remarked by Dessler[1] and by Cole's discussion in this session. Although this is a secondary effect, the point is worth studying.

(iii) Possible experiments by space probe to verify theories.

Until now we have had important results of satellite experiments by Sonett *et al.*[3] who carried out magnetic measurements in the inner to outermost exosphere. Also we had a paper by Hepper *et al*[4]. in this symposium, which reported the magnetic field fluctuations observed by a rocket and a satellite. The results of these experiments have a great significance to the hydromagnetic study of disturbance phenomena. Our proposal here concerns the measuring apparatus to be borne in satellite. We notice that the *O* mode wave is accompanied by density fluctuations as well as magnetic field fluctuations, while the *X* mode wave has only magnetic field fluctuations, and that also the polarizations for both modes are different. If some apparata can be devised for measuring the polarization of magnetic field fluctuation and the density fluctuation at the same time, this will be very useful to verify the theories on generation and transmission of disturbances.

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