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SOME EFFECTS WHICH CAN ACCOMPANY MAGNETIC STORMS

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ABSTRACT

Some effects are examined—the probability of penetration of a part of the flow of particles from the sun to the earth's atmosphere, as a consequence of the compression of the plasma—and formation of an electrical current along the motion of the plasma.

Apparently, the main results of observations cannot be explained by these effects. But the latter may probably cause some secondary phenomena which could perhaps be discovered by means of special observations.

Modern theories of magnetic storms and aurorae proceed from the suggestions by S. Chapman and V. Ferraro [1] of a quasi neutral stream of corpuscules from the sun, flowing around the earth at a distance of several radii. These theories explain satisfactorily the first stage of the magnetic storm. As a consequence of these theories it was found by D. Martyn that the mean concentration of the stream is about 20 cm^{-3}, its distance from the earth constituting 5·5 radii. According to D. Martyn the polarization of the stream creates an electric field, which causes an acceleration up to large energies of the particles moving towards the earth.

Self-induction is not taken into account in these considerations. This self-induction reduces strongly the energy of the particles because the time of relaxation of the current through the earth's atmosphere is several years. H. Alfvén's theory [2] introduces also currents flowing from the internal surface of the stream towards the earth. Storm-time variations represent, according to the above theories, the magnetic field of these currents. Observations show, however, that magnetic disturbances consist of short fluctuations, the amplitudes of which usually exceed the mean variations. At the same time currents of large scales are changing more slowly. In addition, it was shown by A. Nickolski that the magnetic field of the earth during quiet hours of stormy days does not differ from the usual undisturbed field.

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This was the reason for the author to investigate the principal arguments which lead to the conclusion of the impossibility for the stream to reach the earth. This impossibility is the sequence of diamagnetic properties of the plasma. The gradient of the magnetic pressure retards the motion of the plasma in places where the density of the magnetic energy is about equal to the initial density of the kinetic energy of the flow. However, the compressibility of the plasma is not taken into account in this suggestion. In the course of the first phase of the magnetic storm, when the stream compresses the magnetic field of the earth, the state of the stream is non-stable. Individual elements and jets are formed, which penetrate into the field of the earth, as the denser parts of the stream are less retarded by the magnetic field than the surrounding parts.

The field contracts these elements, their density will be increased and they will be able to penetrate further, than in the case of constant density.

We suppose for quantitative calculation the internal pressure of elements to be equal to the external magnetic pressure. The pressure of the earth's atmosphere is not taken into account. The internal magnetic pressure for isothropic compression is proportional to $\rho^{4/3}$, and the gas pressure is proportional to $\rho^{5/3}$, this being an adiabatic compression. When the initial field of the stream is about 10^{-6}–10^{-5} [3] the magnetic pressure inside the elements will be less than the gas pressure and may be omitted. The system of equations is:

$$P=\frac{1}{8\pi}H^2,$$

$$\frac{P}{\rho^{5/3}}=\frac{P_0}{\rho_0^{5/3}}=\frac{kT_0}{n_0^{2/3}m_H^{5/3}},$$

$$\tfrac{1}{2}\rho V^2=\tfrac{3}{2}P_1+\frac{1}{8\pi}H_1^2=\frac{5}{2}\frac{1}{8\pi}H_1^2,$$

where the index 0 or 1 means that the value is taken previous to the compression, or at the moment when the element is stopped.

The solution of the system is the following:

$$H_1=\frac{\sqrt{(8\pi)}}{5^{5/4}}\frac{n_0^{1/2}m_H^{5/4}}{(kT_0)^{3/4}}V^{5/2}\approx 2,$$

if $n_0\approx 20$, T_0 about $5000°$, V about 10^8 cm/sec. The stream may penetrate into the upper layers of the atmosphere ($H_1\approx 0{\cdot}2$) at 'direct' collisions, if $V\approx 4\cdot 10^7$ cm/sec.

The concentration and the temperature are determined during compression by the expressions:

$$n = \left(\frac{1}{8\pi} H^2\right)^{3/5} \frac{n_0^{2/5}}{(kT_0)^{3/5}}; \quad T = \left(\frac{n}{n_0}\right)^{2/3} T_0.$$

If $H = 0{\cdot}2$, the concentration $n \approx 10^6$, $T \approx 6 \times 10^6$ degrees.

The linear dimensions are reduced considerably and probably constitute some tens of kilometers.

Hot dense clouds may be expected to penetrate during magnetic storms into the upper layers of the atmosphere. They are optically unobservable, but may perhaps be discovered by means of radio methods.

Only a part of the retardation forces is taken into account by the diamagnetic effect. If the cloud propagates across the lines of force, both the condensation of these lines in front of the cloud and their elongation must be taken into account.

The condensation of the lines of force may be estimated by means of the theory of magnetic-hydrodynamical shock waves by F. Hoffman and E. Teller [4] and by L. Helfer [5]. The degree of compression of the matter is about $1{\cdot}2$ to $1{\cdot}5$ in a comparatively strong magnetic field.

The increase of H is close to this value. The retardation is estimated similarly as before, but a value of H^2 two times greater than before is accepted. The motion across the magnetic field will be retarded, if the transversal component of the velocity will be less than 5×10^7 cm/sec.

The upper limit of the effect of elongation of the lines of force may be obtained on the assumption that a plane layer is moving inside of which the outer field has already penetrated. The time of retardation of this layer may be approximately taken as the time of crossing of the layer by the magnetic-hydrodynamical waves. The computations including the inhomogeneity of the magnetic field of the earth show that the movement normal to the field is retarded most strongly in the vicinity of the earth. Actually the field penetrates into the element comparatively slowly and not very deep, especially on great distances from the earth, where the element itself is of much greater dimensions. The element may, probably, move across the lines of force, when the distances from the earth are considerable but the transverse motion close to the earth is rapidly retarded. A more definite calculation is impossible at present.

Besides the above mechanisms there is another effect, which may influence essentially the motion of an element. If the plasma moves through some other plasma, retardation of the electrons is much more strong than the retardation of protons. This was indicated by W. Bennet and E. Hulburt [6], who suggested that the stream must consist of high-velocity protons and slow electrons. However, such combination of different velocities represents an electrical current, the increase of which from zero being restricted by self-induction. In reality the value of the current must be deduced from Maxwell's equations.

Let the space-charge always be zero (this being not quite correct, but causing no large errors). Then the following equations are valid:

$$\Delta\mathbf{A}-\frac{4\pi\sigma}{c^2}\frac{\partial\mathbf{A}}{\partial t}=-\frac{4\pi}{c}\mathbf{j}^{(e)};\quad \mathbf{j}=\mathbf{j}^{(e)}-\frac{\sigma}{c}\frac{\partial\mathbf{A}}{\partial t},$$

where $\mathbf{j}^{(e)}=ne\mathbf{V}$. In the co-ordinate system $u=Vt-z$ the value of $j^{(e)}$ does not depend on time.

It may be accepted that $j^{(e)}=j_0\exp(-r^2/r_0^2)$ for $u>0$. Boundary conditions are: for $u=0$, $j=0$; for $u\to\infty$ j is restricted; for $r\to\infty$, $j\to 0$ and $\partial j/\partial r\to 0$.

Let us pass to the system u and solve the equations by means of successive approximations. Then for $u\ll r_0^2$

$$j=\frac{c^2}{\pi\sigma V}\left(1-\frac{r^2}{r_0^2}\right)j^{(e)}\frac{u}{r_0^2}\ll j^{(e)};$$

the electrons and ions are moving with about the same velocity. The current increases linearly with the distance from the front of the stream. The radial current and space-charge must, consequently, be present. The magnetic field of the current is insignificant.

The current in the magnetic field of the earth must be influenced by the force

$$\mathbf{f}=\frac{1}{c}\mathbf{j}\times\mathbf{H}.$$

This force differs as compared with Lorentz forces by the scalar coefficient only, as the direction of $\mathbf{j}$ is the same as that of $\mathbf{v}$. The equation of the motion of the element of plasma is identical with the equation of the motion of a charged particle in the field of the earth. This equation was investigated by C. Störmer. The plasma must move according to Störmer's trajectory calculated for particles of a mass

$$M=\frac{\pi\sigma V}{c^2}\frac{r_0^2}{u}m_H.$$

The value of M will be increased, if we take into account that the influence of the field exists only in the layer, into which the field has penetrated. The effect of the force $\mathbf{f}$ being therefore essential only close to the earth where the dimensions of the element is of the order of several tens of kilometers. Therefore we may expect that the above compressed gaseous clouds will enter the atmosphere in places located on a spiral, close to the one by Störmer, but sufficiently far from the poles, since $M \gg m_H$.

This may possibly be connected with the regularity recently discovered by A. P. Nickolski [7], according to which the magnetic disturbances in polar regions commence in places, distributed along Störmer's spiral. These disturbances are the greatest in places where this spiral intersects the auroral zone. It cannot be supposed that the magnetic disturbances may be explained by the moving clouds, as the magnetic field of an element is

$$H = \operatorname{curl}_\alpha A = \frac{2c}{\sigma V} \frac{ur}{r_0^2} j_0 e^{-(r/r_0)^2}.$$

This field is not small, but it decreases rapidly with distance.

A shock-wave arises when the moving clouds penetrate into the earth's atmosphere. This wave is becoming rapidly damped as it propagates in a medium of increasing density. The wave may ionize atoms and cause excitation of the upper layers of the atmosphere, which will be accompanied by a faint luminosity (time of recombination from a day to a year). The aurorae cannot be, obviously, explained by the above mechanism.

The giant local pulsations of the earths magnetic field and the reflexion of the radio waves from the heights up to 1500 km observed by Harang [8] may be associated with the penetration of such clouds into the upper layers of the atmosphere.

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