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Origin of Sudden Commencements

GEOMAGNETIC storms fall into two distinct categories: recurrent and sporadic. Recurrent storms are produced by continuous streams of particles issuing from the solar M-regions. Swept round by the rotating Sun, the corpuscular streams overtake the Earth in its orbit at monthly intervals. By contrast, a sporadic magnetic storm marks the arrival of a single cloud of plasma, ejected at the time of a solar flare.

Sudden commencements are more frequent among storms of the sporadic type. This has been known for some time[1], but the observation has not received a satisfactory explanation. Recent theories on the nature of sudden commencements seem to provide a key to the answer. According to these theories[2], a sudden commencement results when the velocity of the solar plasma exceeds the ambient Alfvén velocity, thereby creating a hydromagnetic shock wave. A shock wave of this kind could form at the stream boundary, either in interplanetary space or in the region of impact at the Earth[2]. On the latter hypothesis it follows that the solar plasma must advance into the Earth's field with a velocity exceeding the local Alfvén velocity:

$$V_A = \frac{B}{\sqrt{\mu_0 \rho}} \text{ (M.K.S.)}$$

Fig. 1 gives the values of V_A calculated for the Earth's exosphere in the plane of the magnetic

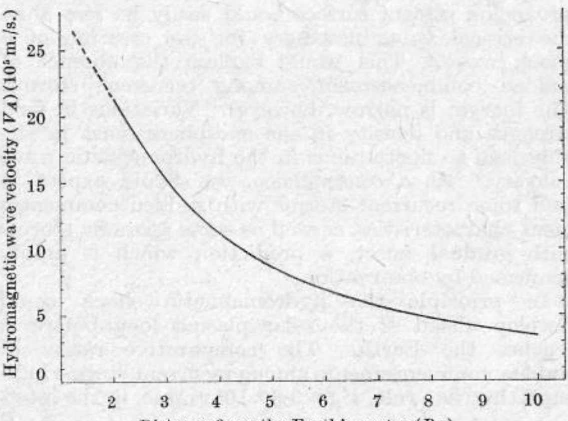

Fig. 1

equator ($B = B_0 (R_E/r)^3$) out to a distance of 10 Earth-radii. Beyond that point the calculations become uncertain because of field irregularities. The ion-density was taken to be:

$$\rho = 2 \cdot 58 \times 10^9 \, m_H \left(\frac{R_E}{r}\right)^3 e^{3 \cdot 03 \, R_E/r} \text{ kgm./m.}^3$$

in accordance with recent results obtained by the study of nose whistlers[3].

A plasma cloud ejected at the time of a solar flare is propagated towards the Earth with a mean velocity of $\sim 6 \times 10^5$ m./sec. (ref. 4). The cloud front probably reaches the Earth with a speed of 7×10^5 m./sec. In extreme cases (great magnetic storms) the velocity of approach may exceed 2×10^6 m./sec. Because of the low value of the Alfvén velocity near the boundary of the geomagnetic field (Fig. 1) a shock wave is likely to develop in that region ($\sim 10 \, R_E$), particularly when the velocity of the incident plasma is higher than usual.

As regards the corpuscular streams which produce recurrent magnetic storms, the situation is quite different. In this case the velocity of approach of the stream surface (v_1) is no longer equal to the velocity of individual stream particles (v). Instead the relation:

$$v_1 = \left(\frac{1}{\omega^2 a^2} + \frac{1}{v^2}\right)^{-\frac{1}{2}}$$

holds, where ω is the solar (synodic) angular velocity of rotation and a the astronomical unit. The maximum possible value of v_1 is 4×10^5 m./sec. (as $v \rightarrow \infty$). Adopting the most probable value of v (6×10^5 m./sec.) (ref. 4) we obtain $v_1 = 3 \cdot 3 \times 10^5$ msec. Comparison with Fig. 1 shows that the velocity of the advancing stream surface could easily be less than the critical value necessary for the creation of a shock wave. This would explain the absence of sudden commencements among recurrent storms. The margin is narrow, however. Variations in field strength and density in the exosphere must inevitably lead to fluctuations in the hydromagnetic wave velocity. As a consequence, we should expect to find some recurrent storms with sudden commencement-characteristics, as well as some sporadic storms with gradual onset, a prediction which is amply confirmed by observation.

In principle the hydromagnetic shock could develop ahead of the solar plasma long before it reaches the Earth. The comparative rarity of sudden commencements among recurrent storms indicates that, as a rule, $V_A > 3 \cdot 3 \times 10^5$ m./sec. in the interplanetary medium. Since $V_A = 2 \cdot 2 \times 10^{16} \dfrac{B}{\sqrt{n}}$

m./sec., where n is the number of protons/m.^{3}, we deduce that $n < 4{\cdot}4 \times 10^{21} B^2$. This relation gives an upper limit to the ion-density when the field strength is known. Measurements obtained from satellite *Explorer X* (1961 $\varkappa$) showed $B = 1\text{–}2 \times 10^{-8}$ w/m.^{2} at a distance beyond 30 R_E (ref. 5). Assuming this to be a representative figure, we conclude that the density of interplanetary gas near the Earth's orbit does not exceed 10^6 particles/m.^{3} under normal conditions.

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