ON THE ORIGIN OF THE AURORA POLARIS

By S. Chapman

Abstract

Hulburt's new theory of the aurora polaris is criticized on the ground, principally, that free high-atmospheric ions in middle and low latitudes cannot travel far towards the poles along the earth's lines of magnetic force, because they must at the same time descend into the lower levels where their motion is interrupted by collisions. Upward moving ions will travel towards the equator.

In the June issue of the Physical Review a new and interesting suggestion as to the origin of the aurora polaris is made by E. O Hulburt.[1] The theory generally current, due mainly to Birkeland and Störmer, is that the aurora is caused by the entry into the earth's amosphere of charged particles emitted from the sun, and directed towards the polar regions of the earth by the terrestrial magnetic field; in spite of many attractive features, this theory, when examined in detail, is found to offer some serious difficulties. The chief of these arises from the electrostatic repulsion which such charges exert on one another, tending to disperse the cloud of particles during their passage from the sun. There is consequently room for new auroral hypotheses which like that of Hulburt, do not involve this difficulty, if in other respects they are not less satisfactory than the current theory. The object of this note is to examine whether Hulburt's theory is really capable of explaining some of the principal facts about auroræ: the conclusion arrived at is adverse.

The new theory supposes that the aurora is due to the rapid diffusion of ions and electrons, produced by the sun's ultra-violet radiation at great heights in the atmosphere where the frequency of collisions is small, in neutral streams along the lines of magnetic force, resulting in a concentration of ions in the polar regions. There they move to lower levels and recombine, setting free their energy of recombination, which in some way causes the aurora. Thus the auroral energy comes from the sun in the form of ultra-violet radiation.

It is certainly true that at high levels there exist ions and electrons which between infrequent collisions, move almost freely subject only to gravity and the electromagnetic force due to the presence of the earth's magnetic field. The latter causes them to spiral round the lines of magnetic force, so that the average motion of the ions is in either direction along these lines. Except at the magnetic equator the lines are not horizontal. Assuming that the earth's magnetic field is that of a uniformly magnetized sphere (which is sufficiently exact for the present purpose) the equation of a line of force is

$$r/a=\cos^2\lambda/\cos^2\lambda_0,$$

[1] Hulburt, Phys. Rev. **31**, 1038 (1928).

where r is the radial distance from the earth's center, and λ the latitude, of a typical point on a line of force which passes through the point $r=a$, $\lambda=\lambda_0$. It is convenient to take a as corresponding to the level in the atmosphere where the mean free path is still short compared with the radius of the free spiral paths of the ions. The free ions are supposed to start from higher levels than this; they may move either upwards or downwards along a line of force in the inclined direction of the line. If they move upwards their horizontal motion is towards the equator, and they will travel in this direction, through layers of decreasing density, so far as is permitted by infrequent collisions and the retardation due to gravity. If they move downwards along the line of force they travel polewards, but they cannot go far in this direction before they reach the level $r=a$, where since they can no longer spiral freely, they become subject to ordinary gaseous conditions and have no appreciable tendency to move further along the lines of force.

Suppose that a particle starts at a height of 1000 km above the level $r=a$; in descending through this 1000 km along a line of force its horizontal poleward traverse will be largest if it starts above the equator, where the lines of force are horizontal. The latitude to which it will travel is obtained by putting $a=6000$ km $r=7000$ km,$\lambda=0°$ in the above equation (the value for a, given in round figures is rather too small, and will result in a somewhat too large value of λ_0); the result is approximately 22°. For a particle starting at the same level as this, but in latitude 30°, the poleward traverse is 6°. The value 22° can be regarded as an upper limit to the poleward traverse of an ion, since the level at which the ion-density must become insignificant for the purpose of this auroral theory is much less than 1000 km above the absorbing layer $r=a$. If the starting point is only 500 km above $r=a$ (and even this is excessive) the poleward traverse in the above two cases ($\lambda=0°$, $\lambda=30°$) is reduced to 16° and 4°; if $r-a=100$ km, $\lambda_0-\lambda=7°(\lambda=0)$, $1°(\lambda=30°)$. Thus except near the equator the ions cannot travel far towards the poles before they become absorbed in the denser layers beneath; and any ions diffusing upwards from these layers will, as they become free from collisions, travel equatorwards instead of polewards. There seems therefore to be no possibility of a stream of electrons passing from the middle belt of the earth into auroral latitudes. For an ion above the equator to travel freely even so far polewards as to latitude 60°, r must equal $4a$; at this height ($r-a=3a$ or 18000 km) there is no atmosphere. Hence the proposed theory seems incapable of explaining a polar concentration of ions produced in low latitudes by ultra-violet solar radiation.

Other objections against the theory may be stated.

(1) The aurora should, on the proposed theory be primarily a day-time phenomenon, its occurrence at night being simply a survival due to ions formed during the day, aurorae probably do occur invisibly during the day, but they are not seen most often just after sunset, but increase in intensity during the early hours of the night, while they have been seen to endure strongly until dawn.

(2) The theory seems incapable of accounting for the existence of the zone of maximum auroral frequency and for the thinness of auroral curtains, auroral features of which Störmer's theory offers an explanation.

(3) The earth's magnetic field does not increase the energy of the ions, and their power of penetrating the absorbing layer of the atmosphere will correspond merely to their velocity at their starting point. Aurorae appear to indicate the penetration of the atmosphere down to 90 or even at times, to 80 km which requires an amount of kinetic energy corresponding to some thousands of volts. Such energy is hardly likely to be acquired by many ions during the process of ionization by ultra-violet radiation.

(4) The tendency shown by marked outbursts of aurorae and magnetic disturbance to recur after the lapse of a solar rotation period is strong evidence for their production by means of a limited corpuscular stream from the sun, rather than by ultra-violet radiation. Such a stream might be regarded as the source of the ionization considered in Hulburt's theory without modifying the latter essentially: but the above arguments would still render it difficult to accept the theory of much poleward migration of ions formed in middle and low latitudes.

(5) It therefore seems necessary to suppose, as heretofore that aurorae are manifestations of the entry into the earth's atmosphere of solar corpuscles, which are deflected polewards, while still outside the earth's atmosphere, by the earth's magnetic field.

Imperial College of Science and Technology,
London, England.
June 4, 1928.