# PAULSEN'S RÉSUMÉ OF RECENT THEORIES OF POLAR LIGHTS.[1]

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The author gives a résumé of the principal theories of the cause of the aurora published since 1896,—those of Birkeland, Arrhenius and Nordmann—and points out the flaws in each one. All agree in considering the auroral rays as a luminescence produced by the absorption of cathode rays in the atmosphere, but none seem capable of explaining all the phenomena. Birkeland's first theory rests on the hypothesis that cathode rays emitted by the Sun are attracted by the Earth's magnetic poles, producing the aurora by their absorption in the atmosphere. This seems incapable of explaining the diverse forms of the aurora, and the changes taking place in a single appearance of the phenomenon. If the cathode rays are forced to follow the lines of magnetic force, it is difficult to imagine how the auroral bands and streamers can be produced unless the lines of magnetic force present great and sudden changes in their aptitude to allow the cathode rays to pass. According to Birkelaud's second theory, the cathode rays emanating from the Sun do not immediately produce the aurora but set up electric currents in the atmosphere, which in turn emit secondary cathode rays, whose absorption in the atmosphere produce all the auroral phenomena. He produced artificial aurora about a magnetized steel ball in a tube of rarified air exposed to cathode rays. The theory is also supported by the admitted fact that electric currents do exist in the upper atmosphere, especially near the poles.

Opposed to this theory is the fact that great, but quiet auroral displays covering the whole heavens produce very little magnetic disturbance, whereas such widespread atmospheric currents as would account for such a display would produce a large effect. The observed fact is, that smaller but more active auroras of serrated forms produce greater magnetic effects; this phenomenon the theory fails to explain. Another objection is that actual measurements of the height of the aurora show that it is often 400 to 500 km. above the Earth and sometimes 600 to 900 km. while at such heights and in ordinary circumstances the air is too rarified to be a conductor. The experimental conditions are too different from the actual conditions under which auroras are produced to permit to conclude that "artificial auroras" are of the same nature as those appearing in the atmosphere.

The theory of Arrhenius, published in 1900, supposes that solar eruptions throw out negatively charged particles larger than molecules into space, which are propelled by the pressure of light. A constant rain of these particles reaches the Earth, charging the upper regions of the atmosphere negatively, thus producing cathode rays emanating from the molecules of air at the limits of the atmosphere. The greatest discharge will be during the day and between the tropics. At the great height at which this takes place the

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[2] Acad. R. Sci. et Lettres Danemark, Extr. du Bulletin, 1906, No. 2, pp. 109-144, with 1 pl.

air is too rarified to be made luminous by the absorption of the cathode rays, while the lines of the Earth's magnetic force, running parallel to the surface of the Earth prevent the rays from penetrating to the lower regions of the atmosphere till they reach the regions near the poles where the lines of force bend downward, and there the aurora is produced as the cathode rays are absorbed in the denser layers of the atmosphere. This theory does not account for the occurrence of auroras in the lower latitudes nor for their magnetic effect, and leads one to expect a minimum frequency of auroras in the Arctic regions in winter, whereas the contrary is true. Numerous other objections based on the behavior and appearance of the rays of polar light are also raised.

Nordmann in 1903 advanced the theory that the aurora is produced by electric waves emitted by the Sun, which in penetrating our atmosphere produce there a luminescence and an abundance of cathode rays. The experiments of Ebert and Wiedemann have shown that luminescence and cathode rays are produced in a rarified gas by the impact of electric waves. One would then think that during the night the whole sky in all latitudes would be lighted. Nordmann seeks to avoid this by showing by diagram that as one approaches the poles the penetration of the solar rays increases as the Sun goes down—that is at the moment when the auroras become visible. The proof is not very clear. One would expect a second maximum of the aurora just before sunrise, but the absence of this maximum is accounted for by the greater ionization of the air in the evening, rendering it more excitable to luminescence. This could hardly account for the maximum frequency of the aurora during December in the Arctic regions.

The author then advances a theory of his own. He first divides auroras into two classes, the first, those without a structure of rays, quite tranquil, slow-moving and producing a steady light, and in polar regions producing little or no magnetic disturbance. These include the cloudy forms of aurora and the vague light which sometimes covers the whole sky. The second class is made up of auroras of a radiate structure. These in general are subject to active movements and may be of great height and very narrow. The lower part is always the most luminous. The form often resembles a sheet. They are closer to the Earth than those of the first class and affect the magnetic field of the earth strongly. They have the properties of cathode rays, and their spectrum has been shown to contain the cathode spectrum of nitrogen. Careful measurements of their height have shown that they can not be less than 400 to 500 km. above the Earth, at which height the atmosphere should, under ordinary circumstances, be too rarified to permit discharges or electric luminescence.

The fundamental hypothesis is then made that the cause of the aurora is to be sought in an immense ionization of the upper layers of the atmosphere above the zone of maximum frequency of the aurora, of such sort that this alteration of the air renews itself each day, beginning at the limits of the atmosphere.

The cathode rays from the Sun following the magnetic lines of force in the regions above the atmosphere, will, in the neighborhood of the magnetic poles, be drawn down into the atmosphere, causing during the day an enormous ionization and a negative charge of the upper layers of the atmos-

phere, producing a great expansion of these upper layers so that they rise far above the levels that they ordinarily occupy. This negative charge increases until it is balanced by the emission of cathode rays into space. This mixture of negative corpuscles and molecules of air is called auroral material. The motion of the particles and the emission of cathode rays lead to perpetual variations of potential of different parts of the mass, and the radiation being under the control of electric forces, constantly varying, will not necessarily follow the lines of force of the Earth's magnetic field.

Sir William and Lady Huggins have shown that the strong radiation of radium in a gas produces a luminescence giving the spectrum of the surrounding gas. The spectrum of the auroral light contains the characteristic lines of the nitrogen spectrum suggesting that the light is of a source similar to that of the radium luminescence.

The constant changes in the form of the aurora are explained by the constant variations of electric potential in the mass of auroral material. The greatest ionization of the upper atmosphere will be where the sheet of magnetic lines of force directing the cathode rays bends down into the atmosphere, causing the auroral arcs which are in general perpendicular to the magnetic meridian. The increase of the width of the zone of light during the night is due to the repulsion of the negative particles having the effect of broadening the zone of maximum auroral frequency. The radiate structure is due to the cathode rays emitted by the auroral material following the magnetic lines of force. The motion of translation then arises from motions of the electric masses, while the undulatory motion is caused by displacement of the points of issue of the rays. The rays carry with them a certain quantity of the auroral material, which, left behind by the rays as they disappear, causes the auroral haze, disposed in striations parallel to the lower edge of the band. As the band becomes weaker, the motion of translation generally stops and the band is transformed into a luminous cloud—the remnant of the auroral material. The light of the rays which increases toward the bottom is due principally to the auroral material which they carry and not to the absorption of the rays in the atmosphere, thus accounting for auroral phenomena at the extreme heights at which they are observed to take place, where the absorption would be insufficient to produce luminescence.

The auroras of the first class being insulated by layers of air of great rarification can produce no magnetic effect, but the radiate auroras bringing the great masses of electrified matter in communication with the layers of atmosphere where electric currents can and probably do exist, produce great oscillations in the intensity of these currents, producing widespread disturbances of the magnetic needle.

The "auroras" claimed to be seen near the surface of the Earth, e. g., below the summit of a mountain may be produced in the same manner as the light about radium which is increased by increased pressure. The surface of the Earth in these regions may receive a negative charge by the descent of masses of air from the upper regions of the atmosphere, bringing with them auroral material, which under the greater pressure produces luminescence. In lower latitudes the appearance of an aurora is probably caused by the transportation of auroral material by winds directed towards the south in the upper layers of the atmosphere, from the zone of maximum. In transport it can not remain entirely insulated from the lower layers which are good conductors and thus magnetic disturbances always accompany auroral displays in the lower latitudes.

This hypothesis explains quite simply the diurnal and undecennial periods of the aurora, but brings the annual maximum at the equinoxes rather than in winter.

In the lower latitudes rays extending downward toward the Earth are rarely seen, while rays shooting out toward celestial regions visible up to the zenith are frequent, reaching heights surpassing 1000 km., which can not be explained unless the rays carry with them a material which of itself produces the light since such altitudes are much beyond the limits of our atmosphere.