quently we should expect to find a cyclonic circulation in the level in which the replacement is taking place. The cyclonic circulation may operate to prevent the pressure being made up overhead, but it can not prevent the cold air from flowing downhill unless the reduction of pressure is enough to reduce the density by as much as the low temperature increases it, and this is a difficult task, for near sea level it takes more than 3 millibars loss of pressure to make up for a single degree loss of temperature.

Hence we may suppose that the constant drainage of the land areas would result in the superposition of a cyclonic distribution at high level over them, and the continental lobes of Teisserenc de Bort's isobars for the upper air may well be due to this cause.

But the cause is obviously a very variable one, depending upon the distribution of cloud and other circumstances. Statistically, its effect upon the circulation of the upper air is to exaggerate the pressure gradient for westerly winds over the Temperate Zones of the continents, and to diminish the gradient northward. Thereby we introduce into the circulation local accentuation of current, which must be disposed of by some dynamical process.

The next step in the consideration rests upon the fact that by superposing a cyclonic depression upon the circumpolar circulation we displace a part of that circulation to the southward and reduce the northern part. Taking the case of Teisserenc de Bort's map for January, the westerly run of isobars over America and Asia is about 10° to 20° of latitude lower than over the oceans, and these two positions of westerly circulation have to be connected by isobars which cross the parallels of latitude, and therefore have a south-to-north and a north-to-south component respectively. Therefore, they can only be maintained persistently under the conditions set out in Proposition 1. Now, it has been shown in the discussion of Proposition 1 that permanence of a quasi-steady character might be realized in the case of an anticyclonic ridge having a south-to-north current on its western side, and *vice versa*, provided that momentum was being taken out of the westerly circulation in order to provide a slight eastward deviation from the isobars setting to the north. Such a case would be fairly represented by the deviation from circular isobars shown over the oceans on Teisserenc de Bort's map for January, and hence the form of those isobars may be arrived at by the influence of a steady flow-off of air down the land slope of the Arctic regions and the steady deviation of the wind from the direction of the southwest to northwest isobars on the western sides of the oceans in consequence of the momentum of the westerly circulation.

Meanwhile, what happens to the cold air which has run off the land areas? That has to be steered about by the distribution of pressure in the upper air as modified by any special peculiarities of temperature in the lower regions, and all sorts of complications may arise from this cause. So far as it goes, its density tends to set up high pressure over the regions which it covers, and so to make a slope of pressure southward and cause easterly winds on its southern side. Whenever in a mass of air temperature-fall is in the opposite direction to pressure-fall, great change in the horizontal distribution of pressure underneath is the result, and many of our local variations of pressure may fairly be attributed to the reactions which these cold masses of air offer to the attempt (in the end futile) on the part of the upper air to steer them round the pole from west to east. By their eastward motion these masses of cold air are always reminding us that if left to themselves, without the overpowering guidance of the pressure distribution of the upper air, they would form a circulation round the pole in opposition to the circulation of the upper air, with which they are in perpetual conflict.

TURBULENT MOTION.

In the study which has been the subject of the foregoing pages we have always considered the motion of the air to be regulated by a distribution of pressure balanced by the rotation of the earth, except in regard to the surface layer and one other suggested exception when the momentum of the general westerly circulation was invoked. It should here be noted that by this limitation to what may perhaps be called "great circle motion," we are considering almost exclusively the circulation above that half of the earth's surface which is north of the northern tropic and south of the southern one. There is another section of meteorology which has to deal particularly with the region between the Tropics, where the beginnings of tropical revolving storms are to be found. These storms, which have a diameter of some hundred miles or more, as well as the tornadoes which have a diameter of perhaps a quarter of a mile, belong to the subject of turbulent motion, with which the eddies and whirls that are produced by obstacles on the surface of the ground are also associated. All these phenomena of turbulent motion, important as they sometimes are in real life and death, must be treated in a manner different from that of the present communication.

BIRKELAND'S THEORY OF THE ZODIACAL LIGHT.[1]

[Dated Weather Bureau, Washington, D. C., May 1, 1914.]

Birkeland finds that several of his experiments [2] with a magnetized, phosphorescent terrella in a large vacuum chamber, furnish phenomena which serve him as a starting point for an explanation of the zodiacal light and the gegenschein.

The position of the zodiacal light has now been definitely shown to be closely related to the position of the solar equator, rising and sinking with it, and is not so immediately related to the ecliptic as former general opinion held it to be. One of the most significant, and heretofore unexplained, characteristics of the zodiacal light is the pulsatory character of the variations in its brightness or intensity, and in its shape. These pulsatory changes appear to an observer to be akin to those shown by the aurora and by terrestrial magnetism, and have been correlated with pulsatory oscillations in the terrestrial magnetic field. There is no lack of impeccable observations and records of this pulsation in the zodiacal light, witness writings by Humboldt, Birt of Kew, George Jones of the United States Exploring Expedition to Japan, and Birkeland at Halde, Kaafiord, and Khartum. Evidently an adequate theory of the zodiacal light must account for this feature of it. Birkeland therefore thinks "it very probable * * * that the zodiacal light must be primarily occasioned by electrical phenomena."

Birkeland regards the sun as a great magnet, having a "magnetic moment of the order 10^{28} or about 150 times as great as that of the earth," and that its magnetic equator is essentially coincident with its heliographic equator. Further he finds no good reason for supposing that the sun's magnetic axis is not coincident with its axis of rotation.

[1] The Norwegian Aurora Polaris Expedition, 1902-1903. V. 1, sec. 2, chap. 5. Christiania. 1913. f°.

[2] Described in "The origin of worlds." By Prof. K. Birkeland, Sci. Amer. suppl., Nos. 1957, 1958. New York, July 5, 12, 1913.

Constant rays of corpuscle-currents composed of atoms, molecules, and electrons are continuously given out by the sun, but apparently these rays are of two kinds: (1) Those of a somewhat less stiff magnetism, which are the rays continually given off by all portions of the sun but probably most strongly from the neighborhood of the heliographic equator; and (2) the very stiff corpuscle rays that radiate in short periods from the portions in greatest activity, viz, at and about the sun spots. The constant, less stiff rays, are less penetrative through matter, and probably come from lesser depths in the solar atmosphere. The very stiff rays from the sun spots are those which it is supposed specially occasion magnetic storms upon our earth.

Birkeland has investigated, experimentally, the behavior of these corpuscle-rays in the magnetic equator of a magnetic globe, and he feels justified in expecting to find that on repeating his previous experiments and using his largest discharge box, he will secure a perfectly flat ring of light 30 centimeters in diameter about the 8-centimeter globe. This will be with a difference of tension of only 700 volts between the globe and the positive pole, and a current of 21 amperes. With a low magnetizing current the ring is broad and small in extent, and when there are slight irregularities in the surface of the globe luminous rays are seen proceeding from the magnetic poles in addition to the luminous ring about the magnetic equator. If the surface is highly polished there is but the luminous equatorial ring. At times this equatorial ring was distinctly divided by a dark circular band into two concentric rings.

When polar rays were also visible they showed deflections equatorward, and the resemblance to the solar corona of May, 1901, became rather striking. In this connection he promises to conduct further experiments wherein he expects to secure even more perfect resemblances between experiment and nature.

Now he finds, mathematically, that—

> If radiation starting from the surface of a sphere in the plane of the magnetic equator, and only subject to the magnetic influence of the magnetic field of the sphere, reaches a distance from the center greater than 2.414 times the radius to [of] the sphere, the radiation will not be able to return to the sphere but will pass on toward infinity.

This result is independent of the magnetic moment of the sphere and the stiffness of the rays, but presumes the sphere uniformly magnetized or to have a magnetization which is a function of the distance from the center. His experiments make it—

> * * * very possible from a physical point of view, that a ring of radiant matter has been formed round the magnetic equator of the sun, the dimensions of this ring being greater than those of the earth's orbit. [We are here dealing with] corpuscular rays of very great stiffness * * * which partially consist of atoms and molecules, and not merely of electrons, thus * * * the radiant matter in thick layers is both slightly luminous and capable of absorbing and scattering solar light.

Let us now see how we can explain the observed characteristics of the zodiacal light, by supposing that in the sun's equatorial plane there exists a flat ring of radiant streams of matter, consisting principally of primary rays and streams of atoms from the sun, and perhaps also of secondary rays emitted from cosmic dust moving in the same plane and which are irradiated by the primary beams from the sun.

This theory resembles somewhat both the exploded one of Mairan (1731) and that now known as the meteoric theory. In equal degree it resembles that put forward by Jones after discussing his own observations, viz, "the hypothesis of a nebulous ring with the earth for its center." But really Birkeland's theory combines the advantages of the earlier theories and also explains phenomena of the counterglow (gegenschein), and pulsations of the zodiacal light, both heretofore unexplained.

As the earth advances in this assumed ring of radiant matter that surrounds the sun, the magnetism of the earth will sweep away the corpuscles of radiant matter from a space or cavity about it. This cavity is probably not the regularly shaped ring supposed by Jones. The experiments with the terrella show how the stream of corpuscles from the sun will be deflected when they sufficiently approach the earth, in such a way as to readily explain the brightness in the east before sunrise and the brightness in the west after sunset. In the latter case, we are looking into the deep layers of radiant matter lying in the sun's magnetic equator where therefore we see the brightest glow, and the brightness disappears at the boundary formed where the rays spread out to pass around the earth or below its magnetic equator.

From analogy with the terrella experiments, it may be concluded that after passing around the earth the rays will gather into a second sectional line (second line of precipitation) where, however, their density will be much less although still considerable. The concentration in this second line is always greatest when the magnetic axis of the earth (terrella) is perpendicular to the cathode rays, but the position of the line is always approximately on the magnetic equator of the earth and the brilliant origin of the line is always close to the point opposite to the location of the cathode (the sun). Brorsen had come to the conclusion that at both the vernal and the autumnal equinoxes "the brightest part of the gegenschein is directly opposite the place of the sun, so that a calculation of the greatest light frequently coincides to a degree with the point of opposition to the sun," and it appears that all accurate work since his confirms this and other conclusions made by him.

Now, at the time of the equinoxes the "second sectional line" of the corpuscle rays passing around the earth should be most strongly marked and it would lie in the earth's magnetic equatorial plane at a point about 180° from the sun, and also somewhat in the ecliptic or near the sun's equatorial plane. At this season we shall see the points of intersection of the corpuscle rays, the "second line of precipitation," lined up with the sun's magnetic equatorial ring of radiant matter, and which we assume extends beyond the earth's orbit. When regarding this "second line" we see into a considerably thicker stratum of the radiant matter opposite the sun, therefore perceive more diffused light; this increased quantity of diffused light along the "second line of precipitation" may be regarded as the origin of the gegenschein.

Spectrum analysis of the zodiacal light shows it to be essentially sunlight. Occasionally the auroral line is seen superimposed on the zodiacal light spectrum. Birkeland, though accepting analogies guardedly, finds that the known diffusion of light even on the very clearest days, and that his own observations (see below, p. 211) of what he concluded were daylight auroral rays scattering the sunlight and therefore appearing as pulsating daytime clouds, together with researches into optical conditions of electrically luminous gases and vapors by Ladenburg and by Wood, all indicate that "there is comparatively a very large number of dispersion electrons [in the radiant solar matter] that can take up and be in resonance with the light waves from the sun, and that *possibly here, too, this number of dispersion electrons is proportional to the enormous electric current intensity that*

emanates from the sun in the manner here assumed." It is not improbable that the great mass of radiant matter into which we suppose we look when observing the zodiacal light, is capable of diffusing enough sunlight to produce the luminosity of that phenomenon.—[C. A., jr.]

A POSSIBLE CONNECTION BETWEEN MAGNETIC AND METEOROLOGIC PHENOMENA.

By KRISTIAN BIRKELAND.

[Reprinted from Miss Jessie Muir's English text of "The Norwegian Aurora Polaris Expedition, 1902–1903." v. 1, 2d section. Christiania. 1913. p. 449–450.]

93. If the view we have maintained is correct, namely, that the magnetic storms are due to corpuscular rays that are drawn in in zones round the magnetic poles, where they pass directly down into the atmosphere of the earth, it is clear that these rays, especially in the upper strata of the atmosphere, must be assumed to produce a strong ionisation in the air. In our expedition of 1902–03, atmospheric-electrical measurements were made, which will be gone into later on; but it may be remarked here, that the result of these measurements showed that the "Zerstreuung" of the air at those stations averaged about twice as much as in Christiania, indicating that the air up there is considerably more ionised than in lower latitudes. In an expedition which I made in company with my assistant, Mr. Krogness, to Kaafiord at the time when Halley's comet crossed the sun's disc in May, 1910, I had an opportunity of studying this matter more closely.

Instead of, as before, making the measurements at places that are at no great height above sea-level, I on this occasion investigated it at my old aurora observatory on the top of Haldde Mountain, about 910 meters above the sea. Here there proved to be sometimes tremendous variations. On the 20th May, for instance, values were found that went up to about 500 times the normal. Unfortunately the attempt was interrupted in the middle of these measurements; but I had an opportunity of making insulation-tests twice at that time, which proved there was no perceptible leakage. If we can demonstrate this circumstance with certainty, we presumably have before us a phenomenon that is closely connected with the peculiar light-phenomena that Lemström discovered in 1882–3 on a mountain-top at Sodankylä.

There is no doubt that such strong ionisations will have a very great influence upon atmospheric conditions, especially upon the formation of clouds, and must thus be assumed to be a meteorological factor of no small importance, especially for the districts in the vicinity of the auroral zone. I am of the opinion that this is a very important connecting link between terrestrial-magnetic and meteorological phenomena. I have therefore recently submitted to the Norwegian State authorities, a suggestion that a permanent up-to-date magnetic-meteorological observatory be established upon the top of Haldde, for the purpose, if possible, of throwing light upon these interesting and meteorologically important matters.

There was another phenomenon, striking examples of which we had the opportunity of seeing on this expedition in May, 1910, namely, the formation of what may be called auroral clouds. In addition to the usual polar bands, which in a clear sky, could very often be observed in the form of several evenly luminous arcs, of which, however, *one* was especially conspicuous, exactly similar to parallel auroral arcs, we very frequently found formations of cirrus clouds, which exhibited the most perfect agreement with various auroral formations. Several times we had capital examples of the manner in which such clouds are formed, how drapery-formations appeared in a short time, exactly in the same manner as an auroral drapery. The first observer, who has called attention to this very interesting fact seems to be Adam Poulson [Paulsen].[1] As far as I know, no one has, however, studied this phenomenon in connection with simultaneous magnetic registrations at the same place. This we had the opportunity of doing, and the very interesting fact came out, that the formation of these clouds was always accompanied by simultaneous magnetic storms and earth-currents; and there thus appears to be no doubt that these are direct cloud-forming effects of the same rays that occur in the auroral phenomena. From this it seems, that these cirrus-clouds are directly formed by the corpuscular rays which we suppose to be the cause of magnetic storms and aurora. The first hypothesis that one naturally might form as to this phenomenon is, that the clouds are due to water-vapor brought to condensation by the ions formed by the impact of negative rays. It is, however, also a probability that some of the observed "auroral clouds" are not real clouds, but merely a very strong concentration of corpuscular rays, which in the case of darkness might appear luminous; in the daytime the concentration of corpuscles should have the effect of making the places where they occur less transparent, and able to diffuse light, and thus become visible. In such a way also possibly certain faint polar bands observed in the polar regions might be explained. According to circumstances these concentrations may disappear, or perhaps give rise to real clouds.

[1] Paulsen, Adam. Wolkenbildung durch das Nordlicht. (Aus einer Mittheilung an die k. dänische Akad. d. Wiss., 1895.) Meteor. Ztschr., Wien, 1895, 12.Jhrg. p. 161–169.

RADIOTRANSMISSION AND WEATHER.

By A. H. TAYLOR.

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In a previous paper on this subject [1] the writer submitted evidence which seemed to show that unusually good radiotransmission across long overland distances at night is preceded the day before by generally cloudy conditions prevailing in the region across which the nocturnal good transmission takes place.

The evidence presented in that paper has been greatly strengthened by subsequent observations. In particular it may be mentioned, that out of some 60 cases of good transmission studied since September 24, 1913, 44 have followed a generally cloudy condition over the area in case, while of the other 16, a majority have occurred during the shortest days of the year, when the hours of sunlight in the latitude of Grand Forks, N. Dak., are relatively few.

Before discussing the bearing of this evidence on the idea of the reflection and refraction [2] of electric waves by ionized layers of the earth's atmosphere, it will perhaps be well to examine some of the data collected at this station since September 24, 1913, for evidence of a somewhat different character.

In commenting upon the previous paper, the editor of the Electrical World suggested that the effects noted

[1] Electrical World, Aug. 30, 1913.
[2] Dr. Eccles, in The Electrician, Sept. 27, 1912, and Sept. 19, 1913.