

shown in the seventh column of the table is little affected by differences in the limiting brightness. This divergence indicates that, as compared with both Kapteyn and Mount Wilson, their results are not homogeneous; and noting, further, that the numerous and careful gauges of the Herschels which extend to the 14th magnitude give a galactic condensation agreeing closely with Kapteyn (Herschel 12.9, Kapteyn 11, Chapman and Melotte 3.9), one gains the impression that, through some unknown cause, their counts in the richer fields fail to include many of the fainter stars.

<sup>1</sup> Wright, T., *Theory of the Universe*, London, 1750.

<sup>2</sup> Kapteyn, J. C., *Pub. Astr. Lab. at Groningen, Groningen*, No. 18, 1908, (1-54). This memoir includes bibliographical references to earlier investigations.

<sup>3</sup> Chapman, B. A. and Melotte, P. J., *Mem. R. Astr. Soc., London*, 60, 1914 (145-173).

<sup>4</sup> Parkhurst, J. A., *Researches in Stellar Photometry, Washington, Carnegie Inst., Pub.*, No. 33, 1906, (1-192). Similar results for the fields of several variable stars have appeared from time to time in the *Astrophysical Journal*.

<sup>5</sup> Seares, F. H., *These PROCEEDINGS*, 3, 1917, (188-191).

#### A CORRECTION

Professor Alexander McAdie has kindly drawn my attention to an error in dates occurring in my paper, *Inferences Concerning Auroras*, published in the *Proceedings* for January, 1917, pages 1-7. In reference to the "Aurora of April, 1883", he has convinced me from his data that the particular event occurred on November 17, 1882. My mistake was due to faulty references, and in no way affects the general argument.

ELIHU THOMSON.

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INFERENCES CONCERNING AURORAS

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It seems doubtful if any extensive auroral display has occurred without coincident existence of exceptional areas of disturbance on the sun. We may assume that at such times great jets or streams of electrified matter (electrons perhaps) akin to cathode rays in a vacuum, are projected with high velocities outward, and that occasionally some of these jets cross the earth's orbit or pass near to it, being when leaving the sun in a general radial direction, bent backwards for obvious reasons.

That electrified matter in a vacuum does move in jets or streams for indefinite distances is a fundamental fact. Moving charges of the same name in paths, straight or curved, act like parallel currents and attract one another, the more as their velocity is greater, until the static repulsion of such like charges sets a limit to further approach. It is possible that the space around the sun may be crossed by many such jets or streams of electrified matter moving at very high velocities into the vacuous space. The coronal streamers may be the visible composite effects of the projected jets. Such electrified jets may act inductively by proximity to the earth or directly by conduction of electricity to the earth's outer atmosphere.

In the present paper, however, it is hoped to prepare the way for further study by pointing out certain physical facts regarding the relations of auroral phenomena to the earth and its atmosphere: to locate and give direction to the streamers seen in auroras; and to explain the nature of the so called auroral arch, the zenith crown, and other characteristics. It is believed that the following propositions may be shown to be true.

1. Streamers seen in auroras, singly or in composite masses, are in reality vertical, or approximately so, to the earth's surface, nearly parallel when adjacent, and only slightly divergent even when miles apart; the divergence being due to curvature of the earth's surface.

2. In any aurora, the streamers appear to be located in bands or zones more or less wide in latitude extending generally in east and west direction, or forming belts or zones between parallels of latitude in which the streamers extend vertically upward like trees in a forest.

3. In some rare auroras the vertical streamers are closely limited to a narrow belt of latitude; sometimes only 2 or 3° or even less, in width north and south, while the east and west extent of the narrow belt may be very great.

4. In wide spread auroras the belt of vertical streamers may cover great extents of latitude and extend east and west unlimited distances. This appears to have been the case in the recent great aurora of August 26, 1916.

5. The curvature of the so called auroral arch is an optical effect of perspective, slightly added to by the curvature of the earth. The appearance of folded curtains of streamers is a similar effect of superposition and perspective when the active band or zone covers many degrees in latitudes. It is probable that the lower ends of auroral streamers have about the same height in the earth's atmosphere; a layer from which they stream upward to heights which vary in different displays or even in the same display. This layer probably exists at a height of about fifty miles and conducts laterally or horizontally, thus distributing the electricity discharged from it into the streamers.

6. The convergence of long streamers toward the zenith seen in the greater auroras, is purely an optical effect of perspective, the streamers being vertical.

7. The so called zenith crown is in reality due to bundles of streamers, nearly vertical but seen on end. They appear as patches of shifting light in or near the zenith, sometimes surrounded by apparently converging streamers from the north, east, and west, and even from the south; converging in appearance only.

8. The convergence of streamers is of the same nature as the convergence of straight parallel railway tracks in the distance, or better, the apparent convergence toward the sun, of the sunbeams seen in dust-laden air, when the sun itself is obscured by a small irregular cloud, or is back of a broken mass of clouds.

In April, 1883, at near the middle of sunspot period and coincidentally with the occurrence of an enormous sunspot, there was perhaps the

greatest auroral display seen in our latitudes for more than half a century. Telegraph lines from east to west could not be operated owing to arcing at the keys. The display as witnessed by me, was characterized by colored streamers passing upward from all around towards the zenith from north, east, west and south. The coloring gave me the first clue to the true relations existing. In the north the sharply defined streamers beginning their appearance low in altitude with the usual greenish auroral light, shot, or spread upward with changes of tint, finishing at their upper ends in a deep crimson. The light patches of the zenith crown went through the *same succession* of coloring constantly, each time ending in deep crimson. This fact suggested in the strongest way that in the crown one was observing bundles of streamers on end, but of the same character as all the other streamers in the field of view. Great masses or broad bands to the east and west though steady were colored likewise. These dense masses in the east and west were unquestionably due to the composite effect of great numbers of streamers superposed in the line of sight through great distances to east and west; the colors less pure blurred by distance and failure of exact superposition. Other observers at places far to east and west of my position might observe zenith crowns but composed of other streamers seen on end. A necessary consequence of the display presenting the same appearance to observers in many places far apart, up to hundreds of miles east and west, and through a zone north and south, is that the streamers everywhere were in reality vertical, or approximately so, to the earth's surface. In Chicago, a distance west of about eight hundred miles, this aurora was described in the same way, the appearances coinciding with my observations. The effects being so similar in places far apart, the only inference possible is the one stated, namely, nearly vertical streamers wherever seen.

In this view observations upon subsequent auroras could be made more intelligently than before. But auroral displays of great magnitude are rare in our latitudes, especially such as are so far south as to cause a belt of streamers directly over the place of observation giving the zenith crown. While several highly instructive displays occurred meanwhile, one on September 29, 1908, gave streamers converging from all directions joining the crown in the zenith which had the usual characteristics. My note of it says "The rapid procession of streamers and the waving curtains make this display quite exceptional; though far inferior to that of April, 1883." On August 26, of this year (1916) there occurred a display second only in my experience to that of April, 1883, but without the remarkable coloring of the display of that year.

It was observed by me in the Adirondacks, and served to confirm the inferences drawn from the earlier displays.

But on August 28 there occurred a simple type of aurora which I had only seen on two former occasions. It may be said to contain a single element only. It consisted of a single band a belt of light, estimated at from  $1\frac{1}{2}^{\circ}$  to  $2^{\circ}$  wide extending across the sky due east and west, from horizon to horizon and passing through the zenith. It lasted for an hour or a little more. At the zenith and for  $2$  or  $3^{\circ}$  east and west thereof, the band was broken into patches which shifted, faded and were replaced by others of different shapes and positions. A friend observed the same appearance in Maine hundreds of miles to the east on the same night.

The explanation of this simple type of aurora is not difficult when made in accordance with the ideas here presented. No streamers were seen as such. At the zenith they were directly over the observer, and though present were seen only on end as small patches of light constantly changing: while in the extensions or narrow bands to east and west from the zenith the luminous streak was a composite of super-posed streamers in the same latitude as the observer, which streamers overlapped each other all the way down to the apparent horizon along the overhead arch east and west. They were like the palings of an extended fence located far above the observer. He would see the separate palings, directly above him but only on end. Otherwise they overlap and obscure each other or one another. To appreciate fully the reality, the observer is better placed if the auroral arch when, as in this case, very narrow is not directly overhead. The usual auroral arch is the location of the lower ends of the vertical streamers extending upward from it. This location would appear from the work of Störmer and others to be in a layer of atmosphere about fifty miles high. This layer on which the feet of the streamers may be said to rest is probably a conducting layer like the partial vacuum in a Geissler tube.

The so called auroral arch appears as an arch or curve merely because of perspective vision, just as a searchlight beam or a long straight cloud appears bent when crossing the sky, or as a cloud layer, known to be horizontal appears above us as a great inverted bowl.

The streamers in the aurora of August 26, were, as in the aurora of 1883, directed towards the zenith crown from all sides. The appearance of the whole aurora when at its height, and looking upwards towards the zenith was as if one were looking into a truncated hollow cone from below its base, with the slant sides composed of ribs of light; these ribs as well as the blunt apex, constantly changing, shifting, fading, and

returning and traversed by waves of light of varying intensity. These appearances were not, of course, peculiar to the particular post of observation but were observed from points far east and west without substantial differences. A vivid description by Dr. C. C. Nutting is found in *Science* for October 6, 1916, pp. 496 and 497. See also *Science* of November 10 to November 17 and December 8, 1916, for other letters concerning this great aurora.

The belt covered by this display was evidently of very great extent east and west and spread far to the north in latitude. One is compelled to recognize that observers far apart seeing the same appearances are looking up between nearly parallel and vertical streamers, seeing those on end as a zenith crown when directly above them; while laterally they are superposed by being back of one another at varying distances. The same auroral appearances are possible to be seen alike at different places simultaneously, *only* when a system of *vertical streamers exists*.

Let us for illustration assume an extended horizontal flat surface and that there be erected above it a set of vertical and very long rods in a vertical plane extending east and west, the rods being spaced apart like the paling in a long straight picket fence. An observer on the plane faces north looking towards the rods or paling the lower ends of which are high above his position, appearing say at an altitude of  $60^\circ$  in the north direction. The lower ends will now appear to lie east and west in an arch of curve convex upward owing to diminished angle of vision with distance and the rods or palings will appear to converge upward if long enough almost to the observer's zenith, much foreshortened; the whole effect being that of perspective. Removing the point of observation further to the south, the middle point of the arch drops more and more, the arch becomes flatter, and the vertical rods appears less foreshortened and longer, while still converging towards the observer's zenith. These varied appearances, modified to a minor degree by the earth's curvature, are just what are seen in auroras. If the vertical rods are spaced apart irregularly, increased in number and spread into a band so that they do not lie exactly in a vertical plane east and west, but in an arrangement like a long strip of forest extending east and west and of considerable width north and south (an arrangement corresponding to a belt or zone of streamers instead of a single line), the analogy to the auroral arrangement at any instant is much closer.

It can readily be seen that the recognition of the vertical relation of streamers to the earth's surface and the nearly constant level of their lower ends simplifies to a great extent the study of auroras, particularly

the determination of the total height reached by them, curvature of the earth being allowed for. The effect of this curvature will be less the higher in altitude the auroral arch, or the nearer it is to being overhead. The streamers are often observed to rise from the arch first as short streamers, gradually developing and extending upward until their upper ends are a few degrees from the zenith. When they originate in an arch which is of low altitude and extend nearly to the zenith, as they appear to do in the greater displays, their length must be hundreds of miles, possibly in some instances reaching one thousand or more. It would appear that no limit can be set for their possible height. In most auroras, however, the visible extent of the streamers is more limited. A low altitude auroral arch implies great distance north from the observer and for a given actual streamer length a less apparent height or length. Paulsen's class of auroras without streamers may mean either that the streamers are too short and too many to be noted separately, or that the electrification is too feeble for their development, the observed luminous glow being due to flow of current in the conducting layer itself, an arch forming horizontally, but without outward projection.

If our assumptions are approximately correct the arch of an aurora, if located farther north than about 600 miles from an observer will be below his horizon but the streamers extending upward from it if long enough may be seen. Auroras far north of this will probably be invisible or be seen merely as a luminous glow well down on the northern horizon. When the breadth in latitude of the auroral zone is great and the display is seen from the south, the streamers may overlap or be arranged in apparent curtains or folds, the lower ends of the streamers being in that case at varying apparent altitudes above the northern horizon even when in the same general line of view. In such case they may be superposed in the line of sight and therefore be composite, or increased in apparent length owing to imperfect superposition in their lengths with respect to those back or front of them. It is believed that these and like considerations will suffice for the explanation of observed appearances of auroras in spite of their great variety.

The direction of streamers, as indicated, being vertical to the earth's surface, is suggestive of electrical discharges, ions or electrons projected outward into space from the conducting layer of our atmosphere; discharge into space in which the mean free path is unlimited. These discharges might have their origin in a charged conducting layer in which the potential suddenly rose to a critical value, or might be brought about inductively by the presence in the space around the earth of

opposite charges possibly arriving in great jets from the sun. Further the charges might be communicated to our air from such jets followed by discharge into space beyond.

A sudden uplift of a highly charged thin air layer itself in waves or ridges might easily disturb the normal potential distribution and precipitate discharges from the crests. Atmospheric currents or displacements may cause such uplifts as when a colder stream strikes down under a warmer charged layer.

A set of vertical streamers would deflect a compass needle on the earth's surface one way or the other depending on whether such streamers exist to the north or to the south of the position of the compass. Observations seem to confirm this but more work is needed. The direction of the compass deflection would determine the direction of the virtual streamer currents to which the deflection was due. Aside from these and other considerations, the effort has, however, been to present in this communication a rational theory which will at least enable a proper conception of the actual space relations of the visible portions of an aurora in relation to the earth's surface to be obtained; and to place on record ideas which through many years of consideration by the author have seemingly received at each appearance of an aurora with streamers, repeated confirmation.

While I have in former papers, as in "Thoughts on Osmical Electricity," an address before the Franklin Institute of Pennsylvania (December 19, 1893) and notably in an address on "Atmospheric Electricity" delivered at Princeton University October 21, 1909, and published in *Science*, December 17, 1909, pp. 857 to 869, given a brief sketch of some of the views presented, particularly the outward direction of the streamers, later observations have served to provide cumulative evidence and extend their application.

## APPLICATION OF THE LAWS OF ACTION, REACTION AND INTER-ACTION IN LIFE EVOLUTION

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AMERICAN MUSEUM OF NATURAL HISTORY, NEW YORK CITY

Read before the Academy, November 13, 1916

Since 1893 I have been working upon the interrelations of the various so-called factors of evolution and have published a series of studies of this subject. In 1908 I presented before the American Society of Naturalists an exposition of a law which I termed "the law of the four inseparable factors of evolution," these factors being regarded as the