Country.	Population.	Contribution.	Country.	Population.	Contribution.
German Empire....	60,000,000	£160	Italy..............	33,000,000	£160
Belgium............	7,000,000	40	Mexico	13,600,000	80
Bulgaria...........	3,700,000	20	Norway...........	2,300,000	20
Chile...............	3,000,000	20	The colonies of the Netherlands	5,500,000	40
Kongo State........	19,000,000	80	Portugal...........	5,400,000	40
Spain...............	19,000,000	80	Roumania.........	6,300,000	40
United States.......	76,000,000	160	Russia............	129,000,000	160
Greece	2,500,000	20	Switzerland.......	3,300,000	20
Hungary............	19,250,000	80			
Japan	48,000,000	160			

It was decided at the Berlin meeting that Professor Kövesligethy, of Budapest, should be secretary and Professor Palazzo, of Rome, the vice-president of the International Seismic Association. Professor Gerland had already previously been designated as director of the central bureau. The office of president of the association was left vacant until the final decision of Great Britain as to its adhesion had been settled. There the matter stands for the present.

The disastrous results of recent earthquakes and volcanic eruptions have directed increased attention to the subject. Its thorough investigation is indeed likely to yield important information on the interior constitution of the earth. A hearty cooperation to obtain and circulate the material for a detailed discussion can not fail to bear fruit, and even though there may be legitimate grounds for dissatisfaction at the manner in which a particular scheme has been organized, I must express my own opinion that at the present moment the permanent interests of this country would be best secured by our joining the association and helping to direct its work in a manner which would assist rather than hamper the present organization of the British Association.

THE SPECTRUM OF THE AURORA BOREALIS.

By Dr. W. MARSHALL WATTS. Dated Sydenham, England, September 14, 1907.

Among the rare and striking phenomena of nature, the aurora borealis, or "northern lights", has always excited much interest. The earlier explorers of the Arctic regions made frequent observations of it, and speak of it in glowing terms, describing it as either a long tranquil arc of silver light, stretching along the northern horizon, with its highest point in or near to the magnetic meridian; or as broken cloud-like masses of a glowing ruddy light, with streamers and golden rays, compared to aerial spears, shooting from the arc and sometimes reaching to the zenith, forming an appearance resembling a crown—the "corona borealis".

Upon the invention of the spectroscope scientific observers were eager to apply the new method of investigation to the aurora. Among the earliest observers of the spectrum was Ångström, who, in the winter of 1867–68, observed[1] on several occasions the spectrum of the luminous arc bordering the dark segment, which is always to be seen in the aurora even when faint. Its light proved to be almost monochromatic, and consisted of a single brilliant greenish line to the left of a group of known lines of calcium.

Measuring the distance of the auroral line from this group, Ångström determined its wave length to be 5567.[2] Besides this line, of which the intensity is relatively great, Ångström observed also, by widening the slit, traces of three faint bands extending nearly to *F*. Ångström remarks that this chief auroral line does not coincide with any known line in the spectra of simple or compound gases. Otto Struve, of Pulkowa, to whom Ångström communicated his result, also made measurements, which gave for the position of the line 1259 of Kirchhoff's scale, or wave length 5552.

[1] Ångström: "Recherches sur le Spectre Solaire".

[2] That is, 5567 "Ångström units" or hundred-millionths of a centimeter, or 5567 ten-millionths of a millimeter, or 556.7 micro-millimeters or 556.7 $\mu\mu$, or 0.5567 microns, or 0.5567 μ.—EDITOR.

55——3

In a paper of later date[3], Ångström discusses the probable origin of the auroral line, and gives it as his opinion that the spectrum consists of two portions, the chief line being due to phosphorescence (or fluorescence) and the other lines to rarified air, the conditions of temperature and pressure, so different in the upper regions of the atmosphere from those in the laboratory, sufficing to explain all divergencies. He says:

> The one spectrum results from the monochromatic yellow light which is always seen even in the feeblest traces of the aurora, and which, on clear winter nights, is perceived from all parts of the sky. The other spectrum consists of extremely feeble lines or bands, and it is only in the strongest auroras that it is possible to measure their position even approximately. Piazzi Smyth[4] observes that the chief line of the aurora falls between the second and third lines of the greenish yellow hydrocarbon group; and Vogel[5] remarks that it is coincident with a line in the spectrum of rarified air. This latter observation is correct, but in my opinion this is the result of the purest accident. The red lines—first observed by Zöllner—seldom occur. There is no doubt that the spectrum varies at different times. The discharge is sometimes disruptive, and sometimes by conduction; it occurs sometimes in the extreme limits of the atmosphere, and sometimes at short distances from the earth's surface.

Ångström observed (on April 18, 1873) lines at 5567, 521–, 501–, 487–, 472–. He quotes the observations (of presumably the same lines) by Barker[6] as 431–, 4705, by Vogel[7] as 4694, 5233, and Lemström[8] (November 19 and 22, 1872) as 5568, 5235, 4694, 4262, and thinks that the means of these measurements agree fairly well with the lines 5227, 4707 and 4272 observed in the violet light at the negative pole in rarified air.

Vogel[9] observed the auroral spectrum on several occasions in 1870 and 1871. The instrument he used was the star spectroscope belonging to the 11-inch equatorial of the Bothkamp Observatory, consisting of a set of direct vision prisms, with slit, collimator, and observing telescope with a magnifying power of four. The measuring apparatus consisted of a micrometer screw, the head of which was divided into 100 parts. This moved a fine steel point in the field of view, and the point could be illuminated by a small lamp if required. The readings of the micrometer were reduced to wave lengths by means of readings of about 100 Fraunhofer lines found in Ångström's Normal Map of the Solar Spectrum. After each observation of the auroral spectrum readings of the sodium line or of the hydrogen lines were taken by way of control.

A very bright aurora was observed on October 25, 1870. The spectrum showed the green line and several fainter lines toward the blue on a dimly lighted background, extending over *E* and *b*, and half-way from *b* to *F*. No measurements were taken on this occasion.

On February 11, 1871, an aurora was seen; the average of six readings of the brightest line was 5573. No lines in the red were seen. On February 12 an average of six readings gave 5572; Doctor Lohse also took six readings and obtained 5569. The appearance of the spectrum on this occasion was essentially different from that of February 11. The green continuous spectrum was present from 5572 to *b* and traversed by some bright lines between *b* and *F*, one line beyond *F*, and just before *G* a faint broad band. Later a red line between *C* and *D*, but nearer *C* than *D*, made its appearance.

On April 9, 1871, a very bright aurora was seen, showing a red sheath rising nearly to the zenith. The spectrum was similar to that of February 12, but much more intense, showing five lines in the green, and a broad band in the blue. The red ray allowed him to recognize seven lines, for which the

[3] Ångström, Pogg. Ann., Jubelband, p. 424.

[4] Piazzi Smyth, C. R. [Comptes Rendus], LXXIV, p. 597.

[5] Vogel, Pogg. Ann., CXLVI, p. 582.

[6] Barker, American Journal of Science, (3), II, 465; V, 81.

[7] Vogel, Pogg. Ann., CXLVI, p. 573.

[8] Lemström, Polarljuset och Polarljusspektrum. Helsingfors, 1873.

[9] Vogel, Pogg. Ann., CXLVI.

wave lengths (in each case the mean of four readings) were as follows:

6297 ± 14 very bright.

5569 ± 2 the brightest line in the spectrum—becomes fainter on the appearance of the red line.

5390 very faint.

5233 ± 4 moderately bright.

5189 ± 9 very bright when the red line appears at the same time.

5004 ± 3 very bright.

4694 to 4663 a broad band, less bright in the center.

4629 ± 3 very faint in those parts of the aurora in which the red line appears.

On April 14 a faint aurora occurred, only the green line being seen; the mean of two readings was 5569. The probable wave length of the chief line Vogel estimates at 5571.3.

In discussing the observations of the spectrum of the aurora it will be convenient to deal separately with (*a*) the chief auroral line in the greenish-yellow; (*b*) the lines in the red, which are only occasionally observed, and (*c*) the lines at the blue end of the spectrum, which seem to be related to the band spectrum of nitrogen, as seen at the positive or negative pole in a Geissler tube.

Professor Scheiner, in his Treatise on Astronomical Spectroscopy, quotes the following observations of the chief line, as compiled by Gyllenskiöld,[10] to which I have added a few others, with references:

Year.	Observer.	Reading.	Authority.
1867..	Angström.....	5567 ± 1	
1868..	Struve	5552 ± 15	Bull. Acad. St. Petersbourg, xiii, 449.
	Lemström.....	5569 ± 14	Arch. de Genève, (2), 1, 225, 355.
1869..	Peirce	5565 ± 11	Am. J., (2), xlviii. 123, 404.
1870..	Proctor	5595 ± 25	Nat. iii, 6; vii, 242.
1871..	Smyth	5579 ± 95	Piazzi Smyth, v. 282, 324.
	Lindsay.......	5680 ± 50	Nat. iv, 347, 366; vii, 182.
	Barker........	5594 ± 13	Am. J., (3), ii, 465; v, 81.
1872..	Vogel.........	5571 ± 1	Pogg. Ann., cxlvi, 569.
	Denza.........	5568 ± 12	
	Donati........	5569 ± 10	
	Oettingen.....	5548 ± 30	Pogg. Ann., cxlvi, 284; Ann. Chim. Phys. (4). xxvi, 269.
	Respighi......	5574 ± 10	Nat. v, 511; C. R., lxxiv, 743.
	Wijkander....	5572 ± 1	Arch. de Genève, (2), li, 25.
1873..	Backhouse....	5660 ± 10	Nat. iv, 66; vii, 182, 463; xxviii, 209, 212.
	Barker........	5569 ± 14	Am. J., (3), ii, 455.
	Lemström.....	5569 ± 5	Arch. de Genève, (2), i, 225, 355.
1874..	Maclear.......	5533 ± 37	Nat. vi, 329; xvii, 11.
	Backhouse....	5570 ± 10	Nat. iv, 66; vii, 182, 463; xxviii, 209, 212.
	Huggins	5571 ± 0.5	Proc. Roy. Soc., xlv, 430; xlvi, 133.
1879..	Nordenskiöld .	5563 ± 10	Vega Expeditionens, tome 1.
1880..	Copeland	5572 ± 2	Nat. xii, 510.
1882..	Gyllenskiöld..	5568 ± 2	Aurores Boréales, Stockholm, 1886.
	Schroeter	5587	
	Krafft.........	5591	
1884..	Gyllenskiöld..	5569 ± 6	Aurores Boréales, Stockholm, 1886.

The mean of all these measurements is 5569.8, but Professor Scheiner selects the following as the most trustworthy:

Year.	Observer.	Reading.
1867..	Angström.....	5567 ± 1
1872..	Vogel.........	5571 ± 1
	Wijkander....	5572 ± 1
1873..	Lemström.....	5569 ± 5
1874..	Huggins......	5571 ± 0.5
1880..	Copeland.....	5572 ± 2
1882..	Gyllenskiöld..	5568 ± 2

The mean of these numbers is 5570.0.

This result is, of course, on Ångström's scale; to reduce to Rowland's scale we must add 1.3, thus obtaining for the wave length of the chief auroral line 5571.3.

Eighteen measurements by Professor Campbell at Mount Hamilton[11] gave a mean result of 5571.6.

It is only within recent times that the spectrum of the aurora has been photographed. The first success in this direction was obtained by E. S. King at Harvard College Observatory in 1897.[12] Two photographs obtained on April 1, 1897, and March 15, 1898, with an exposure of 147 minutes showed four lines whose wave lengths are given as 4694, 4288, 3922, and 3862. The strong yellowish-green line does not seem to have been recorded, probably because the plates were insensitive to this region of the spectrum.

Paulsen, in Iceland, obtained photographs of the aurora spectrum in January, 1900. Besides the chief line at 5570 the photographs showed 21 lines between 4700 and 3370. Their wave lengths were determined to be:[13] 470, 463, 456, 449, 443, 436, 432, 422, *420*, 417, 412, 406, 402, 397, 393, *391.5*, 381, 376, 371, *358*, 353, and *337*; those italicized were strong lines, the rest weak. Paulsen remarks that the strong lines seem to belong to a different spectrum from the weak lines. Experiments made later at Copenhagen seemed to show an agreement with the negative-pole spectrum of nitrogen, and Professor Scheiner, to whom the photographs were submitted, writes: "There appears to me no doubt that the auroral spectrum is absolutely identical with the kathode spectrum of nitrogen".

The best photographs of the auroral spectrum hitherto obtained seem to be those of the Russo-Swedish expedition taken at Konstantinovka, Spitzbergen, in the winter of 1899–1900 by Professor Sykora.[14] The instrument employed was a spectrograph (see fig. 1) specially constructed for the purpose with objectives of 110 mm. focus, provided with either a simple prism or a compound Rutherford prism. It was found necessary to expose for many hours or even for several days, and trouble was experienced from variations of temperature during the long exposure resulting in want of definition of the lines. The best results were obtained with the single prism, and five negatives (see fig. 2) were obtained from which measurements could be made. As reference lines the Fraunhofer lines *F*, *G*, and *K* and certain hydrogen lines from a vacuum-tube were adopted. From these the wave lengths of the auroral lines were calculated by means of Hartmann's formula. Negatives 1, 2, and 3 showed only three lines; the other two negatives showed these three and several other lines besides. The following were the values obtained for the three brighter lines:

	Green line.	Violet line.	Ultraviolet line.
No. 1..	5567.0	4273 1	3912.1
	5573.9	4276.2	3912.4
	5574 6	4276.4	3913.1
Mean...........	5571.8±1.6	4275.2±0.7	3912 5±0.2
No. 2.............	5569.1	4264.7	3911.0
	5589.0	4268.7	3910.7
	5587.2	4268.2	3910.7
	5594.0	4268.7	3911.8
Mean...........	5584.8±3.7	4267.4±0.7	3911.0±0.2
No. 3.............	5558.3	4279.4	3908.0
	5549.8	4279.6	3914.6
	5547.5	4279.2	3914.8
	5548.6	4277.1	3913.7
Mean...........	5551.0±1.7	4278.8±0.4	3912.8±1.1
No. 4.............	5572.6	4275.1	3911.2
	5576.1	4280.5	3911.8
	5569.1	4273.1	3908.1
	5574.3	4275.1	3911.1
	5576 1		3910.5
Mean...........	5573.6±0.9	4275.9±0.8	3910.8±0.3

[10] Gyllenskiöld: "Aurores boréales", Stockholm, 1886; p. 166, in the Swedish Polar Expedition.

[11] Campbell, Astro-Phys. Jour., x, 1897.

[12] E. C. Pickering, Nature, LVII, p. 591.

[13] Express in micro-millimeters ($\mu\mu$), instead of the Ångström unit.—EDITOR.

[14] Sykora, Mem. St. Petersb., (8), xi No. 9.

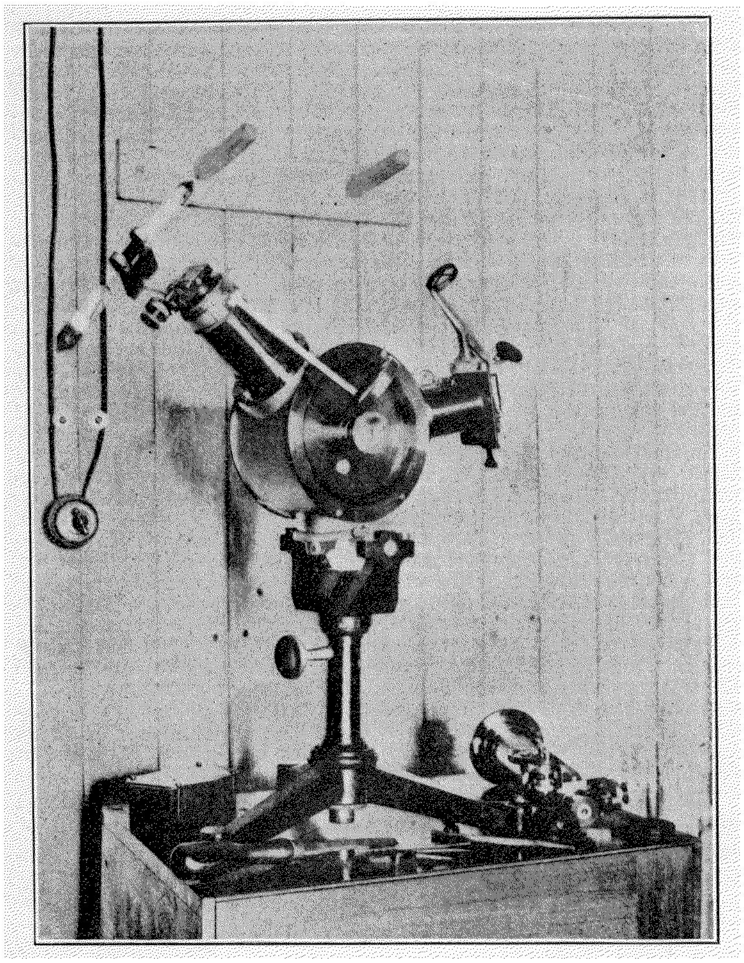

FIG. 1.—Toepfer spectrograph used by Professor Sykora in Spitzbergen, 1899–1900.

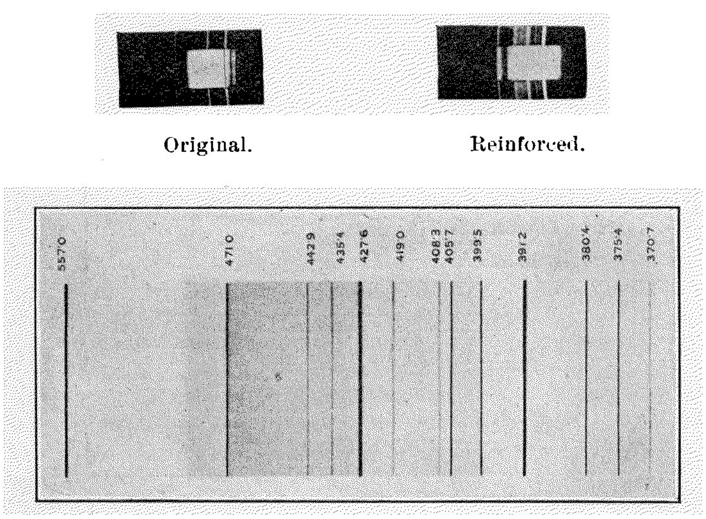

FIG. 2.—Photographic negatives and plot of the spectrum of the aurora by Professor Sykora.

From these means, giving each a weight inversely proportional to the square of its probable error, the following definitive values are obtained:

Green line	5570. 3±3. 4
Violet line	4274. 3±1. 6
Ultraviolet line	3911. 8±0. 3

From these values the wave lengths of the other feeble lines were obtained; negative No. 5 was used only to measure the feebler lines from the first three lines. The final results are given below:

Characteristic green line	5570±3. 4
First feeble line	4710±0. 5
Second feeble line	4429±1. 7
Third feeble line	4354±3. 1
Characteristic violet line	4274±1. 6
Fourth feeble line	4190±2. 3
Fifth feeble line	4083±2. 0
Sixth feeble line	4057±0. 8
Seventh feeble line	3995±0. 8
Characteristic ultraviolet line	3912±0. 3
Eighth feeble line	3804±0. 8
Ninth feeble line	3754±0. 5
Tenth feeble line	3707±0. 8

We may, then, sum up our knowledge of the wave length of the chief characteristic green line of the auroral spectrum as follows:

Mean of observations 1867–1882 (Scheiner)	5571. 3
Campbell's mean	5571. 6
Sykora's mean	5571. 8

These numbers present a fair agreement with a strong line in the spectrum of krypton, the wave length of which is given by Baly as 5570.50 and by Runge as 5570.417. Its intensity is given as ten in the first spectrum (without Leyden jar and spark-gap) and three in the second spectrum (with jar and spark-gap).

In the Astrophysical Journal of 1903,[15] Professor Runge writes:

In his report on the aurora Paulsen compares its spectrum with the bluish light near the kathode of a vacuum tube filled with oxygen and a little nitrogen and carbonic oxide. He concludes that there is a close connection between them.

This conclusion seems to me misleading, since there is quite as striking a coincidence with krypton as with oxygen. These comparisons of spectra have very little value so long as wave lengths of the aurora lines are not measured more accurately. The only aurora line which has been measured with a considerable amount of accuracy is the green line, and here the coincidence seems to be in favor of krypton as I pointed out some years ago.

In the same journal, for April, 1904, Baly,[16] after referring to Runge's paper, writes:

Sykora's measures are probably at least as accurate as any hitherto published. In the table given below lines are taken from both spectra of krypton. The aurora discharge takes place through very rarefied gas, especially if the atmospheric krypton is the main carrier of the electricity. It has long been known that when the ordinary discharge passes through argon at reduced pressure the red spectrum only is visible, unless the pressure is too low when both the red and blue spectra are seen simultaneously. The same is true of krypton, for when the pressure is greater than a certain small value, only the first krypton spectrum is seen, if the pressure be now reduced a stage is soon reached at which the second (or jar and spark-gap) spectrum makes its appearance, so that the two spectra are seen together. Such a condition might perfectly well obtain in the case of the aurora, and therefore lines are taken from both spectra.

Aurora spectrum (Sykora).	Krypton spectrum.	Intensities.	
		First spectrum.	Second spectrum.
5570, strong	5570. 5	10	3
4710, weak	4710. 7	....	1
4429, very weak	4431. 8	....	4
4354, very weak	4355. 7	1	10
4276, strong	4274. 1	10	2
4190, very weak	4185. 3	....	2
4083, very weak	4082. 6	....	4
4057, weak	4057. 2	....	8
3995, weak	3995. 0	....	6
3912, strong	3913. 0	....	1
	3912. 7	....	5
3804, weak	3804. 8	....	4
3754, weak	3754. 3	....	5
3707, very weak	3708. 2	....	1

There seems hardly any doubt, from the above figures, of the very close connection between the aurora spectrum and the krypton spectra;

[15] Runge, Astrophysical Journal, XVIII, page 381.
[16] Baly, Astrophysical Journal, XIX, page 187.

further, it seems that it is the second spectrum that is most concerned. This is only to be expected if we consider the probable rarefied condition of this gas at the high altitudes at which the discharge takes place.

In endeavoring to reconcile the observations of different observers one is forced to the conclusion that the spectrum varies at different times, and this also is the opinion exprest by Ångström and others. This is conspicuously the case as regards the lines in the red portion of the spectrum. Some auroras are described as "red auroras". The aurora observed in America, November 9, 1871, is described by Barker[17] as "a crimson aurora (with lines at 623, 562, 517, 502, and 482) giving place in half an hour to a white aurora which showed only the last four of these lines". Backhouse[18] says that he has observed the green line in 83 auroras, but the red in only 11.

In attempting to discover the wave length of this red line it seems to be justifiable to correct the measurements by the measurements of the green line made at the same time by each observer to agree with 5570. We have thus the following results:

Observer.	Observed wave length.	Corrected.
Vogel	....	6297
Piazzi Smyth	6300—(5579—5570)	6291
Ellery	6350—(5600—5570)	6320
Zöllner	....	6279
Oettingen	6290 + (5570—5548)	6312
Rowland	6283 + (5570—5543)	6310
Gyllenskiöld	6306 + (5579—5568)	6308
Mean		6302.4
Mean reduced to Rowland's scale		6303.4

There is a strong red line in the spectrum of neon with wave length 6304.99. This identification of the red line with a line of neon seems pretty nearly as satisfactory as the identification of the green line 5571.6, with the krypton line 5570.5.

Sir James Dewar, in a lecture delivered at the Royal Institution in 1902, exprest the opinion that "the rosy tint in the streamers (of the aurora) appears to be due to neon".

We are not able to arrive at satisfactory conclusions as to the origin of the other lines which have been recorded by different observers in the spectrum of the aurora. There is much doubt in the identification of a line as the same line in the different observations. H. R. Proctor, in an article in the Encyclopedia Britannica[19] attempted a summary of the observations then available. Rand Capron, in his book, Auroræ and their Spectra (London, 1879), gave another attempt. A very good summary was given by Backhouse in Nature[20] of 1883. Other attempts are those of Berthelot[21], who sought to identify the lines with those of argon, and Stassano[22], who enumerated as belonging to the aurora more than a hundred lines, of which he identifies two-thirds with lines of the atmospheric rare gases; but it is evident that Stassano has multiplied any one line of the aurora into as many lines as there are observers, so that the comparison can not be considered of much value.

The wave lengths of lines in the accepted auroral spectrum are given in Table 1, and these are compared with spectra of atmospheric gases in Table 2. Fig. 3 gives a graphic presentation of the work of all observers.

Professor Sykora says[23]:

The photographs show that the spectrum of the aurora borealis does not resemble any known spectrum. It is most natural to refer the lines of the aurora to those of nitrogen. According to wave lengths some of the lines seem to agree with lines of nitrogen, but we have too few data to justify a definite conclusion; the more so as the spectrum of nitrogen has numerous lines in the ultraviolet region which, for want of quartz prisms, could not be obtained in our photographs of the aurora. The simple comparison of the wave lengths of different spectra seems to be less important for the explanation of the nature of the aurora than the study of the spectra of rarefied air or nitrogen under the most varied conditions. In taking account of the relations between the aurora borealis, terrestrial magnetism, and the physical life of the sun, we may conclude that the phenomena of the aurora are luminous effects produced in the upper atmosphere under the influence of the electromagnetic induction of the sun. These phenomena are observed, especially in high latitudes, partly in consequence of the meteorological conditions and the purity of the air in these regions, and partly on account of the neighborhood of the magnetic and geographical poles of the earth. The relation between the aurora and terrestrial magnetism is shown by the greater number and greater intensity of the auroras observed in the regions surrounding the north and south poles, and the fact that the magnetic needle is disturbed during the occurrence of auroras. As to the relationships between auroras and the physical life of the sun, they are shown indirectly by the undoubted connection between solar spots and the magnetism of the earth, and directly by the statistics of solar spots and auroras.

The how and the why of the production of auroras are still unknown. All that can be asserted is that we have to do with a phenomenon resembling the light of a rarefied gas produced by electromagnetic induction in the anelectrogenic tube (without ordinary electrodes). We know that the rarefied gas in a tube may be rendered luminous not only when the tube is provided with electrodes, but also in their absence, as shown by Tesla's experiments. It would be of the greatest interest to make experiments similar to those of Tesla, and to study the spectra of nitrogen in the anelectrogenic tube by means of quartz prisms or a concave diffraction grating. That such experiments might lead to results appears probable from the fact that the spectrum of nitrogen at the negative pole differs from that of the positive pole. Among the other conditions under which the gas might be placed, we mention here only the great variations of temperature and density, which, as the experiments of Lockyer, Scheiner, and others show, may influence the character of the spectra obtained, and the position of the lines.

There seems now little doubt that the chief line of the aurora, i. e., Ångström's green line, must be assigned to krypton, and there is considerable probability that the red line is due to neon. What is difficult to understand, on this hypothesis,

TABLE 1.—*Wave lengths of lines in the accepted auroral spectrum as determined by various observers.*

Proctor.	Capron.	Backhouse.	Paulsen.	Gyllenskiöld.	Sykora.	Mean.
6303	6297	6289		6306		6299
				5776		5776
				5664		5664
5569	5567	5569.7	5570	5569	5570	5570
	5390 (?)					(?)
5342		5359		5353		5351
		5285				5285
				5264		5264
	5233	5237				5235
		5226		5228		5227
5214		5199				5206.5
	5189					5189
5161						5161
	5004	5001		5001		5002
4984						4984
		4870				4870
	4835			4837		4836
4823						4823
			4700	4707	4710	4706
	4694	4688				4691
4667	4663					4665
				4642		4642
	4629		4630			4629.5
			4560			4560
			4490			4490
			4430		4429	4429.5
		4366	4360			4363
	4350				4354	4352
			4320			4320
4299						4299
		4278			4276	4277
			4220			4220
			4200		4190	4195
			4170			4170
			4120			4120
					4083	4083
			4060		4057	4058.5
			4020			4020
					3995	3995
			3970			3970
			3930			3930
			3915		3912	3913.5
			3810		3804	3807
			3760		3754	3757
			3710		3707	3708.5
			3580			3580
			3530			3530
			3370			3370

[17] Barker. American Journal of Science, (3), ii., p. 465.
[18] Backhouse. Observations at the Observatory. Sunderland. Vol. II.
[19] Ninth edition, Vol. III, p. 90.
[20] Vol. XXVIII, p. 209.
[21] C. R., March, 1898.
[22] Ann. Chim. et Phys., (7), XXVI, p. 40.
[23] Sykora, Mem. St. Petersburg, (8), XI, No. 9.

TABLE 2.—*Wave lengths of spectrum lines for the aurora and for certain atmospheric gases.*

Aurora.	Neon.	Krypton I.	Krypton II.	Nitrogen. Band.	Nitrogen. Line.
6299	6305 (8)	...	...	...	
5776	5764.5 (8)	...	...	...	
5664	5663 (1)	...	...	...	
5570	...	5570.5 (10)	... (3)	...	
5351	...	...	...	...	
5285	...	...	...	...	
5264	...	...	...	...	
5235	...	...	...	...	
5227	...	...	5229.7 (1)	...	
5206.5	...	...	5208.5 (3)	...	
5189	5188.8 (1)	...	5187.2 (1)	...	
5161	...	...	...	...	
5002	...	...	...	...	{5005.7 / 5002.7} (10)
4984	...	...	4982.9 (1)	...	
4870	...	...	4870.2 (1)	...	
4836	4837.5 (1)	...	4836.7 (2)	...	
4823	...	...	4825.4 (3)	...	
4705.7	4704.6 (4)	...	4710.7 (1)	4709.3	
4691	...	4691.1 (2)	4691.5 (2)	...	
4665	...	...	...	4666.3	
4642	...	...	...	4648.4	
4629.5	...	4624.5 (10)	...	...	
4560	...	...	4556.8 (4)	4555.2	
4490	...	...	4490.0 (4)	4489.6	
4429.5	4430.3 (1)	...	4431.8 (4)	...	
4363	...	...	4362.8 (9)	4356.3	
4352	...	4351.5 (3)	4355.7 (10)	...	
4320	...	4319.8 (10)	... (1)	...	
4299	...	...	4300.7 (5)	...	
4277	...	4274.1 (10)	... (2)	4269.1	
4220	...	...	4222.4 (1)	4239.0	
4195	4198.7 (4)	...	4185.3 (2)	4200.8	
4170	...	...	4172.0 (2) }	4141.2	
4120	...	...	4118.3 (2) }		
4083	...	...	4082.6 (5)	4094.0	
4058.5	...	...	4057.2 (8)	4059.0	
4020	...	...	...	...	
3995	...	...	3995 (6)	3998.0	
3970	...	...	3965.0 (4)	...	
3930	...	...	3929.3 (3)	3942.5	
3913.5	...	...	3912.7 (5)	3913.7	
3807	...	...	3804.8 (4)	3804.8	
3757	3754.3 (2)	...	3754.3 (5)	3755.1	
3708.5	3701.3 (6)	...	3708.2 (1)	3710.1	
3580	...	...	3580.1 (1)	3581.5	
3530	3529.9 (1)	...	3535.5 (6)	3536.5	
3370	3370.0 (6)	...	3375.1 (4)	3371.2	

is why the other strong lines of krypton and neon are not also seen. It is reported[24] that at the soirée of the Royal Society in 1901 Sir W. Ramsey exhibited an "artificial aurora", and said: "An electrodeless discharge in air gives a spectrum in which the leading green line of krypton is distinctly visible at low pressures. The discharge was deflected by the magnet, sending out streamers along the lines of magnetic force."

Among other experiments bearing upon this question may be mentioned those of Liveing and Dewar[25] on the spectrum of the most volatile gases of the atmosphere, not condensed at the temperature of liquid hydrogen. A vacuum-tube filled from liquid air after passing thru liquid hydrogen so as to condense nitrogen, oxygen, argon, and carbonic acid gave a brilliant spectrum of hydrogen, helium, and neon, and a large number of less brilliant lines. There was no line observed in the neighborhood of 5570.

Moissan and Deslandres[26] found that in a vacuum-tube containing air when exhausted to pressures less than one millimeter the nitrogen spectrum became weaker, and other lines became more prominent, especially the argon line at 4158.6 and the helium line at 4143.7.

Sir James Dewar, in a lecture delivered[27] at the Royal Institution in November, 1903, has dealt with various problems of the atmosphere. Dalton's theory assumes that each constituent of the air forms a separate atmosphere, completely independent of the other constituents except for temperature; and thus, if we fix an altitude and assume the rate of fall of temperature as known, we can calculate the pressure of each constituent for that altitude and thus calculate the composition of the atmosphere at that altitude. If, at the surface of the earth, the air contains one volume of hydrogen in 10,000, then at an altitude of 37 miles we should find that water vapor and carbonic acid had disappeared and that the air contained about 12 per cent of hydrogen and only 10 per cent of oxygen; and at 47 miles, where the temperature might be —132° C., only hydrogen would be left.

The aurora has been observed at very different heights varying from a few hundred meters to several tens of kilometers, of which altitudes the lower are most frequently observed in the Arctic regions. With increasing altitude the temperature of the air must decrease down to the absolute zero, and at extreme elevations we must reach a point where the different constituents of the air would condense.

In a bath of liquid air argon, krypton, and xenon are condensed, and neon and helium become dissolved in the liquid. The denser gases will accumulate in the lower strata, and the lighter gases in the higher strata. From its low density and relatively greater abundance we should expect neon to manifest itself in the highest strata of the atmosphere.

Table 3 gives us useful data in considering this question.

TABLE 3.—*Data relating to certain gases of the atmosphere.*

Gas.	Approximate quantity in 10,000,000 volumes of air at earth's surface.	Density.	Boiling point—absolute scale.	Freezing point—absolute scale.
			°	°
Nitrogen	7,711,600	14	91	....
Oxygen	2,065,900	16	80	....
Hydrogen	1,000	1	21	15
Helium	15	2	6	....
Neon	150	10	34	....
Argon	92,300	20	86	82
Krypton	10	40	121	104
Xenon	5	64	....	....
Carbon dioxide	3,360	22	195	....

It appears probable that at the requisite great elevation we should have strata of mist consisting of the solidified constituents of the atmosphere.

The writer has made certain experiments to discover what might be expected to be the effect of a conducting layer interposed at a certain height between the negatively electrified surface of the earth and the positively charged upper atmosphere.

For this purpose a brass sphere one and one-half inches in diameter was taken and a glass tube 12 inches long, into which the brass ball would just fit. The glass tube was converted into a vacuum tube and connected to a Fleuss pump; when exhausted to a pressure of seven millimeters, with a kathode at the bottom and anode at the top, the tube gave the usual discharge with the violet glow about the kathode, of which the spectrum showed the characteristic negative-pole spectrum of nitrogen, recognized in particular by the characteristic band at 3913.7, whilst the greater part of the tube was occupied by the brick-red positive column.

The experiment was now interrupted, the tube dismounted and the brass ball inserted, being supported at a point about two-thirds of the height by a short tube of glass fitting inside the larger one, and the tube again exhausted. It was then seen that the ball gave rise to a new kathode and anode spectrum within the tube, discharging negative electricity upward and positive electricity downward. Fig. 4 is a photograph of the discharge within the tube, and Fig. 5 shows the spectroscopic analysis of the discharges, the characteristic negative spectrum of nitrogen being seen at the bottom kathode and also at the top of the brass ball, and the usual positive pole spectrum being seen at the top of the tube, and also below the brass ball. This latter figure is a photograph of the discharge taken thru a Thorp transparent diffraction grating.

[24] Nature, LXVI, p. 204.
[25] Proc. Roy. Soc., LXVII, p. 467 (1901).
[26] Comptes Rendus, CXXVI, p. 1689.
[27] See Monthly Weather Review, January, 1904, Vol. XXXII, pp. 10–12.—EDITOR.

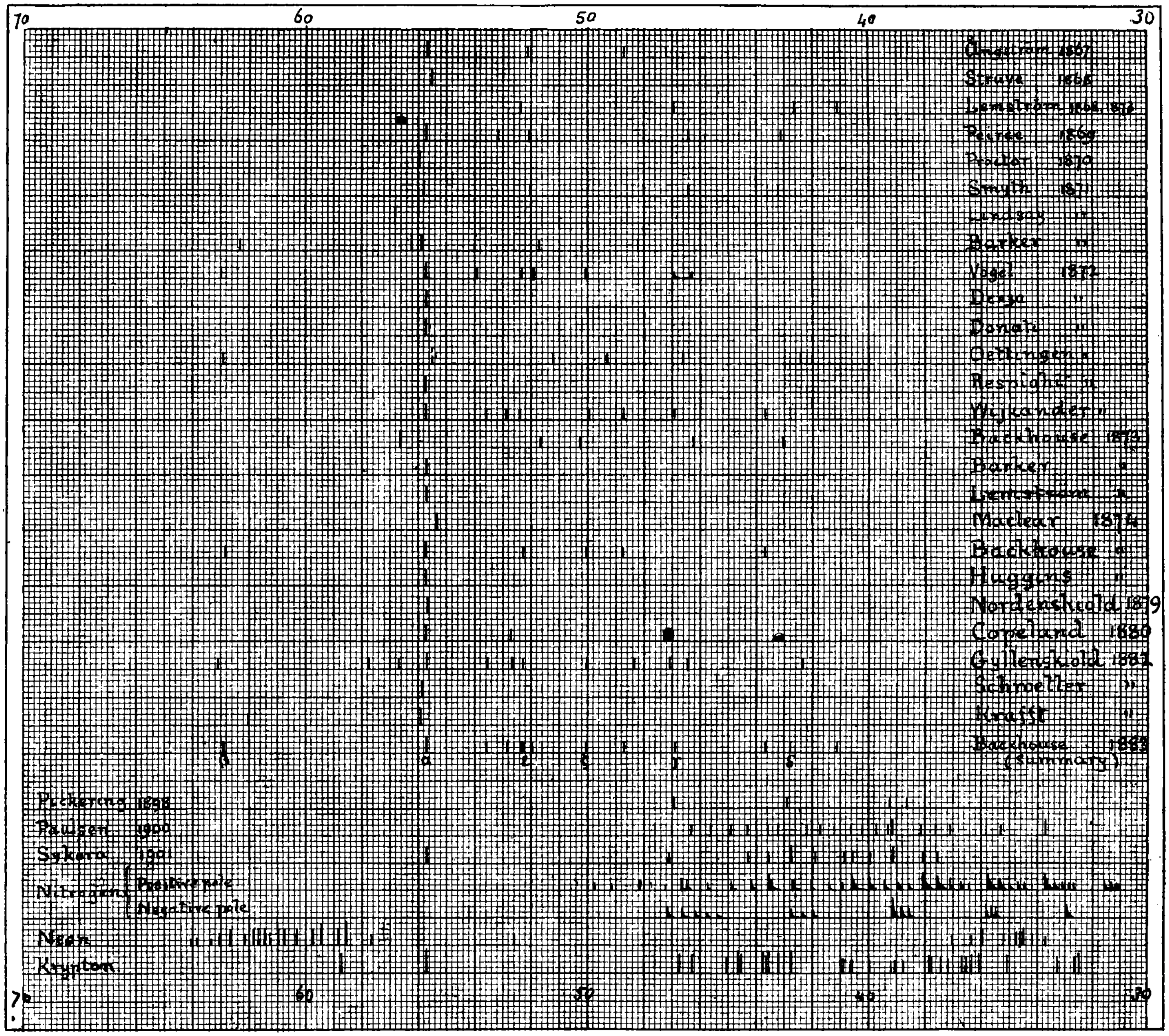

FIG. 3.—Auroral spectrum and gaseous lines as recorded by various observers.

The behavior of the discharge in the tube was observed whilst the pressure of the gas was varied. An ordinary vacuum tube filled with air shows the brightest nitrogen band spectrum at a pressure of a few millimeters; as the pressure increases the band spectrum gradually fades and gives place to the second spectrum of nitrogen with characteristic lines at 5005.7 and 5002.7, and when the pressure reaches about 300 millimeters the band spectrum has disappeared. If the pressure is further increased the second spectrum of nitrogen becomes brighter, until with increase of pressure the spark refuses to pass.

In the experiment with the brass ball it was found that at one particular pressure the band spectrum was seen in the upper and smaller compartment of the tube, whilst the lower compartment was not luminous. It would seem that at this pressure the electricity past by conduction thru the lower compartment sufficiently to produce luminosity by discharge in the upper one. It seems possible that the conducting stratum of condensed gases at a certain height above the earth may play the same part in the auroral discharge as the brass ball plays in the experiment described. There is difficulty in propounding any theory of the auroral discharge which will apply both to auroras observed at low elevations and also to those which have been observed at elevations of 400 or 500 kilometers; since at these extreme heights ordinary electrical discharges would be impossible.

In the reports of results obtained by the Danish polar expedition of 1882–83, the late Professor Paulsen, in an article [28] "Sur la nature de l'aurore polaire" seems to think that the observed facts of the aurora are fairly in agreement with Edlund's theory of atmospheric electricity. He writes:

M. Edlund's theory [29] of the origin of the aurora is based upon the well-

[28] Exploration internationale des regions arctiques. Expedition danoise.

[29] Recherches sur l'induction unipolaire. Kongl. Svenska Vetenskaps akademicus Handlingar, vol. XVI.

known phenomenon of unipolar induction. M. Edlund has shown that in consequence of the diurnal rotation of the earth, the terrestrial magnetism produces a difference in electric potential between the surface of the earth and the upper layers of the atmosphere, the latter being positively electrified, and the surface of the earth negatively. The force of induction which produces this difference of potential is always at right-angles to the direction of the dip needle. In the equatorial regions of the earth this force is vertical, whereas in other latitudes it may be resolved into a vertical force, and a horizontal force. The vertical component tends to propel positive electricity into the upper regions of the atmosphere. In high northern latitudes the same effect is produced by the vertical component, but the horizontal component propels it toward the magnetic zenith. In this way the upper atmosphere accumulates positive electricity of which the potential increases from the equator toward the polar regions.

In the equatorial regions the vertical force offers a great resistance to the reunion of the positive electricity of the air and the negative electricity of the earth. As we approach the poles, the vertical component of the force of induction decreases, and with it the resistance to the flow of positive electricity toward the earth.

When the difference in electric potential between the atmosphere and the earth reaches such a point that the tension can overcome the resistance opposed by the force of induction and the subjacent layers of air, the positive electricity of the air will flow, following the direction of the dip needle, to unite with the negative electricity of the earth. M. Edlund shows by calculation that the regions where such a flow can take place form a continuous zone embracing both the terrestrial and the magnetic poles of the earth, and reaching a lower latitude in America than in the old continent. According to M. Edlund's theory it is to the flow of these currents thru the rarefied air that the aurora borealis is to be attributed.

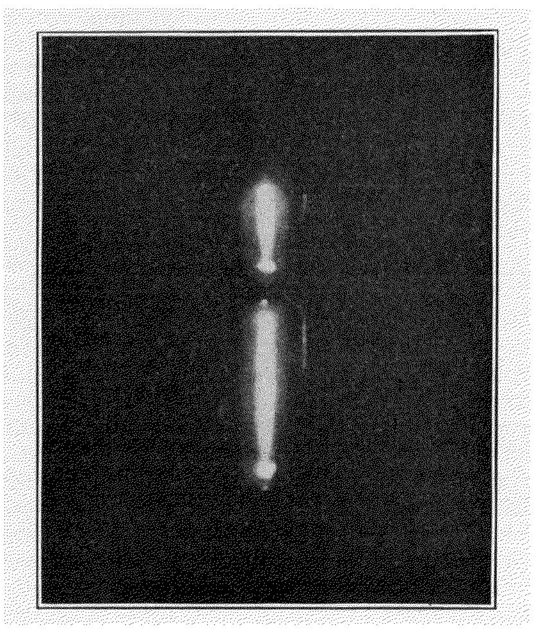

FIG. 4.—Electric discharge within a vacuum-tube containing a brass sphere.

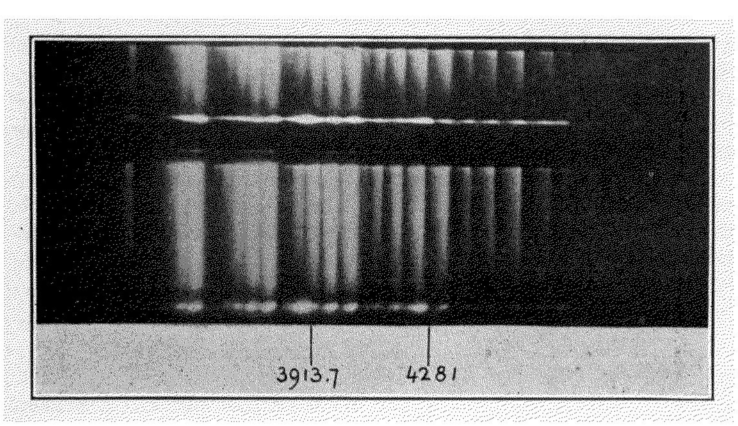

FIG. 5.—Spectroscopic analysis of the electric discharge.

In later papers Paulsen[30] regards the aurora as due to kathode rays, produced by solar agency in our atmosphere, and in fact no theory can be considered complete which does not take account of the statistical correspondences between auroras, sun spots, magnetic storms, etc.

In 1894 Paulsen[31] writes:

An impartial consideration of the phenomena of the aurora leads to the conclusion that we have to do with energy propagated by means of radiation. The source of the radiation can not be in the aurora itself. We can not suppose that an auroral ribbon of almost insensible thickness suspended often at a small height from the earth should be the center of an activity emitting rays darting upward to a height of a hundred kilometers. When a form of energy is propagated by radiation the rays are only the channels by which the source loses its energy. Many of the auroras preserve their radiant structure right up to the base of the phenomenon. How are we to imagine a source of energy animated by a movement surpassing that of the most violent hurricanes possessing the remarkable property of emitting vertical luminous rays as far as the limits of the atmosphere without losing energy in other directions? And how can we explain the origin of an energy having its center of action in the midst of the atmosphere, often in its lower parts, producing the grand phenomena of the aurora borealis, without that energy ever becoming exhausted? We must then admit that the source of emission of the auroral rays is to be sought in the upper regions of the atmosphere, or outside of it; but in any case the constant direction of the rays shows us that the source must participate in the diurnal rotation of the earth.

In radiation the energy is propagated without loss unless the radiation is absorbed by the medium which it traverses. It is only as the auroral rays penetrate into the denser portions of the atmosphere that their traces become visible by absorption and transformation of their energy into light. We are thus led to consider the aurora as a fluorescent light produced by the absorption of energy propagated by radiation, of which the source is found in the upper regions of the atmosphere.

The electric radiation of the negative pole in an exhausted tube presents many analogies with the radiation which produces the aurora. We know that these kathode rays travel in straight lines, without reference to the position of the positive pole, and that they produce fluorescence when they impinge upon the walls of the tube. We know that these rays may penetrate air at atmospheric pressure, being then absorbed with production of light. The passage of these rays modifies the molecular condition of the air, rendering it a conductor.

As to the region of the auroral radiation we must admit the existence of a stratum of negative electricity in the upper regions of the atmosphere. The existence of negative electricity on the surface of the earth is generally admitted. The removal of electricity by rising vapor of water will tend to diminish the potential of the air near the surface of the earth. This action being greatest in the equatorial regions, the mean potential of the air ought to be greatest in the polar regions, and least in the equatorial regions, whereas the exact opposite is the case; and this is to be explained only by supposing an accumulation of negative electricity in the upper regions of the atmosphere toward the poles. The auroral radiation which we suppose is emitted by molecules charged with negative electricity produces a loss of energy which, in accordance with the law of the conservation of energy, can only take place by means of energy supplied to the electric layer from without. It can hardly be doubted that the origin of this energy is solar. The observation that the auroral activity has its maximum in the early hours of the night, and diminishes during the night, suggests that the source of energy has to be renewed each day.

The auroral radiation results from energy stored up in the electric layers. If this storing up of energy is greater in the equatorial regions it does not follow that the transformation of potential energy into actual energy by means of auroral radiation will also be greater in the equatorial regions, if in consequence of movements in the upper atmosphere we suppose these insolated molecules carried toward the poles, there to lose their stored-up energy under the form of auroral radiation. The zone of auroras will be found where this transformation takes place most actively; beyond this zone the energy has diminished, and auroras will be less frequent.

The situation of this zone thus depends upon the movements of the upper atmosphere. It may be an accident that it includes the magnetic pole, but it is possibly not an accident that its central axis coincides with the axis of low atmospheric pressure which extends from the south point of Greenland toward Spitzbergen.

An important paper by Arrhenius[32] appeared in 1900, in

[30] 1906. Sur les recentes theories de l'aurore polaire. Résumé et critique des theories de MM. Birkeland, Arrhenius, et Nordmann. Idées personnelles. (Academie royale des sciences et des lettres de Danemark. Extrait du bulletin de l'année, 1906. No. 2.)

[31] "Sur la nature et origine de l'aurore polaire." Bull. Ac. Roy. Copenhagen, 1894.

[32] Physikalische Zeitschrift, 1900, Vol. II, pp. 81 and 97.

which he pointed out the possibility of a discharge of negatively electrified particles from the sun, which form nuclei of condensation, of which the earth receives its share on the side turned toward the sun.

Maxwell, in his original presentation of the electromagnetic theory of light, in 1873, pointed out that light should exert a pressure, and showed how to calculate its amount. He found that sunlight at the earth's surface should exert a pressure of 0.592×10^{-10} grams on one square centimeter, a quantity so small that it would seem to be hopeless to observe it. Nevertheless Poynting thinks he has obtained experimental proof of the existence of such a pressure. At the surface of the sun a cubic centimeter of water, which on the earth weighs one gram, would weigh 27.47 grams, and the pressure of sunlight on a square centimeter would amount to 2.75 milligrams. Such a mass would be attracted to the sun, but the case is quite different with bodies of extreme minuteness. A cube of water whose edge measures one-thousandth of a millimeter [a micron or μ] would experience an attraction of 27.47×10^{-12} grams and the pressure of light on its side would be $2.75 \times 10^{-3} \times 10^{-8} = 27.5 \times 10^{-12}$, or rather more than its weight. If, then, the cube has smaller dimensions than 1μ it will be repelled. The diameter of a molecule of hydrogen is possibly about 0.0002μ, and this contains perhaps 2000 "corpuscles". Negatively electrified ions of this order of magnitude are given off as kathode rays from the negative pole in a highly exhausted tube, from substances upon which kathode rays impinge, from hot bodies, and from radioactive substances; and these ions are capable of producing fresh ions by collision with the molecules of the gas thru which they pass.

Professor Poynting remarks that "one effect of this radiation pressure worthy of note would be its sorting action on dust particles. If the particles in a dust cloud circling round the sun are of different sizes or densities, the radiation accelerations on them will differ. The larger particles will be less affected than the smaller, will travel faster round a given orbit, and will draw more slowly in toward the sun. Thus a comet of particles of mixed sizes will gradually be degraded from a compact cloud into a diffused trail lengthening and broadening, the finer dust on the inner and the coarser on the outer edge".

A good account of Arrhenius's theory as applied to the explanation of comets' tails, the aurora, etc., has been given in the Popular Science Monthly, Vol. LX, p. 265, New York, 1902, by Prof. John Cox, of McGill University.

With reference to the aurora, Professor Cox says:

Perhaps the most interesting application of Arrhenius's theory is his explanation of the aurora. In a well-known experiment the streams of negative particles forming kathode rays in a Crookes tube are exposed to a magnetic field, when they are seen to describe helices round the lines of force. If the field is powerful enough they may thus be bent into a complete circle inside a moderately large tube.

Now the negative particles discharged from the sun arrive most thickly over the equatorial regions of the earth, which are most directly opposed to him. Long before they reach any atmosphere dense enough to excite luminescence, they are caught by the lines of force of the earth's magnetic field, which are horizontal over the equator, and have to follow them, winding round them in helices whose radii are so much less than their height above us that the effect to a beholder on the earth is as if they moved *along* the lines of force. Over the equator there is little luminescence for want of atmosphere. But as the lines of force travel north and south they dip downward, making for the magnetic poles, over which they stand vertical. Soon the particles find themselves in lower layers of the atmosphere, comparable in density with our highest artificial vacua, and begin to give out the darting and shifting lights of the kathode ray. But this can only be at the cost of absorption, and by the time the denser layers of air are reached their energy is exhausted. Hence the dark circles round the magnetic poles from which, as from behind a curtain, the leaping pillars of the aurora rise. From this point of view it is significant that Dr. Adam Paulsen, who has made a special study of the Northern Lights, found so many points of correspondence between them and kathode rays that in 1894 he was led to regard the aurora as a special case of the latter, tho unable to give any account of their origin in the upper atmosphere, such as is supplied by Arrhenius's theory.

In communicating the above article Mr. W. M. Watts makes the following appeal to American meteorologists:

I have come to the conclusion that it is most desirable that other and more accurate observations of the spectrum of the aurora should be obtained. I would respectfully suggest that the duty of obtaining such rests chiefly with you Americans, since your opportunities are, no doubt, greater than ours. Simple arrangements seem to me quite sufficient. In the first place choose a locality away from the lights of a town, preferably on an elevation. I should propose to construct a light observatory, or dark room, of wooden framework, mounted so as to revolve horizontally on a support, so as to oppose the slit side to the brightest part of the aurora. In one wall I would have a vertical slit, and outside of this the largest lens I could obtain for the purpose of concentrating the light upon the slit. This lens need not be achromatic, and, therefore, need not be costly. Inside I would have ready the photographic apparatus, and would supplement the photographic attempts by eye observations of the spectrum at every opportunity. For these eye observations I should choose my binocular spectroscope with large gratings. For the photographs I should use a spectrograph, consisting of a Thorp (or Wallace) grating as large as could be obtained, in front of a lens (telescope) of sufficient aperture to correspond to the grating, and of about 15 inches focal length; and last, but not least, I should use Wratten and Wainwright panchromatic plates.

Measurements of wave lengths are easily made with my binocular spectroscope. I have two different arrangements for the purpose, but in the case of the aurora I should place a nitrogen (or other) vacuum tube so as to occupy a portion of the slit—such vacuum tube being illuminated at will by means of a switch at the observer's position.

Altho such great institutions as the Carnegie Observatory on Mount Wilson, the Lick Observatory on Mount Hamilton, the Yerkes Observatory at Williams Bay, the Harvard College Observatory at Cambridge, and Mount Weather station at Bluemont, may have all the apparatus and men needed for the above-mentioned research, yet the help of others favorably located is still greatly to be desired. The outfit above recommended by Mr. Watts is not expensive as compared with the outfits for many other researches, but the work must be carried out by expert physicists such as are now found in every university.—EDITOR.

SMITHSONIAN METEOROLOGICAL TABLES.

The steady demand for the Smithsonian Meteorological Tables has justified the preparation of a revised edition, dated December, 1906, which is essentially a revision of the edition of 1893, prepared by the late Mr. George E. Curtis, as replacing the previous editions by Guyot, Libbey, and others.

The new edition of 1906 contains an introduction, followed by tables that are classified as thermometric, barometric, hygrometric, wind, geodetical, conversion, and miscellaneous. Among the new or enlarged tables we note the following:

Marvin's pressure of aqueous vapor at low temperatures—English and metric measures.

Bigelow's standard system of notation—formulas and constants.

Hanzlik's list of meteorological stations thruout the world, with their latitudes, longitudes, and altitudes.

Fergusson and Clayton's revision of international meteorological symbols, cloud notation, and cloud definitions.

The Beaufort notation for the use of navigators at sea.

The acceleration of apparent gravity on the earth.

The total number of pages (ix, 280), as compared with that in the revised edition of February, 1896, Smithsonian Miscellaneous Collections, 1032 (lix, 274), shows that the changes have been very conservative. The volume as a whole is a monument to the practical aspects of the work of the Smithsonian Institution.

KITE FLYING FROM MOUNTAIN TOPS.

In his address, October 28, 1907, at the opening of the Aeronautical Congress in New York, N. Y., the president, Prof. Willis L. Moore, referred to the Weather Bureau kite work, as follows: