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A SPECTROPHOTOMETRIC STUDY OF THE LUMINOUS RADIATION FROM THE NERNST LAMP GLOWER UNDER VARYING CURRENT DENSITY.

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THE character of the luminous radiation from different sources of light has occupied the attention of physicists for many years. The numerous problems related to this subject which have been studied represent widely diversified interests and extend over a wide range of investigation. Thus, in radiation, for example, the luminous radiation and the radiant efficiency of the magnesium light were studied by Rogers;[1] the luminous radiation from the Auer mantle was studied by Miss Hill;[2] that from zinc oxide by Nichols and Snow;[3] that from the lime light by Pickering,[4] by Nichols and Franklin,[5] and by Nichols and Miss Crehore;[6] the total radiation and the radiant efficiency of the mercury arc were studied by Arons,[7] Geer,[8] and Geer and Coblentz;[9] that from platinum has been studied by numerous investigators, among whom mention may be made of

[1] Rogers, Am. Jour. Sci., 43, p. 301, 1892.
[2] Nichols, Lab. Manual, 2, p. 373, 1894.
[3] Nichols and Snow, Phil. Mag., [5], 32, p. 401, 1891.
[4] Pickering, Proc. Am. Acad. Arts and Sci., 15, p. 236, 1880.
[5] Nichols and Franklin, Am. Jour. Sci., 38, p. 100, 1889.
[6] Nichols and Miss Crehore, PHYS. REV., 2, p. 161, 18 94.
[7] Arons, Wied. Ann., 47, p. 767, 1892; 58, p. 73, 1896.
[8] Geer, PHYS. REV., 16, p. 94, 1903.
[9] Geer and Coblentz, Phys. Zeitschr., 4, p. 257, 1903.

Magnus,[1] Violle,[2] Draper,[3] Nichols,[4] Chatelier,[5] Becquerel,[6] Crova[7] and Zöllner.[8]

The radiation from heated pigments was studied by Nichols and Snow.[9] The radiation from different forms of carbon has been thoroughly and carefully studied by Weber,[10] Schumann,[11] Nichols and Franklin,[12] Nichols,[13] Blaker,[14] Stewart,[15] Janet,[16] Le Chatelier[17] and others. In perusing some of the work mentioned above, it occurred to the writer that a study of the radiation from the rare-earth oxides used in the "glower" of the Nernst lamp would be of theoretical interest and of practical importance. In a paper on the behavior of these "glowers" when carrying an electric current,[18] mention is made of a spectral and bolometric study of the radiation from these luminous sources, but apparently no work was done in this direction. Inasmuch as no published work has appeared on this phase of the radiation from the Nernst lamp glower, it was decided to investigate this problem.

Inasmuch as no spectrophotometer was available for this work, a Kirchhoff spectrometer having a collimator with two unilateral micrometer slits was adapted for the purpose. This instrument has been described elsewhere.[19] This spectrometer has a broad circular horizontal plate of metal mounted upon a massive hollow cast-iron

[1] Magnus, Ann. der Phys., **124**, p. 476, 1865.

[2] Violle, C. R., **88**, p. 171, 1879; **92**, pp. 866, 1204, 1881; **95**, p. 163, 1887; **94**, p. 734, 1892.

[3] Draper, Phil. Mag., [3], **30**, p. 345, 1847.

[4] Nichols, Am. Jour. Sci., **18**, p. 446, 1879.

[5] Chatelier, C. R., **114**, p. 470, 1892; Bul. Soc. Chim. Paris, **47**, p. 42, 1887.

[6] Becquerel, Annals de Chem. et de Physique, [3], **68**, p. 47, 1863; C. R., **55**, p. 876, 1863.

[7] Crova, C. R., **57**, p. 497, 1878.

[8] Pogg. Ann., **100**, p. 381, 1857; **109**, p. 256, 1869.

[9] Nichols and Snow, Phil. Mag.,[5], **32**, p. 401, 1891.

[10] Weber, Wied. Ann., **32**, p. 256, 1897; PHYS. REV., **2**, pp. 112, 197, 1894.

[11] Schumann, Electrotech. Zeitschr., **5**, p. 220, 1884.

[12] Nichols and Franklin, Am. Jour. Sci., **38**, p. 100, 1889.

[13] Nichols, Proc. Am. Acad. Arts and Sci., **37**, p. 73, 1901.

[14] Blaker, PHYS. REV., **13**, p. 345, 1901.

[15] Stewart, PHYS. REV., **13**, p. 257, 1901; **15**, p. 306, 1902.

[16] Janet, C. R., **123**, p. 690, 1896; **126**, p. 734, 1898.

[17] Le Chatelier, Jour. de Phys., [3], **1**, p. 203, 1892.

[18] Nernst and Wild, Zeitschr. für Electrochemie, **7**, p. 373, 1900.

[19] Wüllner, Lehrbuch der Experimentalphysik, Bd. 4, p. 168, 1899.

column, which in turn is supported by three massive feet. Mounted upon this plate is the collimator and the swinging arm which supports the observing telescope. This arm is rigidly attached to a revolving pivot passing downward through the vertical axis of the instrument. In a vertical plane beneath the plate is mounted a plane mirror which is rigidly attached to the pivot of the telescope arm ; thus when the telescope is rotated about its axis, the mirror rotates about the same axis. Through an opening in the cast-iron support of the spectrometer plate a beam of light from an illumi-

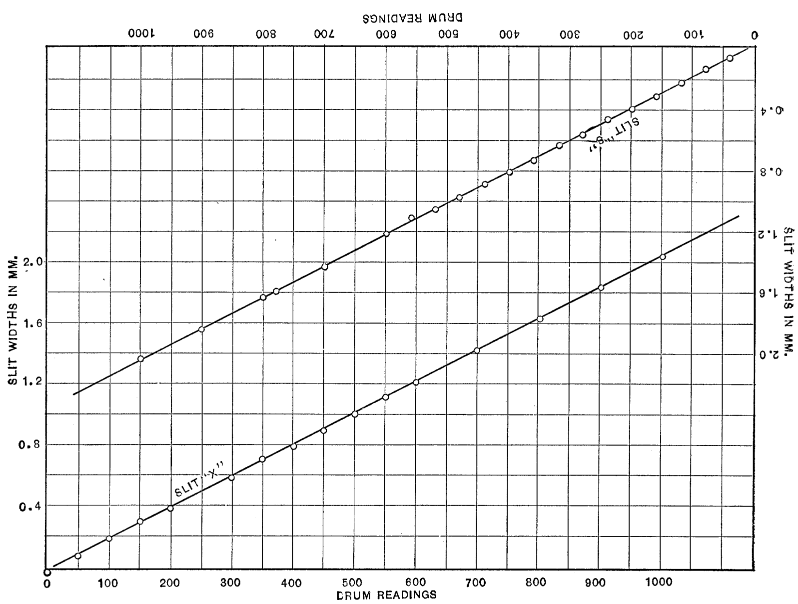

Fig. 1.—Calibration Curves of the Spectrophotometer Slits.

nated scale falls upon the mirror and is reflected into another observing telescope which is rigidly attached by metal supports to the lower surface of the circular plate as shown in Fig. 4.

The train of glass prisms belonging to the instrument was removed and replaced by a Rowland plane grating, having 14,437 lines to the inch, ruled on speculum metal. This grating was mounted in the axis of the instrument on a metal base having three leveling screws, and was therefore in the axis of rotation of the observing telescope. Thus an increased intensity in the less visible portions of the spectrum was secured, and a normal spectrum and a straight line calibration curve were obtained. The collimator slits were then removed and calibrated under a high power microscope mounted on a Hilger dividing engine. Proper precautions were taken to avoid any error in measurement due to the "back lash" of the screw of the dividing engine or of the screws of the slits. The calibration curves given in Fig. 1 show that the screws of the slits are remarkably uniform and perfect. In Fig. 1 slit *S* refers to the slit which throughout was used with standard No. 1; slit *X*, therefore, was the slit before which was placed the Hefner lamp, the Nernst lamp and standard No. 2. In front of the upper slit of the collimator a totally reflecting prism was then mounted upon a blackened brass arm which swung about a vertical axis. By means of a screw adjustment this prism could be raised or lowered at will. The position of the prism in front of the collimator can be seen in Fig. 4. After remounting the slits the collimator and telescope were adjusted for parallel light. The collimator was then turned so that its axis passed normally through the vertical axis of the spectrometer, after which it was securely clamped in position. Thus, a beam of light passing through the collimator fell upon the middle portion of the Rowland grating. The observing telescope of the spectrometer, the ocular of which contained the cross-hairs and an adjustable slit so that only a narrow band of the spectrum could be observed at once, was then rigidly attached to its arm so that it had motion on this arm only in a vertical plane. As was noted above, this arm was attached to the axis of the instrument about which it could be swung in a horizontal plane. Thus the center of the grating was in the axis of rotation of the telescope. The spectrometer was then mounted in a dark room where this investigation was conducted. After the grating was adjusted so as to give a suitable intensity and dispersion in the spectrum of the first order, a scale divided into millimeters was suspended in front of the spectrometer mirror, by means of cords from one corner of the dark room. The spectrometer was then calibrated, by reference to the lines produced by vaporizing various metal salts in a Bunsen flame placed in front of the collimator slits. The calibration curve thus obtained was a straight line. The dispersion was found to be sufficient to separate appreciably the two sodium lines and a difference of 0.001 μ was found to be equivalent to about 3.6 mm. on the scale. By virtue of certain changes that were made before any observations were taken several calibrations of the spectrometer were necessary, the final one of which is given in Fig. 2. The only difference found in these curves was a definite vertical shift throughout the whole length of the curve. Hence the calibration of the instrument could be tested at any time by reference to a sodium flame. As a precaution this was frequently done. As a

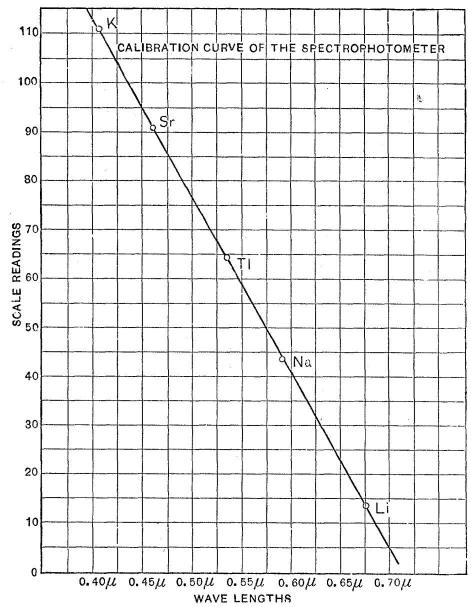

Fig. 2.

matter of fact the dark room in which this work was carried out was kept locked and no one but the writer was supposed to enter it, so that once adjustments were finally made, they were not disturbed by any one outside. The spectrometer observations and scale readings therefore never showed an appreciable difference from the calibration curve readings.

As a standard source of light an acetylene flame burning under constant pressure was used. The acetylene was produced in a Colt Automatic Acetylene Generator, in which finely divided calcium carbide was automatically dropped into water. The gas thus generated was passed over into a gasometer whence it was conducted through a pressure regulator of the Moler pattern[1] into the dark room. By means of a glass **Y** placed in the line of gas tubing leading from the regulator, one branch of which lead to a **U**-tube water manometer, while the other branch lead to the burner, the gas pressure at the burner could be observed at will through a telescope placed near the observer at the spectrometer. To prevent evaporation from the manometer, the open end of the **U**-tube was closed with a cork having a small groove along the side. The acetylene was burned in a No. 4 Naphey burner[2] of the type shown in Fig. 3. In front of the flat flame of this burner and parallel to its plane was mounted a sheet of blackened tin containing a circular diaphragm 7.94 mm.[3] in diameter so that the opening was opposite the most uniform portion of the flame. This burner with diaphragm was then mounted to the right of the collimator slits with the sheet of tin facing the totally reflecting prism and its plane 10 cm. from the face of the prism. When this diaphragmed source of light was placed in the proper position before the reflecting prism, the burner was rigidly clamped in place and remained undisturbed throughout the whole investigation. It has been shown that such a source of light under constant pressure gives an intensity which remains uniform[4] and is therefore suitable for this investigation.

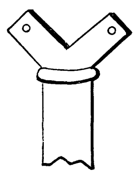

Fig. 3.

The Nernst lamp used was a 104-volt A. C. lamp. The "holder"[5] of the lamp was removed and the lamp was mounted on a support at a proper height so that the glower was horizontal and 100 cm. in front of the uncovered collimator slit. In series with the lamp was a rheostat (R) and a new accurately calibrated Weston A. C. ammeter (A), and to the platinum terminal wires of the glower were soldered the terminal wires of a recently calibrated Weston D. C. and A. C. voltmeter (V). Thus the voltages given in the data are

[1] Nichols, Jour. Frank. Inst., **150**, p. 359, 1900.

[2] A No. 4 Naphey burner is rated to burn one cubic foot of gas per hour.

[3] $\frac{5}{16}$ inches = 7.94 mm.

[4] Nichols, Jour. Frank. Inst., **150**, pp. 360, 386, 1900.

[5] The Nernst lamp and its parts have been fully described by Mr. A. J. Wurts, Trans. Am. Inst. Elect. Eng., **18**, p. 545, 1901.

those between the ends of the glower under varying current. It may be noted in passing that the lamp in this horizontal position was not entirely automatic, but inasmuch as the holder of the lamp had been removed, the heating circuit in each case was closed by hand, and when the glower became conducting the heating circuit was opened automatically. The arrangement of the apparatus is shown in Fig. 4.

In order to secure an alternating current of constant potential, a direct current of 110 volts was connected to the terminals of a 110-volt storage battery, and from the leads of the battery a line was run to the terminals of a motor belted to a line of shafting, from which was furnished the power to run the alternator and its exciter. Thus the A. C. voltage could be kept constant at any desired value

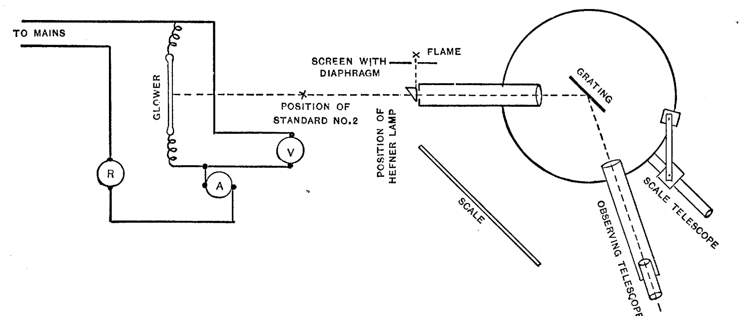

Fig. 4.—Diagram of Apparatus.

below its maximum. When the maximum value was reached, current was taken from the city A. C. mains which entered the laboratory.

To obtain results in terms of definite known units the Hefner-Altneck standard lamp[1] was used. That is, the diaphragmed acetylene flame used as a standard was determined in terms of the Hefner standard. This had previously been done, and the results obtained here are concordant with the earlier measurements. As has been pointed out it is desirable to compare the acetylene flame with the Hefner standard since in the latter the flame is produced by the combustion of a fuel of definite chemical composition under very nearly constant conditions.[2]

[1] Zeitschr. für Instrumentenkunde, 13, pp. 257–265, 1893.

[2] Nichols, Jour. Frank. Inst., 150, p. 371, 1900.

The method of taking the observations was as follows: Ten centimeters in front of the uncovered collimator slit, the Hefner lamp was adjusted in position. The lamp was allowed to burn twenty minutes or half an hour and then adjusted to the proper flame height, after which readings at various points in the spectrum were taken. Throughout the whole work eight or ten, and sometimes thirty or forty, readings were taken at each setting of the telescope. The mean of these readings was then taken for the position in question. Thus on different days a number of such curves were taken with the Hefner lamp, and the curves thus de-

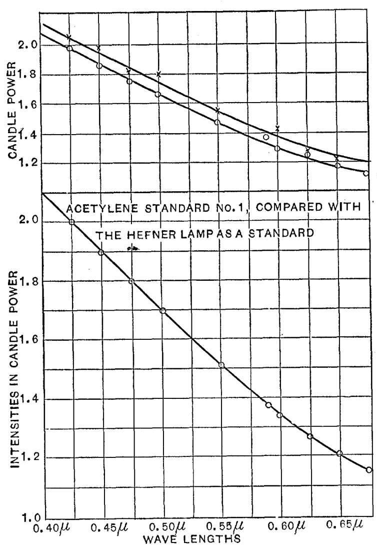

Fig. 5.

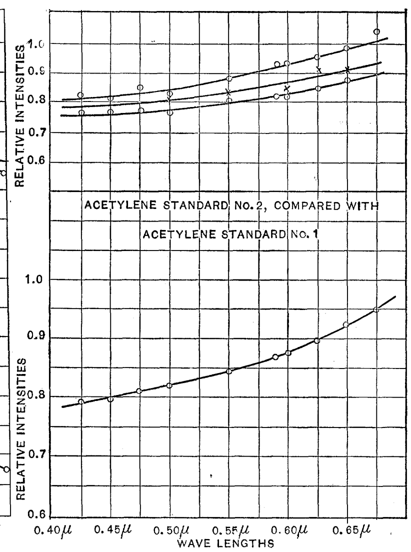

Fig. 6.

termined were found to agree so closely that a mean curve of the two agreeing most closely was taken. The latter is shown in Fig. 5. The data for these curves is given in Table I.

Fifty centimeters in front of the collimator slits was temporarily mounted another No. 4 Naphey burner having a blackened screen mounted in front of it with a circular diaphragm of exactly the same size as that used with the burner previously mentioned. This acetylene source is called standard No. 2; the former acetylene source, standard No. 1. The spectrophotometric curve of standard No. 2 in terms of No. 1 was then determined. This curve, shown

TABLE I.

Comparison of Standard No. 1 with Hefner Lamp.

Wave-Lengths.	Barometric Pressure = 764.4 mm. P = 7.4 cm. Psychrometer Readings { Dry Bulb = 23.2° C. Wet Bulb = 15.5° C.						Barometric Pressure = 764.9 mm., P = 7.4 cm. Psychrometer Readings { Dry Bulb = 22.5° C. Wet Bulb = 15.8° C.						Mean Ratio of Intensities in Candle Power from Curves.
	Drum Readings of Micrometer.		Slit Widths in mm.		Ratio of Intensities in Hefners.	Ratio of Intensities in C. P.	Drum Readings of Micrometer.		Slit Widths in mm.		Ratio of Intensities in Hefners.	Ratio of Intensities in C. P.	
	S_1	S_H	S_1	S_H			S_1	S_H	S_1	S_H			
λ=0.425 μ	73.44	150	0.121	0.287	2.37	2.05	75.25	150	0.125	0.287	2.30	1.98	2.010
λ=0.450 μ	74.90	150	0.125	0.287	2.30	1.99	78.88	150	0.133	0.287	2.16	1.86	1.900
λ=0.475 μ	80.11	150	0.1365	0.287	2.10	1.82	82.40	150	0.141	0.287	2.04	1.752	1.800
λ=0.500 μ	81.11	150	0.1380	0.287	2.08	1.80	86.00	150	0.149	0.287	1.925	1.658	1.701
λ=0.550 μ	92.00	150	0.1610	0.287	1.78	1.54	94.75	150	0.167	0.287	1.72	1.480	1.515
λ=0.589 μ	99.87	150	0.179	0.287	1.605	1.39	102.13	150	0.179	0.287	1.603	1.378	1.372
λ=0.600 μ	98.30	150	0.176	0.287	1.640	1.42	104.9	150	0.190	0.287	1.51	1.30	1.340
λ=0.625 μ	107.40	150	0.195	0.287	1.470	1.272	107.4	150	0.195	0.287	1.470	1.262	1.268
λ=0.650 μ	109.70	150	0.200	0.287	1.435	1.242	114.4	150	0.210	0.287	1.368	1.175	1.205
λ=0.675 μ	126.25	150	0.236	0.287	1.217	1.052	118.8	150	0.220	0.287	1.304	1.125	1.147

in Fig. 6, is the mean of several sets of independent observations taken on different days. This curve was obtained for the purpose of eliminating the absorption of the totally reflecting prism, which was not only marked but was also selective, as will be seen by referring to Fig. 6. Obviously, therefore, when the Nernst lamp is compared with a bare acetylene flame the results will be different from those obtained in the comparison with standard No. 1 in which the use of the reflecting prism is necessary.

Lastly, the Nernst lamp glower while carrying currents of different densities was compared spectrophotometrically with standard No. 1. At each observation throughout the whole series the current strength and the gas pressure were observed to see that they remained constant while a given set of observations was being taken. From eight to ten readings were taken for each point on the curve. In some cases as many as fifty observations were made for each point and then the mean was taken. The gas pressure was most conveniently kept constant at 7.4 cm. of water pressure.

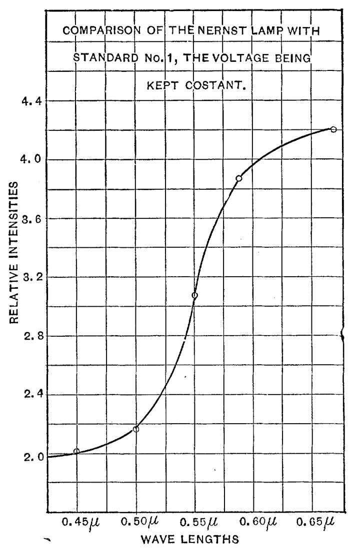

Fig. 7.

In using the Hefner-Altneck lamp corrections for humidity and barometric pressure according to Liebenthal's method[1] were made. Humidity was determined by observing the wet and dry bulb psychrometer and by using the values of vapor pressure obtained from Regnault's measurements.[2]

In taking the measurements on the Nernst lamp the first observations were made on another glower than on the one used throughout the series of measurements given in this paper. It was the original intention to obtain the spectrophotometric curves with the voltage maintained constant for a given set of observations. This, however, proved to be unsatisfactory. As an

[1] Liebenthal, Electroteck. Zeitschr., 16, p. 655, 1895.

[2] Hempel's Gas. Analysis. Translated by Dennis, pp. 255, 373-4, 1892.

Table II.

Comparison of Standard No. 2 with Standard No. 1.

Wave-Lengths.	(1) $P=7.4$ cm.					(2) $P=7.4$ cm.					(3) $P=7.4$ cm.					Mean Relative Intensity of 1, 2 and 3 from Curves.
	Drum Readings of Micrometer.		Slit Widths in mm.		Ratio of Intensities.	Drum Readings of Micrometer.		Slit Widths in mm.		Ratio of Intensities.	Drum Readings of Micrometer.		Slit Widths in mm.		Ratio of Intensities.	
	S_1	S_2	S_1	S_2		S_1	S_2	S_1	S_2		S_1	S_2	S_1	S_2		
$\lambda=0.425\ \mu$						89.30	100	0.152	0.183	0.830	82.6	100	0.141	0.183	0.770	0.793
$\lambda=0.450\ \mu$	86.6	100	0.150	0.183	0.820	86.33	100	0.150	0.183	0.820	82.8	100	0.1416	0.183	0.771	0.799
$\lambda=0.475\ \mu$	83.0	100	0.142	0.183	0.776	89.63	100	0.156	0.183	0.853	83.0	100	0.142	0.183	0.777	0.810
$\lambda=0.500\ \mu$	86.0	100	0.149	0.183	0.805	87.45	100	0.152	0.183	0.830	81.8	100	0.140	0.183	0.765	0.820
$\lambda=0.550\ \mu$	87.9	100	0.153	0.183	0.836	92.90	100	0.164	0.183	0.896	85.0	100	0.147	0.183	0.804	0.844
$\lambda=0.589\ \mu$						95.25	100	0.170	0.183	0.930	86.1	100	0.150	0.183	0.820	0.868
$\lambda=0.600\ \mu$	89.6	100	0.156	0.183	0.853	96.50	100	0.171	0.183	0.935	86.2	100	0.150	0.183	0.820	0.873
$\lambda=0.625\ \mu$	93.75	100	0.1655	0.183	0.905	97.75	100	0.174	0.183	0.950	89.3	100	0.1555	0.183	0.850	0.895
$\lambda=0.650\ \mu$	94.0	100	0.1660	0.183	0.907	100.55	100	0.180	0.183	0.985	91.1	100	0.160	0.183	0.875	0.923
$\lambda=0.675\ \mu$						105.75	100	0.1905	0.183	1.040						0.950

illustration, the curve shown in Fig. 7 was obtained in this manner. The readings began in the long waves and extended into the short ones. The potential difference was kept constant but no attention was paid to current strength. The curve obtained is a smooth curve but very different from those obtained later with constant current. On repeating these observations, passing through the spectrum in the reverse order, a curve of quite different shape was obtained. This method, therefore, was evidently unreliable. It is probable that the current strength gradually decreased in value with the time without giving an apparent change in voltage,[1] thus accidentally giving the curve mentioned. Thereafter, observations were taken with the current kept constant and a series of curves were obtained which were similar to those shown in Fig. 9.

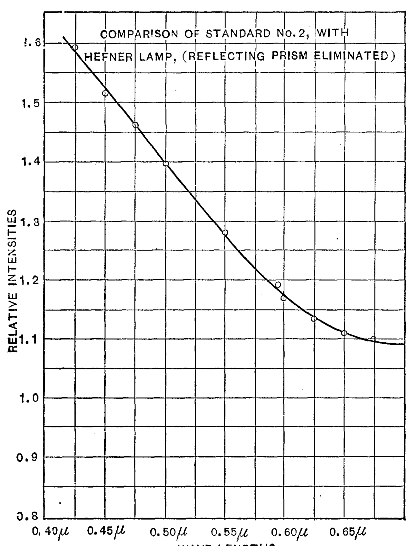

Fig. 8.

An accident, however, necessitated the remounting of a new glower. The first observations were taken at the rated normal current capacity of the lamp, namely, 0.8 amperes. Observations were then taken with decreasing currents down to 0.2 amperes. Then observations were taken with increasing currents; the maximum value reached was 1.50 amperes, at which point the platinum wire attached to the glower fused off after a few observations had been taken. The mean readings thus taken are recorded in Table III. in the order in which they were taken and are lettered accordingly, beginning *a*, *b*, *c*, . . . , etc. The curves obtained from these data are lettered likewise. No stress is laid upon the data obtained in the last set of readings and the curve obtained from these data is given only once — in Fig. 9 — after which it is not considered.

[1] This possibility is suggested by a characteristic curve of the glower given by Wurts, Trans. Am. Inst. Elect. Eng., 18, p. 552, 1901.

Table III.

Comparison of Nernst Lamp with Standard No. 1.

Wave-Lengths.	(a) $V=86.2$; $I=0.80$; $P=7.4$ cm.					(b) $V=86.0$; $I=0.70$; $P=7.4$ cm.					(c) $V=84.0$; $I=0.60$; $P=7.4$ cm.				
	Drum Readings of Micrometer.		Slit Widths in mm.		Ratio of Intensities.	Drum Readings of Micrometer.		Slit Widths in mm.		Ratio of Intensities.	Drum Readings of Micrometer.		Slit Widths in mm.		Ratio of Intensities.
	S_1	S_n	S_1	S_n		S_1	S_n	S_1	S_n		S_1	S_n	S_1	S_n	
$\lambda=0.425\ \mu$						118.6	200	0.219	0.395	0.555	75.0	200	0.125	0.395	0.316
$\lambda=0.450\ \mu$	67.5	80	0.108	0.140	0.772	52.75	80	0.076	0.140	0.542	45.1	100	0.060	0.185	0.328
$\lambda=0.475\ \mu$						71.5	100	0.117	0.185	0.640	49.0	100	0.069	0.185	0.377
$\lambda=0.500\ \mu$	82.5	80	0.141	0.140	1.008	75.4	100	0.125	0.185	0.684	51.6	100	0.074	0.185	0.404
$\lambda=0.550\ \mu$	97.5	80	0.175	0.140	1.250	73.5	80	0.121	0.140	0.865	63.5	100	0.100	0.185	0.546
$\lambda=0.575\ \mu$											71.0	100	0.116	0.185	0.631
$\lambda=0.589\ \mu$	104.0	80	0.187	0.140	1.340	83.6	80	0.143	0.140	1.020	77.5	100	0.130	0.185	0.710
$\lambda=0.600\ \mu$											76.3	100	0.128	0.185	0.700
$\lambda=0.625\ \mu$	112.8	80	0.206	0.140	1.471	91.3	80	0.160	0.140	1.140					
$\lambda=0.650\ \mu$											84.5	100	0.145	0.185	0.793
$\lambda=0.675\ \mu$	122.9	80	0.228	0.140	1.630	126.0	100	0.235	0.183	1.281	92.1	100	0.162	0.185	0.885
	(d) $V=81.5$; $I=0.50$; $P=7.4$ cm.					(e) $V=77.9$; $I=0.40$; $P=7.4$ cm.					(f) $V=76.6$; $I=0.30$; $P=7.4$ cm.				
$\lambda=0.425\ \mu$	57.0	200	0.086	0.395	0.216	43.9	200	0.057	0.395	0.1430	44.0	400	0.057	0.800	0.0713
$\lambda=0.450\ \mu$	59.9	200	0.091	0.395	0.230	45.2	200	0.060	0.395	0.1580	41.6	400	0.053	0.800	0.0663
$\lambda=0.475\ \mu$	62.4	200	0.097	0.395	0.246	49.9	200	0.067	0.395	0.1696					
$\lambda=0.500\ \mu$	69.1	200	0.112	0.395	0.284	52.0	200	0.075	0.395	0.1900	49.1	400	0.069	0.800	0.0863
$\lambda=0.550\ \mu$	85.12 81.0	200	0.147 0.138	0.395	0.372 0.350	62.5	200	0.097	0.395	0.2456	53.6	400	0.078	0.800	0.0976
$\lambda=0.589\ \mu$	97.5	200	0.173	0.395	0.438	69.0	200	0.113	0.395	0.2860	61.5	400	0.095	0.800	0.1187
$\lambda=0.600\ \mu$	94.5	200	0.171	0.395	0.433	70.9	200	0.115	0.395	0.2910	65.2	400	0.103	0.800	0.1290
$\lambda=0.625\ \mu$															
$\lambda=0.650\ \mu$	108.6	200	0.198	0.395	0.501	80.6	200	0.136	0.395	0.3440	75.9	400	0.126	0.800	0.1575
$\lambda=0.675\ \mu$	116.3	200	0.215	0.395	0.545	86.4	200	0.150	0.395	0.3800	85.5	400	0.147	0.800	0.1837
$\lambda=0.700\ \mu$	133.0	200	0.250	0.395	0.633	98.6	200	0.175	0.395	0.4430	93.1	400	0.165	0.800	0.2062

Wave-Lengths.	(g) $V=82.0$; $I=0.20$ $P=7.4$ cm. Drum Readings of Micrometer. S_1	S_n	Slit Widths in mm. S_1	S_n	Ratio of Intensities.	(h) $V=78.5$; $I=0.40$: $P=7.4$ cm. Drum Readings of Micrometer. S_1	S_n	Slit Widths in mm. S_1	S_n	Ratio of Intensities.	(i) $V=87.0$; $I=0.80$; $P=7.4$ cm. Drum Readings of Microm. S_1	S_n	Slit Widths in mm. S_1	S_n	Ratio of Intensities.
$\lambda=0.425\ \mu$	41.1	1000	0.051	2.040	0.0250	68.4	400	0.110	0.800	0.1378	73.6	70	0.122	0.120	1.018
$\lambda=0.450\ \mu$	38.8	1000	0.046	2.040	0.0226	73.5	400	0.121	0.800	0.1515	80.2	70	0.136	0.120	1.133
$\lambda=0.500\ \mu$	40.7	1000	0.050	2.040	0.0245	76.6	400	0.128	0.800	0.1602	90.5	70	0.156	0.120	1.300
$\lambda=0.550\ \mu$	45.1	1000	0.060	2.040	0.0294	91.8	400	0.160	0.800	0.2000	113.5	80	0.207	0.141	1.470
$\lambda=0.589\ \mu$						111.2	400	0.203	0.800	0.2540	{110.7	70	0.202	0.120	1.683}
											{127.0	80	0.240	0.141	1.701}
$\lambda=0.600\ \mu$	47.9	1000	0.065	2.040	0.0319	113.0	400	0.207	0.800	0.2582	110.6	70	0.201	0.120	1.675
$\lambda=0.625\ \mu$											{112.0	70	0.205	0.120	1.708}
											{110.8	70	0.203	0.120	1.692}
$\lambda=0.650\ \mu$	57.7	1000	0.087	2.040	0.0426	131.8	400	0.248	0.800	0.3100	132.4	80	0.252	0.141	1.788
$\lambda=0.675\ \mu$	78.0	1000	0.131	2.040	0.0644	149.6	400	0.286	0.800	0.3580					
$\lambda=0.700\ \mu$						152.0	400	0.292	0.800	0.3650					

Wave-Lengths.	(j) $V=87.0$; $I=0.90$; $P=7.4$ cm. Drum Readings of Microm.		Slit Widths in mm.		Ratio of Intensities.	(k) $V=87.0$; $I=0.90$; $P=7.4$ cm. Drum Readings of Micrometer.		Slit Widths in mm.		Ratio of Intensities.
	S_1	S_n	S_1	S_n		S_1	S_n	S_1	S_n	
$\lambda=0.425\ \mu$	97.2	70	0.174	0.120	1.450	81.0	50	0.137	0.072	1.905
$\lambda=0.450\ \mu$	101.5	70	0.182	0.120	1.517	79.3	50	0.135	0.072	1.877
$\lambda=0.475\ \mu$						83.6	50	0.144	0.072	2.000
$\lambda=0.500\ \mu$	108.4	70	0.197	0.120	1.642	85.6	50	0.148	0.072	2.060
$\lambda=0.550\ \mu$	128.5	70	0.240	0.120	2.025					
$\lambda=0.589\ \mu$						94.8	50	0.172	0.072	2.385
$\lambda=0.600\ \mu$	134.5	70	0.253	0.120	2.108					
$\lambda=0.625\ \mu$	136.9	70	0.257	0.120	2.140	100.1	50	0.180	0.072	2.500
$\lambda=0.650\ \mu$	149.0	70	0.285	0.120	2.380	104.3	50	0.187	0.072	2.600
$\lambda=0.675\ \mu$	160.3	70	0.310	0.120	2.580	122.0	50	0.226	0.072	3.140
	(l) $V=86.8$; $I=1.00$; $P=7.4$ cm.					(m) $V=87.1$; $I=0.80$; $P=7.4$ cm.				
$\lambda=0.425\ \mu$	88.6	50	0.155	0.072	2.151	100	76.8	0.179	0.135	1.253
$\lambda=0.450\ \mu$	90.4	50	0.159	0.072	2.210					
$\lambda=0.475\ \mu$	91.8	50	0.161	0.072	2.239	100	71.9	0.179	0.124	1.441
$\lambda=0.500\ \mu$	97.3	50	0.173	0.072	2.400	100	69.9	0.179	0.129	1.390
$\lambda=0.550\ \mu$	104.5	50	0.189	0.072	2.622	100	63.9	0.179	0.108	1.656
$\lambda=0.589\ \mu$						100	60.8	0.179	0.101	1.772
$\lambda=0.600\ \mu$	108.4	50	0.197	0.072	2.740	100	59.6	0.179	0.099	1.810
$\lambda=0.625\ \mu$	109.9	50	0.200	0.072	2.780	100	59.3	0.179	0.097	1.826
$\lambda=0.650\ \mu$	111.1	50	0.203	0.072	2.820	100	56.2	0.179	0.091	1.970
$\lambda=0.675\ \mu$	116.5	50	0.215	0.072	2.980					

Wave-Lengths.	(n) $V = 87.0$; $I = 1.00 \pm 0.02$; $P = 7.4$ cm. Drum Readings of Micrometer. S_1	S_n	Slit Widths in mm. S_1	S_n	Ratio of Intensities.	(o) $V = 87.0$; $I = 1.10 \pm 0.02$; $P = 7.4$ cm. Drum Readings of Micrometer. S_1	S_n	Slit Widths in mm. S_1	S_n	Ratio of Intensities.	(p) $V = 86.1$; $I = 1.20 \pm 0.02$; $P = 7.4$ cm. Drum Readings of Micrometer. S_1	S_n	Slit Widths in mm. S_1	S_n	Ratio of Intensities.
$\lambda = 0.425\ \mu$	117.7	80	0.226	0.140	1.613	118.4	70	0.219	0.120	1.828					
$\lambda = 0.450\ \mu$	126.0	80	0.235	0.140	1.680	123.0	70	0.232	0.120	1.935	200	94.0 94.4	0.394 0.394	0.171 0.172	2.300 2.290
$\lambda = 0.475\ \mu$	135.6	80	0.255	0.140	1.821	128.8	70	0.241	0.120	2.010	200	92.0	0.394	0.167	2.360
$\lambda = 0.500\ \mu$	136.1	80	0.257	0.140	1.835	129.1	70	0.247	0.120	2.060	200	89.6	0.394	0.1595	2.470
$\lambda = 0.550\ \mu$	152.3	80	0.293	0.140	2.092	144.8	70	0.275	0.120	2.290	200	82.8	0.394	0.146	2.700
$\lambda = 0.600\ \mu$	163.9	80	0.317	0.140	2.260	149.3	70	0.280	0.120	2.330	200	80.4	0.394	0.142	2.780
$\lambda = 0.625\ \mu$	169.8	80	0.329	0.140	2.344	162.5	70	0.315	0.120	2.620	200	77.6	0.394	0.135	2.920
$\lambda = 0.650\ \mu$	183.0	80	0.356	0.140	2.540	170.1	70	0.330	0.120	2.744	200	75.7	0.394	0.131	3.000
$\lambda = 0.675\ \mu$	195.2	80	0.384	0.140	2.740	179.6	70	0.350	0.120	2.920	200	60.14	0.394	0.105	3.080

Wave-Lengths.	(q) $V = 85.05$; $I = 1.30 \pm 0.02$; $P = 7.4$ cm. S_1	S_n	S_1	S_n	Ratio	(r) $V = 84.6$; $I = 1.40 \pm 0.02$; $P = 7.4$ cm. S_1	S_n	S_1	S_n	Ratio	(s) $V = 84.0$; $I = 1.50 \pm 0.02$; $P = 7.4$ cm. S_1	S_n	S_1	S_n	Ratio
$\lambda = 0.425\ \mu$						200	87.4	0.394	0.154	2.560					
$\lambda = 0.450\ \mu$	200	90.4	0.394	0.164	2.400	200	85.9	0.394	0.151	2.610	200	83.3	0.394	0.148	2.660
$\lambda = 0.475\ \mu$	200	87.9	0.394	0.158	2.495	200	83.9	0.394	0.148	2.661					
$\lambda = 0.500\ \mu$	200	85.3	0.394	0.152	2.592	200	80.6	0.394	0.143	2.758	200	78.5	0.394	0.137	2.880
$\lambda = 0.550\ \mu$	200	79.6	0.394	0.140	2.818	200	77.0	0.394	0.134	2.940	200	77.3	0.394	0.135	2.920
$\lambda = 0.600\ \mu$	200	76.9	0.394	0.134	2.940	200	75.5	0.394	0.130	3.030	200	74.5	0.394	0.130	3.030
$\lambda = 0.625\ \mu$	200	76.5	0.394	0.133	2.960	200	74.0	0.394	0.127	3.100					
$\lambda = 0.650\ \mu$	200	73.1	0.394	0.128	3.080	200	71.9	0.394	0.122	3.230	200	72.7	0.394	0.125	3.155
$\lambda = 0.675\ \mu$	200	70.1	0.394	0.121	3.260	200	70.0	0.394	0.120	3.280					

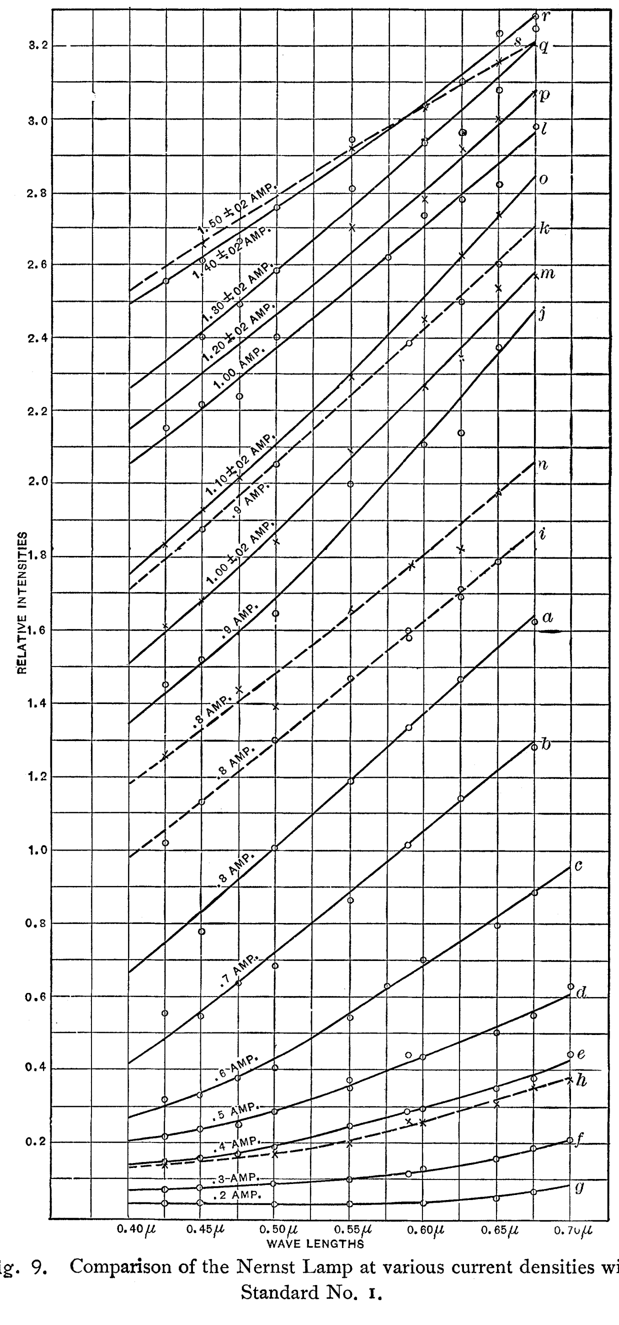

Fig. 9. Comparison of the Nernst Lamp at various current densities with Standard No. 1.

At 1.20 amperes the ballast of the lamp burned out after which the leads to the lamp were connected directly to the terminals of the glower and observations were continued with increasing current strength for each successive set until the maximum was reached. In all about 2,500 observations are represented in the data given in the tables.

In tabulating the data the following symbols are used: P represents the gas pressure in centimeters of water; V, the potential difference in volts between the terminals of the glower; S_1, the slit width of the collimator for standard No. 1; S_2, the slit width of the collimator for standard No. 2; S_H, the slit width of the collimator for the Hefner lamp; S_n, the slit width of the collimator for the Nernst lamp, and (a), (b), (c), $\cdots$, etc., will represent the order of the observations.

At this point it may be noted that the writer is familiar with the work done by Murphy[1] and Capps[2] on the correction for slit widths necessary in spectrophotometric work. No data for this correction with such an instrument as was used here, however, are available. In the second place, correction for slit widths is not so essential here because in the method of using the data given in the tables, the error due to this cause is eliminated, or at least reduced to a minimum. In obtaining the curve showing the relation between the intensities of the Hefner-Altneck lamp and standard No. 1 for waves of different lengths, two curves on different days were carefully determined, and the mean values of the ordinates of these curves were taken and plotted as the ordinates of the curve in Fig. 5. The two curves mentioned are shown in the upper part of Fig. 5 and the data therefor are given in Table I. Thus the intensity in candle power of standard No. 1 for different wave-lengths is determined. The values obtained in the comparison of standard No. 1 with standard No. 2 were treated in a similar manner and the curve, as shown in Fig. 6, obtained. If now the values of the ordinates of the curve in Fig. 6 be multiplied by the corresponding ordinates of the curve in Fig. 5, and if these new values thus obtained be plotted as ordinates with the corresponding wave-lengths as abscissæ, the curve shown in Fig. 8 will be obtained. This

[1] Murphy, Astrophys. Jour., 6, 1, 1897.

[2] Capps, Ibid., 11, 25, 1900.

curve shows the relation existing between the intensity of the acetylene flame used as a standard unit of comparison and the intensity of the Hefner lamp when the influence of the totally reflecting prism is eliminated. This curve agrees with results previously obtained.[1] It is to be noted here that the Hefner lamp was 10 cm. from the collimator slit while the acetylene standard No. 2 was 50 cm. from the slits. Their relative positions are indicated in Fig. 4.

If the values of the ratios of intensities given in Table III. are plotted as ordinates and corresponding wave-lengths as abscissæ, the curves shown in Fig. 9 are obtained. If the ordinates of these curves are divided by one fourth of the corresponding ordinates of Fig. 6 and the values thus obtained are plotted as ordinates with wave-lengths as abscissæ, a series of curves will be obtained showing the relation between the intensities of the Nernst lamp glower at different current strengths and standard No. 2, when both are at a distance of 100 cm. from the collimator slits. These curves are shown in Fig. 10. In these curves the absorption of the totally reflecting prism has been eliminated and the error due to slit widths reduced to a minimum. From an inspection of these curves it is obvious that until a current strength of one ampere is reached the increase in intensity of the glower as compared with acetylene is more rapid in the long waves and less rapid in the short ones. Above this value of the current, the increase in intensity in the region of the short waves is more rapid and there is an apparent decrease in intensity in the region of the long waves beyond 0.600 μ.

If the ordinates of the curve in Fig. 9 be multiplied by the corresponding ordinates of the curve in Fig. 5 and if the values thus obtained be plotted as ordinates with corresponding wave-lengths as abscissæ, the curves shown in Fig. 11 will be obtained. These curves show the relation, wave-length by wave-length, between the relative intensities of the Hefner lamp when it is placed 10 cm. in front of the collimator slits and the Nernst lamp when the latter is placed 100 cm. in front of the slits. These curves confirm the conclusion deduced from the curves in Fig. 10, showing that with a current above 0.90 or 1.00 ampere there is a marked increase in

[1] Hartman, PHYS. REV., 9, p. 185, 1899.

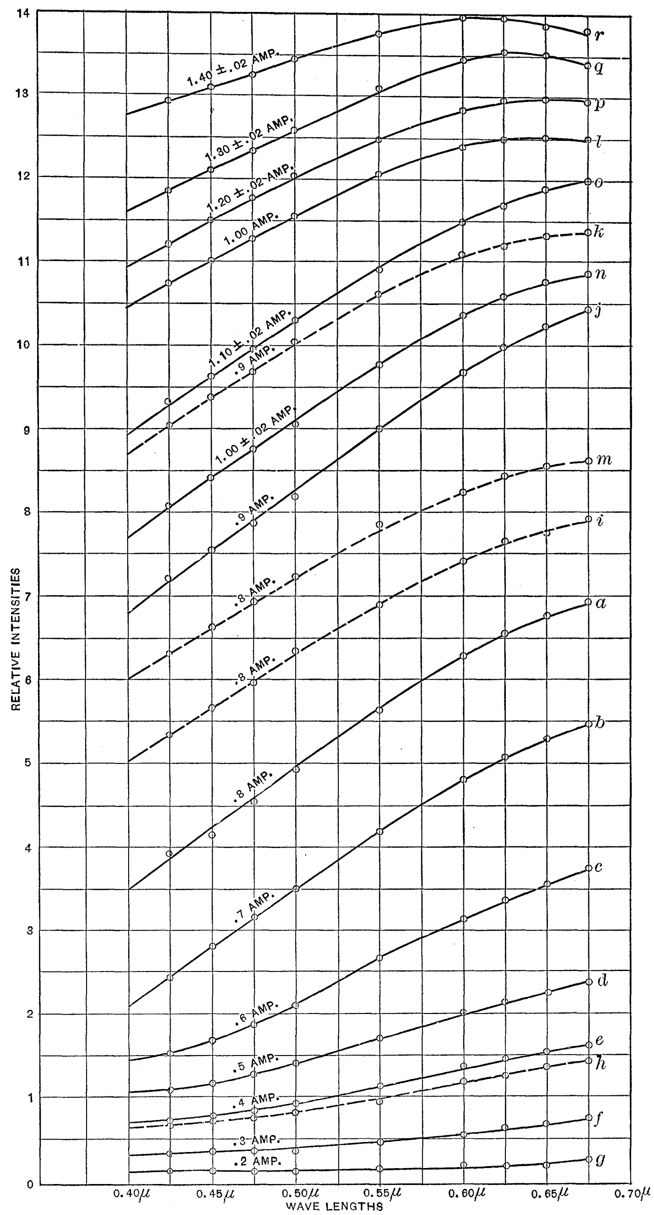

Fig. 10. Comparison of the Nernst lamp at various current densities with standard No. 2. The curves are corrected for absorption and slit widths. Intensities compared with both sources 50 cm. from the collimator slit.

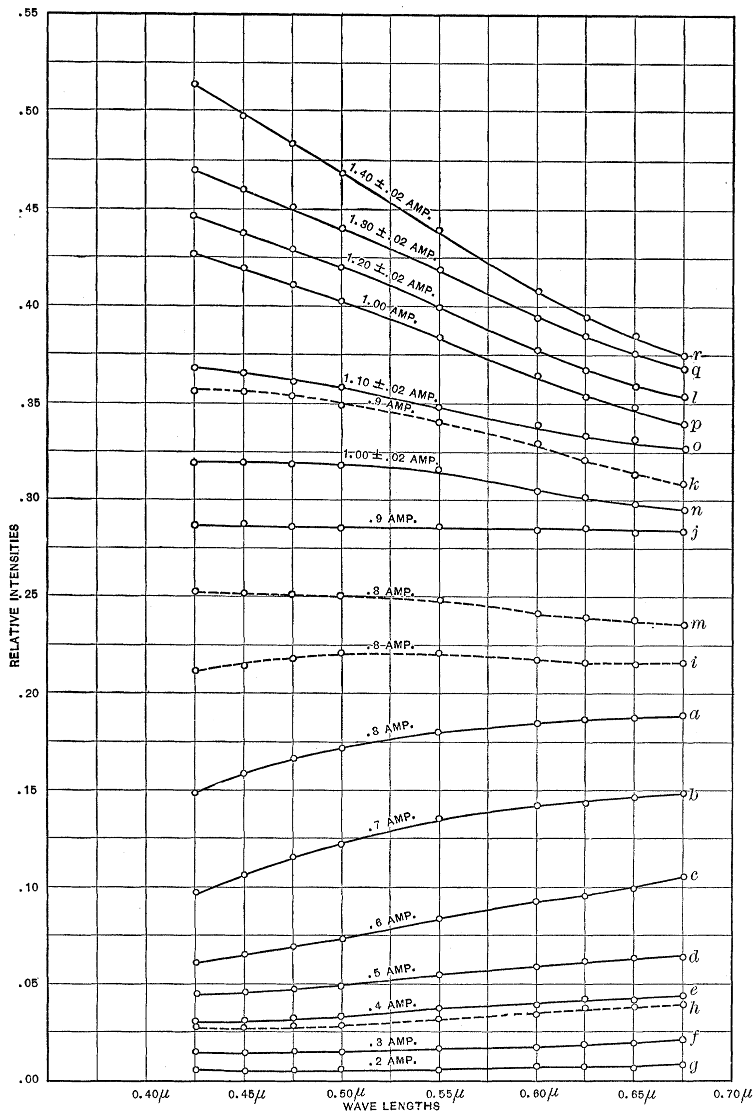

Fig. 11. Comparison of the Nernst lamp with the Hefner lamp.

intensity in the region of the short waves and a corresponding decrease in the intensity of the long waves. Below this value of the current the opposite is true, the increase in intensity being most rapid in the long waves.

It will be noted that a number of the curves are drawn in dotted lines and that these dotted curves bear the same values of current strength as some one of the full line curves beneath them. To this statement there is but one exception, in which case the difference is so small that it may reasonably be ascribed to errors in observation. In the other cases this explanation will not suffice. It will be noted, however, that these dotted curves were obtained at a date later than that on which the full line curves of the same current strength were obtained. Apparently, therefore, this indicates an increase in the intensity of the light emitted from the glower as it ages, even though the current be kept constant. One would expect this if the glower gradually wastes away with continued use and thus decreases in cross-section, for under these conditions a given current would make the glower corresponding hotter the smaller it becomes. There is, however, a probable limitation to this.

In the case of the curves in which the current was furnished by the department alternator, the disturbing factors were under such complete control that the current was kept practically constant. The maximum voltage of the alternator, however, could not be raised to a value high enough to send through the glower a current above 1.00 ampere. After this value was reached, the city 208-volt A. C. mains were used. The conditions were now more unsteady and the needle of the ammeter vibrated through a range of 0.04 amperes and the current values are so indicated. Thus 1.00 ± 0.02 amp. means that the current fluctuated between 0.98 and 1.02 amperes. The reason for the decrease in intensity when current taken from this source was used is not evident to the writer; in both cases current was furnished by a 60-cycle machine.

It will be interesting to compare the luminous radiation from the glower of the Nernst lamp with the radiation from a number of other luminous sources which have been previously studied. To do this the radiation from the acetylene flame is again taken as the standard of comparison, and its relative intensity throughout the spectrum is arbitrarily taken as unity. In the other sources considered that portion of the spectrum in the region of the D line is taken as unity. Plotting wave-lengths as abscissæ and relative intensities as ordinates the series of curves shown in Fig. 12 is ob-

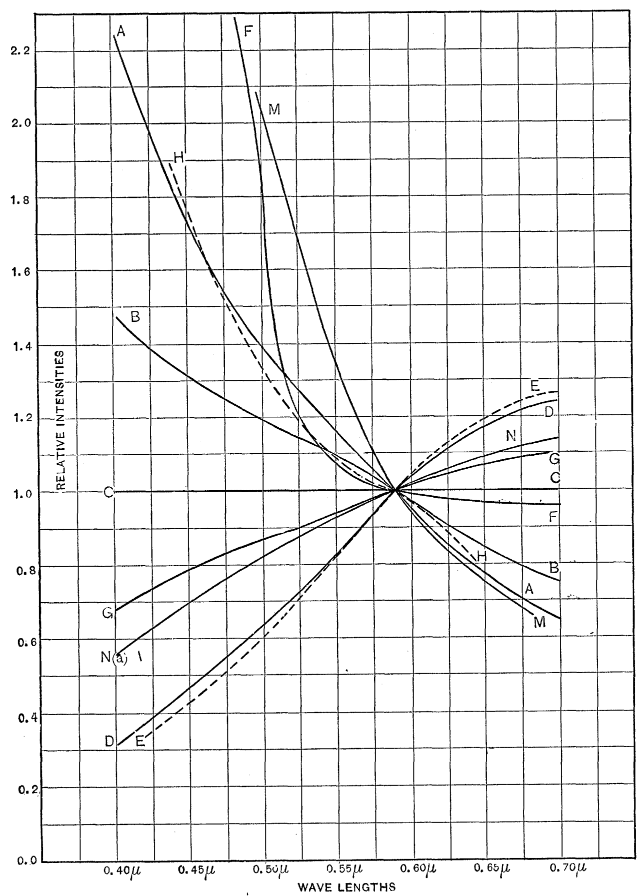

Fig. 12. Color of (A) acetylene in oxygen, (B) acetylene-hydrogen in oxygen, (C) acetylene in air, (D) kerosene lamp, (E) ordinary gas flame, (F) fresh lime light, (G) old lime light, (H) arc light, (M) magnesium light and (N_a) Nernst lamp. Standard, an acetylene flame.

tained. It will be observed that the curve for the Nernst lamp glower, which was taken for the rated normal current strength of 0.80 ampere corresponds most nearly to the radiation from old lime.

The data for many of these curves have been taken from a paper by Professor E. L. Nichols.[1]

In order to have a basis from which to start, it has been arbitrarily assumed in Fig. 13 that the values given by Abney for the luminosity curve of the normal eye[2] would give the luminosity curve of the acetylene flame. The luminosity curves of the Nernst

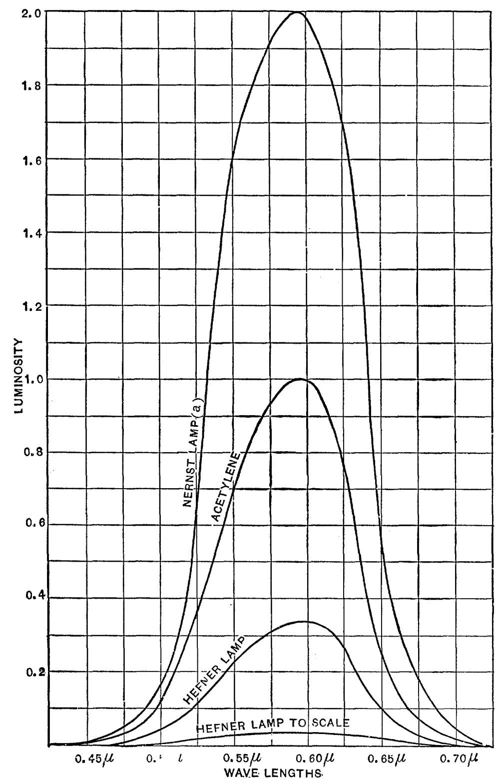

Fig. 13. Luminosity curves of acetylene, Nernst lamp, and Hefner lamp. Abney's normal luminosity curve assumed for acetylene.

lamp and the Hefner lamp were then plotted on the same sheet with this curve. The luminosity of the spectrum of acetylene is taken as unity in the region of the *D* line. In this figure the Nernst lamp curve is reduced to one third its actual size and the curve of the Hefner lamp is magnified ten times. The lower curve repre-

[1] Nichols, Jour. Frank. Inst., 150, p. 356, 1900.

[2] Abney, Color Vision, p. 211, 1895.

sents the actual luminosity curve of the latter as compared with the acetylene standard No. 2. The luminosity of the Nernst lamp is therefore much greater than that of the acetylene flame.

Since preparing the above, through the courtesy of Dr. Frank Allen, of Cornell University, a luminosity curve of the acetylene flame has been obtained. The luminosity curves of the Nernst and Hefner lamps as compared with acetylene, using this luminosity curve as a basis, are plotted, as described above, in Fig. 14.

To summarize, it appears that at the rated normal current strength the radiation from the glower of the Nernst lamp is relatively rich in the more luminous waves of the spectrum; it exhibits no marked selective radiation; its light intensity apparently increases with age; its light is relatively less rich in the short, but richer in the long waves than that from the acetylene flame, but its radiation rapidly becomes more like that from burning acetylene with increasing current strength; at current strength below the rated normal value, the increase in intensity with increasing current strength is most marked in the long waves, and above this rated normal value of current strength the increase in intensity is most rapid in the short waves; at current strengths below the rated normal value the Nernst lamp is relatively less rich in short waves than the flame of the Hefner lamp, while above this current strength the opposite is true; at rated normal current strength, or slightly above this, the color of the Nernst lamp radiation is very similar to that of the Hefner lamp. The luminous radiation from the Nernst lamp corresponds very closely to that from incandescent old lime.

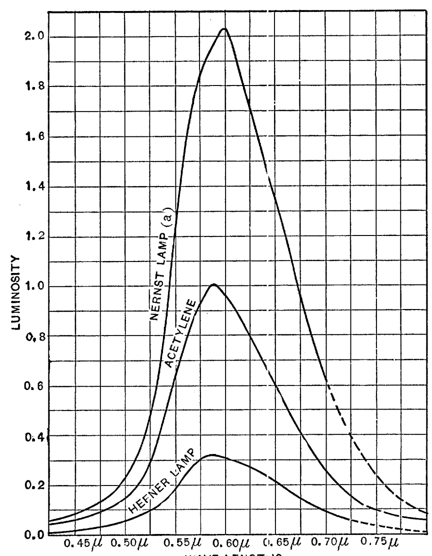

Fig. 14. Luminosity curves of acetylene, Nernst lamp, and Hefner lamp. Luminosity of the acetylene flame based on Allen's curve.

The apparatus used in this investigation has been generously placed at my disposal by Professor Arthur W. Goodspeed, of the Department of Physics, and it is with a sense of gratitude and pleasure that I acknowledge all that he has done to satisfy my every need and thus make this investigation a success. In conclusion, therefore, I take pleasure in thanking him, as well as Dr. Horace C. Richards, for the suggestions they have made and the courtesies they have shown in the course of this investigation.

RANDAL MORGAN LABORATORY OF PHYSICS,
UNIVERSITY OF PENNSYLVANIA, April 10, 1903.