# A SPECTROPHOTOMETRIC COMPARISON OF THE RELATIVE INTENSITY OF LIGHT FROM CARBON AT DIFFERENT TEMPERATURES.

By Ernest Blaker.

FOR many years the idea advanced by Draper,[1] that all solid bodies, when heated, begin to give off light at the same temperature, that the rays first emitted were dull red and as the temperature was raised the shorter wave-lengths were added in succession, was accepted. E. Lecher[2] showed this to be not true and H. F. Weber[3] made an investigation of the subject in which it was shown that in general Draper's views would not hold. Weber's observations on carbon in the form of a glow lamp show that red does not appear first, but that to the unaided eye first appears a misty indistinct gray light, which is followed, as the temperature rises, by a series of characteristic changes before there is any appearance of red; passing through an ashen gray, then a pale yellow. The emission then changes to a bright yellow gray and the next addition is of an uncommonly bright red, which is intermittent at first, then is steady with no more flickering, being a fiery red. With rising temperature the light becomes orange, yellow, yellowish-white, then white. In studying the spectrum of the carbon filaments in the first stages of incandescence, Weber found the misty gray light to appear in that portion of the spectrum that is occupied by yellow and light green when the temperature was higher. With increasing current in the lamp, the gray band had a middle of yellowish-gray, shaded off at the ends into dull gray. At the time that the red flicker appears to the unaided eye the spectrum shows a delicate band of red on one edge and almost immediately a weak grayish-green border on the other side. The spectrum broadens out both ways with more current and when the center is a bright

[1] Draper, Phil. Mag., May, 1847, pp. 345–360.
[2] Lecher, Wied. Ann., No. 32, 1887, p. 256.
[3] H. F. Weber, Wied. Ann., No. 32, 1887, pp. 256–270.

yellow gray it extends from the middle of the red into the blue. Then with a yet further increase of temperature the whole spectrum presents itself.

Further heating increases the intensity of the light for all wave-lengths, but the wave-lengths of higher frequencies, as has been shown by Nichols and Franklin,[1] show the greatest increase. That this rate of change is not continuously greater toward the shorter wave-lengths, has been noted by Dr. Nichols,[2] and it was the purpose of the investigation herein described to obtain new data upon this subject.

## Temperature of Glowing Carbon.

The lowest temperature at which the light emitted by carbon was studied in this investigation was such that in the longest red rays used the color was very dull, and no reading could be made for wave-lengths shorter than .470 $\mu$.

The amount of light given off at certain temperatures was for some time simply a guess. M. Lucas[3] has made measurements of the temperature of glowing carbon, based on relations between resistance of the carbon and the current passing through it, and on that between resistance and temperature. In the special case treated, he found the temperature to be a simple function of the current. Lucas also measured the intensity of the light emitted.

H. F. Weber[4] has, on theoretical grounds, arrived at a relation between the radiation from incandescent carbon and its temperature, and has made many experimental determinations of the constants of the relation. His results, however, are thought to be too low.

M. Le Chatelier[5] has measured the temperature of incandescent lamps by a photometric comparison and has given his results in terms of the ratio $\frac{R_\theta}{R_0}$, where $R_\theta$ is the resistance of the lamp at a temperature $\theta$ and $R_0$ is its resistance cold.

M. P. Janet[6] has indicated how the temperature of incandescent

[1] Nichols & Franklin, Amer. Jour. Sci., 3d series, Vol. 38, 1889, pp. 111–115.
[2] Nichols, Physical Review, Vol. XIII., p. 65, 1901.
[3] M. Felix Lucas, C. R., No. 100, 1885, pp. 454–456.
[4] H. F. Weber, Phys. Rev., Vol. II., 1894, pp. 112–121, 197–210.
[5] M. Le Chatelier, Jour. de Phys., 3d Serie, Vol. I., p. 203.
[6] M. P. Janet, C. R., No. 123, 1896, pp. 690, 691.

carbon may be obtained, based on the mean specific heat of carbon as determined by Violle,[1] and later[2] has given some determinations on four different lamps, expressing results in terms of $\frac{R_\theta}{R_0}$ for purposes of comparison with the results of Le Chatelier. In three of the lamps the values obtained are very close to values obtained by plotting Le Chatelier's results and interpolating. The average of these three gives a temperature of 1620° C. for a value of $\frac{R_\theta}{R_0}$ equal to .53 and the interpolation gives a value of 1600° C. for the same value of $\frac{R_\theta}{R_0}$. Using Le Chatelier's results as a basis, the temperature of the carbon filament, when there was a difference of potential of sixty volts between its terminals, was 1738° C., the

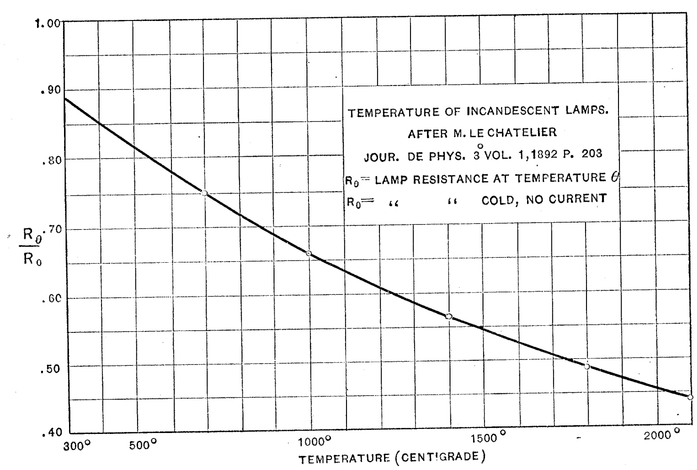



Fig. 1.

power loss in the lamp being 1.95 watts per candle. Lucas's results, reduced, give a temperature of about 1857° C. for the same power development and the mean of several results of Weber give a temperature of 1635° (abs.). Abney and Festing[3] conclude that the temperature appears to be nearly a simple function of the re-

[1] M. J. Violle, C. R., No. 120, 1895, pp. 868–869.

[2] M. P. Janet, C. R., No. 126, 1898, pp. 734–736.

[3] Abney and Festing, *Phil. Mag.* (5), No. 16, Sept., 1883, p. 225.

sistance, with which Le Chatelier's results applied to this experiment seem to agree. The results of Le Chatelier have been used as a basis for temperatures in this work, representing something near the truth.

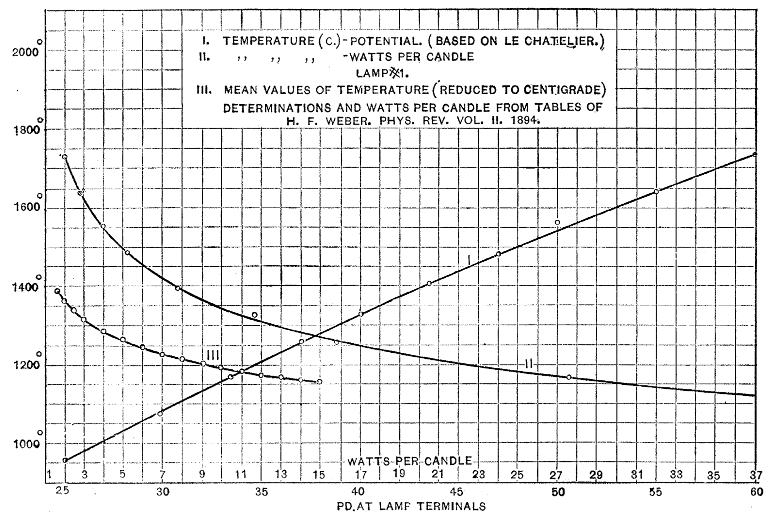



Fig. 2.

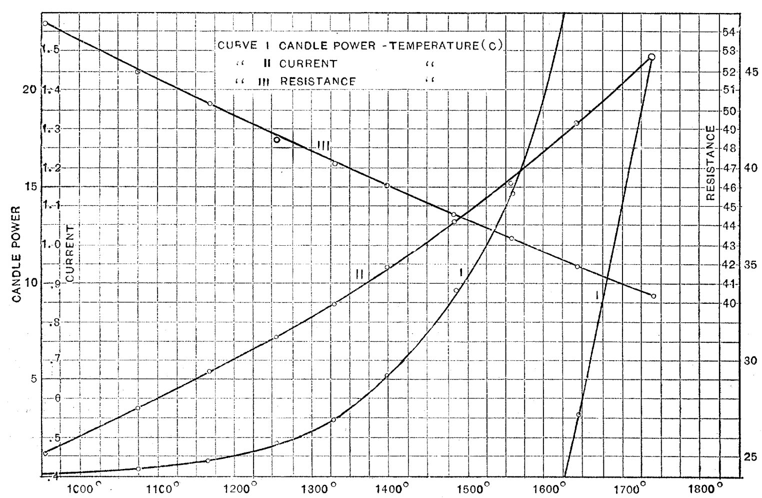



Fig. 3.

The curve in Fig. 1 shows the temperature of incandescent lamps plotted with $\frac{R_\theta}{R_0}$ from Le Chatelier's determination; Fig. 2 contains two curves showing (I.) the relation between potential differences at lamp terminals and temperature and watts per candle of the test lamp used in the measurements to be described in this paper, based on Le Chatelier's values; (II.) the temperature, watts per candle curve for the same lamp. A curve showing the relation between temperature and watts per candle as deduced from the mean of values taken from the data of several tests by Weber is given in the same figure (curve III.).

Fig. 3 shows the relation between the candle power, current and resistance of the test lamp and its temperature; the scale of temperatures being that derived from the determinations of Le Chatelier.

The following table gives the data upon which the curves relating to the test lamp were based:

TABLE I.

(*Test lamp No. 1.*)

| $V$ | $I$ | $R_\theta$ | $\frac{R_\theta}{R_0}$ | $\Theta$°C. | C. P. | $W$ | $\frac{W}{\text{C. P.}}$ |
|---|---|---|---|---|---|---|---|
| 24.85 | .456 | 54.5 | .673 | 954 | | 11.32 | |
| 29.90 | .575 | 52.0 | .642 | 1075 | .33 | 17.18 | 52. |
| 33.4 | .668 | 50.15 | ·619 | 1168 | .81 | 22.31 | 27.55 |
| 37.0 | .763 | 48.49 | .599 | 1255 | 1.8 | 28.24 | 15.7 |
| 40.0 | .846 | 47.22 | .583 | 1328 | 2.92 | 33.84 | 11.59 |
| 43.5 | .943 | 46.02 | .568 | 1398 | 5.25 | 40.93 | 7.8 |
| 47.0 | 1.055 | 44.55 | .550 | 1484 | 9.62 | 49.59 | 5.16 |
| 50.0 | 1.16 | 43.29 | .535 | 1559 | 14.63 | 58.00 | 3.96 |
| 55.0 | 1.31 | 41.89 | .519 | 1643 | 27.00 | 72.05 | 2.67 |
| 60.0 | 1.48 | 40.54 | .501 | 1738 | 45.60 | 88.80 | 1.95 |

$R_0 = 80.96$ *ohms at* 18° *C.*

APPARATUS AND ITS ARRANGEMENT.

The voltmeter used in this work was a large standard Weston instrument with a 150-volt, and a 3-volt scale. It was carefully calibrated for the 150-volt scale by a potentiometer method, balancing a standard Clark cell around a known resistance and then calculating the fall of potential through another known resistance. about which the voltmeter was shunted.

To measure the current, a standard Weston milli-voltmeter, with shunt box, was used. It was calibrated for two shunts; one using the one-ampère scale, and the other for the five-ampère scale, by placing it in series, first with a standard Hartmann and Braun ohm and then with a standard tenth ohm (H. & B.) around which was shunted the standard voltmeter, mentioned above.

In pursuing this investigation a Lummer-Brodhun spectro-photometer[1] was used. It consists of two collimator tubes at right angles to each other, the path of light from one source being directly through a glass cube, the path of light from the other source entering the cube and being reflected at a silvered surface within the cube in such a manner that it has the same length of path in the cube, and passes out of the cube parallel with and in the same vertical plane with the first ray, whence they are dispersed by a flint glass prism and may be examined in the telescope in juxtaposition. The instrument was supplied with two arms fastened rigidly to the base of the instrument, one being placed directly beneath and parallel with the axis of each collimator. On these arms two sources of light were placed at equal distances of 22.6 cm. from the collimator slits. One source was the standard of comparison, a flat acetylene flame from a Naphey burner, in front of which was placed a screen in which was a circular opening of 2.5 mm. radius, over which was placed a piece of glass from an incandescent lamp globe of the same type of lamp which was used as a source of incandescent carbon, on the other arm. The lamp used was one with a short thick gray carbon filament of the "hair pin" type, made to be used at 50 volts pressure. A screen was placed in front of this lamp cutting off all light from the collimator slit excepting that from a straight portion about two centimeters long, care being taken that the portion of the filament used be parallel with the axis of the slit. The instrument was so set up that this lamp was at one end of a thousand part photometer bar, at the other end of which was placed a secondary standard 16 c.p. fifty-five-volt lamp, which was used throughout below normal pressure the current being furnished by storage cells. The voltage was carefully adjusted each time the standard was used, to 50 volts. This secondary standard was

[1] Zeit. für Inst., No. 12, 1892, pp. 132–139.

standardized by comparison with an amyl-acetate lamp. The acetylene flame was used at a constant pressure throughout the work, of 7.35 cm. of water; the acetylene being produced by using commercial calcium carbide. The gas, as tested by Mr. Rands, was about 98.7· pure. For the lamp being tested, the current was furnished by a storage battery.

## Outline of Method.

The order of experimentation was as follows: The test lamp was brought up to the desired brightness and its candle power measured by comparison with the standard lamp, using a Bunsen photometer; then with a definite opening of collimator slit the collimator slit of the standard acetylene source was varied until, for the rays being compared, the intensity was alike for both sources. In nearly all cases at least ten readings were taken for each wave-length. Eleven wave-lengths were compared, extending almost the whole length of the visible spectrum. In some instances whole sets were run over again as a check. In order that the test lamp might last throughout the experiment, it was used with small voltages and currents first, then gradually increased. The lamp was not used for a very long time at voltages near the normal and consequently did not deteriorate appreciably in candle power until used at sixty volts. Then it fell off about seven per cent. in candle power between the beginning and end of the run at that voltage. In this run the red end of the spectrum was tested first. All readings were corrected for slit width from curves based on those obtained by C. V. Capps[1] for a sixty-degree flint glass prism; both prisms being furnished on instruments made by Schmidt and Haensch.

The intensity of the acetylene source was taken as unity for the luminous intensity of the various wave-lengths and from the data obtained were drawn, for each wave-length, "isochromatic curves," using in one case, intensities and temperatures ($C$) for coordinates and in the other case log. of intensities and reciprocals of temperatures (abs.). (See Figs. 4 to 14 inclusive.) The intensity-temperature curves would have the same form whether plotted with the temperatures, centigrade or absolute, since the difference would be

[1] Capps, Astrophysical Journal, Vol. II., January, 1900, pp. 25–35.

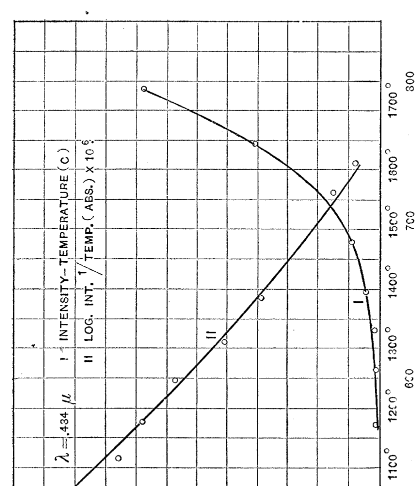



Fig. 4.

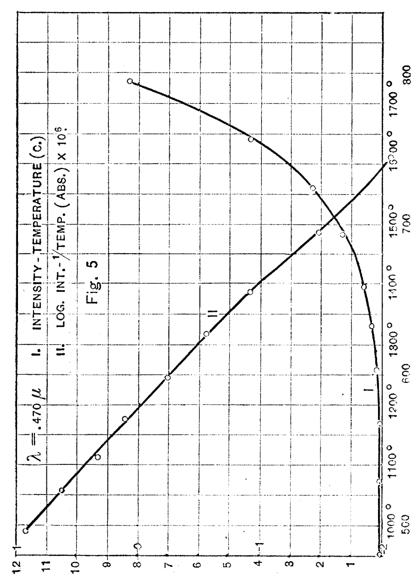



Fig. 5.

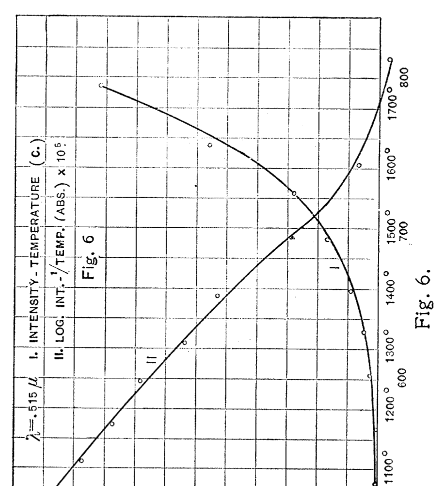
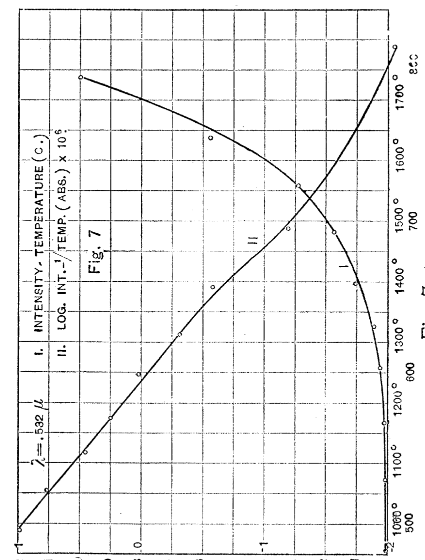



Fig. 6.

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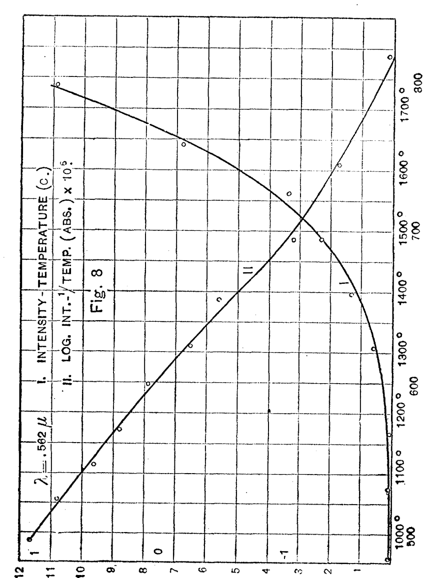
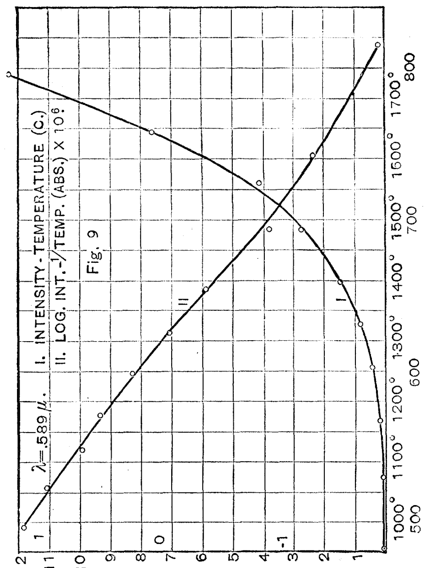



Fig. 8.

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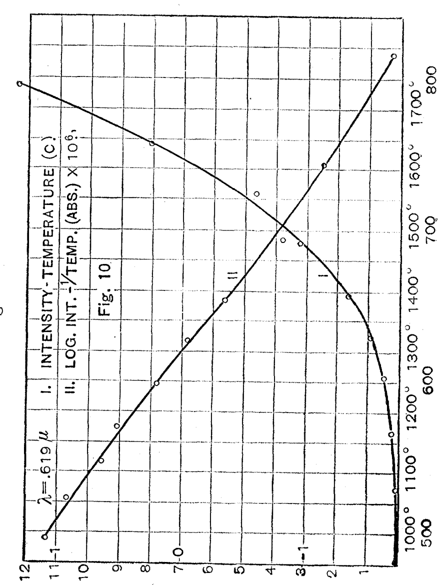



Fig. 10.

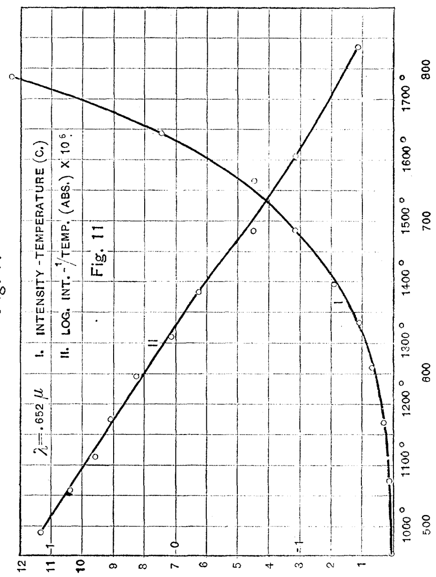



Fig. 11.

only a shifting of the origin of temperatures. From W. Wien's[1] equations for black bodies,

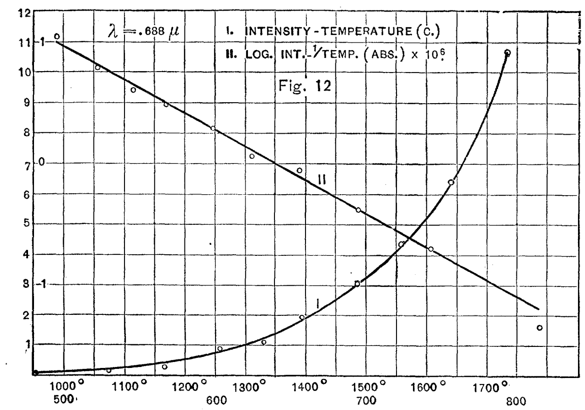



Fig. 12.

$$E = C_1 \lambda^{-5} e^{-\frac{c_2}{T\lambda}}$$

it will be seen if it be transformed into a logarithmic equation,

$$\log E = \log C_1 - 5 \log \lambda - \frac{C_2}{T\lambda} \log e,$$

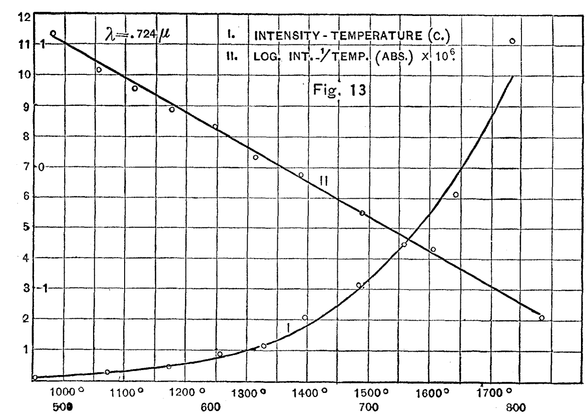



Fig. 13.

that if logarithms of intensity and reciprocals of absolute temperature be plotted as coördinates for a given value of $\lambda$, that a straight

[1] W. Wien, Wied. Ann., 58, 1896, p. 662, etc.

line would be the result; and that if intensity and temperature were plotted an exponential curve would result. Paschen's[1] modifications of Wien's equation,

$$E = C_1 \lambda^{-a} e^{-\frac{c_2}{T\lambda}}$$

in which the exponent of $\lambda$ is changed to the more general form, shows the same general form of curves. Lummer and Pringsheim[2] in testing Wien's equation, arrive at the conclusion that $C_1$ and $C_2$ have a progressive variation such as to make the curves plotted

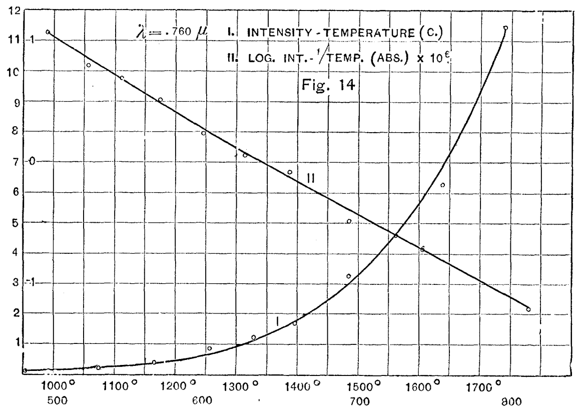



Fig. 14.

with log $I$, and reciprocals of absolute temperatures, convex to the $1/T$ axis. It will be seen from the "isochromatic curves" that for the longer wave-lengths at the temperatures of these experiments the radiation seems to follow very closely the laws of radiation for "black" bodies; and that for the higher temperatures used, the intensity of all the rays followed the same laws, nearly, but that for light of a refrangibility greater than $\lambda = .619\mu$, the deviation from this becomes greater and greater, reaching a maximum at about $\lambda = .515\mu$ and then decreases again.

From these curves were obtained the data from which curves were drawn using intensities and wave-lengths as coördinates, which show the relative increase in intensity of the various wave-lengths as the potential, and consequently, the temperature, was increased.

[1] F. Paschen, Astro. Phys. Jour., No. 10, June, 1899, p. 40.

[2] Lummer & Pringsheim, Verh. Deutsch. Phys. Ges., I., 1, 1900.

These curves show first that the intensity is a maximum, as compared with acetylene, in the longest wave-lengths. With the higher voltages the increase in intensity is more rapid toward the shorter wave-lengths and the ratio of increase is such that the maximum

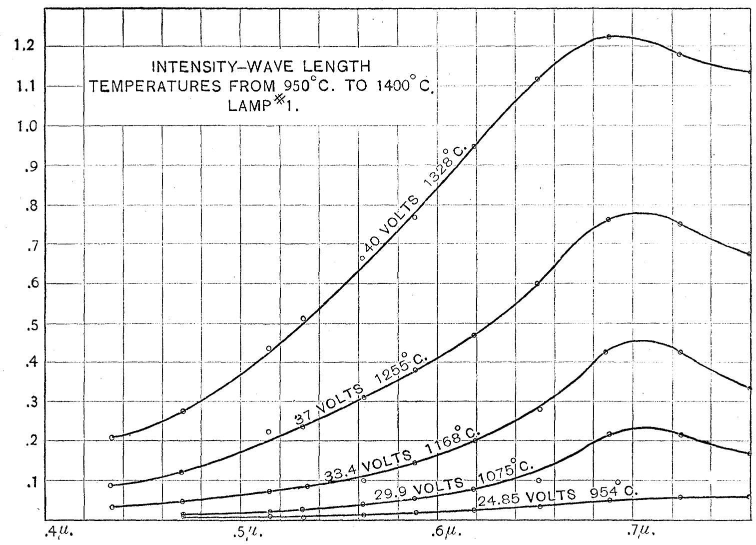
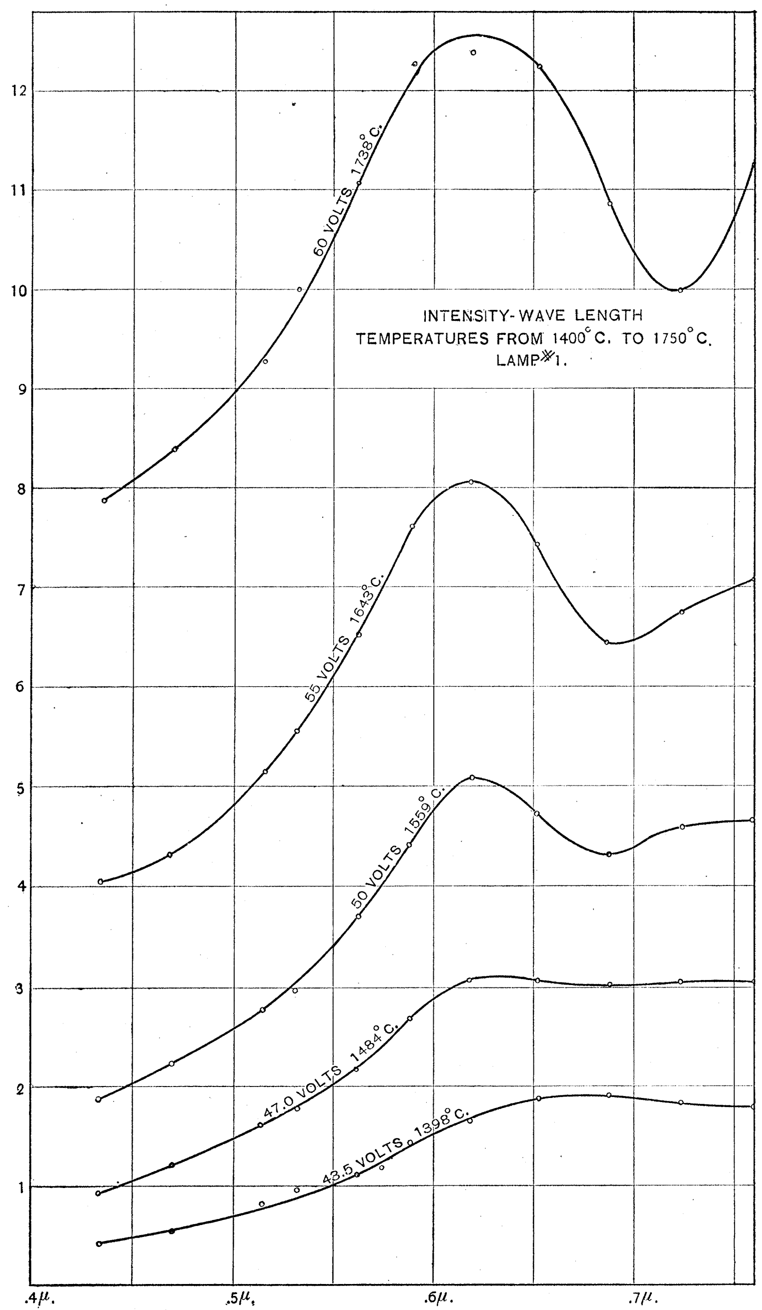



Fig. 15.

shifts toward the violet. With yet higher voltages the longer wave-lengths near the limits of the visible spectrum increase more in their intensity than near the maximum intensity, and this part of the curve also becomes concave to the axis of wave-lengths. In order to show the variation of intensity with temperature the curves for wave-length and temperature have been plotted on the same sheet. (See Figs. 15 and 16.)

In Table II. are given the data complete for each test. *Pd* refers to the difference of potential between the terminals of the test lamp. *I* refers to the current, *W* refers to the watts, and *R* gives the resistance corresponding for the lamp. *P* denotes the pressure of the gas burned in the comparison lamp in centimeters of water; $O_C$ and $O_A$ give the zero reading on the screw heads regulating the width of the slit openings, *C* referring to the test carbon source, and *A* referring to the acetylene comparison source. For opening slits the numbers on the screw heads increase so that on reaching the



INTENSITY-WAVE LENGTH
TEMPERATURES FROM 1400° C. TO 1750° C.
LAMP #1.
60 VOLTS 1738° C.
55 VOLTS 1643° C.
50 VOLTS 1559° C.
47.0 VOLTS 1484° C.
43.5 VOLTS 1398° C.
12
11
10
9
8
7
6
5
4
3
2
1
.4μ.
.5μ.
.6μ.
.7μ.


Fig. 16.

# Table II.

*Pd* = 24.85 ; *I* = .456 ; *W* = 11.36 ; *R* = 54.5 ; *P* = 7.35 cm.; $O_C$ = 95.8 ; $O_A$ = 79.

| C Slit Open 1 mm. | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| λ = .760 | .724 | .688 | .652 | .619 | .589 | .562 | .532 | .515 | .470 | .434 |
| 88.00 | 84.6 | 83.9 | 82.2 | 81.3 | 80.3 | 80.3 | 80.1 | 79.3 | 79.9 | |
| 89.60 | 85.6 | 84.1 | 82.8 | 81.6 | 80.6 | 80.3 | 79.9 | 80.0 | 79.8 | |
| 87.60 | 87.4 | 84.2 | 82.2 | 81.0 | 81.0 | 80.5 | 80.0 | 80.0 | 79.3 | |
| 90.00 | 85.2 | 84.7 | 82.5 | 81.2 | 80.7 | 80.6 | 80.0 | 79.9 | 79.7 | |
| 88.00 | 86.1 | 84.4 | 82.9 | 81.2 | 81.0 | 80.2 | 80.3 | 79.8 | 79.7 | |
| 86.60 | 87.0 | 84.0 | 82.3 | 81.2 | 81.3 | 80.6 | 80.1 | 80.1 | 79.6 | |
| 85.4 | 86.6 | | | | | | | | | |
| 88.1 | 86.9 | | | | | | | | | |
| 89.0 | 87.4 | | | | | | | | | |
| 87.2 | 87.2 | | | | | | | | | |
| 87.95 | 86.4 | 84.22 | 82.48 | 81.25 | 80.82 | 80.42 | 80.07 | 79.85 | 79.67 | |
| *A*[1] open | | | | | | | | | | |
| 8.95 | 7.40 | 5.22 | 3.48 | 2.25 | 1.82 | 1.42 | 1.07 | .85 | .67 | |
| Int. | | | | | | | | | | |
| .06 | .059 | .047 | .034 | .02 | .015 | .014 | .009 | .008 | .007 | |
| Log. *I*. | | | | | | | | | | |
| -2.7782 | -2.7709 | -2.6721 | -2.532 | -2.301 | -2.1761 | -2.1461 | -3.9542 | -3.9031 | -3.8451 | |

*Pd* = 29.9 ; *I* = .575 ; *W* = 17.18 ; *R* = 52.0 ; *P* = 7.35 cm.; $O_C$ = 95.8 ; $O_A$ = 79.

| C Slit Open 1 mm. | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| λ = .760 | .724 | .688 | .652 | .619 | .589 | .562 | .532 | .515 | .470 |
| 107.0 | 104.8 | 101.8 | 89.8 | 89.0 | 83.8 | 83.0 | 82.2 | 81.0 | 80.0 |
| 108.3 | 105.6 | 106.0 | 97.6 | 87.8 | 85.5 | 83.4 | 81.5 | 80.7 | 80.0 |
| 103.8 | 106.1 | 99.8 | 89.8 | 85.2 | 84.0 | 83.0 | 81.7 | 80.5 | 80.0 |
| 106.3 | 105.0 | 101.6 | 91.7 | 88.0 | 85.2 | 83.1 | 81.0 | 80.6 | 80.1 |
| 106.1 | 105.2 | 96.8 | 90.8 | 85.1 | 85.0 | 82.4 | 81.8 | 80.5 | 79.9 |
| 108.0 | 107.8 | 104.0 | 91.8 | 86.9 | 84.0 | 82.8 | 81.6 | 80.9 | 79.8 |
| 106.7 | 105.0 | | | | | | | | |
| 104.0 | 107.7 | | | | | | | | |
| 104.0 | 105.5 | | | | | | | | |
| 102.6 | 106.6 | | | | | | | | |
| 105.68 | 105.93 | 101.67 | 90.92 | 87.0 | 84.58 | 82.95 | 81.63 | 80.7 | 79.97 |
| *A* open | | | | | | | | | |
| 26.68 | 26.93 | 22.67 | 11.92 | 8.0 | 5.58 | 3.95 | 2.63 | 1.7 | .97 |
| Int. | | | | | | | | | |
| .194 | .219 | .201 | .11 | .076 | .053 | .038 | .023 | .015 | .009 |
| Log. *I*. | | | | | | | | | |
| −1.2878 | −1.3414 | −1.3032 | −1.0414 | −2.88 | −2.72 | −2.579 | −2.352 | −2.17 | −3.9542 |

[1] "C slit open" refers to the collimator slit opening of test lamp. "*A* open" refers to the number of scale divisions of opening of the standard. 100 divisions = 1 turn = 1 mm.

*Pd* = 33.4 ; *I* = .668 ; *W* = 22.31 ; *R* = 50.0 ; *P* = 7.35 cm.; $O_C$ = 95.8 ; $O_A$ = 79.0.

| C Slit Open .5 mm. | | C Slit Open 1 mm. | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| λ = .760 | .724 | .688 | .652 | .619 | .589 | .562 | .532 | .515 | .470 | .434 |
| 100.0 | 104.2 | 118.8 | 106.1 | 96.0 | 90.0 | 88.2 | 86.9 | 84.6 | 82.4 | 81.0 |
| 96.5 | 102.6 | 117.0 | 105.0 | 96.3 | 92.5 | 88.3 | 85.9 | 85.0 | 82.3 | 81.0 |
| 100.0 | 103.1 | 115.3 | 104.3 | 96.3 | 90.0 | 87.2 | 86.0 | 84.3 | 82.6 | 81.0 |
| 100.6 | 100.1 | 117.2 | 105.3 | 96.0 | 91.7 | 87.5 | 87.0 | 84.8 | 82.2 | 80.8 |
| 97.0 | 103.9 | 117.6 | 103.8 | 96.6 | 93.1 | 87.3 | 85.4 | 85.2 | 82.0 | 81.0 |
| 96.0 | 99.3 | 115.2 | 106.0 | 95.8 | 91.8 | 87.6 | 86.8 | 84.3 | 81.9 | 81.2 |
| 96.3 | 100.3 | 117.4 | 105.1 | 95.6 | 91.0 | 87.0 | | | | |
| 96.9 | 101.0 | 118.1 | 106.0 | 96.1 | 92.0 | 88.0 | | | | |
| 94.2 | 101.3 | 117.5 | 104.8 | 97.1 | 89.8 | 88.2 | | | | |
| 97.0 | 100.5 | 118.0 | 104.7 | 97.2 | 92.2 | 87.3 | | | | |
| 97.45 | 101.68 | 117.21 | 105.11 | 96.3 | 91.41 | 87.66 | 86.32 | 84.7 | 82.23 | 81.0 |
| *A* open | | | | | | | | | | |
| 18.45 | 22.68 | 38.21 | 26.11 | 17.3 | 12.41 | 8.66 | 7.32 | 5.7 | 3.23 | 2.0 |
| Int. = | | | | | | | | | | |
| .328 | .428 | .343 | .247 | .164 | .12 | .082 | .065 | .051 | .032 | .017 |
| Log. *I* = | | | | | | | | | | |
| −1.516 | −1.631 | −1.535 | −1.392 | −1.22 | −1.07 | −2.91 | −2.81 | −2.71 | −2.51 | −2.218 |

*Pd* = 37.0 ; *I* = .763 ; *W* = 28.24 ; *R* = 48.49 ; *P* = 7.35 cm.; $O_C$ = 95.8 ; $O_A$ = 79.0.

| C Slit Open .5 mm. | | | | | | | | C Slit Open 1 mm. | | |
|---|---|---|---|---|---|---|---|---|---|---|
| λ = .760 | .724 | .688 | .652 | .619 | .589 | .562 | .532 | .515 | .470 | .434 |
| 126.8 | 126.0 | 123.7 | 114.8 | 102.4 | 100.2 | 95.8 | 92.9 | 101.6 | 90.6 | 89.2 |
| 124.5 | 120.0 | 124.1 | 112.2 | 102.5 | 98.1 | 97.0 | 91.3 | 102.0 | 91.8 | 91.9 |
| 119.1 | 126.0 | 125.6 | 112.0 | 105.0 | 100.0 | 96.0 | 91.8 | 100.9 | 90.0 | 87.8 |
| 122.0 | 123.7 | 126.0 | 110.0 | 104.7 | 99.0 | 96.4 | 92.0 | 101.9 | 94.0 | 90.0 |
| 122.3 | 118.0 | 124.6 | 115.0 | 102.0 | 98.1 | 94.8 | 91.9 | 101.3 | 91.8 | 91.0 |
| 119.0 | 121.5 | 120.4 | 111.2 | 103.0 | 98.9 | 95.6 | 91.4 | 102.1 | 92.6 | 89.5 |
| 116.0 | 127.0 | 123.1 | 113.1 | 102.1 | 100.3 | 96.0 | 92.4 | 101.5 | 91.2 | 89.8 |
| 119.0 | 122.6 | 120.8 | 116.7 | 103.2 | 97.0 | 96.0 | 93.8 | 102.2 | 91.5 | 89.0 |
| 115.8 | 124.0 | 124.7 | 113.2 | 101.2 | 99.0 | 95.7 | 93.1 | 100.0 | 93.6 | 90.6 |
| 117.2 | 123.0 | 119.8 | 113.3 | 101.8 | 97.2 | 95.2 | 91.9 | 101.7 | 92.0 | 89.0 |
| 120.17 | 123.18 | 123.28 | 113.15 | 102.79 | 98.78 | 95.85 | 92.25 | 101.52 | 91.91 | 89.78 |
| *A* open | | | | | | | | | | |
| 41.17 | 44.18 | 44.28 | 34.15 | 23.79 | 19.78 | 16.85 | 13.25 | 22.52 | 12.91 | 10.78 |
| Int. = | | | | | | | | | | |
| .802 | .874 | .866 | .661 | .461 | .386 | .328 | .252 | .203 | .119 | .095 |
| Log. *I* = | | | | | | | | | | |
| −1.904 | −1.942 | −1.938 | −1.820 | −1.664 | −1.587 | −1.51 | −1.40 | −1.308 | −1.75 | −2.975 |

$Pd = 39.9$; $I = .845$; $W = 33.72$; $R = 47.22$; $P = 7.35$ cm.; $O_C = 95.8$; $O_A = 79.0$.

| C Slit Open .25 mm. | | | | | C Slit Open .5 mm. | | | | C Slit Open 1 mm. | |
|---|---|---|---|---|---|---|---|---|---|---|
| λ = .760 | .724 | .688 | .652 | .619 | .589 | .562 | .532 | .515 | .470 | .434 |
| 109.3 | 107.5 | 105.8 | 107.5 | 100.0 | 117.2 | 107.3 | 105.6 | 100.6 | 108.0 | 100.0 |
| 109 3 | 108.0 | 109.0 | 106.5 | 104.0 | 117.6 | 106.4 | 103.2 | 100.7 | 107.4 | 98.2 |
| 106.9 | 109.0 | 106.0 | 106.0 | 103.2 | 117.4 | 105.3 | 107.6 | 98.7 | 110.0 | 102.7 |
| 109.0 | 106.5 | 107.8 | 107.6 | 103.2 | 113.8 | 107.4 | 102.1 | 100.0 | 112.5 | 96.5 |
| 106.0 | 107.0 | 106.8 | 105.0 | 103.1 | 113.9 | 108.0 | 101.8 | 101.6 | 113.0 | 96.5 |
| 109.2 | 108.0 | 111.4 | 104.0 | 104.4 | 118.2 | 109.8 | 103.8 | 101.5 | 111.0 | 96.8 |
| 108.5 | 110.0 | 104.8 | 105.6 | 101.6 | 117.0 | 108.8 | 103.8 | 100.2 | 108.3 | 99.3 |
| 108.6 | 108.8 | 106.1 | 104.1 | 100.8 | 119.5 | 106.9 | 103.5 | 98.5 | 109.8 | 101.8 |
| 109.0 | 110.0 | 109.8 | 105.7 | 102.8 | 114.2 | 106.4 | 104.8 | 100.0 | 108.1 | 98.8 |
| 105.0 | 109.9 | 106.0 | 103.2 | 104.2 | 119.1 | 107.9 | 104.6 | 103.0 | 109.1 | 98.2 |
| 107.98 | 108.52 | 107.35 | 105.53 | 102.73 | 116.49 | 107.42 | 103.78 | 100.48 | 109.72 | 98.88 |
| *A* open | | | | | | | | | | |
| 28.97 | 29.52 | 28.35 | 26.53 | 23.78 | 37.49 | 28.42 | 24.78 | 21.48 | 30.72 | 19.88 |
| Int. = | | | | | | | | | | |
| 1.161 | 1.193 | 1.138 | 1.07 | .945 | .756 | .56 | .482 | .413 | .286 | .182 |
| Log. *I* = | | | | | | | | | | |
| .065 | .077 | .056 | .029 | −1.975 | −1.879 | −1.74 | −1.683 | −1.616 | −1.456 | −1.259 |

$Pd = 43.4$; $I = .943$; $W = 40.93$; $R = 46.2$; $P = 7.35$ cm.; $O_C = 95.8$; $O_A = 79$.

| C Slit Open .25 mm. | | | | | | | | | .5 mm. | 1 mm. |
|---|---|---|---|---|---|---|---|---|---|---|
| λ = .760 | .724 | 688 | .652 | .619 | .589 | .562 | .532 | .515 | .470 | .434 |
| 119.7 | 127.0 | 129.8 | 123.8 | 120.0 | 114.0 | 111.8 | 105.3 | 101.7 | 106.6 | 123.7 |
| 118.1 | 129.6 | 126.9 | 129.0 | 121.3 | 118.5 | 110.6 | 103.0 | 100.1 | 107.6 | 127.7 |
| 124.0 | 125.5 | 126.1 | 125.6 | 121.0 | 113.0 | 109.5 | 104.4 | 102.0 | 108.5 | 121.2 |
| 123.4 | 125.6 | 131.1 | 125.8 | 119.0 | 113.0 | 109.3 | 102.8 | 100.5 | 108.0 | 117.5 |
| 123.8 | 129.0 | 125.7 | 124.7 | 122.8 | 121.0 | 111.0 | 106.5 | 101.0 | 108.6 | 130.0 |
| 117.2 | 130.5 | 124.5 | 121.1 | 117.2 | 116.0 | 112.8 | 103.2 | 100.8 | 105.7 | 132.0 |
| 121.1 | 125.6 | 128.0 | 128.1 | 117.5 | 115.9 | 113.0 | 105.5 | 102.5 | 106.7 | 127.0 |
| 118.0 | 128.0 | 127.4 | 125.9 | 118.0 | 115.0 | 110.8 | 105.3 | 102.0 | 108.3 | 128.0 |
| 117.8 | 124.5 | 124.5 | 125.2 | 119.6 | 118.5 | 109.8 | 107.8 | 99.1 | 108.5 | 130.5 |
| 121.8 | 125.0 | 126.0 | 125.6 | 121.0 | 114.5 | 111.0 | 104.6 | 98.8 | 106.4 | 122.5 |
| 120.49 | 127.03 | 127.0 | 125.48 | 119.74 | 115.94 | 110.96 | 104.84 | 101.65 | 107.31 | 126.0 |
| *A* open | | | | | | | | | | |
| 41.49 | 48.03 | 48.0 | 46.48 | 40.74 | 36.94 | 31.96 | 25.84 | 22.65 | 28.31 | 47.0 |
| Int. = | | | | | | | | | | |
| 1.77 | 2.01 | 1.96 | 1.99 | 1.65 | 1.49 | 1.28 | 1.03 | .91 | .55 | .459 |
| Log. *I* = | | | | | | | | | | |
| .248 | .3032 | .295 | .299 | .219 | .173 | .108 | .01 | −1.96 | −1.747 | −1.662 |

*Pd* = 47.0 ; *I* = 1.055 ; *W* = 49.59 ; *R* = 44.55 ; *P* = 7.35 cm.; $O_C$ = 95.8 ; $O_A$ = 78.2.

| C Slit Open .2 mm. | | | | | | | C Slit Open .25 mm. | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| λ = .760 | .724 | .688 | .652 | .619 | .589 | .562 | .532 | .515 | .470 | .434 |
| 134.0 | 135.6 | 135.0 | 144.6 | 141.0 | 131.0 | 119.6 | 121.0 | 116.7 | 107.1 | 99.7 |
| 133.2 | 137.2 | 136.0 | 142.8 | 144.5 | 127.9 | 121.7 | 121.0 | 118.0 | 110.1 | 101.1 |
| 136.4 | 135.3 | 137.1 | 140.0 | 137.0 | 131.8 | 122.0 | 121.4 | 118.2 | 112.2 | 102.7 |
| 136.2 | 136.0 | 137.2 | 140.0 | 140.1 | 135.2 | 118.8 | 124.0 | 119.4 | 111.1 | 102.2 |
| 134.4 | 136.6 | 137.8 | 142.7 | 138.5 | 130.0 | 122.1 | 122.2 | 119.5 | 107.2 | 101.0 |
| 134.0 | 136.2 | 136.0 | 138.0 | 141.0 | 131.5 | 118.6 | 125.2 | 116.0 | 111.0 | 104.5 |
| 133.9 | 134.6 | 138.5 | 144.0 | 144.2 | 133.0 | 119.7 | 123.2 | 119.0 | 111.0 | 99.5 |
| 133.1 | 130.8 | 138.4 | 142.2 | 137.8 | 129.0 | 119.2 | 123.0 | 117.8 | 110.2 | 101.0 |
| 135.5 | 134.6 | 135.5 | 141.9 | 138.5 | 133.8 | 119.3 | 123.0 | 119.0 | 112.0 | 98.5 |
| 136.3 | 137.2 | 136.3 | 140.2 | 142.0 | 130.3 | 122.2 | 122.2 | 119.2 | 109.0 | 100.5 |
| 134.7 | 135.41 | 136.78 | 141.64 | 140.46 | 131.35 | 120.32 | 122.62 | 118.28 | 110.09 | 101.07 |
| *A* open 56.4 | 57.21 | 58.58 | 63.44 | 62.26 | 53.15 | 42.12 | 44.42 | 40.08 | 31.89 | 22.87 |
| Int. = 3.20 | 3.07 | 3.04 | 3.295 | 3.265 | 2.77 | 2.16 | 1.79 | 1.64 | 1.29 | .91 |
| Log. *I* = .505 | .487 | .483 | .518 | .514 | .443 | .335 | .253 | .214 | .111 | —1.957 |

*Pd* = 50.0 ; *I* = 1.155 ; *W* = 57.75 ; *R* = 43.29 ; *P* = 7.35 cm.; $O_C$ = 95.8 ; $O_A$ = 78.2.

| C slit open .2 mm. | | | C slit open .10 mm. | | | | | | | .25 mm. |
|---|---|---|---|---|---|---|---|---|---|---|
| λ = .760 | .724 | .688 | .652 | .619 | .589 | .562 | .532 | .515 | .470 | .434 |
| 157.8 | 157.8 | 156.0 | 123.6 | 122.8 | 118.0 | 109.0 | 107.0 | 107.0 | 102.3 | 111.2 |
| 150.5 | 157.2 | 159.7 | 119.5 | 124.0 | 120.5 | 109.9 | 107.5 | 105.2 | 98.0 | 115.8 |
| 152.0 | 156.8 | 156.8 | 121.8 | 124.5 | 116.1 | 109.1 | 106.9 | 106.5 | 103.0 | 115.0 |
| 161.8 | 159.8 | 161.0 | 120.2 | 120.9 | 120.6 | 111.2 | 108.0 | 104.6 | 100.0 | 113.8 |
| 157.4 | 157.0 | 161.8 | 120.0 | 120.5 | 117.0 | 112.7 | 106.9 | 105.9 | 99.5 | 109.0 |
| 153.4 | 159.0 | 158.6 | 123.3 | 125.0 | 119.1 | 111.5 | 107.9 | 105.3 | 102.6 | 118.6 |
| 155.0 | 156.3 | 158.5 | 122.1 | 120.2 | 122.0 | 110.3 | 107.2 | 105.0 | 101.0 | 112.0 |
| 154.2 | 158.0 | 156.8 | 122.6 | 121.2 | 115.0 | 112.8 | 109.0 | 105.0 | 100.0 | 116.0 |
| 154.8 | 159.0 | 159.4 | 122.1 | 123.0 | 115.2 | 110.0 | 109.3 | 105.9 | 99.9 | 111.0 |
| 153.0 | 155.7 | 157.7 | 123.0 | 123.6 | 116.7 | 111.8 | 108.0 | 104.4 | 99.0 | 108.0 |
| 154.99 | 157.66 | 158.63 | 121.82 | 122.57 | 118.02 | 110.83 | 107.77 | 105.48 | 100.53 | 113.04 |
| *A* open 76.79 | 79.46 | 80.43 | 43.62 | 44.37 | 39.82 | 32.63 | 29.57 | 27.28 | 22.33 | 34.84 |
| Int. = 4.67 | 4.50 | 4.33 | 4.46 | 4.64 | 4.18 | 3.34 | 2.98 | 2.78 | 2.22 | 1.42 |
| Log. *I* = .669 | .653 | .637 | .649 | .665 | .621 | .524 | .474 | .444 | .346 | .153 |

$Pd = 55.0$; $I = 1.31$; $W = 72.05$; $R = 41.98$; $P = 7.35$ cm.; $O_C = 95.8$; $O_A = 78.2$

| C Slit Open .1 mm. | | .075 mm. | C Slit Open .1 mm. | | | .075 mm | C Slit Open .1 mm. | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| λ = .760 | .724 | .688 | .652 | .619 | .589 | .562 | .532 | .515 | .470 | .434 |
| 132.3 | 136.0 | 122.8 | 152.4 | 155.0 | 154.8 | 129.2 | 134.5 | 133.3 | 123.1 | 118.5 |
| 133.8 | 136.0 | 127.5 | 148.2 | 152.5 | 150.1 | 128.3 | 135.0 | 129.1 | 118.9 | 114.8 |
| 131.0 | 137.2 | 122.4 | 149.5 | 156.8 | 146.8 | 126.7 | 131.8 | 132.0 | 120.0 | 116.5 |
| 134.8 | 137.1 | 122.8 | 151.5 | 151.2 | 151.0 | 128.0 | 131.0 | 134.2 | 116.0 | 116.2 |
| 131.4 | 132.6 | 126.8 | 146.2 | 154.8 | 146.0 | 123.0 | 135.8 | 127.0 | 120.6 | 114.8 |
| 132.6 | 134.9 | 124.5 | 153.8 | 155.2 | 148.8 | 123.8 | 132.2 | 130.5 | 116.9 | 113.0 |
| 129.4 | 132.0 | 127.8 | 152.2 | 152.1 | 149.7 | 123.6 | 135.0 | 138.0 | 120.3 | 116.5 |
| 129.5 | 133.8 | 126.0 | 145.1 | 151.8 | 150.0 | 124.2 | 131.4 | 133.0 | 124.6 | 115.1 |
| 133.3 | 134.2 | 125.2 | 147.5 | 154.8 | 149.1 | 129.0 | 132.6 | 129.8 | 124.0 | 118.8 |
| 133.0 | 137.2 | 124.1 | 149.2 | 152.9 | 146.3 | 126.3 | 136.4 | 133.1 | 123.2 | 116.7 |
| 132.11 | 135.1 | 124.99 | 149.56 | 153.71 | 149.26 | 126.21 | 133.57 | 131.0 | 120.76 | 116.09 |
| *A* open | | | | | | | | | | |
| 53.91 | 56.9 | 46.89 | 71.36 | 75.51 | 71.06 | 48.11 | 55.37 | 52.8 | 42.56 | 37.89 |
| Int. = | | | | | | | | | | |
| 6.24 | 6.12 | 6.42 | 7.48 | 8.06 | 7.68 | 6.72 | 5.73 | 5.53 | 4.36 | 4.05 |
| Log. *I* = | | | | | | | | | | |
| .795 | .787 | .808 | .874 | .906 | .885 | .827 | .758 | .743 | .639 | .607 |

$Pd = 60.0$; $I = 1.48$; $W = 88.80$; $R = 40.54$; $P = 7.35$; $O_C = 95.8$; $O_A = 7.80$.

| C Slit Open .08 mm. | | | | .619 | .589 | .562 | .532 | .515 | .470 | .434 |
|---|---|---|---|---|---|---|---|---|---|---|
| λ = .760 | .724 | .688 | .652 | | | | | | | |
| 146.0 | 158.1 | 155.0 | 170.6 | 173.6 | 163.5 | 158.8 | 156.6 | 144.0 | 137.5 | 133.2 |
| 145.1 | 155.6 | 156.2 | 167.8 | 172.5 | 161.4 | 160.8 | 152.0 | 145.2 | 141.0 | 135.2 |
| 148.6 | 152.2 | 156.4 | 164.3 | 175.0 | 167.0 | 160.4 | 155.9 | 146.9 | 142.2 | 134.4 |
| 148.8 | 158.2 | 154.0 | 172.8 | 175.2 | 161.2 | 160.4 | 149.4 | 144.1 | 140.2 | 134.8 |
| 151.9 | 156.6 | 163.2 | 171.5 | 166.2 | 163.2 | 158.6 | 154.8 | 145.1 | 140.0 | 133.6 |
| 152.0 | 156.0 | 161.2 | 165.3 | 170.6 | 164.1 | 159.4 | 149.4 | 147.2 | 140.6 | 132.4 |
| 149.6 | 154.4 | 162.2 | 172.9 | 161.0 | 162.8 | 157.5 | 157.1 | 140.6 | 142.0 | 135.7 |
| 152.5 | 153.1 | 155.6 | 170.5 | 161.5 | 168.0 | 158.6 | 150.3 | 144.2 | 140.2 | 130.0 |
| 147.8 | 156.7 | 155.1 | 169.4 | 180.9 | 167.2 | 160.0 | 152.4 | 148.0 | 137.0 | 134.4 |
| 146.3 | 152.8 | 161.8 | 166.7 | 168.0 | 160.0 | 161.1 | 152.6 | 146.1 | 139.1 | 132.0 |
| 148.86 | 155.37 | 158.07 | 169.18 | 170.45 | 163.84 | 159.56 | 152.45 | 145.14 | 139.98 | 133.57 |
| *A* open | | | | | | | | | | |
| 70.86 | 77.37 | 80.07 | 91.18 | 92.45 | 85.84 | 81.56 | 74.45 | 67.14 | 61.98 | 55.57 |
| Int. = | | | | | | | | | | |
| 11.42 | 11.18 | 10.83 | 12.25 | 12.38 | 12.26 | 10.90 | 10.00 | 9.25 | 8.40 | 7.86 |
| Log. *I* = | | | | | | | | | | |
| 1.050 | 1.048 | 1.035 | 1.088 | 1.094 | 1.089 | 1.037 | 1.000 | .966 | .924 | .895 |

the zero of the scale 1 was prefixed to the reading for the sake of clearness, there being 100 divisions on the screw head and one complete turn equaling an increase in opening of the slit of one millimeter. "*A* open" gives the number of divisions of the comparison

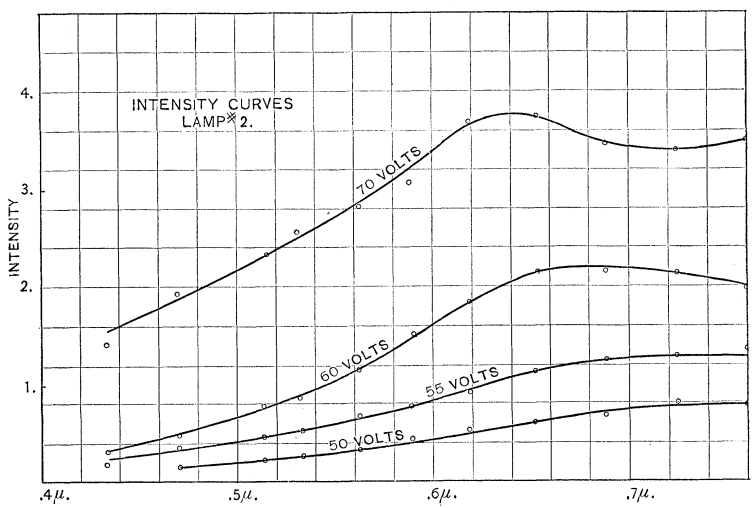



Fig. 17.

slit open to produce equality of illumination and the row marked "I n t" gives the ratio of the intensity of the carbon light radiation to the intensity of the acetylene for the given wave-length.

Gray and black carbon show marked differences in their efficiency, as has been shown by M. Evans [1] and confirmed by J. T. Bottomley [2] and J. C. Shedd,[3] and later by Dr. Nichols [4] in his study of the spectrum of the glow lamp. It was desired to find whether this change in the rate of change of luminosity was a characteristic of gray carbon alone, or whether it also was apparent in black carbon. A lamp was accordingly taken the filament of which had been carefully treated by coating with lampblack.[5] This lamp showed a

[1] Mr. M. Evans, Proc. Royal Soc., Vol. XL., Feb. 18, 1886, pp. 207–214.
[2] J. T. Bottomley, Phil. Trans., 1887, p. 429.
[3] J. C. Shedd, Thesis, Cornell University Library, 1892.
[4] Dr. E. L. Nichols, PHYS. REV., Vol. II., 1895, pp. 260–276.
[5] Same, p. 264.

much lower efficiency than lamp No. 1 with the gray filament. It will be noticed from the data given in Table III. that as the voltage increased the resistance also increased and that, therefore, it is impossible to apply Le Chatelier's results to determine the rise in temperature.

TABLE III.

| *V* | *I* | *W* | C. P. | $\frac{W.}{C. P.}$ | *R.* |
|---|---|---|---|---|---|
| 50 | 1.51 | 75.5 | 4.58 | 16.5 | 33.11 |
| 55 | 1.65 | 90.75 | 8.68 | 10.45 | 33.33 |
| 60 | 1.78 | 106.8 | 14.30 | 7.46 | 33.71 |
| 70 | 2.04 | 142.8 | 31.24 | 4.57 | 34.31 |

As will be seen from Table IV. and Fig. 17 the same characteristic form of curve, with maximum shifting to the small wavelengths as the voltage rose, was likewise found in the case of this lamp.

As a final check on the results obtained using the Lummer-Brodhun spectrophotometer, a Nichols spectrophotometer was used. This instrument is made up of a horizontal collimator at one end of which are placed two totally reflecting prisms, the sources being studied being placed on a line perpendicular to the axis of the tube. The amount of incident light is regulated by means of two adjustable horizontal slits which are governed by micrometer screws.

TABLE IV.

$Pd = 50.00$ ; $I = 1.51$ ; $W = 75.5$ ; $R = 33.11$ ; $P = 7.35$ cm.; $O_C = 95.8$ ; $O_A = 78.0$.

| 1 mm. | C Slit Open .5 mm. | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| λ = .760 | .724 | .688 | .652 | .619 | .589 | .562 | .532 | .515 | .470 | .434 |
| 165.0 | 117.1 | 111.1 | 106.4 | 103.4 | 98.8 | 95.0 | 92.0 | 89.3 | 85.8 | |
| 163.1 | 117.5 | 114.6 | 108.5 | 103.3 | 100.3 | 94.0 | 90.7 | 89.1 | 85.1 | |
| 160.0 | 118.2 | 111.2 | 108.2 | 102.2 | 99.2 | 93.2 | 91.6 | 88.1 | 84.1 | |
| 161.6 | 118.0 | 113.2 | 109.0 | 104.9 | 98.8 | 94.7 | 91.0 | 89.2 | 85.0 | |
| 164.1 | 117.8 | 111.3 | 108.9 | 103.2 | 100.0 | 93.0 | 91.1 | 89.0 | 85.0 | |
| 160.0 | 119.0 | 112.0 | 108.2 | 104.1 | 99.9 | 94.5 | 90.8 | 88.8 | 84.2 | |
| 162.3 | 117.93 | 112.24 | 108.2 | 103.52 | 99.5 | 94.07 | 91.2 | 88.92 | 84.88 | |
| *A* open | | | | | | | | | | |
| 84.3 | 39.93 | 34.24 | 30.2 | 25.52 | 21.5 | 16.07 | 13.2 | 10.92 | 6.88 | |
| tIn.= | | | | | | | | | | |
| .76 | .78 | .655 | .582 | .499 | .421 | .312 | .251 | .201 | .123 | |

$Pd = 55.0$; $I = 1.65$; $W = 90.75$; $R = 33.33$; $P = 7.35$ cm.; $O_C = 95.8$; $O_A = 78.0$.

| C Slit open .5 mm. | | C Slit Open .25 mm. | | | | | | | | 1 mm. |
|---|---|---|---|---|---|---|---|---|---|---|
| λ = .760 | .724 | .688 | .652 | .619 | .589 | .562 | .532 | .515 | .470 | .434 |
| 143.3 | 136.8 | 106.6 | 108.0 | 100.0 | 97.6 | 93.6 | 91.1 | 89.8 | 87.2 | 97.1 |
| 139.1 | 134.6 | 111.5 | 109.1 | 100.2 | 97.2 | 94.0 | 92.0 | 90.0 | 87.6 | 96.0 |
| 144.4 | 140.3 | 111.8 | 103.6 | 100.3 | 96.8 | 94.0 | 90.6 | 90.0 | 87.0 | 98.7 |
| 143.0 | 138.6 | 108.5 | 106.2 | 101.0 | 97.2 | 95.4 | 91.3 | 88.4 | 86.2 | 95.2 |
| 141.5 | 141.0 | 107.0 | 107.7 | 102.0 | 96.0 | 95.4 | 92.6 | 89.3 | 87.8 | 94.8 |
| 143.5 | 143.0 | 105.0 | 106.3 | 101.5 | 98.5 | 92.2 | 91.9 | 89.4 | 86.2 | 97.2 |
| | 138.2 | 105.7 | 106.2 | 102.1 | 98.2 | 96.0 | 91.0 | 89.1 | 86.0 | 96.8 |
| | 141.0 | 108.6 | 102.8 | 100.8 | 98.3 | 94.0 | 93.0 | 89.7 | 85.8 | 96.2 |
| | 144.5 | 108.8 | 103.2 | 99.8 | 97.1 | 95.8 | 92.8 | 89.1 | 86.0 | 95.8 |
| | 140.0 | 107.9 | 106.5 | 101.3 | 97.8 | 95.2 | 91.0 | 89.4 | 86.1 | 98.0 |
| 142.47 | 139.8 | 108.14 | 105.96 | 100.9 | 97.47 | 94.56 | 91.73 | 89.42 | 86.59 | 96.58 |
| *A* open | | | | | | | | | | |
| 64.47 | 61.8 | 30.14 | 27.96 | 22.9 | 19.47 | 16.56 | 13.73 | 11.42 | 8.59 | 18.58 |
| Int. = | | | | | | | | | | |
| 1.35 | 1.27 | 1.22 | 1.12 | .91 | .77 | .66 | .53 | .45 | .35 | .17 |

$Pd = 60.0$; $I = 1.78$; $W = 106.8$; $R = 33.71$; $P = 7.35$ cm.; $O_C = 95.8$; $O_A = 78.0$.

| C Slit Open .25 mm. | | | | | | | | | | 1 mm. |
|---|---|---|---|---|---|---|---|---|---|---|
| λ = .760 | .724 | .688 | .652 | .619 | .589 | .562 | .532 | .515 | .470 | .434 |
| 125.6 | 132.3 | 129.5 | 129.8 | 120.8 | 114.6 | 104.8 | 102.6 | 95.8 | 91.3 | 114.0 |
| 122.4 | 131.3 | 131.6 | 131.0 | 125.0 | 115.3 | 107.2 | 101.9 | 97.8 | 93.4 | 109.0 |
| 122.0 | 129.0 | 129.0 | 129.5 | 122.0 | 114.2 | 105.9 | 102.4 | 98.3 | 91.8 | 114.7 |
| 122.0 | 126.8 | 129.0 | 127.5 | 121.4 | 116.0 | 104.9 | 102.3 | 97.0 | 92.2 | 112.3 |
| 125.0 | 129.0 | 132.8 | 130.0 | 125.0 | 114.2 | 105.8 | 101.8 | 97.7 | 93.7 | 110.3 |
| 124.1 | 130.9 | 127.4 | 129.7 | 122.8 | 114.0 | 109.0 | 101.2 | 97.9 | 91.8 | 107.8 |
| 121.6 | 125.2 | 130.0 | | | | | | | | |
| 124.7 | 126.5 | 129.0 | | | | | | | | |
| 122.1 | 128.3 | 130.0 | | | | | | | | |
| 124.2 | 126.0 | 131.2 | | | | | | | | |
| 123.37 | 128.53 | 129.95 | 129.58 | 122.63 | 114.72 | 106.27 | 102.03 | 97.42 | 92.37 | 111.35 |
| *A* open | | | | | | | | | | |
| 45.37 | 50.53 | 51.95 | 51.58 | 44.63 | 36.72 | 28.27 | 24.03 | 19.42 | 14.37 | 33.35 |
| Int. = | | | | | | | | | | |
| 1.96 | 2.13 | 2.14 | 2.12 | 1.82 | 1.49 | 1.13 | .96 | .78 | .58 | .32 |

$Pd = 70.0$; $I = 2.04$; $W = 142.8$; $R = 34.31$; $P = 7.35$ cm.; $O_C = 95.8$; $O_A = 78$.

| C Slit Open .1 mm. | | | | | | | | | | .5 mm. |
|---|---|---|---|---|---|---|---|---|---|---|
| λ = .760 | .724 | .688 | .652 | .619 | .589 | .562 | .532 | .515 | .470 | .434 |
| 108.1 | 110.8 | 110.0 | 113.1 | 113.2 | 108.1 | 105.7 | 102.8 | 102.0 | 97.1 | 145.2 |
| 111.5 | 112.3 | 114.2 | 113.3 | 115.0 | 107.8 | 103.6 | 102.4 | 100.3 | 96.0 | 151.2 |
| 111.0 | 112.5 | 113.8 | 115.5 | 111.0 | 110.0 | 106.2 | 104.0 | 101.5 | 98.0 | 140.0 |
| 108.8 | 110.0 | 113.7 | 116.9 | 114.3 | 105.4 | 107.2 | 100.7 | 99.1 | 95.6 | 144.8 |
| 111.0 | 112.2 | 112.2 | 113.7 | 113.3 | 106.5 | 105.8 | 104.2 | 102.4 | 97.5 | 149.5 |
| 110.7 | 109.9 | 111.3 | 116.2 | 113.3 | 108.8 | 105.7 | 104.8 | 100.2 | 98.0 | 143.7 |
| 110.18 | 111.28 | 112.53 | 114.76 | 113.36 | 107.43 | 105.7 | 103.15 | 100.92 | 97.03 | 145.73 |
| *A* open | | | | | | | | | | |
| 32.18 | 33.28 | 34.53 | 36.76 | 35.35 | 29.43 | 27.07 | 25.15 | 22.92 | 19.03 | 67.73 |
| Int. = | | | | | | | | | | |
| 3.49 | 3.42 | 3.45 | 3.74 | 3.68 | 3.07 | 2.81 | 2.54 | 2.31 | 1.92 | 1.39 |

The two beams of light impinge upon a metal grating placed with the lines horizontal, so that the spectrum produced is vertical. The examining telescope swings in a vertical plane, as does also the grating, for purposes of adjustment. The spectrum produced by this instrument is a distinct normal one of about ten degrees dispersion between the limits of the visible spectrum. The character of the spectrum afforded by this instrument and the conditions of working with it differ so widely from those of the Lummer-Brodhun spectrophotometer as to offer an admirable control of the general correctness of the measurements made with the latter. Runs upon the lamp with the gray filament were made at fifty volts and at sixty-two and one-half volts. The curves obtained show the same general form with the shifting of the maximum toward the shorter wave-lengths, thus confirming the previous work and showing that the effect was a real one. No particular stress is laid on the readings for .76 $\mu$ or for .434 $\mu$ as to their real value but they do show the general trend of the curves. The data given in Table V. are for this test.

Table VI. gives the percentage, taken from the curves, for each wave-length, of the intensity at a given voltage over the value of the intensity of the same wave-length at the next lower voltage, for the lamp with the gray filament.

The results of the experiments here described are in accordance with the phenomenon observed by Dr. Nichols in his spectro-pho-

## Table V.

$Pd = 50.0$; $I = 1.15$; $W = 57.5$; $R = 43.45$; $P = 7.35$ cm.; $O_C = 3.6$; $O_A = 88.5$.

| | A Open 1 Turn. | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| λ = .760 | .724 | .688 | .652 | .619 | .589 | .562 | .532 | .515 | .470 | .434 |
| 40.4 | 43.8 | 43.0 | 52.5 | 59.2 | 66.4 | 61.5 | 67.2 | 68.5 | | |
| 46.3 | 44.8 | 42.5 | 53.6 | 55.2 | 60.5 | 67.8 | 66.4 | 73.0 | | |
| | 46.4 | 42.2 | 50.8 | 57.5 | 61.6 | 63.8 | 70.5 | 72.5 | | |
| | 44.4 | 41.3 | 51.8 | 55.8 | 62.6 | 66.6 | 69.6 | 71.1 | | |
| | 43.4 | 41.2 | 51.9 | 55.7 | 64.2 | 67.1 | 69.5 | 68.0 | | |
| 43.35 | 44.56 | 42.4 | 52.12 | 56.68 | 63.06 | 65.36 | 68.64 | 70.62 | | |
| *C* open | | | | | | | | | | |
| 39.75 | 40.96 | 38.46 | 48.52 | 53.08 | 59.46 | 61.76 | 65.04 | 67.02 | | |
| Int. = | | | | | | | | | | |
| 2.52 | 2.44 | 2.60 | 2.06 | 1.88 | 1.71 | 1.62 | 1.54 | 1.49 | | |

$Pd = 62.5$; $I = 1.56$; $W = 97.5$; $R = 40.5$; $P = 7.35$ cm.; $O_C = 3.4$; $O_A = 88.5$.

| 2 Turns. | A Open 1 Turn. | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| λ = .760 | .724 | .688 | .652 | .619 | .589 | .562 | .532 | .515 | .470 | .434 |
| 33.0 | 21.2 | 22.1 | 20.9 | 20.8 | 24.6 | 24.8 | 27.7 | 27.3 | 33.1 | 63.0 |
| 31.5 | 20.8 | 23.4 | 20.8 | 21.1 | 22.6 | 26.1 | 29.8 | 29.5 | 31.3 | 66.2 |
| 31.4 | 21.4 | 21.9 | 21.2 | 20.9 | 23.1 | 25.5 | 25.6 | 29.2 | 33.5 | 66.8 |
| 31.9 | 20.4 | 20.7 | 20.8 | 21.1 | 23.8 | 25.3 | 25.5 | 27.3 | 29.3 | 63.5 |
| 31.4 | 21.4 | 21.8 | 21.2 | 21.8 | 24.8 | 24.5 | 26.7 | 29.1 | 29.5 | 64.3 |
| 31.84 | 20.96 | 21.98 | 20.98 | 21.14 | 23.78 | 25.24 | 27.06 | 28.48 | 31.34 | 64.76 |
| *C* open | | | | | | | | | | |
| 28.44 | 17.56 | 18.58 | 17.58 | 17.74 | 20.38 | 22.84 | 23.66 | 25.08 | 27.94 | 61.3 |
| Int. = | | | | | | | | | | |
| 7.03 | 5.69 | 5.38 | 5.68 | 5.64 | 4.91 | 4.38 | 4.23 | 4.00 | 3.58 | 3.2 |

## Table VI.

| Volts. | Wave-Lengths. | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | .434 | .470 | .515 | .532 | .562 | .589 | .619 | .652 | .688 | .724 | .760 |
| 24.85 | — | — | — | — | — | — | — | — | — | — | — |
| 29.9 | — | 167 | 244 | 267 | 362 | 353 | 343 | 358 | 436 | 369 | 285 |
| 33.4 | — | 372 | 367 | 345 | 287 | 270 | 251 | 225 | 199 | 196 | 198 |
| 37.0 | 274 | 260 | 283 | 287 | 282 | 263 | 235 | 210 | 178 | 176 | 198 |
| 40.0 | 241 | 227 | 213 | 212 | 209 | 207 | 202 | 186 | 161 | 159 | 170 |
| 43.5 | 212 | 207 | 182 | 174 | 174 | 181 | 182 | 169 | 156 | 156 | 158 |
| 47.0 | 218 | 214 | 208 | 204 | 196 | 192 | 182 | 163 | 158 | 166 | 169 |
| 50.0 | 188 | 184 | 171 | 170 | 169 | 164 | 165 | 155 | 142 | 150 | 153 |
| 55.0 | 215 | 194 | 186 | 182 | 176 | 172 | 159 | 157 | 148 | 148 | 152 |
| 60.0 | 195 | 196 | 181 | 177 | 170 | 160 | 156 | 165 | 169 | 148 | 160 |

tometric observations on incandescent rods, cited above. The observations at the higher temperatures at which it was possible to work, with some fair degree approximating that of the acetylene flame, show that the distribution of energy in the spectra of acetylene and of the carbon filaments at the same temperature is not the same, as has been thought to be the case. The isotherms for the gray carbon rod, figure 22 in the paper of Dr. Nichols, begin to show the same characteristics that are brought out in the present work at the higher temperatures, namely, that after passing a maximum, compared to acetylene, in the orange a minimum is reached in the red, the comparative intensity again increasing toward the infra red. By a reference to the intensity-temperature curves it will be seen that crossing of the isochroms predicted at higher temperatures, in Dr. Nichols's paper has really taken place, the curve for wave-length .562 $\mu$ cutting those of .688 $\mu$ and .724 $\mu$, while the curve for wave-length .589 $\mu$ cuts every one of wave-length greater than .562 $\mu$ excepting that for wave-length .619 $\mu$ which it would likely intersect at a temperature not much higher.

It is also seen by a comparison of the isotherms for gray carbon and for the black filament that the same characteristics are brought out and this phenomenon of selective radiation is one not due to the nature of the carbon surface.

I desire, in concluding, to express my gratitude to Dr. Nichols, at whose suggestion this investigation was taken up, for many valuable suggestions and his inspiring interest in the work.

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