A DIRECT MEASUREMENT OF THE INTENSITY VARIATIONS OF THE HELIUM LINES WITH VOLTAGE

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Abstract

The intensity variations with voltage of some of the brighter lines of the low voltage helium arc spectrum were determined by means of a recently developed photoelectric spectrophotometer. The radiation was developed in a copper ball, 20 cm in diameter. The equipotential cathode and grid from a commercial three-electrode tube formed the internal structure, the sphere itself being the anode. This arrangment gave an extremely bright spectrum, even at the striking voltage, with a relatively low current density in the space. The results on 5016 (1^1S-2^1P) and on 6678 (1^1P-2^1D) were generally smooth curves. Lines 4026 (1^3P-4^3D), 4471 (1^3P-3^3D), and 5876 (1^3P-2^3D), show a region of constant intensity with arc voltages from 27 to 35 volts, thereafter increasing smoothly. Line 4713 (1^3P-3^3S) shows definite maxima near the critical exciting potentials. The accurate linear relationship between the intensity of the light admitted to the photoelectric cell and the amplified output of the photoelectric cell was established by a separate experiment. For the measurements on the spectrum lines, every intensity measurement was referred to a standard lamp operated at a constant resistance. The absence of oscillations in the arc current was shown by a vacuum tube voltmeter.

Introduction

Knowledge of the intensity variations of spectrum lines as a function of the excitation voltage is of considerable importance in certain theoretical discussions in spectroscopy. It has been customary to obtain this knowledge by photographing the spectrum repeatedly, each exposure being made at a definite voltage, and all other variables kept as nearly constant as possible. The intensity of the lines was then determined by means of some form of densitometer.[1,2,3,4] Although this method has yielded valuable results nevertheless many difficulties and sources of error are involved. The photographic method is very time-consuming and many exposures must be made to get a sufficient number of points to plot a curve. Since the exposures are frequently very long, it is difficult to keep all the arc conditions constant. Furthermore, the relation between the actual light intensity and the resultant blackening of the plate is always subject to uncertainty, since it is influenced by many factors difficult to control. The various densitometers at present available are quite satisfactory, and so they introduce no source of error as important as the others mentioned.

[1] Hughes and Lowe, Proc. Royal Soc. **A104**, 480 (1923).
[2] Bazzoni and Lay, Phys. Rev. **23**, 327 (1924).
[3] Cornog, Phys. Rev. **32**, 746 (1928).
[4] Harrison, J.O.S.A. and R.S.I. **19**, 267 (1929).

For reasons above mentioned, a direct method for determining line intensities is desirable. The property of a photoelectric cell of translating light values into electrical quantities is at once suggested. However, when a photoelectric cell is used, it is found that the currents resulting from the very small amount of energy in a given line, are so feeble that they must be read with an electrometer,[5] or amplified by means of some form of vacuum tube amplifier. The electrometer has the disadvantage of being slow and somewhat difficult

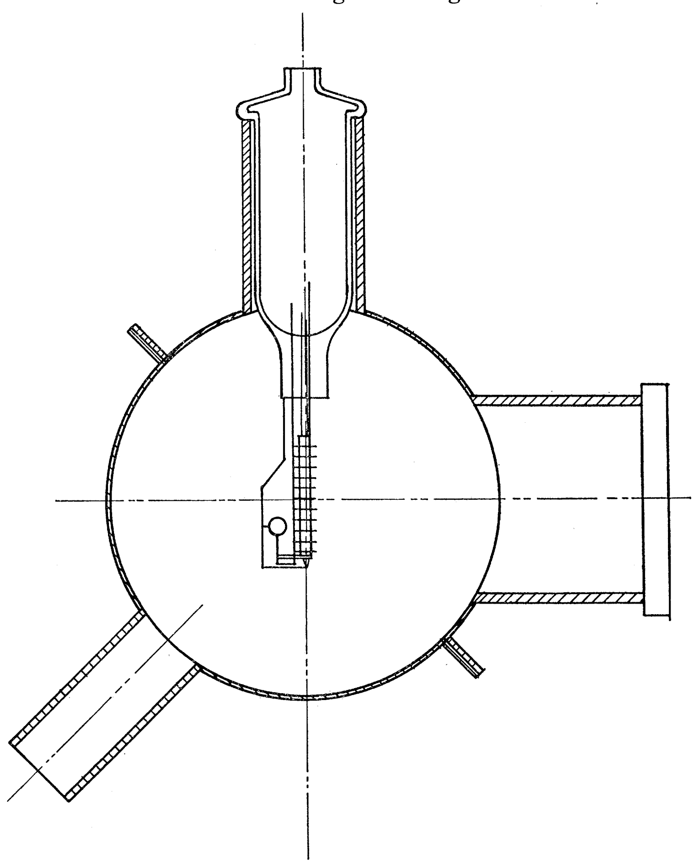

Fig. 1. Diagram of spherical low voltage arc discharge tube.

to keep in constant adjustment. The vacuum tube amplifiers used heretofore have employed the usual type of a.c. amplification.[6] The research to be described employed a resistance coupled d.c. bridge grid resistor amplifier.[7,8]

Description of the Spectrum Tube

The spectrum tube in which the arc was formed is shown in Fig. 1. The tube differs from conventional designs in that the volume in which the dis-

[5] Hulburt, Phys. Rev. **31,** 1109 (1928).
[6] Wheeler, Phys. Rev. **33,** 114 (1929).
[7] Mulder and Razek, J.O.S.A. and R.S.I. **18,** 466 (1929).
[8] Razek and Mulder, J.O.S.A. and R.S.I. **19,** 390 (1929).

charge takes place is quite large. The body of the tube was made of spun copper hemispheres, heavily silvered and polished. The two hemispheres were soldered together on an equatorial flange. The vacuum connection was made on the pole of one of the hemispheres, while the cathode and grid structures were admitted through a tube in the other hemisphere. The arc was observed through a slit in the upper hemisphere, over which a tube and glass plate were attached.

The cathode and grid structure were taken from a commercial three electrode tube, Arcturus type 247. This consists of a heating filament within a

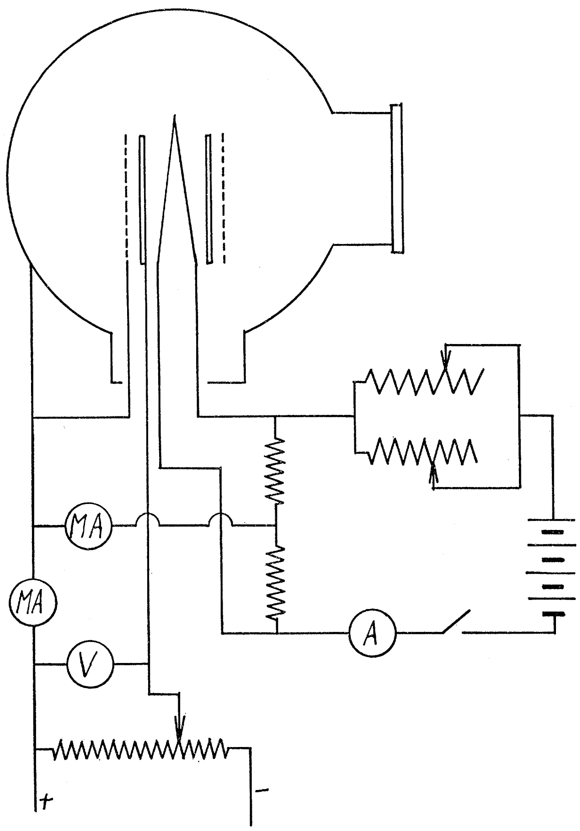

Fig. 2. Wiring diagram for low voltage arc discharge tube.

tube on which the active material is placed. A coarse grid is concentric with the cathode tube. The usual plate structure was removed, and the metal of the hemispheres used instead.

The tube was wired as shown in Fig. 2. The fact that the filament was entirely insulated from the cathode made it possible to put all structures within the tube, except the cathode, at nearly the potential of the anode. In this way, the potential of the entire space within the hemispheres, with the exception of the small volume between the cathode and grid, was nearly uniform. The filament was heated by means of a storage battery in the usual manner. A center tapped resistance was connected across the filament with the center tap connected to the anode through a milliameter. The anode to cathode voltage was applied from a potential divider across a bank of batteries, and a milliammeter indicated total cathode to anode current. The voltmeter across the potential divider indicated the voltage applied to the anode, with the slight and constant potential drop in the milliameter and leads.

Description of Laboratory Set-Up

The tube described was connected to a vacuum system, and after a short preliminary treatment to condition the active deposit on the cathode, helium gas was admitted to the tube by means of the conventional arrangement of bulb and stop-cocks. Due to the presence of the waxed joints, no effort was

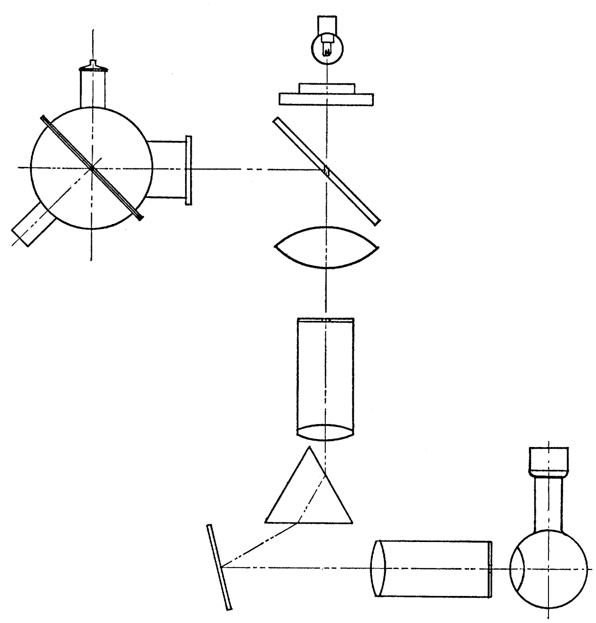

Fig. 3. Diagram of optical arrangement for determining intensities of spectrum lines by means of a photoelectric cell and standard lamp.

made to degas the metal sphere. Since the actual runs were only of a few hours duration at the most, the amount of impurities was very slight. The majority of the data for the curves shown was obtained with no trace of mercury or hydrogen observable in a direct vision spectroscope.

The spectroscope, photoelectric cell and amplifier were those of the Razek-Mulder color analyzer described elsewhere.[9] A diagrammatic sketch of the optical arrangement is shown in Fig. 3. Light from the arc is reflected and brought to a focus on the slit of the spectroscope by means of a mirror and cylindrical lens. After dispersion by means of a prism, the spectrum is reflected by a mirror through the lens of the exit tube on to the slit at the end

[9] Mulder and Razek, J.O.S.A. and R.S.I. **20**, 155 (1930).

of the tube. A slight tilting motion of the mirror moves the spectrum across this slit, admitting the selected line to the photoelectric cell. The current resulting in the photoelectric cell is amplified in a bridge grid resistor amplifier, and the amplified current noted on a galvanometer.[7,8]

To provide a standard of intensity, and to correct the readings for the slowly changing sensitivity of the amplifier, a calibrating lamp was employed. A 6–8 volt automobile headlight bulb was mounted over the 45° mirror. A small scratch through the silvered back of the mirror admitted light from this bulb into the spectrometer. The light from this bulb could be cut off from the spectrometer by means of a bulb-operated camera shutter. In this way it was possible to calibrate the sensitivity of the system at a given wave-length against the standard lamp. In order to keep the current through the lamp constant to a high degree of precision, an arrangement due to Richardson was used. This is shown in Fig. 4. The lamp is made one arm of a Wheatstone

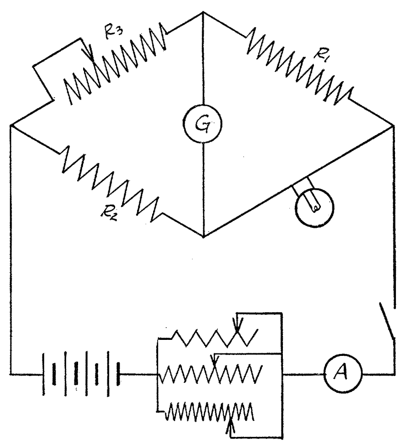

Fig. 4. Wiring diagram for Richardson bridge for holding standard lamp at constant operating resistance.

bridge, while the arm R_2 consists of a standard ohm, of a capacity sufficient to carry the lamp current without overheating. The arm R_1 was fixed at 1000 ohms, and the arm R_3 was variable. The current through the lamp, and hence the resistance at which it was operating was regulated by a bank of rheostats. When set up in this manner, the lamp was actually operated at constant resistance. During the short runs which were necessary to get data on a given line, it is safe to assume that the deterioration of the lamp was negligible, especially since the lamp currents which gave light intensities of the same order of magnitude as the arc, were well below the rated current values. The temperature at which the lamp was operated in a given set of readings was determined so that the deflection for the standard lamp was approximately equal to the maximum deflection due to the line under study. The value of R_3 was then set so that the bridge was balanced when the lamp operated at the selected temperature. After this setting was made, the bridge was kept balanced by adjusting the rheostats controlling the current through the lamp.

The procedure in actual operation was as follows: The tilting mirror in the spectrometer is set so that the desired line is admitted to the photoelectric cell. The light from the arc is cut off from the spectrometer by interposing a shutter in front of the window in the sphere, and the vacuum tube bridge balanced to give a zero galvanometer deflection. On opening a shutter in front of the sphere, a galvanometer deflection is obtained, which is proportional to the light intensity of the line admitted to the cell. The light of the arc is then cut off and the shutter in front of the adjusted calibrating lamp opened, giving a galvanometer deflection proportional to the light of the standard lamp. In this way, every reading for the arc intensity can be referred to the

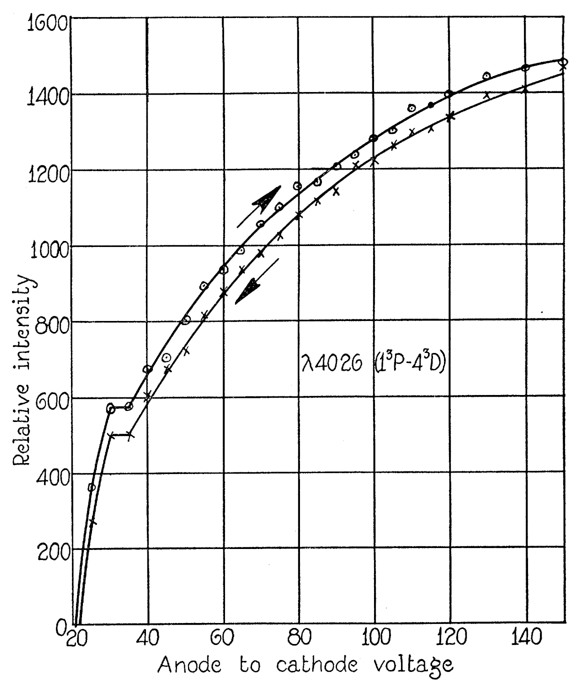

Fig. 5. Intensity variation with arc voltage, helium line 4026 (1^3P-4^3D).

standard with a minimum of delay. This procedure was repeated for various arc voltages.

In this work, the arc current was kept constant by adjusting the temperature of the filament as the anode to cathode voltage was raised. Arc currents of 30 and 50 milliamperes were used. Currents as high as 300 milliamperes could be passed through the arc, with only 25 volts across the anode to cathode. The pressure of the helium was about 0.25 mm of mercury.

Direct light from the filament and cathode was eliminated entirely by blanking out the central portion of the glass observation window with a diaphragm, and viewing the arc from a slight angle. The effectiveness of this procedure was shown by the fact that when the filament was operated at a temperature considerably above that used during a run, no deflection of the galvanometer could be observed, even in the red end of the spectrum, with no anode voltage on the hemisphere.

The dispersion of the prism used was small, but since the lines of the helium spectrum are spaced rather far apart, no difficulty was experienced in making certain that only the desired line was admitted to the photoelectric cell. Previous to every group of tests, the wave-length scale was calibrated against a mercury arc, and the corrections which must be applied to the wave-length scale on the color analyzer were determined. In cases where a bright line has a companion, this companion line is so faint in comparison to the

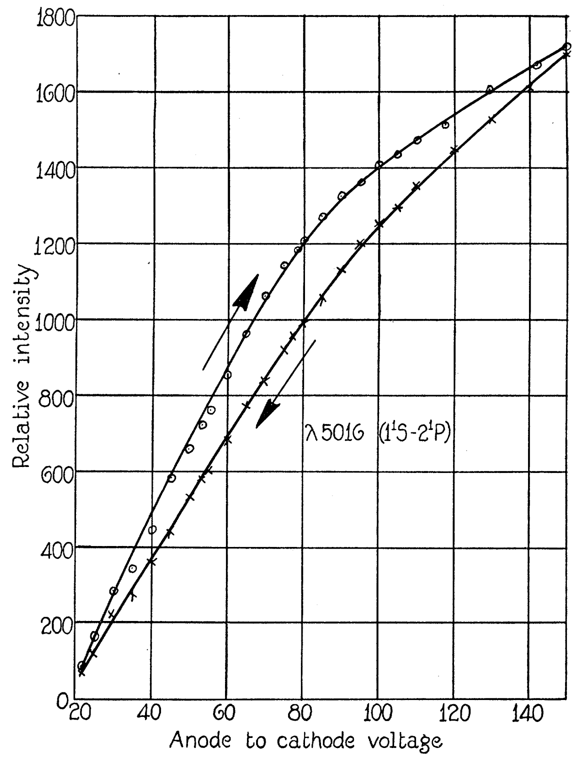

Fig. 6. Intensity variation with arc voltage, helium line 5016 (1^1S-2^1P).

brighter line that its influence on the photoelectric cell current is entirely negligible, or, in any case, the combined effect is obtained.

The question as to the propriety of taking the deflection of the galvanometer as proportional to the light intensity, is of fundamental importance in this work. The linear relationship between the intensity of the light and the galvanometer current was determined by using a point source at varying distances from a diffusing screen in front of the cell. The relative intensity was determined by employing the inverse square law. The galvanometer response was shown to be linear with the light falling on the photoelectric cell at least to one tenth of one percent—far above the precision of these tests.

Discussion of Results

In order to determine whether the direction of the changing arc voltage influenced the intensity of the line, the intensity was determined for both increasing and decreasing voltage. It was found that in every case, the intensity at a given voltage was somewhat higher for increasing voltage than for decreasing voltage. This is shown in Figs. 5 and 6, which are the intensity-voltage curves for the 4026 and 5016 lines. This effect is independent of the time in that the same effect is obtained even when a given operating point is approached as rapidly as possible, the intensity being determined by the direction of approach. No explanation is offered at this time, but the existence of this phenomenon indicates the necessity of controlling the experimental procedure so that the voltage always changes in the same direction.

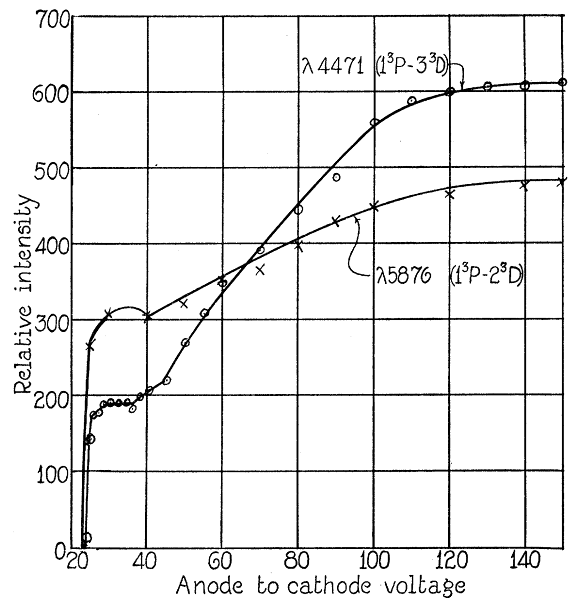

Fig. 7. Intensity variation with arc voltage, helium lines 4471 (1^3P-3^3D), 5876 (1^3P-2^3D).

The remaining curves were all made with the voltage increasing. Since it is at times difficult to approach a given operating point without overshooting, especially at the higher voltages, the accidental variations in the curves at these points may be due to this cause.

Lines 5026, 4471 and 5876 show a region of nearly constant intensity in the region from 27 to 35 volts. This is probably related to the fact that the lines have a series relationship, line 4471 being (1^3P-3^3D) and 5876, (1^3P-2^3D) and line 4026 (1^3P-4^3D). These are shown plotted in Figs. 5 and 7.

Line 4713 shown in Fig. 8, shows a most unusual behavior. The intensity of the line is a maximum, very near to the striking voltage, around 25 volts, dropping to almost half value at about 40 volts. From this point the intensity rapidly increases to about 53 volts, in the vicinity of the second ionization potential, and thereafter remaining nearly constant. This is consistent with the observations of Bazzoni and Lay[2] and with those of Cornog.[3] All observations made on this line were generally consistent with these results.

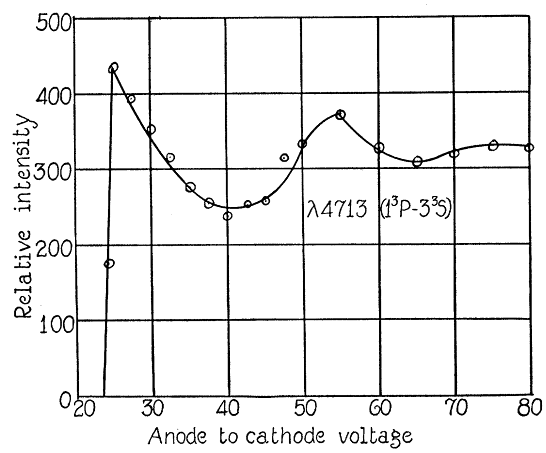

Fig. 8. Intensity variation with arc voltage, helium line 4713 (1^3P 3^3S).

Line 6678, shown in Fig. 9, increases regularly with increasing voltage, generally similar to line 5016.

The results obtained on all these lines were in general agreement with those of Bazzoni and Lay,[2] but inconsistent with those of Hughes and Lowe.[1] The latter used a non-equipotential cathode and a rather long tube of gas. The falling off in intensity which they show may be caused by the absorption of the radiation by the gas itself.

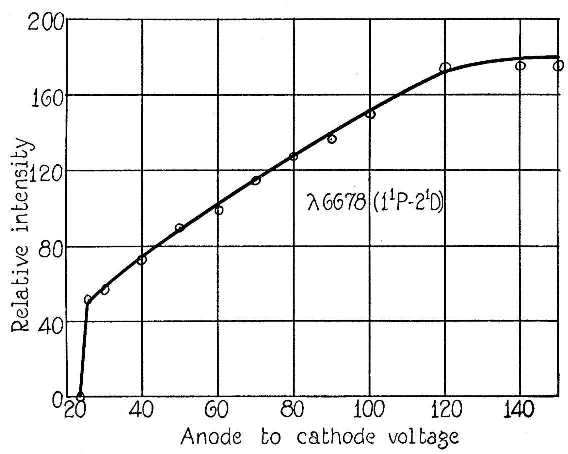

Fig. 9. Intensity variation with arc voltage, helium line 6678 (1^1P-2^1D).

The arc currents used in this work were quite low. On account of the unusually large volume of the discharge tube, these low currents resulted in extremely low values of current per unit volume. However, since the cathode and grid structures were approximately of the same dimensions as those used by Bazzoni and Lay[2] and Cornog,[3] the current densities in the vicinity of the cathode were comparable. It is desirable that the current densities be kept as low as possible to minimize space charge effects, which might have an important influence on the effective potential of the arc.[10]

The voltage exciting the arc can differ from that indicated by the voltmeter due to several causes. Since the voltage could not be read any closer that 0.2 volt, the various differences were negligible if they did not amount to that quantity. The voltage drop across the plate milliammeter was only about 0.05 volts and hence could be neglected. The first ionizing potential for helium is 24.48 volts, and since the arc struck at 24.5 volts, the contact difference of potential at the cathode was negligible. No error was introduced by the voltage equivalent to the initial velocity of the electrons leaving the cathode since this was operated at a relatively low temperature. Furthermore, an equipotential cathode was used, and hence there was no voltage drop for this element.

The absence of peak voltages in the arc, due to oscillations was verified by an appropriately connected vacuum tube voltmeter. No oscillatory voltages as great as 0.2 volt were detected, although the vacuum tube voltmeter could readily show these.

By changing the potential of the center tapped filament return, it was possible to change the distribution of the current between the grid plate structure and the filament. Under ordinary conditions, about ten percent of the current returned through the filament structure. No change in the intensity of the lines could be observed, even if half of the current returned through the filament structure. This probably showed that the internally silvered sphere was quite effective in integrating the light output, and completely avoided the difficulties caused by "wandering" of the discharge.

Conclusion

These results show that the photoelectric spectrophotometer can be used to study intensity variations in spectra with a speed and ease of operation which tends to minimize many of the difficulties inherent in work of this kind. This is especially apparent when it is noted that all the data for a given curve can be obtained in about fifteen minutes. The greater light intensity possible with the use of a large spherical radiation space overcomes the difficulties caused by the feeble light output of the conventional designs of low voltage arcs.[11]

In conclusion, the writer desires to express his appreciation to Dr. C. B. Bazzoni, who suggested this problem, and under whose direction and supervision this work was done. The writer is further indebted to his collegue, Mr.

[10] Mott-Smith and Langmuir, Phys. Rev. **28**, 727 (1926).

[11] Eckart and Compton, Phys. Rev. **24**, 97 (1924).

Peter J. Mulder, for his collaboration in developing the automatic spectrophotometer, and in taking the data here presented.[12]

Note added in proof:

Obviously, the intensity relationships existing between the lines relative to one another cannot be deduced from the curves shown. The absolute value of the intensity scale unit is different for every line and is determined by the wave-length energy curve of the standard lamp, the color response curve of the photoelectric cell, and other factors.

[12] Razek and Mulder, Phys. Rev. **35**, 1423 (1930).