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ABSOLUTE ENERGY MEASUREMENTS ON ULTRAVIOLET RADIATION

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ABSOLUTE ENERGY MEASUREMENTS
ON ULTRAVIOLET RADIATION

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When absolute measurements of radiant energy are made it is necessary to have a detecting device whose response is independent of wavelength or one whose response is known over the range of wavelengths to be investigated. The former method is the one usually employed. If the latter method is used, the device must be calibrated, and this by comparison with a standard having a response independent of wavelength. It happens that with this latter method the equipment is generally of greater practical usefulness. Discussions of both methods will be found in the references listed at the end of this article.

This paper is concerned with the absolute measurement of ultraviolet radiation by means of a calibrated photocell. Monochromatic radiation, obtained using a grating spectrograph, when incident upon the photocell caused an emission which was measured by a thermionic amplifier. This current could then be interpreted in terms of energy by referring to the calibration curve of the photocell.

1. Source of Radiation

The source whose output was examined was the Hanovia Sc 2537, a low pressure mercury arc in a quartz tube approximately 10 mm in diameter and with a 1 mm wall thickness. This tube was operated by a 110 volt transformer supplying 120 milliamperes at 7500 volts. The ultraviolet source was placed at several different distances from the slit of the spectrograph and the response noted at each position. Maximum light on the photocell, as indicated by its response, was obtained when a 7.5 cm diameter quartz lens was used to focus the radiation from a 10 cm portion of the tube on the 0.27 mm wide slit of the spectrograph. This occurred in spite of the absorption in the lens and the necessarily greater distance of the source from the slit. Best results were obtained with the lens 27.5 cm from the slit and the tube 58.0 cm from the slit.

2. Segregation of Wavelengths

The spectrograph was an Eagle mounting of a concave reflection grating. The grating, an original speculum of 100 cm radius, was ruled with 30,000 lines per inch over a four inch surface. The slit width was adjusted to find the optimum separation of the jaws. When opened the maximum amount a greater quantity of light than necessary to fill the aperture of the frating was admitted. This was decreased by closing the slit until the response of the photocell showed a decrease. At this position the maximum usable amount of light was assumed to be incident upon the grating. The full length of the grating was used. This spectrograph was used as a monochromator by placing a sheet of fiberboard in the position of the plateholder. A one inch diameter hole in this sheet admitted radiation to the photocell which was placed with its window in alignment with and close to the hole. Successive portions of the spectrum were directed upon the cell window by turning the grating to change the angle it made with the cell.

3. Detection Photoelectrically

The window of the photocell was masked with black paper to an area 13 mm by 17 mm. This area at the central portion of the window was used when one of the calibrations of the cell was performed by its manufacturers. The sensitive surface is metallic sodium. This high vacuum cell, the General Electric PJ-405, has a re-entrant window whose thickness is so small that ultraviolet radiation may readily pass.

It was found necessary to shield the photocell electrostatically with an ordinary tube shield. This shield was covered with black paper to cut out stray light; only the rectangular aperture in front of the cell window remained uncovered. Grounding the tube shield kept that enclosure at the same potential as the case of the amplifier.

Leads to the photocell were tried in various types. The final arrangement used lacquer covered conductors which were supported by the binding posts to which their ends were attached. All other points were in the open air, which minimised leakage currents. This arrangement allowed electrostatic disturbances to come into full play, but with careful manipulation these were not troublesome.

The photocell was designed by its manufacturers to be operated at inter-electrode potentials up to 200 volts, one-third of that being an ordinary working voltage. It was found that for the small currents being measured a potential of 67 volts caused inconveniently large leakage currents to flow when the cell was not illuminated. Using only 22½ volts caused these currents to be reduced to one-third of their former value. Voltages below 22½ volts caused instability.

4. Thermionic Amplifier

With radiation incident upon the cell and a potential applied to make the central collector ring positive with respect to the sensitive surface a small current will flow. This current flowing through a high resistance will create between the ends of the resistor a potential difference of such a magnitude as to be readily measurable. However, the measurement of electromotive forces in high resistance circuits cannot be done by ordinary methods. A thermionic amplifier, Leeds & Northrup model 7673, has been developed for such measurements. It uses the Westinghouse RH-507 electrometer tube.

The electrometer tube was enclosed in a separate compartment in the case housing the amplifier. This compartment was kept dry with anhydrous calcium sulfate. The tube was cleaned with absolute alcohol before being placed in the compartment in order to remove from its surface any material which might cause current leakage.

The thermionic amplifier needs a high quality resistor for calibration puppposes. The manufacturer of the amplifier has designed a shielded resistor with special adapters. Since one of these was not available and even if available would have had to be modified, a high quality molded resistor made by the S. S. White company was used. When this resistance in the phptocell circuit is connected to the emf terminals of the amplifier it completes the plate circuit of the electrometer tube.

Leakage currents across the resistor were minimised by cleaning the resistor with absolute alcohol just before data were taken. Foreign matter, water vapot or dust particles, would affect the value of the resistance and give erratic results. Connections to the resistor were soldered in order to insure good contact. A ferrule was made to fit on the negative emf terminal of the amplifier; this fitted snugly and caused no contact trouble. The other connections in the photocell circuit were made with knurled thumbscrews on binding posts.

The potential difference between the ends of the resistor is balanced by one supplied from a potentiometer. The condition of balance is indicated by zero deflection of a galvanometer. This galvanometer is connected in the grid circuit of the electrometer tube so that it may be adjusted for zero deflection at the grid potential existing when the plate is grounded. When the potential of the grid differs from this value, due to the plate being at other than ground potential, the galvanometer shows a deflection. When the potentiometer exactly balances the potential difference between the ends of the resistor, the plate is at ground potential and the galvanometer shows no deflection. The potentiometer used was a Leeds & Northrup model 7655-S, a self-contained unit including standard cell and work battery. Potentials supplied by it of the order of 0.5 volt could be read to four significant figures.

The amplifier is ordinarily used with a grid potential of 4$\frac{1}{2}$ volts. Twice this value may be used when maximum sensitivity is desired. Since all obtainable sensitivity was needed for these measurements the full 9 volts was used for the grid.

A bias adjustment on the amplifier makes it possible to adjust the circuit so that no current will flow between filament and plate when the emf and potentiometer terminals are short circuited. This bias adjustment is in the plate circuit, and when the plate current is adjusted to zero under the conditions stated, any measurements of potential across the resistor are not affected by currents flowing in the amplifier circuit. A constant error in determinations is introduced otherwise.

The filament current of the electrometer tube is controlled by two resistors. One is a fixed resistor which can be switched in or out of the circuit. The other is a variable resistor of the dial type which incorporates an on-off switch. When first using the tube it was possible to get the rated filament current of 60 milliamperes when a 6 volt source was used. Later it was necessary to increase the voltage to about 8 volts to obtain the rated current. With 6 volts it was impossible to increase the current to its rated value even when both resistors were out of the circuit.

Since the potentiometer adjustment was checked against its standard cell between each set of data and found to remain nearly constant, it is assumed wo be without error.

In obtaining measurements of radiation intensity it was necessary to have conditions most opportune. The model of galvanometer used, a Leeds & Northrup 2420-C, was that for which the amplifier was designed and better performance was obtained with it than with others. The type of potentiometer used greatly affected the ease of handling of the amplifier. All models tried were manufactured by the maker of the amplifier. The enclosed type previously mentioned was used finally. This particular kind apparently was the one best suited to the amplifier. The galvanometer did not show fluctuations as it did with the other types, and the apparatus was much more manageable. Weather conditions influenced the ability of the apparatus to give results. On days of heavy rain and high humidity the water vapor on exposed parts caused variations which prohibited the taking of data. The manufacturers of the photocell state that on mid-summer days when the humidity is high they are unable to make a calibration.

5. Curves Obtained

In the data shown in Tables 1, 2, and 3 a favorable day allowed measurements to be taken, but the apparatus had not been running so had not reached a steady state. The

TABLE 1

Listing resistor voltage caused by photocell current and power supplied to ultraviolet source. Cold start.

Grating Units (arbitrary)	Resistor Volts	Source Volts Primary	Source Amps Primary
Slit Covered	.3355		
4.5	.3461	115.6	9.8
4.6	.3499	115.5	9.9
4.7	.3559	116.5	10.0
4.8	.3625	116.6	10.0
4.9	.3650	116.8	10.0
5.0	.3650	116.7	10.0
5.1	.5842	116.7	10.0
5.2	.6275	116.8	10.0
5.3	.3700	116.5	10.0
5.4	.3645	116.3	10.0
5.5	.3594	116.3	10.0
5.6	.3631	116.8	10.0
5.77	.3623	116.5	10.0
5.8	.3679	116.0	9.9
5.9	.3701	115.8	9.8
6.0	.3738	115.8	9.9
6.1	.3722	115.3	9.8
6.2	.3880	117.0	10.0
6.3	.3937	116.2	10.0
6.4	.3742	115.7	9.9
6.5	.3740	115.7	9.8
Slit Covered	.3710		

TABLE 2

Listing resistor voltage caused by photocell current and power supplied to ultraviolet source. Warming up.

Grating Units (arbitrary)	Resistor Volts	Source Volts Primary	Source Amps Primary
Slit Covered	.3730		
4.5	.3834	115.6	9.9
4.6	.3868	115.5	9.8
4.7	.3927	115.8	9.9
4.8	.3975	116.2	10.0
4.9	.3933	116.0	9.9
5.0	.5927	116.0	9.9
5.1	.6220	115.9	9.9
5.2	.5134	115.9	9.9
5.3	.4087	116.0	9.9
5.4	.4040	115.5	9.8
5.5	.3967	115.3	9.8
5.6	.3967	115.9	9.9
5.7	.3967	116.1	9.9
5.8	.3988	116.1	9.9
5.9	.3988	115.8	9.9
6.0	.3958	115.8	9.9
6.1	.3940	115.5	9.8
6.2	.4122	116.1	9.9
6.3	.4160	116.9	10.0
6.4	.3948	116.8	10.0
6.5	.3953	116.6	10.0
Slit Covered	.3894		

TABLE 3

Listing resistor voltage caused by photocell current and power supplied to ultraviolet source. Near equilibrium.

Grating Units (arbitrary)	Resistor Volts	Source Volts Primary	Source Amps Primary
Slit Covered	.3903		
4.5	.3992	116.2	10.0
4.6	.4040	116.8	10.0
4.7	.4091	116.5	10.0
4.8	.4148	116.7	10.0
4.9	.4153	116.5	10.0
5.0	.5754	116.4	10.0
5.1	.6317	116.8	10.0
5.2	.4200	116.7	10.0
5.3	.4174	116.8	10.0
5.4	.4114	116.8	10.0
5.5	.4059	116.8	10.0
5.6	.4039	117.1	10.0
5.7	.4020	117.0	10.0
5.8	.4043	116.5	10.0
5.9	.4050	116.8	10.0
6.0	.4020	116.8	10.0
6.1	.4012	117.0	10.0
6.2	.4162	116.8	10.0
6.3	.4185	116.5	10.0
6.4	.3990	116.4	10.0
6.5	.3982	115.8	9.9
Slit Covered	.3935		

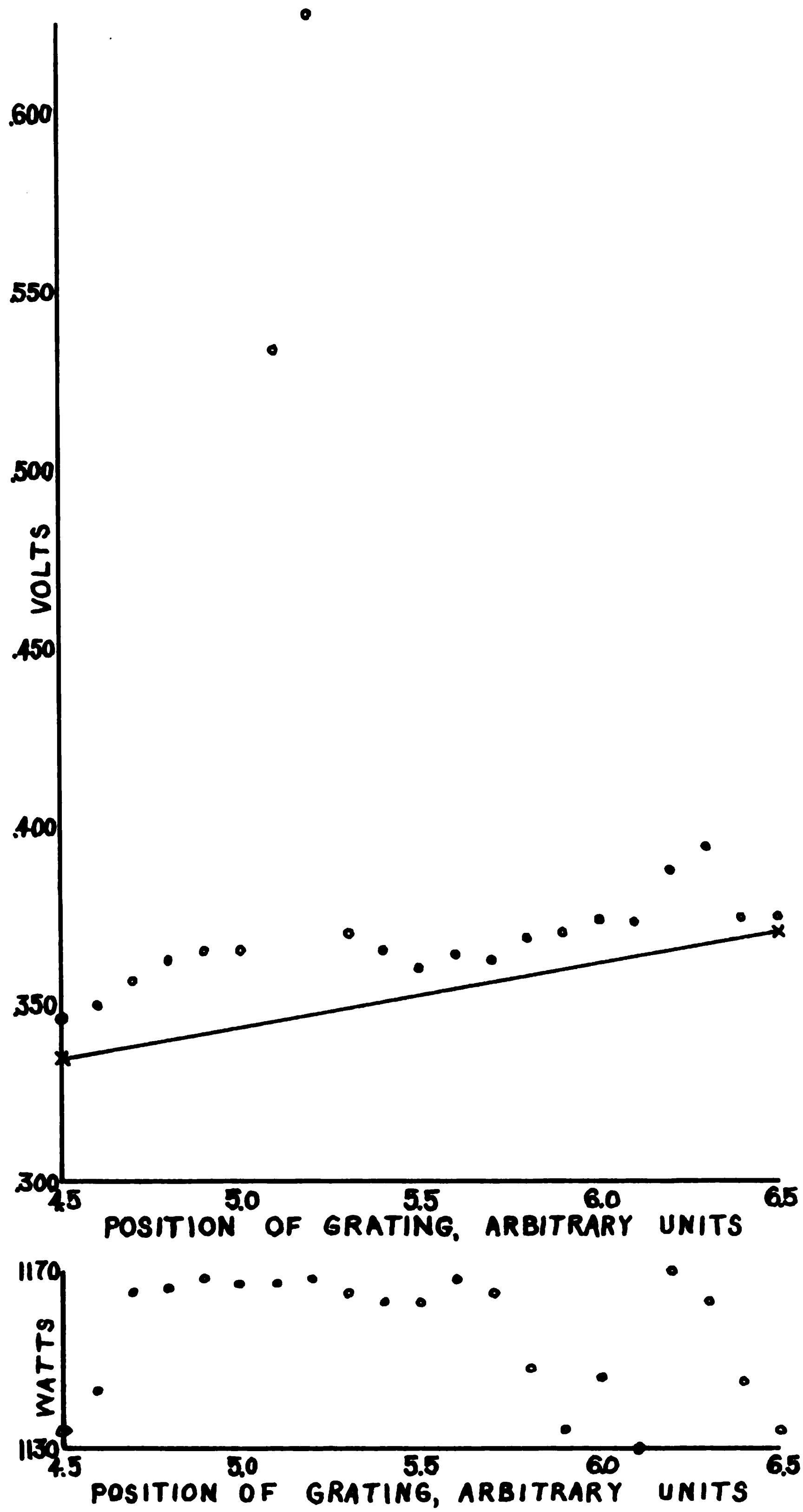

FIGURE 1

Upper plot is original data of Table 1 including dark current. Lower plot is power supplied to transformer for ultra-violet source. Cold start.

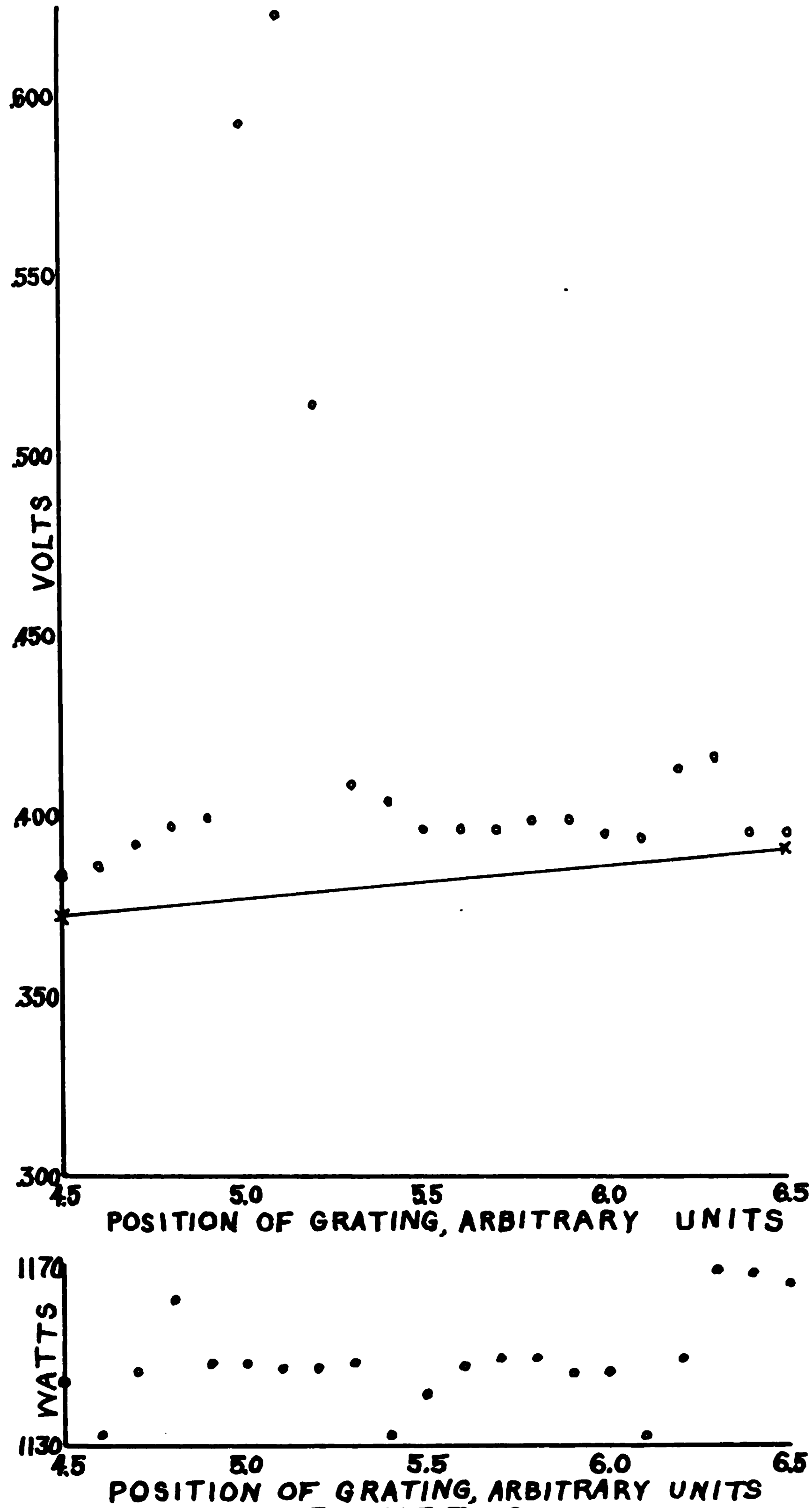

FIGURE 2

Upper plot is original data of Table 2 including dark current. Lower plot is power supplied to transformer for ultra-violet source. Warming up.

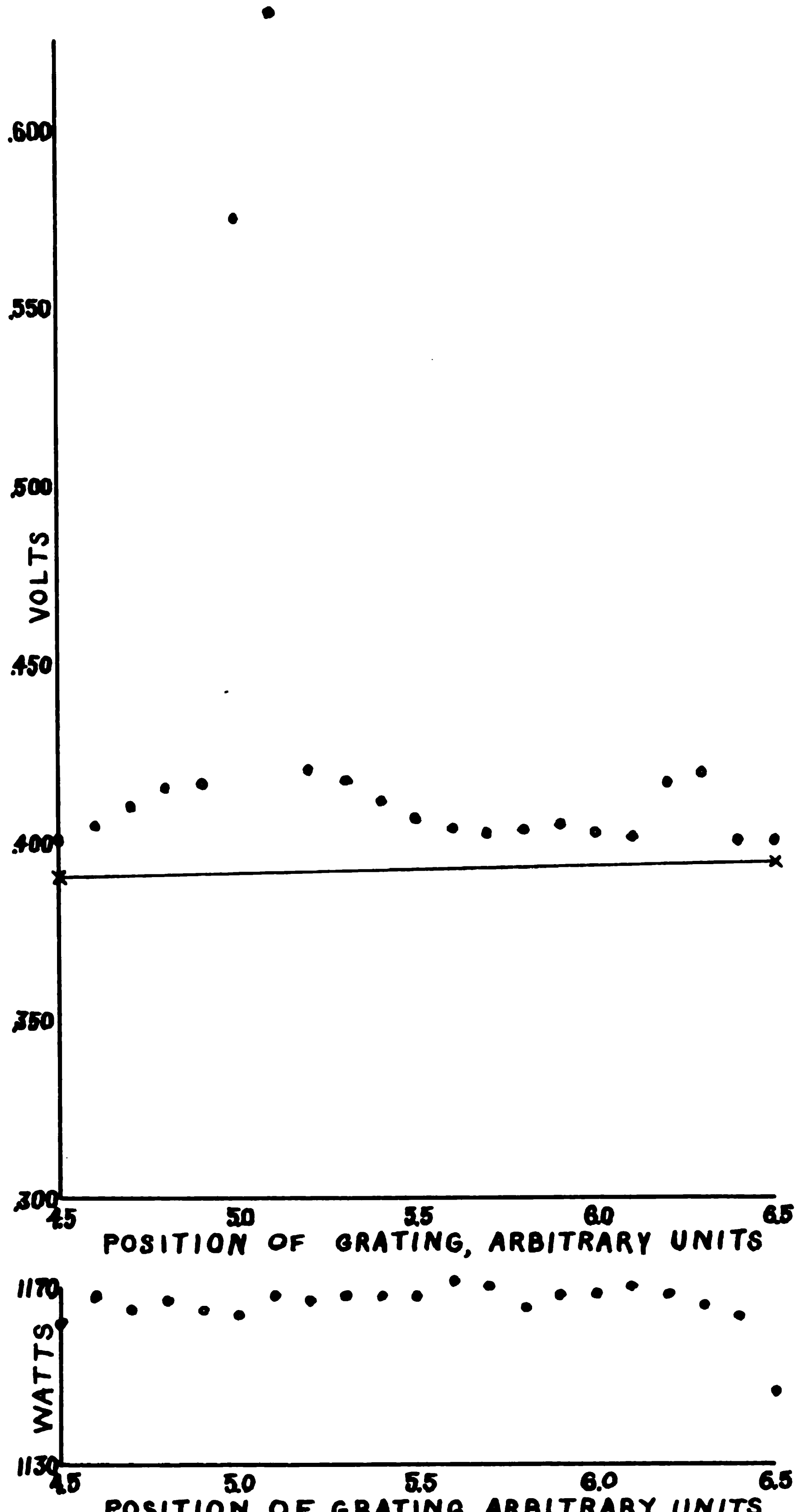

FIGURE 3

Upper plot is original data of Table 3 including dark current. Lower plot is power supplied to transformer for ultraviolet source. Near equilibrium.

three sets of data were taken in succession and in the order of the number of the tables. It will be noticed that the background or dark current when the slit of the spectrograph was covered increased in each table and from one table to the next. The dark measurements before and after each set show a trend toward constancy, the values obtained for the last set being nearly equal at the beginning and end of the run.

These data are plotted in Figures 1, 2, and 3. The lower part of each figure shows the power supplied to the transformer operating the light source, obtained by multiplying source volts by source amperes, plotted against grating position. The upper part shows the voltage across the resistor, as balanced by the potentiometer, plotted against grating position. The straight line beneath these points connects the two values obtained as dark current when the slit was covered at the beginning and end of the run. Since each of these sets of data was obtained under different background conditions, they cannot be compared in their original form.

Using the lines connecting the dark currents as new horizontal axes, these points were replotted to give Figures 4, 5, and 6. In these figures an abrupt rise and fall will be noticed in the left part of the curve with a smaller

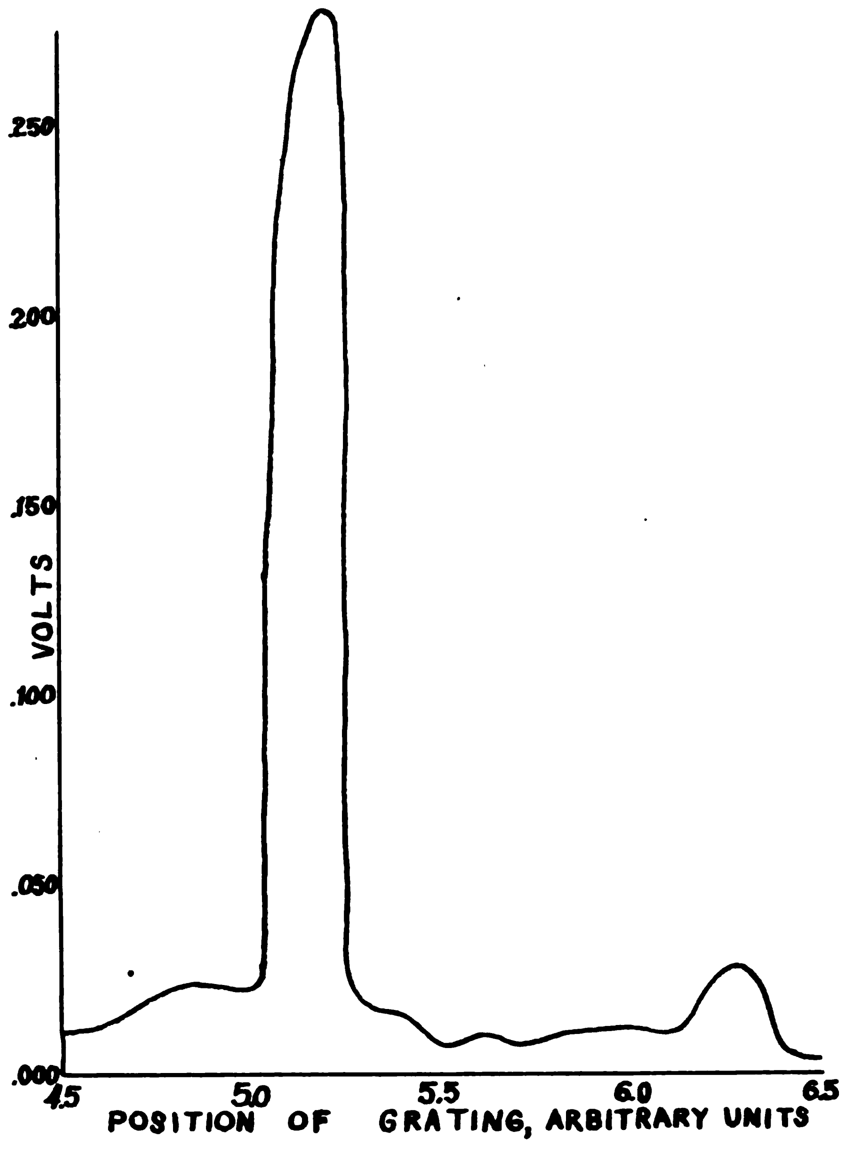

FIGURE 4

Curve obtained from Figure 1 when corrected for dark current.

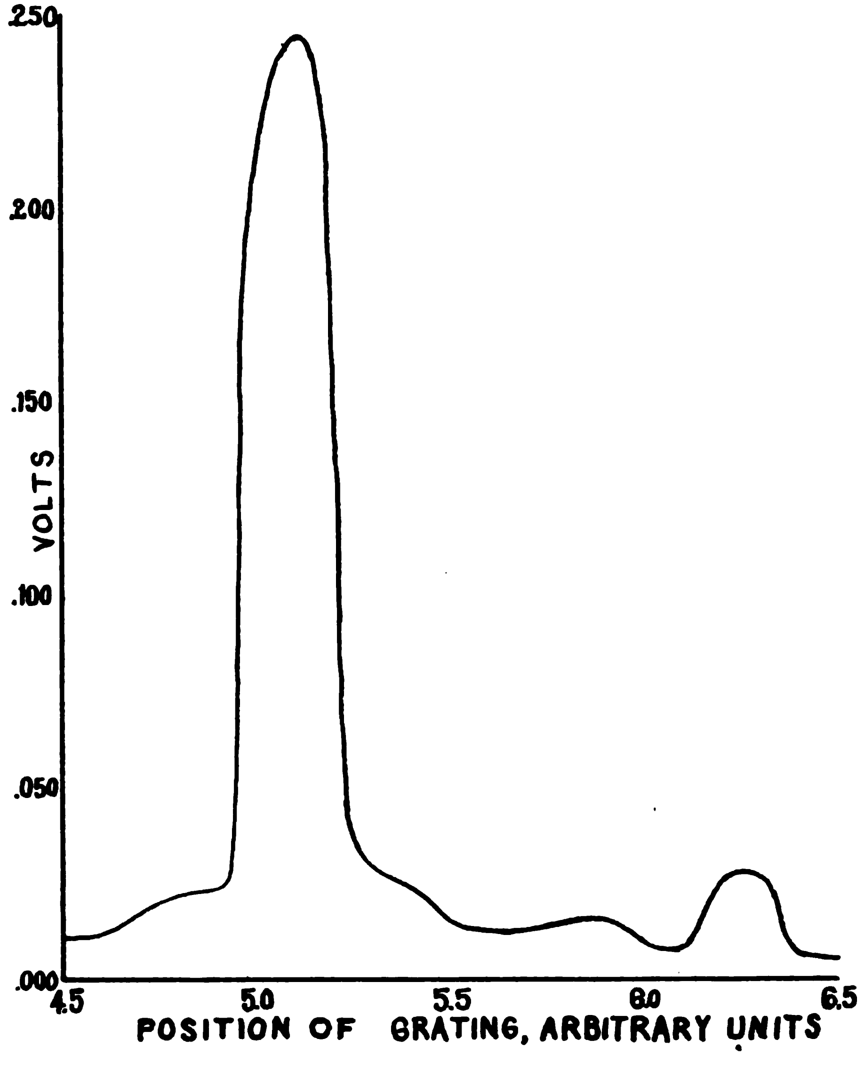

FIGURE 5

Curve obtained from Figure 2 when corrected for dark current.

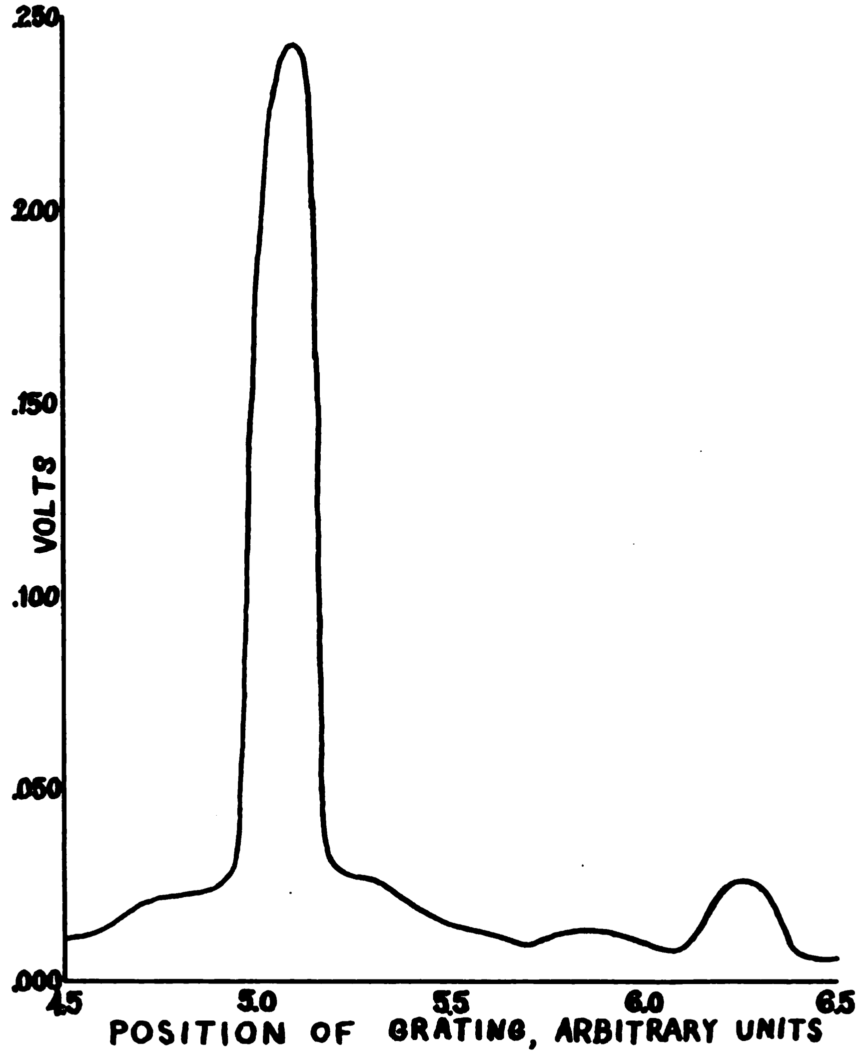

FIGURE 6

Curve obtained from Figure 3 when corrected for dark current.

but definite peak in the right part. However, these peaks do not occur at exactly the same grating settings nor do they rise to the same height on the ordinate in each of the figures. Since the voltage values could be read on the potentiometer more accurately than the curve can be read, and the setting on the spectrograph was accurate only to the nearest tenth of the unit used, both of these discrepancies may be attributed to the error in setting the spectrograph.

To minimise this error in setting, the three curves were superposed and a new curve drawn having as its ordinates the averages of the ordinates of the other curves. This averaged curve is given in Figure 7. It shows the same characteristics as the other curves, the only apparent difference being a more abrupt rise in the central portion of the left peak.

Photographs at intervals over the range investigated indicate that the high peak at the left is due to the intense 2537 A. line of the mercury spectrum, as was expected. The smaller peak on the right is due to the 3131 A. doublet and the 3126 A. line. The intervening ripples are possibly due to weaker lines which showed in the photograph.

The ordinate at any point on the curve in Figure 7 may

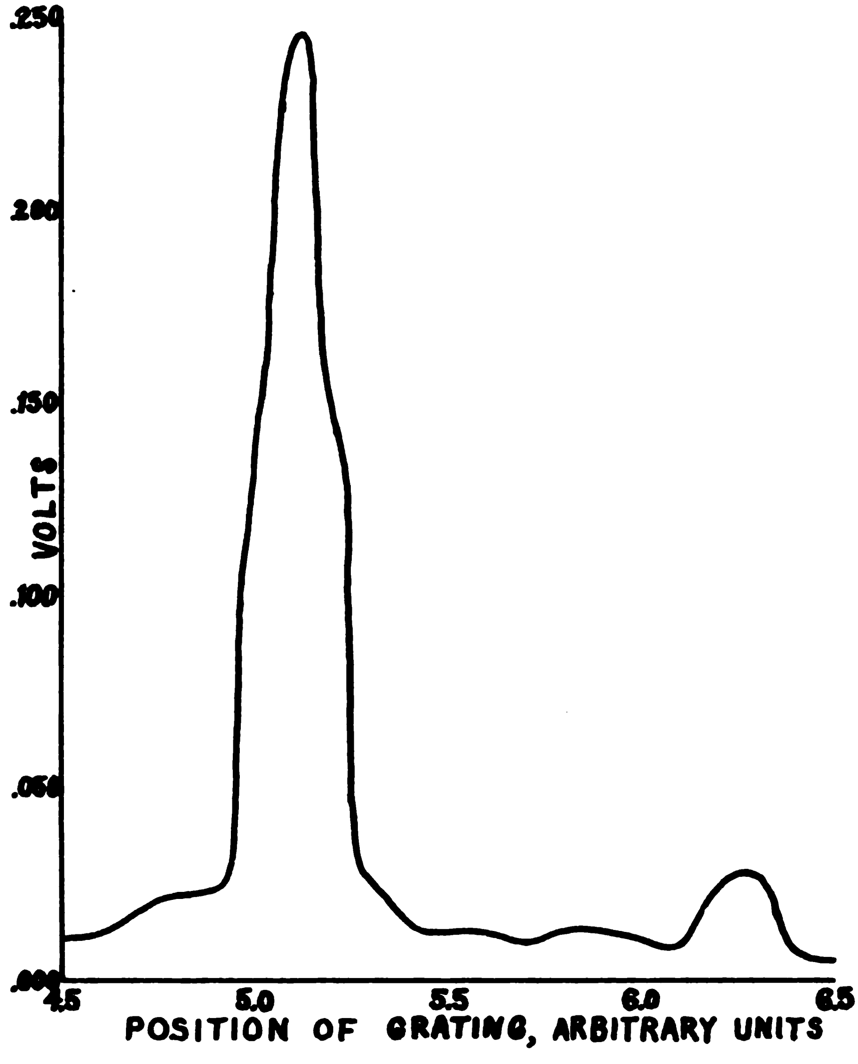

FIGURE 7

Error in grating setting minimized by the superposition of Figures 4, 5, and 6.

be taken as an indication of the energy incident upon the photocell for the grating setting given by the corresponding abscissa when the cell is illuminated under the specified conditions. The curve is not an energy contour of a portion of the spectrum because the aperture of the photocell was very wide in comparison with the width of the spectrum lines. Thus it is not the area of the region under a peak which is indicative of the intensity of a line, but the maximum height of the peak, since at the abscissa corresponding to the maximum point the greatest energy was incident. At any point ot either side of the maximum the response may be less because the most intense part of the line may be falling on a thicker portion of the cell window or be partially obstructed by the mask or internal elements of the cell.

6. Results

The maximum for the 2537 A. line rises to a value of 0.245 volts, which was effective over a resistance of 9820 megohms. The sensitivity of the photocell at that wavelength is 2.75 microamperes per milliwatt according to the calibration curve obtained from the manufacturer. This gives an intensity of 9.07×10^{-9} watts incident upon the photocell.

A maximum of 0.0275 volts across the 9820 megohm resistor with a cell sensitivity of 1.825 microamperes per milliwatt for the 3131 A. line gives an intensity of 1.537×10^{-9} watts.

In both of these cases nearly all of the energy was confined to an area of only a few square millimeters as confirmed photographically, but the area of the cell window exposed was greater than two hundred square millimeters. Thus any determination of the energy incident per unit area is likely to be quite misleading. However, the results obtained give the energy under the conditions of operation.

The experiment which has been described gives numerical answers, correct to about 5 percent, to the question, "How many watts of monochromatic radiation in the region 2300 A. to 3200 A. are falling in bands about 100 A. wide on the central rectangular area, 13 mm by 17 mm, of the FJ-405 photocell?"

The writer wishes to express his appreciation of the interest shown in this work and of the loan of equipment by many members of the Physics Department and by Professor Carl P. Swanson of the Botany Department of Michigan State College. Professor Thomas H. Osgood and Professor C. D. Hause of the Physics Department contributed many ideas and suggestions. Their guidance and inspiration throughout the course of this work is gratefully acknowledged.

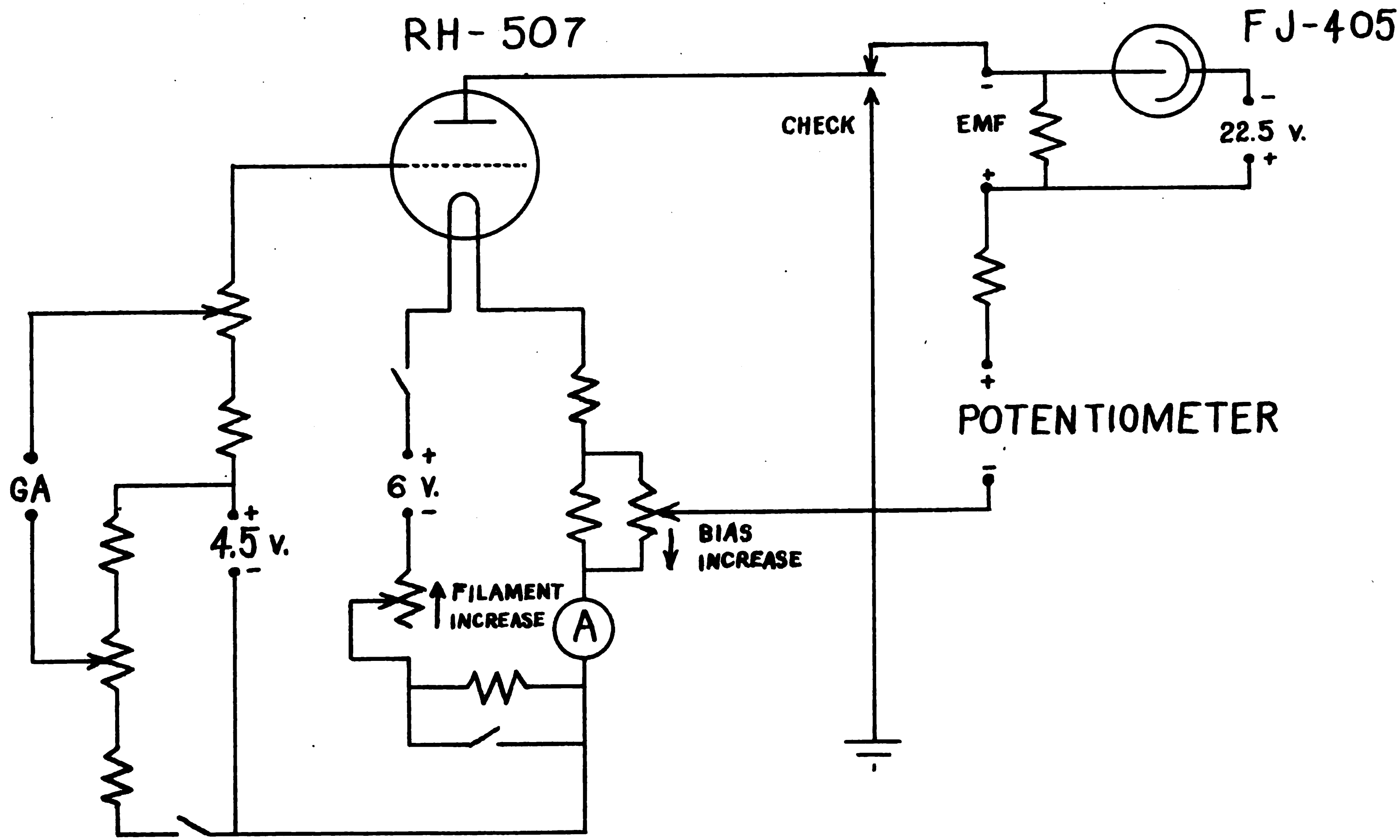

FIGURE 8
THERMIONIC AMPLIFIER

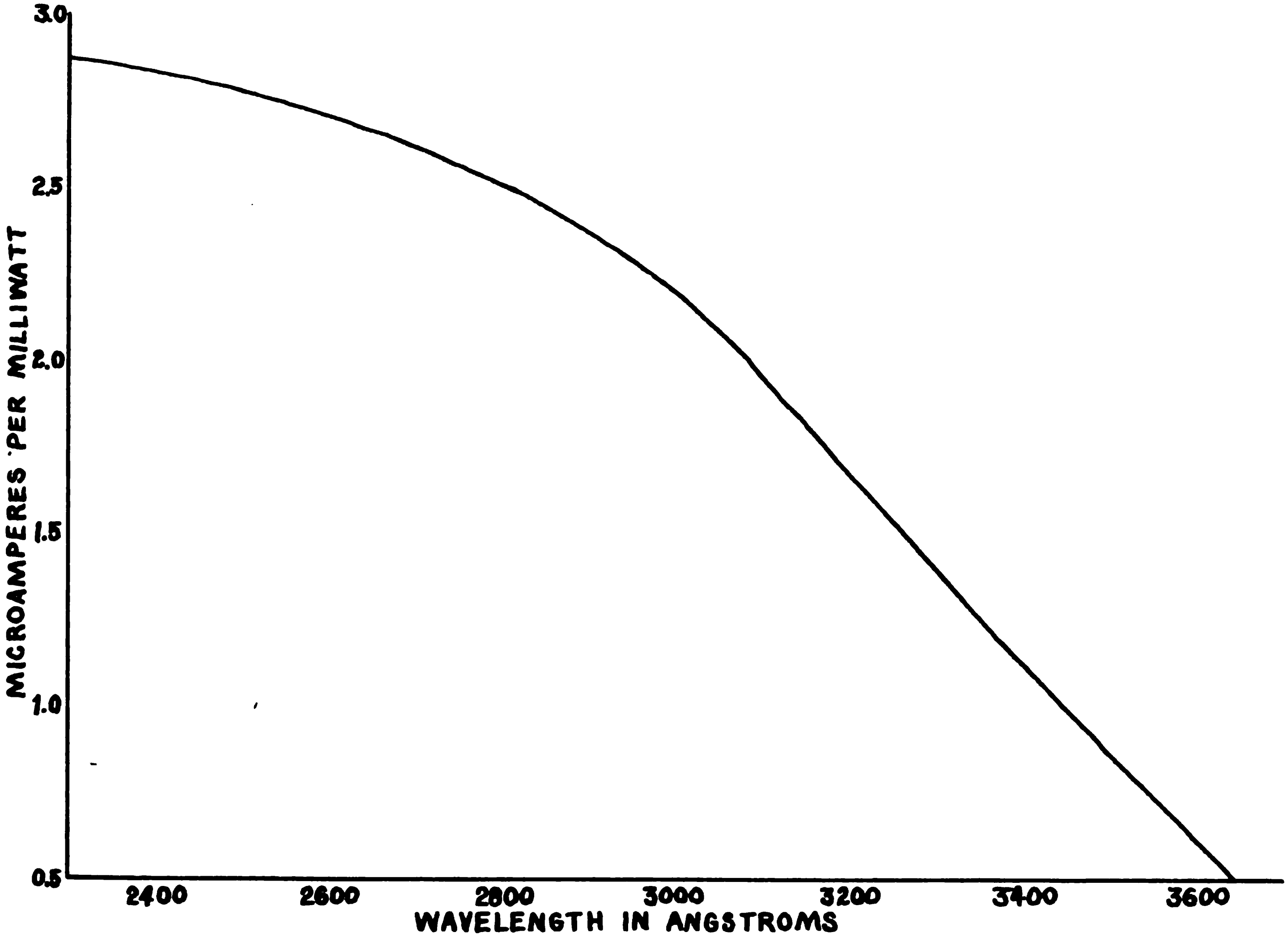

FIGURE 9
PHOTOCELL SENSITIVITY

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