

**WORK-FUNCTION STUDIES ON NICKEL**

**by**

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of Agriculture and Applied Science, 1944**

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**A THESIS**

**submitted in partial fulfillment of the**

**requirements for the degree of**

**MASTER OF SCIENCE**

**Department of Physics**

**KANSAS STATE COLLEGE  
OF AGRICULTURE AND APPLIED SCIENCE**

**1947**

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## INTRODUCTION

The classical theory of metals assumed that in a conductor there is a great number of "free" electrons capable of moving with little interference in the space between the atoms, the interior of the metal being at a constant potential. On the basis of the equipartition theory these electrons were assumed to have the same mean kinetic energy as the atoms, namely  $3/2 kT$ , and the energy of the individual electrons was distributed about the mean energy according to the Maxwell distribution function. This was called the classical electron-gas theory, and was formulated by Drude, Lorentz, and others.

This theory had distinct success in explaining many physical phenomena, but in the field of photoelectricity it offered no straightforward explanation of the energy distribution of photoelectrons and the variation of photocurrent with frequency which were the two fundamental problems in the field. In fact, since the mean kinetic energy was equal only to about 0.04 electronvolts at  $300^{\circ}$  K, the classical theory offered no reasonable conclusions concerning these problems. This mean energy was so small compared with the average energy of the impinging quantum of light that it could be neglected.

Einstein, in 1905 (21) and 1906 (22), applied the quantum theory to the photoelectric effect, which was first discovered by Hertz (31), and arrived at the equation  $E = \frac{1}{2} mv^2 = h\nu - \phi$  where

$E$  = kinetic energy of the emitted electron

$m$  = mass of emitted electron

$v$  = velocity of emitted electron in cm./sec.

$h$  = Planck's constant

$\nu$  = frequency of the incident light

$\phi$  = work-function in ergs (the energy necessary to remove the electron from the surface)

This equation was later verified by Hughes (33), Richardson and Compton (43), and Millikan (43).

Neglecting the small mean thermal energy postulated by the classical theory, the Einstein theory led to two important conclusions.

1. There was assumed to be a sharply defined maximum velocity,  $v_m$ , of emission related to the frequency by the equation

$$\frac{1}{2} m v_m^2 = h\nu - h\nu_0.$$

2.  $\nu_0$  in the above equation is the supposed sharply defined threshold frequency such that incident light of frequency less than  $\nu_0$  will produce no photoelectric emission, no matter how intense.

Sommerfeld (50), in 1928, laid the basis for the new electron theory of metals. The new theory discards the equipartition theorem and treats the "free" electrons as a degenerate gas obeying the Fermi-Dirac statistics. According to these statistics the energy of an electron at normal temperatures is so large that it can not be neglected when considering the photoelectric effect.

The new theory then emphasizes that the two conclusions drawn from the Einstein theory are accurately true only for a metal surface at a temperature of  $0^\circ$  K., while at higher temperature there will not be a sharply defined maximum velocity or threshold

frequency. The great achievement of the new theory is, however, that it predicts the form of the energy distribution and spectral distribution curves near the threshold frequency at any temperature. It also gives at the same time a method of determining the value of  $v_m$  and  $\nu_0$  which the surface would show at  $0^\circ$  K., provided the lowering of the temperature produced no other changes in the surface.

Fowler (26), in 1931, using the Sommerfeld theory as a basis, developed a theory of spectral distribution of photoelectrons which predicts the form of the distribution curve in the vicinity of the threshold frequency. By proper use of experimental data, the experimental curve may be fitted to the theoretical curve and the important characteristics of the metal determined. Fowler's theoretical curve is given in Fig. 1.

Up until a few years before Fowler developed his theory, photoelectric data were very difficult to obtain, because stable conditions were hard to reach with the degree of vacuum then available. High vacuum technique was greatly improved within a few years and it was possible to attain stable conditions on a metal surface from which reliable photoelectric data could be obtained. This improvement of photoelectric technique brought about investigations on a great number of metals. A list of the metals investigated and their investigators are given in Table 1.

In the great amount of work that has been done on photoelectric properties, it has been found that a change in crystal structure or lattice spacing as well as gases on the surface of the metal will produce a very marked effect on the photoelectric and

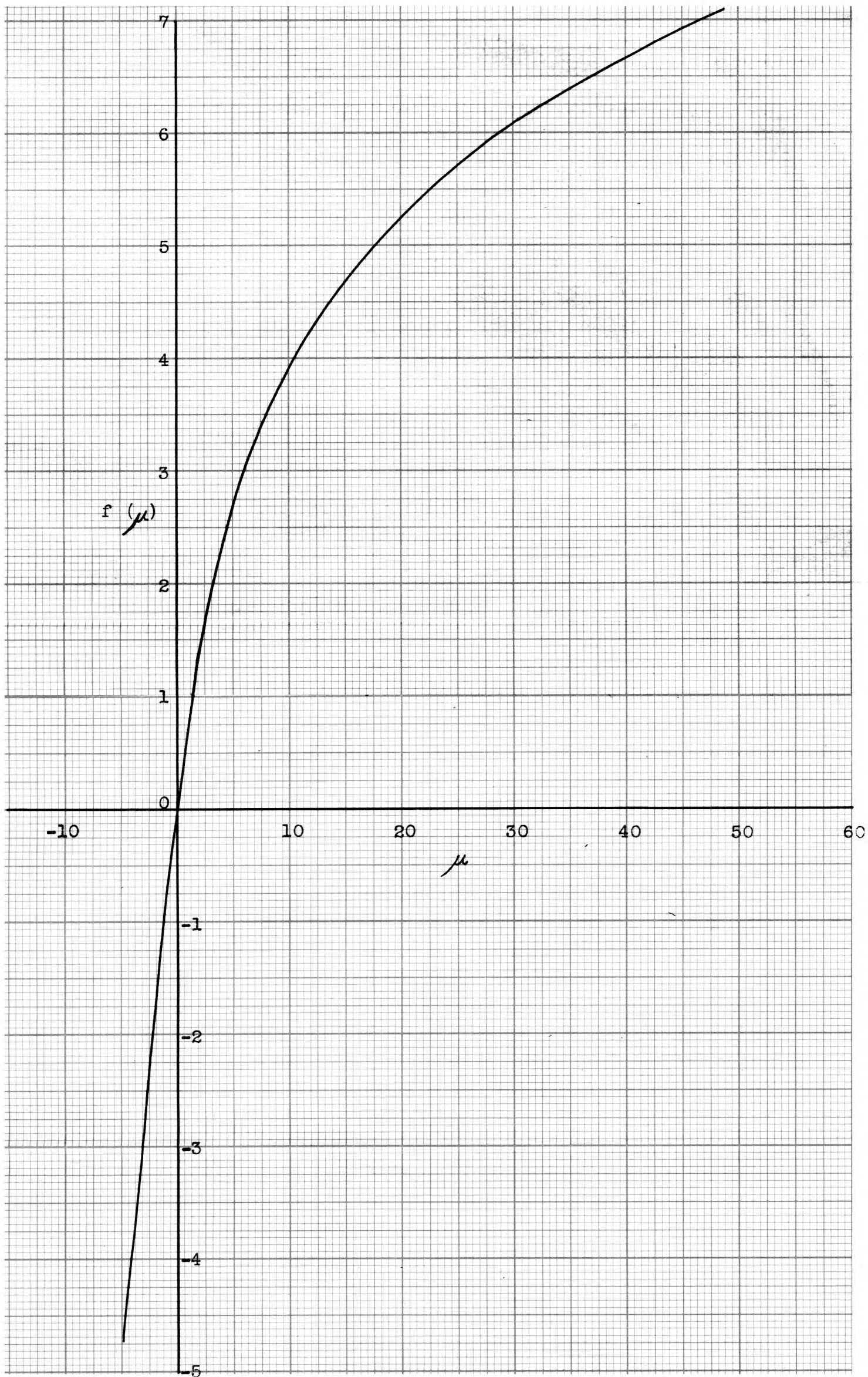


Fig. 1. Fowler's theoretical curve.

Table 1. Metals which have been investigated for their photoelectric properties.

Metal	Investigator
Barium	Cashman and Bassoe (9) Jamison and Cashman (34)*
Beryllium	Mann and DuBridge (38)*
Bismuth	Jupnik (36)*
Cadmium	Bonke (2)
Cobalt	Cardwell (6, 8)
Gold	Morris (44)
Iron	Cardwell (5) Glasoe (28)*
Magnesium	Cashman and Huxford (10, 11) Mann and DuBridge (38)*
Molybdenum	DuBridge and Roehr (19)* Martin (39)
Nickel	Glasoe (28)* Peterson (47)*
Palladium	DuBridge and Roehr (18)*
Platinum	DuBridge (16, 17)
Rhenium	Engelmann (23)*
Rhodium	Dixon (15)
Silver	Winch (59) Winch and Farnsworth (60)*
Sodium	Hill (32) Mann and DuBridge (38)*
Tantalum	Cardwell (7)*
Tin	Goetz (29)
Tungsten	Warner (54, 55, 56*)
Zinc	DeVoe (13)* Dillon (14)

\* Indicates investigations by the Fowler method.

thermionic characteristics of the metal. Of particular interest is the change of these characteristics on a "gas-free" surface which undergoes a crystallographic change. Already this effect has been observed in the case of iron (5), cobalt (6, 8), and tin (29).

The Curie point of nickel is  $350^{\circ}$  C., and in view of the above, a study of the photoelectric and thermionic properties of nickel should be of interest.

It has been found that nickel exists as face-centered cubic crystals at temperatures above and below the Curie point, but in the region of the Curie point there is considerable disagreement as to the structure in which nickel exists. Bredig and Allolio (3), in 1927, first announced the discovery of hexagonal structure in nickel. In 1929, Thompson (51), by X-ray diffraction methods, found evidence of hexagonal crystals. He concluded that because of the low density reported by Bredig and Allolio, they had worked with a hydride of nickel rather than the pure metal. Bredig and von Bergkampff (4), two years later, prepared nickel films by two different methods and again obtained evidence of hexagonal nickel. Mazza and Nasini (41), by crystallization of nickel in several ways, found that it always crystallized in the face-centered cubic form. In an attempt to see if the hexagonal form of nickel was obtained due to quenching, Jesse (35) carried out an X-ray analysis of nickel from  $450^{\circ}$  C. to  $1200^{\circ}$  C. and found only the face-centered cubic form. He concluded that the hexagonal form was due to the type of deposition in obtaining the nickel.



Merica (42), in 1929, reported a change in the specific heat and specific resistance of nickel between 300° C. and 400° C.. Masumoto (40) had found in his work on other metals that such a change in physical properties was usually associated with a crystal transformation. Owen and Yates (45), by X-ray methods, found that although the nickel retained its face-centered structure throughout the range, the thermal expansion showed a marked change in the region of the Curie point. In 1936, Ewert (24) concluded that the change of  $\alpha$ -nickel from the ferromagnetic to the feebly paramagnetic  $\beta$ -state was not accompanied by a change in crystal structure. However, between the two states there may exist a hexagonal close-packed nickel. These conclusions were arrived at from a study of atomic heats in which he found hexagonal nickel existing from 345° C. to 351° C..

Since there is a question as to the state in which nickel exists in the neighborhood of the Curie temperature, it was felt that a study of the photoelectric properties of the metal might give some helpful information.

There is considerable disagreement among workers in the field as to what constitutes a gas-free surface. Many workers contend that even at a pressure of the order of  $10^{-8}$  mm. of mercury the surface can not be entirely freed of gas or occluded material.

#### EXPERIMENTAL APPARATUS

Plate I shows the general arrangement of the equipment. The experimental tube, which will be more fully described later, is

EXPLANATION OF PLATE I

Photograph of the apparatus.

PLATE I



under the metal box near the center of the photograph. The ionization gauge is located above the metal box. The experimental tube is connected through a liquid air trap to the oil diffusion pump and associated forepump on the left.

The source of ultraviolet radiation, a quartz mercury arc, is located in the large box to the right rear of the picture. To the left of the box is the monochromator.

In the foreground are the controls and meters for the filament circuit, the ionization gauge, and the amplifier necessary for measuring the extremely small photoelectric currents. The amplifier controls are on the panel to the right.

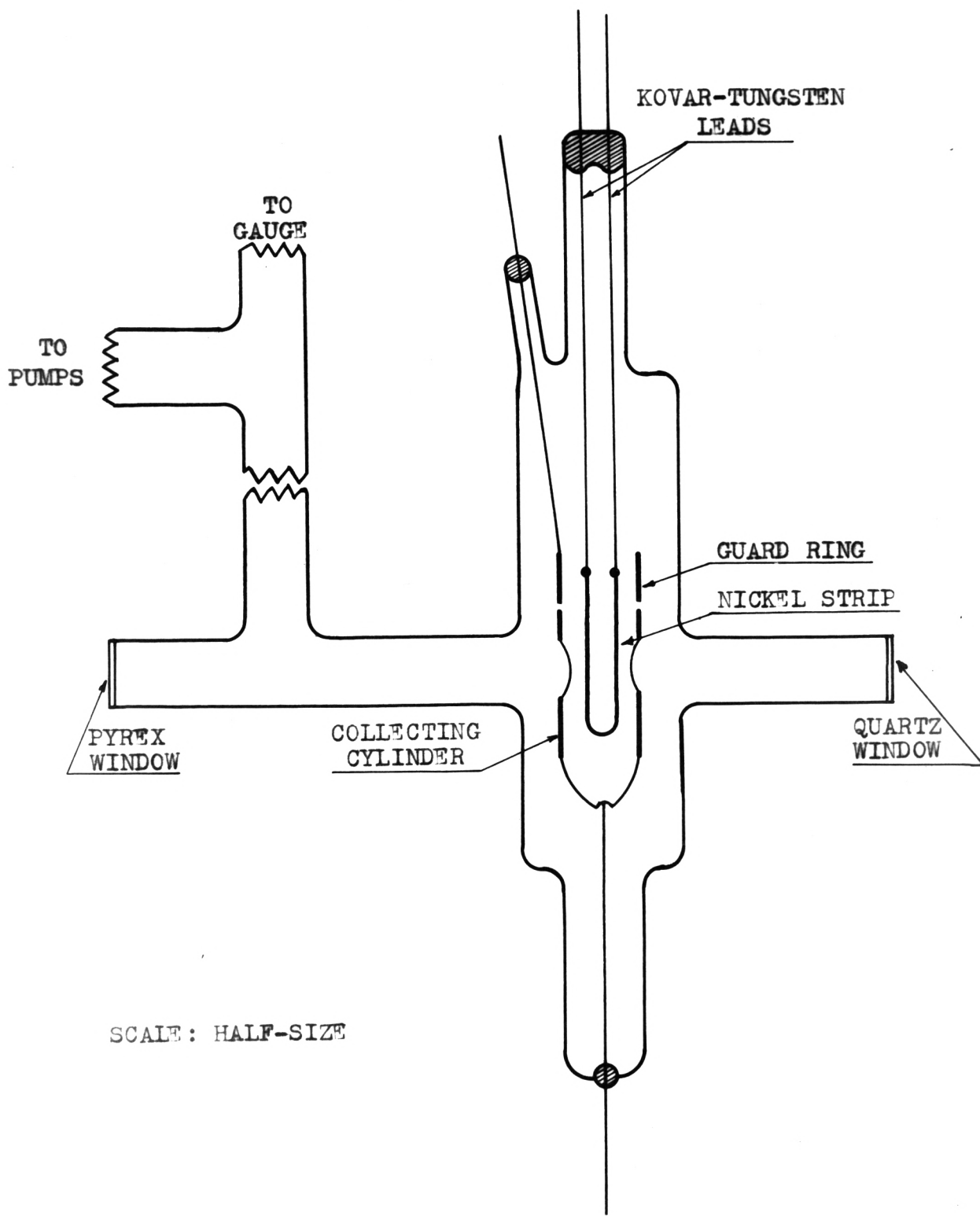
#### The Experimental Tube

Plate II is a schematic drawing of the experimental tube. The nickel, in the form of a strip 0.03 mm. thick, 4 mm. wide, and 14 cm. long, was suspended by Kovar-tungsten leads inside the molybdenum collecting cylinder. The nickel was spectroscopically pure, electrolytic nickel obtained from Adam Hilger, London. The ultraviolet radiation entered through the quartz window and passed through a window in the collecting cylinder onto the nickel strip. Temperature readings were taken with an optical pyrometer through the optically flat pyrex window. An opening through the metal cylinder made observation of the nickel strip possible. When the filament was heated at high temperatures, the cylinder could be rotated by an external magnet to prevent sputtering of the nickel onto the pyrex and quartz windows. The experimental

EXPLANATION OF PLATE II

Diagram of the experimental tube.

PLATE II



tube was enclosed in a metal box to prevent stray induced currents.

### The High Vacuum System

The high vacuum system consisted of a three-stage, water cooled, oil diffusion pump of the type GF-25W, manufactured by Distillation Products, Inc., backed by a Welch Duo-seal mechanical pump.

Using Octoil-S pumping oil, the pump had a maximum pumping speed of 25 liters per second at a pressure of  $10^{-4}$  mm. of mercury. The pumping speed and hence the ultimate vacuum attainable were dependent on the temperature to which the oil in the three stages was raised. In order to find the best possible operating condition for the particular system, it was necessary to vary the temperature by changing the heating current and observe the pressure in the system. Figure 2 is a typical curve obtained in this process in which pressure is plotted as a function of the heating current. It is evident from this figure that for a temperature above that corresponding to 1.65 amperes there was no apparent decrease in the pressure attainable. The optimum point of operation for this pump was then 1.65 amperes.

With the aid of a liquid air trap a pressure of the order of  $10^{-8}$  mm. of mercury was obtained.

### The Electrometer Circuit

The currents to be measured in this experiment were of the

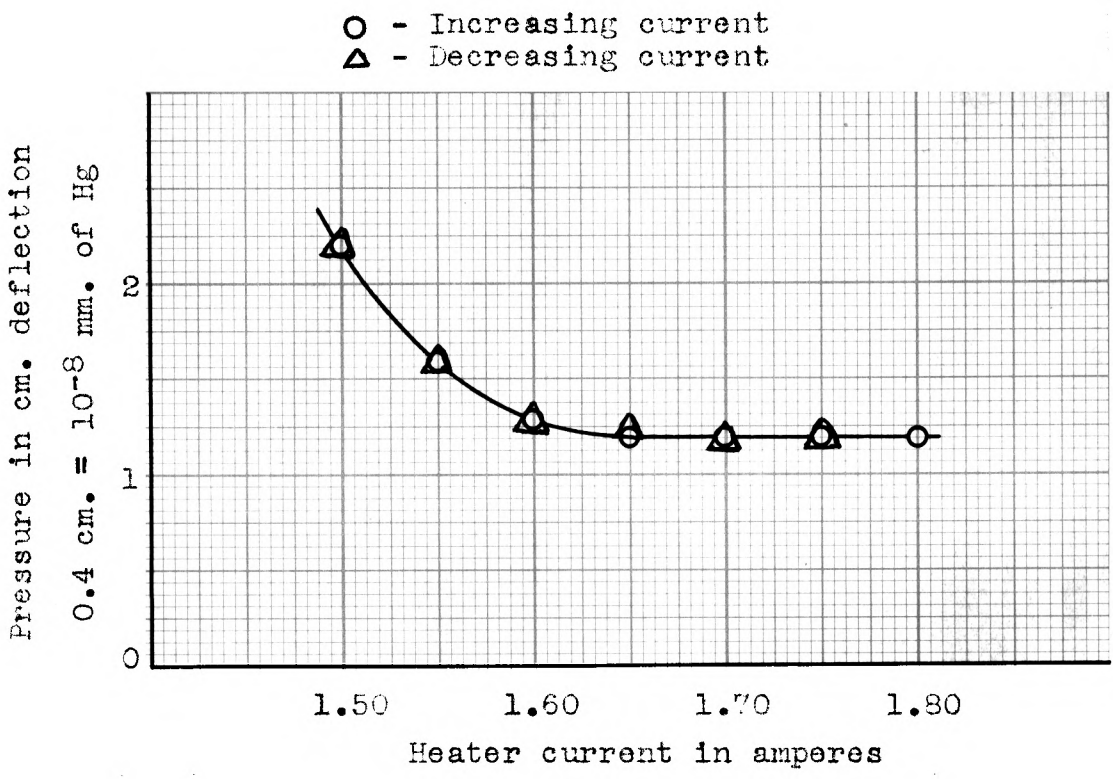


Fig. 2. Typical curve of pressure as a function of the current through the coils of the diffusion pump.



order of  $10^{-14}$  amperes. Early workers in this field used a Comp-ton quadrant electrometer (12) for measuring these small currents, but in recent years rapid progress had been made in the use of specially designed vacuum tubes with high input resistance for this purpose. The Western Electric D-96475 tube was used in this case.

Plate III is a schematic representation of the electrometer circuit, of the type developed by Barth (1), which was used in this experiment. Since the sensitivity of this type circuit is limited by the stability of the circuit, much work has been done in trying to improve this stability. By comparing many circuits, Penick (46) has concluded that the modified Barth circuit offered the best possibilities of maximum stability with maximum sensitivity.

For maximum stability the circuit must be balanced carefully. The balancing procedure is as follows:

1. The circuit was set up so that  $I_f$  equalled 270 ma.  $E_{nt} = 8.81$  v. at this setting for a specific case.
2.  $E_{pt}$  was set by varying  $R_g$ . For this case, the setting was 6.3 v.
3. With the galvanometer circuit open,  $R_p$  and  $R_n$  were adjusted so that  $(E_{pt} - I_p R_p) = (E_{nt} - I_n R_n)$  with  $I_n$  and  $I_p$  lying in the region recommended for operation of the D-96475 tube.
4. With the galvanometer circuit closed,  $R_p$  was adjusted until the galvanometer current equalled zero.
5. In order to check the balance of the circuit,  $I_f$  was varied in small steps by changing  $R_f$  and the galvanometer deflection

### EXPLANATION OF PLATE III

The electrometer circuit, including connections to the experimental tube.

A - Experimental tube.

B - Western Electric No. 96475 tube.

G - Leeds and Northrup galvanometer, sensitivity  $0.0001 \mu\text{a/mm.}$ , damping resistance 18,000 ohms, internal resistance 539 ohms, period 14.1 sec.

R<sub>1</sub>-  $5 \times 10^9$  ohms fixed resistance.

R<sub>2</sub>- 11.1 ohms fixed resistance.

R<sub>3</sub>- 18,000 ohms fixed resistance.

R<sub>4</sub>- 523 ohms fixed resistance.

R<sub>5</sub>- 1046 ohms fixed resistance.

R<sub>6</sub>- 523 ohms fixed resistance.

R<sub>7</sub>- 13 ohms fixed resistance.

R<sub>8</sub>- 0 to 7 ohms variable resistance.

R<sub>9</sub>- 6 ohms fixed resistance.

R<sub>p</sub>- 0 to 100,000 ohms variable resistance.

R<sub>n</sub>- 0 to 100,000 ohms variable resistance.

R<sub>f</sub>- 0 to 7 ohms variable resistance.

K<sub>1</sub>- High insulation key.

K<sub>2</sub>- SPDT switch.

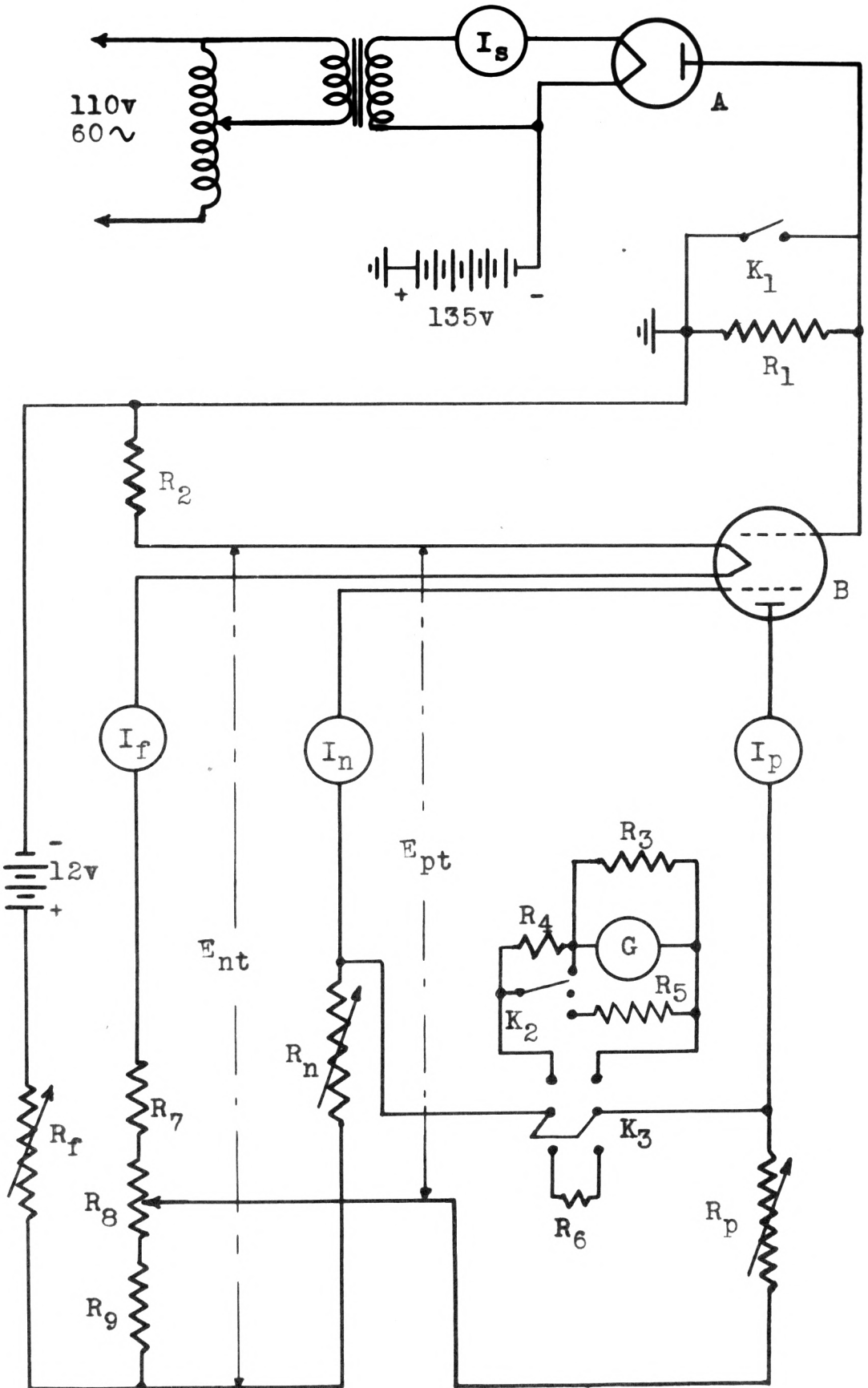
K<sub>3</sub>- DPDT switch.

I<sub>a</sub>- Westinghouse AC ammeter, 0 to 10 amp.

I<sub>f</sub>- Weston DC milliammeter, 0 to 300 ma.

I<sub>n</sub>- Triplett DC milliammeter, 0 to 1 ma.

I<sub>p</sub>- Triplett DC microammeter, 0 to 100  $\mu\text{a.}$



was plotted as a function of filament current.

6. The galvanometer was connected so that it gave a positive deflection when the plate was more positive than the space-charge grid. A positive slope then indicated a value of  $E_{pt}$  which was too low, and conversely for a negative slope.

7. The value of  $E_{pt}$  was changed in the indicated direction and the process repeated. This was continued until the desired precision of balance was reached.

Figure 3 is a representation of a typical curve obtained in this balance procedure. There was a five minute time interval between each change in  $I_f$ . The value of the circuit elements when this curve was taken were as follows:

$$E_{nt} = 8.81 \text{ v.}$$

$$E_{pt} = 6.3 \text{ v.}$$

$$R_n = 9190 \text{ ohms}$$

$$R_p = 18,500 \text{ ohms}$$

$$I_n = 0.458 \text{ ma.}$$

$$I_p = 91.8 \text{ a.}$$

The condition for stability was  $(E_{nt} - I_n R_n) = (E_{pt} - I_p R_p)$  or  $8.81 - 0.458 \times 10^{-3} \times 9190 = 6.3 - 91.8 \times 10^{-6} \times 18,500 = 4.6 \text{ v.}$

### Ionization Gauge Circuit

An ionization gauge capable of measuring extremely low pressures was necessary for this experiment. The type VG-1A manufactured by Distillation Products, Inc. was used. This tube is of the type described by Pound and Dushman (25). Plate IV is a sche-

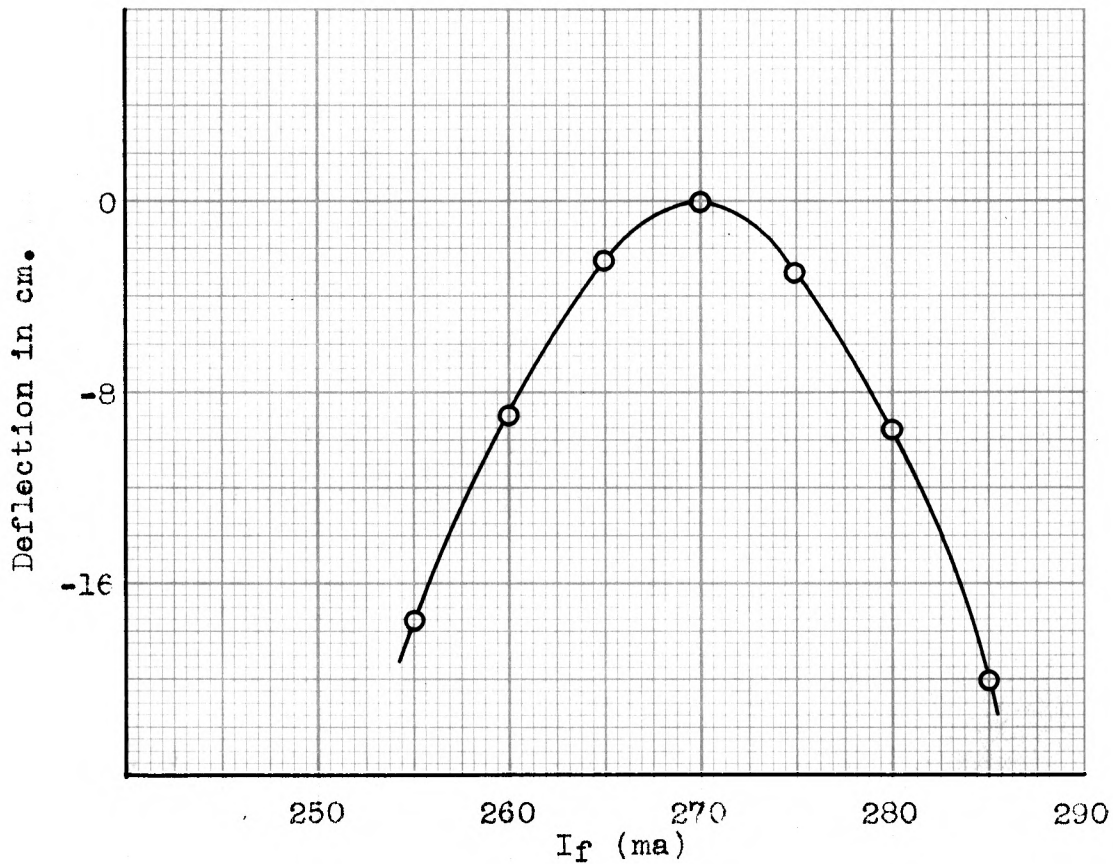


Fig. 3. Typical stability curve obtained in the balancing procedure.

EXPLANATION OF PLATE IV

Ionization gauge circuit, type VG-1A tube.

A - Ionization tube, type VG-1A.

G - Leeds and Northrup galvanometer, sensitivity  $0.00045 \mu\text{a/mm.}$ , damping resistance 9200 ohms, period 6.25 sec., internal resistance 484 ohms.

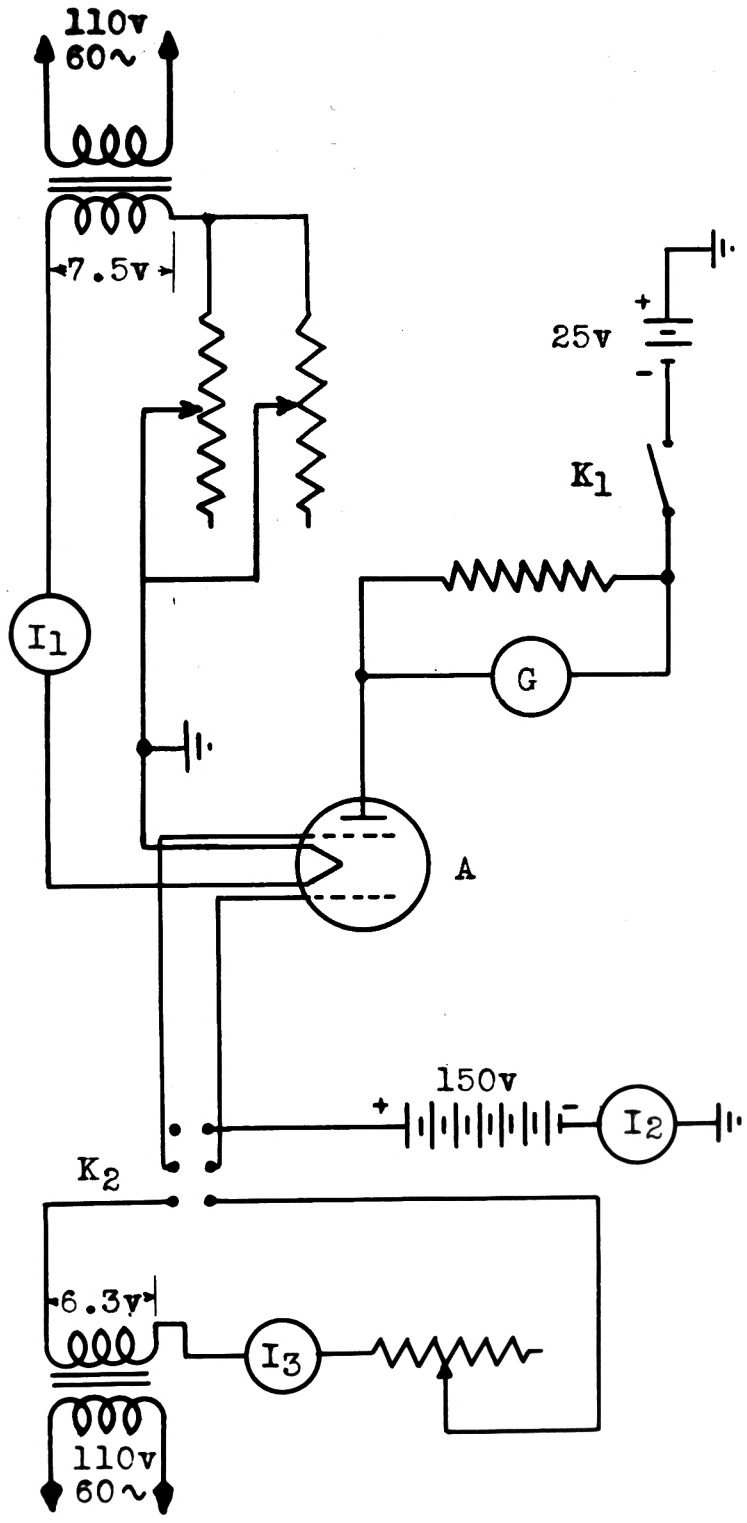
I<sub>1</sub> - Weston AC ammeter, 0 to 25 amp.

I<sub>2</sub> - Weston AC ammeter, 0 to 5 amp.

I<sub>3</sub> - Weston DC milliammeter, 0 to 15 ma.

K<sub>1</sub> - DPDT switch.

K<sub>2</sub> - SPST switch.



matic representation of the circuit used with the VG-1A in this experiment.

The physical characteristics of this tube were as follows:

Collector	thin film platinum
Grid	spiral tungsten
Filament	pure tungsten
Envelope	pyrex glass
Height	3½ inches
Diameter	1½ inches o. d.
Tubulation	½ inch o. d.

The values for typical operation of the VG-1A were:

Filament	3.5 - 5.0 amps.
Grid	150 v., 5 ma.
Collector	-25 v.
$I_p$	0.8 $\mu$ a. at a pressure of $7 \times 10^{-6}$ mm. of mercury.

Using a Leeds and Northrup galvanometer having a sensitivity of 0.00045  $\mu$ a/mm. and with a scale at a distance of 118.5 cm., the following values of pressure and deflection were obtained:

Deflection	Pressure
400 cm.	$10^{-5}$ mm. of mercury
40 cm.	$10^{-6}$ "
4 cm.	$10^{-7}$ "
4 mm.	$10^{-8}$ "

In order for the pressure to be measured accurately, the metal parts of the gauge as well as the glass envelope had to be out-gassed thoroughly. The grid was provided with two leads so that it could be heated externally, and a current of 6 or 7 amperes for



a few minutes was sufficient to outgas the grid. The glass envelope was constructed so that it could be flamed with a torch to remove all possible gas.

#### Source of Monochromatic Light

The source of monochromatic light was a mercury arc of the vertical type, Utility Model 86-5030, manufactured by Hanovia Chemical and Manufacturing Company. The arc when operated on 117 v. at 2.5 amps. had a maximum variation of light intensity of 3 per cent.

Radiation from the lamp was focused by an auxiliary quartz lens onto the entrance slit of a Bausch and Lomb quartz monochromator. The desired wave-length could be selected by the monochromator and was focused by another auxiliary lens onto the nickel strip. The slit widths of the monochromator were 0.04 cm. and 0.03 cm. for the entrance and exit slits respectively. To prevent any stray light from reaching the nickel strip directly from the mercury arc, the arc was enclosed in an opaque box.

The wave-lengths desired were selected with the aid of a characteristic mercury arc spectrum. The intensity of each line was measured by an Epply eight junction, bismuth-silver thermopile mounted on the monochromator. The thermopile had a resistance of 7.1 ohms and a sensitivity of  $0.025 \mu\text{v.}/\mu\text{w.}/\text{cm}^2$  and was mounted on a carriage that made it possible to lower the thermopile over the exit slit of the monochromator when desired. A Leeds and Northrup galvanometer with the following characteristics

was used in conjunction with the thermopile:

Sensitivity	0.0015 $\mu$ a/mm.
Damping resistance	10 $\Omega$
Period	8 secs.
Resistance	15.6 $\Omega$

### Temperature Measurements

Temperatures of the nickel filament were measured with an optical pyrometer of the disappearing filament type, the pyrometer being focused on the filament through the optically flat pyrex window of the experimental tube.

Corrections were made on the pyrometer readings for black body emissivity according to the data given by Wahlin and Wright (53). These values are given in Table 2

Table 2. Temperature scale for nickel (53).

<u>True Temperature : Apparent Temperature</u>	
1175° K.	1111.4° K.
1200	1133.3
1225	1155.8
1250	1178.0
1275	1200.1
1300	1222.2
1325	1244.3
1350	1266.3
1375	1288.5
1400	1310.3
1425	1332.6
1450	1354.6
1475	1376.9
1500	1399.6

## The Outgassing Process

The nickel strip was outgassed until no fatigue was observed in the photocurrent, the fatigue being measured by observing the photocurrent as a function of time. The outgassing time averaged about 1200 hours for the two filaments on which complete observations were taken. The outgassing temperature was increased gradually during this time from about 100° C. up to 1100° C.. It was found necessary to increase this temperature slowly in order to prevent excessive evaporation from the filament.

Four or five times a day, during the initial outgassing stages, the metal parts in the experimental tube were outgassed by heating for a few minutes with a high-frequency induction furnace. The glass tubing was of pyrex and the surface gases on the glass could be removed by flaming with a torch. Heat treatment of the nickel, metal parts, and glassware, made pressures of 3 to  $5 \times 10^{-8}$  mm. of mercury obtainable during the final stages of the experiment.

## EXPERIMENTAL RESULTS

Data were taken on three different nickel filaments. The first filament burned out at the end of 750 hours, before any data in the carefully outgassed condition could be obtained. The second filament was heated for approximately 1500 hours with data for the carefully outgassed condition being obtained. The third filament lasted for approximately the same length of time before

burning out.

The chief interest in this experiment lay in determining the work function of nickel at various temperatures. It had been found by Peterson (47) that the photocurrent plotted as a function of temperature of the filament showed a marked change in the slope of the curve occurring in the neighborhood of the Curie temperature. Figure 4 is a curve of this type taken from data obtained in this experiment, with the temperature given at a few points on the curve.

Data for determining the work-function below, at, and above the Curie point were taken. These data are shown in Table 3. Points on the three different temperature curves were taken simultaneously.

These data are plotted, according to the Fowler method, in Fig. 5, where  $h$  = Planck's constant,  $\nu'$  = frequency of incident radiation,  $k$  = Boltzmann's constant,  $T$  = temperature in  $^{\circ}$  K., and  $I$  = photocurrent per unit light intensity. The amount of horizontal shift necessary to fit this experimental curve to Fowler's theoretical curve permits one to calculate the work-function of the nickel. Or, in equation form,

$$\frac{h\nu'_0}{kT} = \text{horizontal shift}$$

$$h\nu'_0 = \frac{(\text{horizontal shift}) \times kT}{1.6 \times 10^{12} \text{ ergs/electron-volt}}$$

For the particular curve above, when  $T = 1108^{\circ}$  K., the work-function is obtained as follows:

$$\frac{h\nu'_0}{kT} = 53.5$$

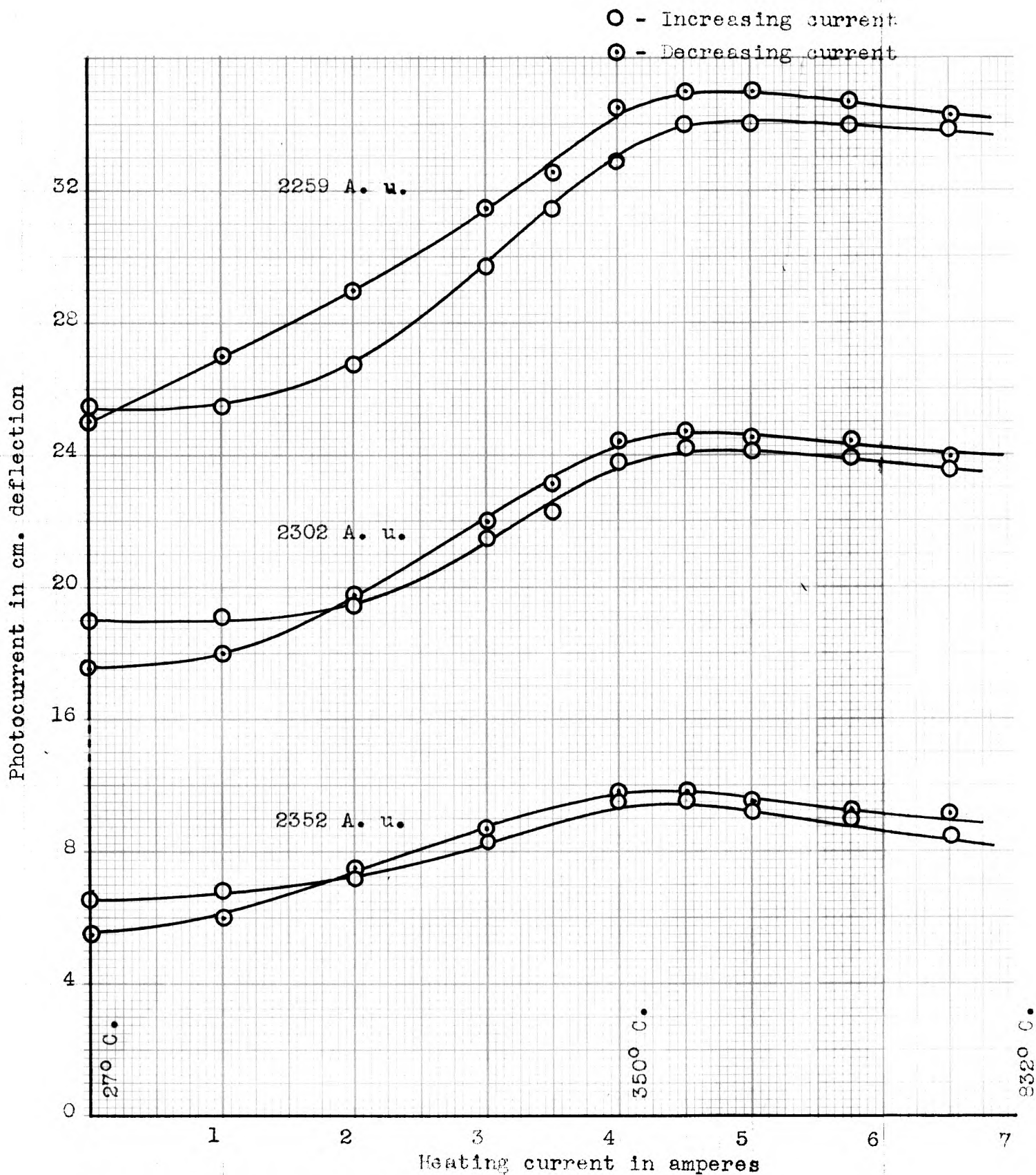


Fig. 4. Photocurrent as a function of temperature.

Table 3. Experimental data for carefully outgassed nickel.

Wave length A. u.	Data		Calculated		
	:Average :photocur- :rent (cm.)	:Average :light :intensity	:Photocurrent :per unit light :intensity	: $h\nu$ : $kT$	: $\log_e I$ : : : $T^2$
T = 300° K.					
2259	31.70	1.34	23.70	212.5	-8.24
2302	19.10	1.59	12.00	208.4	-8.92
2352	7.70	1.69	4.56	204.1	-9.89
2378	4.56	2.26	2.02	201.0	-10.71
2399	4.22	2.60	1.62	200.1	-10.92
2447	1.27	1.55	0.82	196.2	-11.61
T = 623° K. = 350° C.					
2259	39.20	1.34	29.20	102.5	-9.49
2302	25.90	1.59	16.30	100.5	-10.07
2352	11.60	1.69	6.88	98.4	-10.94
2378	8.25	2.26	3.64	97.3	-11.57
2399	6.37	2.60	2.45	96.4	-11.96
2447	1.32	1.55	0.89	94.5	-12.98
T = 1108° K.					
2259	39.90	1.34	29.80	57.6	-10.62
2302	26.20	1.59	16.50	56.4	-11.21
2352	11.90	1.69	7.04	55.3	-12.06
2378	9.00	2.26	3.98	54.7	-12.63
2399	8.10	2.60	3.11	54.2	-12.88
2447	1.73	1.55	1.12	53.1	-13.90

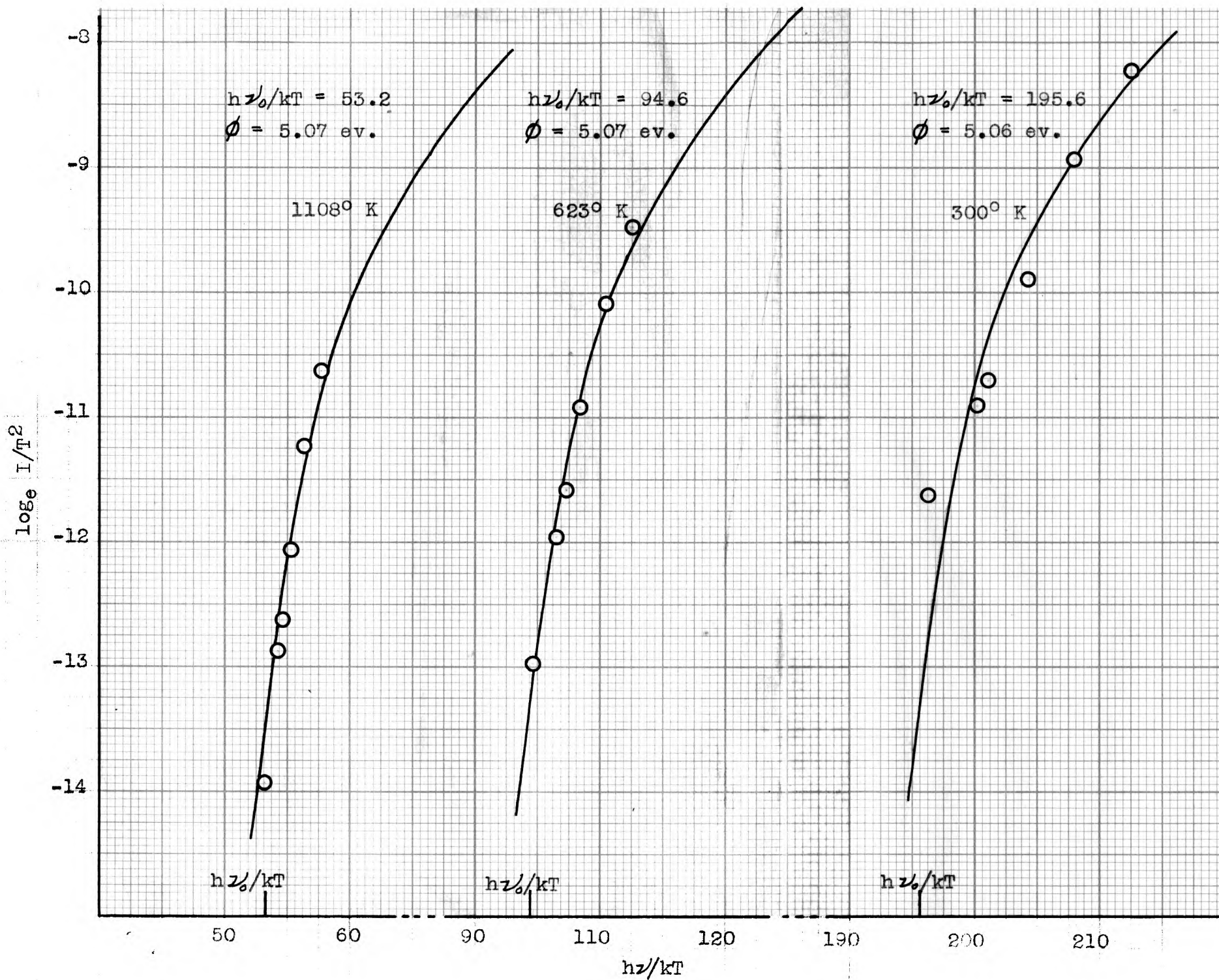


Fig. 5. Experimental points for carefully outgassed nickel at three different temperatures superimposed on Fowler's theoretical curve.

$$\frac{53.5 \times 1.38 \times 10^{-16} \times 1108}{1.6 \times 10^{12}} = 5.07 \text{ electron-volts}$$

The work-function for each of the other two curves was obtained in a similar manner.

Figure 6 is a plot of the above data as photocurrent per unit light intensity vs. wave-length of the incident radiation. Previous to the development of the Fowler theory an extrapolation to zero current was the method used for determining the threshold frequency and from this the work-function was calculated. This method was in error due to the now known asymptotic approach of the curve to the ordinate. Since the development of the Sommerfeld theory of metals, there is known to be no sharply defined threshold frequency at any temperature above 0° K.

In the early stages of outgassing, there was a marked increase in the work function of the metal as the outgassing progressed. As the process continued an apparent stable condition was reached after about 1000 hours where there was no fatigue observed in the photocurrent and no change observed in the work-function. A series of curves were taken at this point, and the work-function was found to be  $5.07 \pm 0.04$  electron-volts.

The temperature of the filament was then increased and it was observed that there was noticeable fatigue in the photocurrent. The filament was heated for approximately 200 hours more, until the fatigue disappeared, and the work-function again measured. The work-function at this point was also  $5.07 \pm 0.04$  electron-volts, showing no change from that previously measured.

In the progress of the experiment, 21 curves, suitable for the Fowler plot, were taken, and in all cases the work-functions



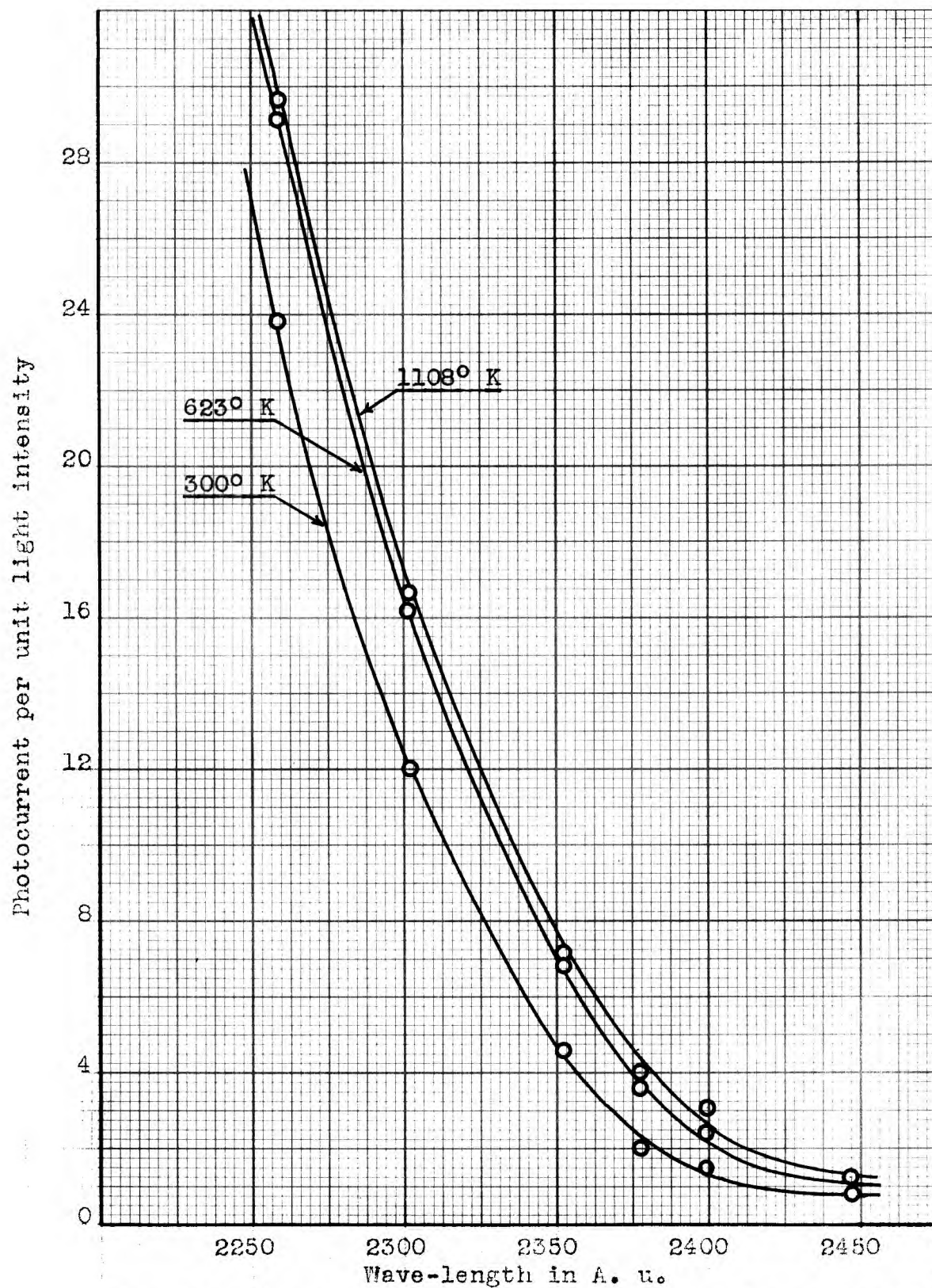


Fig. 6. Photoelectric sensitivity curves for carefully outgassed nickel.

obtained were within the range of experimental error of 5.07 electron-volts.

The value obtained for the work-function of carefully outgassed nickel is somewhat lower than the value of 5.14 electron-volts that was obtained by Peterson (47). However, the value lies close to the range of experimental error. The value obtained in this experiments is quite close to the value of  $5.03 \pm 0.05$  electron-volts obtained by thermionic means by Fox and Bowie (27). It is higher, however, than the value recently obtained by Wahlin (52), who found the thermionic work-function of nickel to be  $4.61 \pm 0.05$  electron-volts. During the early stages of outgassing in this experiment, a value of 4.61 electron-volts was obtained as the work-function; therefore, it is possible that the sample used by Wahlin was not thoroughly outgassed. Welch (58) and Roy (49) found the work-function to be 4.06 and 4.12 electron-volts respectively. Neither of these workers, however, outgassed the metal and consequently was not measuring the work-function of pure material.

Glazoe (28), in 1931, found the work-function of nickel to be 5.01 electron-volts, which is within the region of experimental error of this experiment.

The increase in photocurrent with temperature could be due to a change in the work-function, a change in the reflectivity of the nickel, or a variation of quantum efficiency with temperature. Data taken in this experiment show no variation of work-function with temperature. Weil (57) found no change in the reflectivity of nickel in the region of the Curie point. It therefore seems

probable that the increase in photocurrent with temperature is a result of an increase in the quantum efficiency. In Fig. 7, the data of Fig. 4 have been reinterpreted and plotted as quantum efficiency as a function of temperature. The quantum efficiency at room temperature was assumed to be 100 for use as a basis.

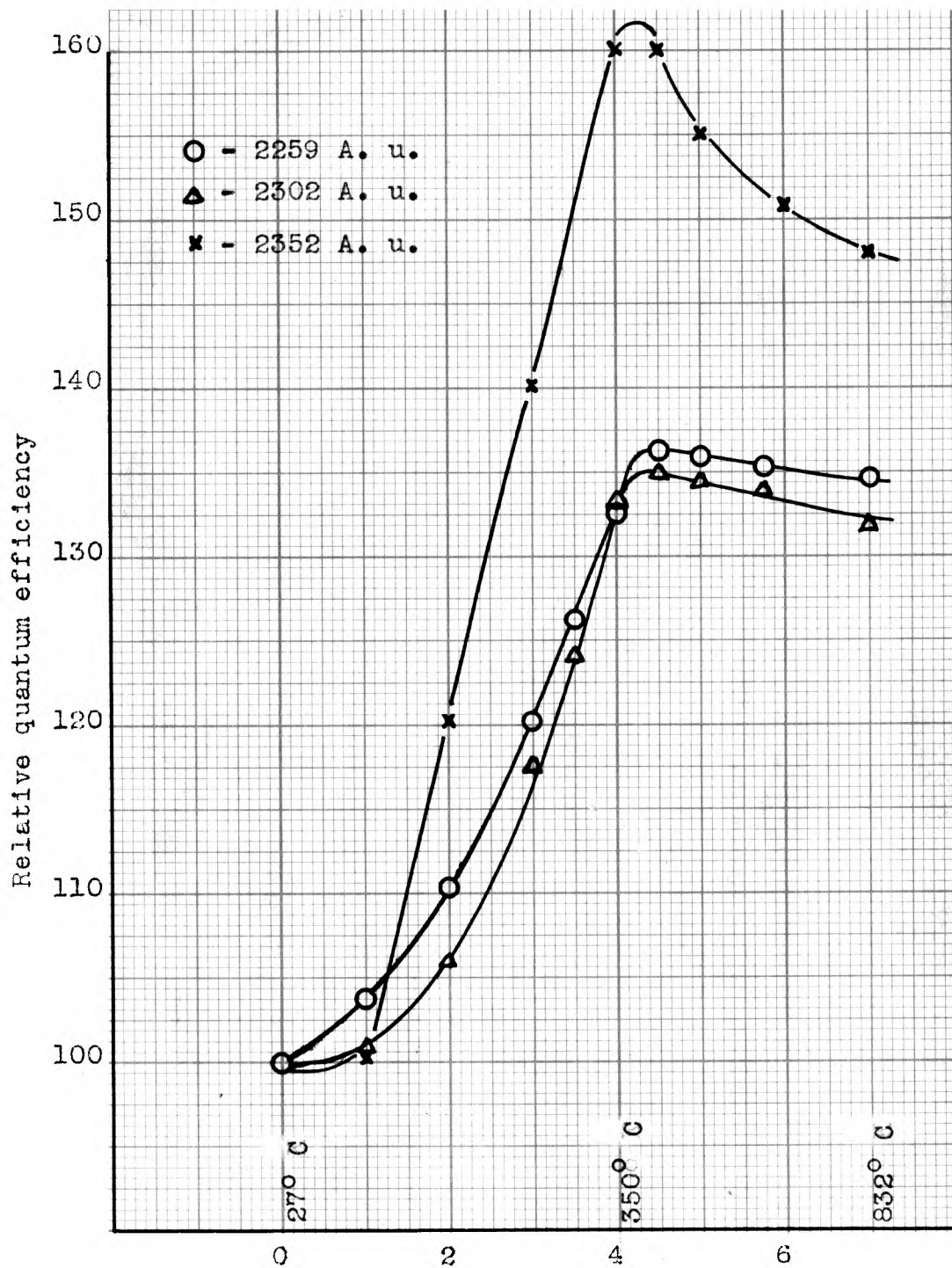


Fig. 7. Quantum efficiency as a function of temperature.

## CONCLUSIONS

1. The photoelectric work-function of spectroscopically pure, carefully outgassed nickel is  $5.07 \pm 0.04$  electron-volts.
2. The photoelectric work-function of nickel does not change with temperature. Consequently, if a crystallographic transformation occurs at the Curie point, there is no change in work-function associated with this transformation.
3. The change in photocurrent with temperature probably is a result of an increase in the quantum efficiency.

## ACKNOWLEDGMENT

Acknowledgment is made to Dr. A. B. Cardwell, Head, Department of Physics, for his excellent advice and helpful criticisms during the progress of this experiment and the preparation of this manuscript. Appreciation is also expressed to the Research Corporation, New York City, for supplying the funds necessary for the pursuit of this problem.

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