

# I. PHYSICAL ELECTRONICS

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## A. ELECTRON EMISSION PROBLEMS

### 1. Study of an Ideal Retarding Potential

The experimental tube designed for investigation of thermionic emission from planar tantalum crystals is now complete and sealed off with a gettered total pressure of  $1 \times 10^{-10}$  mm Hg and a much smaller pressure of adsorbable gas. Most information in this research comes from a retarding potential curve. The explanation of the ideality of the resultant retarding potential curve is evident from Fig. I-1.

Two  $0.003 \times 0.045$  inch ribbons of tantalum with centers that contain single 211 crystals are mounted facing each other in a strong (3000 gauss) magnetic field. To separate them, a rectangular aperture is inserted. Having this positive aperture in conjunction with the magnetic field means that the collected current originates from a small area on the crystal emitter and it is collected on the crystal in the collector.

The difficulties of similar experiments that are obviated by this arrangement are mainly:

- a. patch fields at either emitter or collector are eliminated;
- b. geometric considerations, such as correcting for cylindrical geometry or worrying about trajectories and tangential velocities are removed;
- c. space-charge limitations are reduced because of the positive aperture.

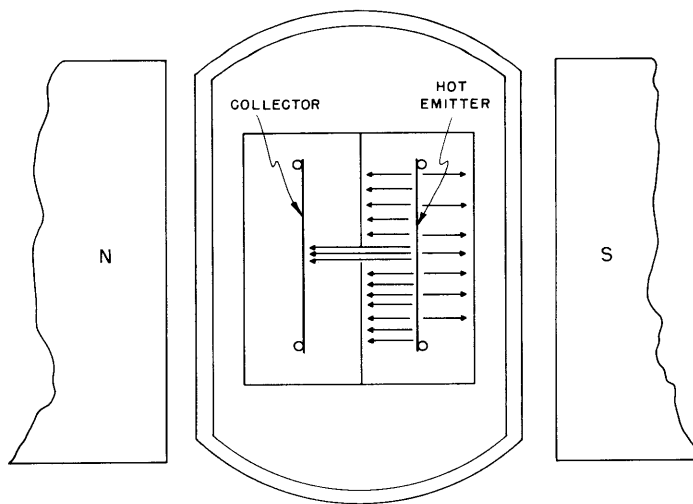


Fig. I-1. Experimental tube.

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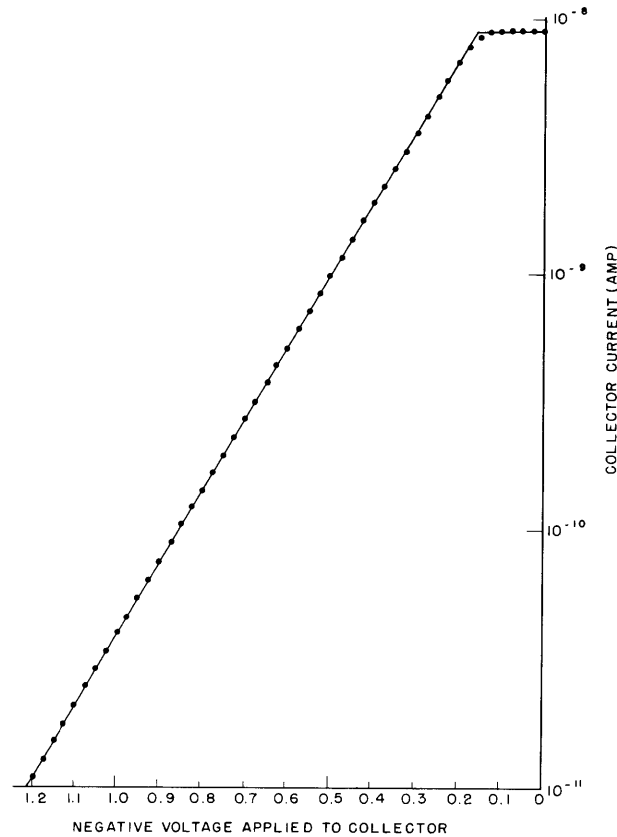


Fig. I-2. Typical retarding potential plot.

The resultant curve of Fig. I-2 is, we believe, one of the best that has been published. It gives graphical evidence of the ideality of the distribution and the lack of an energy-dependent reflection at the collector.

H. Shelton

## B. PHYSICAL ELECTRONICS IN THE SOLID STATE

### 1. Hall Effect in Lead-Sulfide Films

Studies on several samples of polycrystalline lead-sulfide films emphasized the necessity of the extreme care that is necessary to prevent noise. Since contact noise often causes trouble in Hall measurements, techniques for evaporating the gold contacts under the best vacuum conditions were used. Because the samples are seriously changed by baking at temperatures above  $50^{\circ}\text{C}$ , pumping for over twelve hours is necessary to evacuate the envelopes to pressures of the order of  $10^{-7}$  mm Hg. On three samples, evaporation was carried out at pressures of better than  $5 \times 10^{-7}$  mm Hg.

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These low pressures could be maintained only by pulsing the heater filament, thus preventing excessive heating of the gaseous surrounding parts.

For the accurate definition of the boundaries of the samples, a simple scribing device was constructed which was adequate for the purpose. A diamond window-glass cutter was clamped in a holder that was mounted in the tool-post holder of a lathe. The verniers of the lathe were used to rule the samples with sufficient accuracy. The scribed lines were tested at room temperature and were found to have a resistance greater than  $10^4$  times the film resistance. This high resistance was produced by brushing the scribed lines with a camel's hair brush in order to remove loose particles of lead sulfide from the cuts. The removal of particles was noted by means of a microscope.

Three samples were processed, but the presses were found to leak to air. Recently, we found a method for making satisfactory presses. The electric leads are 0.015-inch tungsten wire with beads of Nonex glass. The leads were sealed into pyrex glass. Two presses, made in this way, were vacuum-tested and found to be very satisfactory at temperatures down to that of liquid nitrogen. Also, the electric leakage between the leads was measured as a function of temperature. The leakage on both of these presses, as well as on six other presses with pyrex beads, was always at least a factor of  $10^4$ , which is lower than the conduction current of typical samples. Thus, electrically, the presses seem very satisfactory.

Methods for sealing the samples into the evaporation tube and the sample bottles were perfected and tested. Basically, the technique consists of covering a sample with distilled water, working the large glass areas, pumping the water out through a small tube whose opening is far from the sample, and sealing the small tube into the vacuum system. By this means, only a negligible amount of hot gas reaches the sample. At no time during a typical operation is there any indication of overheating the sample.

A differential dc millivoltmeter was designed and constructed and it is now being tested. The drift of the instrument is less than 0.1 mv per minute, and the noise is about 0.03 mv. When the shielding is improved, this instrument should be able to measure voltages as low as 0.05 mv with an accuracy adequate for this work. This instrument should prove quite satisfactory for measuring the Hall voltages of the high-resistance lead-sulfide samples.

D. H. Dickey

### 2. Surface States on Semiconductors

A tube designed to measure simultaneously the photoconductivity and the contact potential of germanium is now under construction. The germanium sample ( $5 \times 25$  mm) will be attached to the underside of two Kovar cups sealed to the bottom of a large cup-like depression in the top glass wall of the tube; this depression will hold coolant to

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keep the sample at low temperatures. A set of tantalum electrodes will accelerate an electron beam and deflect it toward the germanium, where the electrons will be retarded. One of the electrodes will incorporate a box that houses a tungsten filament which serves as the electron source; a series of baffles and "black-body" boxes will prevent the undesirable filament light from scattering in the tube and illuminating the germanium. A "cold" electron emitter – either oxide-coated or a field emitter – is undesirable for this experiment.

E. Ahilea

## C. GASEOUS DISCHARGES

### 1. Harmonic Analysis of Distribution Functions

An investigation is being made of a method for measuring the velocity-distribution function of electrons in the plasma of a low-pressure mercury arc. The theory of the method involves showing that the velocity-distribution function  $f(\vec{v})$  is proportional to the second derivative (with respect to the retarding potential  $\Delta V$ ) of the electron current density  $I$  to a planar probe. In order to evaluate the second derivative conveniently, a small, monofrequency, ac signal ( $A \sin \omega t$ ) is superimposed upon the retarding potential and the Fourier expansion of the resultant probe current is observed. The coefficient of the second-harmonic term ( $I(2\omega) \cos 2\omega t$ ) has as its leading term the desired second derivative. Within the limits of the approximation, the velocity-distribution function is therefore given by the amplitude of the second-harmonic term in the ac probe current (measured with a tuned amplifier).

The current density to a retarding planar probe is given by:

$$I = q \int_{v_0}^{+\infty} \int_{-\infty}^{+\infty} \int_{-\infty}^{+\infty} v_x f(\vec{v}) dv_y dv_z dv_x \quad \frac{1}{2} m v_0^2 = q\Delta V$$

where  $I$  is the current density in charge per unit area per unit time,  $q$  is the charge of the electron,  $v_x$  is the velocity normal to the probe, and  $f(\vec{v})$  is the velocity-distribution function in particles per unit phase space volume. The velocity  $v_0$  is the minimum velocity in the  $v_x$  direction that an electron must have in order to overcome the retarding potential  $\Delta V$ . If  $f(\vec{v})$  is spherically symmetric, or if we consider the spherically symmetric leading term in the Legendre polynomial expansion, the expression above can be integrated by parts and reduced to

$$I = \frac{q}{4} \int_{v_0}^{\infty} v \left( 1 - \frac{v_0^2}{v^2} \right) f(v) 4\pi v^2 dv$$

where  $v$  is the magnitude of the velocity. The dependence of the probe current  $I$  upon the retarding potential  $\Delta V$  is obtained through  $v_0$ , which is defined in terms of the retarding potential. Differentiating  $I(\Delta V)$  twice with respect to  $\Delta V$  yields the expression for the distribution function:

$$\frac{d^2 I(\Delta V)}{d(\Delta V)^2} = 2\pi q \left(\frac{q}{m}\right)^2 f(v_0)$$

This result was first obtained by Druyvesteyn.

A small ac signal is added to the retarding potential, and the resultant probe current is written as a Fourier series:

$$I(\Delta V + A \sin \omega t) = \sum_{n=0}^{\infty} (a_n \cos n\omega t + b_n \sin n\omega t)$$

In order to evaluate the Fourier coefficients, the current is also written as a power series in " $A \sin \omega t$ ":

$$I(\Delta V + A \sin \omega t) = \sum_{K=0}^{\infty} \frac{1}{K!} A^K I^{(K)}(\Delta V) (\sin \omega t)^K$$

where  $I^{(K)}$  is the  $K^{\text{th}}$  derivative of  $I(\Delta V)$ . If the last two expressions for  $I$  are equated and multiplied by  $\sin n\omega t$  (or  $\cos n\omega t$ ), integration (together with the orthogonality properties of  $\sin$  and  $\cos$ ) will yield the Fourier coefficients. The result is given for the dc term, the first harmonic, and the second harmonic.

$$\begin{aligned} I(\Delta V + A \sin \omega t) = & \sum_{j=0}^{\infty} \pi^{-1/2} \frac{A^{2j}}{(2j)!} \frac{\Gamma(j + 1/2)}{\Gamma(j + 1)} I^{(2j)}(\Delta V) \\ & + \sin \omega t \left[ \sum_{j=0}^{\infty} \pi^{-1/2} \frac{2A^{2j+1}}{(2j + 1)!} \frac{\Gamma(j + 3/2)}{\Gamma(j + 2)} I^{(2j+1)} \right] \\ & - \cos 2\omega t \left[ \sum_{j=0}^{\infty} \pi^{-1/2} \frac{2A^{2j+2}}{(2j + 2)!} \frac{j + 1}{j + 2} \frac{\Gamma(j + 3/2)}{\Gamma(j + 2)} I^{(2j+2)} \right] \end{aligned}$$

Note that the  $\cos \omega t$  and  $\sin 2\omega t$  terms do not exist. The amplitude  $I(2\omega)$  of the second-harmonic term can be written in more explicit form:

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$$I(2\omega) = \frac{A^2}{4} I^{(2)}(\Delta V) + \frac{A^4}{48} I^{(4)}(\Delta V) + \dots$$

For a Maxwell-Boltzmann distribution:

$$\frac{I(2\omega)}{I(\text{dc})} = \frac{1}{4} \left( \frac{qA}{kT} \right)^2 \left[ 1 + \frac{1}{12} \left( \frac{qA}{kT} \right)^2 + \dots \right]$$

If the higher-order terms can be neglected, we have

$$\frac{kT}{qA} \approx \frac{1}{2} \left( \frac{I(\text{dc})}{I(2\omega)} \right)^{1/2}$$

For the general distribution function, if the higher-order terms are negligible, the distribution function is given by

$$f(v_o) = \frac{2}{\pi} \left( \frac{m}{q} \right)^2 \frac{I(2\omega)}{qA^2}$$

To verify the fact that the other terms can be neglected, this quantity  $(I(2\omega)/A^2)$  should be measured for different values of  $A$  (ac signal amplitude). If there is a dependence upon  $A^2$ , we can extrapolate to  $A^2 \rightarrow 0$ . This measurement should also be made for several low frequencies in order to insure that there are no frequency-dependent nonlinear secondary effects. In order to make accurate measurements in the high-energy part of the distribution function a special hollow probe must be used to separate out the positive ion current.

S. Aisenberg

## D. EXPERIMENTAL TECHNIQUES

### 1. High-Vacuum Studies

Mr. Dana H. Dickey measured the equilibrium pressure in a Bayard-Alpert ionization gauge as a function of the electron current in the pressure range from  $2 \times 10^{-9}$  to  $10 \times 10^{-9}$  mm Hg,  $N_2$  equivalent total pressure. His unpublished results indicate that for a new, freshly processed gauge the equilibrium pressure is inversely proportional to the electron current. This can be explained by making two assumptions:

a. The clean-up rate is proportional to the pressure and to the electron current,  $dn_1 = -\alpha P i_- dt$ , where  $\alpha$  is a constant, and  $i_-$  is the electron current.

b. There is a constant "back-flux" of gas caused by a combination of permeation of helium through the glass walls of the tube and outgassing of the metal portions of the

tube structure,  $dn_2 = +\beta dt$ , where  $\beta$  is a constant.

Equilibrium will be established when  $dn_1 + dn_2 = 0$ . Consequently, the equilibrium pressure  $P_o$  is given by

$$P_o = \frac{\beta}{\alpha i_-} \quad (1)$$

However, if the measurements are carried down to lower pressures (to about  $1 \times 10^{-10}$  mm Hg), we would expect to observe that one or both of the following factors affect the current to the ion collector.

a. Ion current to the ion collector:

$$(i_+)_{\text{ions}} = PKi_-$$

where  $P$  is the "true" gas pressure in the gauge and  $K$  is the gauge constant (so defined).

b. Photoelectric emission of electrons from the ion collector

1. From X-rays produced at the electron collector:

$$(i_+)_{\text{X-ray}} = \mu i_-$$

where  $\mu$  is a constant.

2. From light produced at the electron emitter:

$$(i_+)_{\text{light}} = F(i_-) = \text{an unknown function of } i_-.$$

Consequently, the total current at the ion collector will be

$$(i_+)_{\text{total}} = PKi_- + \mu i_- + F(i_-)$$

The apparent equilibrium pressure in the gauge will be given by

$$P_{\text{apparent}} = \frac{i_+}{Ki_-} = \frac{\beta}{\alpha i_-} + \frac{\mu}{K} + \frac{f(i_-)}{Ki_-} \quad (2)$$

where Eq. 1 for the equilibrium pressure  $P_o$  is used.

In order to test this theory, a special Bayard-Alpert ionization gauge with the following characteristics was used in a preliminary experiment.

1. Ion collector, 3-mil (diameter) tungsten wire (with molybdenum coating of negligible thickness);

2. Gauge constant  $K$ ,  $11 (\text{mm Hg})^{-1}$  measured with  $N_2$  in the pressure range 1 to  $10 \times 10^{-4}$  mm Hg;

3. An internal connection to the glass wall upon which a coating of molybdenum had been evaporated;

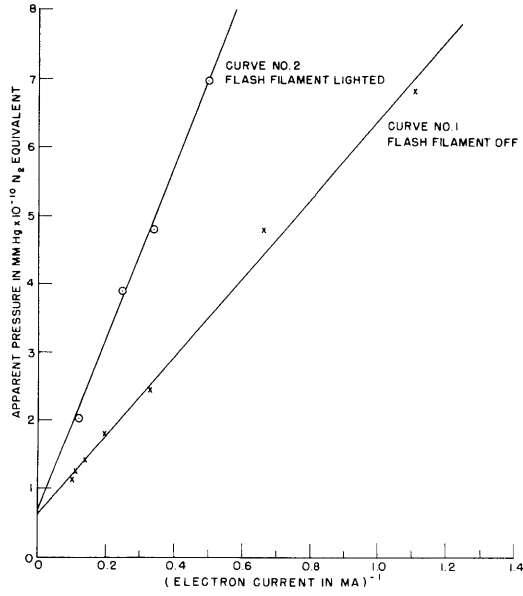


Fig. I-3. Equilibrium pressure versus (electron current)<sup>-1</sup>.

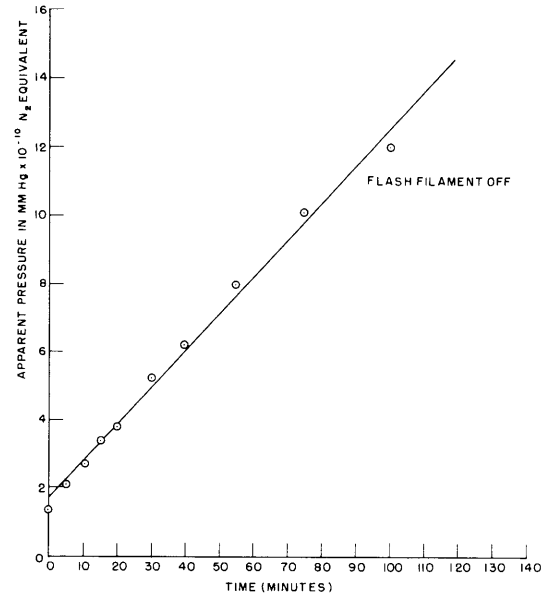


Fig. I-4. Permeation run.

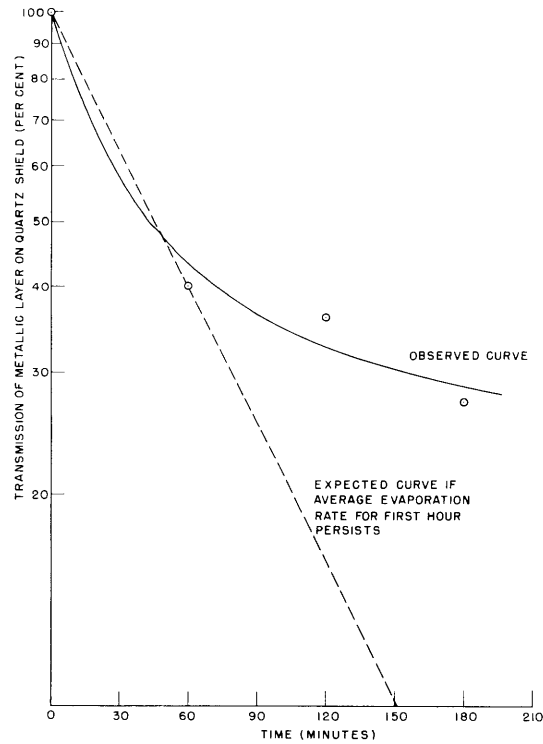


Fig. I-5. Measurements of the evaporation rate of tungsten.



4. Volume of gauge, about 1.1 liters;
5. Glass wall voltage, +16 volts;
6. Filament (electron emitter) voltage, +18 volts;
7. Electron collector voltage, +105 volts; and
8. Ion collector voltage = 0.

Figure I-3 shows the plot of the apparent equilibrium pressure versus (electron current)<sup>-1</sup>. The larger slope of curve 2 is probably attributable to a combination of increased glass-wall temperature (hence, helium permeation) and increased outgassing of the flash-filament mounting posts. It is quite apparent that the two least-square straight lines through the two sets of data have very nearly the same intercept. This would imply that the intercept value is virtually independent of the amount of light generated at the electron emitter. Since this intercept measures the X-ray effect (see Eq. 2), our method should enable the estimation of this parameter. The apparent X-ray limit in this case appears to be about  $6.4 \times 10^{-11}$  mm Hg, N<sub>2</sub> equivalent total pressure.

In order to further test the above theory, a permeation run was made at zero electron current (although the electron emitter remained hot) for the purpose of justifying the assumption of a constant "back-flux" of gas. The permeation rate shown in Fig. I-4 amounts to about  $6.5 \times 10^{-10}$  mm Hg, N<sub>2</sub> equivalent total pressure per hour.

R. D. Larrabee

## 2. The Spectral Emissivity of Tungsten

In measuring the spectral emissivity of any metal, it is quite important to have an estimate of the purity of the metallic specimen. In the case of the refractory metals, the finished specimen can be purified by proper heat treatment. For the present experiment, a tubular tungsten cylinder, 0.125 inch in diameter, constructed from 1-mil ribbon, 0.5 inch wide, supplied by Kulite Tungsten Company, Union City, New Jersey, was maintained at 2750°K for 3 hours. In order to measure the evaporation rate, a 0.75-inch (diameter) quartz shield was placed coaxially over half of the tungsten sample. The optical transmission of the metallic film deposited on this shield was measured by comparing the apparent color temperature of the sample alone and the sample viewed through the quartz shield. If the evaporation rate were constant, we would expect an exponential decrease in the transmission, as a function of time.

The wide departure of the observed data from this exponential law (see Fig. I-5) indicates that the initial rate of evaporation is quite large in comparison with the subsequent rates. In order to determine whether the rapid initial rate is caused by the evaporation of relatively volatile impurities in the specimen (which would purify the specimen), the metal on the quartz shield, the metallic specimen, and a sample of the tungsten are being analyzed.

R. D. Larrabee