

I. PHYSICAL ELECTRONICS

Prof. W. B. Nottingham
E. Ahilea
S. Aisenberg

J. F. Campbell, Jr.
D. H. Dickey

J. Greenburg
R. D. Larrabee
L. E. Sprague

A. ELECTRON EMISSION PROBLEMS

1. Thermionic Emission from a Planar Molybdenum Crystal

The purpose of this research is to study thermionic emission from molybdenum, using an ideal retarding potential experiment with single crystals for both emitter and collector. Essentially, it will involve an application of the techniques used by H. Shelton, of this laboratory, in a similar study of tantalum, the object being to make a comparison of the emission properties of these two refractory metals.

Specifically, we hope to verify the ideal retarding potential plot for molybdenum, and to determine therefrom the emission constant A and the work-function ϕ . It will be of particular interest to determine the existence in molybdenum of a hypothesized reflection of slow electrons at the emitter, the collector, or both, following the empirical relation (1):

$$R = e^{-\frac{V}{0.191}} \quad (1)$$

where V is the kinetic energy of emission (in electron-volts) with respect to the vacuum level. Evidence of such reflection was found by A. R. Hutson in a recent study of thermionic emission from a single crystal of tungsten (2), but it was not observed by Shelton or by W. J. Lange in tantalum (3).

Work was devoted to preparation of a sufficiently large and sufficiently perfect molybdenum crystal. The method used is the one employed by Lange and Shelton (4), that of heating the metal in mercury vapor by ac, using mercury as one electrode to provide a slowly moving temperature gradient along the length of the sample. The molybdenum ribbon in current use is 1 mil thick and 3-5 mm wide. Several fairly large crystals have been grown, with a brightness temperature of approximately 1550°C (by optical pyrometer) and a rate of approximately 1 cm per hour for the gradient. The largest specimens measure about 20 mm \times 2 mm. Back-reflection Laue pictures are being taken in order to determine their orientation, and to verify that the areas defined by the observed boundaries are monocrystalline.

It is evident that molybdenum recrystallizes at a much lower temperature than tantalum; for the latter, brightness temperatures of about 1950°C were used. This is fortunate in view of the greater tendency of molybdenum to evaporate. Temperatures as low as 1650-1700°C have caused excessive evaporation and consequent breakage of ribbon.

The immediate problem is that of obtaining a suitably smooth crystal surface. Crystals obtained thus far have been somewhat pitted, possibly because of initial surface

(I. PHYSICAL ELECTRONICS)

imperfections and inadequate outgassing of the mercury. Experiments are being made to determine the efficacy of electrolytic cleaning before recrystallization in removing these imperfections.

One of the successful techniques employed by Lange and Shelton to enhance crystal size was a 4 per cent cold roll of the tantalum ribbon prior to heating (5). Owing to the large crystal sizes that were obtained in molybdenum, no preliminary cold work was attempted. However, if the present crystals are found to be unsuitable, it would be worth while to investigate the effect of a few per cent cold roll on crystal development.

J. Greenburg

References

1. W. B. Nottingham, Phys. Rev. 49, 78 (1936).
2. A. R. Hutson, Phys. Rev. 98, 889 (1955).
3. W. J. Lange, Ph.D. Thesis, Department of Physics, M.I.T., May 1956, p. 110; H. Shelton, Ph.D. Thesis, Department of Physics, M.I.T., May 1956, p. 73.
4. W. J. Lange, Quarterly Progress Report, Research Laboratory of Electronics, M.I.T., Oct. 15, 1954, p. 1.
5. W. J. Lange, Ph.D. Thesis, op. cit., p. 16.

B. PHYSICAL ELECTRONICS IN THE SOLID STATE

1. Hall Effect in Lead-Sulfide Films

Hall-effect measurements on films of lead sulfide were made at room temperature to an accuracy of 2 per cent. A permanently low noise was obtained in the sample by making the fraction of the conduction current that passes through the Hall probes small. This was accomplished by making small, effective Hall contacts. The noise of three samples, deposited on quartz sheet, has not increased noticeably during a week of sample operation. The most recent Hall measurements show a linear relationship between conduction current and Hall voltage and between magnetic field (0-10,000 gauss) and Hall voltage. No thermoelectric effects were found.

Recently, a sample, employing the low noise contacts described above, was sealed inside a small sample bottle. A technique of protecting the sample by covering it with distilled water during the sealing operation proved to be sound in practice. Measurements are being made of the Hall effect as a function of the temperature of the sample and of the light incident on it.

D. H. Dickey

C. EXPERIMENTAL TECHNIQUES

1. The Spectral Emissivity of Tungsten

a. Purification of tungsten by heat treatment

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, to some extent, by proper heat treatment. For the present experiment, a tubular tungsten cylinder, 1/8 inch in diameter, constructed from ribbon, 1 mil thick and 0.5 inch wide, supplied by Kulite Tungsten Company, Union City, New Jersey, was maintained at 2750°K for 4 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 that was deposited

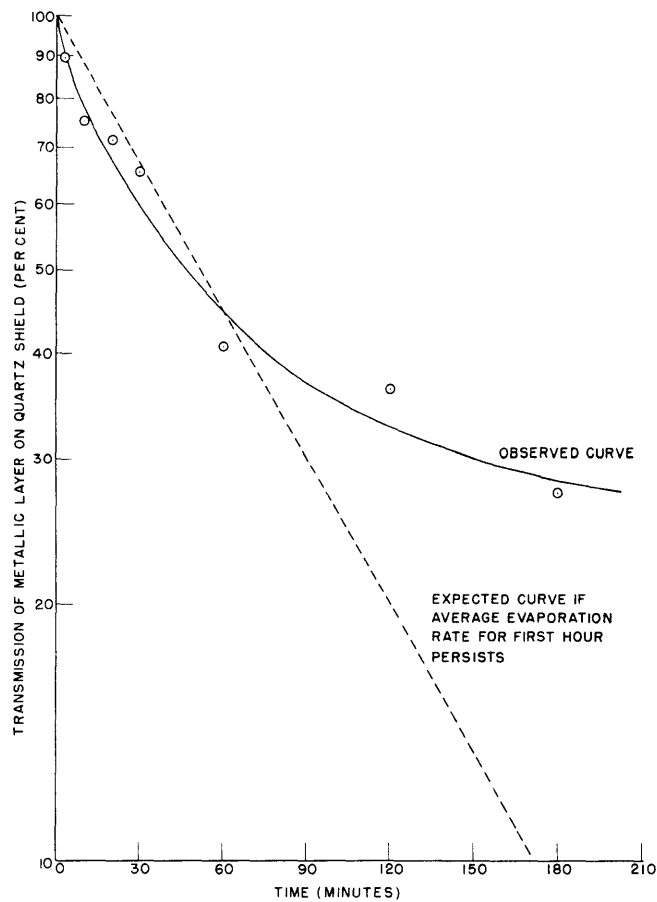


Fig. I-1. Measurements of the evaporation rate of tungsten.

(I. PHYSICAL ELECTRONICS)

on this shield was measured by comparing the apparent color temperature of the sample alone and the sample as 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-1) indicates that the initial rate of evaporation is quite large in comparison with the subsequent rates. In order to determine whether or not the rapid initial rate is caused by the evaporation of relatively volatile impurities in the specimen (which would purify the tungsten sample), the metallic specimen and a sample of untreated tungsten were spectrographically analyzed by Dr. Rockwell Kent, of Raytheon Manufacturing Company, and the following results were obtained:

Impurity Element	Mole Percentage Impurity	
	Untreated Sample	Treated Sample
Ag	0.001 to 0.0001	0.0003 to 0.00003
Ca	0.001 to 0.0001	0.001 to 0.0001
Cu	0.01 to 0.001	0.001 to 0.0001
Fe	0.01 to 0.001	0.001 to 0.0001
Mg	0.001 to 0.0001	0.001 to 0.0001
Mo	0.01 to 0.001	0.01 to 0.001
Ni	0.001 to 0.0001	Not detected
Pb	0.003 to 0.0003	0.001 to 0.0001
Sn	0.003 to 0.0003	0.003 to 0.0003

Although the untreated tungsten sample was comparatively free from impurities, the heat treatment noticeably decreased the concentration of some of the impurities.

With these data in mind, the tungsten sample that will be used in subsequent emissivity measurements was given the heat treatment described in the Quarterly Progress Report of July 15, 1956, page 4. When all the factors are considered, it is felt that this tungsten specimen is better than 99.99 per cent pure.

b. Basic method of measurement

A direct-comparison method is being utilized in which the radiant intensity from the tungsten source is compared with the radiant intensity from an approximative black body, and the spectral emissivity is computed from the basic relation

$$E_{\lambda T} = \frac{S}{B}$$

where $E_{\lambda T}$ is the spectral emissivity at temperature T and wavelength λ , S is the radiant intensity of the tungsten source, and B is the radiant intensity of the approximate black body.

The approximate black-body source is a hollow tungsten cylinder that is 1/8 inch in diameter, 4 inches in length, with a wall thickness of 1 mil. The cylinder has a 13-mil (diameter) hole in its lateral surface that serves as the source of black-body radiation. When the cylinder is heated to incandescence by the passage of well-regulated direct current, the small wall thickness ensures that the temperature differences between the inside and outside wall surfaces will be negligible. Consequently, a selected spot on the outside surface of the cylinder will serve as the tungsten source.

The light whose radiant intensity is to be measured is selected by an optical system that consists of a single quartz lens and a limiting aperture which forms the "entrance slit" of a monochromator. The light passing through the monochromator falls upon a detector (photomultiplier or PbS cell), and its intensity is measured to three-figure accuracy.

A correction, however, must be made for scattered light. A through hole backed by an exponentially shaped horn (see Fig. I-2) can be aligned with the optical axis of the lens system for the purpose of measuring this scattered component of radiation (which

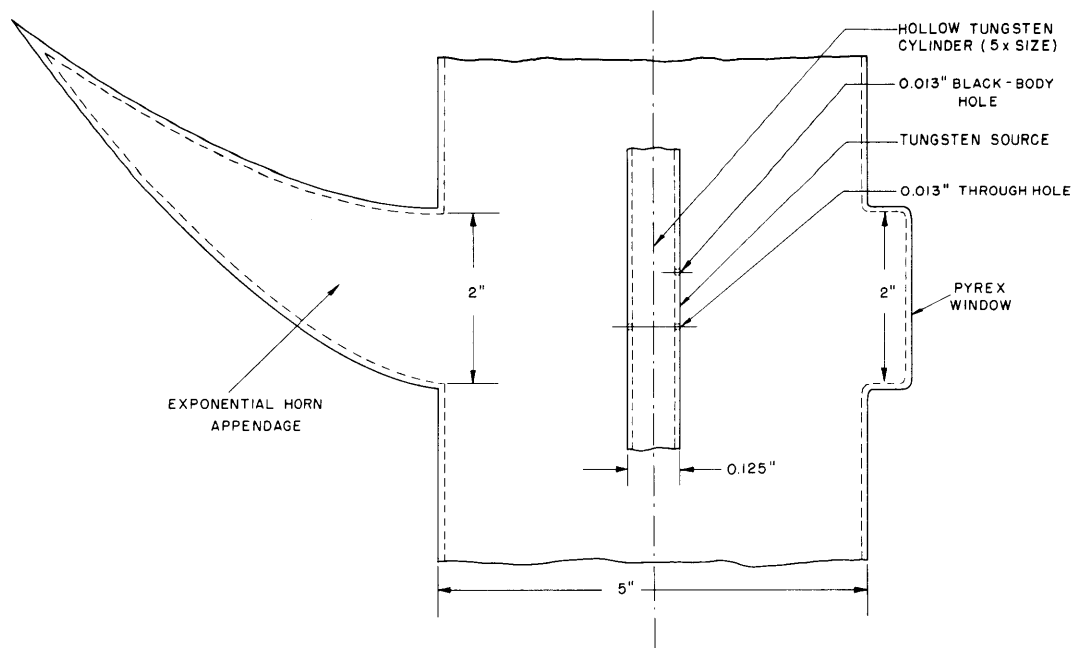


Fig. I-2. Side view of central portion of the emissivity tube.

(I. PHYSICAL ELECTRONICS)

amounts to approximately 2-5 per cent of the measured black-body intensity). If this through-hole reading is represented by α , the emissivity is given by

$$E_{\lambda T} = \frac{S}{B} = \frac{S' - \alpha}{B' - \alpha}$$

where S' and B' are the uncorrected photometer readings for the tungsten source and the black-body hole.

c. Preliminary measurements

Since the temperature coefficient of spectral emissivity is comparatively low, the absolute temperature of the source need not be known with great accuracy. Consequently, an ordinary disappearing-filament optical pyrometer was used to establish the temperature scale from approximately 1100°K to 2700°K. The maximum mean-square error of these measurements was about 10°K. Figure I-3 is a photograph of the tungsten source, as seen through the pyrometer telescope. The black-body hole, the through hole, and the unheated pyrometer filament are quite evident in the photograph.

Since the light that enters the black-body hole normally can be reflected out again by the rear wall of the cylinder, it is necessary to view the black-body hole obliquely to obtain black-body radiation. It was found that for viewing angles of approximately 4° from the normal (measured in the plane of the paper of Fig. I-2), the radiant intensity displayed a maximum value, and the light emerging from the hole at this angle was

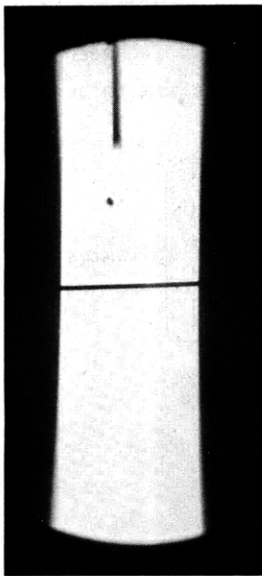


Fig. I-3. Photograph of the tungsten source.

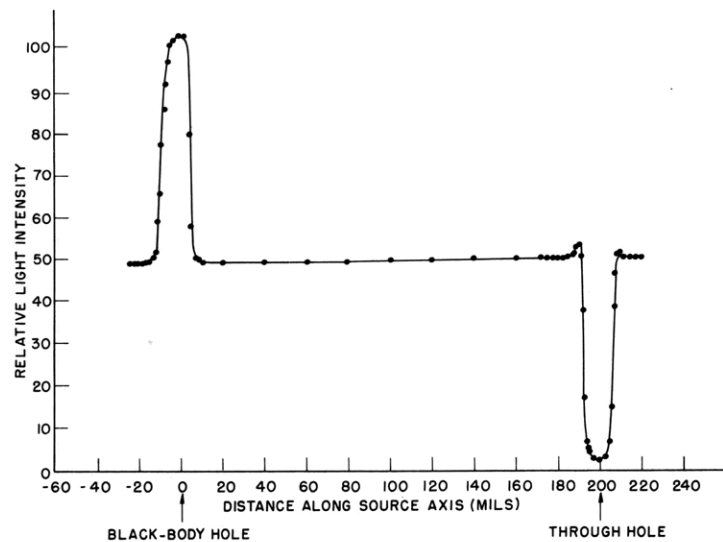


Fig. I-4. Cross section of emitted light along the source axis.

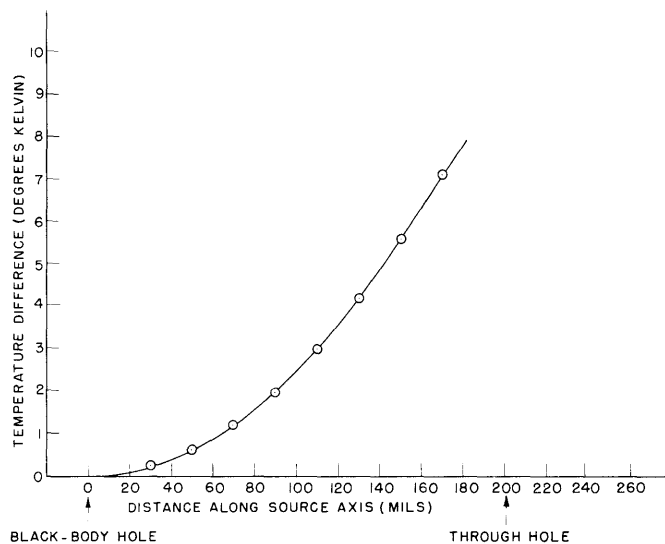


Fig. I-5. Temperature variation between the black-body hole and the through hole, for a black-body temperature of 2000°K .

unpolarized, indicating that black-body conditions were closely approximated.

The variation of light intensity as one scans the length of the cylinder through the black-body hole and the through hole is illustrated in Fig. I-4. The slight rise before the through-hole minimum is attributable to parallax. The photometer can see the edges of the hole in the rear wall of the cylinder; they appear as a thin annular ring of "approximate black-body light" (see Fig. I-3).

The variation of temperature between the black-body hole and the through hole, as determined by photometric measurements, is indicated in Fig. I-5. It is of interest to note that if a spot on the surface of the cylinder is selected close enough to the black-body hole, there will be a negligible temperature difference between them.

R. D. Larrabee

2. High Vacuum Studies: The MassITron

The work begun by H. Shelton (see Quarterly Progress Reports, Jan. 15, April 15, and July 15, 1955) on the MassITron, a mass-sensing ionization gauge, continues with the testing of a newly constructed tube of somewhat simplified design. Initial measurements with the new tube show slightly decreased sensitivity and greatly reduced resolution. The decreased sensitivity was traced to a badly positioned ion collector, and the tube is being reconstructed in order to eliminate this possibility. The cause of the decreased resolution has not been determined, and the original tube of H. Shelton is being retested. Quantitative measurements are planned of the partial pressures of gases

(I. PHYSICAL ELECTRONICS)

that are normally present in high-vacuum systems and of their clean-up, and further studies on the operation of mercury diffusion pumps are planned.

J. F. Campbell, Jr.

3. Ionization Gauge Control Circuit

A fail-safe over-pressure protector circuit was developed for use with the ionization gauge control circuit (see Quarterly Progress Report, Jan. 15, 1956, p. 11). It is designed to turn off the ion gauge filaments and associated equipment when the ion gauge reads approximately 1.5 of full scale on whatever range it is set.

A cascode dc amplifier and a 2-volt threshold feature make the circuit dependable and simple. The protector circuit can be easily connected to the ion gauge control circuit by placing it in series with the cable that goes to the ionization gauge without using any extra control leads. The over-pressure protector can also be built into the original control circuit in the initial construction stage.

S. Aisenberg

D. GASEOUS DISCHARGES

1. Ion Generation, Electron Energy Distributions, and Probe Measurements in a Low-Pressure Mercury Arc

Retarding potential measurements were made, with the use of probes in the mercury arc. The mercury vapor pressure was varied from approximately 2 microns to 30 microns. The residual gas pressure was less than approximately 4×10^{-8} to 3×10^{-7} mm Hg (N_2 equivalent), as measured by a Bayard-Alpert ionization gauge (used in conjunction with a liquid air trap). The probe surface potential was made reproducible by cleaning it by electron bombardment before each reading. A timer was used to make the electron bombardment period constant. The probe current was read about 2 sec after the probe was cleaned. About 48 probe curves (representing a total of more than 4000 individual measurements) were taken, an additional 20 per cent being taken as check points to insure stability and reproducibility. Calculations are still being made, but the check points agree to an average magnitude of approximately 0.9 per cent.

The stability of the arc current (and, therefore, the accuracy of the measurements) was limited by the stability of the 220-volt dc line. The line has a random fluctuation of approximately 1 per cent with occasional jumps of approximately 5 per cent. A method of taking data which was designed to insure detection (and correction) of an arc current change of 1 per cent or more without the loss of more than 5 measurements was developed. By taking most of the measurements between 12:00 A. M. and 6:00 A. M., when the laboratory was relatively deserted, quite satisfactory results were obtained.

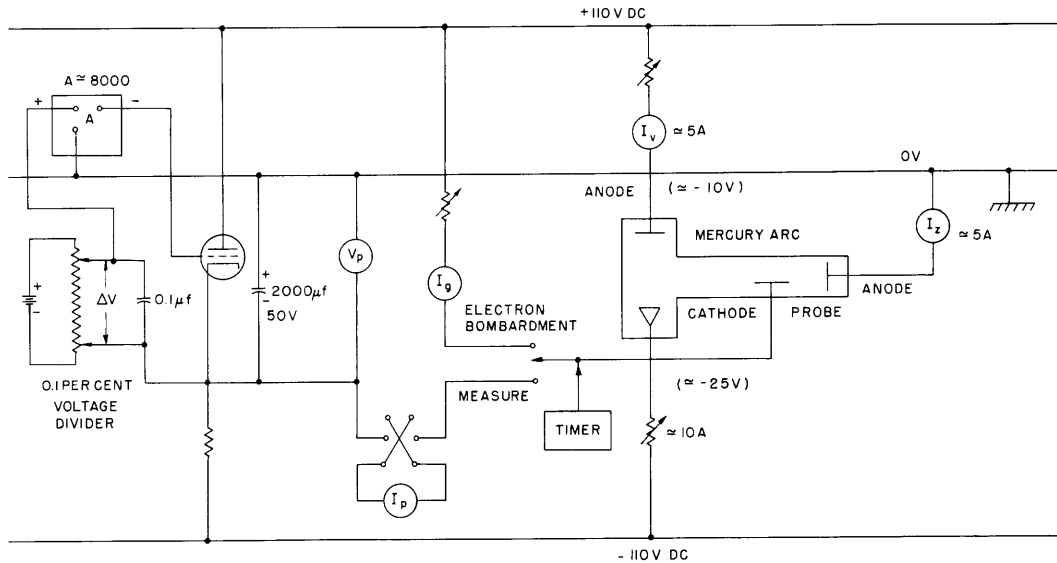


Fig. I-6. Low-impedance voltage source for retarding potential probe measurements.

The time for each measurement was about 15 sec. This included heating the probe for 5 sec by electron bombardment, changing the retarding potential to a new value (accurate to ± 0.1 per cent ± 3 mv), reading the probe current meter 2 sec after the probe was cleaned, recording the data, and determining whether or not the arc remained stable. The remaining time was spent in getting the arc and the equipment stabilized and in restarting and restabilizing the arc when it went out (a tedious job that takes approximately 4 hours).

A novel source of retarding potential was designed and used. The principle of operation is illustrated in Fig. I-6. The desired retarding potential was selected by using a Leeds and Northrup voltage divider (accurate to 0.1 per cent) and a stabilized battery source. The selected retarding potential (plus a feedback voltage) is fed into the grid of a specially designed battery-operated amplifier (with a drift of less than 0.1 mv per hour). The output of the dc amplifier drives a cathode follower which supplies the feedback voltage, and is capable of supplying up to 1 amp to the probe. Because of the negative feedback, the retarding potential will be within 0.01 per cent ± 3 mv of the retarding potential selected on the voltage divider, and the output impedance of the cathode follower will be less than approximately 5 milliohms. A correction, however, must be made for the voltage drop across the meter that is used to read the probe current. Calculations on the data that were obtained are being made.

In the domain of theoretical calculations, however, in order to permit the comparison of experiment with theory, an interesting and useful expression was obtained for the ionization frequency of a Maxwell-Boltzmann distribution with a superimposed drift

(I. PHYSICAL ELECTRONICS)

velocity v_o .

$$f(\vec{v}_1, v_o) \vec{d}\vec{v} = n \left(\frac{m}{2\pi k T_-} \right)^{3/2} \exp \left[- \frac{m(v_z - v_o)^2}{2k T_-} \right] \exp \left[- \frac{m(v_x^2 + v_y^2)}{2k T_-} \right] \vec{d}\vec{v}$$

The ionization frequency is given by

$$\nu_i = \left(\frac{8}{\pi} \frac{q}{m} \right)^{1/2} \frac{1}{(V_T)^{3/2}} \int_{V_a}^{V_b} \exp \left[- \frac{V_o}{V_T} \right] \frac{\sinh \left(\frac{2(V_o V)^{1/2}}{V_T} \right)}{\frac{2(V_o V)^{1/2}}{V_T}} VP(V) \exp \left[- \frac{V}{V_T} \right] dV$$

where ν_i represents the ions generated per second per electron, produced by electrons with kinetic energy between V_a and V_b electron volts; $P(V)$ is the probability of ionization in ions per meter per electron with kinetic energy V ; V_T is the voltage equivalent of T_- of the electron distribution function

$$V_T = \frac{k T_-}{q} = \frac{T_-(^{\circ}k)}{11,606} \text{ volts}$$

and V_o is the voltage equivalent of the drift velocity v_o

$$qV_o = \frac{1}{2} m v_o^2$$

$$qV_o = \left(\frac{8}{\pi} \frac{q}{m} \right)^{1/2} = 6.693 \times 10^5 \text{ m/s (mks)}$$

The ionization frequency integral can be readily evaluated by numerical integration.

S. Aisenberg