

## I. PHYSICAL ELECTRONICS

Prof. W. B. Nottingham  
Dr. H. A. Gebbie  
E. Ahilea

S. Aisenberg  
D. H. Dickey  
W. J. Lange

R. D. Larrabee  
H. Shelton  
L. E. Sprague

### A. ELECTRON EMISSION PROBLEMS

#### 1. Cathode Evaluation in the Presence of Space Charge

A detailed investigation of electron emission as a function of applied voltage has resulted in the development of theoretically derived functions needed for the interpretation of experimental data. In the retarding potential range over which the current is not limited by space charge, the relation between current and applied voltage ( $v$ ) is given by

$$\ln i = \ln i_0 - \frac{P-v}{V_T} \quad (1)$$

where  $V_T = T/11,600$ . The current ( $i_0$ ) is that which would flow with zero field at the emitting surface, but in general it is not observed because of the complications of space charge. The true contact difference in potential between the emitter and the collector is  $P$ .

Equation 1 applies only for a plane emitter located parallel to a plane collector. The more practical problem relates to concentric cylinders, and Schottky (1) developed the theory as it would apply to structures for which  $(r/R)^2$  is very small compared with unity. The radius of the emitter is  $r$  and that of the collector  $R$ . There has been a need for development of the theory of retarding potentials as it should be applied to cylindrical structures with a small ratio ( $R/r$ ). This theory has been developed and tables computed for the ratios 1.5, 2.0, 2.5, 3.0, 4.0, and 5.0.

The results of an experimental investigation with test diodes having well-activated oxide cathodes and a ratio of radii of 2.5 show that both the critical applied voltage at which space charge sets in and the current flowing under that condition can be determined with accuracy with the help of the theoretical analysis described above and a detailed consideration of the space-charge relations as they apply to this structure. These measurements yield the thermionic constants most suitable for a description of the cathode emission properties as a function of the temperature in the presence of space charge. The analysis also yields a direct determination of the temperature coefficient of the contact potential and a determination of the work-function of the collector.

W. B. Nottingham

#### References

1. W. Schottky, Ann. Physik 44, 1011 (1914). Tabulated by L. H. Germer, Phys. Rev. 25, 795 (1925).

## (I. PHYSICAL ELECTRONICS)

### 2. Reflection of Slow Electrons at a Metal Surface

The purpose of this research is a direct measurement of the reflection of very slow electrons at a metal surface. This is to be done by the use of two magnetic velocity analyzers; the first will supply a monoenergetic beam of electrons, while the second will select only those electrons which leave the target with full energy.

The parts of the apparatus to be mounted in a vacuum tube are now finished and out-gassed. The envelope itself has been constructed and vacuum-tested. The only alterations in the design as originally planned are improvements in the electron source and its alignment. To make full use of the slit size in the magnetic velocity analyzer, the source of electrons should be pulse-heated so that electrons are emitted from a uni-potential source. If, for example, the source or filament is ac heated the analyzer can select only those leaving a particular area, and on the average more electrons will be selected from the central portion of the filament. This disadvantage could be reduced by going to a larger filament, but to gain appreciably, a filament which consumed considerable power would be required. This would mean that the anode would receive more incident radiation, and its increase in temperature would mean possible gas evolution.

A consideration of the expected operating voltages on the anode showed that the emission current would be temperature-limited. Since temperature-limited emission

is strongly work-function dependent, it was decided to further insure uniform "illumination" of the entrance slit by using as the filament a tungsten wire in which a single crystal had been grown of length greater than the slit length. The recrystallization of 3-mil No. 218 tungsten wire was carried out, following previous polishing of the wire, in a well-known manner in an emission projection tube so the crystal boundaries and crystallographic directions could be identified. A photograph of the pattern is shown in Fig. I-1. The single crystal obtained was about 4 inches long and slightly twisted in azimuth and contained some slight emission irregularities. However, a portion of the wire is more than sufficient for the experiment.

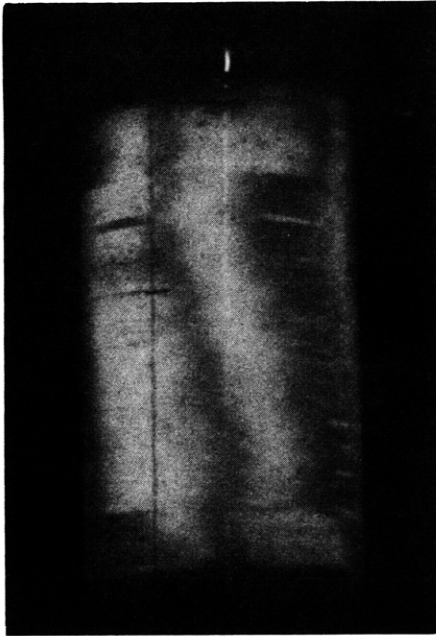


Fig. I-1  
Electron projection of recrystallized tungsten wire.

To ease the alignment problem, the 3-mil filament will be held in position by two cylindrical bearings made from nonmagnetic stainless steel hypodermic-needle tubing. Further,

two electrodes have been incorporated in the design, which will permit deflection of the beam onto the entrance slit of the analyzer, should the filament, anode slit, and analyzer entrance slit not be directly on the beam path.

The surface on which the experiment is to be performed is a single crystal of tantalum grown in a thin ribbon. A large single crystal grown in a 3-mil ribbon and studied both microscopically and with Laue reflection was shown to fill the 4-mm ribbon width for 3 cm in length. A reproduction of a microphotograph is shown in Fig. I-2. The Laue patterns showed the direction normal to the surface to be the 211 direction. This has been the direction found in studying other single crystals grown in tantalum. A typical Laue pattern is shown in Fig. I-3.

W. J. Lange

## B. PHYSICAL ELECTRONICS IN THE SOLID STATE

### 1. Surface Studies on Semiconductors

In the experiments on surface properties of germanium crystals effort was concentrated on the measurement of photoconductivity, and some new results were obtained. Following earlier work (1) we measured steady-state photoconductance in thin crystals of germanium as a function of light intensity for temperatures of approximately 220°K. As before, a nonlinear relationship was found which could be analyzed into a linear component and a saturating component. The latter can be attributed to the presence of traps or localized energy levels. It has now been found that the number of these traps that can be deduced from the saturating component can be changed by changing the ambient in contact with the crystal, suggesting that the localized levels are on the surface. Further, such changes were observed when there was no change in the linear component. The linear component is determined by the recombination of free-electron-

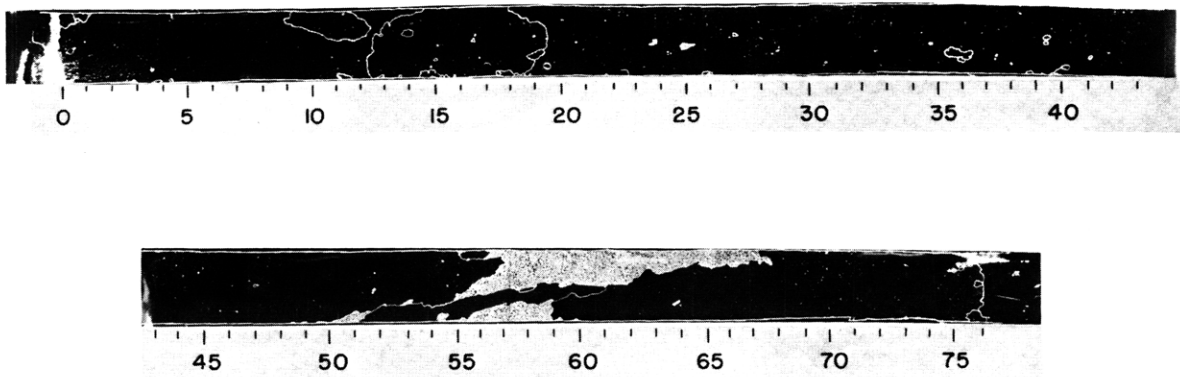


Fig. I-2

Microphotograph of recrystallized tantalum ribbon.

(I. PHYSICAL ELECTRONICS)

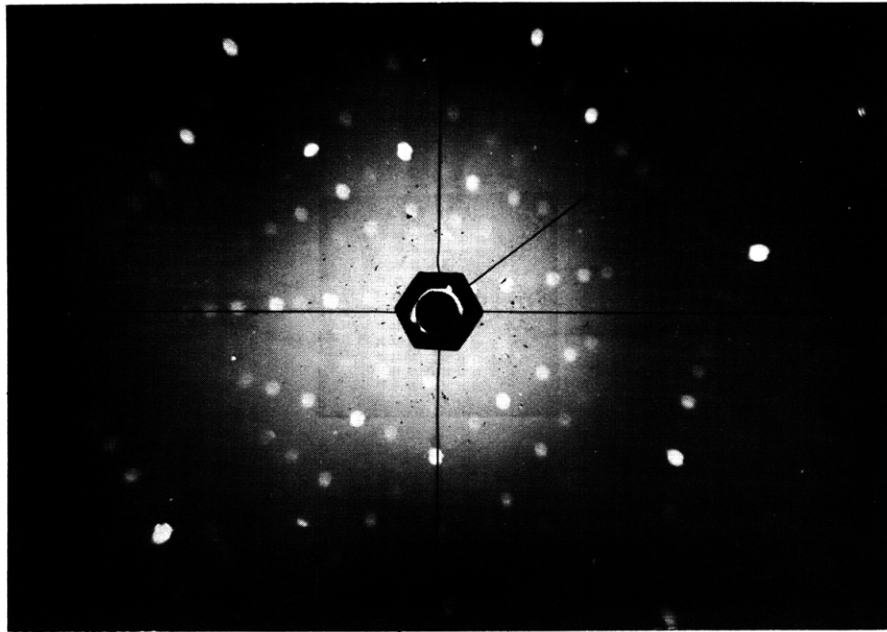


Fig. I-3

Laue back-reflection pattern of single tantalum crystal.

hole pairs which in these crystals was dominated by surface recombination. This suggests that more than one type of surface energy level may be present on the crystals. So far, these experiments have been made in poor vacuum conditions (approximately  $10^{-5}$  mm) so that specification of the state of the surface or of the contamination is impossible. This work will be continued with the specimens in a vacuum of approximately  $10^{-9}$  mm.

The measurements were simplified by a technique for obtaining a known scale of light intensity that will be described elsewhere.

H. A. Gebbie, E. Ahilea

References

1. H. Y. Fan, D. Navon, and H. A. Gebbie, *Physica* 20, 855 (1954).

C. GAS DISCHARGES

1. Ion Generation and Electron Energy Distributions

Knowledge of the electron energy distribution function (d-f) will permit the calculation of many important arc characteristics. Some of these quantities, such as the mobility coefficient, diffusion coefficient, random particle current density, and average electron energy, are predominantly dependent upon the "body" of the distribution function,

since the "body" includes the majority of the electrons. Other properties, such as ion generation and flow to a retarding probe, are dependent upon the "tail" of the distribution function, since these processes involve high-energy electrons only.

Because coulomb interactions are much more effective for slow electrons, the low-energy part of the distribution function is predominantly governed by electron-electron interactions and is therefore close to a Maxwell-Boltzmann (M-B) distribution. The average electron energy has been calculated as a function of  $E/p$  for an M-B distribution and a somewhat arbitrary dependence of electron mean free path upon velocity. Examination of the experimental velocity dependence of mean free path for slow electrons in Hg vapor yields a variation with the  $3/2$  power of electron velocity over most of the range of interest. The resulting calculated variation of average electron energy with  $E/p$  agrees very closely with the limited experimental data of Howe (1). When the experimental arc is in operation, the theory will be tested with additional data.

The diffusion equations are being solved in the ambipolar limit to the next order of approximation to determine the point at which the ambipolar approximations are no longer valid, and to extend the range of solution of the diffusion equations in a cylindrical plasma.

Work is being done on the "tail" of the distribution function. At the high-electron energies (for not too high electron densities) the predominant terms of the Boltzmann transport equation include the applied electron field and the electron-gas collisions. If one neglects the diffusion term in the transport equation and also neglects the inelastic collisions and assumes a constant mean free path for the electrons, one is left with the conditions for the Druyvesteyn distribution (D-D). The general distribution function is being calculated for a varying mean free path by expressions given in Chapman and Cowling (2). The characteristics of the D-D tail may be obtained from a plot of  $\log((V-V_p)^2 I_p)$  vs.  $(V-V_p)^2$  where  $I_p$  is the electron current to a retarding plane probe, and  $(V-V_p)$  is the potential of the probe with respect to the plasma potential. Once the d-f tail has been found experimentally, the direct ion generation can be calculated, and the relative importance of direct and cumulative ionization can be determined. Since the important part of the ion generation integral occurs within several volts of the ionization potential for most Hg arcs, the extensive data for  $P_i$  of Hg by Nottingham have been analytically represented to within several per cent for up to 5 volts above the ionization potential. This particular representation permits the ion generation integral to be easily and accurately calculated by the use of standard tabulated functions without the need for numerical integration.

Work is also being done on the solution of the Boltzmann transport equation; the electron-electron interactions are accounted for by the use of the Fokker-Planck terms calculated by Dreicer in his thesis (3). This equation will probably be programed for solution on Whirlwind I.

S. Aisenberg

(I. PHYSICAL ELECTRONICS)

References

1. R. M. Howe, Ph. D. Thesis, Department of Physics, M.I.T. (1950).
2. S. Chapman and T. G. Cowling, The Mathematical Theory of Non-Uniform Gases (Cambridge University Press, London, 1939).
3. H. Dreicer, Ph. D. Thesis, Department of Physics, M.I.T. (1955).

D. EXPERIMENTAL TECHNIQUES

1. Ionization Gauge Studies

Some additional information was obtained about the nonlinearity of ionization gauges. With the methods and equipment described in the previous reports, the variation of ion gauge constant  $K$  (defined by  $PK = i_+/i_-$ ) with electron emission current  $i_-$  was measured for a Research Laboratory of Electronics (RLE) standard triode ion gauge and a Bayard-Alpert ion gauge (Westinghouse design). The results are shown in Fig. I-4. It appears that an appreciable error in the absolute pressure may result (up to a factor of about 2) if the RLE gauge is calibrated at one electron current and used at another. Accurate relative pressure values may be obtained, however, if the same emission current is maintained.

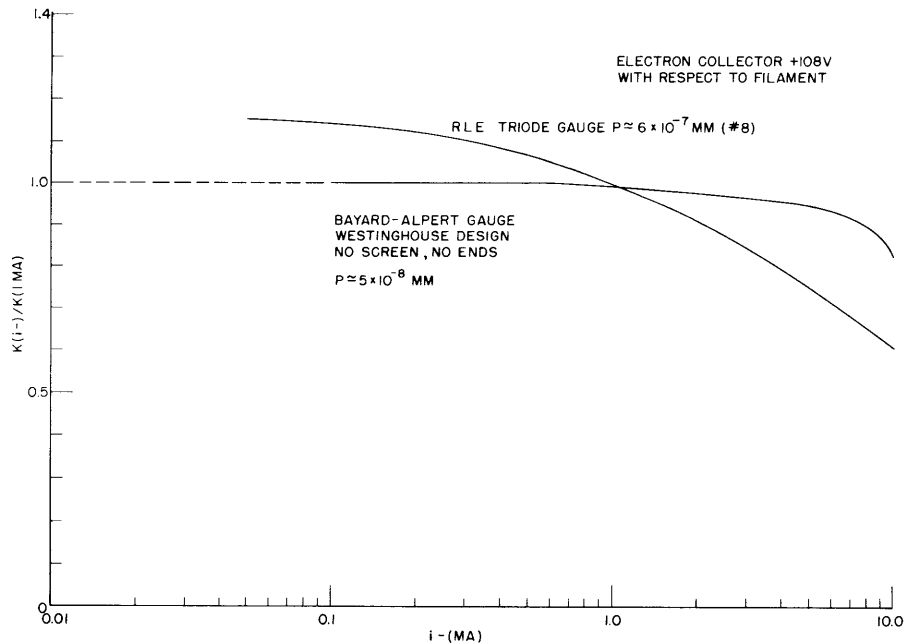


Fig. I-4

Normalized gauge constant vs. electron emission current.

## (I. PHYSICAL ELECTRONICS)

The current nonlinearity appears to be a function of the electron energy. Figure I-5 shows that the sense of the nonlinearity depends upon the electron collector potential.

Simultaneous calibration of a Bayard-Alpert ion gauge and an RLE triode gauge (a MacLeod gauge was used for the absolute pressure measurement) yields a nonconstant gauge constant for the Bayard-Alpert gauge in the  $10^{-4}$  to  $10^{-3}$  mm Hg pressure range with the gauge constant about 30 per cent higher at the higher pressure. Over the same range the RLE gauge constant is relatively independent of pressure.

To verify this pressure nonlinearity, a measurement was made of the ratio of the B-A gauge constant to the RLE gauge constant (for constant electron current) as a function of pressure (measured by the RLE gauge) for the B-A gauge and RLE gauge sealed off together. The pressure in the system was changed by the use of a slightly heated electron collector spiral in the RLE gauge to increase the pressure and by the use of ion cleanup to reduce the pressure. Figure I-6 shows the preliminary results, which indicate that since the normalized ratio of the two gauge constants is not constant with pressure, at least one of the gauge constants must vary with pressure. The variation of the gauge constant ratio is predominantly due to the B-A gauge and is seen to be about 30 per cent per decade in the  $10^{-3}$  to  $10^{-4}$  mm Hg pressure gauge and about 5 per cent per decade in the  $10^{-4}$  to  $10^{-5}$  mm Hg range.

A pressure nonlinearity is expected when the pressure becomes large enough so that the electron mean free path becomes comparable with the tube size, but the expected nonlinearity should lead to a decreasing gauge constant with increasing pressure. The reason for the observed pressure nonlinearity has yet to be determined, but it is probably connected with the increased collisions of ions and atoms with increasing pressure and therefore increased collection efficiency of the axial ion collector of the B-A gauge. The collection of ions for the RLE triode gauge is more direct, and therefore no such significant increase of ion collection efficiency is possible.

In view of this demonstrated pressure nonlinearity, the validity of the extrapolation of the gauge constant for the B-A gauge down to the  $10^{-9}$  mm range has yet to be proved. Calibration of the B-A gauge with a MacLeod gauge in the  $10^{-3}$  to  $10^{-4}$  mm range may result in an appreciable error. If the absolute pressure is not required to more than about a factor of 2, however, the current and pressure nonlinearities will probably not be too troublesome.

S. Aisenberg

### 2. High Vacuum Studies: The MassITron

The model of the MassITron reported on in the April 15, 1955, Quarterly Progress Report proved rather difficult to build. The difficulty stemmed primarily from the exclusive use of tungsten and tantalum. The brittle tungsten-to-tantalum welds broke easily and made the filament alignment very difficult. A better design illustrated in Fig. I-7

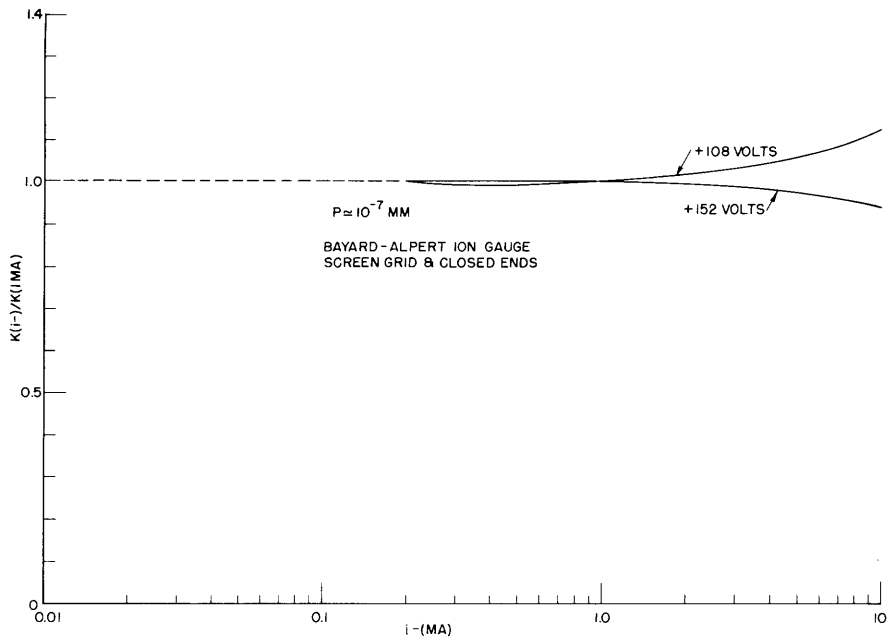


Fig. I-5

Voltage variation of current dependence of gauge constant.

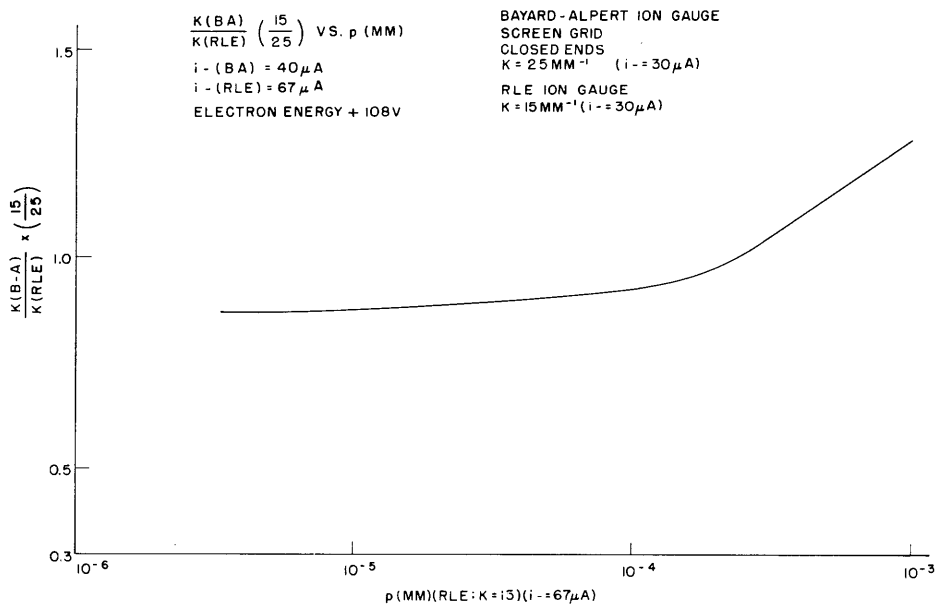


Fig. I-6

Variation of gauge constant with pressure.



is being tried. The main features are: the mounting of the filament with set screws to allow easy alignment and replacement, the mounting of all parts on bent tungsten press leads by use of straps on the parts, and the mounting of ion collector and part of its shield from one end of the tube while the rest of the shield and the box are welded to the assembly mounted on the press.

The dimensions will be the same as previously used, that is, 1 1/4 inches between the 0.025-inch slit and 0.025-inch beam, 7/8 inch of beam about 1/16 inch below center plane, and mounted in a flattened section of 57-mm Pyrex tubing designed to fit between the approximately 1 1/2 inch gap of an available 3000-gauss permanent magnet.

H. Shelton

### 3. Cleanup of Helium in Bayard-Alpert Ionization Gauge

A series of experiments is now being carried on with the Bayard-Alpert ionization gauge and recently constructed control equipment.

It was found that the temperature is being controlled within 2°C at 30°C, that the electron current varies by only 1 per cent, the electron collector voltage is constant to better than 0.5 per cent, and the pressure-measuring ion gauge control circuit is correct to about 2 per cent.

Cleanup curves were taken at two electron collector voltages. At each voltage, cleanup curves were recorded at three different values of electron current: 100, 300, and 500  $\mu$ a. These three curves will allow the determination of constants to be checked by theory. Also permeation curves at the various values of current and voltage were

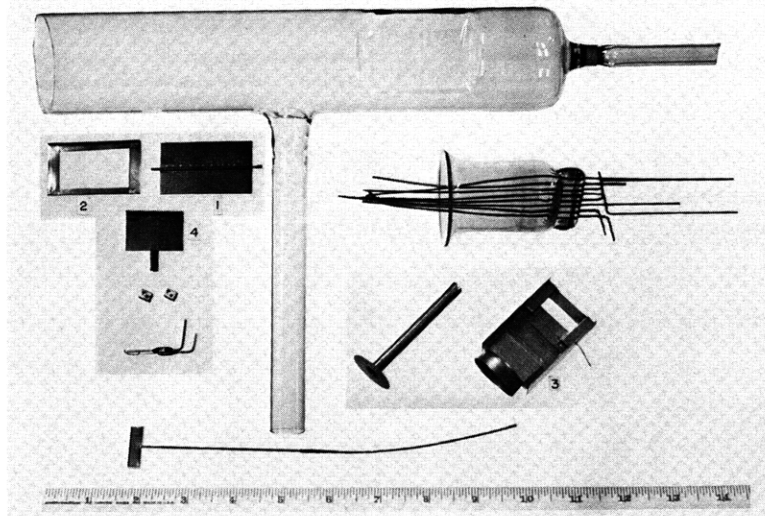


Fig. I-7

MassITron before assembly: (1) negative deflection plate; (2) "guard ring"; (3) center assembly; (4) positive plate.

## (I. PHYSICAL ELECTRONICS)

recorded and should allow a better determination of the relative ionization efficiency at the voltages involved.

After three curves are taken at the third and last values of voltage, the data will be analyzed and compared to theory.

Since the first voltage was chosen below the second ionization potential, the second voltage in the range of accumulative ionization, and the third above the potential required to produce a double ion of helium in one collision, the relative effects of single and double ionization can be determined.

Work was carried out on a special ionization gauge consisting of an extra grid structure completely surrounding a modified ionization gauge such as that used in the experiments mentioned above. The purpose of this grid is to control the number of ions reaching the glass walls of the tube where it is thought that cleanup can be taking place. By varying the potentials on the grid structures, it was found that the cleanup is only a function of the electron collector current and the electron collector voltage within experimental error of the equipment used. These studies are preliminary and will be considered in more detail.

D. H. Dickey

### 4. Hall Effect in Lead Sulfide Films

A research project was undertaken whose purpose is the study of the Hall effect in chemically deposited films of lead sulfide.

If one passes a current through a conductor (or semiconductor), perpendicular to a magnetic field, surface charges arise to produce an electric field transverse to the current and magnetic field. In principle, from the measurement of these transverse voltages, and the conductivity, one can determine the carrier concentration and mobility. In practice, difficulty is often met in interpreting the Hall effect because of unknown facts about the band structure. Usually the Hall data can be satisfactorily interpreted with the help of other experiments.

Experiments will be made on lead sulfide films produced by the Electronics Corporation of America. This organization has already done much research on these films and has found them to be quite stable and worthy of considerable work. In conjunction with their results, it is anticipated that the study of the Hall effect will produce additional knowledge about the films.

In preparing equipment for the measurement of the Hall effect in these films, the following points were considered. The films to be used have quite a high resistance, being about 1 megohm at room temperature and increasing to as much as  $10^6$  megohms at liquid air temperature. Thus very high impedance equipment must be used. Preliminary measurements indicate that one instrument suitable for measuring the small Hall potentials at a high input impedance is the vibrating reed electrometer. As the

## (I. PHYSICAL ELECTRONICS)

films are to be studied under various amounts of illumination and at temperatures of 400°K to 77°K, a special dewar flask with associated temperature-controlling equipment must be used. A dewar flask with a window for illumination purposes and temperature control equipment was designed and is being constructed. A magnet with special pole pieces was set up and is now being calibrated and tested for homogeneity.

D. H. Dickey