ION SOURCE FOR VAN DE GRAAFF GENERATOR

by

John T. Rogers

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Dean of Academic Science and Business Administration

APPROVED:

Head of Department

Supervisor or Major Professor

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INTRODUCTION

The first Van de Graaff accelerator was built in 1931. The advent of the atomic age has accelerated the development and use of such installations, which are used chiefly for the production of monoenergetic nuclear particles. The value of such accelerators as basic research tools is well recognized.

Some of the uses of such machines are for the investigation of the nuclear structure of matter, studies of the behavior of material upon exposure to radiation, and as sources of highly penetrating X-rays.

Briefly, the accelerator consists of a high voltage electrode insulated from ground, a source of charged particles, a charge spraying system with revolving belt, and an accelerating tube through which the particles are accelerated to ground. Associated equipment includes a voltage control and stabilization system, an analyzing magnet, and a vacuum system. High voltage is applied to a polished electrode by spraying charge on an endless belt. Ions from a source within the electrode are accelerated through an evacuated tube to strike a target at ground potential.

The design of this machine has changed greatly since its inception. Size has been greatly reduced and the

energy increased. Perhaps the greatest change has been in the source of charged particles. Early high voltage machines used ion sources of the filament type. However, the r-f type has replaced these in positive ion accelerators. The development of the r-f ion source provided a source which was comparable to other types in size and power consumption and superior in other respects. Its efficient operation permitted further changes in the design of Van de Graaff machines.

Operation of the source is as follows: hydrogen is admitted to a partially evacuated Pyrex vessel; r-f power is applied to remove the electrons from the hydrogen atom; a magnetic field is supplied to increase the ionizing path of electrons; up to 6 kv is applied to the source to extract the protons.

For use with an accelerator an ion source should exhibit[1]:

1. Stability and long life.
2. Large beam current.
3. Low gas consumption.
4. A high proton percentage.
5. Simplicity of construction.
6. Low power consumption.
7. Compactness.

The basic design of the Moak[6] type r-f ion source

fulfills the above requirements. The ion source of the two million volt electrostatic accelerator at Virginia Polytechnic Institute is of the Nook type.

REVIEW OF LITERATURE

There are four classes or types of ion sources. These are the high-voltage canal-ray ion source, the low-voltage capillary-arc ion source, the ion source with oscillating electrons and magnetic focusing, and the high-frequency ion source. The most recent type to be developed is the high-frequency or r-f ion source. It is used on most kevatron and Van de Graaff machines today.

The discovery and early development of the r-f ion source was made in England. The first account of an r-f ion source was published in the British periodical Nature by Thoneman[1] in 1946. The ion source described would produce a beam current of 10 ma at a gas pressure of 10^{-3} mm of mercury and 10 kv extraction voltage. The power consumed was 200 watts.

The following year Rutherglen and Cole[2] published an account in Nature of an improved r-f ion source which produced a beam current of 0.4 ma at a pressure of 15 microns and an extraction voltage of 2.8 kv. They also analyzed the beam of particles for composition. Of the total focused beam of 0.4 ma, the proton current was .24 ma, the diatomic current was .11 ma, the triatomic current was .012 ma, and the heavy ion current was .04 ma. This beam was 60 percent proton in composition.

Various r-f ion sources are described by references 1) thru 7). Foremost among these is the one described by Moak, Reese, and Good[6]. It is typical of the ion sources in use today and has come to be known as the "Moak ion source". The Moak ion source is capable of producing 1.25 ma of positive ions, over 90 percent of which may be protons. The power consumed is approximately 30 watts. The pressure in the discharge vessel is in the micron range.

A comparative survey of ion guns was given by Hoyaux and Dujardin[8] in the July 1951 issue of Nucleonics. Operating requirements and capabilities are discussed. A summary of r-f ion sources developed up to the time of publication is given by Ward[9] in 1950. Hall[5] has also given a summary of ion sources in a paper in which he describes an r-f ion source.

As early as 1920 Wood[10] showed that if a hydrogen discharge is established in a long clean Pyrex tube with electrodes at each end, the middle of the tube exhibits a nearly pure Balmer spectrum while the ends of the tube display principally the molecular spectrum of hydrogen. The experiments of J. J. Thompson and G. P. Thompson[11] in 1928 demonstrated that a hydrogen discharge set up in an electrodeless vessel exhibits an almost pure Balmer spectrum.

Since the mean free path of the ions in the discharge is greater than the dimensions of the discharge vessel for the pressures commonly used, the volume recombination effects are negligible when compared to the surface recombination effects. In 1943 Smith[12] determined the recombination coefficients of various materials. Some of which are as follows: Pyrex, 2×10^{-5}; quartz, 7×10^{-4}; Al_2O_3, 0.33.

The dependence of the discharge upon frequency of excitation, vessel size, magnetic field, gas pressure, and probe voltage has been investigated. It was first shown by Gill and von Engel[13] that larger vessels require lower frequencies in order to sustain the discharge. This result was verified when Koch and Neuert[14] demonstrated that the discharge will have an r-f impedance which is capacitive, resistive, or inductive depending upon the strength of the magnetic field, frequency of excitation, and vessel dimensions. In this survey of r-f ion sources Ward[9] points out that the probe voltage has little effect upon the monokinetic property of the focused ion beam.

The r-f ion source is by no means fully developed. Even though the Moak design is representative of the ion sources in use today, it is constantly being modified and adapted to the particular machine for which it is to be

used. Allison and Norbeck[7] have published a description of an r-f ion source which was developed from the Moak design. This ion source was developed for use with a kevatron. It has provision for isolation from the accelerating tube. This allows the source to be dismantled and cleaned without losing the vacuum in the accelerating tube. There are other internal modifications to the structure.

An r-f ion source has been described by Allan and Sarma[16] in which the height of the silica sleeve above the tip of the cathode may be varied. Thus, the plasma may be focused over the exit canal for optimum performance.

Parameters affecting the resonances of the r-f oscilator were studied by Koch and Neuert[14]. The ion current of an r-f ion source has been studied as a function of r-f power, frequency, gas pressure, and extraction voltage by Eubank, Peck, and Truell[15]. They found that these parameters were related by an additional one, plasma density. The r-f ion source used for this investigation yielded up to 15 ma of hydrogen current consisting of 80 to 90 percent protons.

A general discussion of the problems found in ion sources is given in "The Production of Intense Ion Beams" by P. C. Thoneman[17].

DESIGN

A. Basic Design

The design of the ion source for the Virginia Polytechnic Institute electrostatic generator is essentially that of the Moak ion source. That is, the vessel for containing the discharge is of Pyrex with a minimum of metallic surface exposed, it utilizes capacitive coupling of the r-f power to the ion bottle at 100 megacycles, and there is provision for a magnetic field of approximately four hundred gauss.

The work of Wood[10], the Thompsons[11], and Smith[12] was responsible for the selection of a long Pyrex bottle for the discharge vessel. The ion bottle used has exactly the same shape and size as the Moak design. The orientation of the silica sleeve and aluminum cathode with respect to the ion bottle remain unchanged.

The probe power supply, oscillator power supply, and oscillator are essentially the same as those of the Moak design. Direct current for the magnet coil is supplied by a selenium rectifier.

The flow of hydrogen to the ion bottle is controlled by a palladium leak.

Probe voltage and hydrogen flow to the ion bottle are controlled by variac settings. The focusing rheostat

and variacs are positioned by lucite rods which are driven by selsyn motors mounted at the bottom of the accelerator. Some detail of the arrangement of these parts in the completed ion source may be seen in Fig. 1.

Power for all components is supplied by a five hundred watt alternator which is located within the upper pulley supporting the charging belt.

The design of the focusing rheostat was governed by two basic considerations, the space available and the size of the resistors to be used. The arrangement of the resistors around a circle is shown in Fig. 21. Forty-one 30 megohm S.S. White resistors in series are used to vary the voltage on the focusing electrode with respect to the ion source. This voltage difference is of the order of 70 kv.

Almost the whole focusing depends upon the first electrode[8]. The focusing electrode is mounted on the second aluminum electrode of the accelerator tube. The focusing electrode extends through the first electrode.

B. Modification

The major change that was made in the Moak design is the division of the ion source base into three parts. Part II was made so that the ion source could be removed from the accelerator tube. Part III was made a separate

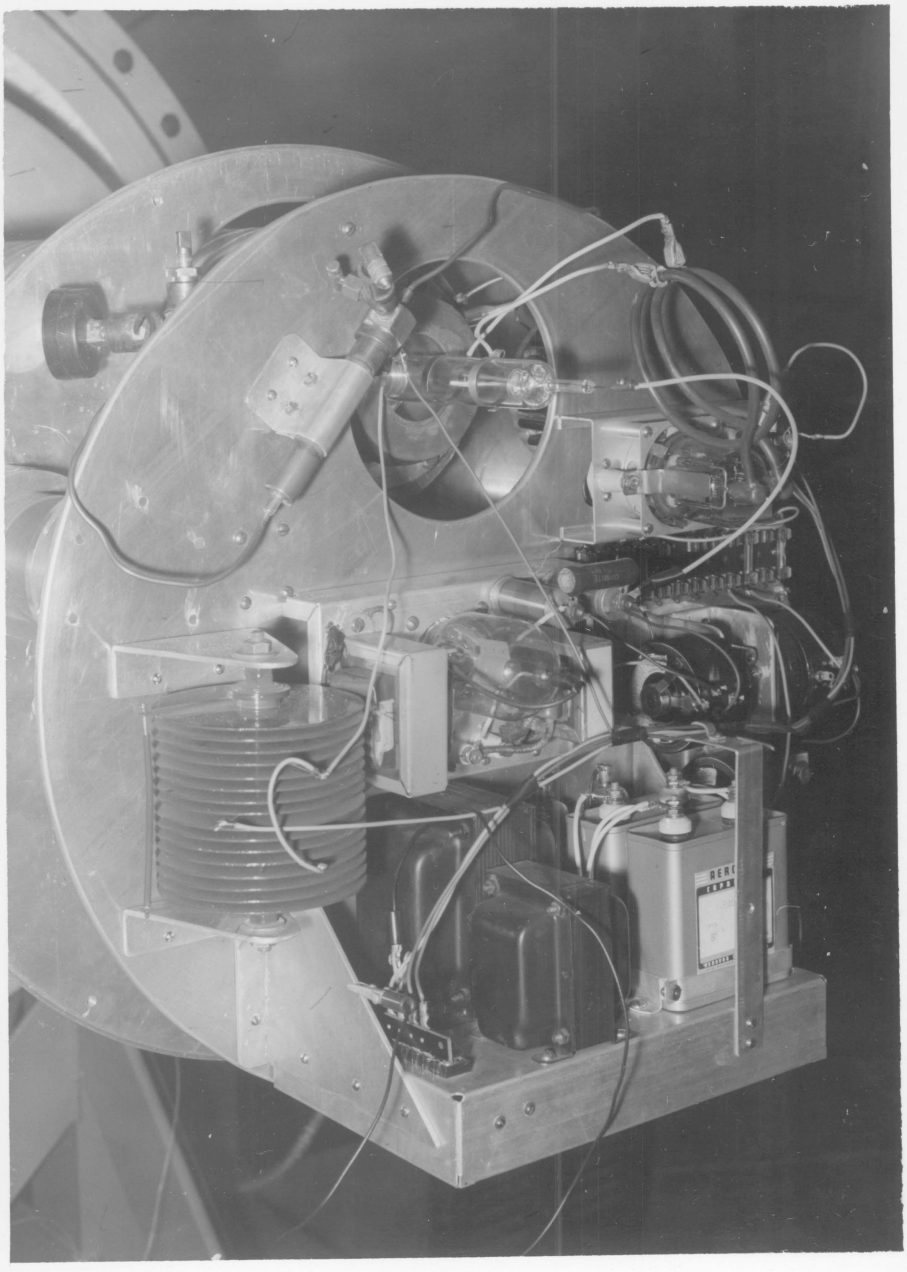


Fig. 1 Completed Ion Source

part for ease in fabrication and renewal. Pitting of the exposed part of the electrode takes place with erosion in the canal. This part must be renewed after approximately 300 hours of operation.

Because of the change in the geometry of the base, The hydrogen entry canal had to be reoriented. Two holes were drilled obliquely from the top surface to meet within Part I.

The diameter of the exit canal for the discharge was reduced from 1/16 inch in the Moak design to .02 inches. After thirty hours of operation the ion source failed to operate properly because of a clogged exit canal. Particles of sputtered aluminum and others of undetermined origin filled the canal tightly. The diameter of the exit canal was increased to .04 inches for satisfactory operation.

The reduction in the canal diameter causes the beam current to be greatly reduced because the beam current varies roughly as the square of the canal diameter[6]. This reduction in beam current is partially compensated for by increasing the magnetic field to about 400 gauss. The advantages of the smaller canal size are that the pressure rise in the accelerator tube is limited and less hydrogen is used, thereby increasing operating time. Even with the reduced beam, the accelerator performance will not be

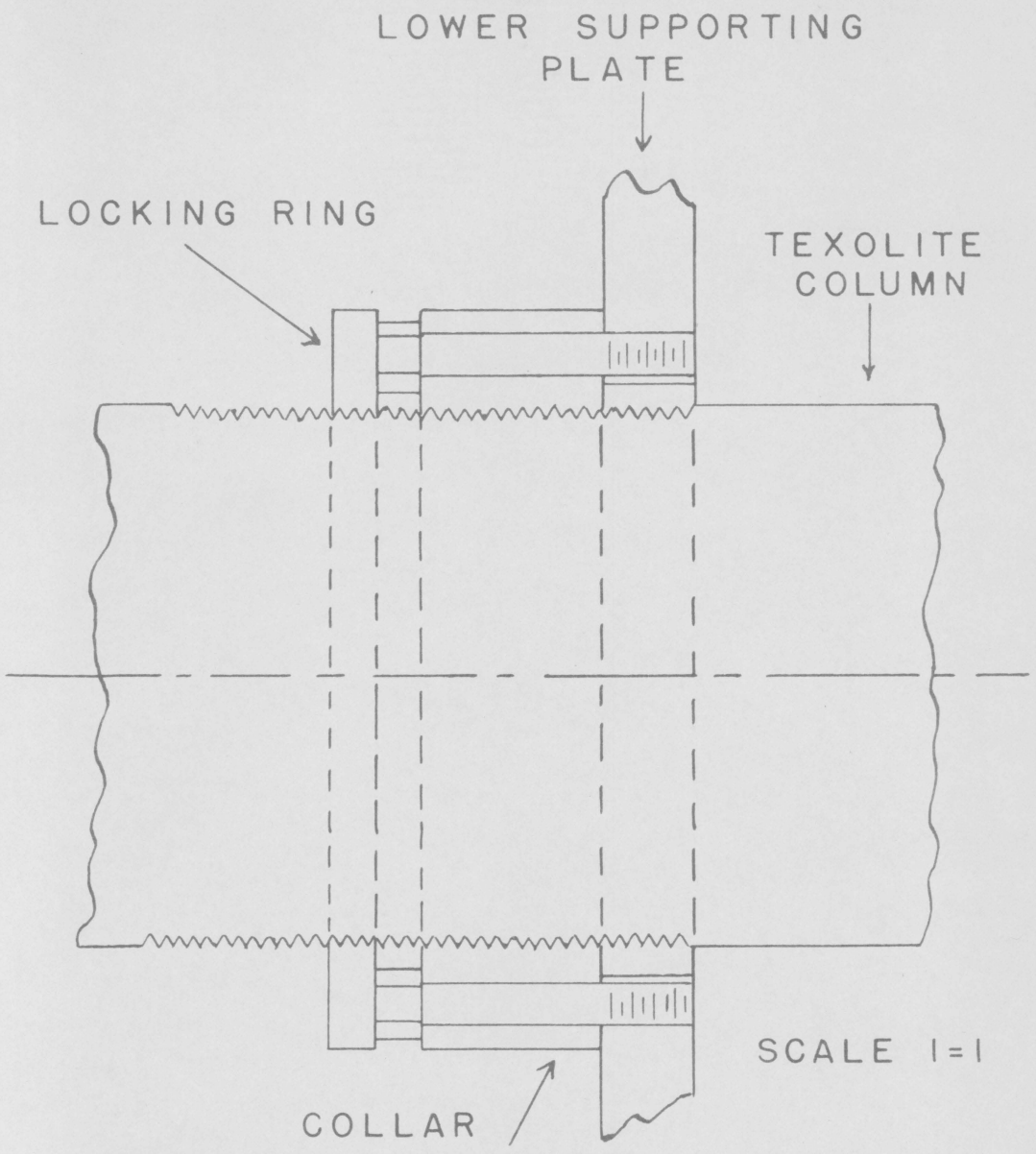
limited by the ion source.

Operation of ion sources of the Moak type has indicated that it is not necessary to provide a steel disc around the ion bottle for defocussing secondary electrons. A Pyrex projection built into the ion bottle stops the secondary electrons and serves to shield the tungsten annode also.

CONSTRUCTION

In the construction of all parts care was taken to avoid leaving sharp edges and rough surfaces. This was particularly true of all surfaces exposed to a large potential gradient such as the high potential electrode, bottom surface of the lower platform, accelerator tube electrodes, and corona ring assembly. Surfaces such as the Texolite columns and charging belt were also given special care to avoid handling with bare hands.

Most conventional electrostatic generators are built with the accelerator tube vertical. Limited space required that the Virginia Polytechnic Institute electrostatic generator be built horizontally. The accelerator proper is mounted on a vertical steel plate which is in turn fastened to a pressure tank end mounted upon a stand of construction steel. An inert atmosphere of nitrogen and carbon dioxide is contained in a tank which is rolled up to the fixed tank end to enclose the electrostatic generator. Three Texolite tubes, three inches in outside diameter, are mounted horizontally from the steel bottom plate. They are held in position by collars and locking devices similar to those shown in Fig. 2. Two aluminum plates are fastened to the ends of the horizontal Texolite columns. Details of the securing collars and locking



SECURING COLLAR

FIGURE 2

rings may be seen in Fig. 2. Most of the ion source components are mounted to these two aluminum plates. The remainder of the components are mounted on the accelerator tube which is bolted to the tank end. A spun aluminum hood serves as the high potential electrode. It covers the ion source entirely and is secured to the innermost of the two aluminum base plates. Control of the ion source is accompolished through the rotation of four Lucite rods which extend from the steel plate to the aluminum supporting plates. Some detail of the general arrangement may be seen in Fig. 3.

The inner aluminum supporting plate is 24 inches in diameter and ½ inch thick. It was fabricated by Spincraft Incorporated of Milwaukee, Wisconsin. The outline of the openings cut into this plate is shown in Fig. 4. The upper plate is 22 inches in diameter and ¼ inch thick. It has a circular opening 6 1/8 inches in diameter to allow room for the ion bottle and r-f coupling leads. The two aluminum base plates or platforms are separated by a distance of six inches.

The aluminum hood which forms the high potential electrode was also made by Spincraft Incorporated of Milwaukee, Wisconsin. The hood is a hollow, hemisphere of aluminum welded to a section of aluminum sheet which has been formed into a right circular cylinder. A cross

Fig. 3 High Potential Electrode

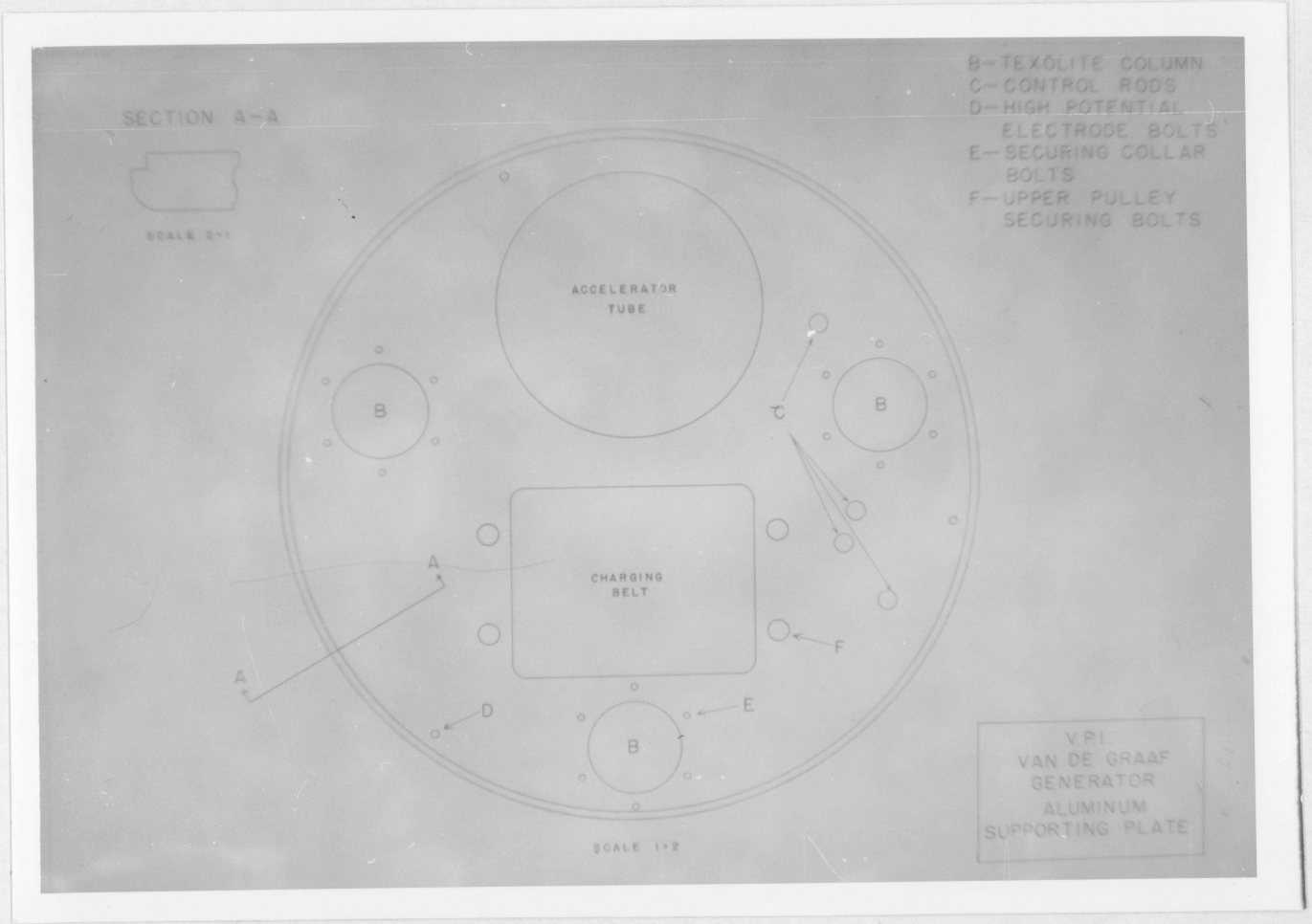


Fig. 4 Aluminum Supporting Plate

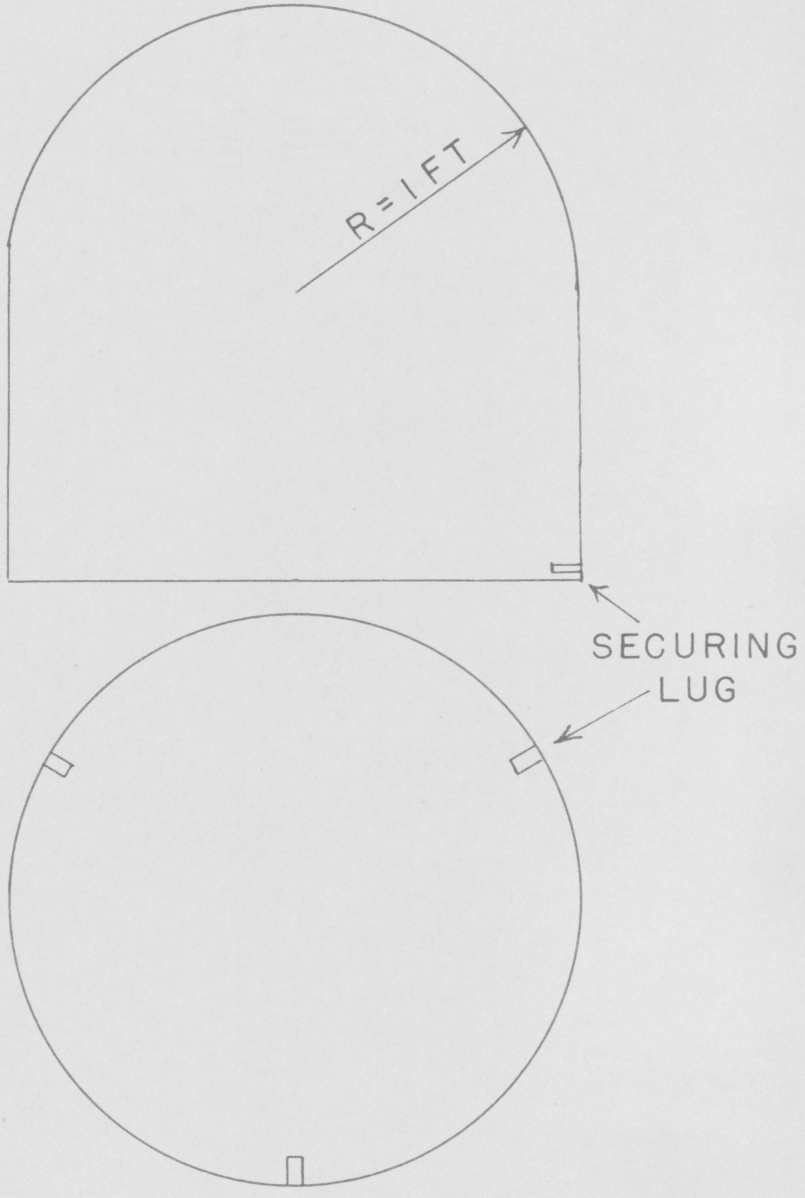
sectional view of the assembled piece is shown in Fig. 5. The hood was made of 1100-Aluminum and has a high lustre finish to reduce electrostatic leakage. There are three lugs measuring 1 x 3/4 x 1/4 inches welded to the inside of the hood. They are equally spaced about the inside circumference at a distance of 1/8 inches from the bottom.

Three securing bolts pass through the inner plate and screw into the lugs welded to the inside of the high potential electrode.

The ion source consists of a Pyrex discharge vessel and three aluminum base parts. The Pyrex ion bottle is the same as that of the Moak design[6]. It was purchased from Radiation Counter Laboratory of Skokie, Illinois.

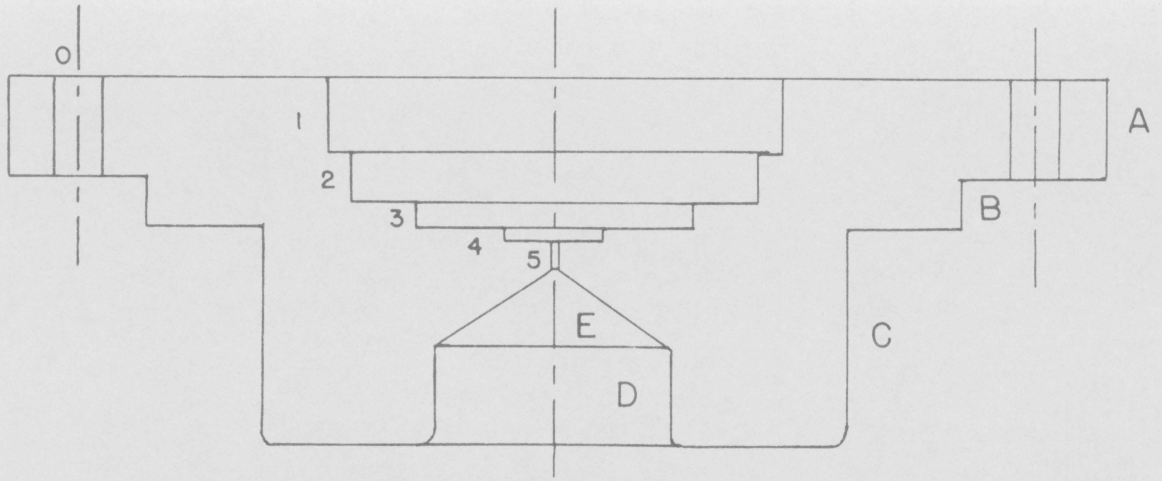
Part I supports the ion bottle and a magnetic coil. Dimensions are shown in Fig. 6. Its position relative to parts II and III is shown in Fig. 10. That portion which fits into the accelerating tube was given a high polish. The hydrogen entry canal is shown in Fig. 7 as a dotted line. It was made by using a brass drilling jig which had been milled to fit the contour of the part. Guide holes in the drilling block were drilled before the block was cut to fit the base part.

Part II was bonded to a porcelain ring of the accelerator tube with Vinyl-Seal during fabrication of the accelerator tube. Again, all exposed surfaces were



HIGH POTENTIAL ELECTRODE

FIGURE 5



ION SOURCE BASE— PART I

	DIA-METER	HEIGHT
0	5.0	——
1	2.375	0.375
2	2.125	0.25
3	1.4375	0.125
4	0.50	0.0625
5	0.04	0.125

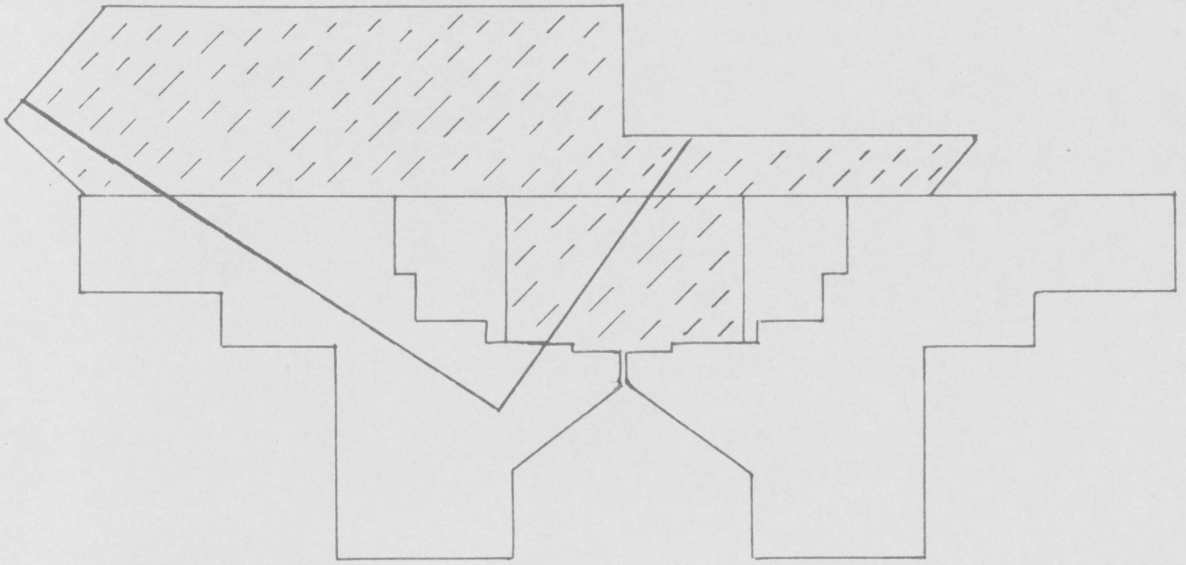
ALL MEASUREMENTS INCHES

	DIA-METER	HEIGHT
A	5.75	0.5
B	4.25	0.25
C	3.0625	1.125
D	1.25	0.4375
E	——	0.50
——	——	——

FIGURE 6

SCALE 1:1

DRILLING BLOCK IN PLACE



HYDROGEN ENTRY CANAL

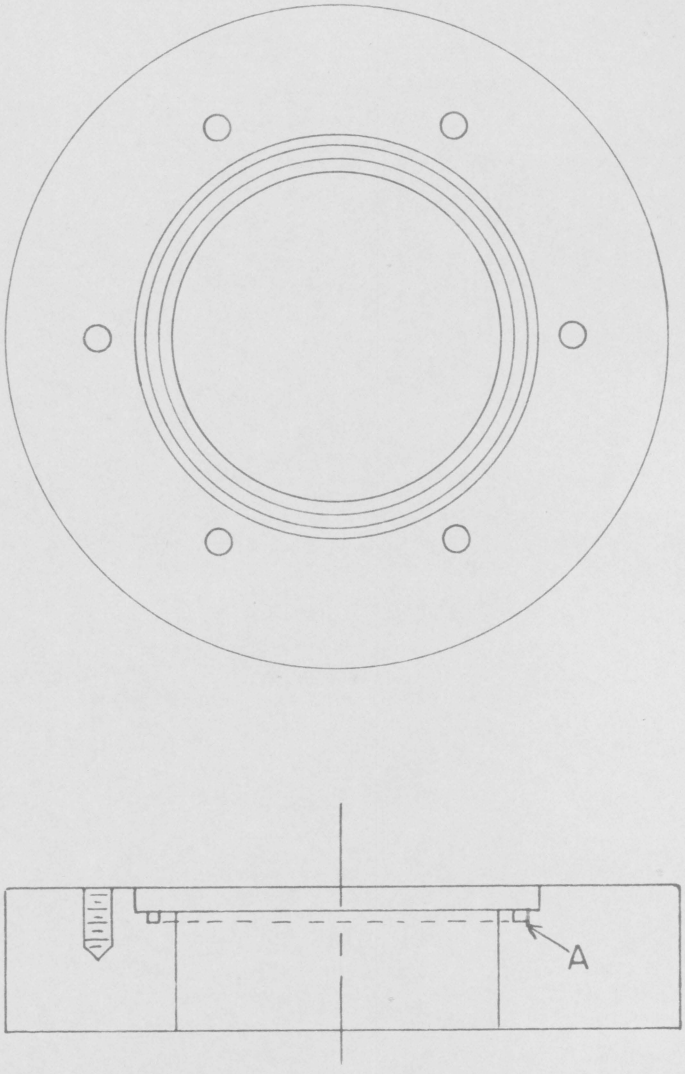
FIGURE 7

highly polished. The "O" ring groove shown in Fig. 8 provides a tight seal between parts I and II.

Part III forms the exit canal for the ions. It also serves as the cathode. Figure 9 shows the shape of this part. The canal diameter is 0.04 inches, which corresponds to a #60 drill. When the ion source is assembled, the silica sleeve extends beyond the cathode by 5/32 inches. Before final assembly Part III was polished and washed with acetone.

The silica sleeve is subjected to extremely high temperatures. For this reason only those sections of a given tube are chosen which are completely free of flaws and uniform in cross section. The length of this part is critical since it focuses the plasma over the exit canal. The ends of a section of tube were ground perpendicular to the length, with a total length of 3/4 inches. The grinding was done with carborundum and water on a copper plate fastened to a potter's wheel. The segment of quartz tubing was held in a brass block during grinding. Perpendicularity was insured by drilling an axial hole for the tube and then cutting the grinding surface in a lathe. After grinding the sleeve was lightly fire polished to cover traces of the carborundum.

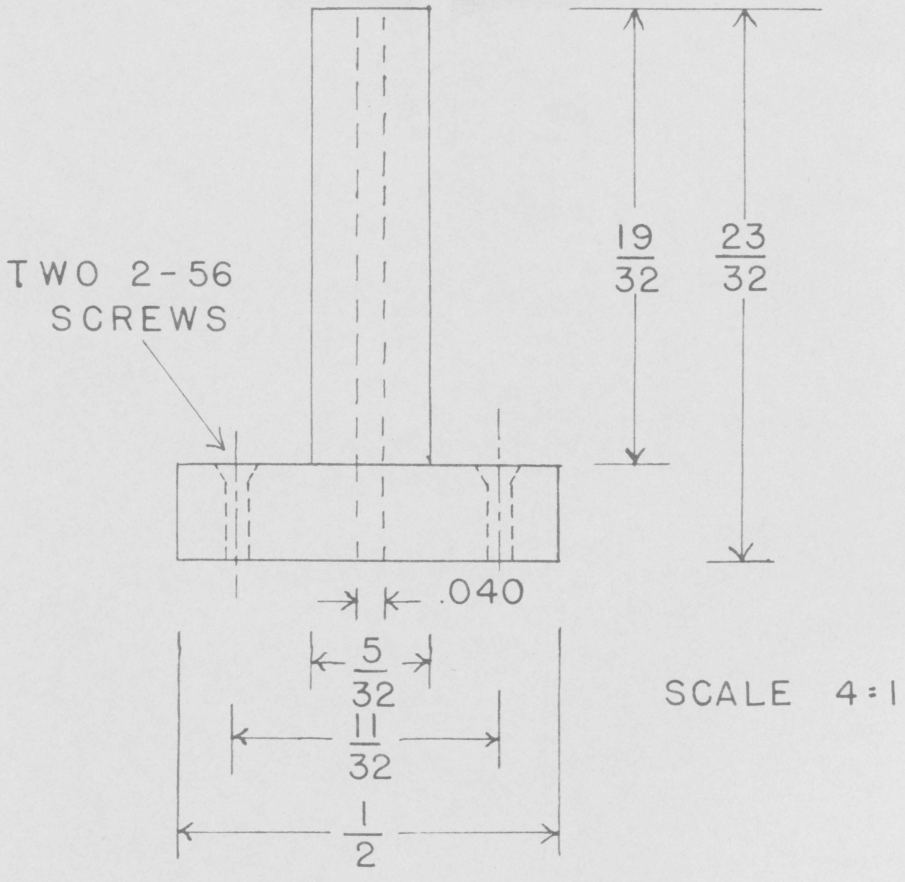
A twenty-five percent normal solution of hydrofluoric acid was used to clean the ion bottle and silica



A — "O" RING GROOVE SCALE 1:2

ION SOURCE BASE — PART II

FIGURE 8



ION SOURCE BASE

PART — III

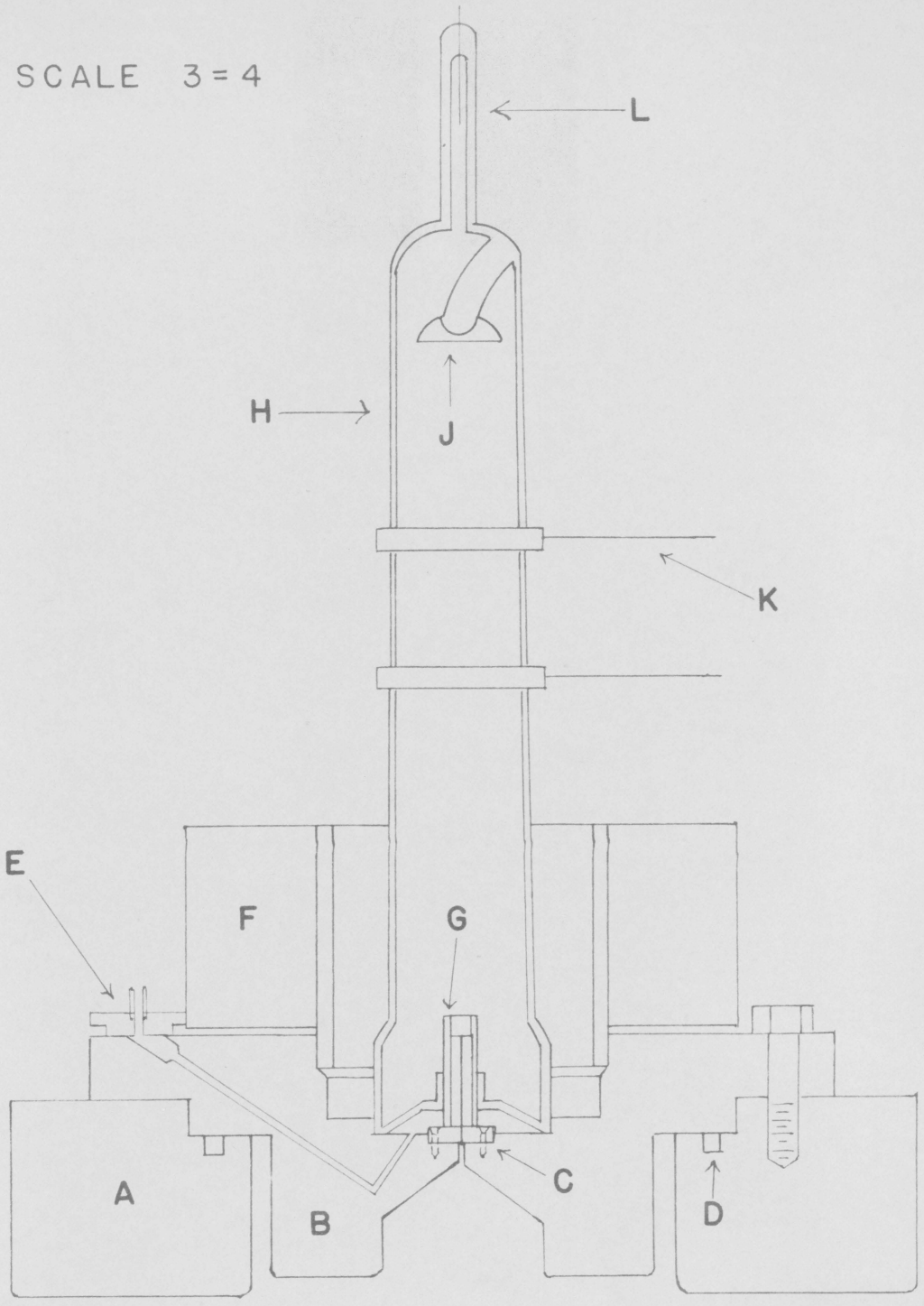
FIGURE 9

sleeve before securing to the aluminum base. Metallic ions in the ion bottle cause protons to recombine with electrons to form molecular hydrogen. A thorough cleaning is therefore essential for a high yield. After washing with the acid solution the bottle was rinsed with distilled water.

The final assembly of the ion source parts is shown in Fig. 10. Vinyl-Seal was used to glue part [illegible] and the ion bottle to part I. A good seal between ion bottle and ion source base was obtained by repeated applications of Vinyl-Seal and baking in a furnace at a temperature of 180 degrees Centigrade for one hour. Part I is secured to part II by screws.

The following items are mounted to the outer aluminum plate: selenium rectifier and transformer, palladium leak, probe power supply, oscillator power supply, oscillator, variacs, and fuse strip. In the space between the two plates are located the hydrogen bottle, ion bottle and magnet, upper pulley, needles for removing charge from belt, and the focusing rheostat.

Within the upper pulley is a self-contained 500 watt permanent-magnet alternator which is the power supply for the ion source. The alternator runs at a speed of 3440 rpm and produces power at 110 volts - 180 cycles. The unit was purchased from High Voltage Engineering Company of



ION SOURCE ASSEMBLY

FIGURE 10

Key to Figure 10

A ... Part II, ion source base

B ... Part I, ion source base

C ... Part III, ion source base

D ... "O" ring groove

E ... Hydrogen supply

F ... Magnet coil

G ... Silica sleeve

H ... Pyrex ion bottle

J ... Secondary electron shield

K ... R-F power coupling leads

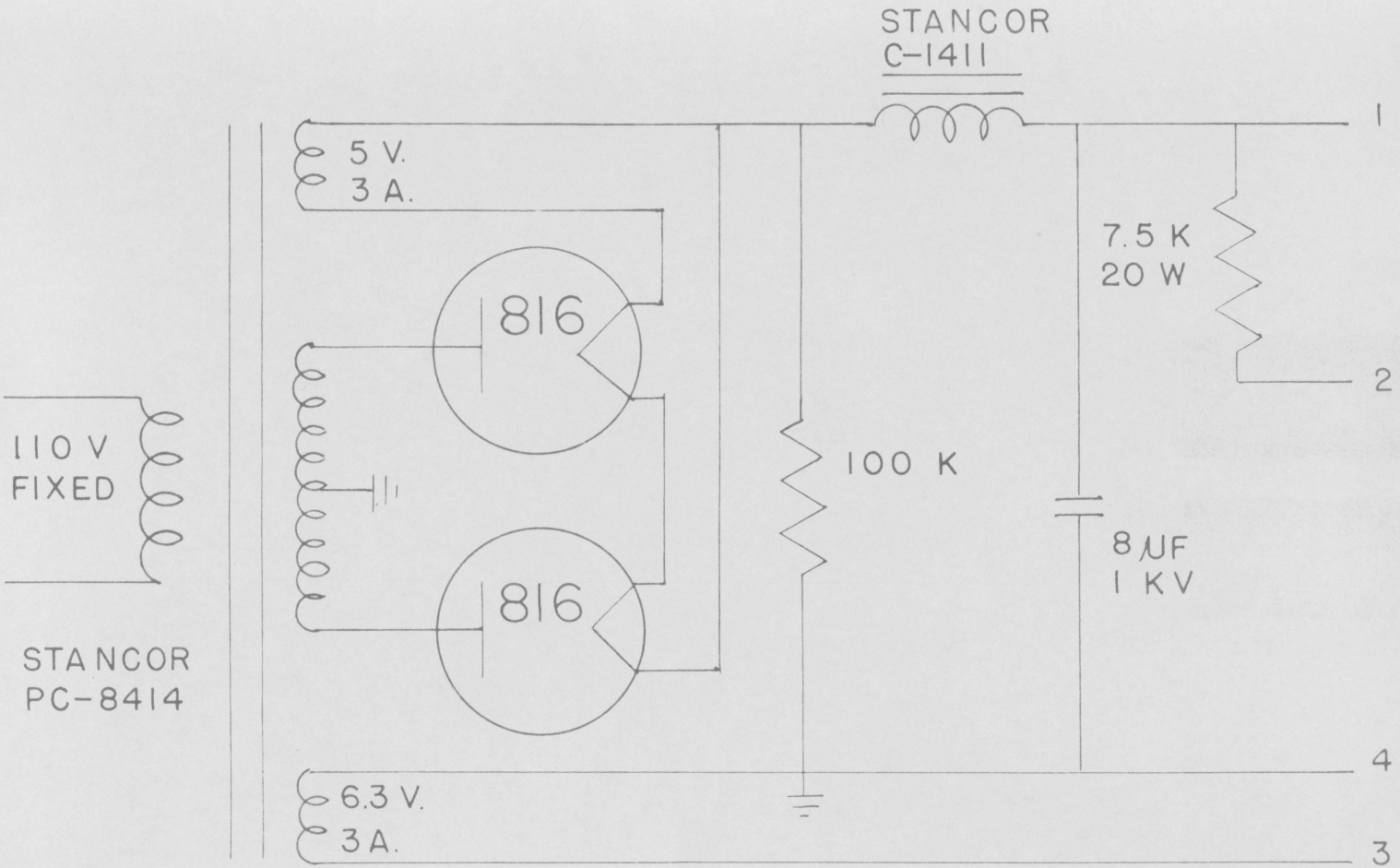
L ... Anode

Cambridge, Massachusetts.

The oscillator power supply and the probe power supply are conventional power supplies. Their circuits are shown in Fig. 11 and Fig. 13 respectively. The power supplied to the ion bottle by the probe power supply is approximately five watts. A one megohm bleeder resistor has been placed across the two 8 uf condensers as a safety measure.

The 100 megcycle oscillator is the same as that shown by Moak, Reese, Good[6]. Figure 14 shows the oscillator circuit. The one micro-micro-farad coupling condensers are 9/16 inch by 2 7/8 inch brass strips mounted next to the 829 B tube. Capacitive coupling is used to transmit r-f power from the oscillator tank coil to the ion bottle. The r-f electrodes are clipped to the oscillator tank coil approximately midway between the center tap and the plate electrodes[6]. Pieces of 1/2 inch round brass stock 3/4 of an inch long were drilled to slip over the plate leads of the tube. The oscillator tank coil was brazed to these pieces which are necessary for cooling.

The supply of hydrogen to the ion source is controlled by a palladium leak. A schematic diagram of this device is shown in Fig. 16. The wall thickness of the palladium thimble is 1/32 of an inch. The thimble is four inches long and has an outside diameter of 1/4 inch. The heating element is made of #34 nichrome wire. The increased



R-F OSCILLATOR POWER SUPPLY

FIGURE 11

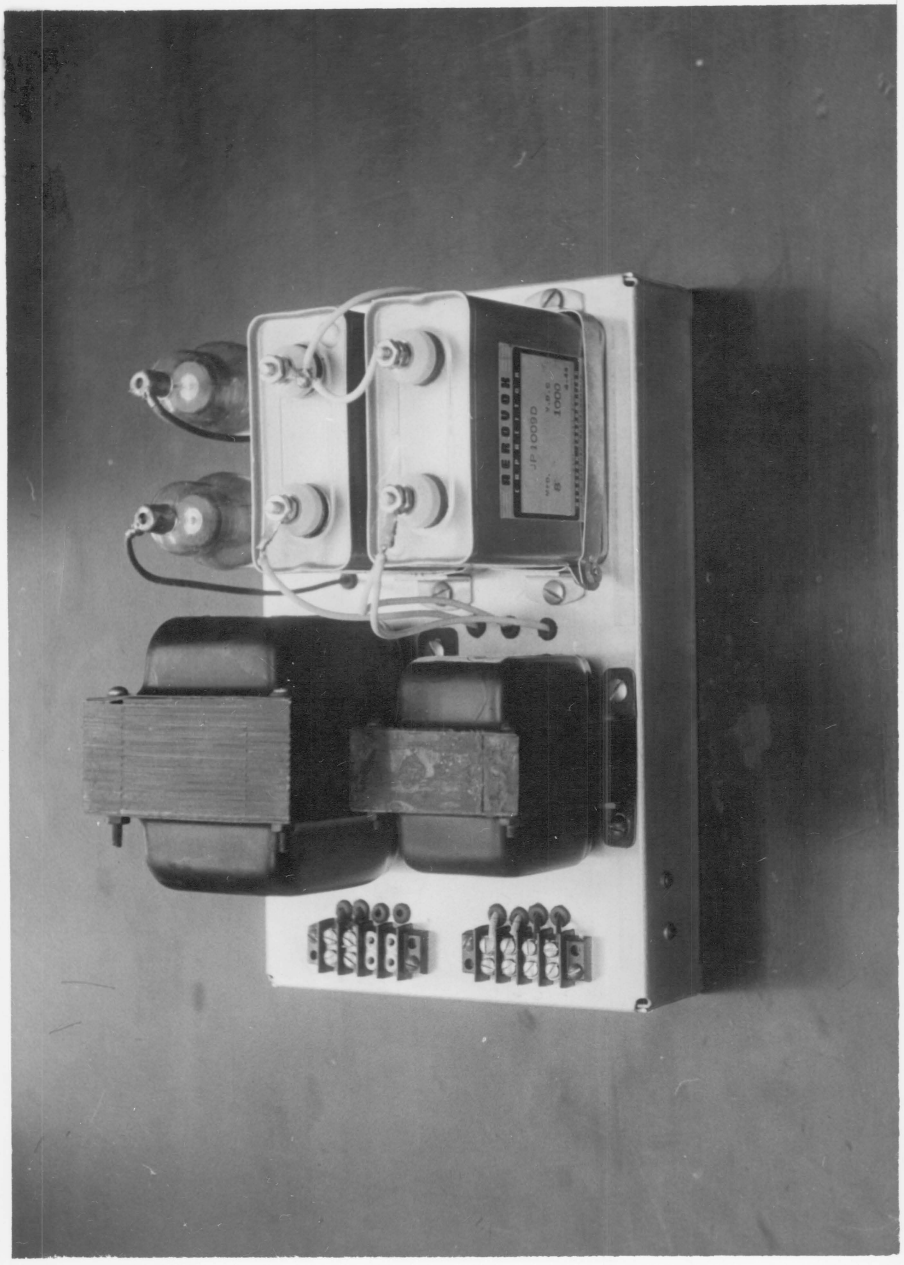
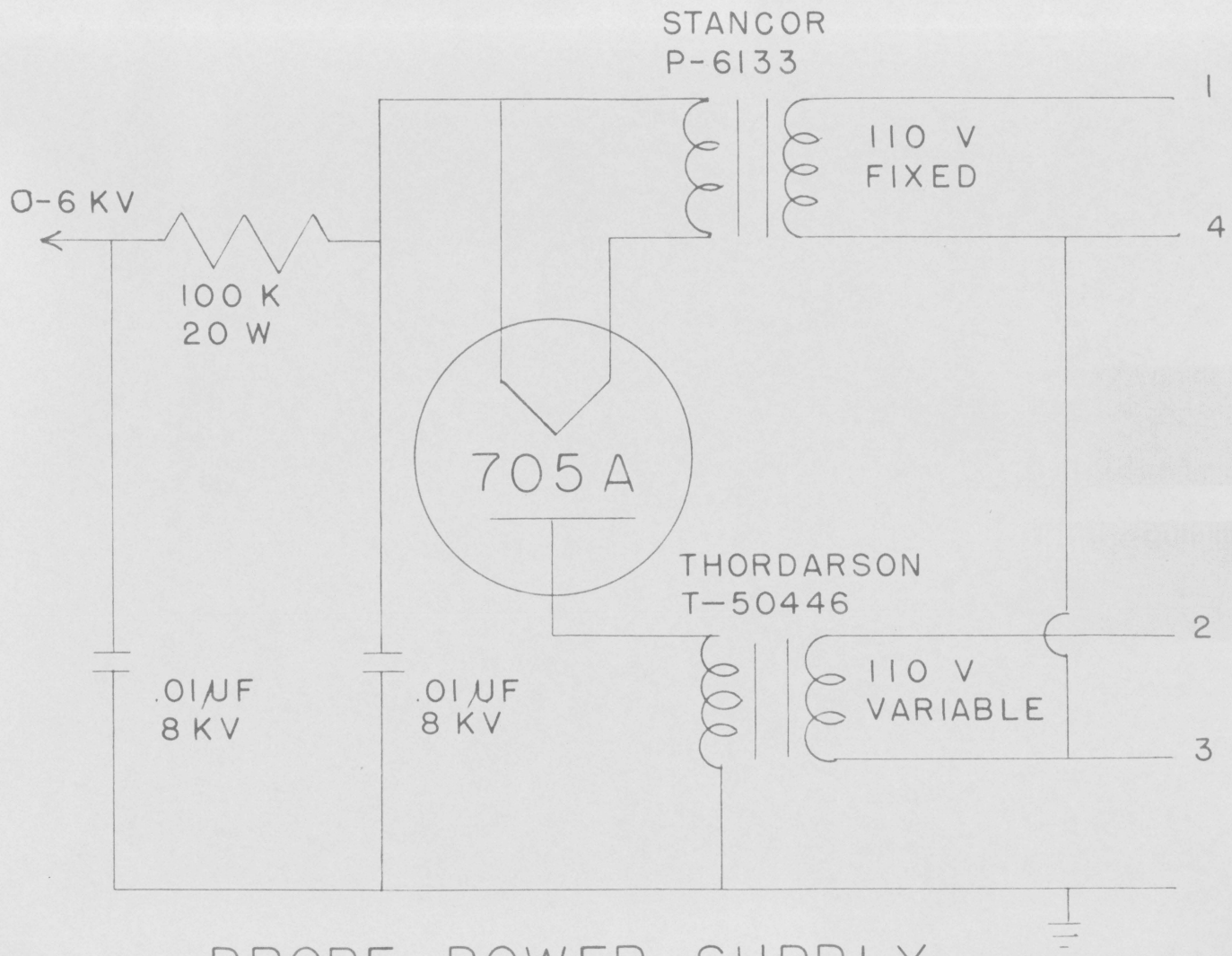


Fig. 12 Oscillator Power Supply



PROBE POWER SUPPLY

FIGURE 13

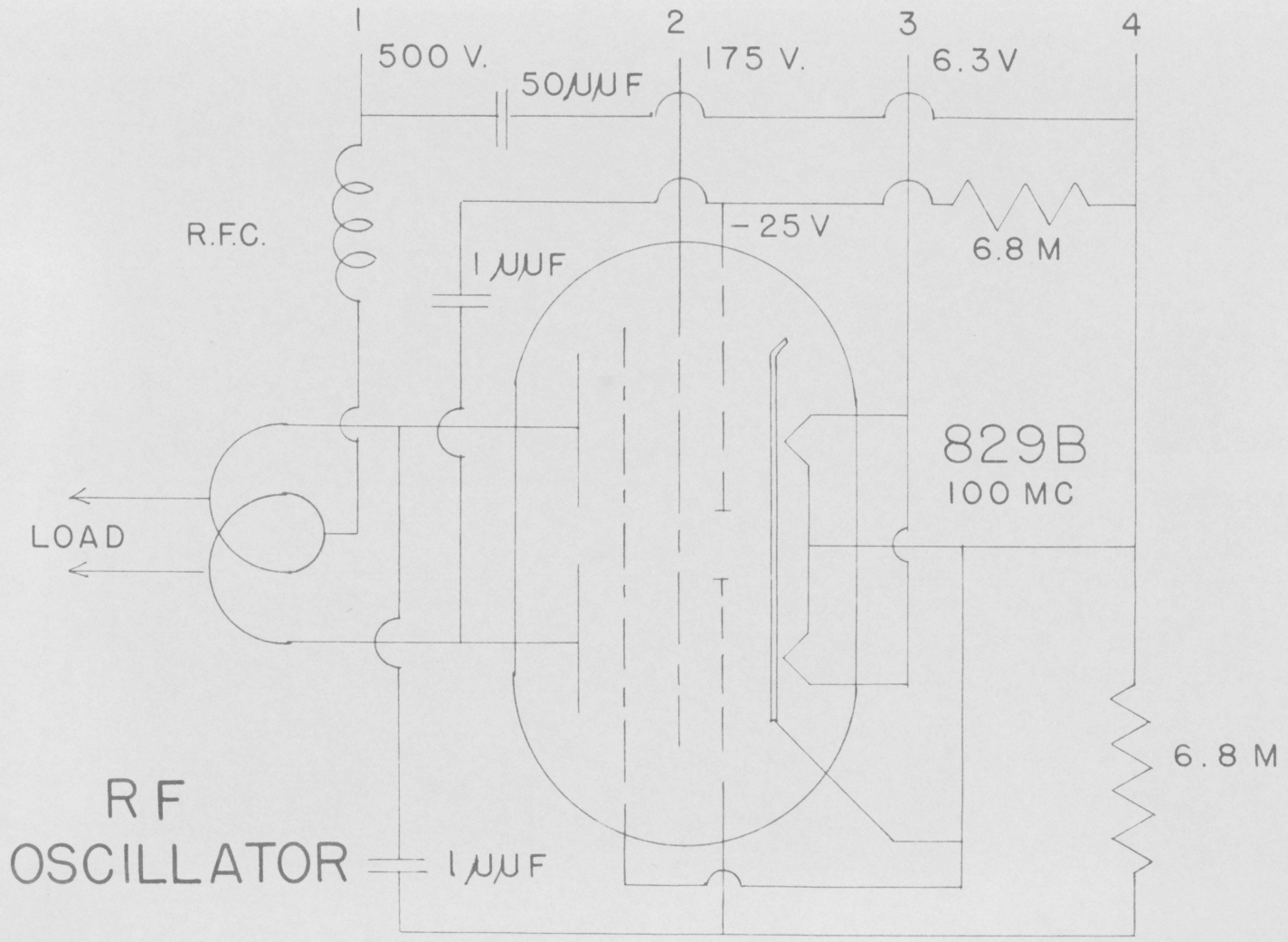

1
2
3
4
500 V.
50 MMF
175 V.
6.3V
R.F.C.
-25 V
6.8 M
1 MMF
829B
100 MC
LOAD
6.8 M
RF
OSCILLATOR
1 MMF

FIGURE 14

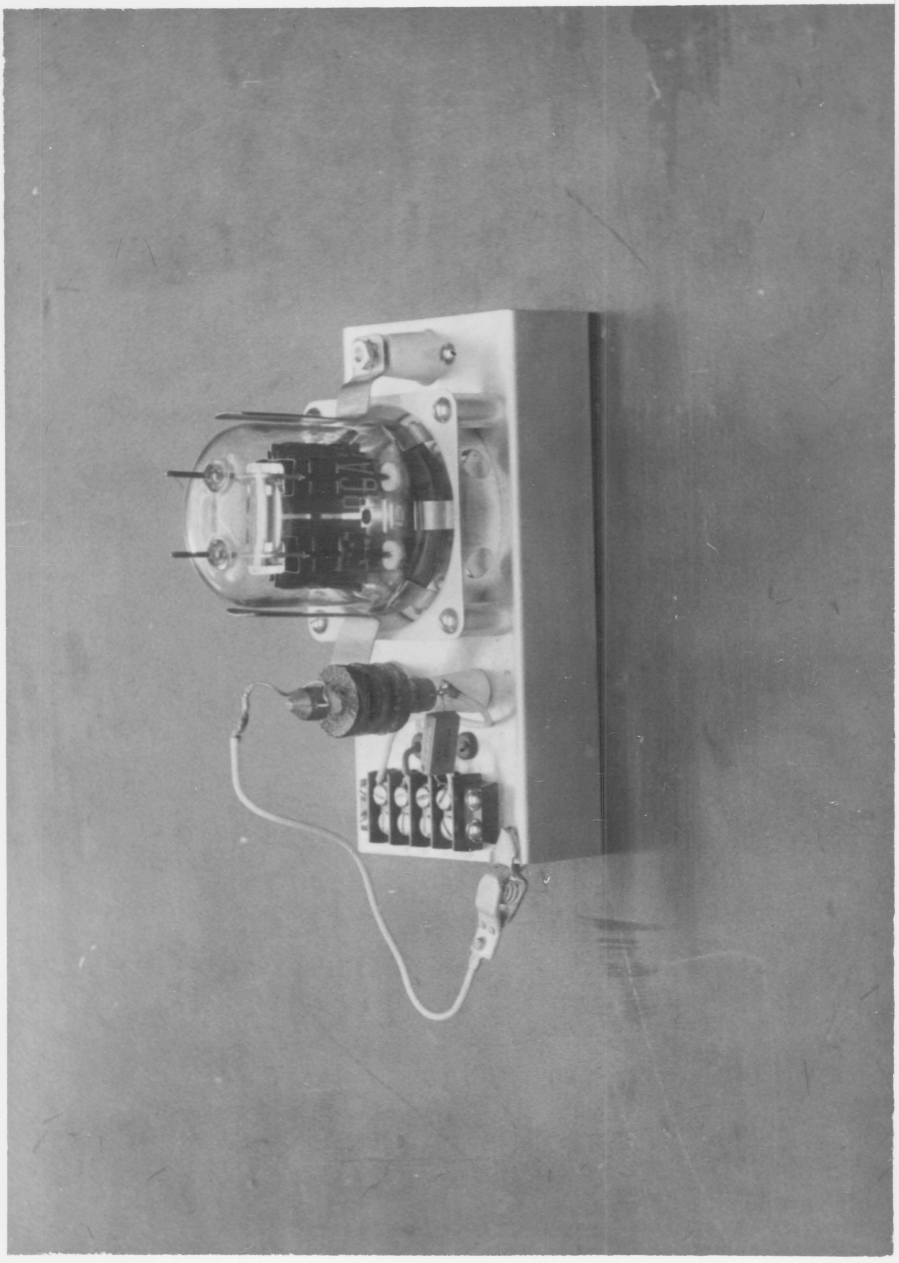


Fig. 15 Oscillator

PALLADIUM LEAK

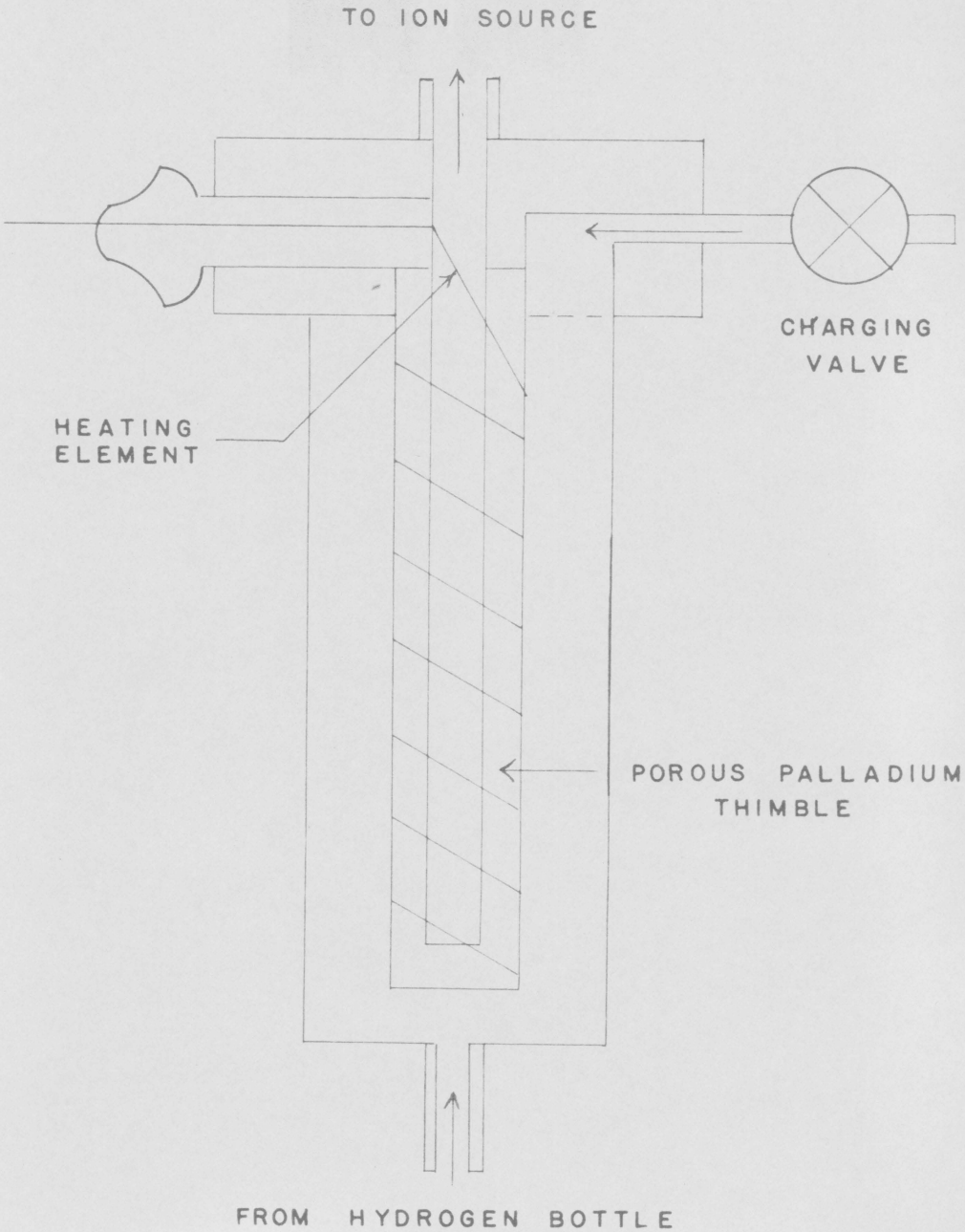


FIGURE 16

solubility of palladium for hydrogen upon heating is the feature which permits the flow of hydrogen to the ion source to be accurately controlled. Variac control of the current to the heater element controls the temperature of the palladium thimble.

The container for the hydrogen supply is an "A" cylinder which was made by the Ohio Chemical and Surgical Equipment Company. It is a steel cylinder with a brass fitting for a pressure guage and copper tube leading to the palladium leak. The capacity of the bottle is approximately one-half liter at standard temperature and pressure. The pressure of the gas in the cylinder is measured by an Ashcroft guage graduated from zero to two hundred pounds per square inch.

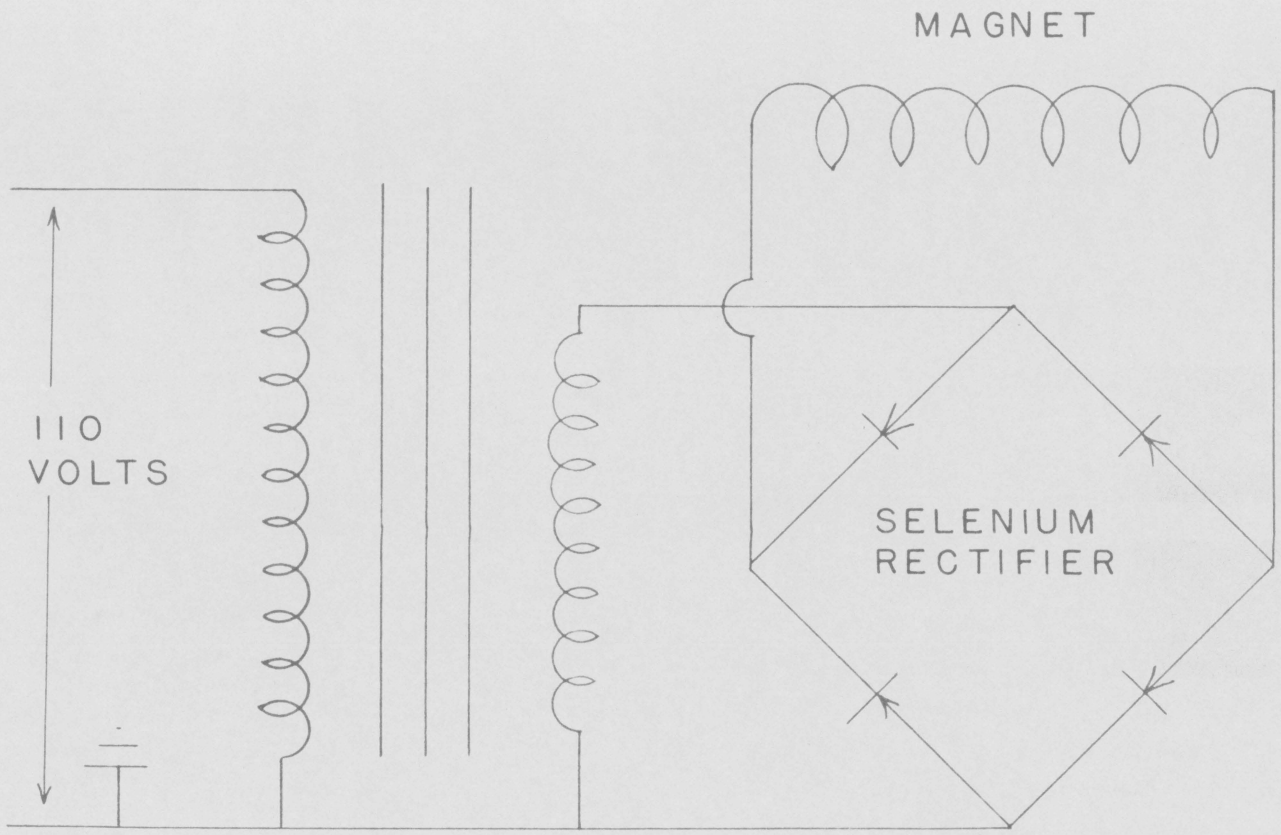
Considerable reduction in the amount of r-f power required may be obtained with the use of a magnetic field. This saving in power is usually lost to the magnet[6]. There is less heat produced in the r-f coupling because of the lower power level. Space charge spreading is also limited by the magnetic field[6]. A coil of 1040 turns of #21 enameled copper wire was wound on a brass spool. The spool is threaded to part I of the ion source base. The strength of the magnetic field is approximately two hundred forty gauss. The number of turns in the coil should be increased to provide an optimum flux of 400-500 gauss.

The difficulty in winding a compact, smooth coil of this number of turns indicates that a commercial coil such as a television focusing coil would be a good substitute.

Direct current for the magnet coil is provided by a selenium rectifier. It is a single-phase, full-wave, power rectifier with an output of 2.5 amperes at 20 volts. Current to the rectifier is provided by a step down transformer which was necessary to prevent the magnet from overheating. The primary side of the transformer has 450 turns of #20 wire. The secondary has 110 turns of #16 wire. The output voltage of the transformer is 25 volts. It is not shown in any of the photographs showing the completed ion source. Figure 17 shows the magnet circuit with transformer.

Probe voltage, magnetic field, and hydrogen flow may be controlled by variac setting. Variac control of the magnetic field has been by-passed since the strength of the field is below optimum. With the installation of a larger magnet variac control may be restored.

The three variacs are positioned by the rotation of 1/2 inch Lucite control rods. There is a ten to one reduction in rotation by the use of a worm and gear arrangement between the control rods and the variacs. Figure 18 shows the connection of the control rods to the variacs with worm and gear. Powerstat Variable



MAGNET CIRCUIT

FIGURE 17

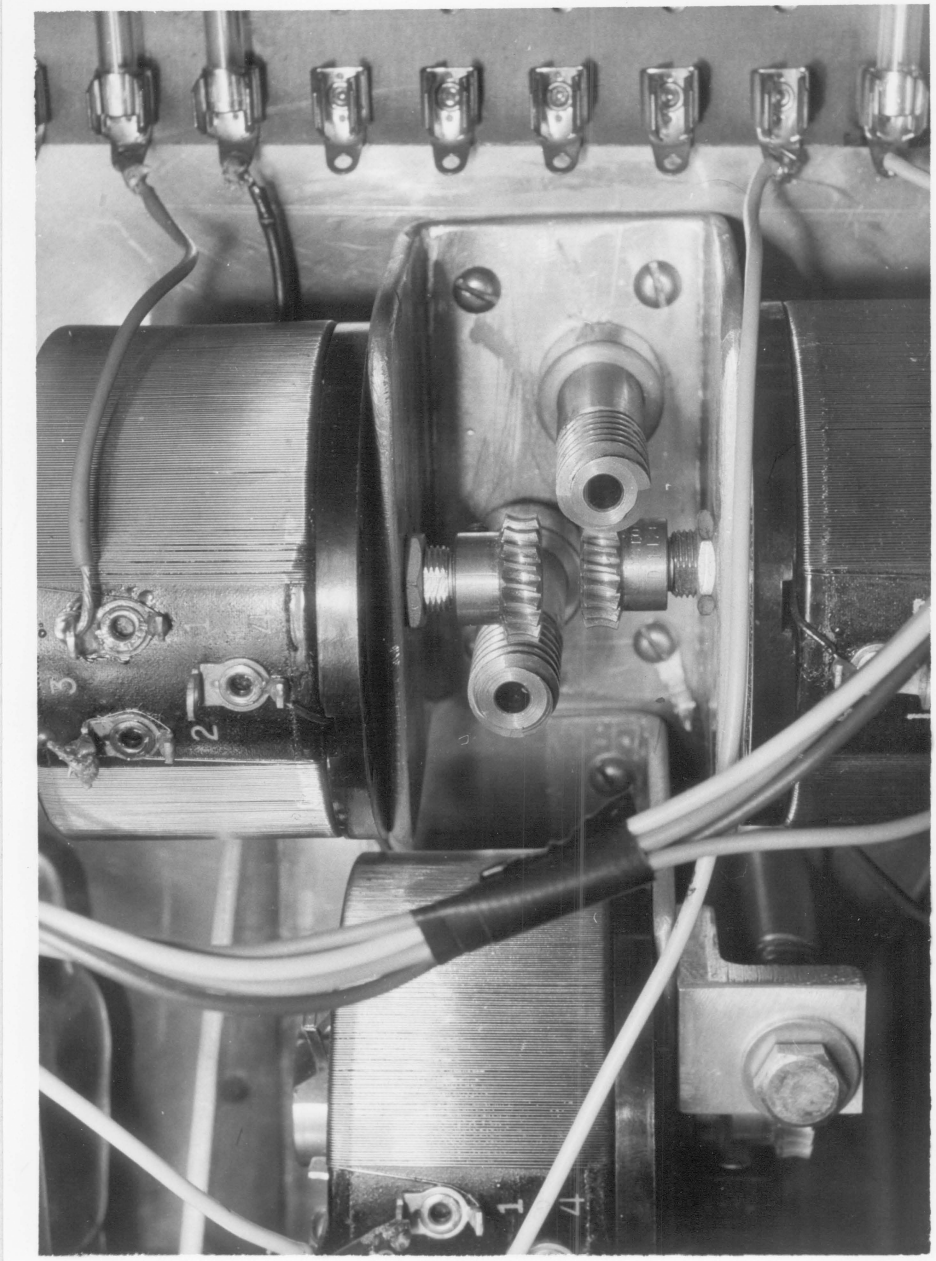
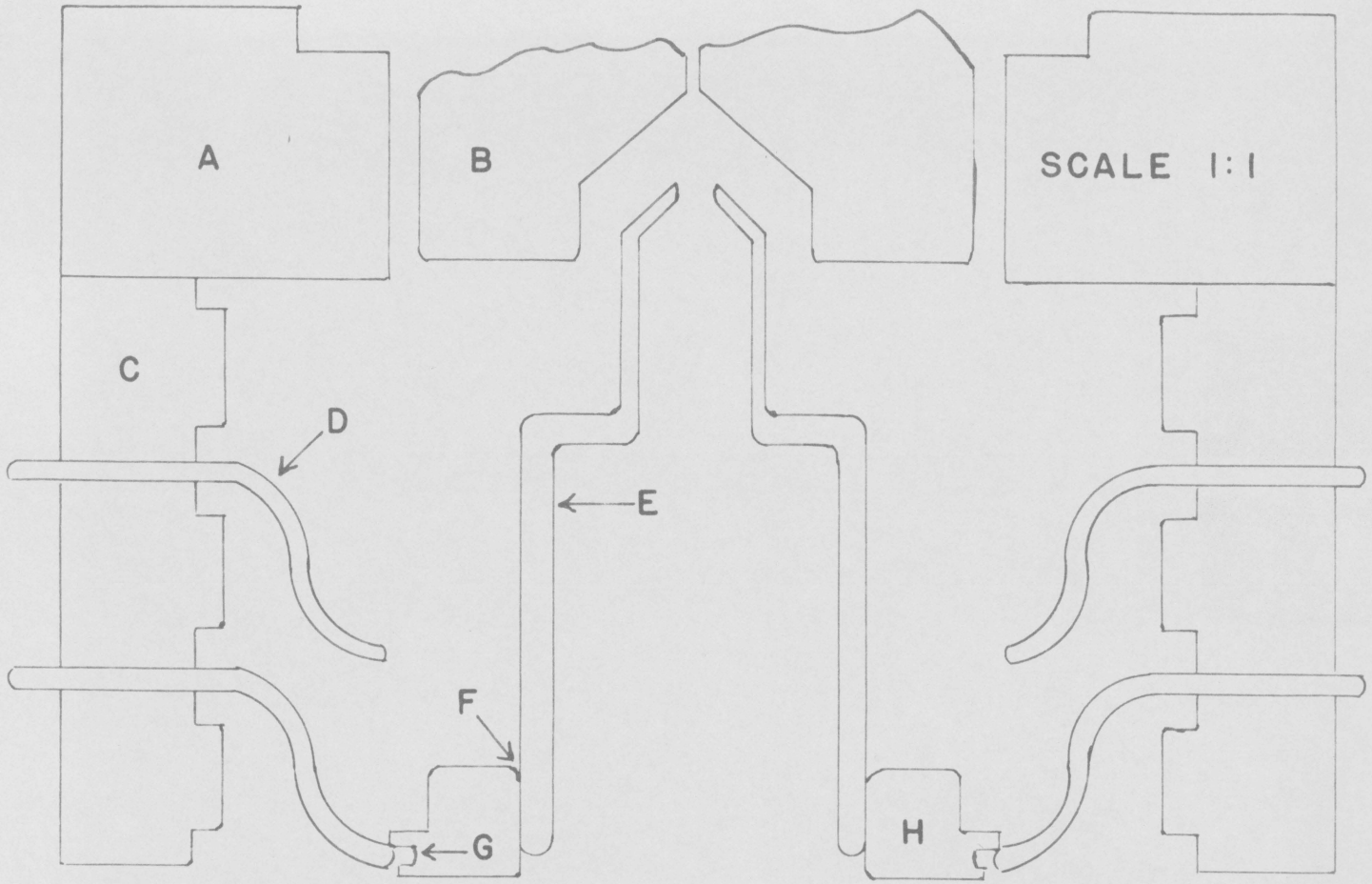


Fig. 18 Variac Mounting

Transformer Type 10 variacs produced by the Superior Electric Company of Bristol, Connecticut were used. They are 120 volt, 60 cycle, single phase. The oscillator power supply is energized by a micro-switch attached to the variac controlling the magnetic field. This increases the lifetime of the oscillator.

The spun aluminum electrodes of the accelerator tube have been arbitrarily numbered beginning with number one at the high potential end of the accelerator tube. The potential difference between the number two electrode and the high potential electrode is varied by a focusing rheostat. The focusing electrode is attached to the number two electrode as shown in Fig. 19. The focusing rheostat is made of Lucite and is connected directly to a Lucite control rod. Figure 21 shows the rheostat and its coupling unit. The precision resistors were manufactured by the S. S. White Dental Manufacturing Company.

Fuses for the various components of the ion source are as follows: oscillator power supply 2 amps; probe power supply 1 amps; palladium leak 1/8 amps; selenium rectifier 2 amps. A schematic of the ion source circuit is shown in Fig. 22.



FOCUSING ELECTRODE

FIGURE 19

Key to Figure 19

A ... Part II, ion source base

B ... Part I, ion source base

C ... Insulating ring of accelerator tube

D ... Aluminum electrode of accelerator tube

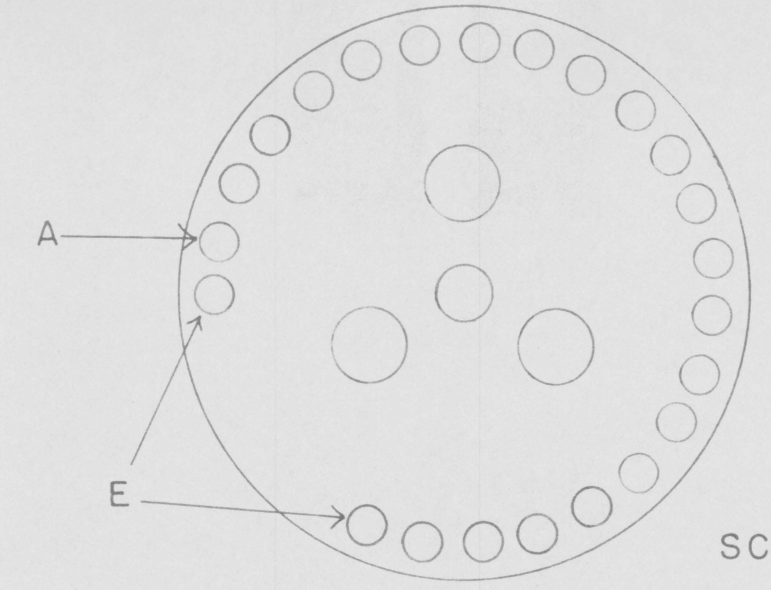
E ... Focusing electrode

F ... Push fit

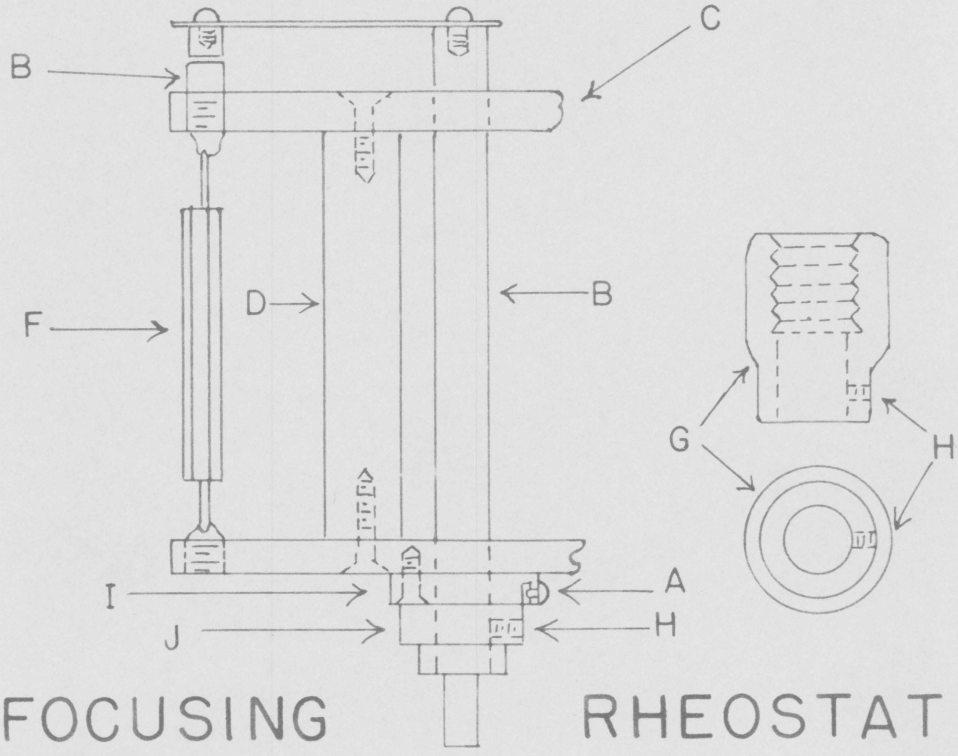
G ... "O" ring groove

H ... Aluminum collar

Fig. 20 Focusing Electrode



SCALE 3=4



FOCUSING RHEOSTAT

FIGURE 21

Key to Figure 21

A ... Electrical Connections

B ... Brass

C ... Lucite Sheet

D ... Lucite Rod

E ... Stops

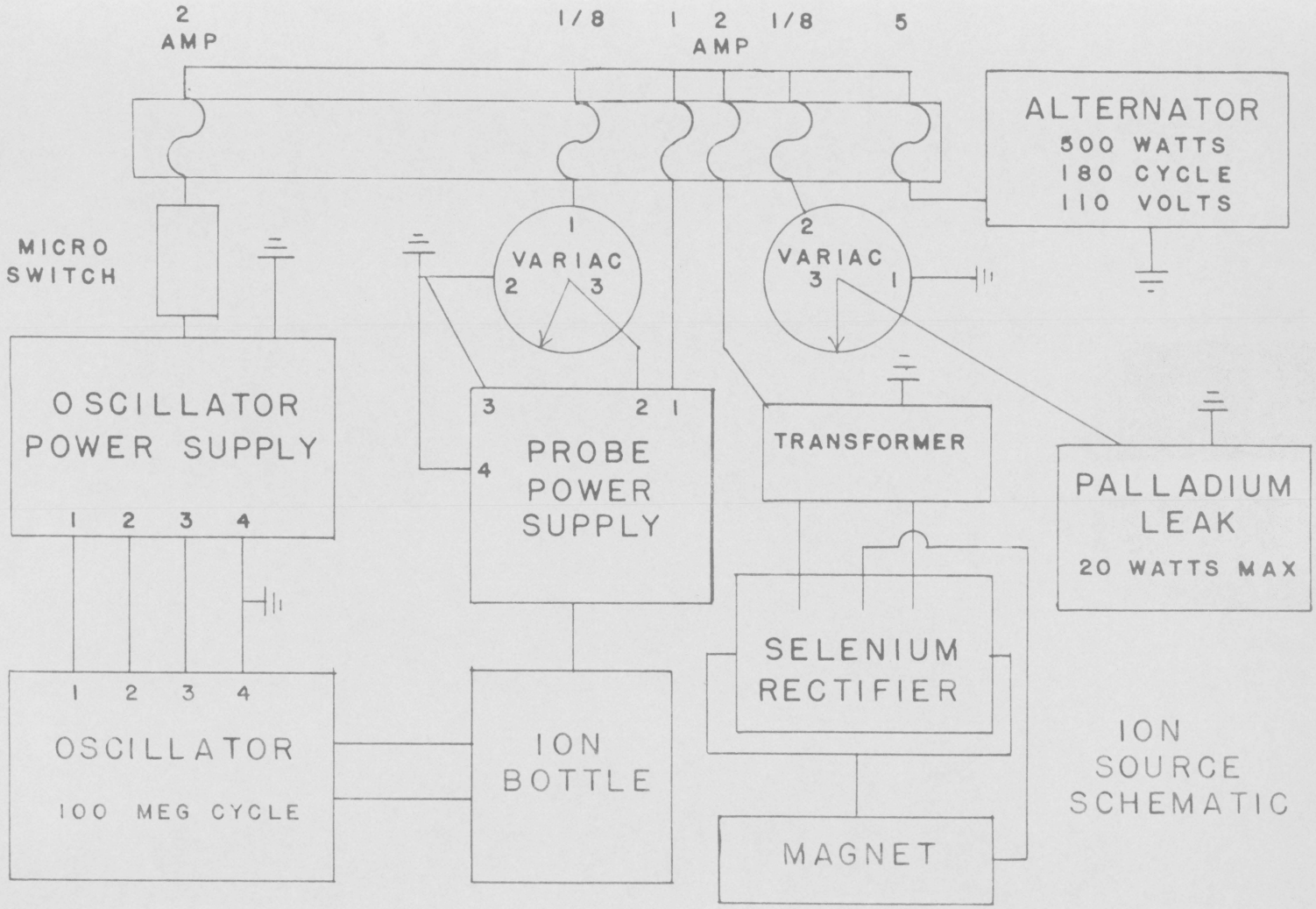
F ... S. S. White 30 meg, 5 kv resistors

G ... Connector to lucite drive shaft

H ... Set screw

I ... Brass collar for bearing and electrical connection

J ... Brass collar



ION
SOURCE
SCHEMATIC

FIGURE 22

OPERATION

The ion source may be operated by selsyn control in the vicinity of the analyzing magnet and at the main control station. The controls at the analyzing magnet have the advantage that the operator can see the effect of adjustment upon the beam. There are no scales associated with the dials because of slippage, lost motion, and friction in the system. The controls for the ion source are set according to number of revolutions and resistance encountered. A sample setting is as follows: Probe - 7 turns, Hydrogen - 1.2 turns. All controls are returned to their zero position when the ion source is cut off.

When the ion source is operating properly, the discharge will be pink. Ten to fifteen minutes of operation must be allowed for clean-up and outgassing. There is a pronounced color change of pink to reddish-pink when the discharge becomes more rich in hydrogen. An excess of hydrogen will reduce the vacuum and beam current.

In order to keep the r-f power requirement low a maximum magnetic field is desired around the ion bottle. The field is applied as soon as power is provided by the alternator. The oscillator power supply is activated by microswitch adjustment. After the beam has attained its optimum value, it is focused to minimum size with an

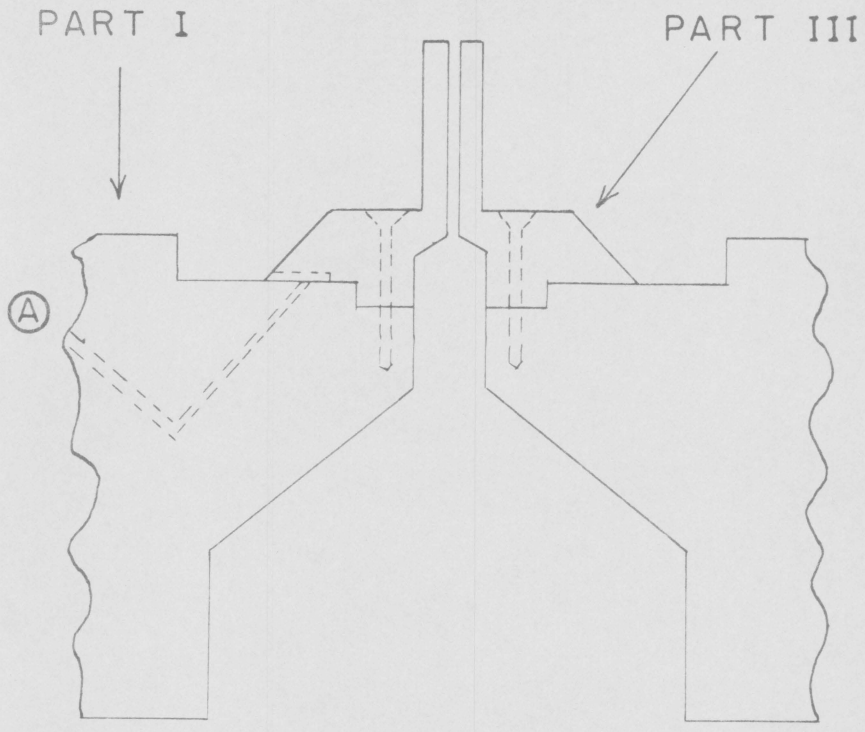
accompanying increase in intensity before entering the analyzing magnet. Quartz viewing mirrows can be placed in the beam both before and after the analyzing magnet for adjustment of the beam size.

PERFORMANCE

The mass one component of a total beam current of 1.5 micro-amperes was found to be 0.1 micro-amperes with the aid of the analyzing magnet. Some of the decrease in intensity may be attributed to the spread in energy of the particles. Mass two and three components were not detected because of the small value of the beam current. These values were obtained just prior to disassembly of the ion source for cleaning.

The ion bottle has been removed from its base three times for cleaning. Total operating time of the ion source was approximately one thousand hours.

An increase in size of the canal diameter from 20 mils to 40 mils did not give a beam current much greater than two micro-amperes; however, a decrease in the length of the canal did increase the beam current greatly. Values of approximately 150 micro-amperes have now been observed. The modified section of the ion source is shown in Fig. 23.



Ⓐ HYDROGEN ENTRY

SCALE 2=1

MODIFIED ION SOURCE

FIGURE 23

SUMMARY

An r-f ion source has been constructed for the V.P.I. electrostatic generator. The ion source has been in operation for approximately one thousand hours with an average beam current of one micro-ampere. This beam has been sufficient to test and calibrate the accelerator.

Experiments which require beam currents in the order of 100 micro-amperes can now be conducted with the ion source operating at its designed capacity.

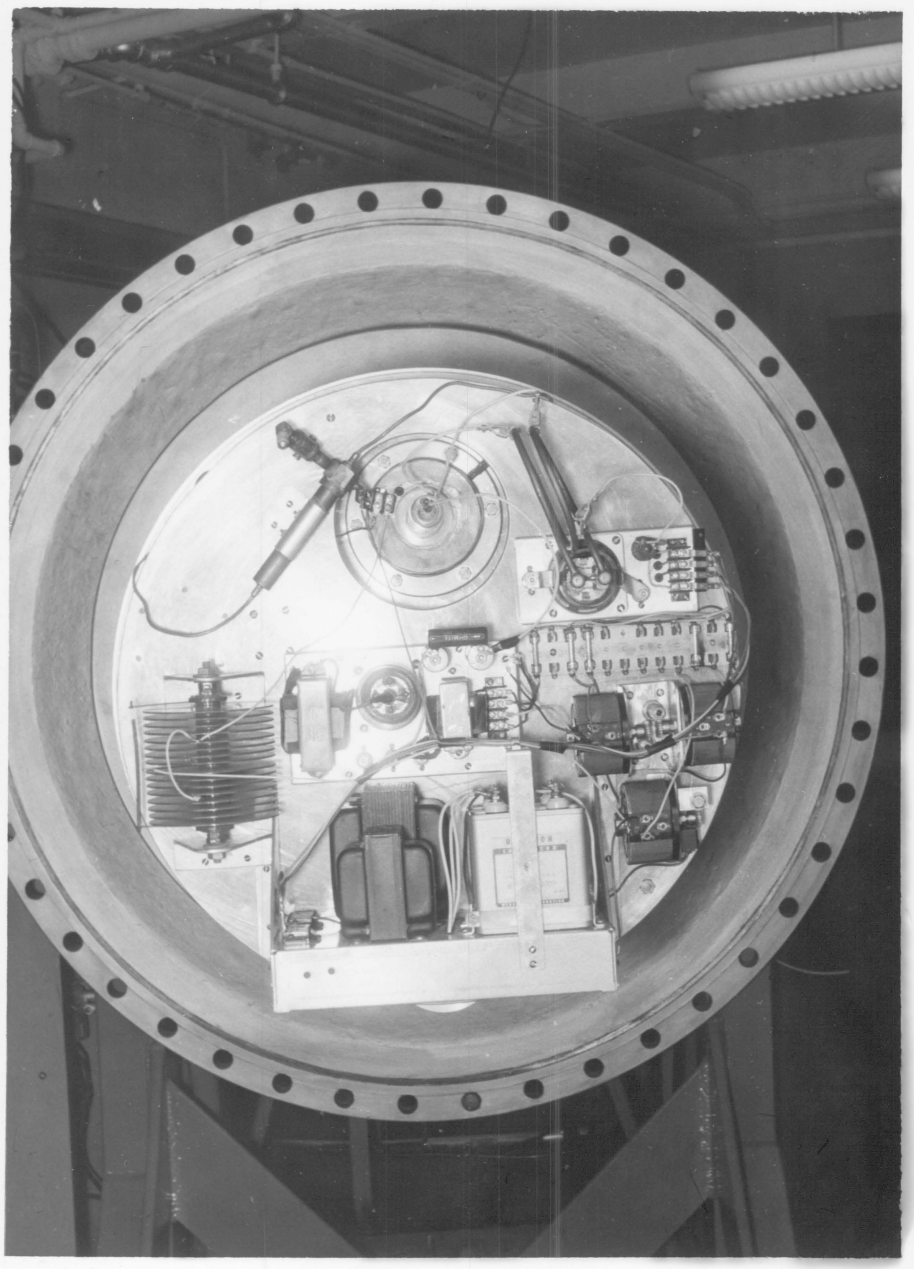


Fig. 24 End View Ion Source

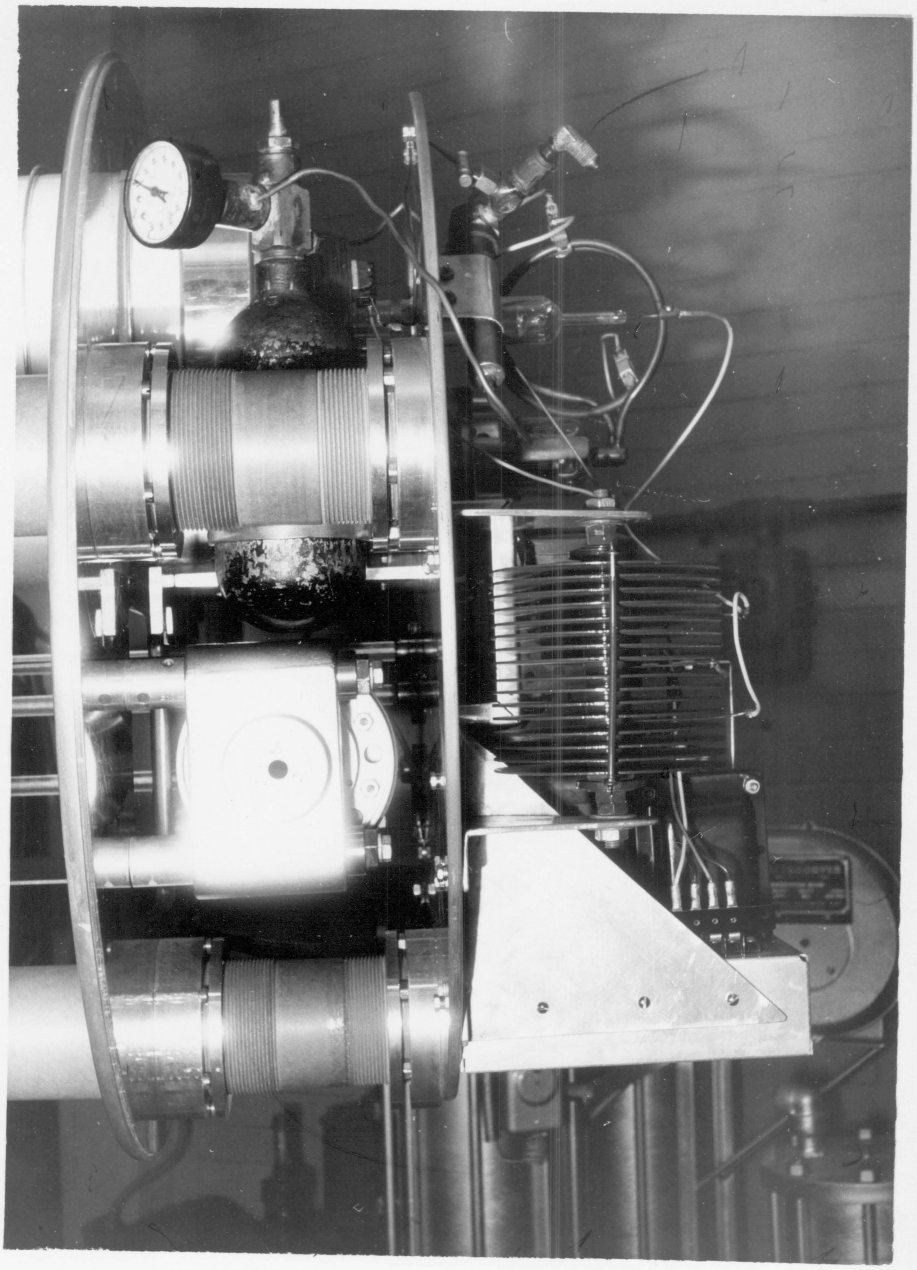


Fig. 25 Side View Ion Source

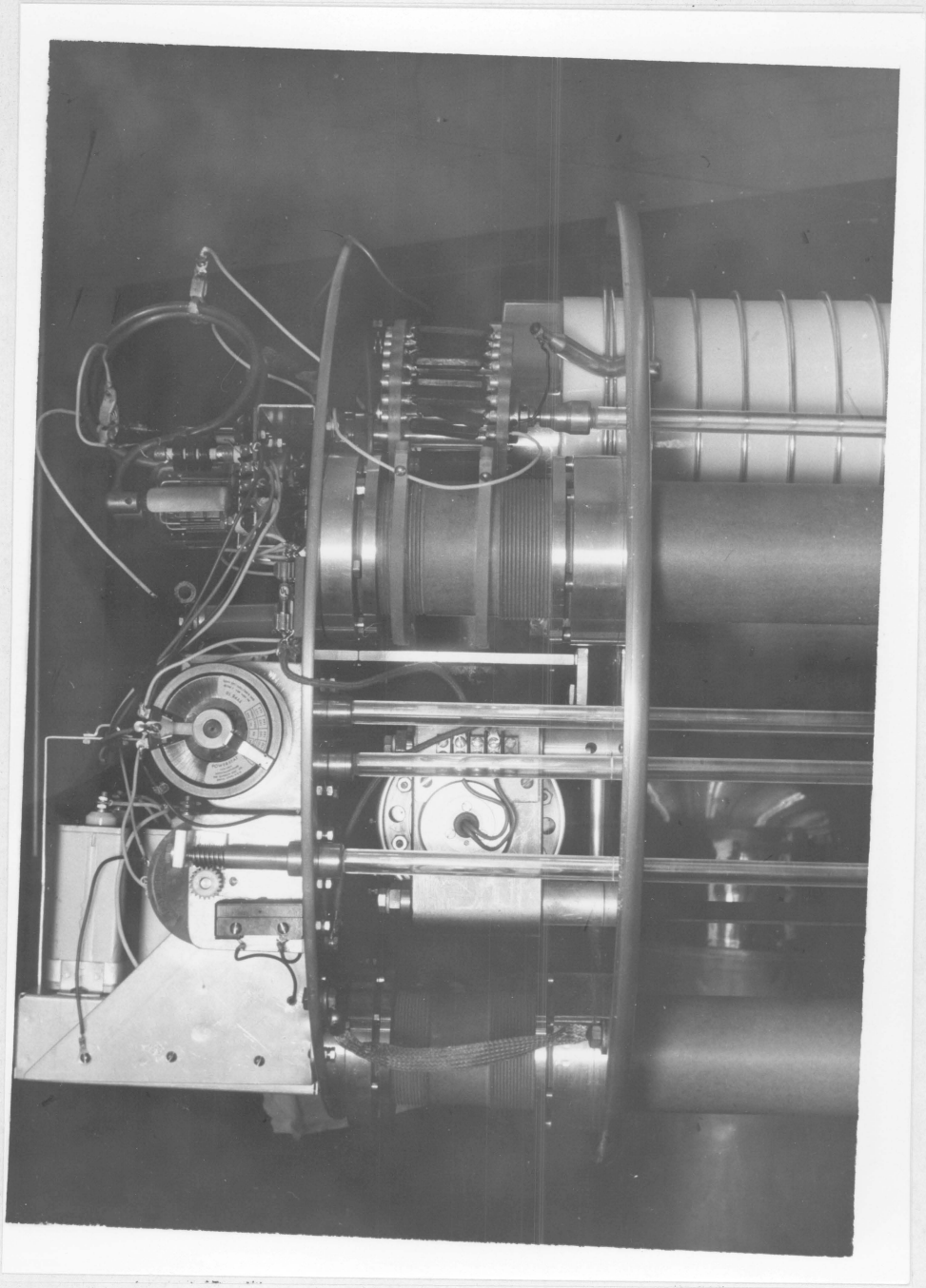


Fig. 26 Side View Ion Source

ACKNOWLEDGEMENT

The author wishes to acknowledge his great indebtedness to Dr. T. M. Hahn for his guidance, assistance, and continued inspiration during the construction of the ion source and the writing of this thesis.

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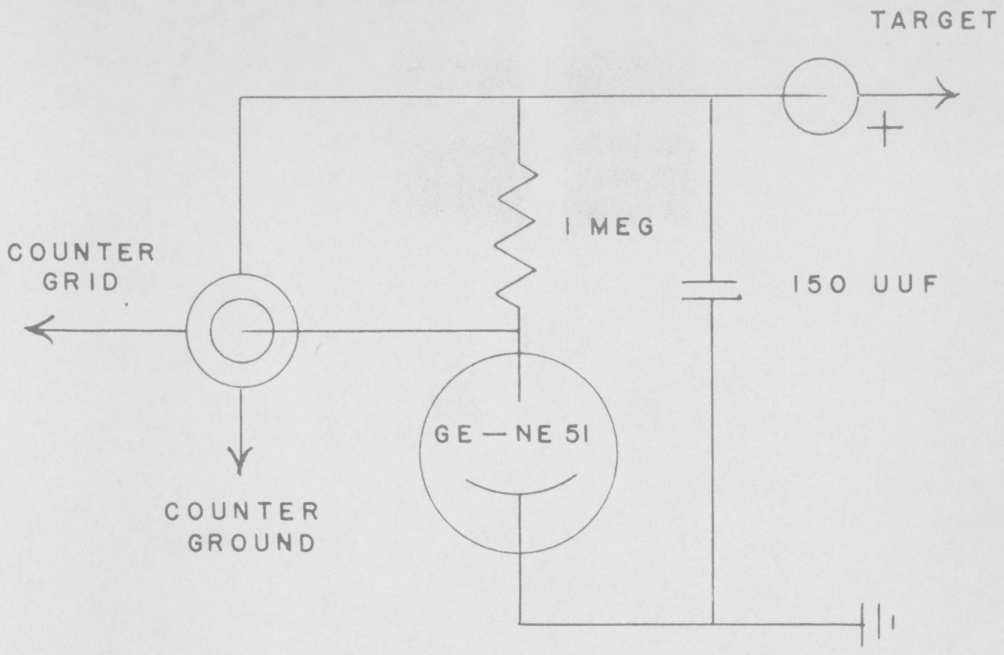
APPENDIX

Current Integrator

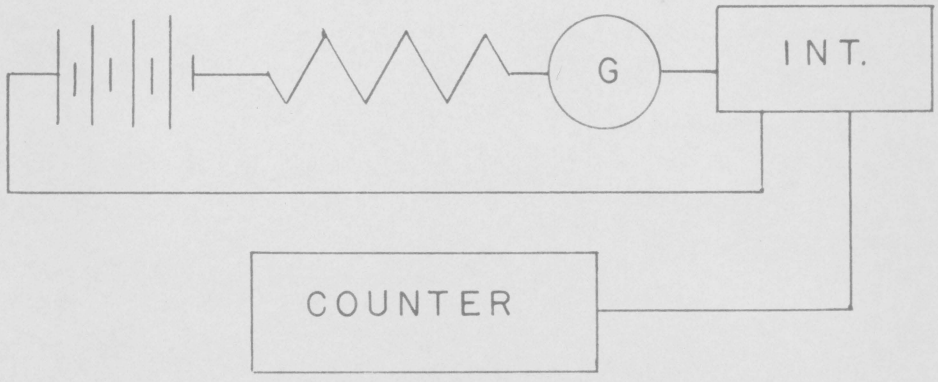
The current before and after beam analysis was measured with a neon glow tube type of current integrator. A diagram of the circuit is shown in Fig. 27a. Charge accumulates on the 150 micro-micro farad condenser until the voltage is sufficient to fire the neon glow tube. Current passing through the one megohm resister produces a pulse which is registered on the counter.

The integrator was calibrated by connecting it in series with a 135 volt battery, resister, and Rubicon Box Galvanometer (G). Figure 27b shows this arrangement. Current to the galvanometer was adjusted by varying the value of the resistance.



INTEGRATOR CIRCUIT

FIGURE 27A



INTEGRATOR CALIBRATION

FIGURE 27 B