THE CONSTRUCTION AND TESTING OF A HIGH CURRENT ION SOURCE

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Robert Bruce Miller

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This is to certify that the

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Robert D. Spence
Major professor

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THE CONSTRUCTION AND TESTING OF A HIGH CURRENT ION SOURCE

by

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A Thesis

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I wish to express my sincere appreciation to Dr. Robert D. Spence for assistance in the choice of this problem and for his patient, stimulating guidance throughout the course of the work.

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Thesis Outline

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I. Introduction.

Purpose.

In numerous experimental problems especially in the field of mass spectroscopy, the problem of producing postive ions arises. In recent years particular attention has been attached to the production of the postive hydrogen ion or the proton. The reason being that since this is one of the fundamental particles of the atom, it is well adapted to studies and uses other than those connected with mass spectroscopy.

Many types of guns have been designed for the production of proton beams. In general they are all based on ionization by electron bombardment, but designs and output differ widely.

It was the purpose of this research problem to build and test an ion source from which one might expect a fairly intense proton beam. The design being such that it could be used in connection with a mass spectrograph, or with certain modification the beam might be adapted for use with other experiments.

A similar source had been constructed at the Sloane Physics Laboratory at Yale. In general our instrument followed the same pattern. The chief exception being that metal cases were used, and that the accelerating voltage was applied by holding the case at ground potential and operating the filament and accelerating electrode below ground. There was no particular reason for this except that it seemed to simplify the construction.

Theortical Considerations Affecting Design.

Generally speaking the construction was straight forward, but a few problems that one does not usually associate with ion production had to be considered. First, to get the necessary density in the bombarding electron beam we would be using extremely high filament currents. For this reason water cooling was supplied to the filament leads and to the gas box. The filament itself had to be of some metal with an extremely high melting point. Tantalum was selected since it has a melting point of approximately 2800 degrees centigrade. It also posseses good electron emission properties.

In order to obtain the most intense beams both for the bombarding electrons and for the protons, it was necessary to provide some type of focusing. This problem proved to be rather simple with the design we were using in as much as both beams were moving in the same direction. Helmholtz coils were designed and placed to provide an axial magnetic field, along which both beams traveled.

Due to the many electrodes present and the various potentials in use one could expect electric fields which in some cases would have dispersive effects on the beams. For the proton beam this was partly offset by leaving a rather large space behind the accelerating electrode.

This had a tendency to dissipate the field effects.

Another rather interesting field effect had to be considered. From previous experiments of this type it had been observed that a rather strong field was built up surrounding the filament, the effect was to more or less shield the latter and to decrease the strength of the electron beam. To counteract this a much larger hole was placed in the filament side of the gas box than one might at first feel necessary or desirable. The effect here seems to be that more positive ions will move back to the filament and counteract this electric field. This of course means a shorter filament life for many of the ions strike the filament, but for high ion emission it seems necessary to overcome this shielding.

In considering the nature of the detector the term high current as applied to ions is rather misleading. In most cases when under steady operation we would be dealing with currents of the order of 10^{-6} amperes. Under the most favorable conditions and with extremely high filament currents and high accelerating potentials currents of the order of 10^{-3} amperes might be expected. With high filament emission and using short pulses on the accelerating electrode currents as high as one ampere have been reported. In respect to the rather low currents which we would usually be measuring, it was decided to include an amplifying devise in the instrument. This is described under a later heading.

II. Construction.

The Outside Case.

Brass cases were designed to house the ion gun and the detector. The cases were temporarily connected by a short piece of brass tubing until the instrument could be tested. The sketch in Fig. I shows the design and assembly of the housing.

The cases themselves were made of four inch brass tubing closed at the back by a brass plate. The gun case was 6½ inches deep and the detector 4½ inches. Placed back to back they were connected by a short length of brass tubing one inch in diameter. The opposite ends of the cases were fitted with brass rings which were soldered to the case and groved for an "O" ring. This made possible there easy removal for adjustment or repair.

The vaccum was provided by mounting three single stage, oil diffusion pumps to the 1 5/8 inch T openings shown in the drawing. These pumps were available and because of their rather limited capacity it was decided to mount all three. The hole (g) in the top of the system was a 1/8 inch tapped hole in which the vaccum gauge was mounted.

A type 501 therocouple gauge from the National Research Corporation, Cambridge, Mass. was used. It had

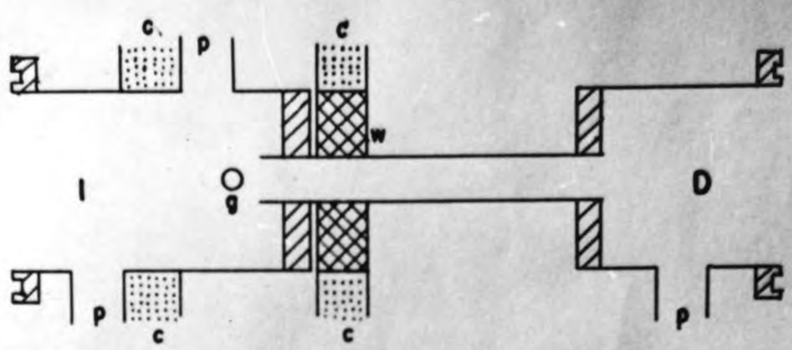

FIG. I HOUSING ASSEMBLY.

I - Ion gun chamber

D - Detector chamber

p - Pump openings

c - Focusing coils

g - Vacuum gauge opening

w - Wooden spool

a working range of 2-500 microns, which while rather limiting its general usefulness as a vaccum gauge, did include the pressure range within which our system was to operate.

The outside assembly was completed by the addition of two coils of wire as shown in the diagram. They consisted of approximately 2500 turns of No. 20 enameled magnet wire. The rear coil was mounted on a wooden spool and was free to slide on the connecting tube. The purpose of the coils was to provide a magnetic field that would serve to focus the ion beams.

The Ion Gun.

The ion gun was designed to produce positive ions by the direct bombardment of the gas by an electron beam. The diagram in Fig. II shows how this was done.

The gun was composed of three primary parts. First, a hot filament was used as a source of electrons. The filament itself was of tantalum foil $\frac{1}{2}$ X $\frac{1}{4}$ X .005 inches. It was mounted on water cooled leads of $\frac{1}{8}$ inch brass tubing. These were passed through the brass face plate and were insulated from it by glass tubing and wax. Tantalum was chosen for the filament because of its extremely high melting point. It is also known that a pure metal emitter will outlast an oxide coated one when subject to ion bombardment as was the case here. The foil was crimped by passing it between two small gears. This provided a

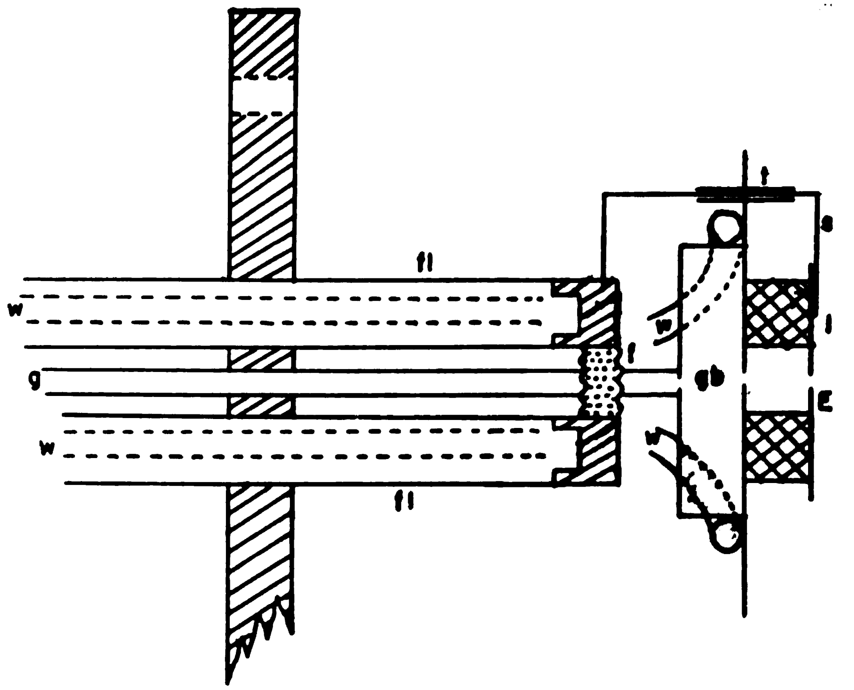

FIG. II THE ION GUN

g - Gas inlet
w - Water cooling leads
fl - Filament leads
f - Filament
gb - Gas box
t - Glass insulating tube
s - Shunt
I - Insulating block
E - Accelerating electrode

greater emission surface in a rather limited area. The filament was then fastened to the leads by means of set screws.

In the center of the diagram is shown the gas box. This was simply a round pill box type chamber, $2\frac{1}{2}$ inches in diameter and 3/4 inch deep, with holes in the center of each of its faces. A 1/8 inch hole was used in the face nearer the filament and a 1/16 inch hole in the side facing the accelerating electrode. The gas box was also arranged for water cooling by wrapping one turn of $\frac{1}{4}$ inch copper tube around the chamber, and bringing the open ends out through the face plate. A third piece of tubing passed through the face plate and directly into the gas box, through this the gas was introduced.

The gun was completed by addition of a third plate or electrode. This was mounted about $\frac{1}{2}$ inch behind the gas box and insulated from it. This also has a 1/16 inch hole in it to allow for passage of the beam. Electrically it was connected to the filament by means of a shunt as shown. Thus when the filament was held at a potential below that of the gas box this plate served to retard electrons and accelerate the flow of positive ions in the desired direction.

The Detector.

The standard device used for the detection of ions is the Faraday cup. The charge collected in the cup is measured by some sensitive measuring instrument. In recent years the measuring instrument is often a D.C. amplifier with its first stage mounted in the detector chamber. This plan was followed in our construction.

Thus as shown in Fig. III, a 955 acorn tube is mounted behind the Faraday cup and arrangement is made to put the output of the cup either on the grid of the tube or to bring it directly out of the chamber when we are dealing with currents whose magnitude is such that they may be measured directly.

The electrical diagram for the detector is shown in Fig. IV. In operation the plate of the tube was supplied by three nine volt dry batteries. These were in series with a microampmeter, which measured the flow of current through the plate circuit. Before the circuit was actually put into operation, the normal plate current was balanced out by the use of a bucking voltage and a variable resistance box.

III. Operation.

The Vacuum System.

Before testing the system it was necessary to produce a rather good vacuum. Not that extremely low pressures were necessary, but instead from the standpoint of fast pumping. Since it was expected that the system would be frequently opened for the replacement

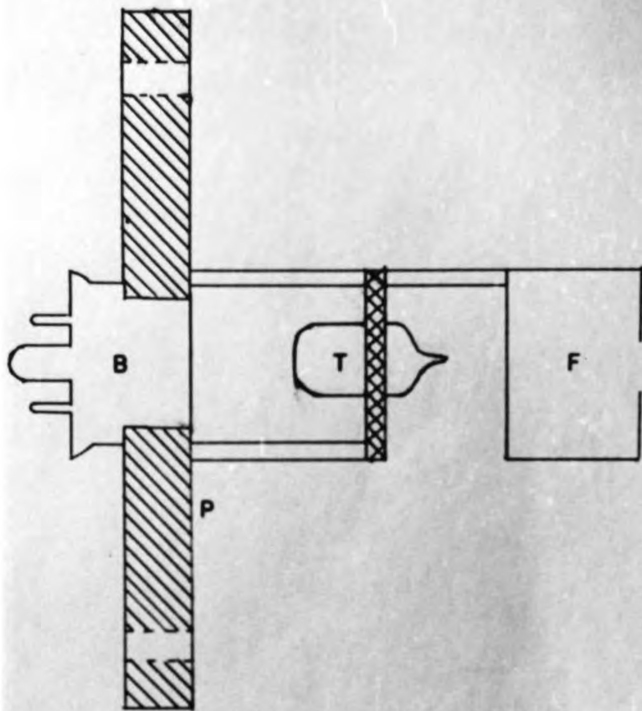

FIG. III THE DETECTOR

B - Base of 8 prong tube

T - 955 acorn tube

F - Fataday cup

P - Brass face plate

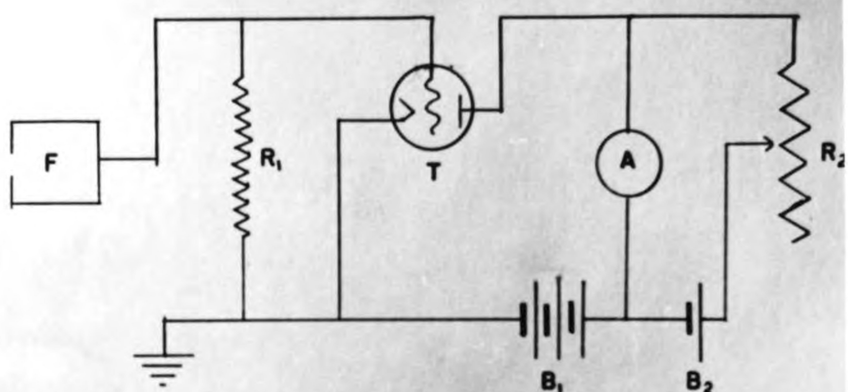

FIG. IV DETECTOR CIRCUIT.

F – Faraday cup

T – 955 acorn tube

A – Microampmeter

R_1 – 1.5 megohm

R_2 – 10,000 ohms

B_1 – 27 volts

B_2 – 1.5 volts

of the filament or other adjustments, this would be a great time saver. Also rapid pumping would permit the introduction of greater volumes of gas and still maintain the desired working pressures.

The three small diffusion pumps operated in connection with two fore pumps easily provided the necessary pumping capacity. Tests showed that the system could be reduced from atmospheric pressure to less than one micron in approximately forty five minutes. With air flowing into the system pressures of 20-40 microns were easily maintained.

Electrical Components.

In operation the system required numerous sources of electrical power. The filament itself together with the leads showed a total resistance of less than one half ohm. This indicated a need for a low voltage high current source. A small, war surplus, welding transformer was available and when used with a 10 ampere variac in the 110 volt primary circuit, proved to be an excellent source of filament supply. In actual operation a small glass covered hole in the face plate was used to judge filament temperatures by the brightness of the emitted light.

Heater current for the vaccum gauge and the 955 tube in the detector were supplied by an ordinary six volt filament transformer. The focusing coils were supplied from the regular D.C. sources available in the building. The two coils in series measured approximately 50 ohms.

Introduction of the Gas.

One of the most difficult problems in the entire construction and operation of the ion source was the introduction of the gas. The hydrogen itself was purchased and came in the standard gas cylinder. The dangers involved in using the gas direct from the cylinder were too great, so the following method was used. A one liter flask was secured. It was sealed at the top and two symmetrically placed stop-cocks were sealed into the neck of the flask. After being pumped out the flask was filled to about five pounds gauge pressure from the cylinder and the gas introduced from here into the system.

To regulate the flow from the flask to the gas box a special valve was constructed. This was the usual tapered type valve that is often used for the regulation of gas flow. The taper was quite flat the needle having a diameter of ½ inch at the top and tapering to 23/32 inch at the bottom. The length of the taper was 1 7/8 inches. Gas was introduced at the top and allowed to flow down between the tapered needle and the seat and out at the bottom. The amount of space between the needle and the seat was controled by fine threads on a shaft extending above the taper.

The seal was also on this shaft and was produced by means of an "O" ring fitted into a groove just below the threads. Tests showed that the seal was vacuum tight.

The valve was checked with air and seemed to work quite well, but in actual use with hydrogen it was not sensitive enough to regulate the flow of gas. For this reason it was possible to test the source only under limited operating conditions, and complete tests must await the construction of a better means of controling the flow of gas into the system.

At the present time two other valves have been constructed and are being tested. One is operated by winding a flattened piece of thin wall, copper tubing around a shaft. Rate of flow of the gas is controled by applying tension to the coiled tubing. The latter is accomplished by means of a micrometer screw adjustment on the shaft. Valves of this type have been reported successful, but tubing with much thinner dimension walls than we had available was used. Our valve when tested using the regular tubing failed to sufficiently limit the flow of gas.

A third type valve was devised which depended on varying the compression on some permeable material and thus regulating the flow by controling the rate of diffusion through the compressed material. This also has failed to give results thus far. One of the difficulties here is that most substances available for compression have too high a vapor pressure for use in a vacuum system.

IV. Performance.

The actual testing was done by first, pumping out the entire system, then by shutting off the storage flask from the rest of the system it could be filled with hydrogen from the cylinder. The cylinder was then resealed and hydrogen from the flask introduced into the gas box.

When the variac was turned up to approximately 70 volts the first ion current was observed. At this point the filament seemed to glow very brightly, but additional current even using the full 120 volts increased the strength of the ion beam. The filament life however, was greatly shortened by using voltages greater than 90 volts.

Two checks rather easily made indicated that we were actually observing a proton beam. This was done by cutting off the focusing magnetic field reversing the accelerating potential. In both cases the beam disappeared. This is not the result one would expect if the observed results were being produced by electrons or some outside disturbance.

With protons actually being produced tests were made to determine something of the pressure dependance of the beam intensity. This was not an easy observation to make in view of the difficulties that have already been described regarding the control of the gas flow. However, one fairly good curve was obtained and is reproduced in Fig. V. In it we have plotted pressure against the beam strength. The first is in microns, but the beam intensity is a relative measurement in as much as the amplifier was in use when the data was taken.

Efforts to reproduce this curve have so far failed due to unsatisfactory control of the gas flow. It is however quite easy to verify the fact that the maximum intensity occured at pressures of 10-15 microns of mercury. This was done by introducing hydrogen into the gas box, then with the valve entirely shut the beam intensity was observed as the pressure was decreased.

It is important that attention be called to the fact that in all cases pressure measurements were made outside the gas box. This means that inside the gas box, where the ions were actually being produced, pressures were 2-4 times higher than those measured and recorded. Observation also indicated that some pressure correction factor is needed due to the fact that the gas in the chamber is hydrogen and not air. The

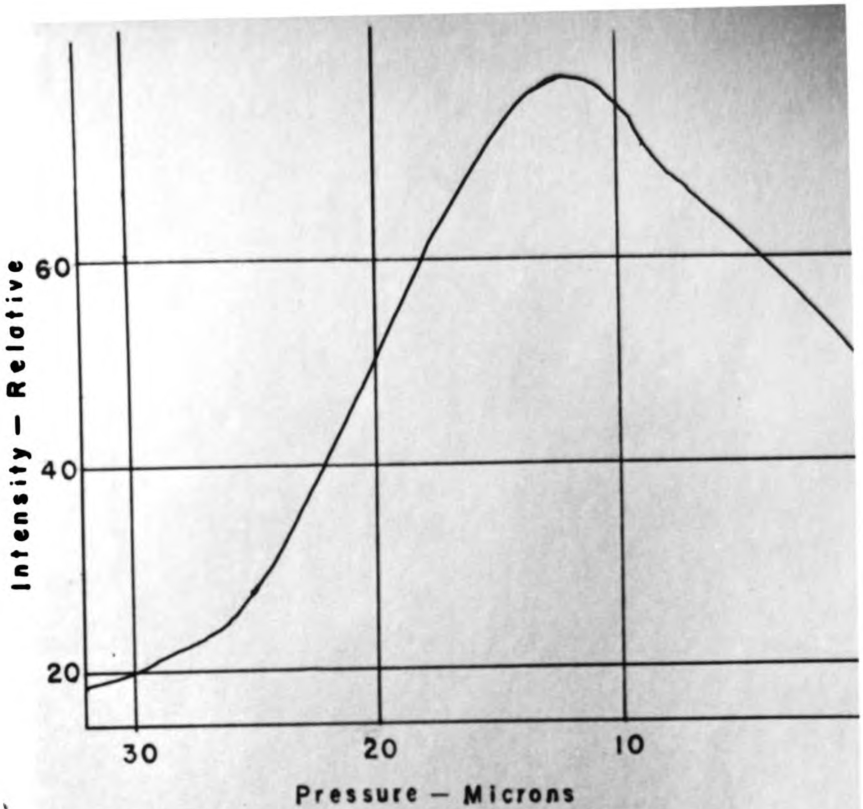

FIG. V PRESSURE vs ION INTENSITY

Pressures were measured outside the gas box, and dry air calibration was used.

The calibration curve we used was for dry air.

An effort was made to get some data relating the focusing, magnetic field to the intensity of the ion beam. This of course required a steady gas flow which we did not have, but a few facts regarding the influence of the field were apparent.

When the coils were operating below 30 volts, which by the formula,

$$H = \frac{4\pi N i a^2}{(a^2 + b^2)^{3/2}}$$

where,

H - Field in gauss

N - No. of turns on the coils

i - Current

a - radius of coils

b - distance from axis center to coil center

gave a field at the center of the axis of approximately 250 gauss, there was practically no ion emission. Very rapid increases in the beam intensity were noted immediately above this field value. Increases could be observed for fields using the full 120 volts that was available. For this voltage the calculated field was approximately 1000 gauss.

It was also noted that when using coil voltages over 100 volts rather excessive heating of the magnetic coils was encountered. A good operating voltage if the instrument is to be used over long periods of time seemed to be about 80 volts. Althrough, we as yet do not have sufficient data to be certain, it seems that field increases above 700 or 800 gauss will not increase the ion intensity by more than 10-15%.

V. Conclusions.

Peculiarities of the Instrument.

Having thus constructed and tested the ion source it is apparent from its output and operation that it might be adapted to use with experiments requiring a postive ion source. In view of this the following observations and remarks are applicable.

(1) After the system had been opened to the air for any length of time four or five hours of pumping were required to get stable output reestablished. This is probably due to absorbtion of gases by the w alls or other parts of the instrument. This observation is supported by the fact that the long pumping time was not found to be necessary if the system was exposed to the air for only a few minutes.

(2) It is possible to reduce the pressure sufficiently to produce a blueish arc between the filament and the gas box. This can be prevented by placing a resistance in the accelerating supply circuit. For extremely high ion currents however, the ionizing electron current is of the order of amperes and the

resistance must be omitted. Actually the phenomenon described here is rather strange and its occurance cannot be predicted even when what seem to be exactly the same conditions are present.

(3) The entire system must be grounded as extremely high static charges are collected on the cases. This introduces an insulation problem in the circuit supplies as parts of the metal cases are at a high potential.

Suggested Improvements.

Certain changes in construction would of course be necessary to adapt the source to any special use, but aside from that a few general improvements might be suggested.

(1) First and absolutely necessary is a good gas control flow valve. This has already been discussed.

(2) Some additional experimental work should be carried out in regard to the size of the holes in the gas box and the accelerating electrode. This can only be done after successful control of the gas flow has been accomplished.

(3) Pulsed operation of the accelerating potential is suggested for obtaining maximum ion intensity. A suitable circuit is described by Setlow.

(4) Judging from the effects of the magnetic field on the observed intensity, it would seem that a more

homogeneous magnetic field would increase the beam intensity. It might also be possible by suitablely shaping the electrodes to produce additional focusing of the electron beam and hence more effacient ionization.

Bibliography

Setlow, Richard B.
1949 A High Current Ion Source. <u>The Review of Scientific Instruments</u>, <u>20</u>: 558-560.

Nier, Alfred O. C., Ney, Edward P., Ingham, Mark G.
1948 Adjustable Gas Leak. <u>The Review of Scientific Instruments</u>, <u>18</u>: 191.

Allison, Samuel K.
1948 Construction and Performance of a Low Voltage Arc as a Source of Positive Ions. <u>The Review of Scientific Instruments</u>, <u>19</u>: 291-298.

Hall, Robert M.
1948 High Frequency Proton Source. <u>The Review of Scientific Instruments</u>, <u>19</u>: 905-910.

Finkelstein, A. Theodore
1940 A High Efficiency Ion Source. <u>The Review of Scientific Instruments</u>, <u>11</u>: 94-99.