DESIGN AND CONSTRUCTION OF A POSITIVE RADIO-FREQUENCY ION SOURCE FOR THE PRODUCTION OF NEGATIVE IONS

APPROVED:

[Signature]
Major Professor

[Signature]
Minor Professor

[Signature]
Director of the Department of Physics

[Signature]
Dean of the Graduate School
DESIGN AND CONSTRUCTION OF A POSITIVE RADIO-FREQUENCY
ION SOURCE FOR THE PRODUCTION OF NEGATIVE IONS

THESIS

Presented to the Graduate Council of the
North Texas State College in Partial
Fulfillment of the Requirements

For the Degree of

MASTER OF ARTS

By

B. Cecil Thompson, B. A.

Denton, Texas
August, 1958
# TABLE OF CONTENTS

LIST OF ILLUSTRATIONS ................................... iv

Chapter

I. INTRODUCTION ........................................... 1

II. INSTRUMENTATION .................................... 5

  High Voltage Terminal
  Accelerating Column
  Vacuum System
  High Voltage Supply
  Beam Measurement Techniques
  Experimental Arrangement

III. DISCUSSION AND SUGGESTION FOR FURTHER
     MODIFICATION ...................................... 16

APPENDIX ................................................. 20

BIBLIOGRAPHY ............................................. 30
**LIST OF ILLUSTRATIONS**

<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Radio-Frequency Oscillator</td>
<td>20</td>
</tr>
<tr>
<td>2</td>
<td>Power Supply for Oscillator</td>
<td>22</td>
</tr>
<tr>
<td>3</td>
<td>Probe Supply</td>
<td>24</td>
</tr>
<tr>
<td>4</td>
<td>Accelerating Column</td>
<td>26</td>
</tr>
<tr>
<td>5</td>
<td>Faraday Cup Attachment</td>
<td>27</td>
</tr>
<tr>
<td>6</td>
<td>Block Diagram of Ion Source</td>
<td>28</td>
</tr>
<tr>
<td>7</td>
<td>Control Panel</td>
<td>29</td>
</tr>
</tbody>
</table>
CHAPTER I

INTRODUCTION

The production of high-energy particles by electrostatic generators has become more difficult as higher accelerating voltages are sought due to electrical breakdown of the vacuum tube in such machines. It is possible (1, 4) to double the energy of protons emerging from any double-ended electrostatic generator if one accelerates negative hydrogen ions to an electrode maintained at a positive voltage with respect to ground, strips off two electrons by passing the negative ions through a thin target inside the electrode, and accelerates the resulting positively charged protons back to ground potential. Even greater gains in energy are possible for elements having a higher atomic number.

An electrostatic generator of this type has additional virtues. In conventional generators some of the machinery requiring high electrical power input is housed within the relatively inaccessible high voltage electrode. Maintenance should be easier in the negative-ion generator since this machinery may now be kept at ground potential. By mass and velocity separation the momentum of the negative ions
can be determined such that only those ions that will ultimately be used need be accelerated. Also considerable freedom of focal conditions is possible before the beam enters the accelerating tube.

Although a few sources of the negative ion type are now in operation (3, 5, 6), these sources can provide very little basic information about the negative particles. Negative hydrogen ions may be withdrawn directly from a glow discharge (2), however, the yield of hydrogen ions from discharges is usually less than one microampere. Further, one cannot measure production cross-sections with this type of ion source.

In 1957, a Frederic Gardner Cottrell research grant was received from the Research Corporation (a Foundation), and development of an ion source was begun which could be used to measure basic quantities such as production and decay cross-sections of the negative ions.

The design for the ion source at North Texas State College consists of a radio-frequency positive-ion source which will allow protons or helium nuclei to be converted to negative ions through electron capture by collision with the molecules of the converter gas. From the number of negative ions produced for a given positive ion input, production cross-section can be measured.
It is the purpose of this paper to present a detailed account of the design and construction of this positive-ion source and associated equipment.
CHAPTER BIBLIOGRAPHY


CHAPTER II

INSTRUMENTATION

In the past almost all ion sources used for negative ion production have been of the filament type. However, a radio-frequency ion source was chosen for the positive ion source at North Texas State College. The radio-frequency ion source has several advantages for production and decay cross-section measurements. The power needed to operate an ordinary filament type of ion source requires that it be at ground potential (3). This measurement makes it necessary to measure the positive beam at a high negative potential. This measurement is difficult to accomplish under such circumstances. Further, the filament type of ion sources is most effective when the high potential extraction is very close to the ion exit hole. The extraction electrode usually serves as a gas conversion chamber as well as an extraction electrode. This is undesirable because the positive ion beam producing the negative ions cannot be measured due to the close proximity of the electrodes. Without the value of the positive ion current, the production cross-section cannot be obtained.
The ion source now in use is a radio-frequency type designed by C. D. Moak (2). The ionization chamber consists of a 8 3/4 inch by 3/4 inch Pyrex tube with a tungsten anode inserted in the closed end for ion extraction purposes. The use of Pyrex was recommended by Moak because of its low recombination property which enables a greater percentage of atomic hydrogen to be extracted from the chamber.

High Voltage Terminal

The radio-frequency exciter is a parallel line oscillator using two 6L46 beam power tubes operating at frequencies between 85 and 100 megacycles (Figure 1 and 2)*. The oscillator is capacitively coupled from a hairpin loop to the ionization chamber by two external copper ring electrodes that slip over the ion chamber. The oscillator voltage is supplied by a D-C power supply with an output of 500 volts under no load operation. Filament voltage for the 5R4-GYA rectifier tubes is supplied by the power transformer. Under maximum load conditions the voltage output to the oscillator is approximately 450 volts at 70 milliamperes.

The small tungsten anode and aluminum cathode comprise the extraction system. The cathode consists of a cylindrical aluminum probe protruding into the discharge tube. A 1/16 inch

*Figure 1 and all succeeding figures will be found in the Appendix.
diameter canal is drilled in the aluminum probe to carry the ions into the accelerator column. This aluminum cathode is cut to its desired dimension from a solid piece of metal three inches in diameter. The cathode is attached to the accelerator column by a flange carrying an "O" ring to keep the system vacuum tight. The extraction voltage is capable of operation in the ranges between 0 and 2300 volts without arcing depending on the pressure inside the ion chamber. The voltage supply is a half-wave rectifier (Figure 3).

When operating at pressures in the vicinity of $10^{-5}$ mm of Hg in the accelerating tube, the maximum beam current is obtained with the probe voltage set at 2300 volts.

When working properly, the ion discharge will show a pronounced red coloring. The most critical adjustments of the ion source are the extraction system and the radio-frequency power to the discharge tube. Without proper extraction voltage which is strongly dependent upon the pressure in the ion bottle, it is impossible to obtain a measurable beam current.

Both the oscillator and extraction voltage power supplies require a nominal 110-115 volt A-C input. Since the entire ion source necessarily operates at the high voltage end of the accelerating column, a 110-115 volt A-C supply isolated at 50 kilovolts above ground must be available. The isolation problem was solved by rewinding an X-ray filament
transformer such that the secondary winding is 410 turns of number 16 varnished cotton covered wire. The coil has an average diameter of 6.14 inches. The isolation transformer produces an output of 120 volts A-C with no load and 105 volts with a six ampere load if the primary voltage is 220 volts.

The oscillator and probe equipment is housed in a high voltage corona shield which is connected electrically and mechanically to the electrode on the accelerator column having the highest potential with respect to ground. Four ports with rounded edges were placed in the sides and top of the corona shield to permit variation of the probe supply, recording the plate current in the oscillator, observation of the ion bottle with the high voltage on the terminal, and air circulation for cooling the components in the terminal. No evidence of corona is observed with the high voltage operating at approximately 50 kilovolts.

Accelerating Column

An accelerating column capable of withstanding 50 kilovolts was constructed. It consists of ten aluminum electrodes 1/4 inch thick and six inches in diameter with a two inch hole in the center (Figure 4). The electrodes are separated by cylindrical glass plates 1/4 inch thick, five inches outside diameter with a central hole three inches in
diameter. These are bonded to the metal with a plastic bonding agent. (Bonding Agent R-313, Carl H. Biggs Company, 2255 Barry Avenue, Los Angeles 64, California).

The electrodes are allowed to pass into the vacuum system at equal intervals along the ion path in such a way that the radial extension of the electrode past the outside of the central hole in the glass insulator is twice the thickness of the glass insulator. This design will adequately shield the ion beam from any asymmetric charge collecting on the glass insulator (1).

The potential gradient across the column is obtained by tapping the voltage drop across a forty-five megohm dropping resistor at five megohm intervals. This arrangement gives approximately five thousand volts drop across each electrode when the potential gradient across the column is forty-five thousand volts.

Vacuum System

The vacuum system consists of a "T" section of brass tubing that is eight inches inside diameter. The bottom of the "T" section is connected to a brass tube also having an eight inch inside diameter. This tube is twelve inches long. Vacuum seals are made at the ends of the cylinder with "0" ring rubber gaskets. This section contains a liquid nitrogen cold-trap which is thermally insulated from the brass walls by 1/4 inch diameter stainless steel tubing. The stainless
tubing also serves as the intake and exhaust ports for the liquid nitrogen. In operation, the trap is at a temperature below \(-180^\circ\text{C}\). The cooling of the liquid nitrogen causes the vaporized oil from the diffusion pump and condensable vapors from the system to condense on the trap and thus be removed from other parts of the system.

The brass section containing the cold-trap is mated to a Electrodyamics Corporation (Model MGF-700) six inch oil diffusion pump. The fore-pressure of the diffusion pump is maintained by a W. M. Welch Duo-Seal mechanical pump having a free air capacity of 140 liters per minute.

With the system at atmospheric pressure, the fore-pump will reduce the pressure to five microns in forty-five minutes. After the fore-pressure has reached equilibrium at approximately twenty-five microns, the diffusion pump may be started. The diffusion pump requires twenty minutes warm up, during which time the pressure in the system will rise to approximately fifty microns. When the diffusion pump begins proper operation, the pressure will drop rapidly to \(3 \times 10^{-4}\) mm of Hg. After ten minutes, the pressure on the high vacuum side of the diffusion pump will reach equilibrium at \(1.3 \times 10^{-5}\) mm of Hg. The high vacuum pressure may be lowered by allowing the diffusion pump to warm up with no cold trap and filling the cold trap with liquid nitrogen when the pressure is approximately \(5 \times 10^{-5}\) mm of Hg. With this method, pressures
as low as $6.5 \times 10^{-6}$ mm of Hg could be maintained as long as the liquid nitrogen was present.

When hydrogen is leaked into the ionization chamber the pressure rises to $3.4 \times 10^{-5}$ mm of Hg for a slow gas flow. When the largest gas flow obtainable was tried, the pressure reached equilibrium at $8.5 \times 10^{-5}$ mm of Hg.

Care should be taken at all times not to increase the high voltage when the pressure is approaching $5 \times 10^{-4}$ mm of Hg. At this pressure, gas becomes conductive, and the possibility of an electrical discharge inside the column will result. Such an arc might damage the electrodes and could possibly break the glass insulators. This would result in permanent damage to the column and damage the hot oil inside the diffusion pump.

The pressure in the range of 1000 to 1 microns is measured by a National Research (Model 501) thermocouple gauge. Measurements of pressure below one micron is accomplished with a National Research (Model 507) hot filament ionization gauge. This gauge is capable of measuring pressures as low as the order of $10^{-7}$ mm of Hg. Under no circumstances should the ionization gauge be turned on at pressures above five microns. Operation at high pressures will result in permanent damage to the gauge filament. In event of vacuum failure while in operation, the power supply is equipped with a circuit breaker that shuts off the power
to the gauge when a pressure three times the full scale deflection is reached.

High Voltage Supply

The high voltage supply, with the exception of the filtering capacitor, is immersed in an oil bath for high voltage insulation. The dropping resistors are placed in a separate oil bath from the rest of the high voltage supply to shorten the high voltage leads to the column and prevent corona. Leads with twenty thousand volt insulation were used to connect the dropping resistors to the electrodes of the column from the oil tank. The filtering capacitor was not immersed in oil because the geometry of its terminals is such that corona would not be a problem. The capacitor is connected to the corona shield with 3/4 inch uninsulated tubing.

The high voltage supply is a bridge rectifier circuit capable of producing 130 kilovolts, sixty-five kilovolts positive and sixty-five kilovolts negative with respect to a grounded center tap. However, since only fifty kilovolts positive are needed for production cross-section measurements, the negative terminal was left unconnected. The positive supply is now used as a half-wave rectifier. The rectifier tubes are General Electric KR-6 oil immersed Kenotrons capable of 140 kilovolts peak-inverse at 30 milliamperes for continuous operation. Care should be taken never to increase
the voltage output above sixty-five kilovolts, or the peak-inverse voltage rating of the rectifier tubes in the high voltage supply will be exceeded and damage will occur to the tubes.

Beam Measurement Techniques

A Faraday Cup (Figure 5) one inch in diameter and 1/4 inch deep is used to collect the beam. A ring one inch in diameter and 1/4 inch in front of the collector is kept at 200 volts D-C below ground to repel the secondary electrons produced in the Faraday Cup by the ions. The beam current is measured with a Radio Corporation of America (Model WV-84A) ultra-sensitive microammeter capable of measuring currents between .001 and 1000 microamperes. Calibration of the microammeter is accomplished by using a battery voltage supply in series with a resistor having a one per cent tolerance. The calibration showed the meter to be correct within the tolerance of the standard resistors.

Experimental Arrangement

A block diagram (Figure 6) shows the experimental arrangement of the components of the ion source. The ion source, with the exception of the high voltage supply, occupies approximately twenty-five square feet of floor space. The high voltage supply is separated from the ion source by five feet to allow freedom of movement around the source.
The electrical connection from the high voltage terminal to the high voltage supply is made by a cable insulated to withstand sixty-five kilovolts which passes over head inside a grounded shield.

The control panel (Figure 7) was constructed in such a way that operation and beam current measurements may be made with a minimum of movement of the operator. The variable input to the high voltage supply and three ten ampere circuit breakers inserted into one panel allows shut down of every electrical component other than the vacuum pumps from one position. Adjusting the probe voltage from the operator position with the high voltage on is accomplished by adjusting the variable input transformer of the probe supply (Figure 3) with a three foot lucite rod that may be inserted into one of the openings provided in the corona shield.
CHAPTER BIBLIOGRAPHY

1. Herb, R. G., private communication, Department of Physics, University of Wisconsin, Madison, Wisconsin.


CHAPTER III

DISCUSSION AND SUGGESTION FOR FURTHER MODIFICATION

Operation of the ion source indicated that several modifications will be necessary before the ion source can be used for the production of negative ions. The low beam current obtainable from the present source is not sufficient to give a measurable beam of negative ions. The percentage of positive ions which can be converted to negative ions is very small. Under best circumstances the per cent conversion is less than one tenth (2). The low conversion ratio makes an intense positive ion beam necessary.

To obtain a higher degree of ionization, a radio-frequency oscillator consisting of a single 829-B pentode running as a self-excited push-pull oscillator was constructed and substituted for the parallel line oscillator described in Chapter II. This oscillator produced sufficient ionization to increase the beam current by a factor of ten.

As the extraction voltage is increased, a circle of fluorescence appears on the flat face of the canal tip. Further increase of the voltage caused this circle to shrink. When the pressure inside the ion bottle is such that the
probe voltage can be increased to the maximum value, the fluorescent circle is approximately the size of the aluminum tip of the cathode. It has been observed that this circle of fluorescence should shrink until it finally disappears into the canal (1). Under these conditions the maximum beam current should be obtainable.

The gas leak system consisting of a constricted copper tube and a "Hoke" bellows type valve is used to admit hydrogen into the ionization chamber. This leak system is adequate, however, a commercial needle valve capable of very low gas flow would improve the control of the gas pressure in the ion bottle.

The high-voltage supply operates well in the ranges of 0 to 50 kilovolts and shows no indication that modification is necessary.

With the Faraday Cup removed, a fluorescent screen was used to observe the beam behind the position normally occupied by the Faraday Cup. This observation was compared to the spot burned on the Faraday Cup. This comparison indicated that the beam was diverging. Calculations to determine the cause of this divergence were carried out. Approximations were made for the space charge spreading effect because the equation for the positive ion velocity could not be solved for displacement of the outside of the beam in closed form. These calculations indicated that space-charge spreading would
be rather small compared to the geometrical spreading. This divergence could be corrected by the use of a saddle field focussing lens in the brass "T" section. Such a lens has been constructed but has not been installed at this date.

The radio-frequency ion source described here is designed to produce positive ions from hydrogen, helium, nitrogen, argon, and neon. With these further modifications, the ion source should be a stable source of positive charged particles requiring no attention for as much as 500 hours of operating time.
CHAPTER BIBLIOGRAPHY


Fig. 1 -- R.F. Oscillator
List of Components for Figure 1

$V_1, V_2$ - 6146 Very high frequency beam power tube.

$H$ - Hairpin loop pick off.

$C_1$ - .003 Microfarad 600 VDC.

$C_2$ - .001 Microfarad 600 VDC.

$R_1$ - 15,000 Ohm, 2 watt.

$R_2$ - 150 Ohm, 2 watt.

$R_3$ - 13,500 Ohm, 2 watt.
Fig. 2 -- Power Supply for Oscillator
List of Components for Figure 2

T - High voltage transformer with 6.3 VAC and 5.0 VAC windings.

R₁, R₂ - 5R4GYA Full-wave vacuum rectifier, 2100 volt peak inverse, 650 milliamperes.

L - 4 Henry inductor coil.

C₁, C₂, C₃ - 4 Microfarad, 1000 VAC.

R₁ - 110,000 Ohm, 4 watt.

P - Output plug to oscillator.
Fig. 3 — Probe Supply
List of Components for Figure 3

V    - 2 x 2 - 879 Half-wave vacuum rectifier, 12.5 kilovolt peak inverse, 60 milliamperes.

T_1  - High voltage transformer, 2150 volt maximum.

T_2  - Variac, 0-135 A-C volts output, 115 A-C volts input.

T_3  - Filament transformer, 2.5 A-C volts, 10 kilovolts insulation.

C    - 4 Microfarad, 2000 volt D-C.

R    - 1.2 Megohms, 8 watts.

F    - Fuse, 3 amperes.
Fig. 4 -- Accelerating Column
Fig. 6 -- Block Diagram of Ion Source
BIBLIOGRAPHY

Articles


Public Documents


Kallmann, H., United States Patent 2, 213, 140.

Unpublished Materials

Herb, R. G., private communication, Department of Physics, University of Wisconsin, Madison, Wisconsin.