A POSITIVE ION SOURCE

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A POSITIVE ION SOURCE

THESIS

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TABLE OF CONTENTS

LIST OF TABLES ........................................ iv
LIST OF ILLUSTRATIONS ............................... v
A POSITIVE ION SOURCE. ................................ 1
   Introduction
   Method of Procedure
   Discussion of Results
   Summary

APPENDIX .............................................. 11

BIBLIOGRAPHY ......................................... 20
<table>
<thead>
<tr>
<th>Table</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 (a)</td>
<td>Typical Analysis of Hydrogen Beam</td>
<td>11</td>
</tr>
<tr>
<td>1 (b)</td>
<td>Analysis of Deuterium Beam Currents in Microamps</td>
<td>11</td>
</tr>
<tr>
<td>2</td>
<td>Comparison of Ion Source</td>
<td>12</td>
</tr>
</tbody>
</table>
**LIST OF ILLUSTRATIONS**

<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Schematic Circuit Diagram of The Power Supply</td>
<td>13</td>
</tr>
<tr>
<td>2.</td>
<td>Schematic Circuit Diagram of The Radio Frequency Exciter</td>
<td>15</td>
</tr>
<tr>
<td>3.</td>
<td>Ion Source</td>
<td>17</td>
</tr>
<tr>
<td>4.</td>
<td>Top View of The Power Supply</td>
<td>18</td>
</tr>
<tr>
<td>5.</td>
<td>Rear View of The Radio Frequency Exciter</td>
<td>18</td>
</tr>
<tr>
<td>6.</td>
<td>Under Chassis View of Radio Frequency Exciter</td>
<td></td>
</tr>
</tbody>
</table>
A POSITIVE ION SOURCE

Introduction

In the study of nuclear physics, protons or deuterons accelerated to high energies are used as a tool. The usefulness of the instrument producing these high energy particles depends on the average energy of the particles, the energy spread of the beam and the average current of atomic ions. The last two properties are determined by the source of the ions to be accelerated. In the ion source a high efficiency is desirable as measured by the ratio of the number of emergent atomic ions to the number of emergent gas molecules and also by the ratio of the beam current of ions of the desired type to the total beam current. The source should have a long life and low power consumption, and should be very stable. The ion beam should be suitably collimated.

A large number of different ion sources have been developed and investigated but they may all be classified under one of the following: electrodeless discharge, ¹

capillary arc, reflection type with magnetic field, and canal ray. In the first type, the electrodeless discharge, the positive ions are formed in a low pressure chamber. This discharge is excited by the radio frequency field of a coil coupled to an oscillator. The ions are extracted from the discharge through a pumping canal by a simple arrangement of electrodes. In the capillary arc type, the ions are produced by a low voltage high intensity electron discharge in the gas stream. The ions are then withdrawn through a suitable capillary tube and accelerated to the required energy.

Information on this type may be found in:


In the reflection type with magnetic field, the ions are produced by making electrons oscillate through a region occupied by a gas with energies corresponding to the maximum ionization probability. The electron space charge is used to withdraw the ion beam and hold it together. In the fourth type, the canal ray source, the ions are produced by a high potential discharge from a cold cathode. The ions are extracted through a hole in the cathode. Since the construction of a positive ion source was to be undertaken, a detailed study of the advantages and disadvantages of the various types was made. The electrodeless discharge type was chosen for the following reasons. (1) The enclosing surface of the discharge can be made of Pyrex glass. (2) This type of source contains no electron emitting cathode which would usually have a short and indeterminate life. (3) The amount of metal exposed to the discharge is very small and is associated with the extracting electrode.

In a study on an electrodeless discharge type of ion source, A. J. Bayly and A. G. Ward report:

The percentage composition of the beam has been determined with a magnetic analyzer. This was placed at the position normally occupied by the target, and the ion currents were measured in a Faraday cylinder after 180° deflection in a magnetic field. Their resolution was such as to allow complete separation of the

mass peaks as far as mass 6, and was determined primarily by the beam diameter at the entrance (about 6 mm.) to the analyzer and the diameter of the aperture in front of the Faraday cylinder (about 1 cm.). Flat topped peaks were obtained as the magnetic field was varied, corresponding to one component of the analyzed beam sweeping across the aperture in front of the Faraday cylinder. The mean radius of curvature in the analyzer was 5 cm. and the analysis were normally made with an overall voltage of 15 kv.

A series of measurements taken with the ion source operating normally are given in Table II. In addition to those peaks listed in Table II, very small peaks were observed which corresponded in energy to atomic ions produced by the breaking up of the molecular ions after they had been accelerated to the maximum voltage. The beam current used in taking these measurements was about 200 microamps. The higher percentage of atomic ions, when deuterium gas is used as compared with that when using hydrogen gas, is a real effect. It could arise from the difference in the impurities in the gases, since commercial samples were used. The hydrogen was stated to be 99.5% H₂ with O₂ as the main impurity, while the deuterium was 95% D₂ with H₂ as the main impurity.

The percentage of atomic ions in the beam increases gradually as the pressure is reduced, but the total beam current decreases rapidly. The normal operating pressure has been chosen to give good percentages of atomic ions and a reasonable rate of gas consumption, but the performance of the ion source does not depend markedly on the pressure, and variations of 25% are easily tolerated.

The characteristics of various types of ion sources are listed in Table III. From an inspection of the data given in this table it can be seen that the radio-frequency type of ion source has a performance comparable to that of the best of other sources. It should be noted that the values given for the energy spread are maximum possible values. In the cases of the Capillary Source with a metal probe and the Radio Frequency Source the great majority of the ions in the beam have a relatively small energy spread, probably less than 100 electron volt.

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6Table II is reproduced in the Appendix as Table I.

7Table III is reproduced in the Appendix as Table II.
The remainder of this paper describes the construction of a positive ion source of the electrodeless discharge type and may be divided into two main topics; (1) the radio frequency oscillator and power amplifier and associated power supply and (2) the ionization chamber.

Method of Procedure

The radio frequency exciter was developed along fairly conventional lines. It is a combination of modified stages taken from the Radio Amateur's Handbook. It consists of a three stage transmitter using a 6AG7 pentode connected in a Pierce crystal oscillator, an 807 as a doubler, and a pair of 813's as a push-pull power amplifier. The final stage operates on a frequency of 27.12 megacycles per second.

The screen grid of the 6AG7 is used as the oscillator anode and the plate circuit of the tube is tuned to the second harmonic of the crystal frequency. Thus, the first stage delivers output at a frequency equal to twice the crystal frequency. The plate circuit of the 807 is tuned to twice the frequency of the grid circuit. Thus, the second stage produces output at the fourth harmonic of the crystal frequency. The 813's operate as straight amplifiers.

Referring to the schematic circuit diagram of Figure 2, 9

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9 See Appendix.
it will be seen that grid-leak bias is used for all stages. Additional bias is obtained for the first two stages by use of by-passed resistors in the cathode circuit, while protection for the final stage in the event of excitation failure, is furnished by the 6L6 vacuum tube in the screen grid circuit of the 813's. If excitation is applied to the final tube there is developed across the resistor in the grid circuit, due to the flow of grid current, a voltage of about -150 volts. Since this bias is applied to the 6L6 grid it is biased far beyond cut-off and draws no plate current. However, if excitation fails the cut-off bias is not developed across the grid resistor and the cathode and grid of the 6L6 are at the same potential. This causes the 6L6 to draw plate current and the 813 screen grid voltage drops to a very low value (approximately 150 volts), low enough to prevent damage to the tubes.

Three metering circuits are provided. They are connected to the three phone jacks mounted on the rear right end of the chassis. An ordinary 1000 ohm-per-volt meter may be used when tuning up the various stages. The top jack is connected to the grid resistor of the 807. The first variable condenser is tuned for maximum voltage, about -65 volts. The second is connected to a 500-ohm section of the 5500 ohm grid resistor of the 813 final. The second variable condenser should be adjusted for maximum voltage, about -15 volts. In case the reading is more than 15 volts or less than 12 volts adjustment
may be made by means of a rotary switch located near the three metering jacks. It controls the screen grid voltage of the 807. The third jack is connected to a 40 ohm resistor in the cathode circuit of the 813 final amplifier. The third tuning condenser should be adjusted for minimum voltage, about 15 volts. This is the equivalent of 375 ma. screen grid and plate current.

Parallel feed is used in all except the final grid and plate circuit. This allows grounding of the rotor of the tuning condensers for the first two stages. Capacitance coupling is used throughout to simplify the circuit.

The transmitter is built on a 17 x 13 x 4 inch chassis with a standard 12 1/4 x 19 inch rack panel. The oscillator section occupies the rear right corner. All the oscillator components, except the plug-in coil, are mounted underneath the chassis to provide shielding. Also mounted underneath the chassis and to the front of the oscillator component are the components of the second stage. They are separated from the oscillator by a removable shield. The 807 doubler socket is mounted on, but behind this shield using metal spacers. This is done to provide shielding between the plate and grid circuit. The coil and condenser forming the tuned circuit for the plate of the 807 and grid of the final amplifier are mounted under the chassis and near the center. The arrangement allows short grid leads. The tuned circuit for the
plate of the final amplifier is mounted on the top left side of the chassis. Directly behind these the 500 ma. radio frequency choke is mounted along with the d-c isolating condenser for the rotor of the final plate circuit tuning condenser. The radio frequency power output, the d-c and a-c power input are supplied through plugs in the rear of the chassis.

The filament transformer for the 813's is mounted in the front left corner under the chassis. The filament transformer supplying the exciter stages is mounted under the chassis in the rear center. The associated voltage dropping resistors are mounted in the remainder of the space under the chassis.

The power supply is entirely conventional. The high voltage rectifiers are 866A's. A single section choke input filter is used. This small amount of filtering may be used since it supplies only the plates of the push-pull 813's. A low voltage power supply is used for the oscillator, the doubler and screen grid of the final. 5R4GY's are used as rectifiers. A double section choke input filter is used. Bleeder resistances of large values were chosen since the transformers would be operating near maximum ratings when the apparatus is drawing its full load.

The constructional details of the ion source are shown in Figure 3.10 The ion source consists of a 600 cc. Pyrex

10 See Appendix.
chemical reagent bottle and three metal electrodes separated by two glass spacers. The reagent bottle fits closely over the top of the first electrode. This electrode extends the full length of the neck of the bottle. The rim of the bottle is ground flat to fit the electrode. The vacuum seal is made with Apiezon W.

The second electrode, called the extracting electrode, is separated from the first electrode by one of the glass spacers. The third electrode, called the focusing electrode, is separated from the second electrode by the other glass spacer.

Two porcelain posts are mounted on the third electrode. These posts support the radio frequency exciting coil. This coil is made of four turns of one-quarter inch copper tubing wound around the reagent bottle and spaced one-quarter inch from it. The radio frequency power is supplied to this coil by means of a parallel wire transmission line connected to the top of the porcelain coil. Radio frequency chokes are wound on these porcelain posts; one end of each choke is connected to the exciter coil and the other end to the extracting electrode.

Gas is supplied to the apparatus through a capillary in the first electrode while pumping is done through the third electrode.
Discussion of Results

Figure 4, Figure 5, and Figure 6 are photographs of the completed radio frequency exciter and power supply. Figure 5 shows the top side of the power supply. The components of the high voltage supply are located on the right while the components for the low voltage supply are on the left. Figure 5, top view, and Figure 6, bottom view, show the placement of components of the radio frequency exciter.

When operating properly the discharge is a deep red. If a small leak is present in the system the color is a white or pale pink. When the operating pressure is raised, the discharge takes on a ring shape. A decrease in radio frequency power is accompanied by flicker of the discharge.

Summary

A positive ion source of the electrodeless discharge type has been constructed. This type has two advantages over other positive ion sources. First, it contains no electron emitting cathode which usually have short and indeterminate lives. Second, a minimum amount of metal is exposed to the discharge. Thus, the discharge chamber may be constructed almost entirely of Pyrex glass.

\[11\text{See Appendix}\]

\[12\text{See Appendix}\]

\[13\text{See Appendix}\]
APPENDIX

TABLE 1 (a)
TYPICAL ANALYSIS OF HYDROGEN BEAM

<table>
<thead>
<tr>
<th>Mass</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>Others</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peak Current, (microamps.)</td>
<td>91</td>
<td>37</td>
<td>51</td>
<td>---</td>
</tr>
</tbody>
</table>

Mass 1 content is 51%

---

TABLE 1 (b)
ANALYSIS OF DEUTERIUM BEAM CURRENTS
IN MICROAMPS

<table>
<thead>
<tr>
<th>Mass</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>Mass 2 Content %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Run 1</td>
<td>4</td>
<td>64</td>
<td>2\frac{1}{2}</td>
<td>17</td>
<td>2</td>
<td>10</td>
<td>62</td>
</tr>
<tr>
<td>Run 2</td>
<td>4</td>
<td>60\frac{3}{4}</td>
<td>2\frac{1}{2}</td>
<td>17</td>
<td>4\frac{1}{2}</td>
<td>15</td>
<td>52</td>
</tr>
<tr>
<td>Run 3</td>
<td>4</td>
<td>57</td>
<td>3</td>
<td>19</td>
<td>4</td>
<td>14\frac{1}{2}</td>
<td>57</td>
</tr>
<tr>
<td>Run 4</td>
<td>4\frac{1}{2}</td>
<td>66</td>
<td>2\frac{1}{2}</td>
<td>18</td>
<td>3</td>
<td>19</td>
<td>58</td>
</tr>
</tbody>
</table>

Average mass 2 content is 57%

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14 Bayly and Ward, op. cit.
<table>
<thead>
<tr>
<th>Type of Source</th>
<th>Canal Ray</th>
<th>Capillary Arc</th>
<th>Reflection with Magnetic Field</th>
<th>Electrode-less Discharge</th>
</tr>
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<tbody>
<tr>
<td>Reference</td>
<td>Bowers, Heyn</td>
<td>Craggs, Zinn</td>
<td>Lamar, Buechner Van de Graff</td>
<td>Metal Glass Probe, Capillary</td>
</tr>
<tr>
<td>Pressure in Discharge Chamber (microns)</td>
<td>20</td>
<td>150</td>
<td>30</td>
<td>≥ 20</td>
</tr>
<tr>
<td>Power Input (watts)</td>
<td>2000</td>
<td>400</td>
<td>235</td>
<td>385</td>
</tr>
<tr>
<td>Canal Dimensions</td>
<td>3x5</td>
<td>1.8x2.5</td>
<td>1x6</td>
<td>.8x0</td>
</tr>
<tr>
<td>Diameter x Length (mm)</td>
<td>3x5</td>
<td>1.8x2.5</td>
<td>1x6</td>
<td>.8x0</td>
</tr>
<tr>
<td>Max. Ion Current (mm)</td>
<td>1.6</td>
<td>1.8</td>
<td>4.3</td>
<td>1.0</td>
</tr>
<tr>
<td>% Atomic Ion</td>
<td>30%</td>
<td>.45</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>H₂ Consumption (cc/min. @ 760 mm)</td>
<td>3.5</td>
<td>6.5</td>
<td>.16</td>
<td>.38</td>
</tr>
<tr>
<td>Ratio of Protons to Gas Molecules (percent)</td>
<td>.07</td>
<td>.17</td>
<td>7.5</td>
<td>.74</td>
</tr>
</tbody>
</table>

15Ibid.
LIST OF COMPONENTS FOR FIGURE 1

$C_1, C_2$ - 2uf 2000 volt oil filled condenser
$C_3, C_4$ - 4uf 1000 volt oil filled condenser

$R_1, R_2$ - 2 megohm 1 watt carbon resistor
$R_3$ - 7 megohm 1 watt carbon resistor
$R_4$ - 1 megohm 1 watt carbon resistor
$R_5$ - 40 ohm wire wound 5 watt resistor

$L_1$ - Filter choke (Stancor C-1403)
$L_2$ - Filter choke (Thordarson T-19C35)
$L_3$ - Filter choke (Thordarson T-19042)

$T_1$ - 4840 centered tapped 300ma. (Thordarson T-19P65)
$T_2$ - 1000 centered tapped 225ma. (Thordarson T-19P56)
$T_3$ - 2.5 volt ampere filament transformer, secondary insulation 7500 volts. (Thordarson T-21F90)
$T_4$ - 0.3 volt 4 ampere filament transformer, secondary insulation 5000 volts. (Thordarson T-79F6C)
A resistor (71 ohms) is inserted to drop secondary voltage to 5 volts under load
$T_5$ - 10 volt 12 ampere filament transformer (Thordarson T-21F19)
$T_6$ - 0.3 volt 3 ampere filament transformer (Thordarson T-19F97)

$S_1$ - S.p.s.t. 12 ampere switch
$S_2$ - S.p.s.t. 10 ampere switch
$S_3$ - S.p.s.t. 10 ampere switch

$I_1$ - 150 watt lamp

$V_1, V_2$ - S66A Mercury vapor vacuum tube
$V_3, V_4$ - 5R4GY High vacuum rectifier vacuum tube

$J_3$ - Metering plug
LIST OF COMPONENTS FOR FIGURE 2

R1, R5 - 50,000 ohm 1 watt carbon
R2 - 400 ohm 1 watt carbon
R3 - 66,000 ohm 1 watt carbon
R4 - 20,000 ohm 10 watt w. w.
R6 - 400 ohm 5 watt w. w.
R7 - 92 ohm 1 watt carbon
R8, R9 - 50,000 ohm 2 watt
R10 - 20,000 ohm 2 watt
R11 - 25,000 5 watt w. w. carbon
R12 - 45,000 60 watt w. w.
R13 - 5000 ohm 25 watt w. w. and 500 1 watt carbon in series.
R14 - 6250 ohm 100 watt w. w. resistor

C1 - .0005 mica
C2, C7, C8 - .01 μF 600 volt paper
C3, C4, C11, C12 - 5000 μF mica
C5 - 100 μF variable
C6 - 100 μF mica
C9 - 0005 μF mica
C10 - 250 μF per section variable
C13 - .0005 μF 5000 volt mica
C14 - 100 μF per section split stator variable 5000 volt insulation
C15 - .001 μF 5000 volt mica

L1 - 5 turns #22 d.c.c. wound 1\(\frac{1}{8}\) in. diameter spaced 3/4 in.
L2 - 4 turns 1/8 in. in copper tubing 1\(\frac{1}{8}\) in. diameter spaced 1/8 in.
L3 - B & W TVL 10

RFC1, RFC2, RFC3, RFC5, RFC6 - 2.5 mh radio frequency choke
RFC4 - Parasitic choke; 16 turns no. 22 D.C.C. on high value 1 watt resistor

X1 - crystal
S1 - 4 position rotary switch

VT1 - 2A77
VT2 - 807
VT3 - 813
VT4 - 6L6

J1, J2 - metering plugs
Figure 4.—Top View of The Power Supply

Figure 5.—Rear View of The Radio Frequency Exciter
Figure 6.—Under Chassis View of Radio Frequency Exciter
BIBLIOGRAPHY


