OPTIMIZATION OF A COCKROFT-WALTON 100 KV IMPLANTATION ACCELERATOR

by

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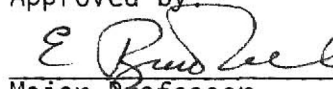

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Chapter I

INTRODUCTION

The purpose behind the series of experiments is to achieve the maximum efficiency of a Cockroft-Walton 100 KV implantation accelerator. The accelerator is to be used to implant Te^{129} into GaAs crystals.

High efficiency is required in order to minimize contamination of the accelerator with radioactive material. A decrease of efficiency by a factor of ten leads to an increase of contamination by a factor of ten. Te^{129} has a half-life of 34.1 days and hence large amounts of contamination would render the accelerator useless for as long as one year.

There are various parameters that can affect the performance of the accelerator. These are: the pressure, arc voltage and arc current pinching magnetic field in the source, extractor voltage, position of the extractor with respect to the source, rate of evaporation of the sample in the oven, and finally the alignment of the accelerator.

The following experiments were done towards the maximization of the efficiency.

a) i. Measurement of temperature inside the source as a function of time and filament current.

   ii. Measurement of temperature inside the source as a function of position of the quartz tube that holds the sample - Rate of evaporation of the sample.

b) Measurements of beam current I_b as a function of the extractor position relative to the source.

c) Efficiency measurements using indium and tellurium samples.

Figure 1. Danfysik Ion Source

(1) Mounting Plate

(2) Topmounting Nut

(3) Isolating Washer

(4) (Gas Inlets) Tube

(5) Insulating Mounting Ring

(6) Top Piece

(7) Filament Support

(8) Anode Cylinder

(9) Internal Bottomplate

(10) Insulating Rings

(11) Centering Ring

(12) Centering Plate

(13) Outlet Plate

(14) Filament

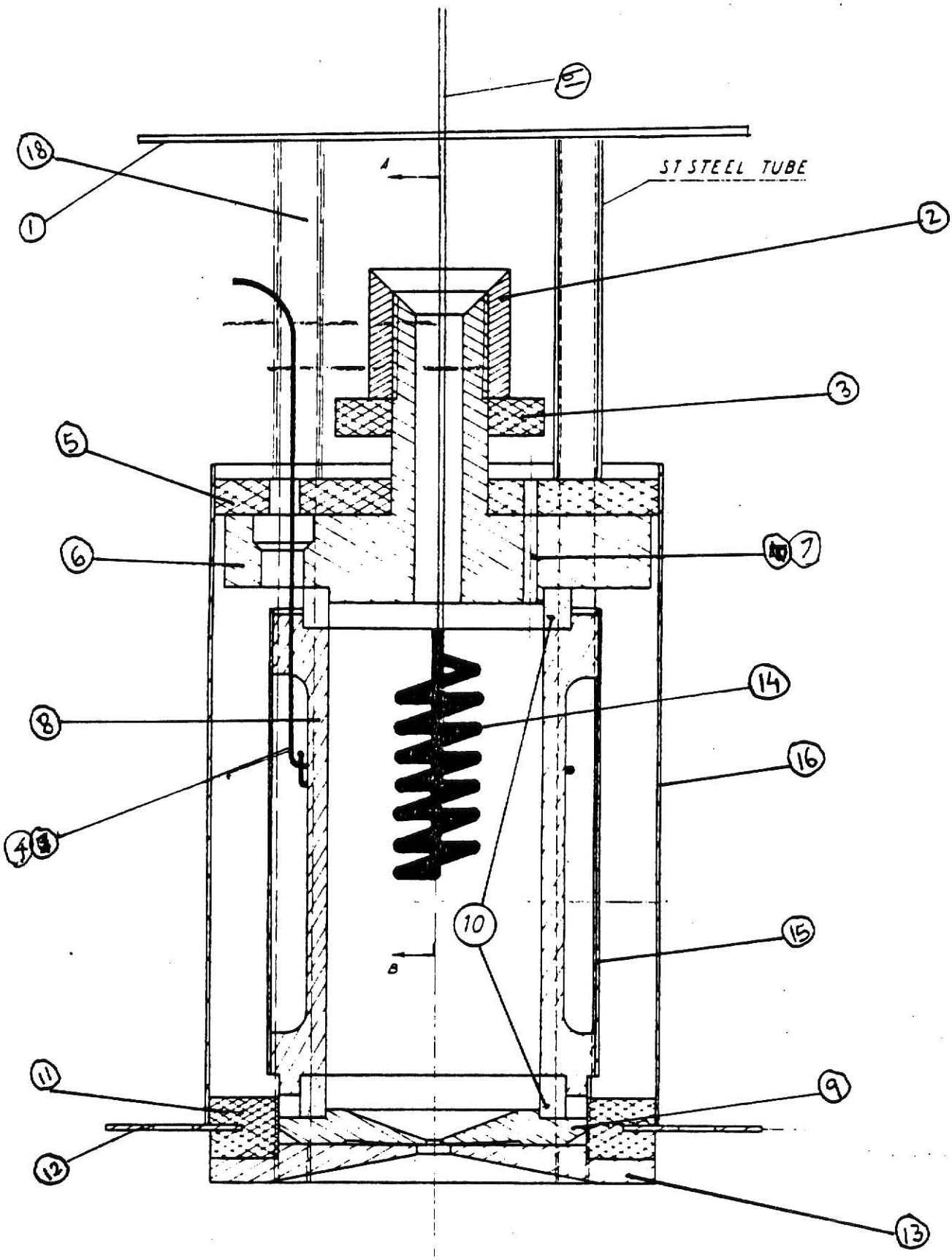
(15) Heat Shield

(16) Heat Shield

(17) Anode Connection

(18) Fixing Rod

(19) Center Support


ST STEEL TUBE
A
B

Chapter II

THE HEAVY ION SOURCE AND THE ACCELERATOR

All the experiments done in this work were performed on a 100 KV Cockroft-Walton accelerator, using a Danfysik ion source. In this accelerator, ions are created from neutral gases by the furnace type source and accelerated from the source potential to ground. This potential difference can be varied over the range 0-100 KV. The operating voltage for this work was 50 KV.

Figure 1 represents a Danfysik heavy ion source. Inside the cylindrical graphite chamber (8), which serves as an anode, is a tantalum filament (14) that provides electrons by thermal emission. It is operated at 25 to 30 amp. The melting point of tantalum is 2996^{o}C and hence it is safe to use at high temperatures and over a fairly long period. The gas tube, shown by a solid line (4) in the figure, serves as an inlet through which gas can be introduced into the anode chamber. In operation, gas is introduced into the anode chamber through either this tube or the sample tube in order to raise the pressure to the value that will sustain the arc. There is a metal diaphragm (outlet plate 13) with a small hole at the top of the discharge chamber. It separates the high pressure region from the accelerating column. There are two insulting quartz rings (10) mounted at the top and at the bottom of the anode. They insulate the anode from filament which is at source ground. The anode connection is a molybdenum wire. The filament is mounted on heavy tantalum supports (7). A centering plate (12) which fits closely in the source housing, centers the source on the accelerator axis. There are two tantalum sheet

heat shields (15) and (16) around the graphite cylinder.

The whole assembly is mounted on a round steel plate that supports the electrical leads for the filament and the anode. A center support holds the sample tube. This support is hollow and communicates with the outside, so that if desired, gas can be introduced through the source tube.

The accelerator consists of an extractor close to the source, a pinching magnet, an accelerating column containing five accelerating electrodes, a copper flight tube between the pole pieces of a bending magnet, and the target chamber. The ion beam is detected on a picoammeter and a plot of beam current against field of the bending magnet (mass spectrum) is obtained using an Omnigraph X-Y recorder.

The Danfysik source is an oscillating electron type ion source. Ionization takes place in the discharge chamber by electron impact. The requirements are, a source of electrons, a small region of relatively high pressure of gas separated from the accelerating column, an electric field to accelerate the electrons and maintain the discharge and a mechanism for concentrating the discharge and pulling out the positive ions in a parallel beam. The filament provides electrons by thermal emission. Collisions between these electrons and the gas in the anode chamber produces a plasma of electrons and positive ions.

Within the arc discharge, a high density of ionization exists. Electrons move toward the anode. Because of their low mass, the mobility of electrons is high and they move rapidly through the gas. Positive ions go to the cathode, but because of their low mobility, they take a longer time. An equilibrium is reached with approximately equal number of positive ions and electrons. (There is a slight excess of electrons.) Under these conditions of equilibrium, the plasma is an almost uniform mixture

of gas, ions and electrons with a very low potential gradient. An axial magnetic field is used to concentrate the arc in the region near the exit hole, where a high density of ionization is needed. Several functions are served by this magnetic field. It also collimates the beam, so the discharge from the source is limited to a cross-sectional area essentially equal to the area of the emitting surface of the cathode. The yield is also increased because the field keeps positive ions from diffusing to the side walls of the chamber and being lost. To reach maximum effectiveness, the average radius of curvature of the ion paths in the field should be about the size of the exit hole.

Positive ions emerge from the exit hole with low velocities. In the absence of a magnetic field they would have random directions because of the thermal impact with gas atoms. Positive ions are extracted through the small hole by means of an extracting electrode which is negative with respect to the source. The potential can be varied from zero to 12 KV. Positive ions are then accelerated to ground through a series of five accelerating electrodes each maintained at a positive potential lower than the previous one.

The beam is focused on the target by manipulation of the current in the pinching magnet (which surrounds the source), and the extractor voltage. This is an iterative process. There is an interaction between the pinching magnetic field and the arc current that depends on the gas pressure in the source and the filament current. The extractor voltage that produces maximum beam current also depends to some extent on the pinching magnetic field.

The adjustable parameters in the heavy ion source are, the electron emission, the gas pressure, the arc voltage, the pinching magnetic field,

the size of the exit hole and the geometry of the cathode. Furthermore, the extractor voltage, rate of evaporation of the sample in the oven, and alignment of the accelerator can be manipulated to achieve maximum efficiency or the best current. The position of the extractor with respect to the source is also significant.

Operating Conditions

Filament Current

The tantalum filament is heated by a current of 25 to 30 amp. After several experiments it was found that a minimum of 25 amp filament current is required to start the arc and obtain a substantial arc current of about 2 amp. Above 30 amp. the filament sags and becomes brittle. If it touches the sample tube, the quartz becomes overheated and devitrifies. Also, if the filament touches the anode, it shorts the arc voltage. A good way to increase the life of filament is to start with a filament current of 18 amp. and slowly increase it to 28 amp. maximum only when the quartz tube is moved all the way inside the oven. The tube should not be moved back and forth after insertion. Initially, a tungston filament was used, but it does not spot-weld well enough to stand a filament current of 30 amp. even for an hour. The problem of sagging the filament is solved by mounting the filament slightly off-center, so that even after sagging, it does not touch the quartz tube or the wall.

Adjustment of Gas Pressure and Arc Current

The gass pressure inside the source is not measured directly. (It would be difficult to measure it directly because the source is at high potential.) Lacking such an arrangement, one can depend only on the measurement of the pressure in the accelerating column, and must determine empirically what

column pressure corresponds to the optimum pressure in the source. This correlation depends on what steady state pressure is obtainable in the column when no gas is being introduced into the source and therefore changes from time to time, depending on the leak rate of the system.

In the current situation, with steady state pressure of about $4x10^{-6}$ torr, the pressure (total) with argon flowing into the source needs to be between $4x10^{-6}$ and $1x10^{-5}$ torr. Outside this range, the beam current drops drastically to a value of around 10^{-9} amp. The optimum pressure, on an average, is found to be $8x10^{-6}$ torr for maximum beam current. The pressure of the gas is controlled by restricting the flow of argon into the ion source by a fine needle valve.

Extractor Voltage

The extractor voltage can be adjusted to focus the beam onto the target and obtain a small bright spot. This adjustment is extremely critical in that a small deviation from the optimum extractor voltage results in a large decrease in the beam current, on the target. In all the experiments performed in this work, the critical voltage to obtain the best focused beam was found to be 8 KV. Below or above this voltage the beam is defocused. The beam is observed by interposing a magnesium oxide coated screen, which can be seen through a window near the target stage. This also helps to check the alignment of the beam.

Pinching Magnetic Field

Adjustment of the current in the pinching magnetic field affects the arc current and the beam current; the latter changes because of both the changed arc current and the focal property of the source. The magnetic field is initially adjusted for maximum arc current and finally, in conjunction with other parameters, adjusted for maximum beam current. The

final value of the magnet current for 50 KV operation of the accelerator is between 0.8 and 1.0 amp. When the magnet current is increased above 2.5 amp., the extractor voltage increases uncontrollably.

We have attempted unsuccessfully to determine the limits beyond which ions start to strike the edges of the extractor electrodes.

Alignment of the Accelerator

There are some problems in alignment caused by the fact that the flanges on the magnet chamber are somewhat off-center vertically and are not exactly normal to the plane of the magnet chamber. This causes the beam to emerge from the chamber very near its upper edge and care must be taken that the beam is not intercepted by the edge of the chamber or by various protuberances into the beam line downstream from the magnet.

Thus the general operating conditions of our experiments were as follows:

To get a beam current of the order of 1×10^{-6} to 2×10^{-6} amp.,

Extractor Voltage	8 KV
Filament Current	25 to 30 amp.
Magnet Current	0.8 to 1.0 amp.
Arc Voltage	100 v
Arc Current	2.5 to 2.8 amp.
Pressure	8×10^{-6} torr
Position of the Extractor	1.25 cm with respect to the source.

Position of Extractor with Respect to the Source

The position of the extractor with respect to the source can affect the beam current substantially, because it affects both the effective

focal length of the ion lens comprised by the accelerator electrodes and the extractor and the effective object position relative to the lens. The extractor is to be adjusted so as not to lose a portion of the ion beam. At the same time, it should not be too close to the source; otherwise arcing may occur between the source and the extractor. When contacted in this regard, Mr. Greg Kelly of Los Alamos National Laboratory suggested that a gap of 1.5 cm between the source and the extractor, and an extractor voltage of 15 KV be used for best results. However, for our apparatus, after some experimentation, a gap of 1.25 cm between the source and the extractor, and an extractor voltage of 8 KV were found to be the most suitable values. Despite the critical adjustment, a portion of the source charge is lost to the extractor. Evidence for this is a heavy encrustation that builds up on the extractor. It is believed that this encrustation is built up by neutral atoms.

Chapter III

SAMPLE PREPARATION

The basic problem in a heavy ion source is that most heavy elements are solids at ordinary temperatures. The function of a heavy ion source is to produce a vapor of these elements or of some compound containing these elements and to ionize this vapor. There are four basic ways of obtaining the vapor: (1) Direct evaporation of the elements, (2) Evaporation of a high vapor pressure compound containing the element, (3) Vapor transport and (4) Sputtering.

The Danfysik source is not readily adaptable for sputtering and it would be hazardous to use high vapor pressure compounds of radioactive species (e.g. TeH_2). So the alternatives are vapor transport and direct evaporation.

Chemical Synthesis of Source Feed Material in the Ion Source By CCl_4 Vapor Transport

The most conventional vapor transport technique is to pass carbon tetrachloride vapor (CCl_4 vapor) over the metal or the heated oxide of the sample material. This method was initially used by Sidenius and Skilbreid in 1961 for the rapid handling of small radioactive samples. It is now commonly used for almost all the elements.

Fig. 2 represents an arrangement for the passage of CCl_4 over the heated oxide of the material. Reproducible separations of microgram amounts can be obtained with high efficiency by this method. The material to be separated is placed in a filter of quartz wool which is placed into

the rear end of the quartz tube. The other end of the quartz tube is connected to a stainless steel tube. By means of a vacuum lock, the tube is connected to the ion source in such a way that the free end containing the oxide sticks about 5 mm into the discharge chamber. The gas inlet tube is via a needle valve connected to a flask containing CCl_4. The rate of flow of CCl_4 is kept sufficiently high to maintain a stable plasma in the source. After a few minutes, when the tube has reached a sufficiently high temperature, oxide converts into chloride. The chloride now feeds directly into the discharge chamber.

According to Nielsen and Almen the efficiency is inversely proportional to the pressure in the discharge chamber. Therefore, if the highest possible efficiency is desired, the pressure in the discharge chamber is just above the minimum working pressure for the ion source. In order to obtain both high current and high efficiency, an adjustable flow resistance should be present between the quartz tube and the discharge chamber so that the pressure in the quartz tube and the ion source can be adjusted independently. This purpose is served by the quartz wool. There are certain advantages and disadvantages of this method.

Advantages:

1) The reaction is carried out at a relatively high temperature to ensure the rapid removal of the reaction products from the solid-gas interface. Hence precise temperature control is not needed.
2) The extracted ion current can be easily controlled by adjusting the flow of CCl^4 vapor.
3) The CCl_4 tends to suppress uncontrollable filament activation with low work function elements. It also reduces the back-streaming and sparking from the extraction electrodes.

4) The method can be used with oxides of elements such as molybdenum or zirconium whose chlorides are difficult to prepare.

Disadvantages:

1) The reaction products from the ionization of CCl_4 are corrosive and tend to erode the metal source components.
2) Excess use of CCl_4 may deactivate the filament.
3) Ionization of CCl_4 itself may result in a complex spectrum of molecular beams.

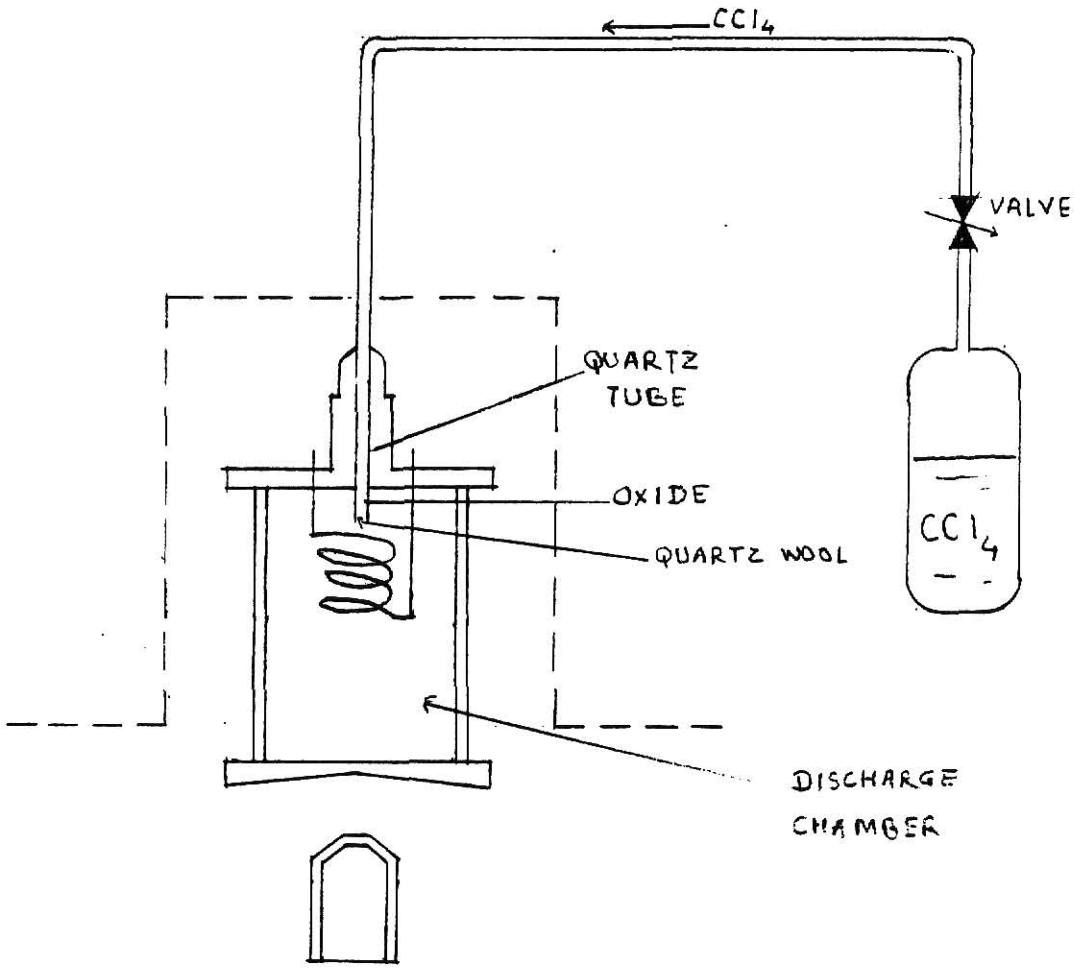
Our initial experimentation with this method indicated the formation of tellurium and other molecular ions. Any such ions formed would be deposited on the walls of the magnet chamber and hence would represent contamination of the accelerator. This and the other disadvantages prompted us not to use this method. The only alternative left then was direct evaporation of the sample.

Direct Evaporation of the Sample

The central problem with direct evaporation is control of the evaporation rate. It is important because it affects the efficiency of the source. It is a difficult problem because the evaporation rate changes rapidly with vapor pressure, which in itself increases exponentially with temperature. It is therefore very important to know a priori what the temperature of the source material is.

In the Danfysik ion source, the sample is carried in a quartz tube that can be moved into or out of the filament coil. Its temperature can be controlled relative to that of the filament by letting more or less of the tube project into the source. Accordingly, measurements of the temperature inside the quartz tube, for various tube positions and filament currents were undertaken.

Figure 2. Apparatus for Chemical Synthesis of Source Feed Material Using CCl_4 Vapor Transport.


CCl_4
VALVE
QUARTZ TUBE
OXIDE
QUARTZ WOOL
CCl_4
DISCHARGE CHAMBER

Chapter IV

TEMPERATURE MEASUREMENT INSIDE THE TUBE HOLDING THE SAMPLE

The first experiment was done by changing the filament current from 15 amp. to 30 amp. and reading the temperature after it had become constant.

A platinum versus platinum 10% rhodium thermocouple was used to record the temperature in the oven. It was introduced through the tube which could be moved in and out of the oven. The thermocouple potential was measured by an electrometer. As the filament current was varied, the thermocouple voltage responded to the temperature change. This was recorded on the electrometer in millivolts.

The tube was moved all the way inside the oven for this experiment. It was never moved back. The temperature was allowed to become steady for a particular value of the filament current. Filament current was not exceeded 35 amp. so as to save the tantalum filament from collapsing.

The data are shown in Figure 3.

Variation of the Temperature Inside the Quartz Tube as a Function of Position of the Tube, at Constant Filament Current

Starting with the innersmost position of the tube, the tube was moved out by 5 mm increments and the corresponding change in the final steady temperature was recorded on the electrometer. A constant filament current of 25 amp. was used throughout the experiment.

As can be seen from the data tables and the graphs, in Figure 4 it took at least thirty minutes to get a steady reading for every change of

position of the tube. The experiment therefore took several hours. Over a period of several hours of continuous heating, the tantalum filament tended to sag. This was taken care of by mounting the filament off-center.

Temperature versus time measurements are shown in Figure 5 for each position of the tube. The final steady temperatures for various positions are shown in Figure 5.

Ion Implantation with Radioactive Dopants

The requirements for radioactive ion implantation differ from those of conventional ion implantation. The beam shape for radioactive implantation should be a sharp line or a bright spot. For conventional implantation, it may cover a large uniform area. In radioactive implantation, the beam intensity must be large enough to yield the desired implanted dose in a reasonable time. On the other hand undesirable effects due to heating may be present with intense beams. These conditions set limits on the acceptable beam current density.

The more important difference between radioactive and conventional implantation is in the requirement of ion source efficiency. The efficiency of an electromagnetic separator is usually at most a few percent. Thus, for a radioactive separation requiring, say, 1 μCi of the separated isotope one must charge the ion source with at the minimum a few tens of microcuries of activity.

Since it can be assumed that the activity that is not implanted in the sample remains in the accelerator somewhere as radioactive contamination, it is important that the efficiency be as high as possible.

Figure 3. Filament Current Versus Temperature

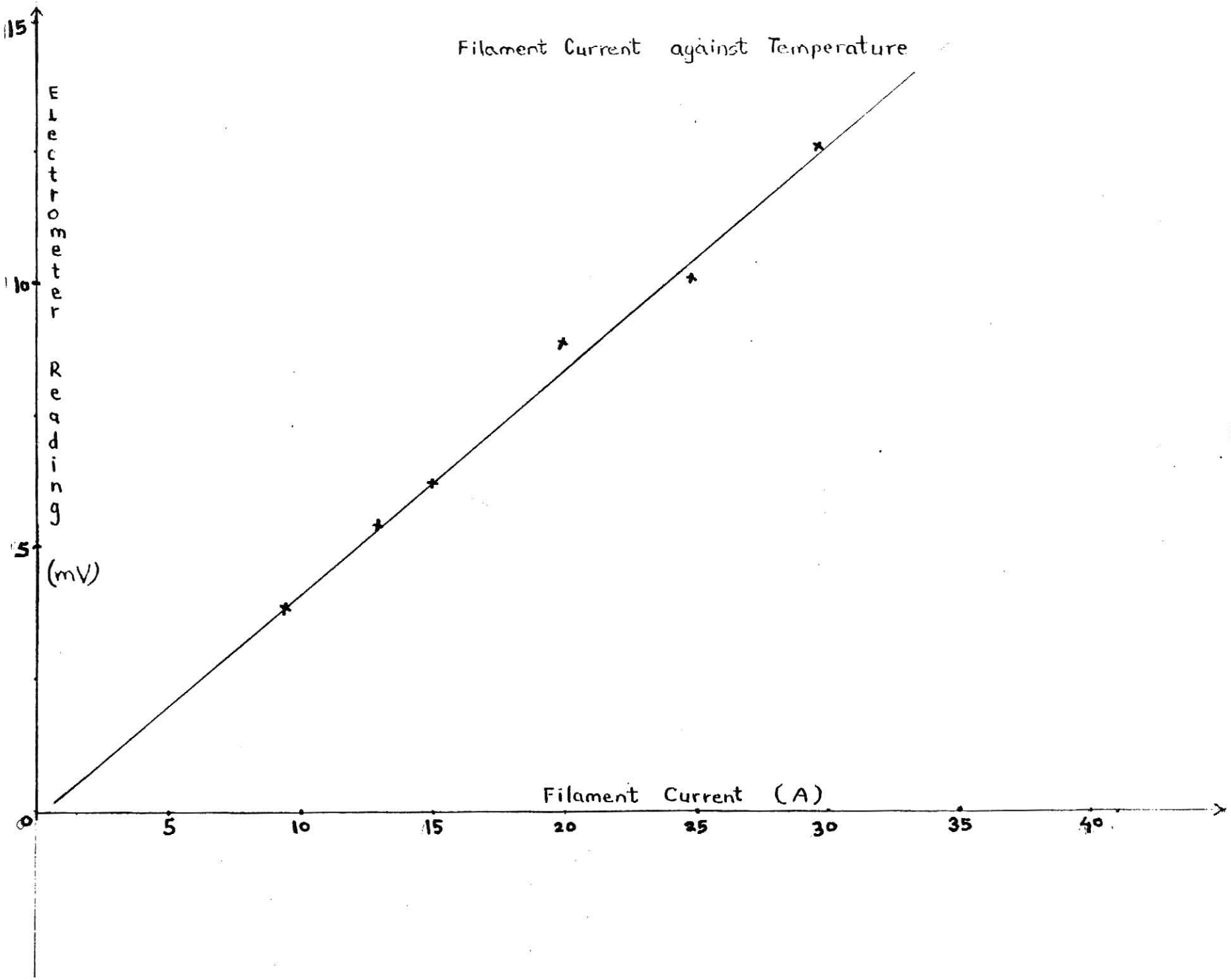

Filament Current against Temperature
Electrometer Reading (mV)
15
10
5
0
5
10
15
20
25
30
35
40
Filament Current (A)

Figure 4. Time Versus Temperature at Constant Filament Current

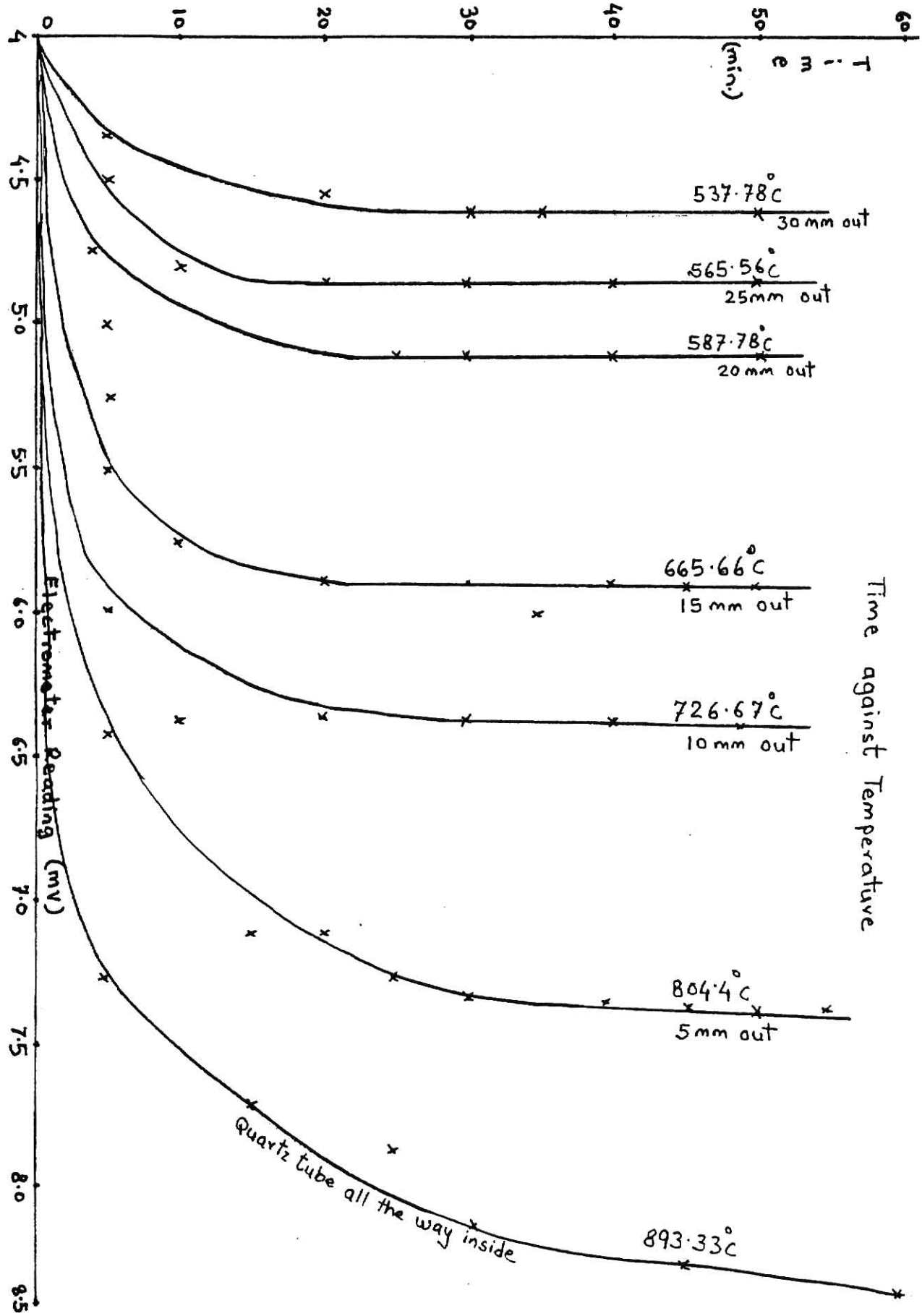

Time (min.)
0
10
20
30
40
50
60
Electrometer Reading (mV)
4
4.5
5.0
5.5
6.0
6.5
7.0
7.5
8.0
8.5
537·78°C
30 mm out
565·56°C
25mm out
587·78°C
20 mm out
665·66°C
15 mm out
726·67°C
10 mm out
804·4°C
5mm out
893·33°C
Quartz tube all the way inside
Time against Temperature

Figure 5. Temperature as a Function of Position of the Quartz Tube.

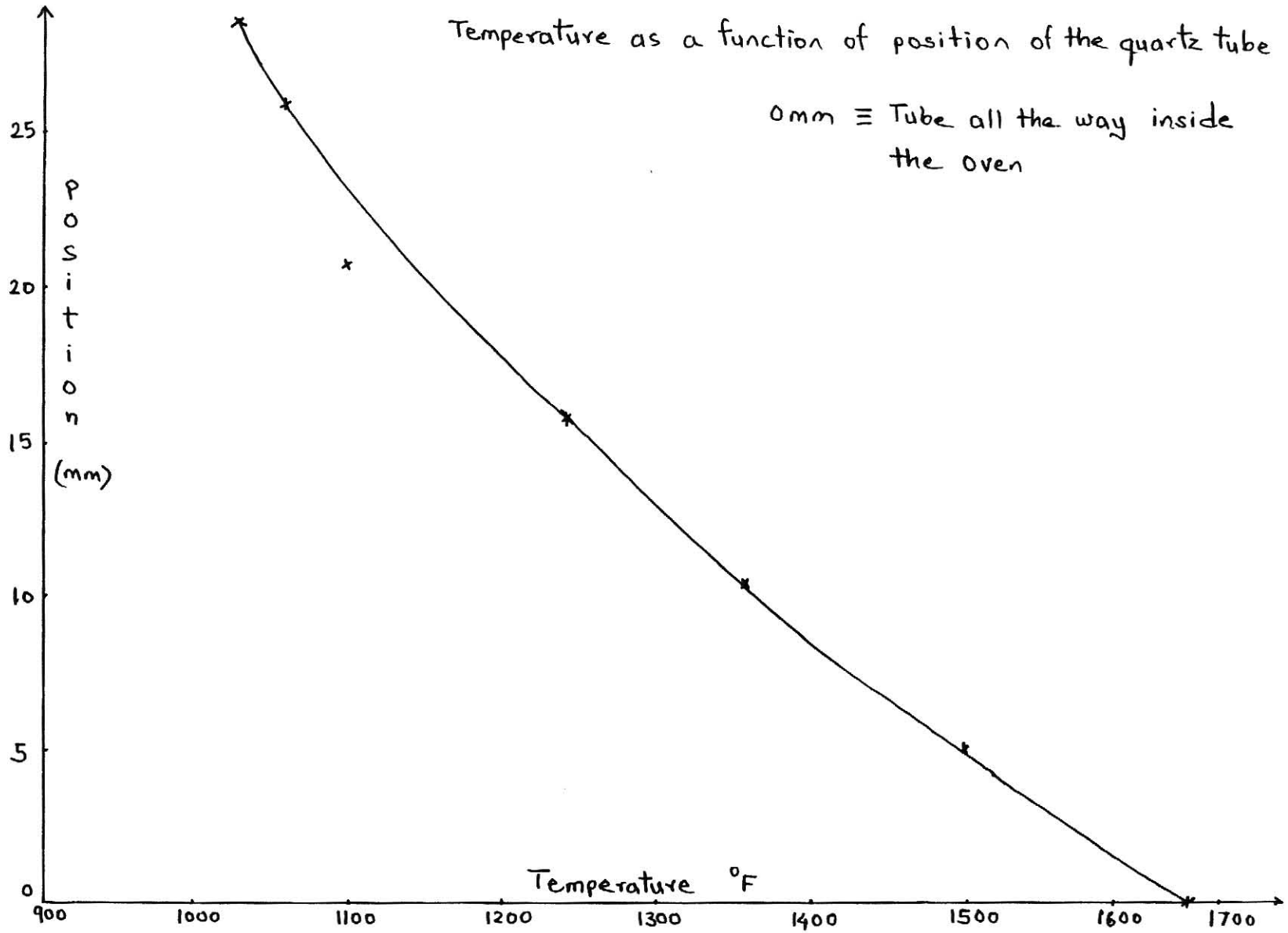

Temperature as a function of position of the quartz tube
0mm ≡ Tube all the way inside the oven
Position (mm)
25
20
15
10
5
0
Temperature °F
900
1000
1100
1200
1300
1400
1500
1600
1700

Figure 6. Arc Control

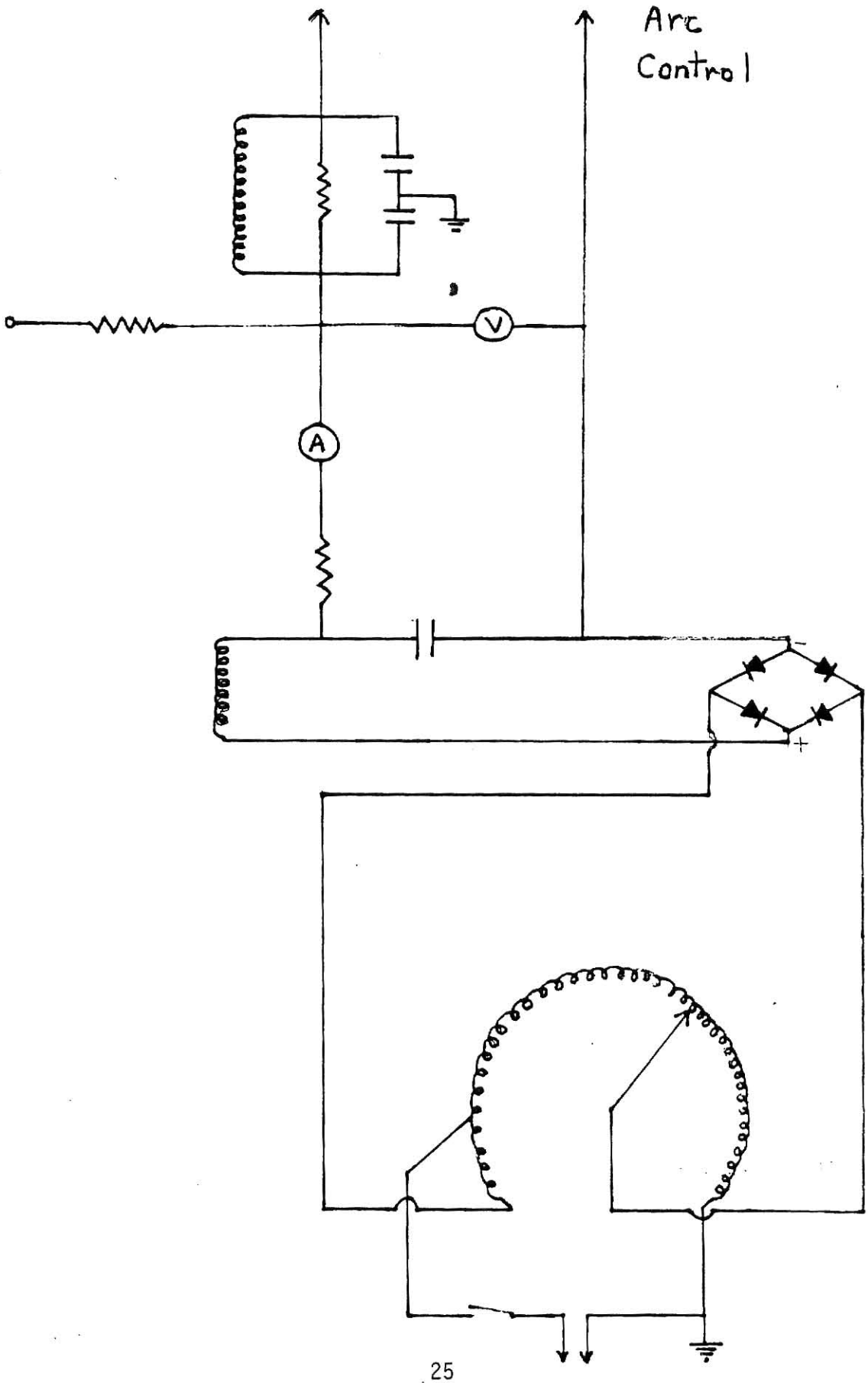

Arc
Control
V
A
-
+

Figure 7. Magnet Control

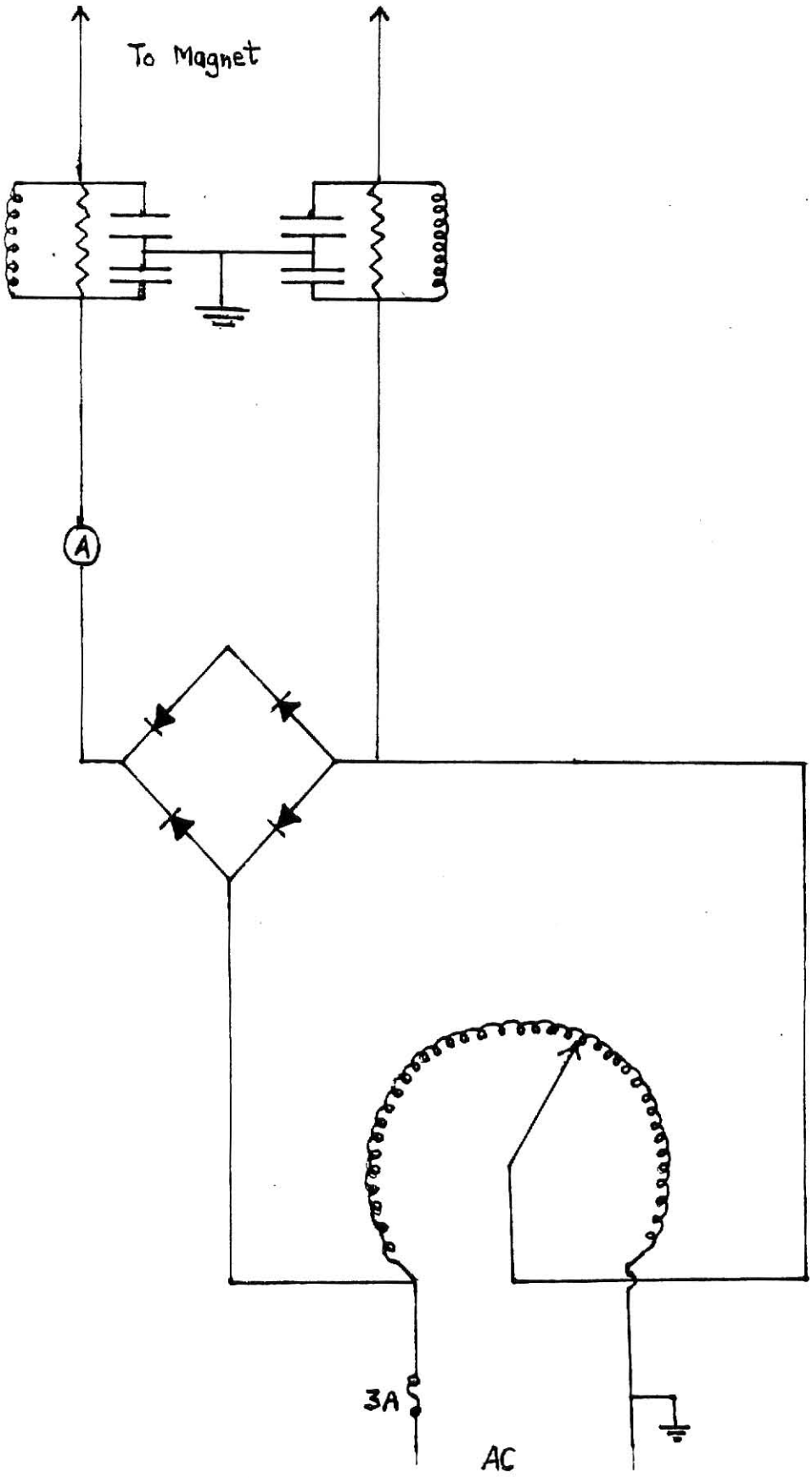

To Magnet
A
3A
AC

Figure 8. Extractor Control

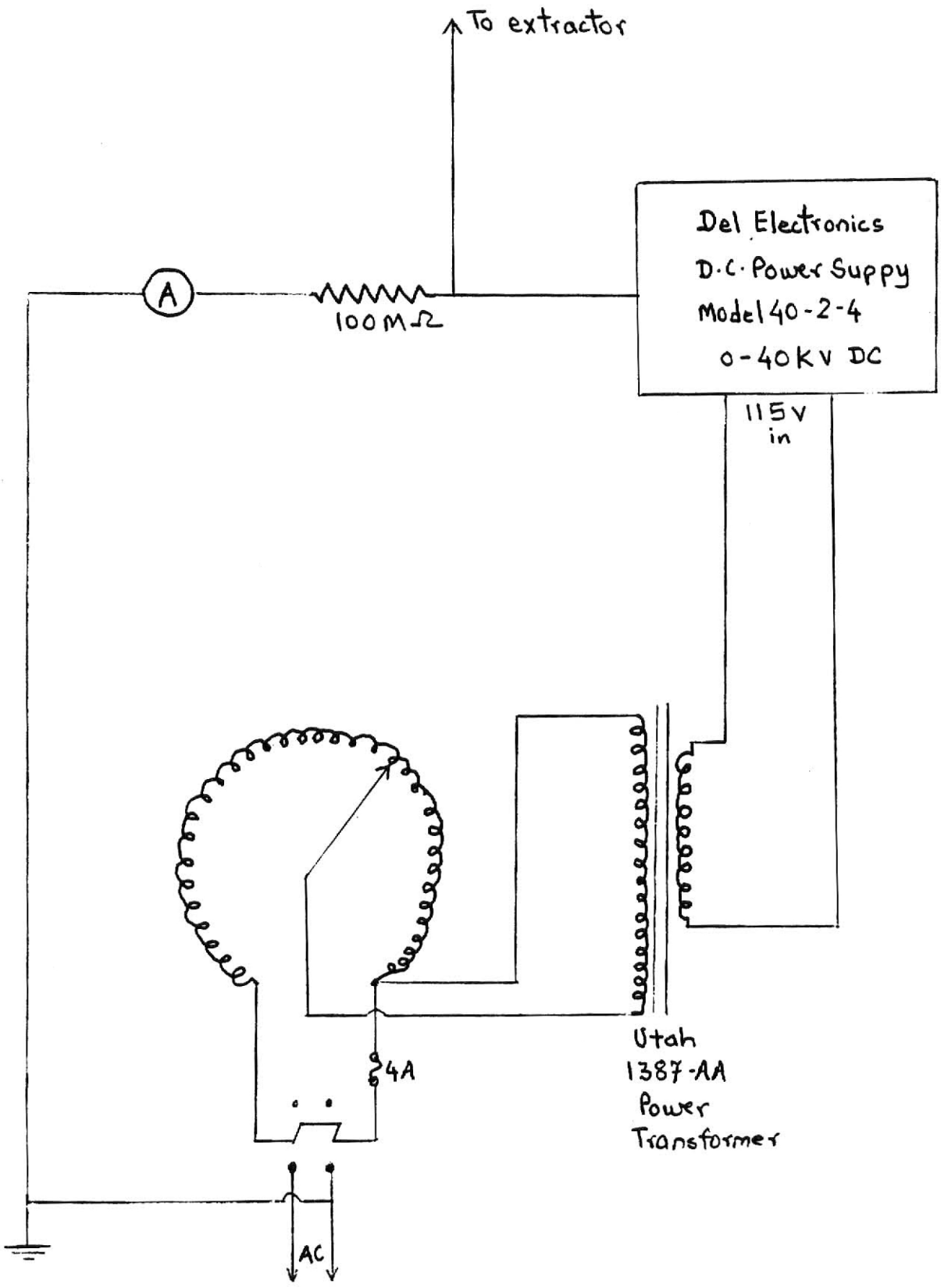

To extractor
Del Electronics
D.C. Power Suppy
Model 40-2-4
0-40 KV DC
A
100 MΩ
115 V
in
4A
Utah
1387-AA
Power
Transformer
AC

Figure 9. Mass Spectrum -- Indium Sample

MASS SPECTRUM

INDIUM

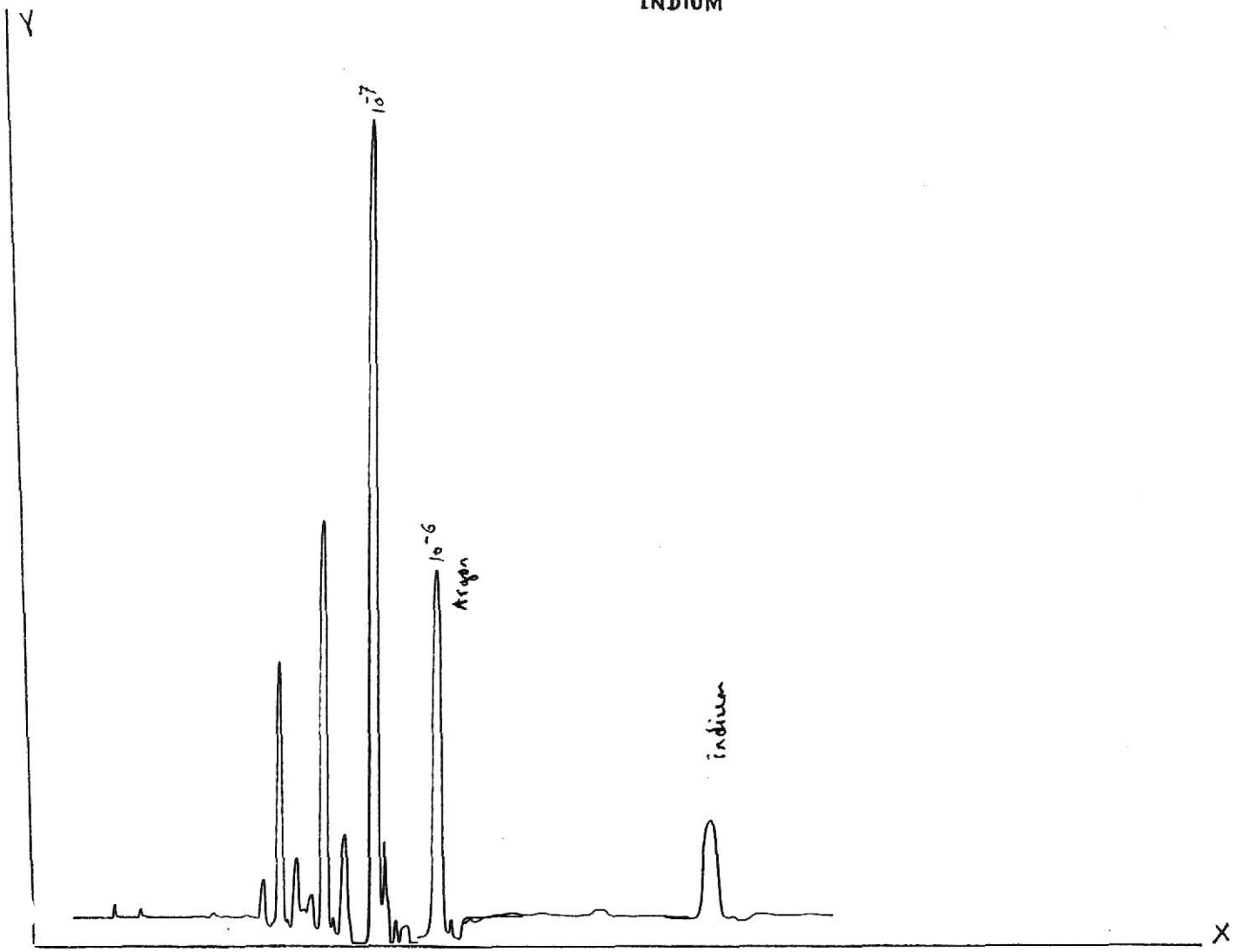
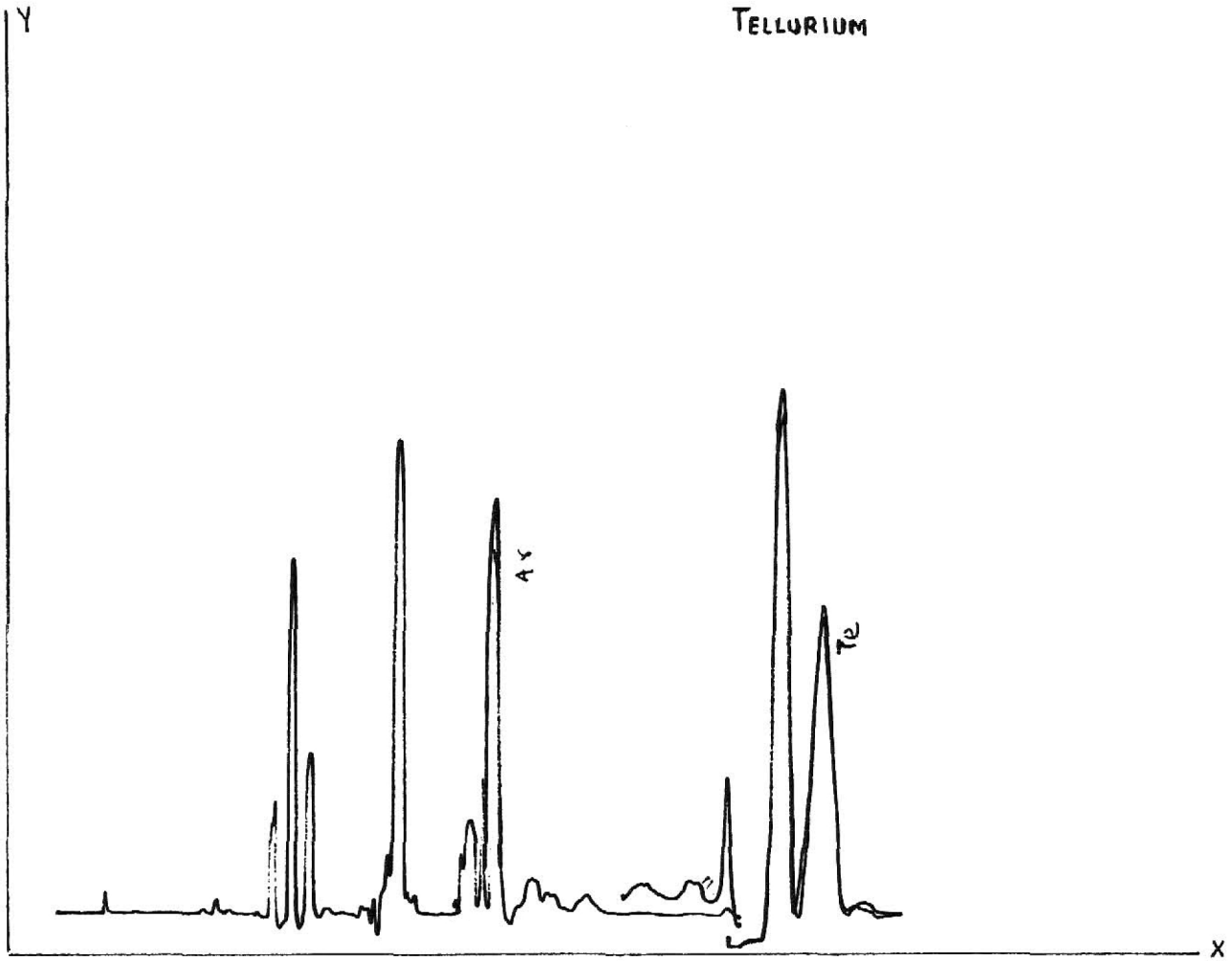


Figure 10. Mass Spectrum -- Tellurium Sample

MASS SPECTRUM

TELLURIUM



Chapter V

MEASUREMENT OF EFFICIENCY

A small piece of pure indium was loaded into the quartz tube in the source. This tube can be moved in or out of the source oven in order to achieve the desired temperature for evaporation. At the outset, a filament current of 15 amperes was used and various parameters such as extractor voltage, magnet current, arc voltage, arc current, and the pressure of the gas were adjusted to obtain a well focused beam. A low initial filament current was used in order to keep the sample from evaporating rapidly while the other parameters were being adjusted. Once the beam current was obtained, it was maximized by increasing the filament current up to 28 A and small adjustments in the gas pressure and the extractor voltage. A mass spectrum was obtained and the indium peak was identified, with the argon peak as a reference calibration. The period over which the maximum beam current stayed constant was measured. Once it began to decrease, the beam current dropped rapidly, so it was reasonable to assume that the metal charge to the source was exhausted. The efficiency was then calculated as follows:

EXPERIMENT 1

Weight of the indium sample	0.00202 gm
Atomic weight of indium	114.82 gm
Avogardro's number	6.023×10^{23}
Pressure	6×10^{-6} torr
Arc Voltage	100 v

EXPERIMENT 1 (continued)

Arc current	2.8 amp.
Magnet current	0.4 amp.
Filament current	28 amp.
Extractor voltage	8 KV
Beam current	1.5×10^{-6} amp.
Time in seconds	14400 sec

CALCULATION

Atomic weight of indium is 114.82 gm.

114.82 gm correspond to 6.023×10^{23} atoms. Hence, 0.00202 gm correspond to 1.06×10^{19} atoms.

Beam current of 1.5×10^{-6} amp. for a period of 14400 sec. implies a charge of

$$14400 \text{ sec} \times 1.5 \times 10^{-6} \text{amp} = 2.1 \times 10^{-2} \text{ coul.}$$

i.e. $\dfrac{2.1 \times 10^{-2}}{1.6 \times 10^{-19}}$ atoms on the target.

$= 1.3125 \times 10^{17}$ atoms

We had put in 1.06×10^{19} atoms and got 1.3125×10^{17} atoms on target.

Hence, % efficiency $= \dfrac{1.3125 \times 10^{17}}{1.06 \times 10^{19}} \times 100 = 1.25\%$

EXPERIMENT 2

Measurement of efficiency using indium sample

Weight of indium sample	0.00121 gm
Atomic weight of indium	114.82 gm
Avogardro's number	6.023×10^{23}
Pressure	9×10^{-6} torr
Arc voltage	110 v

EXPERIMENT 2 (continued)

Arc current	2.5 amp.
Magnet current	0.4 amp.
Filament current	25 amp.
Extractor voltage	8 KV
Beam current	1.0×10^{-6} amp.
Time in seconds	11880 sec

CALCULATION

Atomic weight of indium is 114.82 gm.

114.82 gm correspond to 6.023×10^{23} atoms. Hence, 0.00121 gm corresond to 6.34×10^{18} atoms.

Beam current of 1.0×10^{-6} amp. for 11880 sec. implies a charge of

$$11880 \text{ sec} \times 1.0 \times 10^{-6} \text{ amp} = 1.188 \times 10^{-2} \text{ coul.}$$

i.e. $\frac{1.188 \times 10^{-2}}{1.6 \times 10^{-19}}$ atoms $= 0.7425 \times 10^{17}$ atoms on the target.

We had put in 6.34×10^{18} atoms and got 0.7424×10^{17} atoms.

Hence, % efficiency $= \frac{0.7425 \times 10^{17}}{6.34 \times 10^{18}} \times 100 = 1.17\%$

MEASUREMENT OF EFFICIENCY USING TELLURIUM SAMPLE

The procedure used is the same as for indium sample except that the data is taken in much more detail as follows:

Time	Filament Current (A)	Beam Current (A)	Pressure (torr)	Extractor (uA)	Arc Voltage (V)	Arc Current (A)
11.40	15	10^{-9}	6×10^{-6}	40	150	--
11.45	20	1×10^{-7}	8×10^{-6}	40	140	small
11.48	25	1×10^{-6}	1×10^{-5}	42	50	2.8
11.50	28	1.5×10^{-6}	1×10^{-5}	42	60	2.8
12.00	28	1.5×10^{-6}	1×10^{-5}	42	80	2.8
12.25	28	1.5×10^{-6}	1×10^{-5}	40	80	2.8
12.30	28	1.5×10^{-6}	1×10^{-5}	40	80	2.5
12.50	28	1.4×10^{-6}	1×10^{-5}	40	85	2.5
1.15	28	1.5×10^{-6}	1.2×10^{-5}	40	80	2.5
1.30	28	1.5×10^{-6}	1.1×10^{-5}	40	80	2.8
1.50	28	1.5×10^{-6}	1×10^{-5}	42	80	2.8
2.10	28	1.5×10^{-6}	1×10^{-5}	42	80	2.8
2.15	28	1.2×10^{-6}	1×10^{-5}	42	90	2.3
2.30	28	0.6×10^{-6}	1×10^{-5}	42	100	2.2
2.50	28	10^{-7}	1×10^{-5}	42	100	2.2

For the purpose of calculating the efficiency, only the period over which the beam current stayed constant, i.e. 11:50pm to 2:10am was considered.

Weight of tellurium sample: 0.00131 gm

Atomic weight of tellurium is 127.6 gm

127.6 gm correspond to 6.023×10^{23} atoms. Hence, 0.00131 gm correspond to 6.183×10^{18} atoms.

Beam current of 1.5×10^{-6} amp. for 140 minutes implies a charge of

$$140 \text{ min.} \times 60 \text{ sec.} \times 1.5 \times 10^{-6} \text{ amp.} = 1.26\times10^{-2} \text{ coul.}$$

i.e. $$\frac{1.26 \times 10^{-2}}{1.6 \times 10^{-19}} = 7.875 \times 10^{16} \text{ atoms on the target.}$$

We had put in 6.183×10^{18} atoms and got 7.875×10^{16} atoms.

Hence, % efficiency $= \frac{7.875 \times 10^{16}}{6.183 \times 10^{18}} \times 100 = 1.27\%$

EXPLANATION: SOURCES OF ERROR

In the effiency calculation, we have considered only the period over which the beam current stayed maximum and constant. The period during which the beam current starts decreasing is not considered and this might give us a small error, since not all the sample material is completely evaporated. Similarly, the beam current is not considered before it reaches a maximum. Other sources of error can be an inaccurate variation in arc current, a small vacuum leak (it affects the pressure reading) and the alignment of the accelerator.

APPENDIX I

Why High Efficiency is Required

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Why High Efficiency is Required

The rate of growth of a radioactive species in a nuclear reactor is given by,

$$\frac{dN}{dt} = \phi\sigma(N_o - N) - \lambda N \qquad (1)$$

where

ϕ = Neutron flux n/cm^2 sec

N_o = Number of tellurium atoms irradiated

N = Number of radioactive atoms

σ = Cross section cm^2 or barn

λ = Decay constant sec^{-1}

λN = Number of disintegrations per sec.

From Eqn. (1),

$$\frac{dN}{dt} = \phi\sigma(N_o - N) - \lambda N = \phi\sigma N_o - (\phi\sigma + \lambda)N \qquad (2)$$

and this has a solution

$$\lambda N = \frac{\lambda\phi\ N_o}{\phi\sigma+\lambda}\ [1-e^{-(\phi\sigma+\lambda)t}]$$

Now let us assume $\phi = 10^{15}$ neutrons/cm^2sec and set $t = T_{\frac{1}{2}}$ = half life (for Te, it is 34.1 days). Cross section σ for Te^{129} is 1.4×10^{-25} cm^2. Then $\phi\sigma = 1.4\times10^{-10}$ neutrons/sec and $\lambda = \frac{0.693}{T_{\frac{1}{2}}} = 2.36\times10^{-7}$ sec^{-1}.

Thus $\phi\sigma << \lambda$ and therefore solution (2) can be simplied as

$$\lambda N = \phi\sigma N_o(\tfrac{1}{2}) \rightarrow N = \frac{\phi\sigma N_o}{\lambda}(\tfrac{1}{2})$$

$$= \frac{1.4\times10^{-10}}{2.36\times10^{-7}} N_o = 2.97\times10^{-4} N_o$$

If we assume 10^{18} atoms on the source, then the number of radioactive atoms

$$N = 2.97\times10^{-4}\times N_o$$

$$= 2.97\times10^{-4}\times10^{18}$$

$$= 2.97\times10^{14} \text{ atoms.}$$

Therefore,

$$\lambda N = 2.36\times10^{-7}\times2.97\times10^{14}$$

$$= 7\times10^{7}$$

$$= 1.94\times10^{-3} \text{ Ci.}$$

Hence at 1% efficiency, the target will have 10^{16} atoms and the activity of the target will be 1.94×10^{-5} Ci, and at lower efficiency, the activity will be higher. This leads to higher contamination.

BIBLIOGRAPHY

G. Dearnaley, J. J. Freeman, R. S. Nelson, J. Stephen, Ion Implantation Series - Defects in Crystalline Solids, Vol. 8.

M. S. Livingston and J. P. Blewett, "Particle Accelerators", McGraw-Hill 1962.

E. Segre, "Nuclei and Particles".

Leighton, "Principles of Atomic Physics".

Sidenius and Skilbreid, "Use of CCl_4 vapor transport in ion implantation", 1961.

Sidenius G., 1965, Nucl. Inst. and Methods.

H. Goldberg, Thesis.

OPTIMIZATION OF A COCKROFT-WALTON 100 KV IMPLANTATION ACCELERATOR

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AN ABSTRACT OF A MASTERS THESIS

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ABSTRACT

For radioactive ion implantation, a high efficiency of the accelerator is required in order to avoid contamination of the system with radioactive material. A decrease in efficiency by a factor of ten may increase the contamination by a factor of ten. Te^{129} has a half life of 34.1 days, and hence large amounts of contamination would render the accelerator useless for as long as one year.

A Cockroft-Walton 100 KV implantation was used for efficiency measurements with a Danfysik heavy ion source. The experiments were done first wtih indium and then with tellurium samples. The samples were heated directly in the source oven.

The efficiency was maximized by different adjustable parameters in the source and the accelerator.