5-20-1950

A New Method of Detecting Low Intensity Nuclear Radiation

Emerson Jones

Jones — Detecting Low Intensity Nuclear Radiation

A NEW METHOD OF DETECTING LOW INTENSITY NUCLEAR RADIATION

By

Emerson Jones

A thesis submitted
in partial fulfillment of the
requirements for the degree of
Master of Science in Physics

The University of New Mexico
1950

This thesis, directed and approved by the candidate's committee, has been accepted by the Graduate Committee of the University of New Mexico in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

E. A. Castetter

DEAN

May 22, 1950

DATE

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Thesis committee

Victor H. Regener

CHAIRMAN

Roy Thomas

John G. Breiland

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CHAPTER I

DESCRIPTION OF PROBLEM

In general there exist in the energy level scheme of many of the elements, transitions which give rise to the liberation of energy in the visible or near visible spectra. This situation gave rise to the hope that a gaseous element could be selected such that upon being excited or ionized by charged particle radiation, the predominant transitions to lower energy levels could be detected by photographic means. If a means of detecting these transitions could be made sufficiently sensitive, one could then hope to detect very low radiation intensities of charged particles. The problem consisted of evacuating a chamber, filling it with a gaseous element, supplying a movable source of radiation in the chamber, and developing a sensitive detecting system.

CHAPTER II

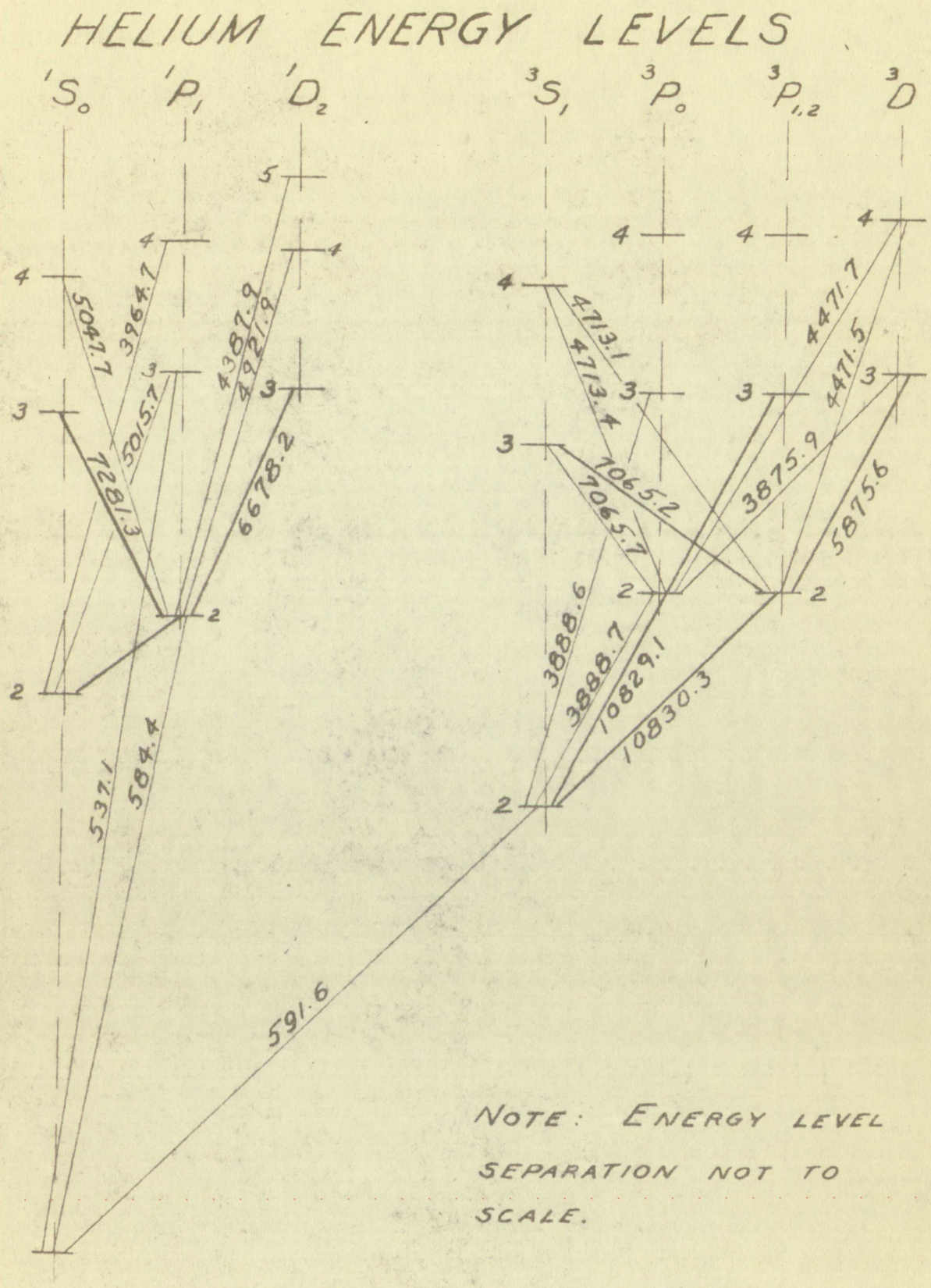
THEORY

Evacuation Requirements

The chamber evacuation required prior to filling by the gaseous element was rather critical. Any impurity contained in the chamber would inhibit the emission of the expected photons. Furthermore, if a resonance phenomenon starting from a metastable level could be hoped for, this metastable state would be short lived if a high population of impurities existed in the chamber. A pressure of $5X10^{-7}$ mm of mercury was selected as the upper limit for the pressure prior to filling the chamber.

Gas Requirements

After surveying the energy level schemes of many of the elements, it was decided that helium offered one of the best possibilities for success. It may be seen from the energy level diagram of helium (figure 1) that there exist two predominant transitions in the infrared (10,830 Å and 10,829.1 Å) both ending in the $2\,^3S_1$ metastable level. Furthermore, these are the only predominant transitions by which an originally ionized helium atom can fall into this


HELIUM ENERGY LEVELS
$^1S_0$ $^1P_1$ $^1D_2$ $^3S_1$ $^3P_0$ $^3P_{1,2}$ ^3D
5047.7
3964.7
3015.7
7281.3
4387.9
4921.9
6678.2
4713.1
4713.4
1065.2
1065.7
3888.6
3888.7
10829.1
10830.3
4471.7
4471.5
3875.9
5875.6
537.1
584.4
591.6
NOTE: ENERGY LEVEL SEPARATION NOT TO SCALE.

Firure 1

lowest energy triplet state. If the detection system is sensitive to these particular transitions, most of the helium which has been excited will be detected, since the excited helium is most likely to terminate in a triplet state. This may be seen from the fact that the triplet states are statistically more probable than singlet states.

Filling Considerations

The helium gas had to be admitted to the chamber in such a way as to minimize the possibility of introducing impurities. This stipulation was somewhat aggravated by the desirability of controlling the amount of helium admitted to the chamber through a stopcock.

Source Requirements

The source of radiation had to present a rather high density of ionization in the early stages of the problem so that a detection system could be found more easily. This requirement coupled with the availability of a polonium plated copper sheet led to the use of the 5.3 mev alpha particles associated with the disintegration of polonium. The source had to be removable from the chamber without breaking the seal.

Detection Requirements

If the system was to offer any possibility of success, an exposure made by laying the chamber directly on a photographic plate should give a noticeable effect. If this was successful an attempt to focus the source on the photographic plate would be the next logical step. If this step was successful, one could then hope to find a focus in the chamber such that an individual alpha track could be recorded.

CHAPTER III

DESCRIPTION OF APPARATUS AND METHODS

Chamber

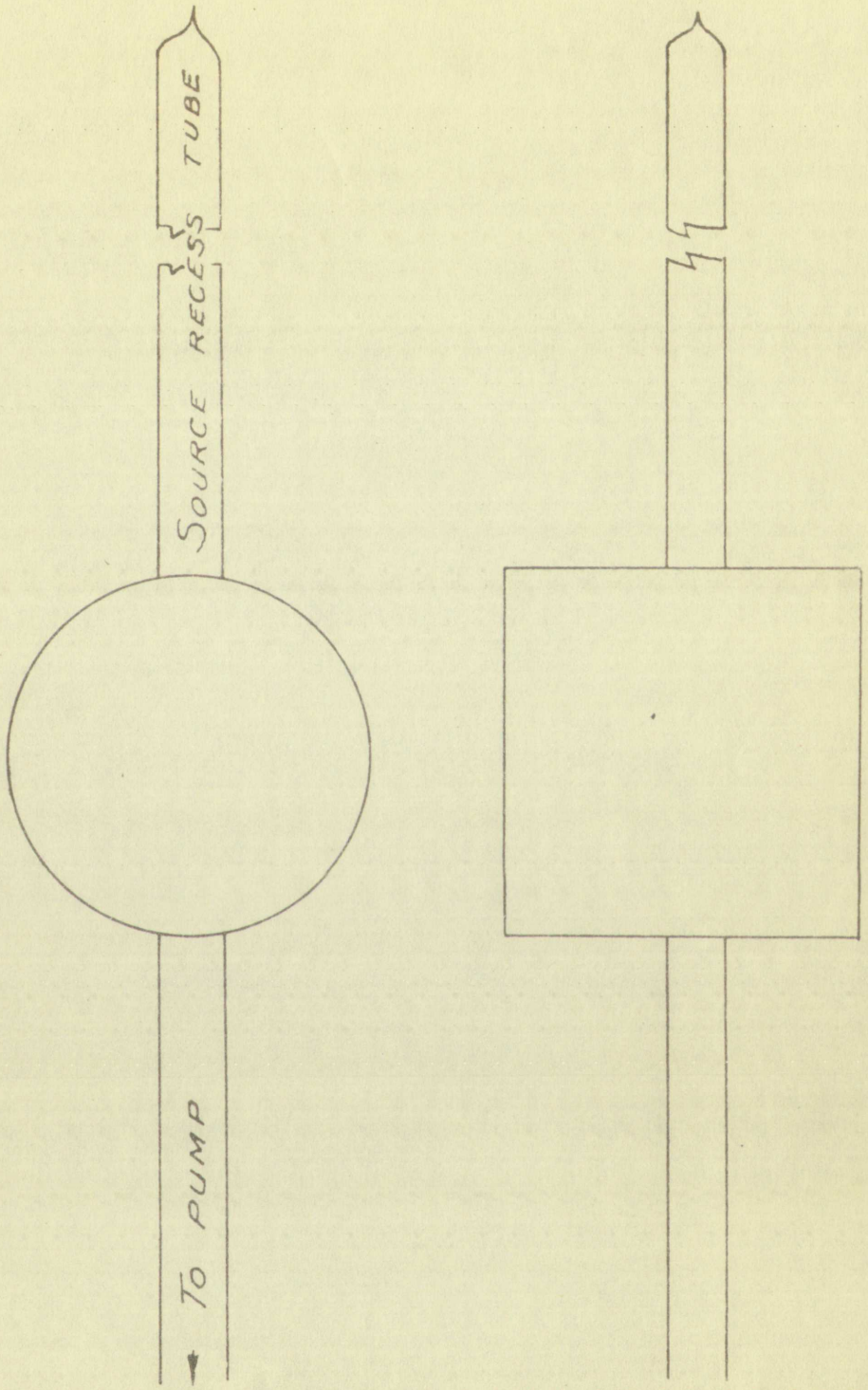
The chamber that was used for the experiment was in the form of a cylinder 5 cm in diameter and 5 cm high as shown in figure 2. Midway between the ends, two tubes were attached to opposite sides of the cylinder. One of these tubes was used to evacuate the chamber and the other tube (approximately 20 cm long) was used as a recess for the source. The cylinder was made out of quartz, although ordinary glass would have served as well. Availability alone dictated the kind of material.

Source

The source was in the form of a polonium plated copper cylinder .25 cm in diameter and 5 cm long. A steel rod (5 cm long) was forced into the end of this cylinder. The position of the source could then be controlled by a magnet outside of the glass tubing.

The intensity of radiation of the source was determined on a Nuclear Instrument Corporation methane flow counter. This particular counter insured a 2π solid angle

CHAMBER SCHEMATIC



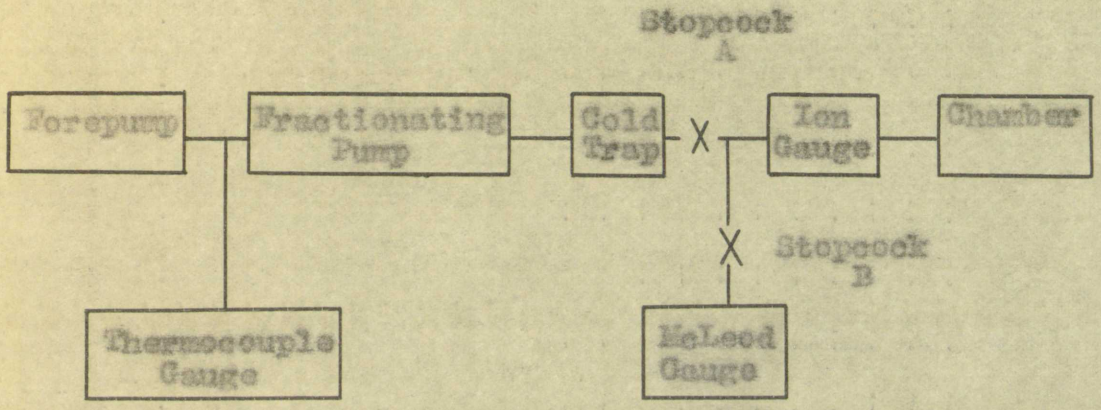
counting geometry. The counting rate indicated an average radiation intensity of one alpha disintegration per square cm per second. For the particular source contained in the cylinder, the average activity was established as 220 alpha disintegrations per minute.

Vacuum System

The vacuum system (figure 3) utilized a standard forepump capable of an ultimate vacuum of $0.5X10^{-3}$ mm of mercury. Following this pump was a Distillation Products Inc. three-stage fractionating pump, type GF25W. This water cooled pump, utilizing Octoil-S oil, was capable of an ultimate vacuum of $5X10^{-8}$ mm of mercury at 25° C. The overflow from the water jackets was admitted to a perforated cup that was mechanically coupled to a microswitch in the heating coil circuit. This precaution eliminated the possibility of having a water failure destroy the pump by overheating. A rheostat having a capacity of 50 ohms and 100 watts was used to vary the heater current from 1 to 2 amperes. The speed of this pump was a function of the heater current and forepressure as indicated by figure 4.

The cold trap was cooled by a combination of dry ice immersed in alcohol. The trap prevented scattered oil molecules from passing into the chamber.

VACUUM SYSTEM SCHEMATIC DIAGRAMS



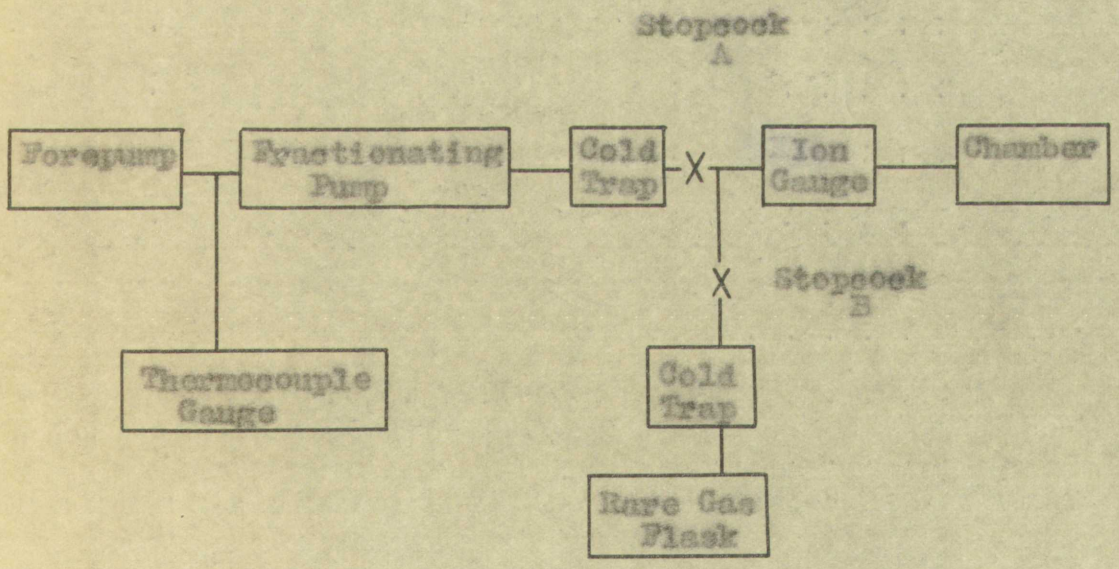
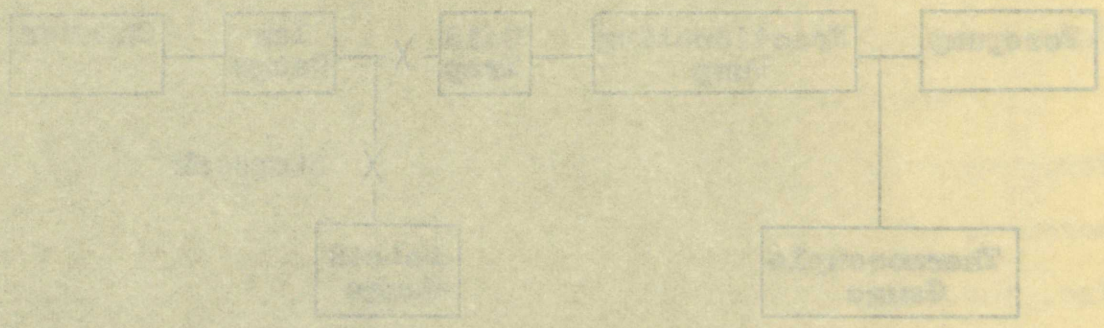


figure 3



GRAPH OF PUMPING SPEED VS. PRESSURE AS A FUNCTION OF HEATER CURRENT

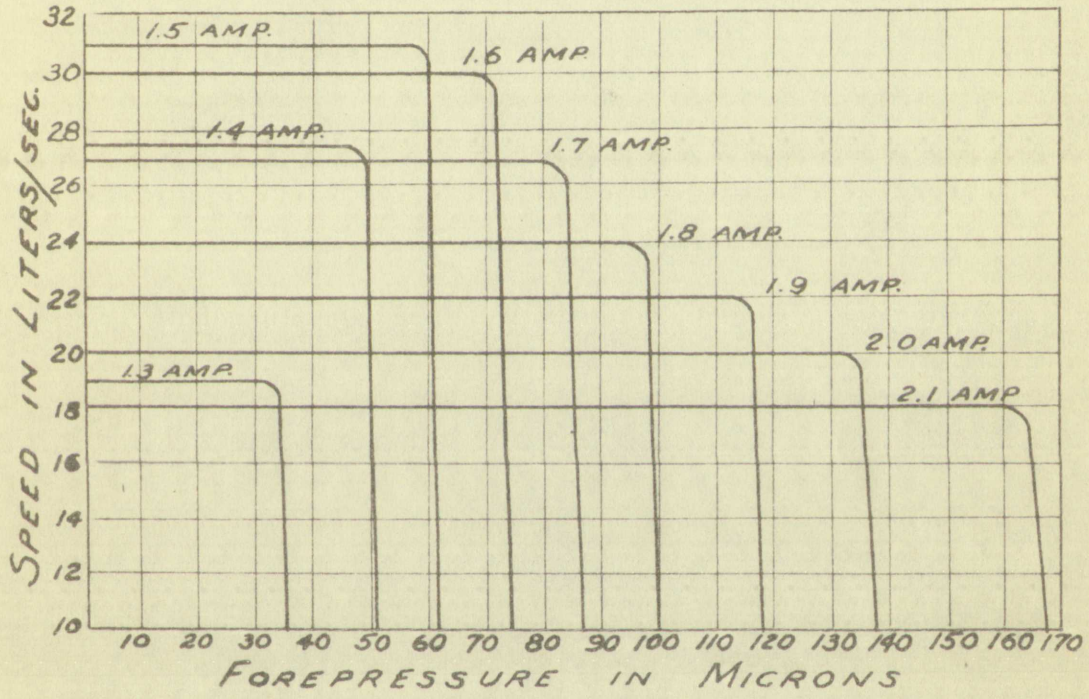


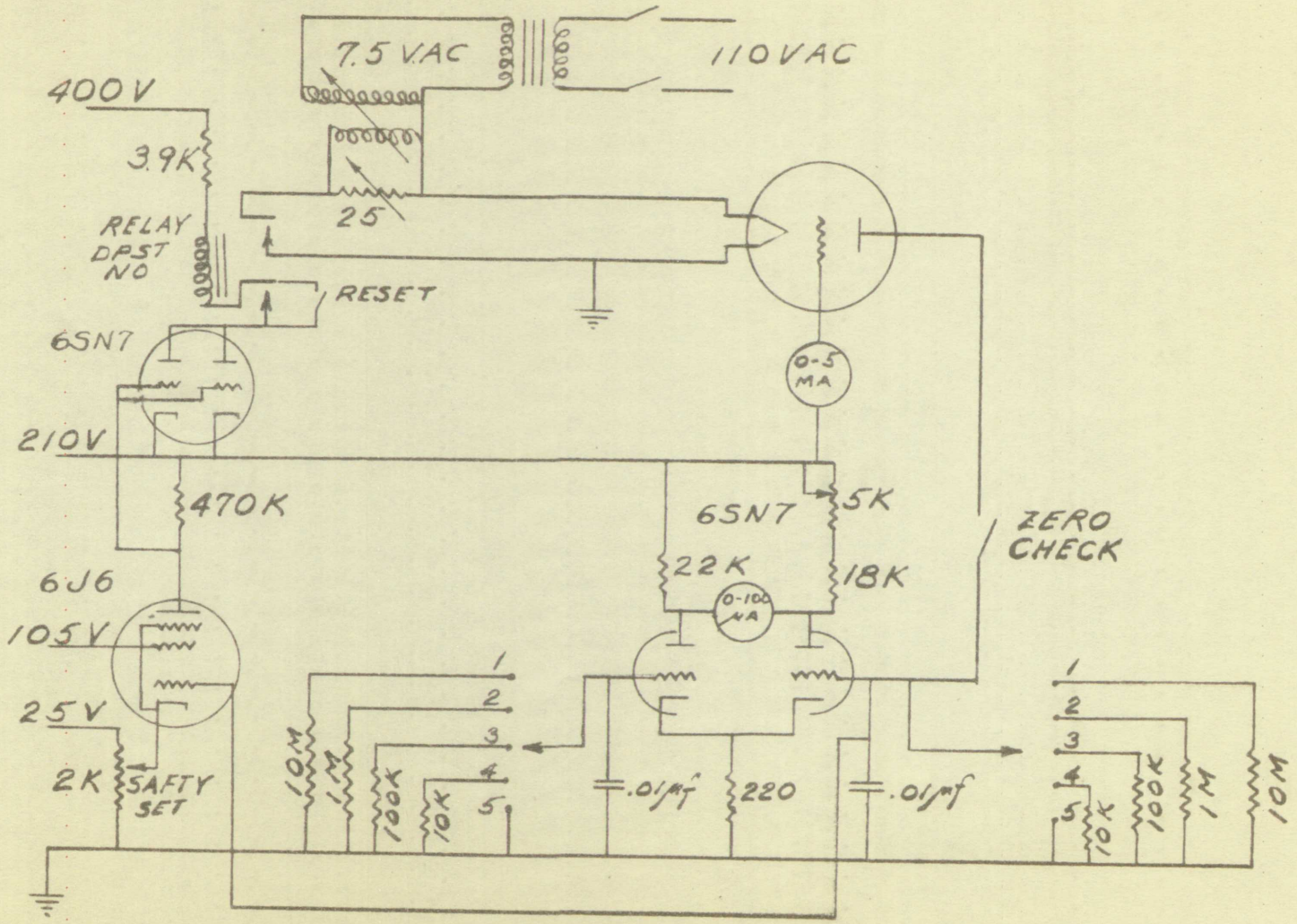
Figure 1

The entire vacuum system following the forepump was made of pyrex glass with the exception of the previously described quartz chamber.

Vacuum Gauges

Two vacuum gauges were used in the final pumping system. The thermocouple gauge was a National Research Corporation type 501. This gauge was used only to indicate the forepressure, thereby insuring optimum operation of the fractionating pump. Since the performance of this gauge was not particularly critical, the manufacturer's calibration was accepted.

The ion gauge (Sylvania VG1A) provided continuous measurement of the pressure in the chamber and was therefore used in preference to the McLeod gauge. The circuit used in conjunction with this tube is shown in figure 5. The grid current was maintained at 1 ma by adjusting the filament current. The amount of unbalance of the two plates of the 6SN7, as indicated by the 0-100 microammeter, was a function of the pressure. If through some failure in the vacuum system the ion gauge plate current became excessive, the relay would open and interrupt the ion gauge filament current. This precaution eliminated the possibility of burning out the gauge.



ION GAUGE CIRCUIT

A McLeod gauge was used only to calibrate the ion gauge. The McLeod gauge was calibrated by computing the internal volumes. The upper capillary of the gauge was removed and 8.32 cm of its length was filled with .995 gm of mercury. From these facts it was possible to compute the cross sectional area ($\sigma = 8.78 \times 10^{-1}$ square mm)of the capillary. The volume (V) of the lower bulb was found by filling it with a measured volume of water and was found to be 423×10^{3} cubic mm. The relationship between the pressure, in mm of mercury, and the height of the mercury may easily be shown to be $PV = (\Delta h)^2 \sigma$ where Δh is measured from the top of the capillary to the surface of the mercury.

The calibration of the ion gauge is portrayed in figure 6, after normal grid and plate degassing procedures had been performed. This outgassing consisted of electrically heating the grid to incandescence while gently heating the plate with a torch.

Outgassing

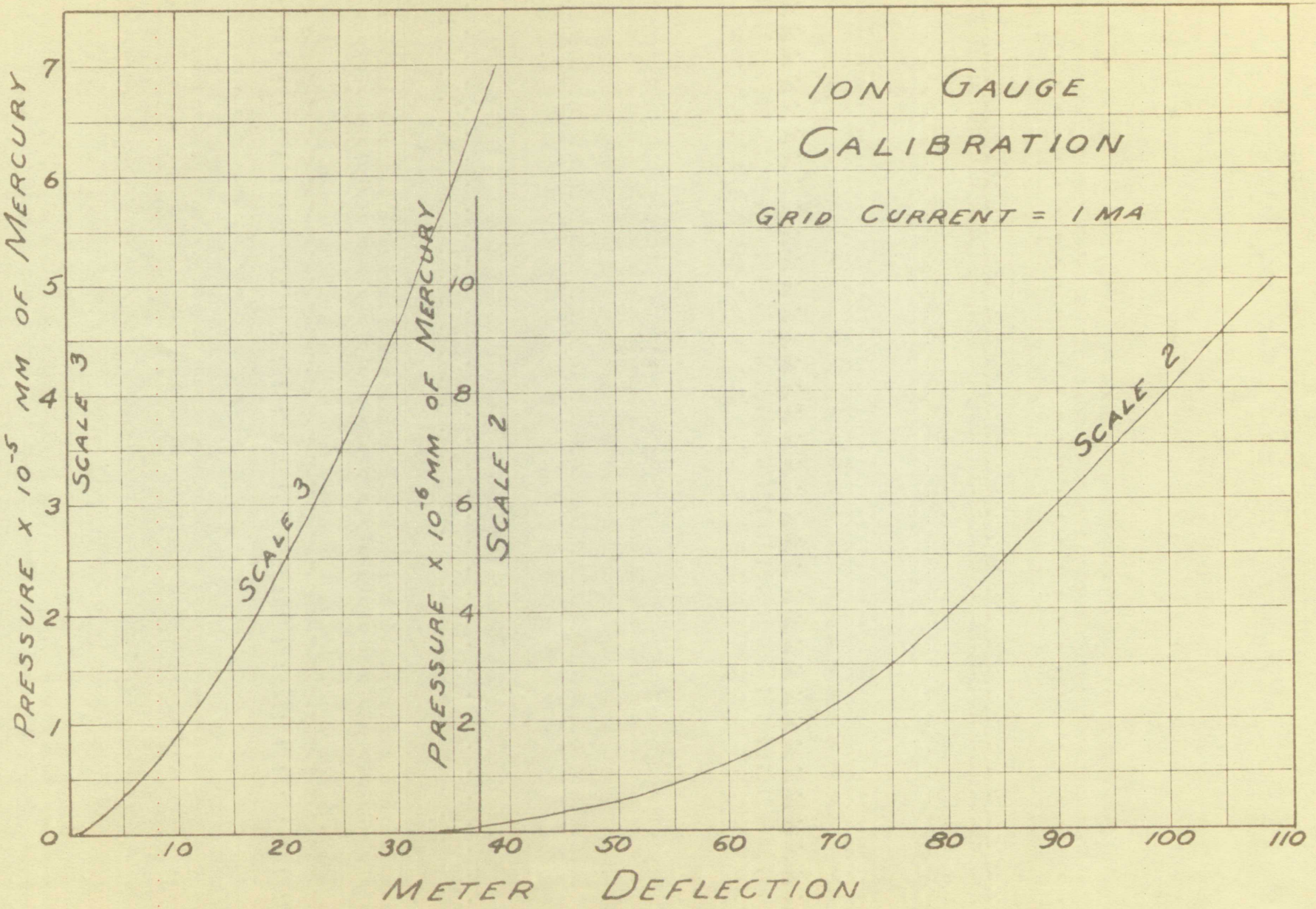
After eliminating the pinpoint holes from the vacuum system a chamber pressure of 10^{-6} mm of mercury was obtained. At this time the entire vacuum system was heated with a torch to outgas the walls of the glass. In addition, the chamber was heated in an oven during pumping. The oven,

A Helmet range pycnometer (Fig. 1) was used for the
gauge. The Helmet pycnometer consists of the cup
internal volume. The upper portion of the cup
moved and 0.32 cm of the length was filled with
mercury. Then there is the glass cover
cross sectional area (0.8 cm²) across
The volume (V) of the lower portion could be
with a measured volume of mercury and was found to
cubic cm. The relationship between the pressure
mercury, and the height of the mercury can easily
to be $V (\Delta h)^2$ where Δh is measured from the top of the
capillary to the surface of the mercury.

The calibration of the pycnometer is performed by
figure 6, after normal grid and glass supported procedure
had been performed. This calibration curve is used
by heating the grid to temperatures until a grain
the plate with a bang.

Outgassing

After pumping the pycnometer from the
vacuum system a chamber pressure of 10^{-5} cm of mercury was
obtained. At this time the metal vacuum system was closed
with a valve to volume the walls of the system. The chamber
the chamber was heated in an oven (Fig. 2) simple. The oven


ION GAUGE
CALIBRATION
GRID CURRENT = 1 MA
PRESSURE X 10⁻⁵ MM OF MERCURY
PRESSURE X 10⁻⁶ MM OF MERCURY
SCALE 3
SCALE 2
METER DEFLECTION
0
1
2
3
4
5
6
7
10
20
30
40
50
60
70
80
90
100
110
2
4
6
8
10

mounted on ball bearing raceways, was rolled over the chamber. A small hole in the back of the oven allowed the source recess tube to protrude about 5 cm. The source was moved to this end of the recess tube during the outgassing to eliminate the possibility of damaging the source by excessive heat. This portion of the tube was outgassed by heating it gently with a torch.

Filling

Immediately after outgassing, stopcocks A and B (figure 3) were closed. The fragile helium seal was then broken by allowing a glass-enclosed steel rod to fall against the seal. The steel rod was originally raised by means of a magnet. The ion gauge was then turned off and stopcock B was opened to admit helium to the chamber. After again closing stopcock B, the chamber was sealed off between the ion gauge and the chamber by means of a torch.

An improvement of this filling system was used to refill the chamber when a leak appeared in the chamber after an elapsed time of about a week after first filling. The improvement was effected by replacing the stopcocks by simple seal-off restrictions in the glass tubing. This eliminated the possibility of stopcock grease vapors filtering back into the chamber. The restriction corresponding

to stopcock A was first sealed off and after the fragile seal on the helium flask was broken, the restriction corresponding to stopcock B was sealed off. This system prohibited the control of the amount of helium that was admitted to the chamber, but this was considered secondary to the importance of minimizing the impurities in the chamber.

Photographic Plate Sensitization

It was decided that the method of detection most likely to succeed was a direct exposure, that is, to place the flat surface of the chamber directly against a photographic plate. It was necessary to select an emulsion highly sensitive to the wave length of 10,830 Å and one of the best selections that could be made was an Eastman Kodak I-Z emulsion, hypersensitized for infrared.

The hypersensitization process consisted of soaking the plates in a 1.1% solution of ammonia at a temperature less than 55° F for 3 minutes. The plates were then immersed in ethyl alcohol for 3 minutes whereupon the plates were quickly dried by placing them in front of a blower. All of the work with the plates was performed in absolute darkness.

Sensitization Effectiveness

To test the effectiveness of the sensitization

process, a helium discharge tube was used as a source in a spectrograph to expose the plates. The plates which had not been sensitized failed to produce the 10,830 Å line, but did produce the 7,281 Å line. The sensitized plate however, showed the 10,830 Å line with an intensity equal to or greater than any other line in the spectrum. This state of affairs offered later a convenient method of separating the density of the plate due to the 10,830 Å line from that due to radiation of other wave lengths. In general, there existed a greater background fogging on the sensitized plates than on the unsensitized plates. All of the plates were developed in the manner described by the manufacturer. This consisted of 3 minute bathings in Eastman's D-19 developer at 68°F, 20 minute bathings in Eastman's F-5 hypo, and 1 hour bathings in moving water.

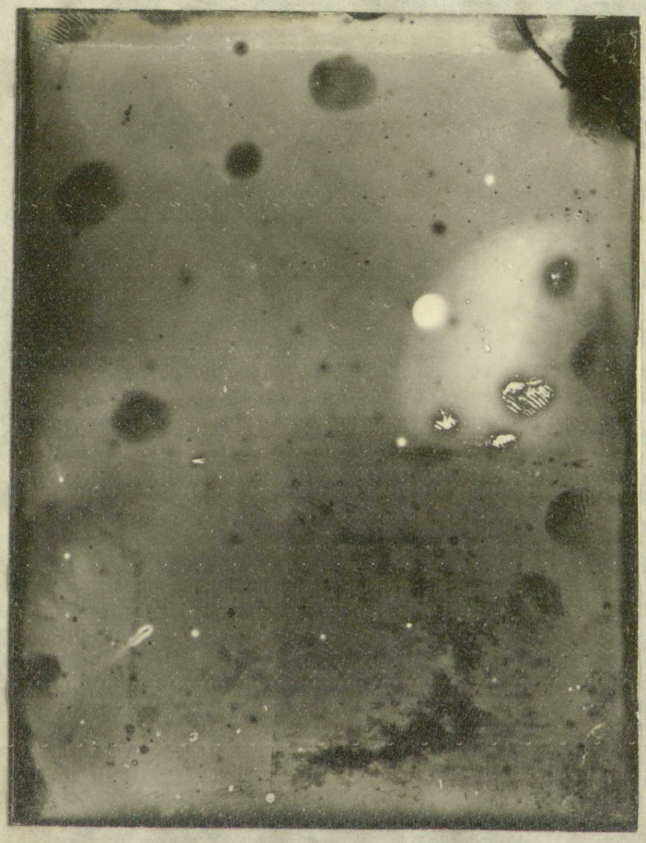
CHAPTER IV

RESULTS

The direct exposure (exposure 1) using a sensitized photographic plate is shown in plate 1. The dark spots on the plate are flaws in the developing process. This direct exposure was accomplished by placing the flat surface of the helium chamber, containing the source, over the junction of a sensitized plate (exposure 1) and an unsensitized plate (exposure 2). In order to maintain a control area on the plates, a piece of cardboard was placed between the plates and the chamber in such a position that half of the chamber was masked from the photographic plates.

This arrangement was placed in a covered black box, the box wrapped in a black cloth and the entire assembly placed in a cupboard in a darkroom. Exposure time was 48 hours.

Although care was taken to avoid having the cardboard mask come into contact with the photographic plate, this is admittedly a possibility and one which was difficult to eliminate when working in complete darkness. If one assumed that the cardboard mask was in contact with the photographic plate, the darkened outline of the cardboard



Chamber image

Cardboard image

plate 1

could be attributed to the pressure. The light area, having the same dimensions as the chamber, could not be due to pressure as one would then be confronted with a paradox of having a single cause give rise to two opposite effects. The light area could not be attributed to fluoresence of the quartz as a completely negative result was obtained when the previous experiment was repeated with the source withdrawn into the recess tube. This was exposure 3 which consisted of a sensitized plate with the cardboard mask, and with the source withdrawn into the recess tube. Exposure time was 48 hours.

A focused exposure was accomplished by focusing the source on a sensitized plate by means of a f2.5 lens having a focal length of 7 inches. The object and image distances were adjusted so that the image of the chamber equalled the plate width of 3¼ inches. This photographic plate (exposure 6) was exposed for 48 hours.

The focused exposure absolutely eliminated the possibility of pressure marks as there was nothing in contact with the photographic plate.

Since the relatively narrow source was focused on the photographic plate, one would expect the appearance of a rather well defined image of the source. The image which

did appear (plate 2) indicates that the source of light was much larger than the source.

This effect could be explained by the possibility that a helium atom, having been ionized by an alpha particle would not regain an electron and emit light until it had struck the wall of the chamber, unless a large number of free electrons existed in the chamber. This source of electrons could not exist inside the volume of the chamber.

Exposure 4 was made with a cardboard mask, but a stronger source was used than in the previous exposures. Exposure time was 30 minutes. This exposure clearly indicates the junction between the cylindrical walls of the chamber and the flat end of the chamber (plate 3). One can also note the outline of the cardboard extending to the left of the chamber. This clearly indicates that diffuse light was present. If this exposure is studied in detail (plate 4), one can see that the cylindrical walls of the chamber (oriented at right angles to the photographic plate) acted as a "light pipe". Again this may be accounted for by assuming that the majority of the ionized helium atoms were unable to obtain an electron until they had struck the wall of the chamber. The resulting light was then carried to the photographic plate along the walls of the chamber.

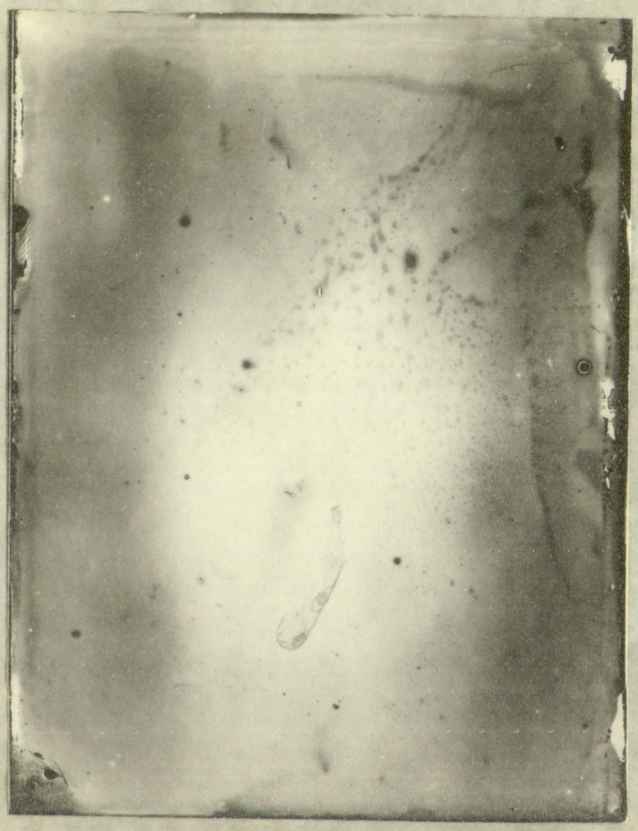


plate 2

plate 3

plate 4

Exposure 5 was made with the stronger source oriented in such a way that the majority of the alpha particles were incident on only one half of the chamber. Exposure time was 45 minutes. This exposure (plate 5) exhibits proof that the emission of light is caused by the source, as the light area which did appear was unsymmetrical with respect to the center of the image. This lack of symmetry corresponded to the orientation of the source.

Exposure 7 was made with the stronger source for 24 hours. This exposure shows (plate 6) in general a light area in the center of the chamber and near the walls of the chamber. Again this can be explained by assuming that the ionized helium emits light only when it strikes the wall of the chamber or the source. Plate 7 which is an enlargement of exposure 7 shows in detail the wall of the chamber. The flaw in the wall of the chamber which appears in plate 7 is present to a lesser degree in some of the other exposures.

This system appears to be quite sensitive in recording the emission of the helium atoms upon recombination with electrons after having been ionized by alpha particles from a very weak source. Exposure 1 (plate 1) was caused by the excitation due to approximately 6×10^{4} alpha disintegrations.

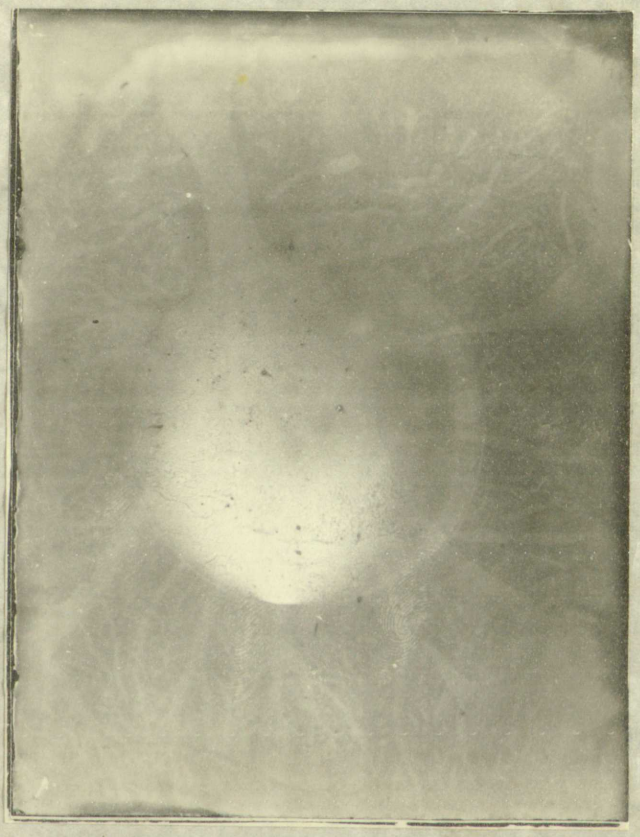


plate 5

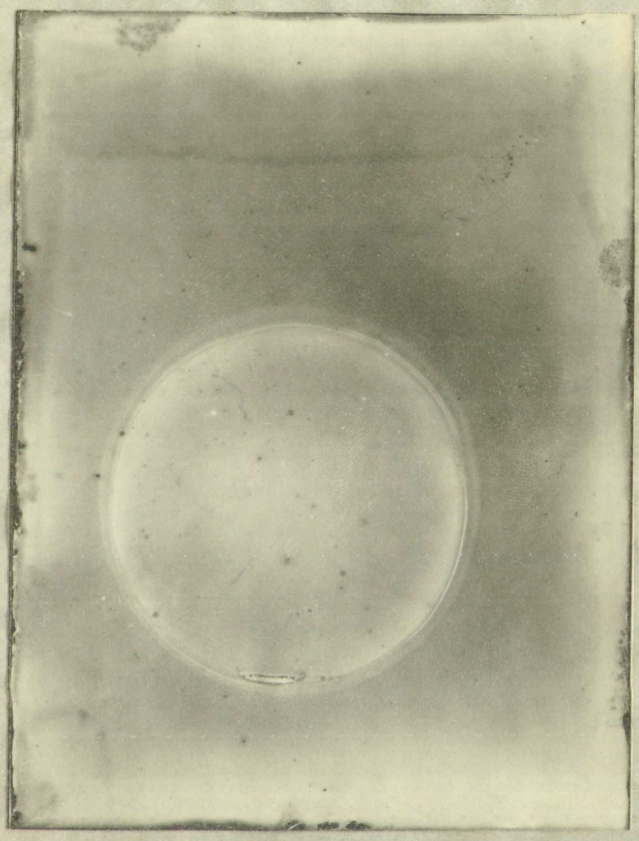


plate 6

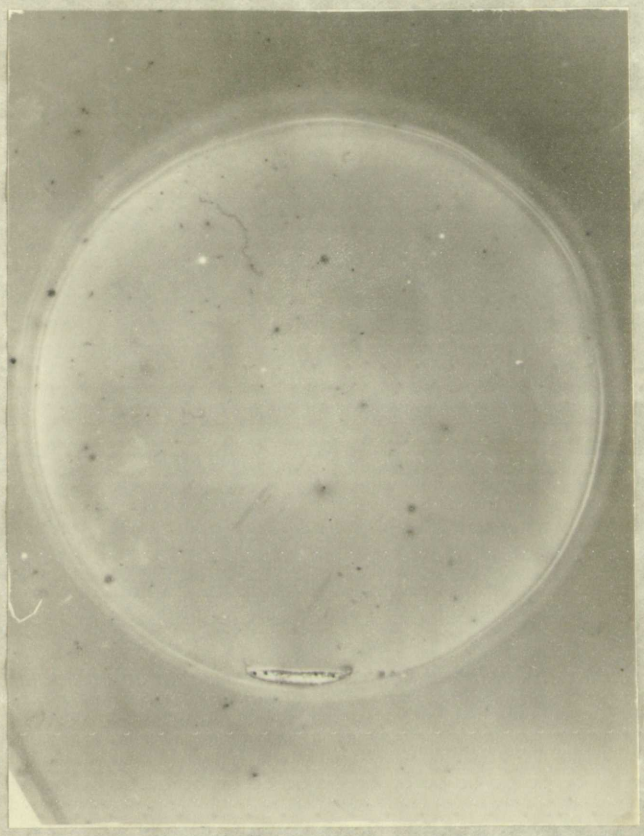


plate 7

The ultimate goal of detecting individual tracks can not be achieved by this method without supplying free electrons to the volume of the chamber.

CHAPTER V

SUGGESTIONS FOR FURTHER RESEARCH

As was previously pointed out, a source of electrons must be supplied inside the chamber if individual alpha particle tracks are to be made visible. One method of realizing this is to use a rare gas with an impurity of an alkali vapor or an alkaline earth vapor. In this case, the chamber would be heated and the metal vapor driven into a vapor state.

Acknowledgements

I wish to thank Dr. V. H. Regener for his guidance in the experimental methods used in this problem, and whose persistent study of the theoretical considerations suggested the problem.