THE CONSTRUCTION, ASSEMBLY, AND OPERATION OF A WILSON CLOUD CHAMBER

G. L. DICKEY, Jr.

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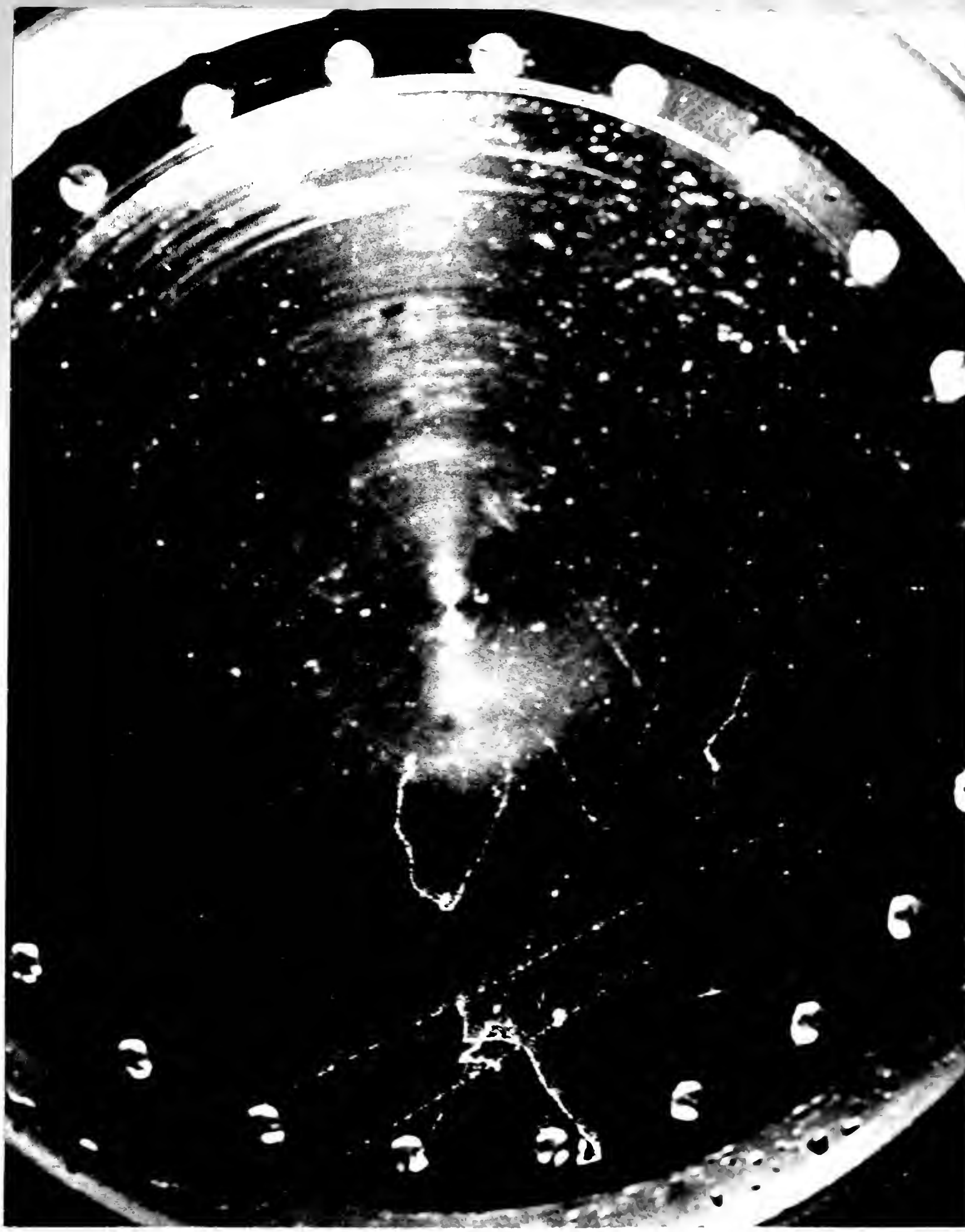

BETA TRACKS

These tracks resulted from the passage through nitrogen of beta particles from Bi^{210}. The partition of energy upon collision and Bragg ionization are prominently displayed.

THE CONSTRUCTION, ASSEMBLY, AND OPERATION OF A WILSON CLOUD CHAMBER

by

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Submitted in partial fulfillment
of the requirements
for the degree of
MASTER OF SCIENCE
IN
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PREFACE

The addition of curricula requiring the study of nuclear physics and nuclear chemistry at the United States Naval Postgraduate School has resulted in a need for specialized apparatus with which to observe the effects of nuclear reactions. In order to provide one of the basic types of equipment to fulfill this need, Dr. N. L. Oleson, Professor of Physics at this institution procured, in 1953, a volume-defined Wilson cloud chamber from the California Institute of Technology. The equipment obtained consisted of interchangeable components of three chambers for which a single control mechanism was provided.

The lack of instructions for the assembly and operation of this chamber and the necessity for the addition of missing parts and essential supplementary elements led to a requirement for a thorough study of the equipment and the development of suitable techniques of operation. This work was undertaken at the Naval Postgraduate School during the latter half of the academic year 1953-1954. It has emphasized the practical aspects of cloud chamber use, both of the equipment in general and of this unit in particular.

The writers wish to express their appreciation to Professors S. H. Kalmbach and N. L. Oleson of the United States Naval Postgraduate School for their guidance in the construction and practical application of this cloud chamber and to Professor W. B. Fretter of the University of California for his time spent discussing the principles and methods of cloud chamber operation.

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CHAPTER I

INTRODUCTION

1. Summary

Since its inception in 1911 the modern cloud chamber has developed in many forms, some aimed at simplicity of operation and improved performance, others at designing specialized equipments for producing specific types of results. Extensive treatises on the theoretical details of cloud chamber phenomena, derived from thorough studies of every phase in the operating cycle, are available in current literature. The practical approach to the use of the instrument has been recorded in more general terms, and workers must develop for themselves the details of putting into operation a specific piece of apparatus.

The expected future use of the cloud chamber in instruction and for experimention by staff and students at the United States Naval Postgraduate School has dictated the aim of the writers. Their purpose has been to restore to utility these cloud chambers, to record methods by which future experimenters may quickly put them into operation and to produce photographic samples of the types of results which may be expected with the units.

Since the theoretical aspects of the apparatus are so widely discussed in the literature, this type of information has been minimized. In recognition of the fact that a certain amount of this theory is essential for successful experimentation, the writers have included certain basic concepts. In addition, the general findings of others

on practical operation have been used by the writers, and the applicable portions have been incorporated into this paper. With this material as background, the application to the specific apparatus on hand is given. After a description of the physical components and their functions, the chamber cycle is treated. The operational procedures applicable to this chamber type, from the initial filling of the assembled unit to the production of track photographs, are then described.

The final chapter is devoted to sample photographs of cloud chamber tracks produced in the instrument, noting the methods of obtaining and recording them.

2. Elementary Features of Cloud Chambers

The basic principle of cloud chamber operation is the condensation of liquid droplets on minute particles in a supersaturated atmosphere. The condition for condensation was demonstrated by C. T. R. Wilson in 1897. In 1911 and 1912 he developed a cloud chamber technique for photographing the tracks of various ionizing radiations, and a great variety of cloud chambers of ever-improving design has evolved in the years following. A large number of equipments constructed for many specific purposes are described in the literature, especially in the period up to 1936.

The cloud chamber consists of an enclosed volume of gas which is initially saturated with a suitable vapor. It is equipped with a bellows, piston or pressure-controlled diaphragm which permits rapid expansion. Actuation produces an essentially adiabatic expansion, and the accompanying temperature drop causes the atmosphere within the

chamber to become supersaturated. The excess vapor will then condense on ions or on uncharged particles which are of sufficient size. The production of supersaturation may be understood by following the steps in the operation of the cloud chamber. Just before expansion the cloud chamber contains a condensible gas at pressure p_1 and temperature θ_1, in a volume v_1. If M_1 is the mass of vapor in the saturated atmosphere and M is its molecular weight, the following equation holds:

$$p_1 v_1 = \left(\frac{M_1}{M}\right) R\theta_1 ,$$

where R is the gas constant.

An adiabatic expansion to the conditions designated by subscript two follows the relations:

$$p_1 v_1^{\gamma} = const.$$

$$\frac{\theta_1}{\theta_2} = \left(\frac{v_2}{v_1}\right)^{\gamma-1}$$

$$\frac{p_1}{p_2} = \left(\frac{\theta_1}{\theta_2}\right)^{\frac{\gamma}{\gamma-1}}$$

in which γ is the ratio of specific heats, $\frac{c_p}{c_v}$, for the gaseous mixture within the chamber. The gas law is still valid, however, so that

$$p_2 v_2 = \left(\frac{M_2}{M}\right) R\theta_2$$

where M_2 is a quantity whose value is dictated by the new physical conditions. Thus $(M_1 - M_2)$ must condense out as free liquid. The supersaturation is defined as the ratio of the density of vapor immediately after expansion, but before condensation, to the saturation density at the lower temperature θ_2.

Its value is given by:

$$S = \frac{M_1}{M_2} = \frac{p_1 v_1 \theta_2}{p_2 v_2 \theta_1}$$

$$= \frac{p_1}{p_2}\left(\frac{1}{1+e}\right)^{\gamma}$$

where ($1 + e$) is the expansion ratio $\left(\frac{V_2}{V_1}\right)$. The actual value will be slightly less than the exact value above because heat is added to the chamber through the walls and during condensation, at variance with the true adiabatic process.

If condensation nuclei exist inside the chamber, droplets will form on them continually until the conditions of supersaturation are lost. The period during which this occurs, about 0.1 sec., is called the sensitive time, and its length is limited by the rate at which heat is liberated in the chamber. The fact that drops will form selectively on small particles is based on work by Lord Kelvin, who demonstrated in 1870 that surface tension causes the saturation vapor pressure over a drop of small radius to be greater than over a plane sheet of liquid. Das Gupta and Ghosh[4] discuss the effect of charged nuclei on drop formation. For drop radii greater than 10^{-7} cm. the effect of charge is negligible. At a given lower radius, however, a higher supersaturation is required for the initial formation of droplets on uncharged nuclei than on those carrying a charge. It follows that proper conditions of supersaturation will allow a marked predominance of droplets condensed on the latter.

During the sensitive time droplets will form on dust, ions or aggregates of molecules of sufficient size. If the gas inside the chamber has been cleared of undesirable condensation nuclei and if supersaturation is great enough for drop formation on ions, yet insufficient to allow condensation on molecular aggregates, tracks formed by the passage of an ionizing agent may be observed under strong light because of the light scattered by the liquid which has condensed

on the ions produced.

The character of the tracks is strongly dependent on the specific ionization of the radiation in the filling gas. This, in turn, is related to the stopping power of the gas, ($-\frac{dE}{dx}$), the amount of energy lost in ionization by the radiation per unit path length:

$$-\frac{dE}{dx} = \text{specific ionization x mean ionization energy}$$

Stopping power for hydrogen-like atoms was treated classically by Bohr (1913, 1915), who gave a result in the form

$$-\frac{dE}{dx} = \frac{A}{B^2}\left[\ln\frac{K}{\beta^2} - \ln(1-\beta^2) - \beta^2\right],$$

where $\beta = \frac{v}{c}$, A and K are constants which depend on the filling gas, and v is large compared with the orbital velocities of the electrons concerned. Bethe (1930) and Bloch (1933) extended the concept quantum-mechanically and derived the following relation:

$$-\frac{dE}{dx} = 2\pi N Z z^2 r^2 \frac{mc^2}{\beta^2}\left[\ln\frac{mc^2 w}{(I Z)^2} + \ln\left(\frac{\beta^2}{1-\beta^2}\right) + (1-\beta^2)\right]$$

provided that $\frac{z}{137\beta} \ll 1$, where a fast particle of charge ze and velocity βc traverses matter of N atoms/cm^3, of atomic number Z and of average ionization energy IZ, and where W is the maximum energy which the fast particle can transfer to a free electron.

Qualitatively, therefore, it may be demonstrated that the density of ionization, hence the apparent size of the cloud chamber track, is directly proportional to the atomic number and density of the permanent gas and the charge of the incident ionizing particle and inversely proportional to its velocity.

3. The Choice of Expansion Ratios, Filling Gas and Condensible Vapor

Air and most elemental gases are suitable for cloud chamber use.

There are two advantages of monatomic gases, their chemical inertness and their rather high adiabatic constant of about 1.66. For other elemental gases and for air the value of γ is around 1.40, and common gaseous compounds have even lower values. The importance of this constant is best demonstrated by computing the temperature drops in each of the types above under the same expansion ratio. Using a ratio of 1.15 and an initial temperature of 20° C, argon will show a temperature drop of 18° C, whereas air will cool only 10° C. As may be seen from the above relations, these constants affect the required expansion ratio directly. Other considerations in the choice of filling gas are:

(a) A gas of low atomic number minimizes electron scattering upon collision. This fact must be weighed against the higher specific ionization of charged particles in gases of high atomic number, the pressures being equal.

(b) The rate of fall of droplets, according to Stokes' Law, is inversely proportional to the viscosity of the gas. A high viscosity permits slow fall of drops, and the ion track may be photographed with a longer exposure time.

(c) The rate of diffusion must not be so great as to allow rapid migration of the newly-formed droplets. This factor also enters into the rapidity with which convection currents are set up under differential heating within the chamber.

(d) Since the sensitive time is controlled by the rate at which the chamber atmosphere absorbs heat after expansion, it is desirable to use a gas with a low heat conductivity. The gases commonly used are air,

nitrogen, hydrogen, helium, and argon, with the last-named giving perhaps the best compromise of conditions.

The choice of vapor (see Wilson[7] and Fretter[5]) depends theoretically on the fact that the critical pressure ratio for supersaturation varies directly with molecular weight and with surface tension raised to the three-halves power and inversely with the density of the droplet. Various liquids are suitable alone, among them water, ethyl alcohol, n-propyl alcohol, isopropyl alcohol, and butyl alcohol. It can be demonstrated that mixtures of one of the alcohols with water allow lower expansion ratios than either component alone as shown in Figure 1. Mixtures of the alcohols themselves, however, give reduced performance in both degree of supersaturation and in quality of tracks formed. The quantity of free liquid introduced into the chamber must be adequate to provide saturation in the compressed chamber state under all conditions of use, but rather large excesses are of no consequence as long as drops are not thrown about during rapid piston motion.

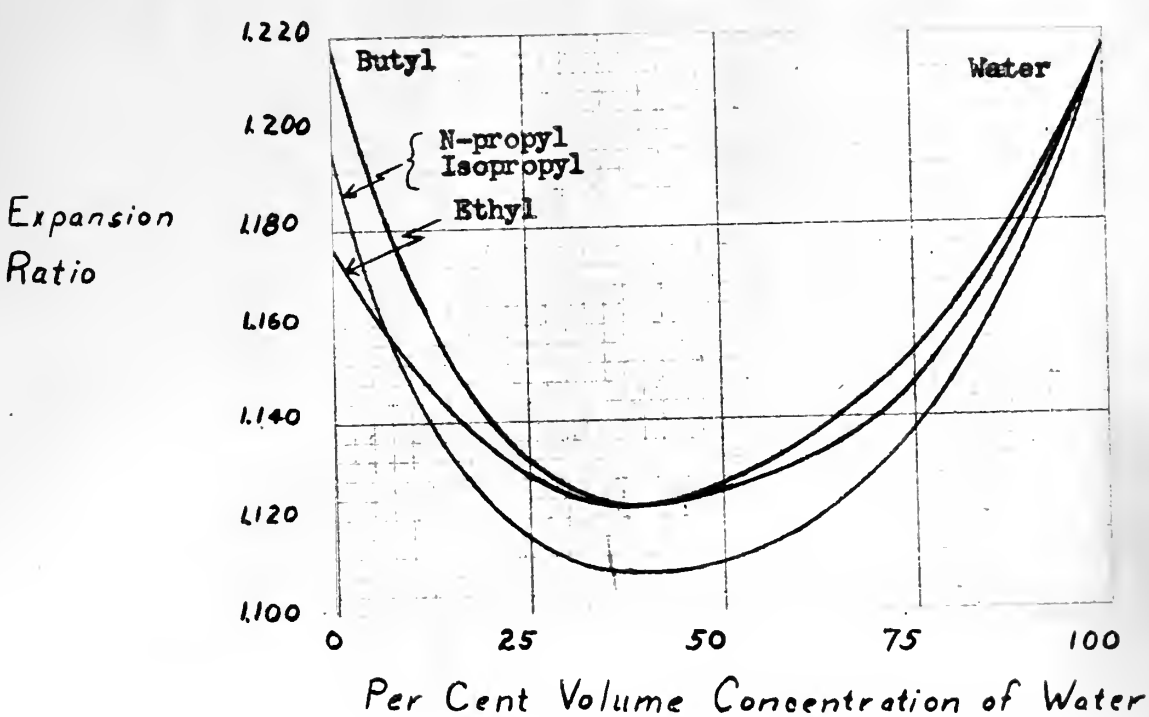
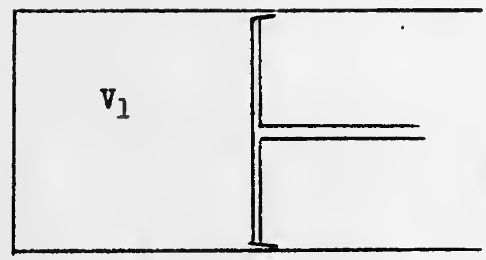
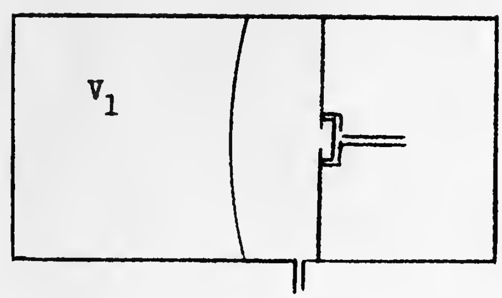


Figure 1. Expansion Ratio as a Function of Concentration for Various Mixtures (Beck[2])



a. Volume-defined chamber



b. Pressure-defined chamber

Figure 2
BASIC CLOUD CHAMBER FEATURES

4. Practical Aspects of Cloud Chamber Operation

Two general types of cloud chambers are commonly constructed: the volume-defined and the pressure-defined chamber (Figure 2). Both types utilize the same adiabatic expansion principle and differ only in the method by which this is obtained. The volume-defined chamber uses a light piston which moves in a definite geometrical fashion, powered by mechanical means or by a pressure difference on the respective faces. The latter is obtained by a bellows or vacuum chamber if operation is at or below atmospheric pressure. Pressure-defined expansion is brought about basically by a pressure difference between two vessels, the higher pressure being in the cloud chamber. If the two are connected and permitted to equalize, the necessary expansion will be effected. In designing the chamber, one may actually allow the filling gas to pass from the sensitive volume, but a more common method utilizes an elastic membrane to divide the chamber into a gas-tight, working portion and an inflatable volume. The pressure is usually vented to the atmosphere by the use of a pop valve. In general, pressure-defined chambers are easier to construct, and many workers prefer a rectangular geometry for the chamber cross-section. Pressure-defined apparatus lends itself well for such designs. Volume-defined chambers are more or less restricted to cylindrical shapes if turbulence is to be kept at a minimum. As a type, they are simpler to use once constructed.

5. Visual Observation; Conditions of Background, Contamination, and Turbulence

It is essential that a sufficiently bright light be available so

that one may distinguish the individual droplets formed in the cloud chamber expansion. A well-collimated beam from a 100-watt globe may serve the purpose. This viewing light allows the worker to make proper adjustments for optimum operation. After filling the chamber and allowing saturation to take place, the first expansion will normally produce a dense fog which has formed on dust and stray ions. A series of slow expansions will cause the droplets to take the dust particles out of suspension if they are allowed to fall to the bottom prior to recompression of the chamber. Obviously this process is shortened by the use of clean filling gas initially. A clearing field of some 20 volts/cm must be provided to neutralize ions. Some sort of grid or other electrode may be mounted within the chamber, with the chamber metallic parts acting as ground. The first few expansions produce little change, but a point is reached at which clearing proceeds rapidly until about one droplet per 10 cm^3 is visible. Further expansions should be made in the presence of a weak radiation source and at successively larger expansion ratios until a few weak tracks appear. Very slight increases in the pressure ratio will sharpen the tracks, and finally a point is reached at which background condensation on uncharged nuclei tends to obscure the tracks. The desired adjustment is then made by trial and error. Two important features should be noted in this phase of putting the chamber into operation. First, the range of expansion ratios between the first appearance of tracks and the excessive production of background is very small. And, secondly, the use of an overly intense radiation source will cause such dense ionization that tracks merge into what appears to be a thick background.

Excessive turbulence is easily seen. The common method of reducing this is to ensure uniform expansion by stretching tightly a piece of black velvet, felt, or silk between the portion of the chamber in which the piston moves and that in which observations are made. The fabric may be sewed or cemented to a mesh or frame, and it provides the additional advantage of giving a good photographic background. Turbulence may also be reduced by operating at lower volume ratios or at lower chamber pressures. It is worth noting, however, that low-pressure chambers require greater expansion ratios to gain the necessary supersaturation.

In the event that the chamber fails to clear after repeated expansions, there is a high probability that either the minimum expansion ratio is too great, or more likely, the chamber is contaminated. In general, this contamination consists of condensation nuclei which are being formed continuously, usually by some chemical process occurring within the chamber. It is probable that the only corrective measure is to locate the source of contamination by a cut and try process and remove same.

Several possible causes of contamination are listed below:
(a) Chamber materials. These must resist chemical action by air, water, and other liquids which may be used; chromium, nickel, and aluminum are found to be clean materials, as is glass. Contamination from base metals is common, and contamination from a ferrous alloy has been reported. Rubber and neoprene are commonly used for diaphragms and gaskets, though some workers have reported trouble from these materials under certain circumstances. Vaseline and stopcock grease

are good sealing materials, and most enamels may be used for darkening the inside of the chamber if they are dried thoroughly. "Aroldite", a commercial, cement-like material, will give a tough, inert metal-to-glass bond for mounting aluminum windows.

(b) Filling gas. The presence of foreign matter other than dust in the permanent gas may preclude proper clearing. Air compressors and the loading mechanisms for filling helium and argon bottles are common sources of oil droplets, and either oil-free gas must be used or else it must be filtered appropriately. If it is suspected that foreign matter is diffusing into the chamber, diaphragms may be made of butyl rubber, through which the diffusion rate is considerably less than that for natural rubber and neoprene.

(c) Vapor. A vapor is required which will not provide condensation nuclei by any means whatever. This topic is intimately connected with the materials in chamber components. Aromatic compounds are to be avoided, as they tend to "poison" the chamber.

6. Temperature considerations

Since a cloud chamber is extremely sensitive to temperature, this factor should be kept constant insofar as is possible, and any changes require compensation in the pressure ratio. After each run the chamber should be recompressed quickly and allowed to stand for a period of about a minute to allow temperature equalization and to permit the internal atmosphere to return to saturation.

Localized sources of heat such as gas pockets, unequal areas of expansion, or heating by the light source will cause convective currents within the sensitive volume and fogging of the glass. It may be

necessary to provide a constant temperature bath to prevent this in certain types of apparatus.

7. Lighting and photography

A prominent worker in the field of cosmic ray studies has stated that there is never enough light available for an experimenter to do all that he wishes in cloud chamber photography. Lighting systems have been described which range from locomotive headlights to mercury or carbon arc discharges. As a rule, incandescent lamps are run at a considerable over-voltage. It is probable that the krypton and xenon discharge tubes described by Fretter[5] give as dependable service as any other system. They have the advantage of providing unidirectional, planar beams with an inexpensive reflector and with no lens system. The construction of a suitable reflector is quite simple. A parabolic cylinder of the desired dimension is cut from a block of wood and a piece of ferrotype is molded into the hollowed out portion to serve as a reflector. The discharge tube is then secured at the focal axis. Light baffles in the beam direction and normal to the tube axis reduce stray light and complete the construction.

It is often necessary to mount the camera so that it is aimed in a direction perpendicular to the axis of the light path. As reference to Wilson[7], Fretter[5], or Das Gupta and Ghosh[4] will show, this gives the least efficient arrangement. Any slight angular incidence of the camera lens axis to the light direction which brings the angle to less than 90° will aid in the gathering of light by the camera.

An ordinary 35 mm. camera of reasonably good quality is adequate for photography in many cases. It must be adjustable for short range

work and needs to have a large aperture size. For experiments in which distortion must be minimal, better lenses are required. Movie cameras adjusted for individual exposures and stereoscopic cameras often may be used to advantage. Recommended film types are linograph ortho, pan, Super XX or Superpan Press. Camera distance and the lens opening needed for the desired depth of field may be determined by photographing a meter stick at a known distance and placed at an angle to the lens axis. By testing various settings a satisfactory combination may be found. A large aperture will normally be used because of the difficulty in getting enough illumination.

The actual shutter operation may vary with the type of illumination in use. Discharge tubes allow the shutter to be opened and the tube to be flashed at the proper time, a method which may be accomplished with relatively simple control devices. Other types of lighting necessitate actuation of the shutter itself, which is commonly done with a solenoid. An effective method of determining the optimum delay between chamber actuation and exposure is described by Crittenden[3]. Visual observation or trial and error methods may be adequate in some cases, especially if the sensitive time is comparatively long.

F. Special Applications of Cloud Chambers

Cloud chambers may be adapted to fulfill a large number of special requirements. The bibliography included by Das Gupta and Ghosh[4] is a useful guide to designs which have been constructed and used for many different purposes. Of particular interest are counter controlled chambers and those with sensitive times of considerable length. Coincidence counter control is discussed by Wilson[7], and Das Gupta and Ghosh[4] describe in detail a typical counter control

mechanism. This type of arrangement is almost essential in cosmic ray studies and in observing particle accelerator beams, in which the whole cycle is triggered by the ionizing agent as it passes through the system. The other alternative would be to take a large number of pictures in the hope of recording a few statistical occurrences, with the attendant use of a large amount of film.

Methods of varying sensitive time are discussed by Hazen[6] and Bearden[1]. A continuously sensitive chamber was built by Langsdorf and is described by Wilson[7].

Since the cloud chamber provides the best graphic picture of ionizing and nuclear events, even those resulting from the passage of a single agent, the uses to which it may be put are innumerable. In some measurements visual indication is essential to the procedure. The unit should be equipped with a strong magnetic field to increase its utility. Range and specific ionization measurements may be made without this, but it is required for such things as positive identification of ionizing particles and mass and momentum determinations[4,7].

CHAPTER II

CHARACTERISTICS AND OPERATION OF THE APPARATUS

1. General

The cloud chamber upon which the work was performed is of the piston operated, volume-defined type. The sensitive volume is 29 cm. in diameter and has a depth of 7.8, 10.3, or 12.8 cm, depending on the size of glass cylinder in use. (Figures 3 and 4). It was designed initially for cosmic ray research and is thus capable of being controlled by coincidence counters. By removing the solenoid system, inserting an elastic diaphragm in place of the piston and substituting for the pressure release valve a suitable pop valve, the chamber assembly shown in Figure 3 may be converted to a pressure-defined type.

2. Description of Individual Parts

The individual parts of the disassembled cloud chamber are shown in Figure 5. A description of each is given below:

(a) Top ring. This is of machined aluminum and is recessed on the inside to permit a fit over the top glass. Bolt holes are drilled in the outer portion.

(b) Top glass. A standard plate glass port lens, 12 inches in diameter by 5/8 inches thick, is used to permit viewing and photography from above. Neoprene gaskets are placed on the top and bottom edges. The gaskets used did not require greasing with vaseline in order to gain sufficient seal.

(c) Clearing voltage electrode. A thin piece of aluminum cut in a "T" served this purpose. The leg of the "T" is insulated and brought to the outside of the glass wall to connect with the source of potential.

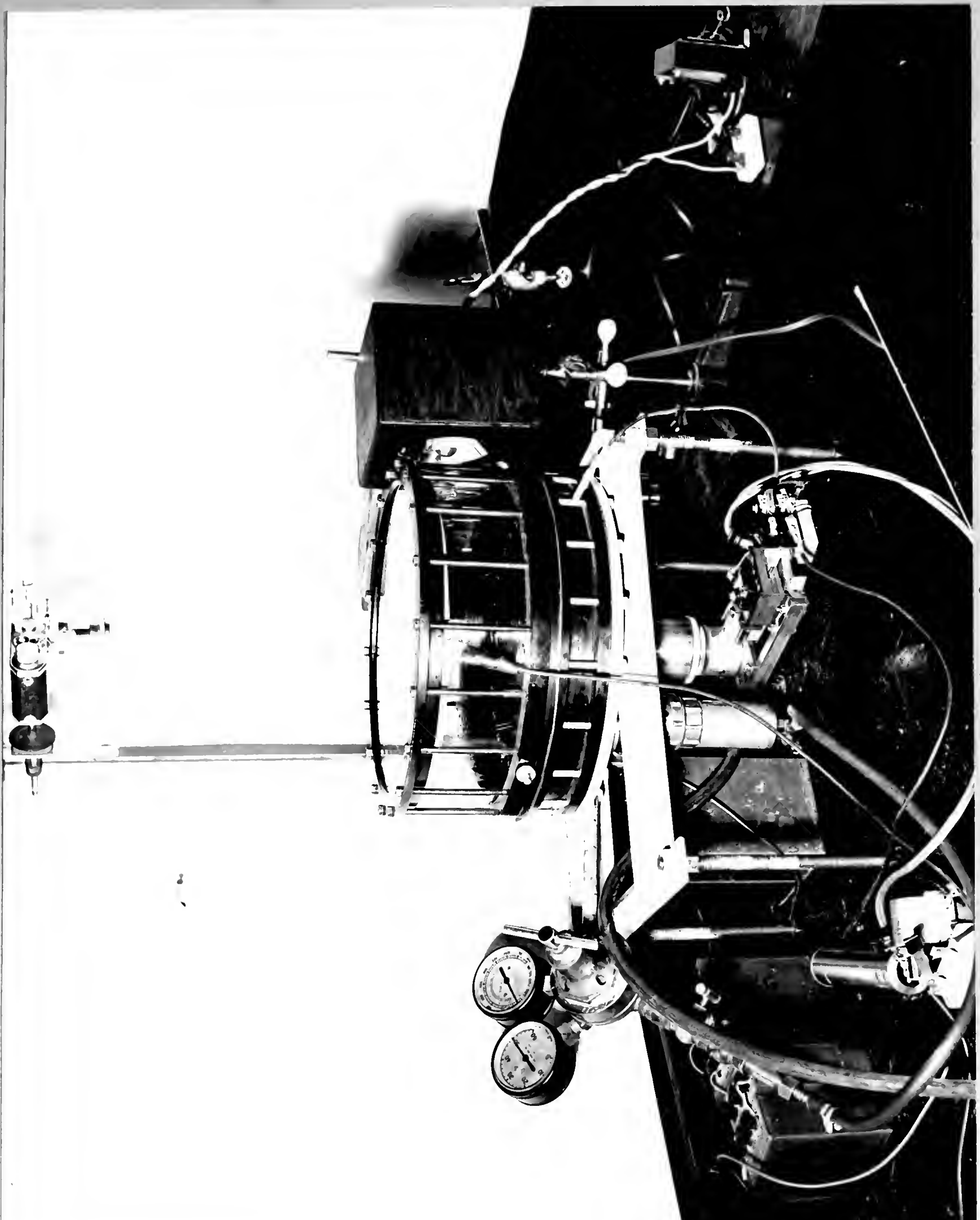


Figure 3
ASSEMBLED CLOUD CHAMBER WITH ATTENDANT AUXILIARY EQUIPMENT

Figure 4
THREE ASSEMBLED CLOUD CHAMBERS

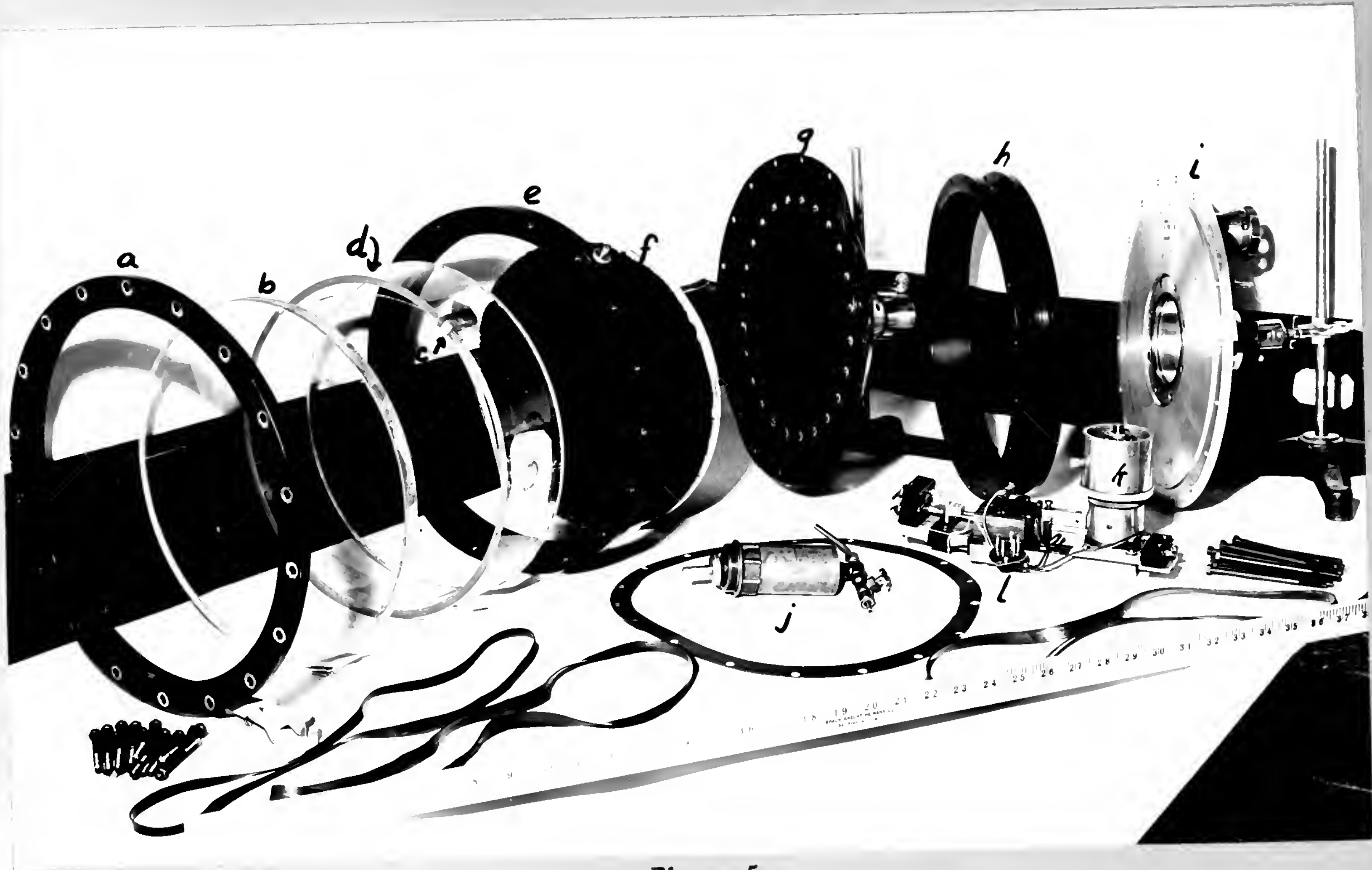


Figure 5
CLOUD CHAMBER COMPONENTS

(d) Glass cylinder. Separate cylinders with depths of two, three and four inches are provided. These are cut from a Pyrex cylindrical jar 12 inches in diameter (outer) and $\frac{1}{4}$ inch thick. The jars are available at laboratory supply houses, where the cutting can also be arranged. All but two of the cylinders on hand have a one inch hole cut in the wall, covered by an aluminum window 0.006 inches thick (36 mg./cm^2). This thickness passes electrons of energies greater than about 0.2 mev. and yet holds the pressures used within the chamber. The aluminum is cemented on with a thin layer of Aroldite. The bonding process requires that the materials be joined and then baked for about four hours at 150°C., five hours at 140°C., or six hours at 130°C., the last named being preferable. The substance is not harmed by prolonging these times.

(e) Bottom ring. This aluminum fitting is grooved to hold the glass cylinder and gasket on its upper side. A gas valve is fitted into it for filling the chamber and measuring the pressures. The inside surface on all but one is threaded. Threaded bolt holes are located at the upper and lower faces.

(f) Grid. In order to allow a piece of velvet to be mounted in the chamber, an aluminum grid is screwed into the lower portion of the bottom ring. The cloth is secured by rubber cement or it may be sewed into place. The function of this cloth is to reduce turbulence and to provide a good photographic background.

(g) Piston. The piston is fabricated from aluminum and stainless steel, though one of the units has a bakelite upper surface. A neoprene diaphragm is secured to the upper face to provide a seal. The lower

part of the connecting rod is capable of being joined to the actuating mechanism. The diaphragm is fixed in gasket fashion between the lower chamber ring and the spacer.

(h) Spacer. An aluminum spacing ring provides the necessary volume for piston motion and for compressed air used in cocking the chamber. It is gasketed at the bottom in the assembled chamber.

(i) Base plate. This circular steel plate provides a positive stop for piston motion. It has bolt holes at its periphery, holes for the gas pressure release valve and its securing screws (this feature is lacking in one of the base plates), a compressed air fitting, and a steel housing for the piston rod. The last-named is bolted in place and must be pressure-tight.

(j) Air release valve. In order to provide a simple, rapid means of returning the space beneath the piston to atmospheric pressure and of allowing the piston to fall without building up a resisting pressure, a brass release valve is fitted to the base plate. The differential pressure principle is used in conjunction with a poppet valve to provide a seal during the cocking process. Closure occurs automatically when air pressure is put to the chamber, and this condition is held until the air is turned off, at which time the valve opens.

(k) Piston release assembly. Figure 6 shows the entire piston actuating mechanism, of which the solenoid system will be discussed separately. At the upper right is a detached piston rod. In its base is a hollow chamber which is grooved on the inside near the end. The second piece from the right consists of several parts;

(1) a threaded cylinder. This has six ¼" ball bearings placed

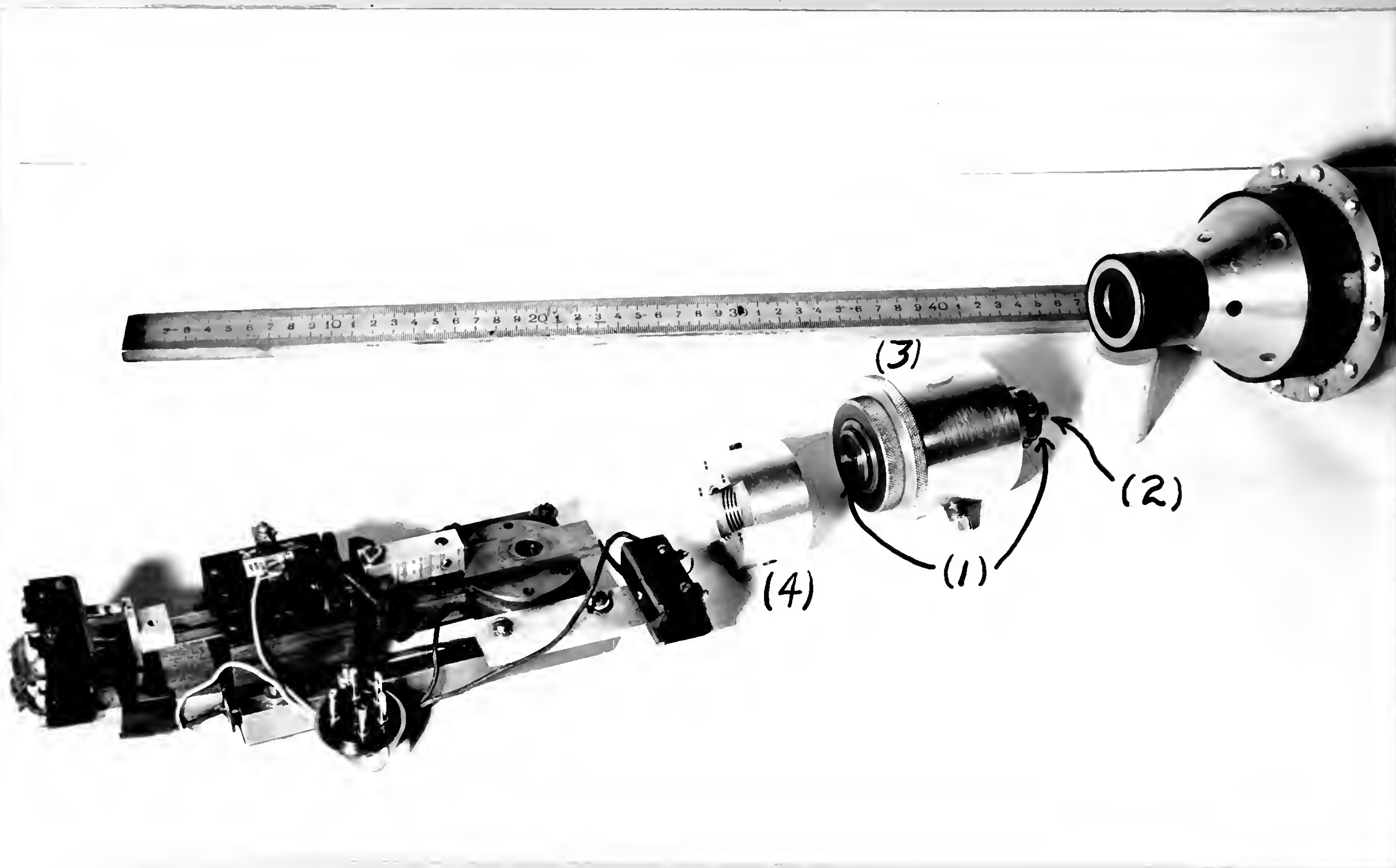


Figure 6
ACTUATING MECHANISM ASSEMBLY

near the top and is hollow.

(2) Spring-loaded plunger. This piece extends internally from the lower extremity of the cylinder (1) to ½" above. In the normal position the ball bearings rest on the lower part of a taper in this plunger. In this position they also fit into the piston rod groove metioned above. If the ball bearings are forced radially inward they will push the plunger downward against spring tension.

(3) Attaching collar assembly. This piece is threaded on the inside and secures the entire actuating mechanism to the cloud chamber. At its bottom is attached a freely-rotating, knurled disc or collar, held in place by set-screws and by a second, smaller knurled disc. The former part is threaded on the inner side and screws onto the cylinder (1). Its purpose is to adjust the cocked position of the piston.

The final piece of this release assembly is an internally threaded cylinder (4) which fits on the hollow cylinder and serves as a guide for the solenoid-controlled bar.

(1) Solenoid system. The device on the extreme left of Figure 6 is the solenoid system which actuates the cloud chamber. It consists of a 110 volt solenoid whose core is attached to a bar. The bar rests on appropriate spacing and bearing elements and moves over six 1/8 inch ball bearings. It fits into the base of the lower cylinder described above and has a hole drilled near its end which accommodates the plunger. On each end are micro-switches which may be used for controlling auxiliary apparatus.

3. The actuation process

With the chamber in the expanded state, the solenoid core has been pulled back into the coil so that the hole in the bar contains the plunger. The ball bearings are riding in the interior of the base of the piston rod and on the small portion of the taper in the upper end of the plunger, held thus by the size of the cylinder surface and thereby holding the plunger down. The succession of events occurring in the cycle of operation from this point follow:

(a) The introduction of compressed air closes the pressure release valve and directs the air into the space below the piston, forcing the latter upward.

(b) When the piston has moved sufficiently, the groove in the base reaches a point opposite the ball bearings. These are forced into the groove by the spring-loaded, tapered plunger.

(c) When the plunger goes up, the solenoid core and the actuating bar are pulled radially inward with respect to the chamber, moving the hole in the bar out of line with the plunger. This action holds the piston in the cocked position.

(d) The movement of the solenoid elements is visible and audible and is a signal to turn off the air pressure. This position should not be overrun as undue strain on the rubber diaphragm would result. In addition, if for any reason the solenoid-controlled bar does not move to restrict motion of the plunger, the ball bearings inside the piston rod base may jump out of their groove.

(e) When the air is turned off, the poppet valve opens to reduce the pressure to atmospheric. The chamber is now ready for expansion.

(f) Putting power to the solenoid or manually pulling its core outward pulls the hole in the bar underneath the plunger.

(g) The force of the gas pressure above the piston is transmitted through the ball bearings to the plunger, pushing it down and allowing the ball bearings to move radially inward.

(h) As soon as the bearings leave the groove in the piston rod, the piston is forced rapidly downward, expanding the chamber.

4. Adjustment of Expansion Ratio

As previously mentioned, the knurled disc or collar through which the threaded cylinder passes is used to control the cloud chamber volume, hence the expansion ratio. With the chamber assembly fixed, rotating this collar clockwise will be seen to lower the threaded cylinder and solenoid unit. This has no effect on the expanded position of the piston, which is resting on the base plate. It does, however, fix the location of the ball bearings with respect to the lowest position of the groove. The described motion reduces the travel neeessary to cock the piston thus reducing the expansion ratio; Figure 7 shows the relation between the number of full turns of the collar from the extreme clockwise position with scribe marks matched and the expansion ratio for various sizes of wall cylinders. The expanded volumes, Vo, are 5305, 6970 and 8635 cm^3 with the 2 inch, 3 inch and 4 inch cylinders, respectively, in place. If the grid and cloth are removed, the volume increase is 208 cm^3. This graph is useful in determining the suitability of various filling gases and condensible vapors with each size of glass cylinder.

5. Supplementary Materials and Devices

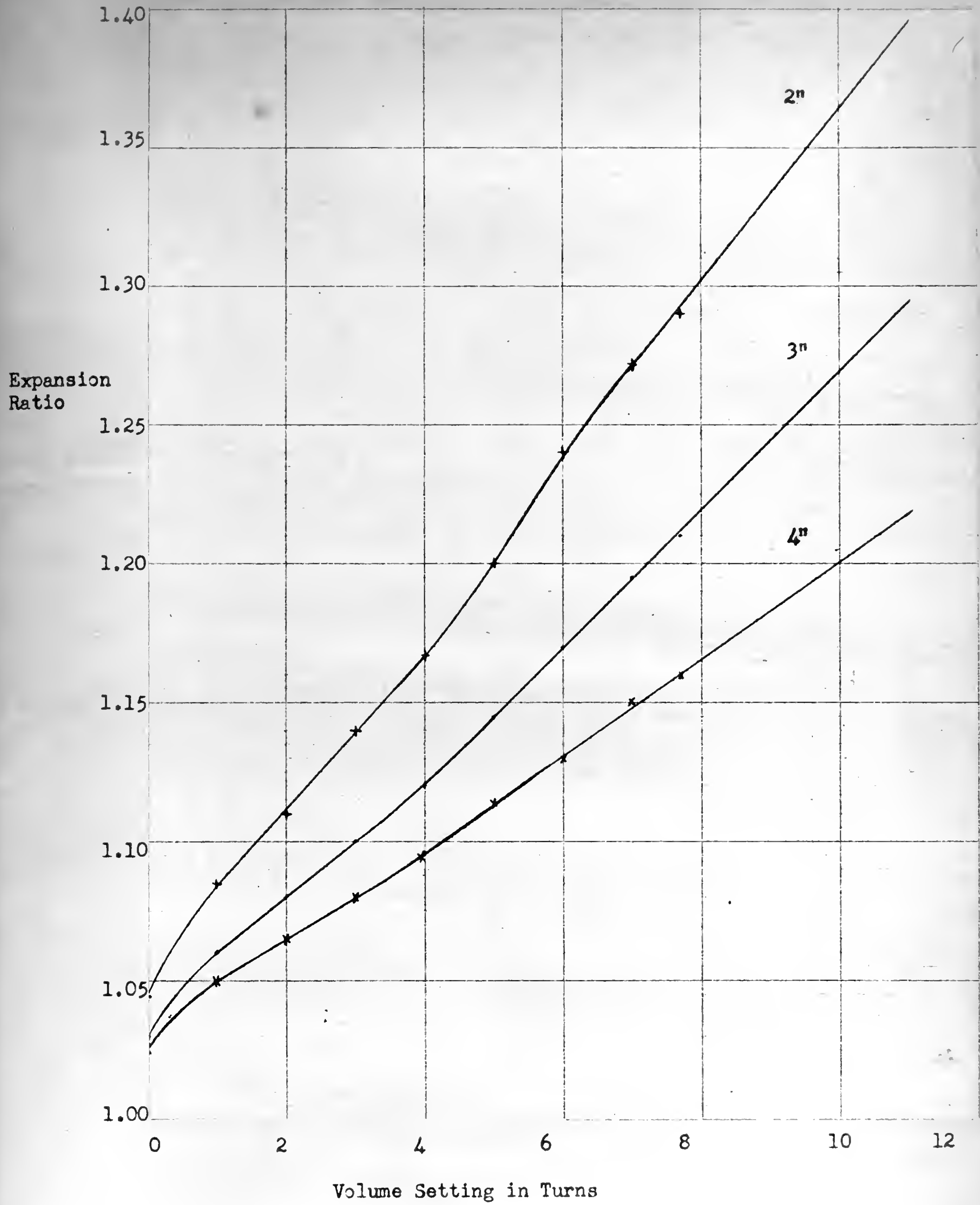


Figure 7
EXPANSION RATIO VS. VOLUME SETTING

Of the several filling gases capable of being used in this chamber, helium and nitrogen were tried, these being readily available in the oil-free state and being typical of monatomic and diatomic gases. The pressures used for both were from 7 to 18 cm. overpressure, measured with the chamber in expanded position. The quality of tracks formed at various pressures within this range was essentially uniform, though the expansion ratios necessary to obtain them was somewhat pressure dependent. The main effect of a higher pressure was to speed the piston motion. This tends to reduce sensitive time, but a high pressure is in itself a compensative factor. The insertion of a small glass cylinder permits a greater variation in expansion ratios; a four-inch glass cylinder was observed to provide finer adjustment, but sufficient expansion was obtained only in the extreme position. A three-inch glass cylinder was used throughout for photography. The difference in the tracks formed in helium and in nitrogen was marked, as might be expected. Nitrogen provided visibly heavier ionization, in accordance with theory and, in addition, extended the sensitive time from the order of 0.2 sec. for helium to about 0.5 sec. These are comparable to the expected values as given by Wilson[7].

As reference to Figure 7 shows, there is little reason to prefer one type of alcohol over another. In this case ethanol and water were used in a mixture of 70% of the alcohol to 30% water. The performance with this solution was quite satisfactory. Pure water and pure alcohol were tested, and each required a much higher expansion ratio.

The chamber was adequately illuminated for visual testing of conditions by an automobile spotlight sealed beam unit. A General

Electric Model 4515 was used, the choice being made because the capped filament reduced aberrations about the outer portions of the parabolic reflector. It was run on 6 volts a.c. derived from ordinary 110 volt supply through a transformer. Neither stops nor a condensing system was found to be necessary. This light has an output of only 30 watts which gave a minimum of heating of the chamber. Photographic illumination was inadequate with the various incandescent and arc lights available at the time so that ph/5 and ph/6 flash bulbs were used for many of the photographs. A beam of small depth and rectangular cross section was formed by placing a slit of ½ inch width at a distance of 4 to 6 inches in front of the ordinary flash bulb reflectors which were used. Tests were made of various bulb types and combinations. It was found that a single bulb was sufficient and that it should be located at an offset of about 20° from the radiation source. Focal plane and medium peak bulbs were superior to fast peak bulbs. Small socket bulbs were used solely, since it was desirable to reduce the physical size of the light source as much as possible.

Several pictures were taken with electronic flash apparatus. It was found that the Sunlite II Speed Flash gave sufficient light. Since this device gives a flash lasting only 10^{-3} sec., the timing of the flash is of utmost importance. The flash was timed manually, though an automatic device would be preferable. A Xenon tube is now on order and will be available for future work.

Photographs were taken with a Canon Mod. III 35 mm. camera, with a "Serena" 50 mm., f/1.9 lens. (Canon Camera Co., Inc., Tokyo, Japan.) The camera had a focal plane shutter, with speeds from 1/1000

to 1 second. For the short range work (46 cm.) the camera was adapted with an intermediate ring. Super XX film was used successfully, though linograph ortho was tried. The latter did not give satisfactory results on one try and was discarded. The test was not significant, however, from the standpoint of rejecting this type of film altogether. Developing was done with Clinitone, a high contrast developer. The developing time was extended to six minutes to increase the contrast. The compressed air supply was reduced by a helium pressure reducer-regulator to the 50 psi or so needed to cock the chamber. Clearing voltage was supplied at 250 volts from dry cells.

6. Details of Operation

In preparing the cloud chamber for use one must connect or put in place the auxiliary equipment, the compressed air hose, camera, lights, and clearing voltage. The clean filling gas and chamber liquid are entered through the inlet valve on the side. Pouring in the liquid at the time of assembly, in sufficient quantity to last through several fillings of gas, will facilitate its introduction. If the chamber is to be operated with an expanded pressure above atmospheric, it is well to flush it in cocked position at a low volume setting and adjust the final pressure with the chamber expanded. In this fashion the pressure will be independent of the knurled collar setting. About ten separate flushing cycles, with a waiting period after each introduction to allow adequate diffusion, were found to suffice. The pressure is measured with a mercury manometer, and the chamber should be so filled that the correct value is reached by bleeding off the excess. An over-pressure of 7-18 cm. Hg was used by the experimenters. The worker

should flush air from the filling hose and commence his refilling while gas is still passing to the atmosphere in order to reduce the quantity of entrapped air forced back into the sensitive volume.

Whether the chamber has been newly refilled or merely left idle for a few hours, actual operation should begin with the clearing process. The threaded adjusting collar should be run to its lowest setting (giving the slowest expansion rate and greatest volume). The following procedure is then followed:

(a) Cock chamber, allow temperature and saturation equilibrium to occur, and expand in the presence of a very weak gamma source. A dense cloud will likely be visible.

(b) Recock chamber as quickly as possible, wait for at least a minute and expand again. Continue this until only a few large droplets are visible, ideally about one drop per ten cc. of volume. If such does not occur, the chamber is probably contaminated.

(c) Increase the expansion ratio by one or two turns and repeat the above process. Continue to augment the expansion ratio by no more than a quarter of a turn and expand.

(d) Upon the appearance of tracks, increase the expansion ratio by no more than a quarter of a turn and expand. With each try the tracks will become better defined.

(e) Shortly after the appearance of the first tracks a background will begin to appear in quantity. This consists of droplets forming on non-ionic nuclei. A small amount of background is tolerable though too much obscures the tracks. The observer must compromise at this point between clarity of tracks and the amount of background he can

allow. The writers found that the chamber could usually be operated with almost no background. At this point the worker using the unit for the first time should note the extreme sensitivity of the chamber to expansion ratio. Final adjustments will be made by turning the knurled collar only a few degrees.

(f) Photography may now commence. Dependable service will be rendered by the chamber over a long period of use if the proper waiting time is allowed, if recocking is immediate and if visual test runs are made after each expansion or two. Sometimes these events will show a need for adjustment due to temperature changes, or for one or two clearing expansions. It was not found necessary to break the clearing voltage circuit during operation, though one of the micro-switches was connected to perform this.

As with most pieces of laboratory apparatus, there will be certain difficulties encountered which must be overcome or circumvented. Several of these will be described and possible courses of action stated.

(a) Contamination. There will be times when the chamber simply will not clear. If it has first been expanded at a high expansion ratio the number of subsequent clearing expansions even at low values will have been increased. If, after some thirty expansions, the cloud persists and if it is known that the expansion ratio is below that required for drop formation on ions, then contamination should be suspected. A check should first be made for weak clearing voltage and for leaks, as contaminated air may have gained entry if the chamber has been standing idle. It is more probable that the chamber will have to be disassembled

and the source of contamination isolated by the elimination of possible sources, one at a time.

(b) Non-formation of tracks in a well cleared chamber. This is usually caused by insufficient temperature drop. The factors affecting the actual expansion ratio, hence the temperature drop, or the expansion ratio needed for a sufficient temperature decrease to give the required supersaturation are:

(1) The height of glass cylinder used. Shallow cylinders allow large pressure drops.

(2) The permanent gas. Monatomic gases require less expansion as explained previously.

(3) The condensible vapor used.

(4) The initial pressure. Higher initial pressures produce greater temperature drops.

(5) Chamber temperature. If the temperature is raised through failure to allow sufficient cooling or because of a change in the ambient temperature, a greater expansion ratio is needed.

(c) Too intense a source of ionizing radiation. This will cause a jagged, dense cloud to form in a cleared chamber instead of scattered tracks. If, after removal of the source, little or no cloud forms, a smaller source should be used.

(d) Photographic difficulties. Blurred images, thin negatives, and other imperfections are corrected by appropriate photographic techniques which are not peculiar to cloud chamber operation.

(e) Condensation on glass parts. Uneven temperatures will ultimately cause undesirable condensation particularly if the outside air

temperature decreases. Careful warming of the affected areas with a light source or with a cloth dampened with hot water will correct the situation.

7. Calibration of Chamber.

It is not worthwhile to attempt a precise calibration of the chamber for there are so many variables that all conditions are almost never duplicated. It is easier to use an approximate calibration in conjunction with visual inspection of tracks for fine adjustments.

CHAPTER III

1. General

The purpose of this chapter is to show some of the results which were obtained with the assembled apparatus. In describing the photographs which follow, procedural details will be recorded so that future operators may compare the various conditions and choose those which are most applicable to their specific problems. The tracks of different radiations are shown in order to demonstrate their behaviors. Where doubt may exist as to which track is being described, a white arrow is used for identification. The location of the source is marked with an S.

Certain conditions were common to all photographic runs and will be listed here. All expansions were made using a chamber fitted with a 3-inch glass cylinder, as it appeared to give sufficiently fine adjustment with an adequate range of expansion ratios. The values of the latter varied with the gas used and with the ambient temperature, which changed through diurnal heating and cooling and weather conditions. The expanded pressures were in the range of 83-94 cm. of mercury. Turbulence was found negligible at these pressures without the use of velvet. The particular piece of cloth available was discarded when it was found to contaminate the chamber atmosphere, with a consequent diminishing in the quality of the photographic background. The camera distance to the center of the light beam was 46 cm except where noted. In every case the camera shutter was opened prior to operating the chamber, the flash was fired and the shutter subsequently

closed. Neutrons were introduced into the chamber for certain shots using a Ra-Be source which gives a continuous neutron spectrum to 13 Mev, with the maximum intensity at about 5 Mev.

2. Electron tracks in Helium

The random directions in which gamma rays eject electrons is compared to the radial travel of beta particles from a small source in Figures 8 and 9. In the former, beta particles from Bi^{210} (E_{max} 1.17 mev; $E_{average}$ 0.33 mev) are entering from the bottom and radiating as shown. Figure 9 is the result of the presence of a Ra-Be neutron source about a foot to the right of the chamber. The reaction gamma rays gave a network of electrons of energies comparable to the above. At the lower left there appears to be an alpha track, probably resulting from the collision of a fast neutron with a helium atom.

Figure 8 was taken with electronic flash illumination at f/5.6. To experiment with the lighting qualities the shot was made with the camera axis slanted about 15° from the vertical. A slight over-exposure may be seen to have resulted.

Figure 9 used an f/8 setting with a flash bulb. The large, light area is a reflected glare from the bottom of the chamber.

3. Comparison of Tracks in Nitrogen and Helium

The density of ionization produced by the passage of a charged particle is proportional to the atomic number of the medium. The effect is readily seen in Figures 10 and 11 using the emissions of Bi^{210}. These beta particles may have a maximum energy of 1.17 mev, but the most probable is about .33 mev.

In Figure 10 the cloud chamber is filled with nitrogen (Atomic Number 7). The beta tracks, originating from the lower left-hand

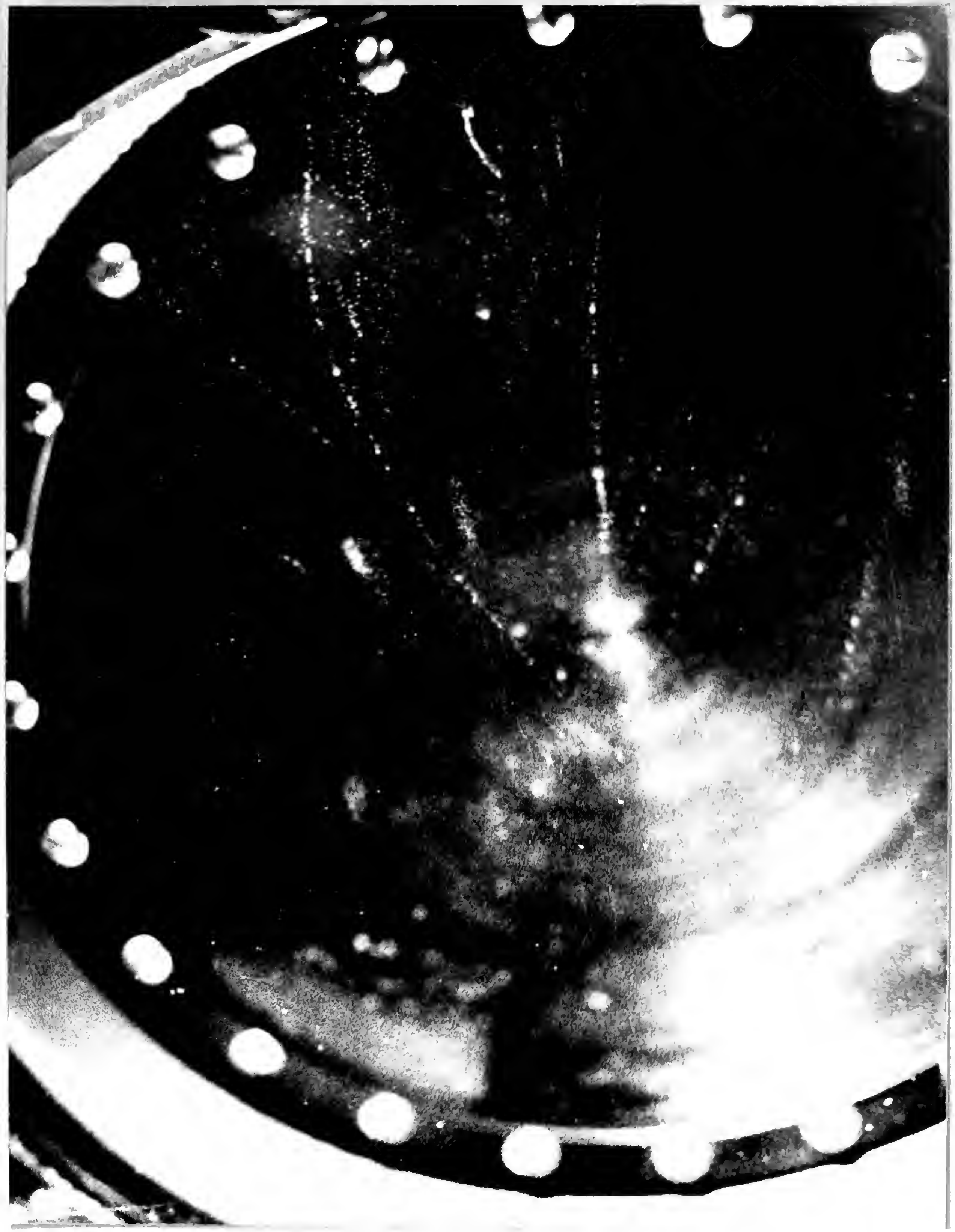


Figure 8
BETA TRACKS IN HELIUM, Bi^{210} SOURCE

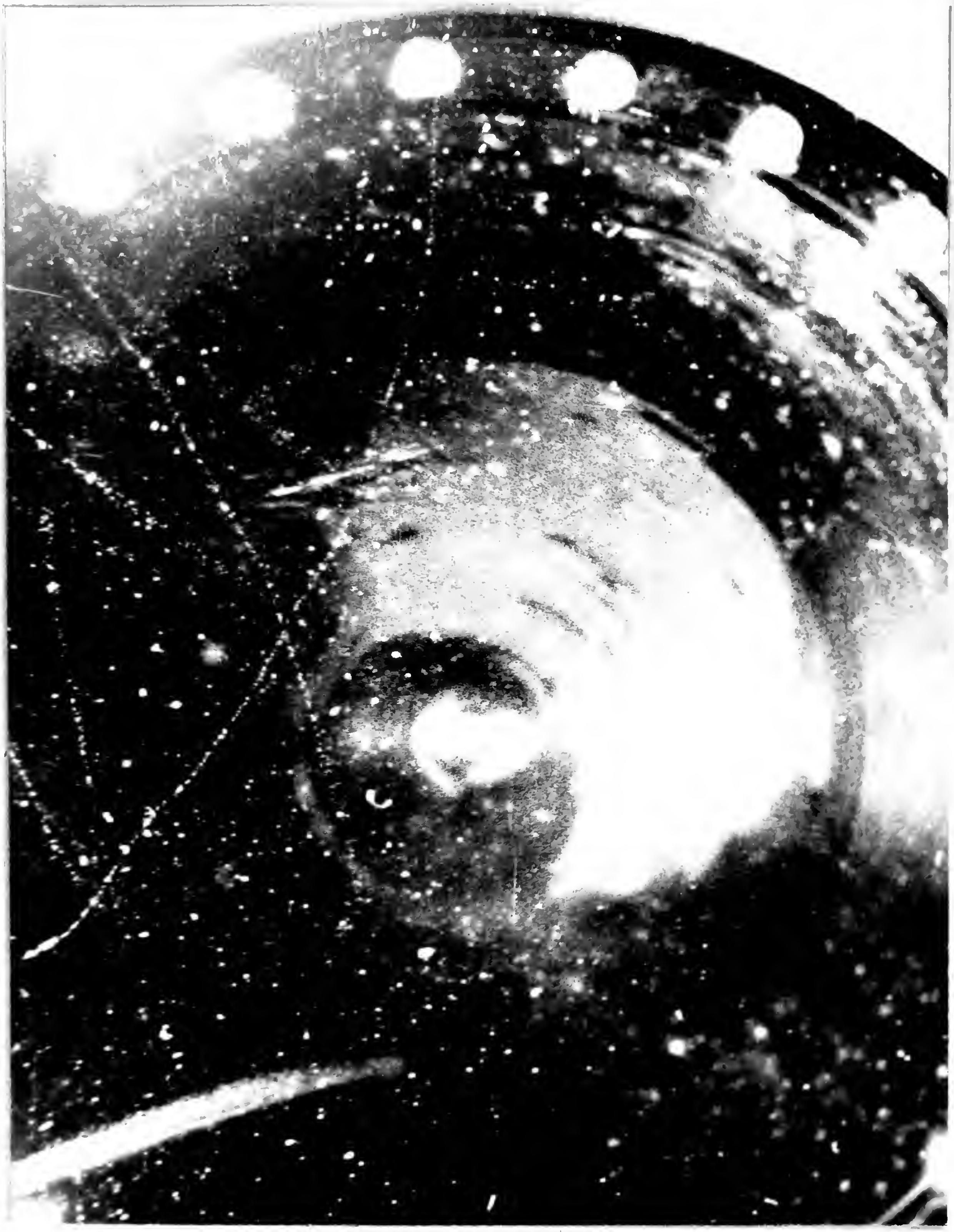


Figure 9
ELECTRON TRACKS IN HELIUM. RA-BE, NEUTRON-GAMMA SOURCE

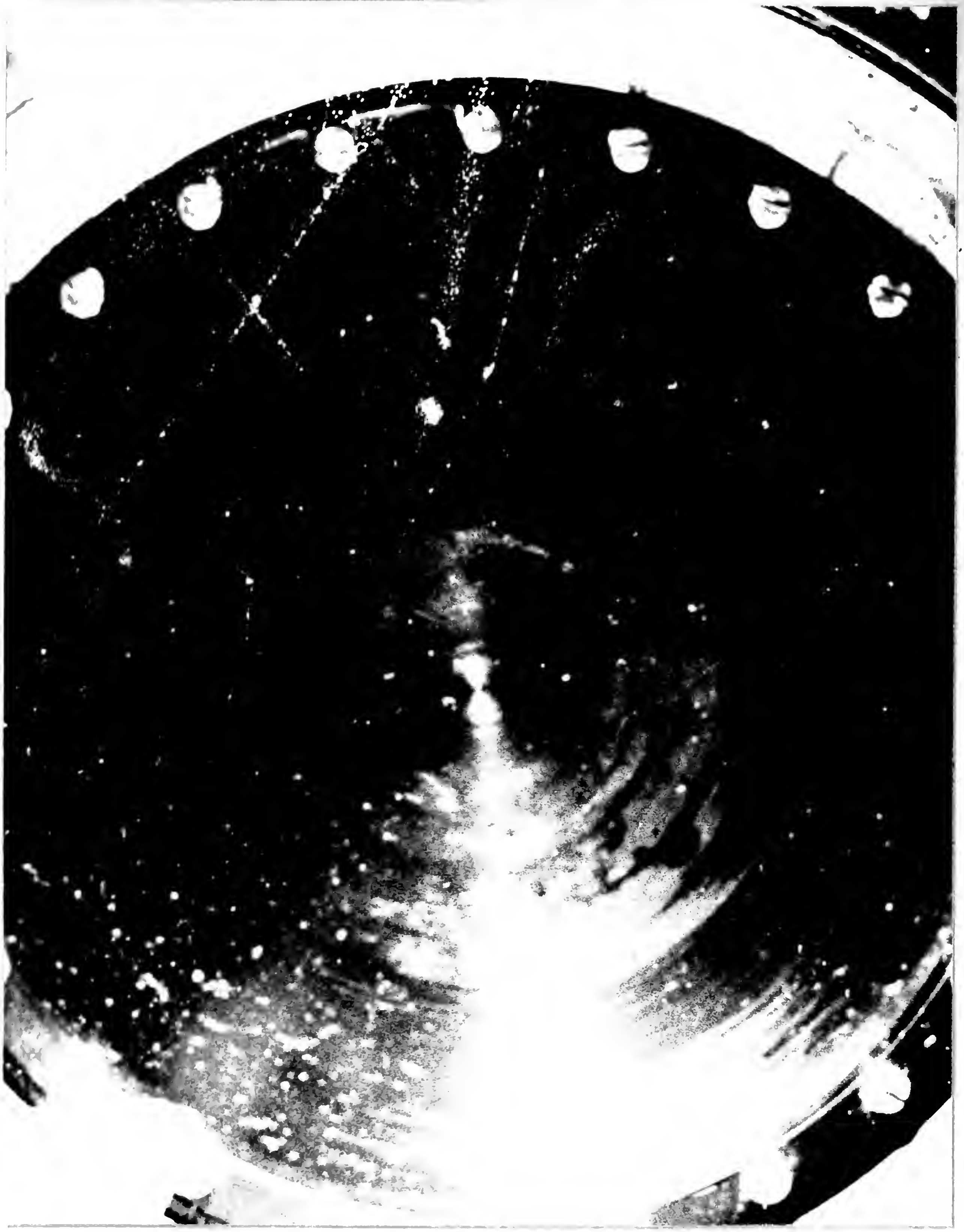


Figure 10
BETA TRACKS IN NITROGEN WITH Bi^{210} SOURCE

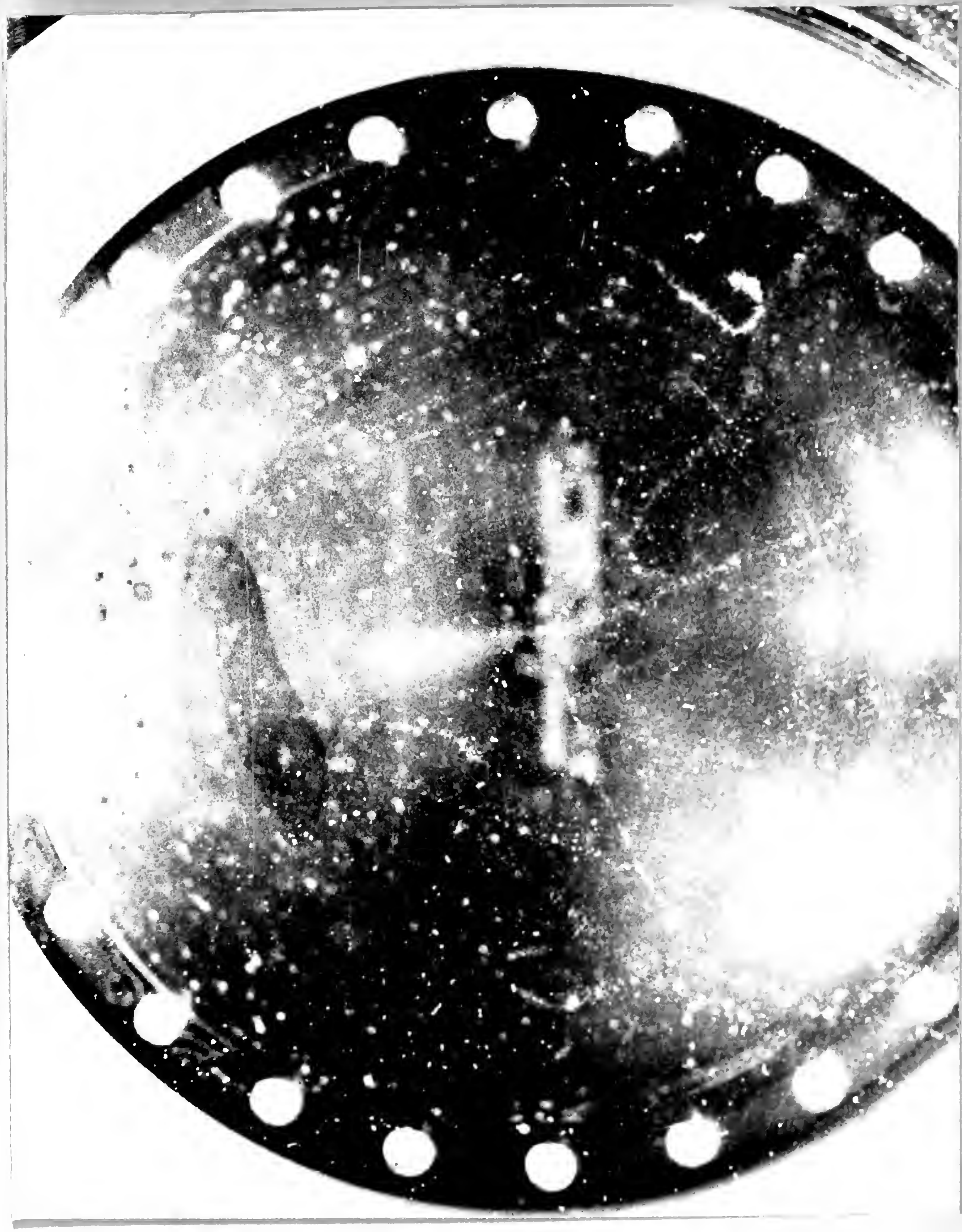


Figure 11
BETA TRACKS IN HELIUM, Bi^{210}, SOURCE

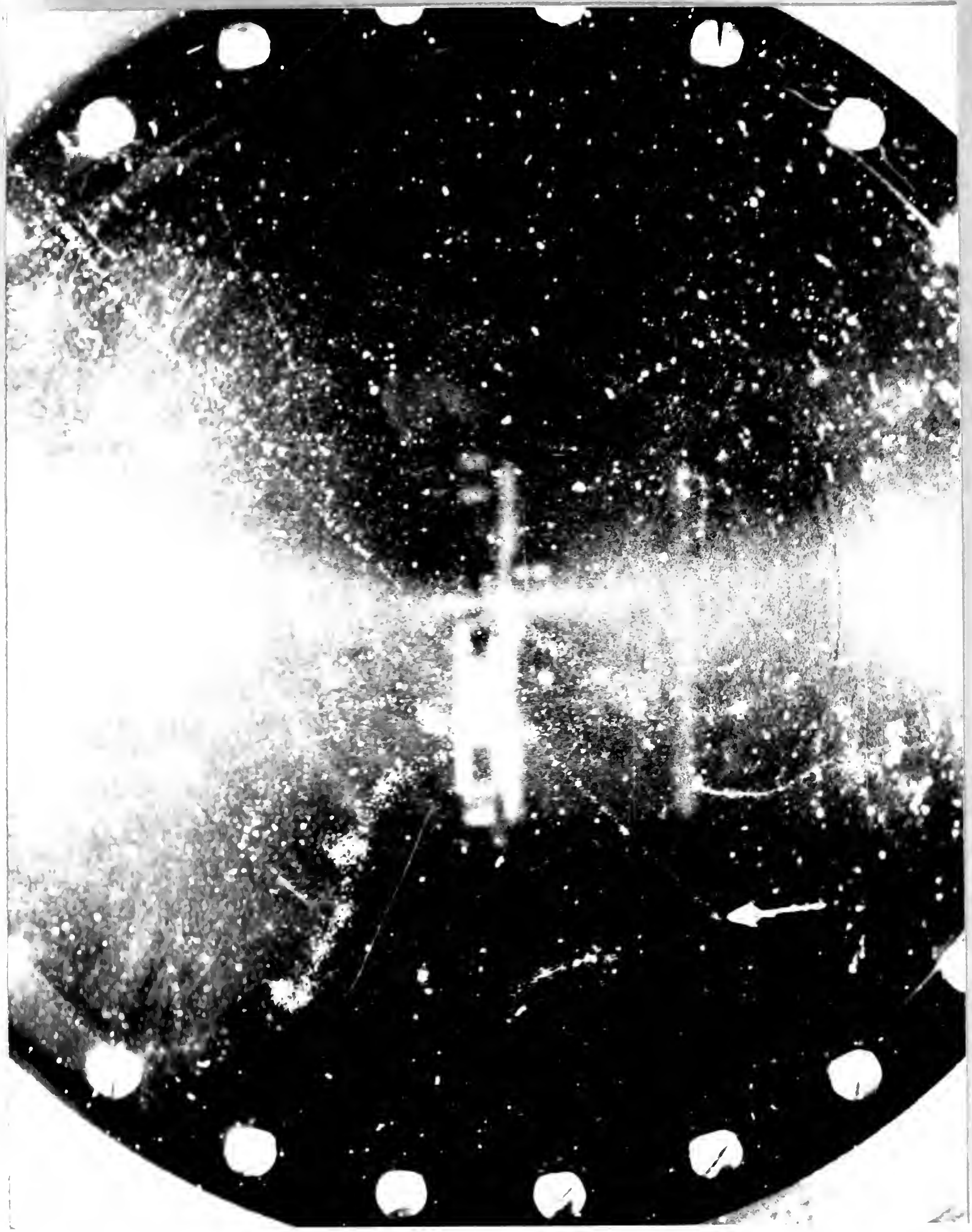


Figure 12
COSMIC RAY IN HELIUM

corner of the picture, are almost continuous. The flash was delayed to the extent that a few of the early tracks may be seen to have begun dispersing. The shot was taken at f/8 with flash bulb illumination.

The same spectrum is seen in Figure 11, except that helium is the permanent gas in the chamber. The tracks, emanating from the left, are considerably less dense than are those in the preceding discussion, as would be expected for ionization in the lighter gas. This picture was made at f/8 with two flash bulbs and a distance increase to 48 cm. Both the over-illumination and the loss in acuity from this combination are evident.

Notable in each figure is a good example of Bragg ionization. The dense ionization and erratic path of an electron as it quickly falls to thermal energy at the end of its travel are prominently demonstrated.

4. Cosmic Ray

Figure 12 was initially planned as a test shot for the type of illumination obtained from a single falsh bulb with the beam aimed at the aluminum window of the chamber. Illumination was from the left, and beta emission from a Bi^{210} source (Emax 1.17 mev) may be seen originating from the right. In addition, however, the transit of a cosmic ray was recorded, entering at lower right.

The double glare resulted from the flash and its reflection. Stopping the lens to f/11 was inadequate to reduce the total illumination. The permanent gas was helium.

5. Beta Tracks

In Figures 13, 14 and 15, ionization by electrons of different energies may be seen. The first photograph shows beta particles

Figure 13
BETA RAYS FROM Po^{234}, IN HELIUM

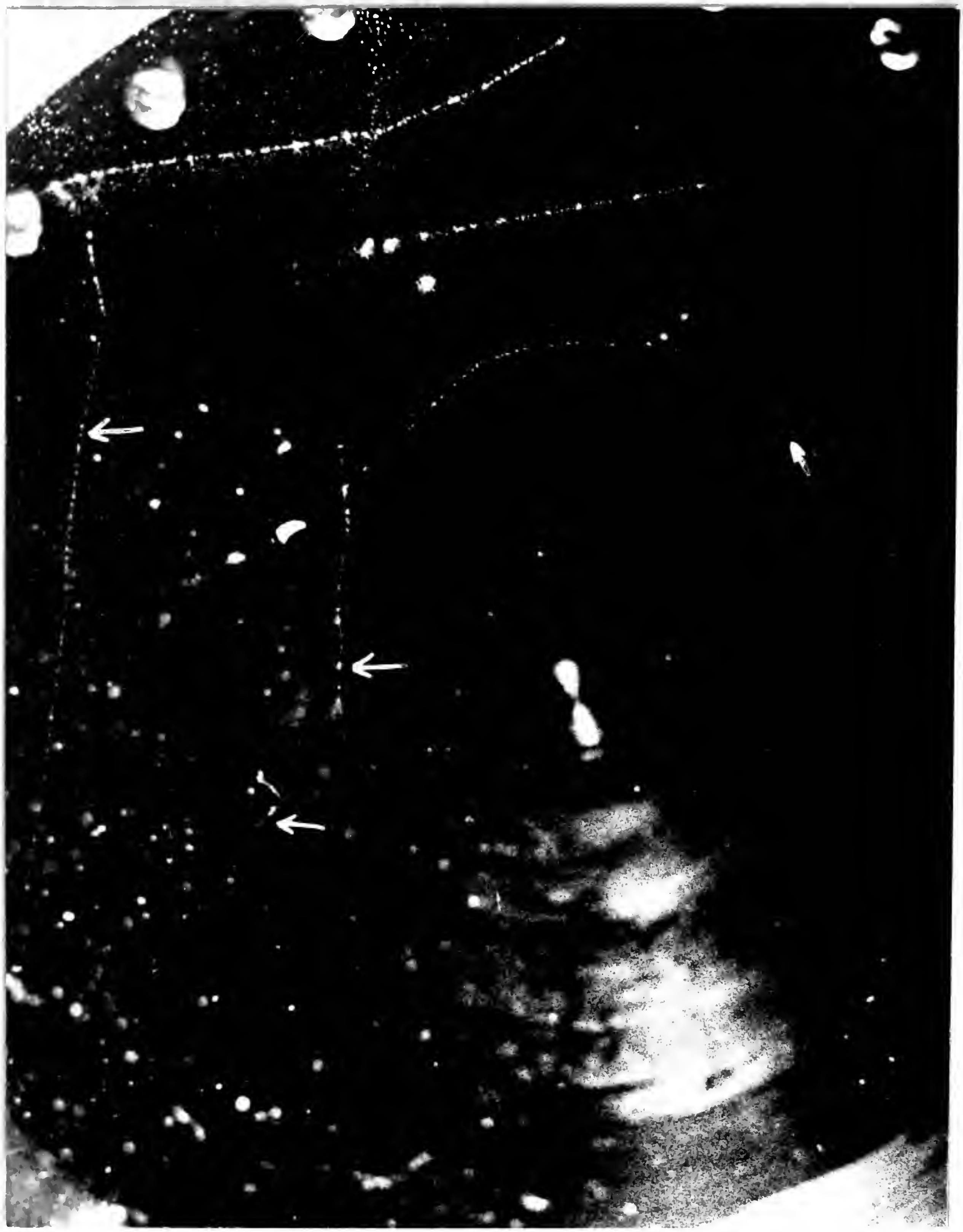


Figure 14
BETA RAYS FROM TL^{204} SOURCE, IN NITROGEN

Figure 15
BETA TRACKS FROM Co^{60}, IN HELIUM

emitted from Pa^{234} (UX_2), the source being under the white strip at the lower right. The maximum energy of these is 2.32 mev; 0.8 mev gamma rays are also given off. The latter may have ejected an electron to cause the nearly-horizontal track at the top. Ionization may be seen to be sparse and dimly illuminated, even though an f/5.6 lens opening was used. The permanent gas was helium, and lighting was with electronic flash.

Figure 14 was also taken at f/5.6 with electronic flash. A Tl^{204} source (0.77 mev. beta, no gamma) was located at the lower left corner and tracks may be seen coming from it. The filling gas was nitrogen, and the beta tracks are seen to be fairly short and continuous. The three prominent tracks at the top (no arrow) are from the random passage of unknown ionizing agents.

The final photograph of this series shows tracks formed by beta particles from Co^{60} (source left of picture). The maximum energy of these is 0.31 mev, though 1.10 and 1.30 mev gamma rays are emitted. The average energy of the betas is 0.099 mev, and about 0.2 mev is required just to pass through the aluminum window. Thus this source, which is three to four times the curie strength of the two above, gives only a few tracks (source at left). The tracks at the bottom typifies the meandering passage of a light particle through matter. This picture was made at f/11 with flash bulb illumination. The filling gas was helium.

6. Electron Collision

The gamma rays produced in a Ra-Be neutron source produced the electron tracks in Figure 16. The source was at the right and was

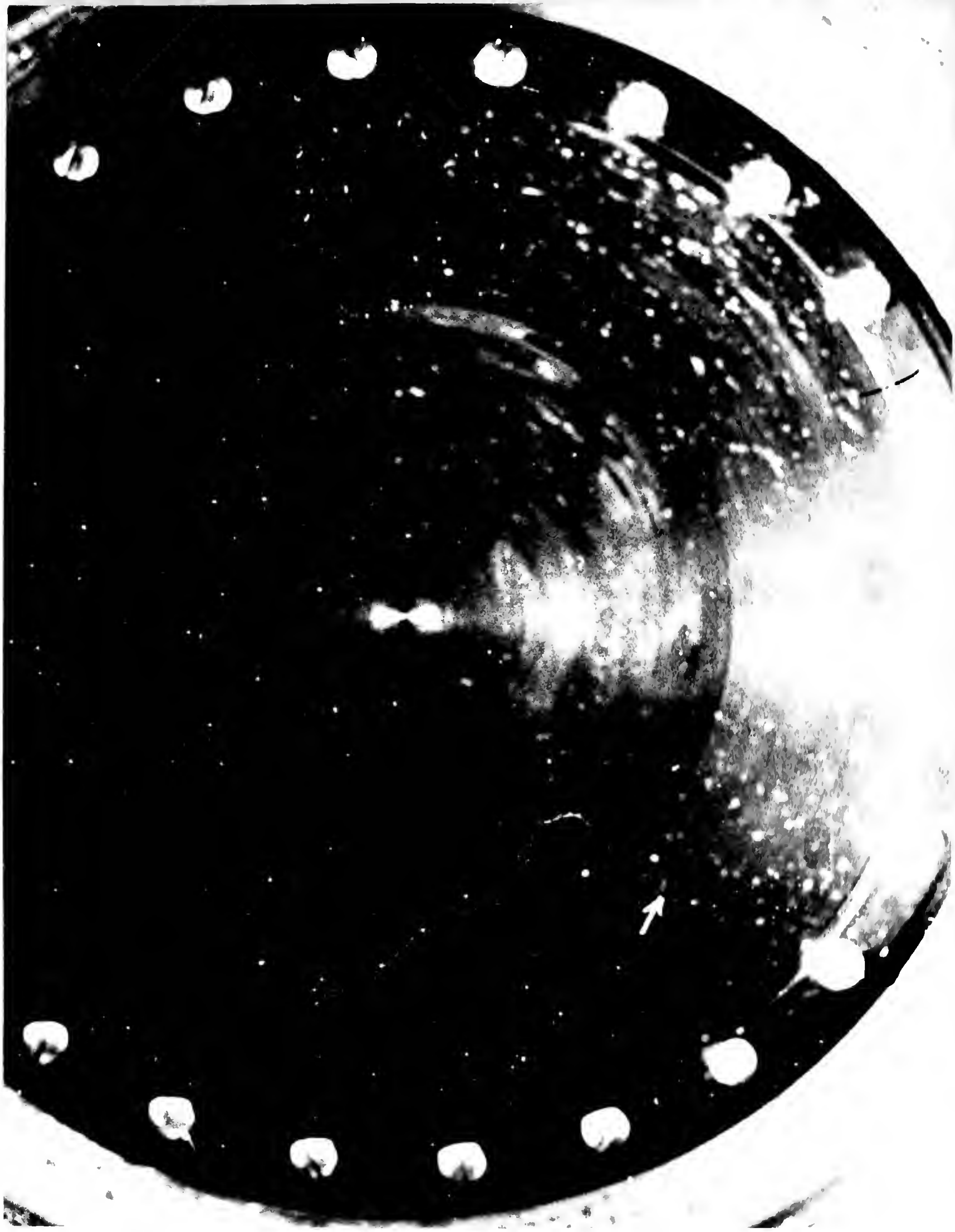


Figure 16
ELECTRON COLLISIONS IN HELIUM FROM RA-BE SOURCE

Figure 17
ALPHA TRACKS IN HELIUM FROM Po^{210} SOURCE

shielded by lead bricks. The tracks show a partition of energy between electrons upon collision with an atom of the gas (at arrow) in which a great deal of kinetic energy is lost by the incident particle. Bragg ionization is also illustrated.

The permanent gas was helium, and flash bulb illumination was used at f/8. As the dispersion indicates, there was a slight delay introduced in the timing.

7. Alpha Tracks

At the lower lefthand corner of Figure 17 is a weak Po^{210} alpha source (5.3 mev alpha, some gamma). Its planchet holder may be seen inside the chamber interrupting the dark line which slants diagonally. Four alpha tracks in helium gas are shown in different stages of dispersion, this being made possible by a delayed flash. The lengths are approximately the same, and the small differences are due either to straggling or to different ejection angles. One of the tracks (see arrow) evidently came from an atom which had become detached and diffused away from the source. The small spot at its origin may be the recoil nucleus or electrons lost by the atom after alpha emission. Illumination was with a flash bulb at f/8.

8. Alpha and Beta Ionization

At the left edge of Figure 18 are located a Po^{210} alpha source and a Bi^{210} beta source, the former inside the chamber. Several beta tracks may be found and compared with the alpha tracks (noted by arrows) as to range, density of ion pairs and linearity. This photograph also illustrates the need for keeping background to a minimum, as many tracks are obscured. Ionization is in nitrogen gas, and the range of alpha particles may be compared with that in helium (Figure 17) in spite of the

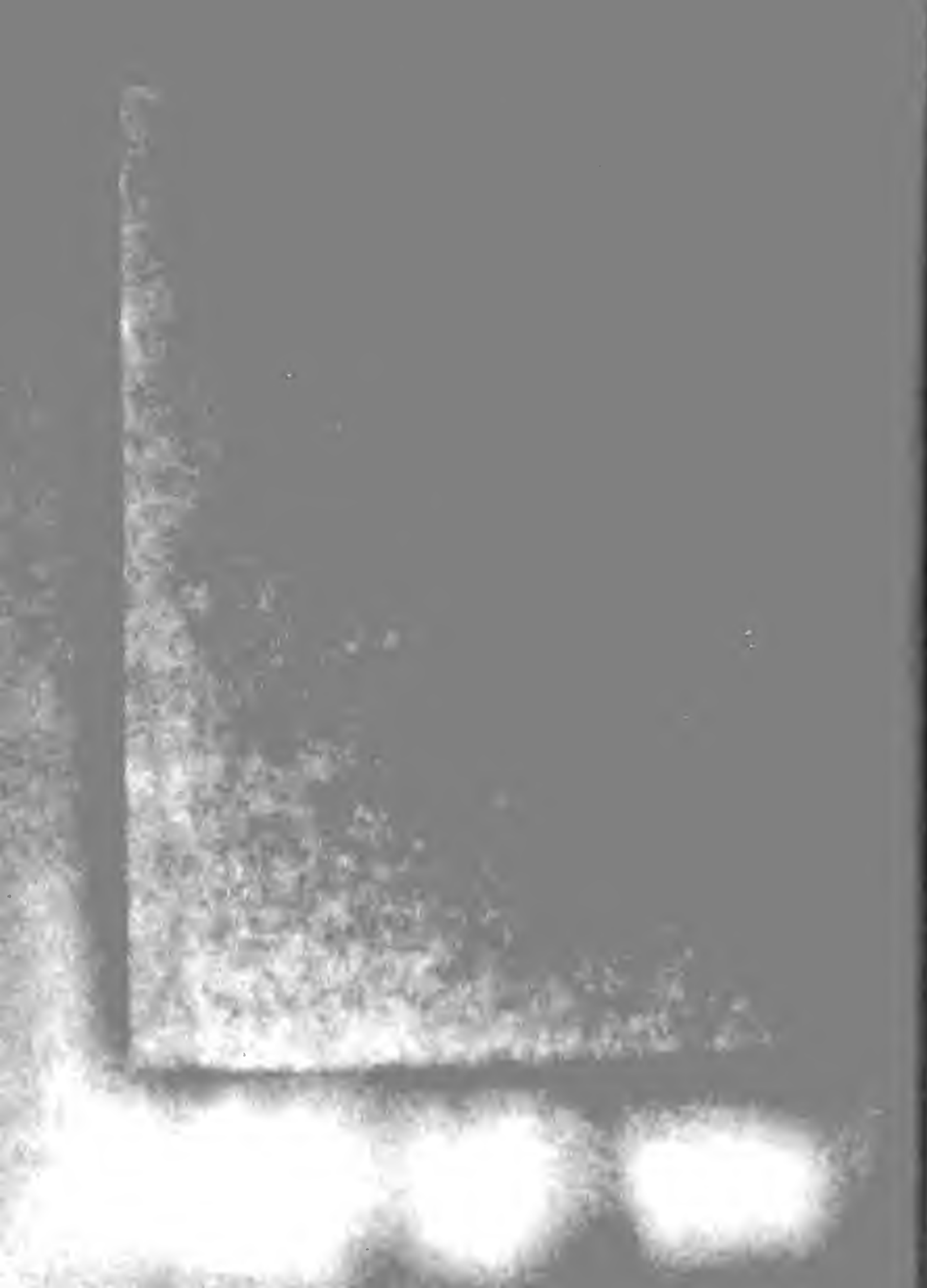


Figure 18
ALPHA (From Po^{210}) AND BETA (From BI^{210}) TRACKS IN NITROGEN

different magnifications by noting the position of the screw heads.

Electronic flash illumination was used at f/8.

9. Alpha Tracks

The effect of stopping down the camera aperture is illustrated in Figures 19 and 20. These were taken of Po^{210} alphas in helium and nitrogen, respectively. In the first case an f/5.6 setting was used, with f/4 in the second. Electronic flash provided illumination in both pictures. The loss in depth of field and definition with the wider opening is apparent after a comparison of the figures.

Straggling effects and the increased range with low atomic number cannot be judged significantly in these photographs due to the variation in angles of the particles.

10. Neutron Irradiation of Chamber

At the bottom in Figure 21 and at the left of Figures 22 and 23 was placed a Ra-Be neutron source, some 12 inches from the chamber. The resulting proton and gamma-produced electron tracks are shown.

In Figure 21 the least amount of lead shielding was provided, resulting in an abundance of electron tracks. Of greater interest are three rather distinct proton tracks in the middle and upper portion (see arrows). As the filling gas was nitrogen and the condensible vapor an alcohol-water mixture, either a N^{14} (n,p) C^{14} reaction or knock-on protons from the vapor produced these particles. The photography was by flash bulb illumination at f/8, and very little delay was allowed.

For Figure 22 more gamma shielding was used and helium gas placed in the chamber. Comparison with Figure 16 indicated that the two tracks at the right are from protons at different levels. The photograph was

taken at f/8 using a flash bulb.

In Figure 23 the same conditions obtained. This photograph shows definite electron trails (at arrows) which may be compared with the proton track. The protons are believed to have been knocked out of water or alcohol molecules in both of the latter two pictures.

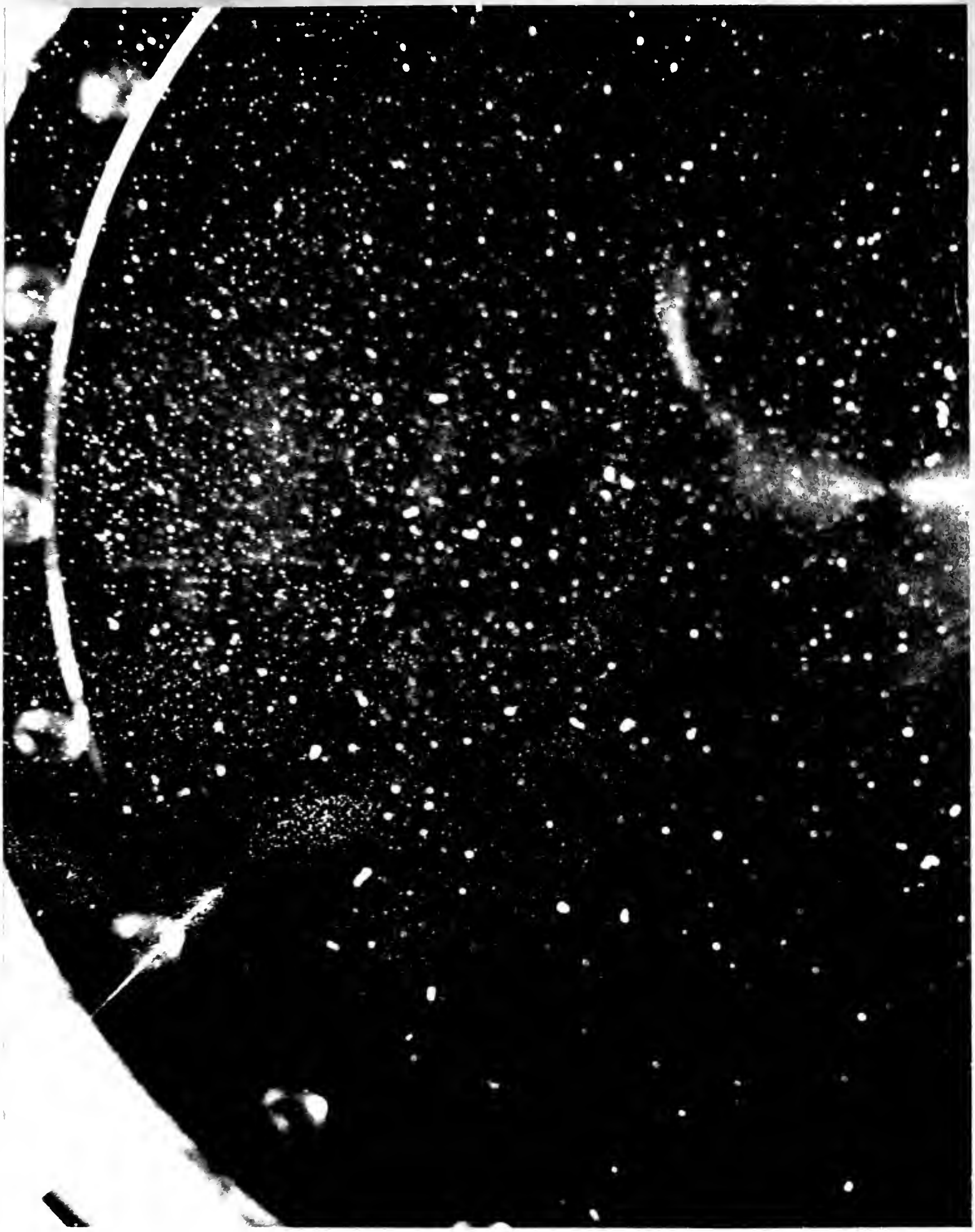


Figure 19
ALPHA TRACK IN HELIUM FROM Po^{210} SOURCE

Figure 20
Po^{210} ALPHAS IN NITROGEN

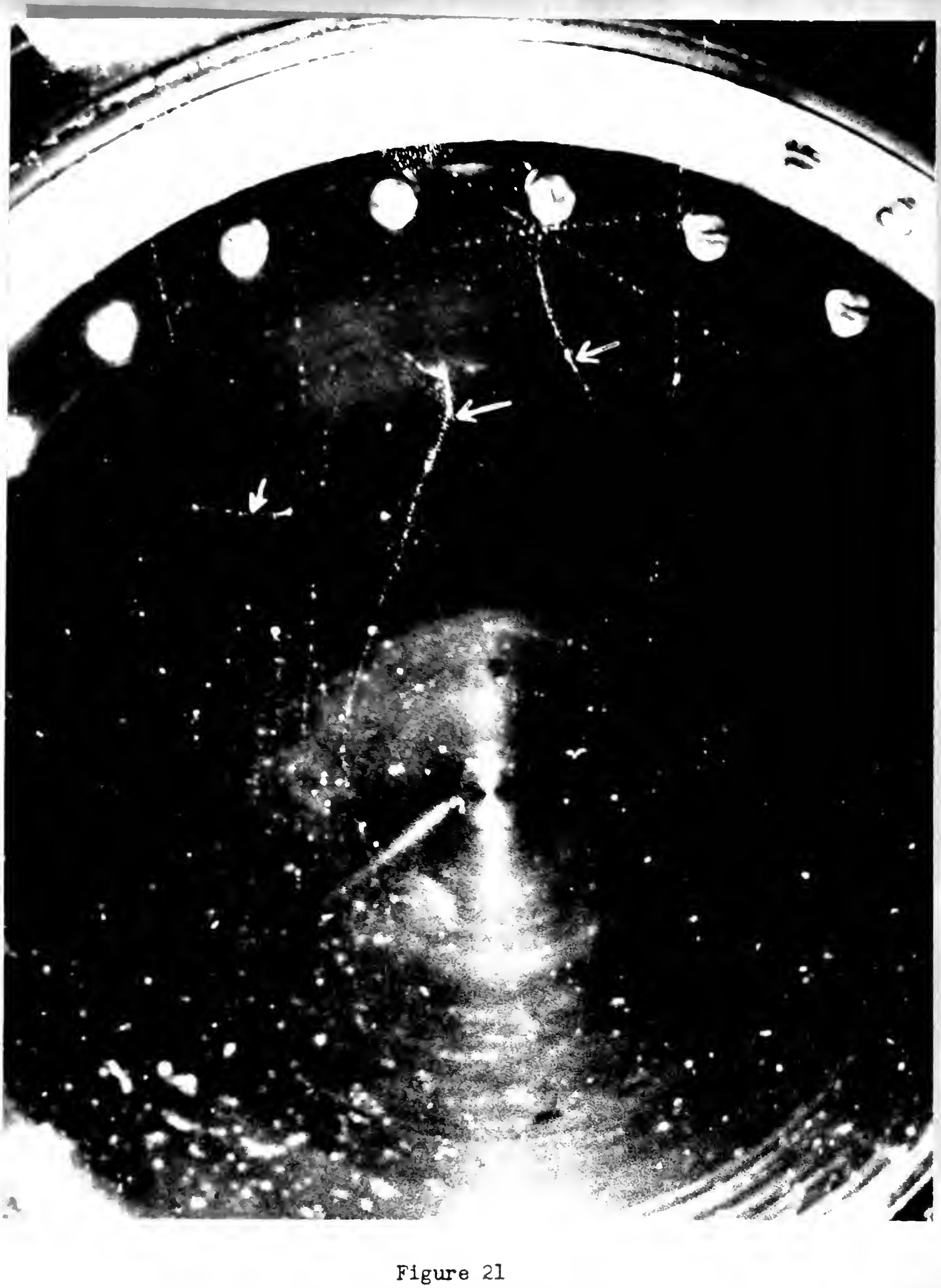


Figure 21
PROTON TRACKS IN NITROGEN

Figure 22
PROTON TRACKS IN HELIUM

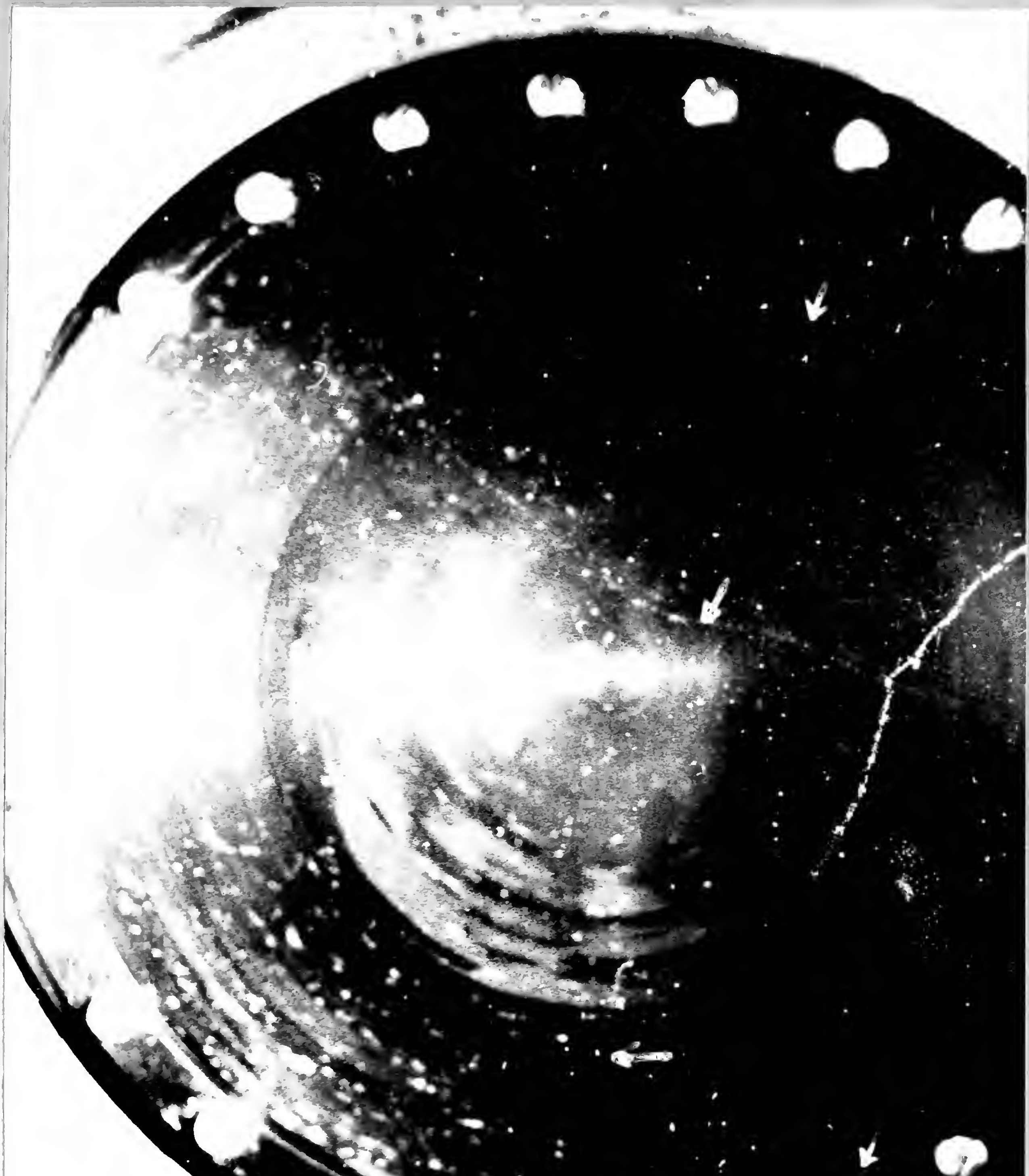


Figure 23
PROTON AND ELECTRON TRACKS IN HELIUM

BIBLIOGRAPHY

1. Bearden, J. A. — Wilson Cloud Chambers With an Increased Time of Sensitivity, Rev.Sci. Instr. 1? 256 (1935)

2. Beck, Clifford — Optimum Liquid Combinations for Cloud Chambers, Rev.Sci. Instr. 12, 602 (1941

3. Crittenden, E. C. — A Study of the Continuous Beta Ray Spect of Several Artificially Radioactive Elements (thesis) Cornell University, 1

4. Das Gupta, N. N. and Ghosh, S. K. — A Report on the Wilson Cloud Chamber and its Applications in Physics, Revs. Mod. 18, 225 (1946)

5. Fretter, W. B. — Introduction to Experimental Physics, New York, Prentice-Hall Inc., 1954

6. Hazen, W. E. — Some Operating Characteristics of the Wilson Cloud Chamber, Rev. Sci. Instr. 13, 247 (1942)

7. Wilson, J. G. — The Principles of Cloud Chamber Technique, London, Cambridge University Press, 1951

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