AN EXPANSION CLOUD CHAMBER FOR DEMONSTRATION

Thesis for the Degree of M. S.

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Winston Harold Heneveld

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This is to certify that the

thesis entitled

"An Expansion Cloud Chamber

for

Demonstration"

presented by

Winston Harold Heneveld

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J C Lee
Major professor

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AN EXPANSION CLOUD CHAMBER FOR DEMONSTRATION

by

Winston Harold Heneveld

A THESIS

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I. Introduction and Historical Review

The Wilson cloud chamber has played an important role in the development of modern physics. It enables one to photograph and study the complicated interactions taking place between individual atoms, nuclei, and charged particles. The operation of the cloud chamber may be stated briefly as follows. A definite volume of vapor-saturated, dust-free gas is adiabatically expanded to produce a super-saturated state. The excess vapor then condenses on ions as nuclei forming a visible trail along the path of the ionizing particle. While Wilson's original design has been modified and developed to suit different investigations, all experimental chambers still operate on this basic principle. The majority of cloud chamber researches has been carried out with the idea of understanding and improving the technique of the Wilson Chamber. The ultimate goal is a chamber which is capable of producing sharp undistorted tracks which can be easily photographed. Some of the more prominent adaptations of Wilson's original design are described below.

Wilson[1] originally utilized a piston as a movable chamber floor to produce a sudden volume expansion. The rapid motion of the piston was accomplished by connecting the rear of the chamber to a highly evacuated vessel. (Fig. 1) Although this gave excellent tracks the procedure was much too slow to be used in investigating nuclear phenomena. Therefore, the first step was to develop an automatic chamber which would be capable of producing repeated expansions.

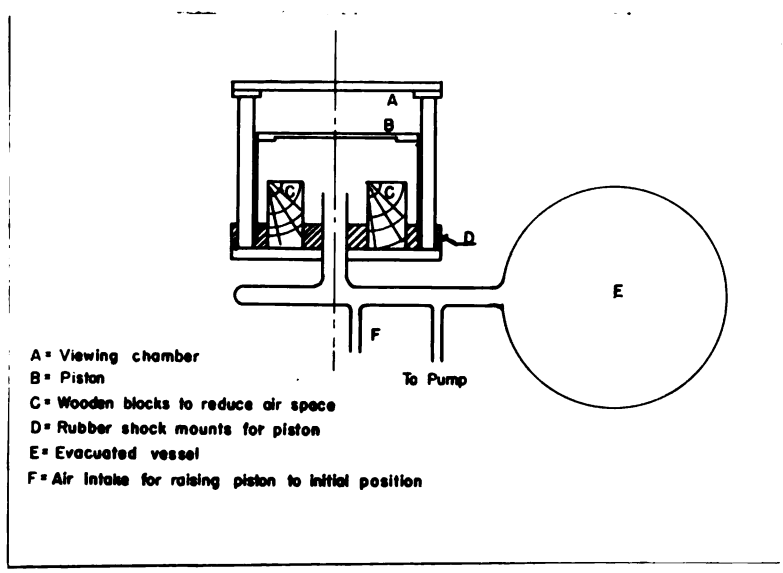

Fig. 1. Wilson's original cloud chamber.

Shimizu[2] designed a reciprocating piston chamber which operated in continuous cycles. However, the relatively slow expansions resulted in indistinct tracks. There were many modifications of this type of chamber. The most important was Blackett's model in 1927[3]. By replacing the reciprocating piston with a more rapid spring action, he succeeded in obtaining sharp tracks with a repeating mechanism. All the cloud chambers used before 1933 were of the type in which a definite volume change was produced by the motion of a piston or plunger forming the floor of the chamber.

An important change in the method of producing expansion was made by Wilson[4] when he replaced the rigid piston with an elastic diaphragm. Compressed air admitted to the back of the chamber forces the diaphragm inward and raises the pressure in the working chamber. Expansion is effected when this air is released to the atmosphere and the elastic diaphragm returns to its original position. There are several advantages to this type of chamber. It is simple to construct; it can be operated in any position; and it is easily modified for the inclusion of various automatic features. Since the diaphragm is elastic a rise in temperature in one part of the cloud chamber, due to heat conduction from the walls or condensation to form tracks, does not cause simultaneous compression and consequent rise of temperature in the rest of the chamber. Thus a longer sensitive time exists in which supersaturation and condensation can take place.

To solve the problem of small leaks Dahl, Halstead, and Tuve[5] added sylphon bellows to produce a permanently sealed chamber. The bellows can be expanded or contracted mechanically to adjust for changes in the expansion ratio. This type of chamber had less turbulence than any of the earlier types.

C. T. R. Wilson and J. G. Wilson[6] developed the radially expanding chamber. Expansion is produced by a sudden reduction of pressure in the annular space by means of a valve which opens to the atmosphere. Then with the chamber inserted between the poles of the magnet the tracks may be illuminated from the rear. This simplifies the problem of photography.

One of the chief factors in track distortion is the effect of gravity on the drops. This is particularly noticeable in the case of the thin, beaded tracks of electrons which disintegrate almost immediately after they are formed. Wilson and Wilson[6] have also tried to develop a falling chamber in which both the chamber and the camera fall freely under gravity. Since distortion due to the effect of gravity on the drops relative to the gas in the chamber is eliminated the time of photographic exposure and the interval between expansion and photographing can be greatly increased. The falling chamber was never used extensively because of the mechanical difficulties involved.

There have been several attempts to construct a continuously sensitive cloud chamber. Vollrath[7] produced continuous supersaturation by allowing HCl and H_2O vapors to diffuse. Brinkman[8] constructed a continuously running chamber which makes several expansions per second. The most successful solution to the problem was one due to Langsdorf[9]. He allowed a warm, saturated vapor to diffuse downwards through a non-condensible gas into a refrigerated space. When the vapor has cooled sufficiently, supersaturation and condensation on ions takes place. The depth of the sensitive layer depends on the height of the chamber. Best tracks are obtained when the temperature gradient between the roof and the floor is from 3^o to 7^oC per centimeter. This is usually done by placing warm water at the top and dry ice at the bottom as shown in Fig. 2.

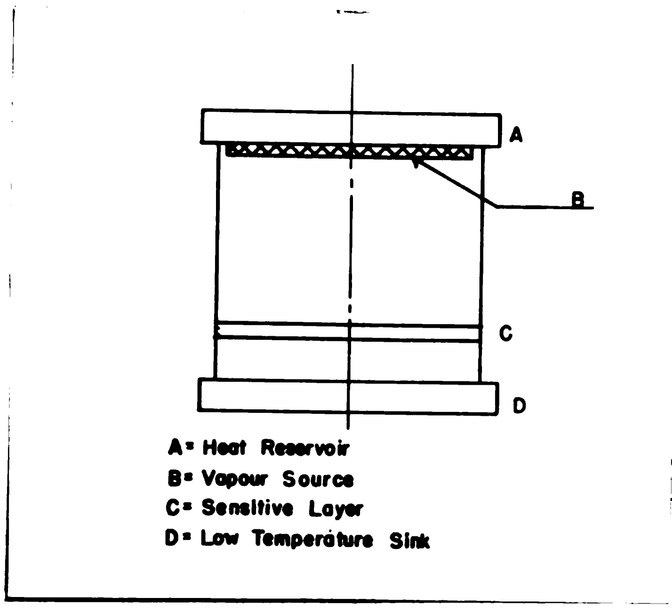

Fig. 2. A typical continuous diffusion cloud chamber.

A highly significant step in the development of the cloud chamber has been the introduction of the counter-controlled chamber by Blackett and Occhialini[10]. The chamber is normally under compression until a cosmic ray or ionizing particle passes through a series of counters placed above and below the chamber. The resulting coincident discharge of the counters excites the grid of a thyratron which short circuits and trips the expansion and light circuits. The chamber is recompressed and camera reset by means of cams so that the entire operation is completely automatic. More than 80 percent of the photographs taken with counter control contain tracks.

Randomly operated slow chambers are still used occasionally to obtain statistical evidence regarding cosmic ray activity. A chamber is made slow, that is, having a large sensitive time, by increasing the depth. Chambers 30 to 60 centimeters deep have been constructed having sensitive times ranging from one-half second to over one second. With a slow chamber it is possible to use a longer exposure time with less light and to photograph more tracks per expansion[11].

Two other modifications are the high and low pressure chambers. Low pressure chambers are particularly useful in recording emissions such as fission fragments whose normal range is only a few millimeters at atmospheric pressure[8].

High pressure chambers are used when a long equivalent path length or high absorption is desired. Thus it is possible to have an equivalent path length of 200 feet of atmospheric argon in a chamber only thirty centimeters in diameter. This is important in observing such phenomena as the disintegration of the meson at the end of its range, the Heisenberg explosion type of shower formation, or neutron energies. High pressure chambers have become increasingly important in observing nuclear effects excited by artificial radiations from cyclotrons and betatrons. The first high pressure chamber, designed to measure neutron energies, was operated at pressures up to 50 atmospheres[12]. One of the later additions has been that of Johnson, Benedetti, and Schutt[13] who designed a hydrostatically supported chamber 30 centimeters in diameter and 9 centimeters deep, that was capable of operating at pressures up to 300 atmospheres.

Further refinements of cloud chambers in recent years have been largely confined to the development of portable models for use in cosmic ray research in the upper atmosphere. However, the most recent innovation (1951) has been the integration of an ionization chamber and a cloud chamber for selective studies of the cosmic-ray nuclear interactions in which heavy ionizing particles are produced. An ionization chamber placed within the cloud chamber and utilizing a common gas is used to trigger the expansion of the cloud chamber (Fig. 3). Then by removing the high potential after the electrons have been collected and before the positive ions have moved appreciably, it is possible to observe the path of the pulse-generating particle within the collector. Geiger counters and proportional counters have also been used successfully in a similar manner[14].

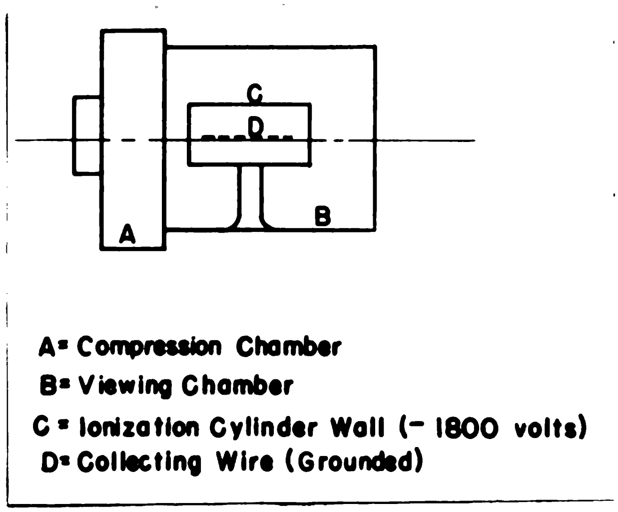

Fig. 3. The cloud - ion chamber.

II. Demonstration Cloud Chambers

To function successfully as a demonstration device a cloud chamber should be relatively simple to construct and operate and should be portable and self-contained as much as possible. In addition, it should provide the observer with an idea as to the principles of cloud chamber operation and be representative of the chambers currently in experimental use.

An expansion type chamber meets the above requirements. Its one disadvantage, the rather limited viewing angle, can be eliminated by a projection system if large groups are to be encountered. Once this type of chamber is set up it will continue to function without adjustments for long periods of time. Another advantage is the elimination of cumbersome heating and cooling agents. The effect of various factors on the degree of supersaturation can also be clearly demonstrated. The expansion chamber to be described later has worked quite successfully as a demonstration device at the University of Minnesota[15].

The continuous diffusion cloud chamber has recently become quite popular as a demonstration device because of its simplicity and low cost of construction. No timing problems are involved and the viewing angle is much larger than that of the expansion chamber without the need for a projection system. Cosmic rays can also be observed without using any of the complicated counting arrangements. However, clearing with electric fields and insertion of metal plates do disrupt the operation somewhat. One other disadvantage is the limited depth of the sensitive layer. The continuous diffusion chamber is primarily a demonstration device and has not been used as yet in any serious experimental work.

III. Design of the Apparatus.

Designed for use in lecture demonstrations, this equipment is portable and self-contained except for the power and air supply. Since all operations are automatic, the unit will function without supervision once the initial adjustments are completed. With its twelve inch diameter the chamber has an ample viewing angle for small classroom groups without exceeding the space requirements for a compact unit. An exploded view and a scale drawing appear in Figures 4 and 5, respectively.

Fig. 4. Exploded view of the cloud chamber.

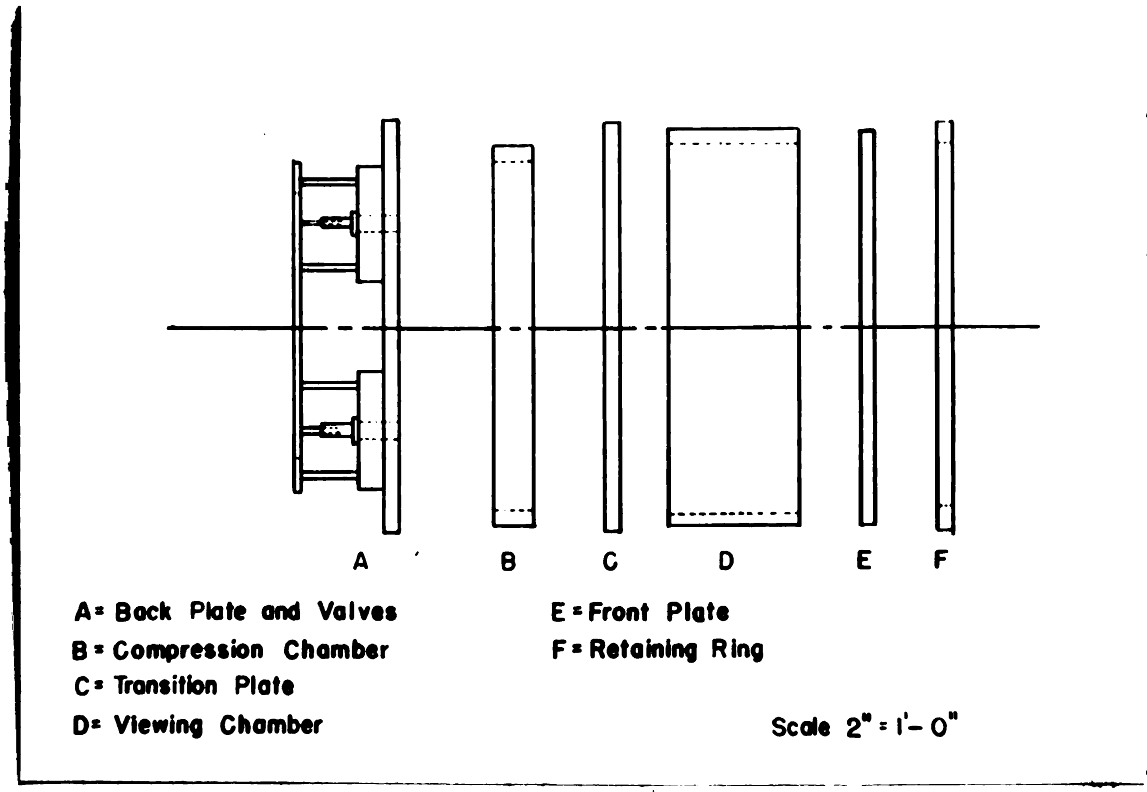

Fig. 5. A side view scale drawing of the chamber components

Compression Chamber.

A 12 x 1¼ inch brass ring and a diaphragm of two pieces of 1/64 inch gum rubber dam comprise the compression chamber which is capable of producing a maximum expansion ratio of 1.31. It was also necessary to place a piece of number 18 mesh screen on both sides of the compression chamber to prevent the diaphragm from being forced into the holes and valves during the compression and equilibrium periods.

All gaskets throughout the chamber are of one-quarter inch pure gum arabic rubber.

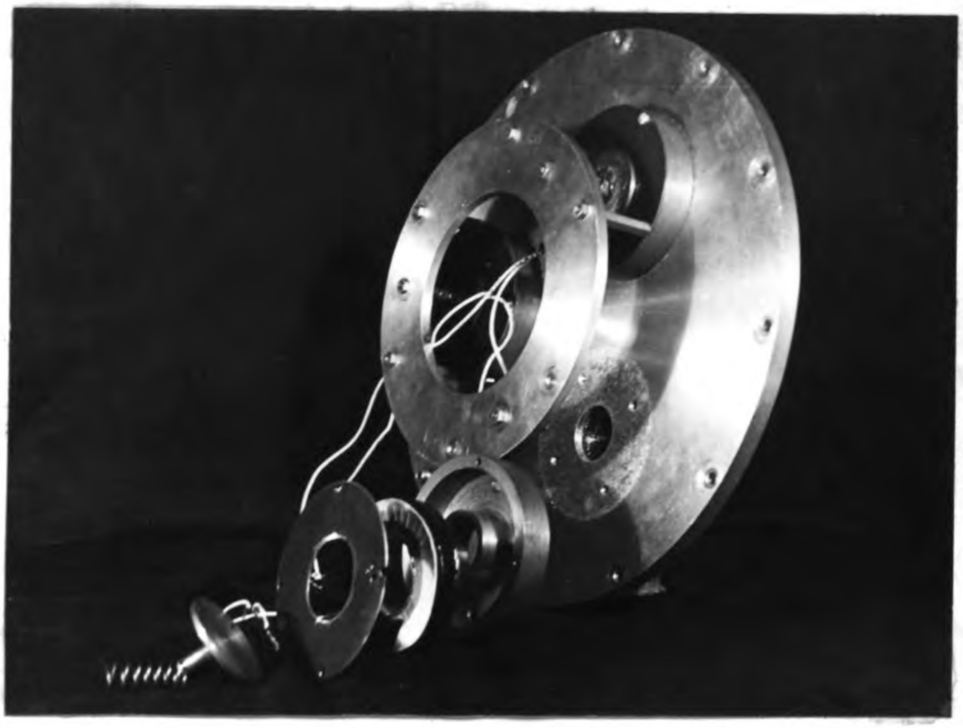

Fig. 6. Escape valves and back plate

The three electromagnetic escape valves (Fig. 6) each have a winding of 2,000 turns of #30 copper wire and require 12 to 16 volts d.c. for successful operation. Although the valve is returned immediately after expansion to its normally closed position by a concentric spring, the compressed air continues to escape until the valve current is applied.

Viewing Chamber.

The aluminum transition plate at the back of the viewing chamber is covered with black velvet to reduce turbulence and to provide a suitable photographic background. Approximately 200 half-inch holes were drilled in this plate leaving a three-quarter inch strip around the edge intact. A hole is also drilled through the edge and a nozzle added to accomodate a manometer tube. Then, with a sponge fixed on the glass cylinder directly in front of this hole, the solution can be added without opening the chamber.

Clearing the chamber of ions is accomplished by means of 300 volts d. c. applied to an aluminum foil ring and a #36 tungsten wire cemented to the front glass plate. The wire and a tab of foil project outside the chamber to serve as the positive connection while the aluminum plate and chamber chassis serve as ground. The voltage doubling circuit shown in Fig. 7 is connected directly to the 110 volt main switch to provide a convenient voltage source.

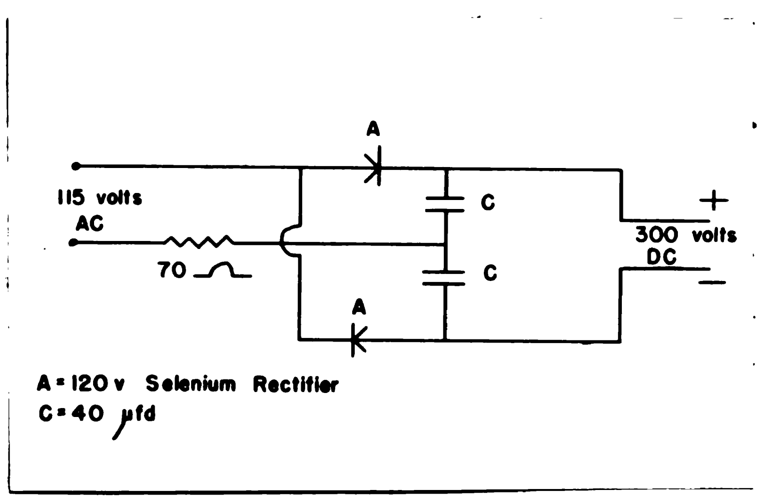

Fig. 7. Voltage doubling circuit used to obtain the clearing field voltage.

Mounting Arrangement.

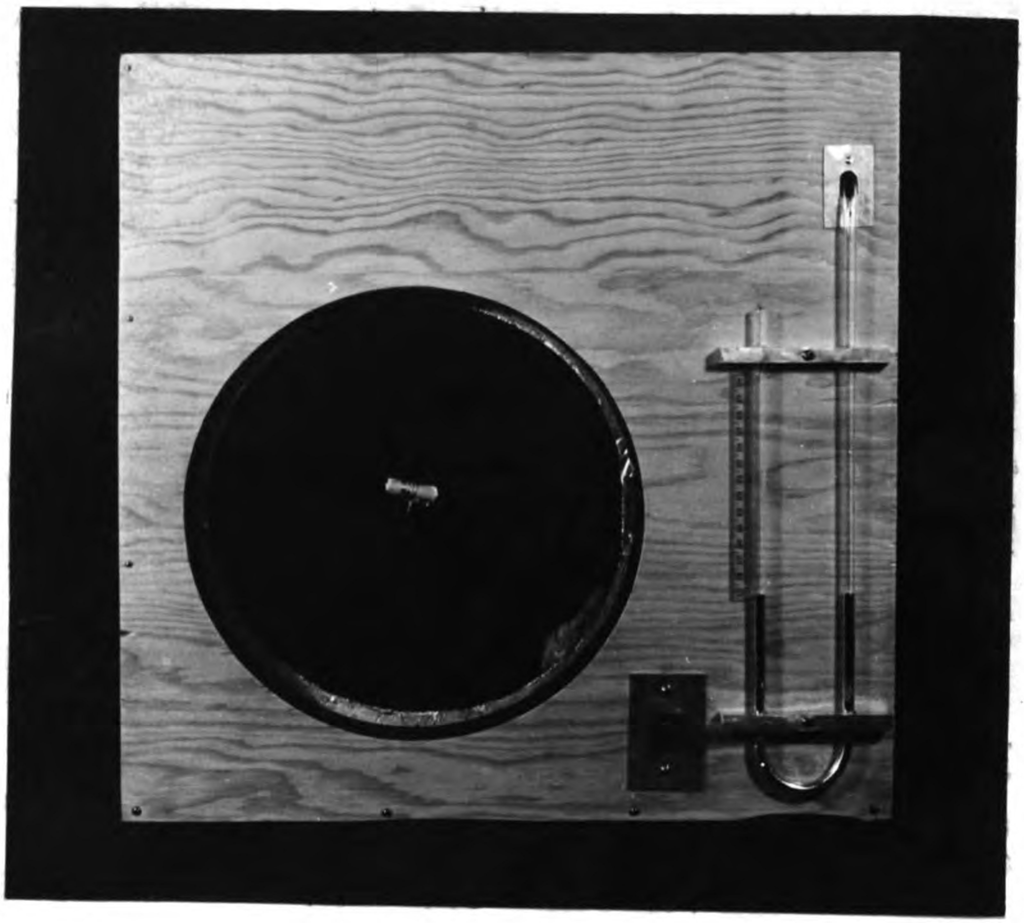

Fig. 8. Front view of the completed unit

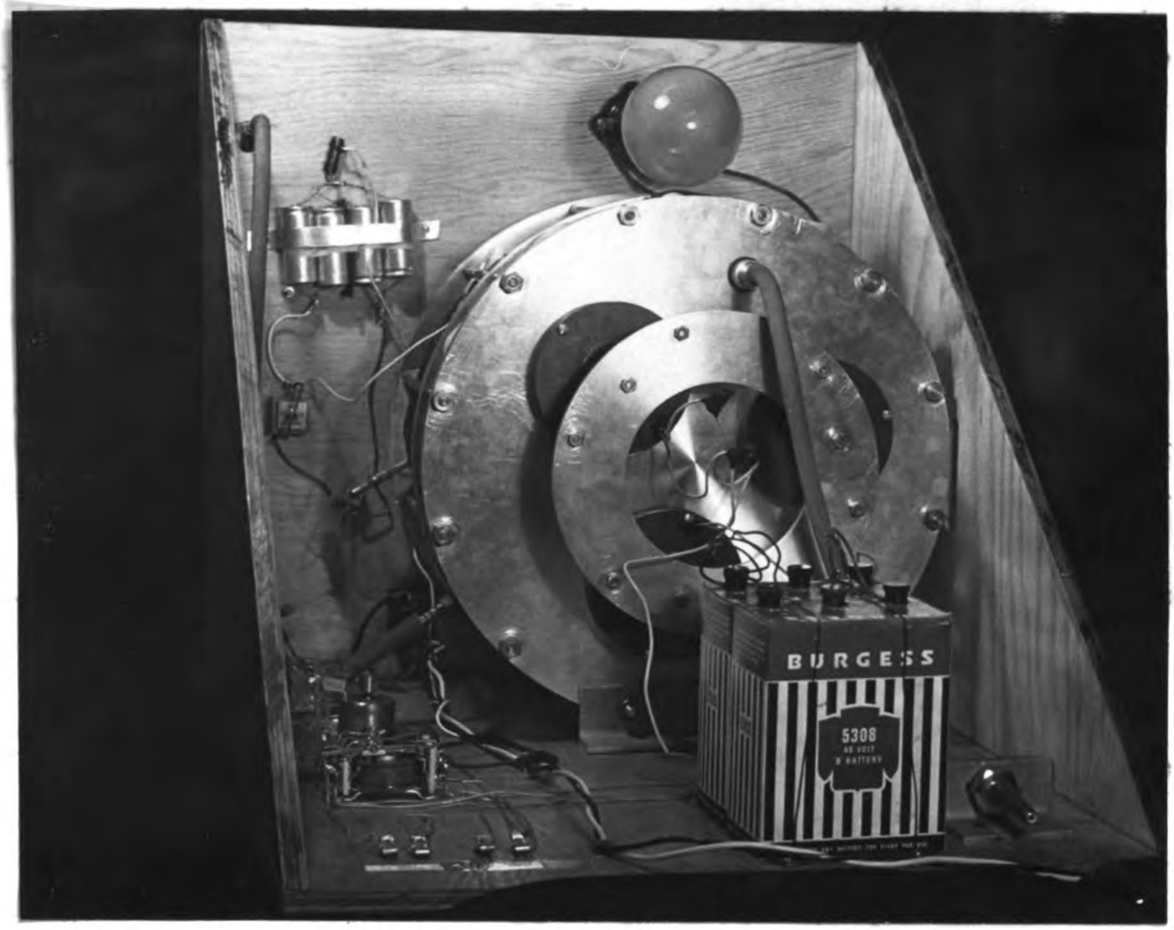

Fig. 9. Mounting of the chamber with accessories

Figures 8 and 9 show the mounting of the complete unit.

Fig. 10. Rotary timing switch.

The timing control for operation of the light and valve relays utilizes a one r.p.m. synchronous motor as a rotary switch. The upper bronze strip, mounted on the plexiglass base as shown in Fig. 10, serves as a contact in the illuminating relay circuit and is adjusted to close the circuit two seconds before expansion and to open the circuit five seconds after expansion. The lower strip is a contact in the valve relay circuit and provides for a 21 second compression time and a 39 second recovery period to allow the chamber to attain temperature equilibrium before the next expansion.

IV. Operation of the Chamber.

Procedure.

The following procedure should be followed if the chamber has been opened. First the glass surfaces are washed thoroughly with ethyl alcohol to remove any grease and other impurities that may be present. The chamber is then assembled and evacuated. Helium is added to a pressure of one atmosphere. After adding about ten cubic centimeters of solution and allowing a few minutes to elapse for the helium to become vapor saturated the chamber will be ready for operation. A few preliminary expansions are usually sufficient to wash down any suspended dust particles in the chamber. Compressed air is now admitted to the rear of the chamber to provide a pressure of 9 cm Hg upon ~~expansion~~ compression and before expansion. Then for each succeeding expansion the pressure is increased until best tracks are obtained. With a solution of 65 percent ethyl alcohol and 35 percent water in helium at 22°C this should occur at about 10 ($\pm \frac{1}{4}$) cm Hg. The critical pressure will then remain at this point until the operating temperature of the chamber changes.

Parameters of Operation.

Since the principle of the cloud chamber is based upon a condition of supersaturation and condensation of vapor on ions, it is important to recognize the factors involved in producing this condition and their effect on the overall efficiency of the chamber in producing sharp tracks with a minimum background. The brief development below will serve as the basis for a discussion on the variation of supersaturation with temperature, expansion ratio, vapor, and pressure.

It is assumed that just prior to expansion there exists a non-condensible gas at a pressure, P_g, and a vapor at a pressure P_1, contained in a volume, V_1, at a temperature, θ_1. Then

$$(1)\quad P_1 V_1 = (M_1/M) R\theta_1$$

where M_1 = total mass of vapor present in V_1 and M = the gram molecular weight of the vapor.

The gas undergoes a rapid expansion to a new volume V_2 with a resultant drop in temperature from θ_1 to θ_2' which can be expressed in the adiabatic relation

$$(2)\quad \theta_1/\theta_2' = (V_2/V_1)^{\gamma-1}$$

where γ is the ratio of the specific heats of the gaseous mixture in the chamber. Before condensation takes place, the original mass of vapor, M, is distributed over the new volume V_2. Therefore, the pressure P_2' is given by

$$(3)\quad P_2' V_2 = (M_1/M) R\theta_2'$$

At this lower temperature, θ_2', less vapor can be held in suspension so condensation takes place reducing the mass to M_2. When equilibrium is again attained, the vapor pressure falls to P_2, the saturation pressure at temperature θ_2. The slight difference between the temperature immediately after expansion, θ_2', and the equilibrium temperature, θ_2, can be neglected so

$$(4) \quad P_2 V_2 = (M_2/M) R \theta_2$$

after condensation. The vapor density, ρ_2', after expansion and before condensation when M_1 is contained in V_2 is

$$(5) \quad \rho_2' = M_1/V_2$$

but after condensation the vapor density is

$$(6) \quad \rho_2 = M_2/V_2$$

By definition supersaturation, S, is the ratio of the density of the vapor to the saturation density at the same temperature. Then

$$(7) \quad S \equiv \rho_2'/\rho_2 = M_1/M_2 = P_1 V_1 \theta_2 / P_2 V_2 \theta_1$$

and from (3) and (4)

$$(8) \quad S = (P_2'/\theta_2') / (P_2/\theta_2)$$

However, $\theta_2 \cong \theta_2'$ and from (2) $\theta_1/\theta_2' = (V_2/V_1)^{\gamma-1}$

so

$$(9)\quad S = P_1/P_2\,(V_1/V_2)^{\gamma} = P_1/P_2\,(1/E)^{\gamma}$$

where E $\equiv$ expansion ratio = the ratio of the volume after expansion to the volume before expansion. The γ for a composite mixture has been given by a formula due to Richarz as

$$(10)\quad 1/\gamma-1 = 1/\gamma_g-1 \cdot P_g/\pi + 1/\gamma_v-1 \cdot P_v/\pi$$

where π = the total pressure = $P_g + P_v$; the subscripts g and v refer to gas and vapor. Now if the expansion ratio is fixed then the variation of γ becomes important in determining the value of supersaturation and it is, therefore, necessary to examine those factors which will influence the of the mixture present in the chamber.

Reference to Table I shows the variation of S with the non-condensible gas and vapor. The following conditions apply for each case: E = 1.25, T_1 = 20°C, P_1 = 1.75 cm Hg, = 1.30, and the total initial pressure = 1.5 atmospheres. Table I clearly shows the advantage of using a monatomic gas as the supersaturation produced means lower expansion ratios are necessary to produce condensation on ions. The advantage of an air-water mixture over air-alcohol mixture is also shown.

TABLE I

NATURE OF GAS AND SUPERSATURATION PRODUCED

Gas	Vapor	γ	θ_2	P_2 in mm Hg	S
A	H_2O	1.66	252.8	0.77	15.6
Air	H_2O	1.40	267.2	2.97	4.2
CO_2	H_2O	1.31	273.4	4.68	2.8
Air	C_2H_5 OH	1.37	269.8	9.45	3.41

It has been found experimentally by Beck[16] that the best solution to use if air is the non-condensing gas is 65 percent ethyl alcohol and 35 percent water by volume. Several other investigators have obtained good results with solutions ranging from 60 percent alcohol - 40 percent water to 70 percent alcohol - 30 percent water. It is generally agreed that the best solution is an alcohol-water solution lying in that range rather than solutions of pure alcohols or other organic liquids.

Equation (1) also indicates the variation of supersaturation with gas pressure. If the total pressure π is increased by raising P_g then P_v/π decreases while P_g/π remains practically the same for $P_g >> P_v$. This increases γ and, from (2), the drop in temperature is greater and the resulting value of supersaturation is increased. The increased pressure also means an increased number of ions will be formed per centimenter of track length which in turn means heavier tracks. Less illumination is then required for successful photography. This advantage is somewhat offset, however, by the problems of leakage and construction that accompany high pressure work.

An increase of initial temperature will result in a decreased temperature drop and lower supersaturation for a given expansion ratio since the increase in P_v/π will be more than P_g/π, if V_1 and π are kept constant, resulting in a lower value for γ. There are other advantages in operating the chamber at lower temperatures which will be discussed later in connection with turbulence.

The most important single factor in the production of a supersaturated state is the expansion ratio. An increase in expansion ratio will raise the value of supersaturation for all liquids, mixtures, and gases. Therefore, regardless of the initial temperature, pressure, solution, supersaturation can still be attained by going to larger values of expansion ratio. Wilson found that an expansion ratio of 1.25 ($S = 4$) with an air - water vapor mixture condensation takes place on ions as centers (ion limit) while at $E = 1.37$ ($S = 8$) a cloud-like condensation fills the chamber (cloud limit) using vapor molecules as centers. To produce a value of $S = 4$ using an air-alcohol mixture an expansion ratio of 1.29 is required. Beck found best tracks with a minimum expansion ratio of 1.125 for 65 percent ethyl - 35 percent water. Later, using a 50 percent ethyl alcohol - 25 percent acetone - 25 percent water solution a minimum expansion ratio of 1.112 was found to produce even better results. The majority of cloud chambers operate at expansion ratios of less than 1.15.

The problem of compression time must be considered in any discussion of cloud chamber operation. It has been found experimentally that for the chamber under consideration a minimum compression time of 18 seconds is necessary in order to reach temperature equilibrium before expansion. If expansion takes place before 18 seconds the resulting value of supersaturation is not sufficient to produce tracks. It has also been found advisable to use a pressure regulator valve in the compressed air line. The pressure in the chamber will then build up quickly to the critical point and be held there until expansion. Maintaining the original volume, V_1, for about 18 seconds reduces the background fog and yields sharper, more well defined tracks. The use of a regulator valve also eliminates the problem of small fluctuations in the compressed air line pressure. Each expansion will then take place at exactly the same pressure each time. Since the valve can be set quite accurately, the problem of locating the critical pressure is simplified.

The problem of turbulence and track distortion is very important in counter-controlled and "slow" chambers and, to a limited extent, in demonstration chambers. For best viewing the tracks should be relatively undistorted for approximately one-half second. The introduction of the copper screen, perforated plate, and velvet backing to reduce turbulence has been mentioned earlier. One should employ a source holder which presents a minimum amount of surface area in the direction of expansion and place the exhaust valves symmetrically with respect to the central axis of the chamber. It is also advisable that the initial conditions (solution, non-condensible gas, temperature, pressure) be such as to require the lowest possible expansion ratio necessary to produce good tracks.

Convection currents are a sizeable factor in track distortion. Immediately after each expansion the gas near the walls warms up first so that a convection current develops causing a rapid fall of the central mass of colder gas. The forces to which this motion is due increase with the third power of the time, thereby introducing appreciable distortion within one-quarter of a second after expansion. Water cooling, insulating, and limiting the operation time of heat producing devices have proved to be quite effective in reducing chamber distortion due to this thermal motion.

Since heavy, well defined tracks are desired in a demonstration chamber is is important that a consideration be given to the emitting nature of the source. The ions formed by an emitted particle begin to diffuse out immediately after emission. If expansion takes place within one second after emission the resulting tracks are fuzzy and indistinct. If the rate of emission is too high the clearing field is unable to clear the chamber of previous ions and the background fog obscures any tracks that are formed. A chamber 30 centimeters by 10 centimeters has a sensitive time of approximately one-tenth of a second. Therefore, if an average of five good tracks per expansion are desired the source should have an average rate of about 50 disintegrations per second. Also, for the sole purpose of showing tracks an α emitter should be used.

Since the margin between the condensation on ions and condensation on other particles is apt to be very small, the effect of contamination on background fog must be considered. There are several factors in cloud chamber practice which reduce the cloud limit to the extent that it may actually be lower than the ion limit or, as in most cases, that it may be lowered enough to produce an objectionable background fog at the ion limit. A survey of these factors is entirely empirical in nature but the results are worth noting as they apply to the majority of cloud chambers[17].

C. T. R. Wilson concluded from a study on the effect of metal surfaces that nuclei in the form of droplets containing hydrogen peroxide acted as centers for condensation of a general background fog. These nuclei were effective in the range of expansion ratios from 1.252 to 1.38 which is the ion limit range for air-water mixtures. The effect of these nuclei in expansion ratios less than 1.25 is negligible. Amalgamated zinc is the largest producer of condensation nuclei followed by polished zinc and lead. It has been found that the base metals are a definite source of contamination unless thoroughly oxidized. The contaminating effect of aluminum is as yet debatable. Rubber and neoprene are clean materials when at rest or moving in constant tension but contribute heavily to background fog if rapid changes in tension occur, e.g., in receiving the shock of the piston. All volatile materials such as sealing materials and adhesives should be thoroughly dried before the chamber is put into operation. Grease and oils must be carefully removed from the glass surfaces as they will obstruct the view after a short period of operation.

Some chemical action may produce contamination after the chamber has been closed but this is easily removed by sweeping the chamber with dry gas. The principal objective of the contamination study has been to prevent the introduction of large molecules or molecular aggregates into the gaseous mixture in the chamber. The ultimate goal is to use the largest available degree of supersaturation in the ion limit range with a minimum amount of background fog.

The usual precautions in mounting a radioactive source must be followed to prevent the spread of radioactivity to other parts of the chamber. Contamination of this type may be extremely difficult to remove.

After each expansion and condensation it is found that there exists some condensation nuclei on which further condensation can take place at very small values of supersaturation. These nuclei are produced by the evaporation of large droplets and, if present in quantity, can be removed by a series of two or three slow expansions. The production of these re-evaporation nuclei increases rapidly as the critical expansion ratio is exceeded and a dense cloud is formed. In general, dust particles and re-evaporation nuclei can be effectively removed by slow expansions and longer recovery periods.

V. Data

Photographs were taken using an Exacta V, 35 mm. camera with special lens adapter tube for close up work. All track photographs were taken at f:4, .02 second, using Kodak Super XX film. It was found that at longer exposures considerable track distortion and blurring occurred, particularly in the case of electron tracks of low density. Illumination was provided by two photoflood lamps placed at an angle of approximately 60° to the central axis of the chamber. Since the lights were operated manually it was necessary to determine the exposure times by the camera shutter. This was accomplished by means of a solenoid attached to the shutter cable release and activated by the time delay circuit shown in Fig. 11. There was a delay of .05 seconds after the valve relay opened and expansion had started before the shutter was opened.

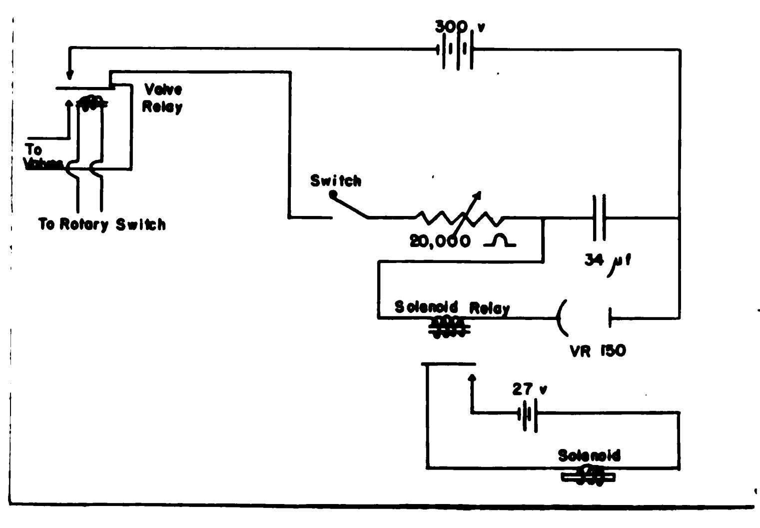

Fig. 11. Time delay circuit used in operating the camera.

Results.

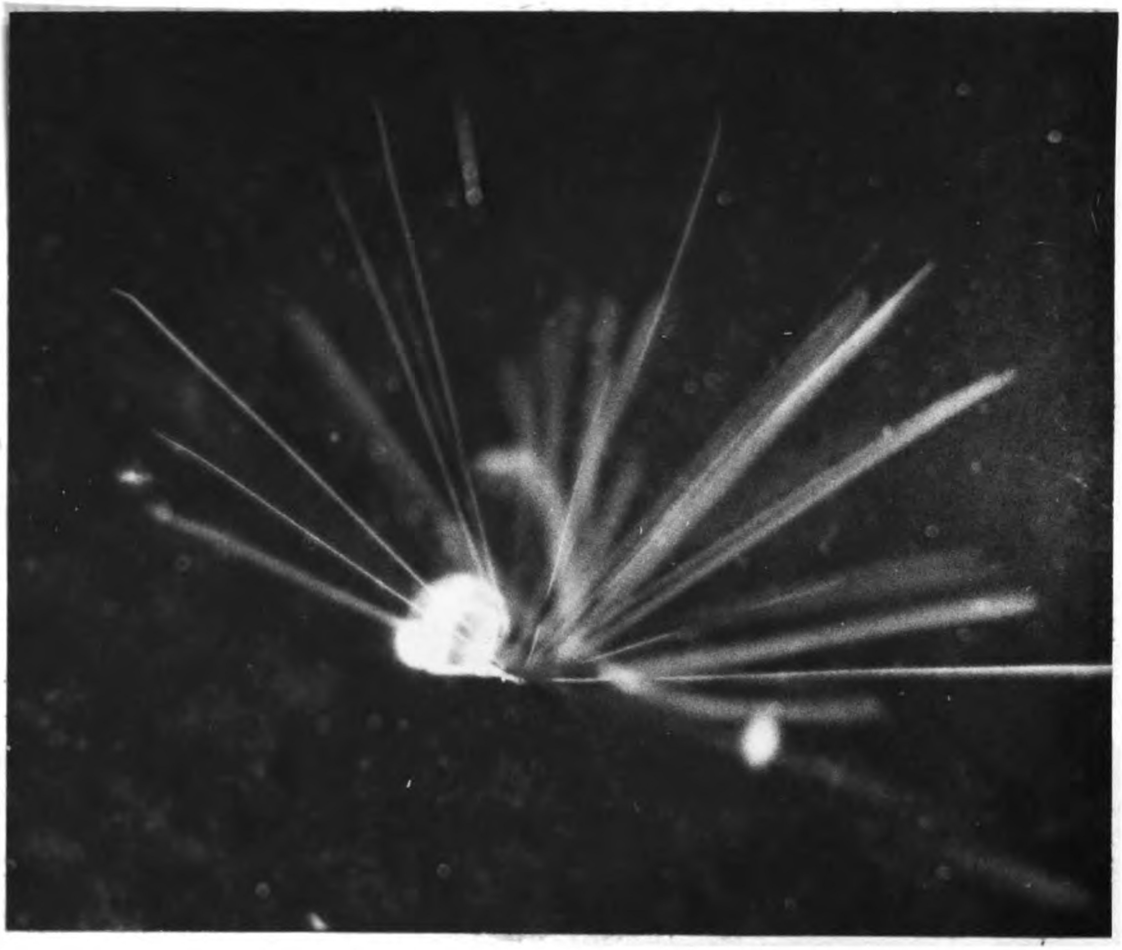

Fig. 12. α tracks from Polonium (Actual size)

The heavy, straight, sharply defined tracks resulting from the α emissions of Polonium are shown in Fig. 12. Also present are the wide feathery tracks of emissions which took place within approximately one second before expansion and have had time to diffuse out before condensation. The extent to which these diffuse tracks will appear is largely a function of the clearing field voltage since the stronger voltage will collect the ions more quickly thereby decreasing the maximum age of the tracks. There is some evidence of curvature in two of the very diffuse tracks due to the thermal motion of the gas near the walls of the chamber. It will be noticed that in cloud chamber photographs in which the source is contained in the chamber all tracks appear to begin some distance from the source. Evaporation of the initial drops of a track due to the thermal capacitance of the source is the most probable reason for this phenomena. Therefore, all measurements of track length are made to the surface of the source rather than the visible beginning of the track. Also apparent in Fig. 12 are the collisions suffered by four of the α particles near the end of their range.

Fig. 13. β tracks from I^{131} (Magnification $1\frac{1}{2}$ x)

The relatively low ionizing power and high velocity of the 1.3 Mev β particles from I^{131} are evident from the track shown in Fig. 13. Near the source the track consists of faint groups or clusters of drops gradually increasing in number and density as the end of the range is approached. The solid white line in the lower left hand corner is a section of the clearing field wire.

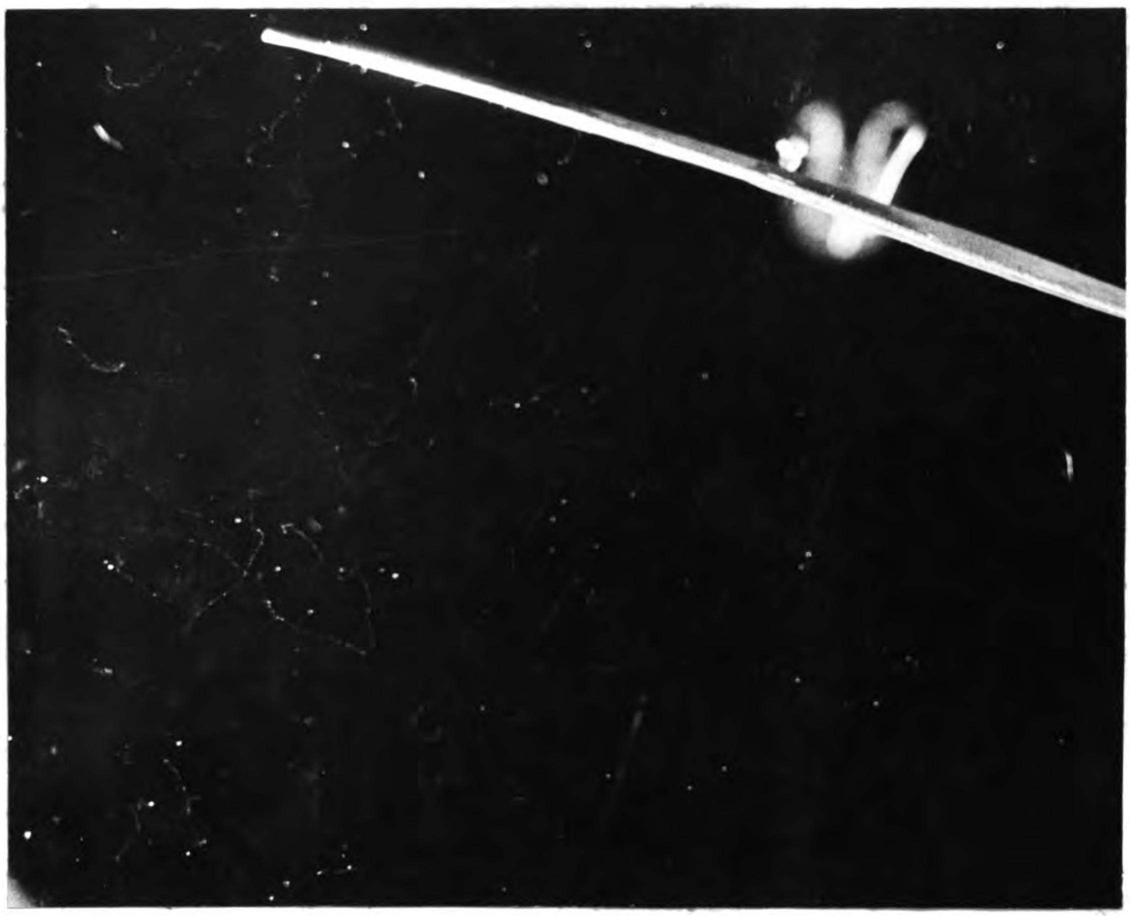

Fig. 14. Compton and photoelectron tracks produced by an x-ray beam. (Magnification $1\frac{1}{2}$ x)

A two millimeter collimated beam of continuous x-rays from a tungsten target, 35 Kv. peak, impinging upon a .01 cm. thick lead foil produced the Compton and photoelectrons shown in Fig. 14. The lower energy and higher ionization of these electrons is particularly noticeable when comparison is made with the β tracks.

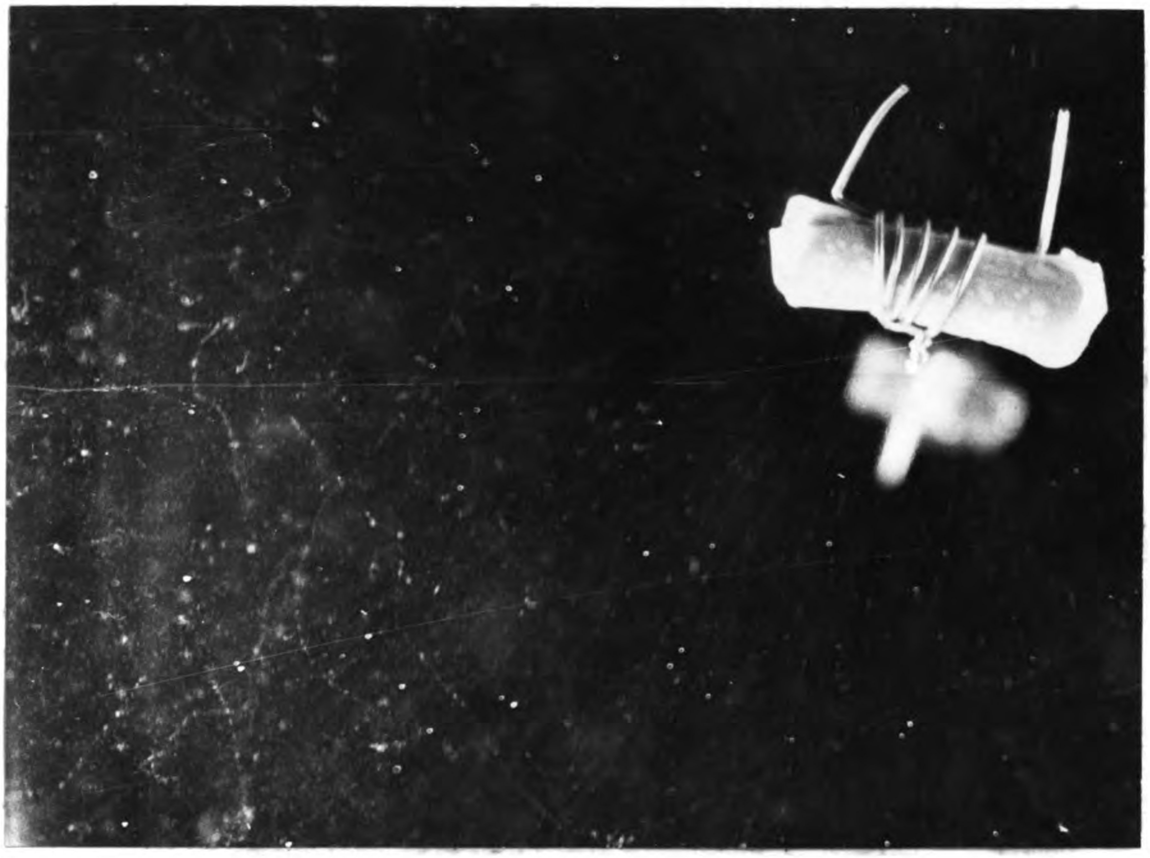

Fig. 15. Compton and photoelectron tracks produced by γ rays. (Magnification $1\frac{1}{2}$ x)

Figure 15 shows the electron tracks produced by γ radiation from a Co^{60} sample encased in several layers of lead foil. The rather high background fog and lack of contrast could be largely eliminated if the radiation were excluded from the chamber until the instant of expansion. The resulting photograph would then contain only the sharp tracks. Also, when photographing electron tracks high intensity flash lamps rather than photofloods should be used so as to increase the depth of focus and reduce the heating effect.

The series of photographs shown in Figs. 16 to 20 illustrate the effect of increasing expansion ratios throughout the critical range. Such factors as exposure time, lighting, developing, and printing were kept constant. In general one observes a gradual increase in the number and density of the tracks as the expansion ratio is increased from the ion limit. However, the onset of background fog (Fig. 20) at E = 1.138 is abrupt. At any higher expansion ratios the tracks are completely obliterated by a dense fog. The pressure noted for each expansion ratio refers to the excess pressure above one atmosphere.

Fig. 16. α tracks at an expansion ratio of 1.112 $P = 8\frac{1}{2}$ cm of Hg

Fig. 17. α tracks at an expansion ratio of 1.118 P = 9 cm of Hg

Fig. 18. α tracks at an expansion ratio of 1.125 P = $9\frac{1}{2}$ cm of Hg

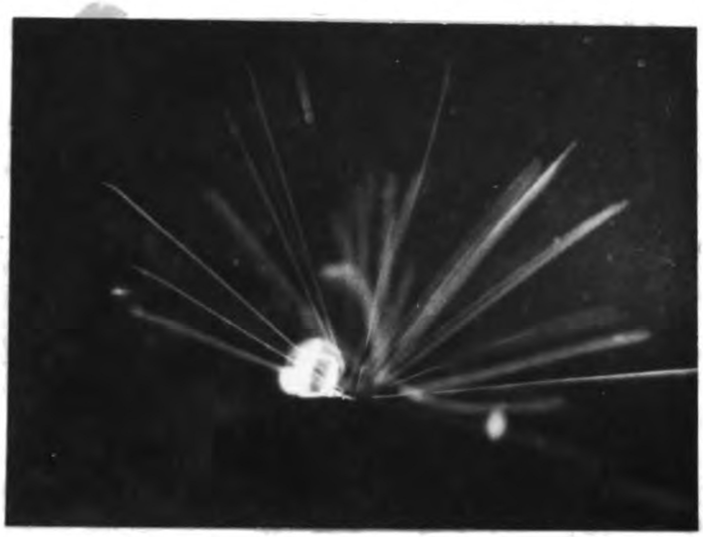

Fig. 19. α tracks at an expansion ratio of 1.131 P = 10 cm of Hg

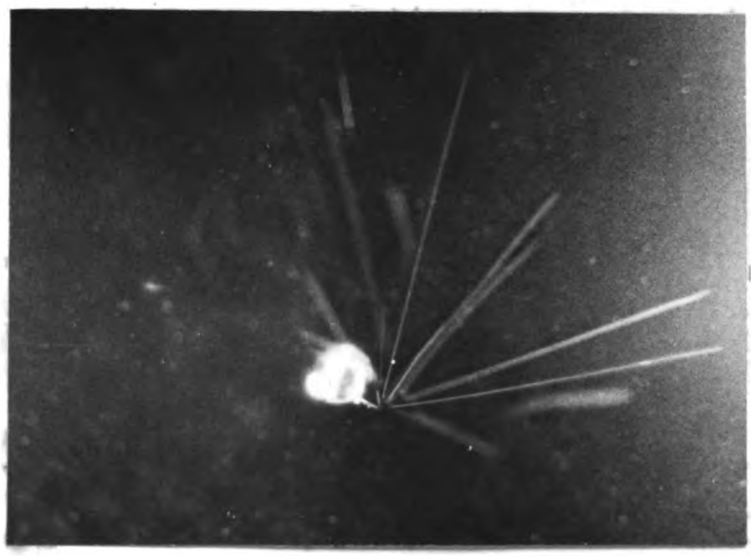

Fig. 20. α tracks at an expansion ratio of 1.138 P = $10\frac{1}{2}$ cm of Hg

VI. Summary

An expansion cloud chamber which complies with the basic requirements for a demonstration device was constructed and operated successfully. It is portable, self-contained, automatic, and of a size suitable for viewing by small classroom groups. Photographs of α and β tracks and the Compton and photoelectric electron tracks produced by x-rays and γ rays were obtained. It was found that while electron tracks can be photographed they are not of sufficient density to be observed. A series of photographs were also taken to demonstrate the effect on α tracks of increasing expansion ratios from the ion limit to the cloud limit. The point of maximum track density and minimum background fog was found at an expansion ratio of 1.131 using a solution of 70 percent ethyl alcohol - 30 percent water in helium gas at 22°C.

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