1958

A study of background in a long sensitive time Wilson cloud chamber

Donald A. Rinker

A STUDY OF BACKGROUND IN A LONG SENSITIVE TIME WILSON CLOUD CHAMBER

BY

DONALD A. RINKER

A

THESIS

submitted to the faculty of the

SCHOOL OF MINES AND METALLURGY OF THE UNIVERSITY OF MISSOURI

in partial fulfillment of the work required for the

Degree of

MASTER OF SCIENCE, PHYSICS MAJOR

Rolla, Missouri

1958

Approved by - James L. Kassner, Jr.
Assistant Professor of Physics

ACKNOWLEDGEMENT

The author wishes to express his sincere appreciation for the assistance and guidance extended to him throughout the course of this research by James L. Kassner, Jr., Assistant Professor of Physics. The numerous discussions with and suggestions made by Richard Schoen, Assistant Professor of Physics, have been greatly appreciated.

The assistance of Mr. James Hornkohl and Mr. Millard Underwood in the building of the electronic apparatus, and the work of Mr. Herbert Pruett in the shop have greatly aided the completion of this project.

Thanks are due C. P. Clare and Company of Chicago, Illinois, for their contribution of many relays used in the electronic circuitry.

This work has been aided by a grant from the Research Corporation, covering a search for new particles in cosmic rays ionizing less than the minimum ionization of the electron.

CONTENTS

ILLUSTRATIONS

TABLES

Chapter I

INTRODUCTION

With the discovery of many new elementary particles, the cloud chamber has become an important tool to research. It is being used in an effort to discover still other particles. Cloud chamber investigators have long been concerned with the existence of background droplets appearing during the critical super-saturation period in the expansion. The existence of these droplets has been attributed to many types of condensation nuclei.

If a chamber is to be used in conjunction with a search for new particles, which may occur very rarely, it is desirable to operate the device in such a manner that it is sensitive to ions for a relatively long period of time, the order of a few seconds, and that the background be sufficiently low to allow accurate counting of droplets along the path of the ionizing particle.

1. Previous Work. Good[4] has made a search for new particles using a chamber with a 1.5 to 2 second sensitive time and, 40 per cent of the time, a background of less than one drop per cm^3 was obtained. He attributes the existence of background to the following types of nuclei:

(a) Photochemical nuclei due to illumination.

(b) Re-evaporation nuclei.

(c) Random ionization and excitation of the gas by soft x-rays.

(d) Polymers, free radicals, and metastable entities produced along the tracks which may carry over from one expansion to the next.

(e) Transient polymers produced by collisions of neutral molecules.

(f) Foreign substances on the walls.

(g) Electrolysis at the sweep electrodes.

Beck[2] found that the production of photochemical nuclei due to lighting is stopped if a filter is used with the source which filters out all radiation below 3900 Å. He states that when irradiating the chamber continuously with a mercury lab arc, the density of photochemical droplets reaches a maximum after 3 minutes. Three minutes after the irradiation is stopped, the background has returned to normal. The author of this thesis believes that the background in this chamber was being controlled by re-evaporation nuclei; that is, the build up of photochemical drops was actually the result of a build up of re-evaporation nuclei, the number of new photochemical drops being produced in each expansion remaining constant. After 3 minutes, an equilibrium has been reached between the number of new drops being formed per expansion and the number of re-evaporation drops falling into the liquid during the previous expansion. It is also believed that it took 3 minutes of expansions occurring at 40 second intervals after the irradiation was stopped for all of the re-evaporation drops to fall into the liquid. Beck's results will be discussed more thoroughly in Chapter IV.

Prior to 1915 a good deal of work was done by Saltmarsh[11] and others on the production of nuclei in gases by irradiation from ultraviolet light. Saltmarsh used C. T. R. Wilson's original cloud chamber apparatus to conduct a study on the formation and characteristics of these nuclei. A summary of her results are as follows:

1. Nuclei produced in air by ultra-violet light which has traversed a few centimeters of air are not affected by an electric field of 50 volts per cm.

2. The nuclei are equally effective in producing condensation of water, toluol and turpentine vapors, and they are formed even by light which has traversed 50 cm of air.

3. Alcohol vapor condenses without expansion on much smaller nuclei than does water vapor.

4. No nuclei were formed by the light unless oxygen or CO_2 were present in the gas.

5. No trace of H_2O_2 could be detected in the clouds formed on the nuclei.

6. Oxygen containing ozone also contains nuclei for condensation, and these nuclei have similar properties to those formed by ultra-violet light.

7. The nuclei can be destroyed by heating the air containing them.

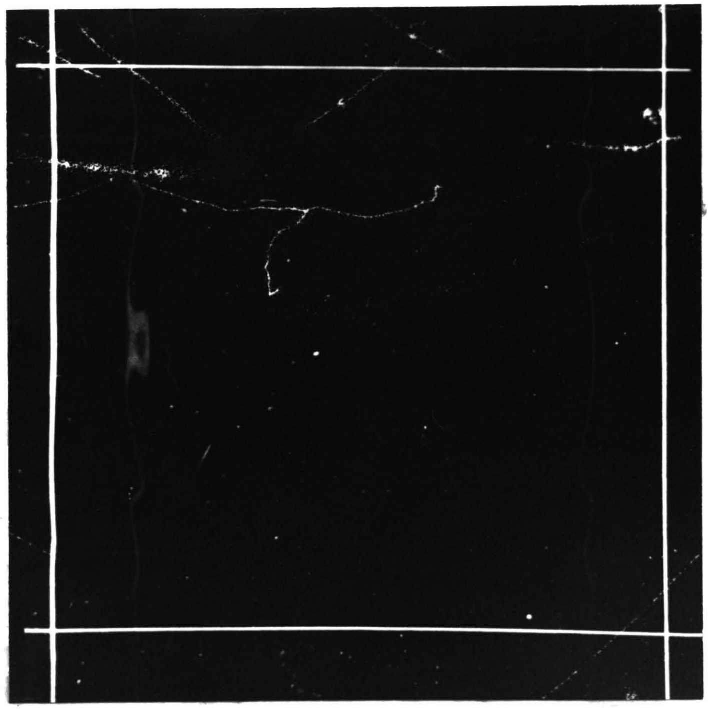
In addition to the above, Saltmarsh also definitely determined that the nuclei are condensed upon at a lower supersaturation than that required for ions. Her observation that the nuclei were formed in the presence of alcohol vapor seems to be in direct contradiction of the observations made by Beck.[2] He states that no such nuclei were formed using alcohol vapor rather than water vapor.

The attempt by Saltmarsh to detect hydrogen peroxide in the condensed nuclei arose from the suggestion by J. J. Thomson that ultra-violet light acting on moist air might result in the formation of particles of H_2O_2 which, by dissolving in the small drops of water, would help them to grow larger and become stable. She concludes that it seems probable that the nuclei formed by ultra-violet light do not cause condensation by virtue of any particular chemical composition, but that they are particles large enough to act like dust particles as centers around which condensation can begin.

Wilson[13] states that C. T. R. Wilson, in investigating nuclei arising from metal surfaces, made the following comments on photochemical nuclei:

> Nuclei arising from metal surfaces were compared with similar, field-insensitive nuclei, formed in oxygen and to a lesser extent in carbon dioxide, but not in hydrogen, by ultra-violet light. The latter nuclei were shown to be capable of continued growth to visible size under prolonged exposure without any expansion; they were found in oxygen and water vapor, both stringently purified and in vessels from which rubber and organic sealing materials were excluded, and in a convergent beam of ultra-violet light the seat of most intense formation and subsequent growth was shown to be in the region of focus and not near the illuminated containing walls. These properties led Wilson to the conclusion that these nuclei were water droplets containing hydrogen peroxide as a non-volatile solute, the amount of which, in each droplet, increased during prolonged exposure to ultra-violet light with a resulting increase in the equilibrium diameter of the droplet.

2. Scope of the Present Work. Of the many new unstable particles which have been found in recent years, it has been assumed that all of the charged varieties have charges equal to that of the electron. However, it is reasonable to ask whether this must be true since present theories give no reason for charge to be quantized. If it were not, one might expect to find relativistic particles whose specific ionization is less than that of the electron. If they do exist, a cloud chamber operating in the manner mentioned previously should be a good device for detection. The largest problem involved is the existence of background, since, if a track of a subionizer were seen with as few as one ion pair per centimeter of path length, it would be difficult, if not impossible, to detect if the chamber background were of the order of magnitude of one drop per cm^3. Figure 1 shows the track of a possible subionizer. There are about 8 ion pairs per centimeter of path (approximately 50 ion pairs per cm in air is minimum ionization for the electron), the path is not more diffuse than the heavily populated



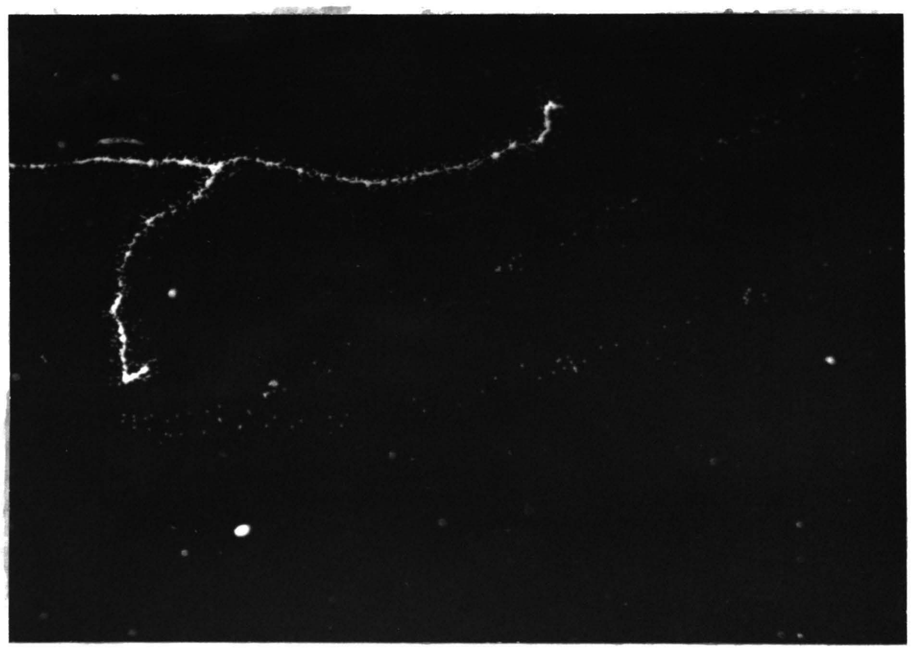


Fig. 1 A Photograph of a Suspected Subionizer
in a Low Background Chamber

track above it, and the background is about one drop in 20 cm^3. However, there were not enough criteria available to establish whether the track in question is an artifact of chamber operation or a bonified sub-ionizer suspect. Other things[6] which must be taken into consideration are:

(a) The time the track entered the chamber. It must enter the chamber after other tracks have already formed to assure that it is not the remains of an old track. Multiple photography can establish this fact.

(b) The exact position of the track in the chamber is required in order to estimate the efficiency of condensation on ions relative to other tracks. The efficiency of condensation is much lower near the walls, the top and the bottom of the chamber. The position of the track can be accurately located with the use of stereoscopic photography.

With a greater background in the chamber this track might not have been seen. Hence, one may have a long sensitive time chamber and employ multiple photography with stereoscopy, but, in a search for subionizers, the most important factor is a low background.

In this study we are concerned with several of the possible sources of background mentioned in the previous section. We believe that the greatest potential source of background is re-evaporation nuclei. The chamber used in this study was versatile enough to produce evidence supporting the existence of these nuclei as well as proof that the chamber can be operated in such a manner as to reduce this source of background to a minimum, possibly zero.

Another source of background of concern is the production of photo-chemical condensation nuclei by the light sources. Beck[2] has stated that filtering out all radiation below 3900 A will stop almost all such nuclei from being formed. However, he was using incandescent lighting which has a relatively small amount of radiation in the near ultraviolet region of the spectrum. We are using a high intensity xenon flash tube with as many as 22 flashes per expansion. For this reason it is desirable to know the threshold wavelength required for this process to take place. This information would enable one to choose a convenient filter which would minimize the production of photochemical nuclei, and at the same time not needlessly filter out wavelengths usable for photography.

Upon beginning this investigation the author became more interested in the type of process which might be taking place and has run a series of experiments in an effort to obtain some understanding of this phenomenon. The latter work is not of great importance in the reduction of background, but may be of interest as a method of studying photolytic processes. The experiments performed, data taken and conclusions reached will be discussed in Chapters IV and V.

3. Theoretical Considerations. The concept of the existence of re-evaporation nuclei arises from the theoretical treatment of drop formation[3]. The fundamental relation, attributed to Lord Kelvin, is

$$\ln (P_r/P_\infty) = \frac{2T}{r} \frac{M}{R\Theta\rho}$$

where T is the surface tension, ρ the density of the liquid, R the gas constant, Θ the absolute temperature, M the molecular mass of the drop, r the radius of the drop, and P_r, P_∞ are the saturated vapor pressures over the drop and over a plane liquid sheet respectively. According to C. T. R. Wilson P_r/P_∞ is the supersaturation. This equation is derived from expressions for the pressure due to surface tension, the volume in terms of the mass of the particle and the gas law. This relation indicates that P_r is always greater than P_∞ except for a drop of infinite radius; then they are equal.

If the condensation takes place on an ion instead of an uncharged particle, an additional term must be added to account for the pressure due to the electric field, and the equation becomes

$$\ln (P_r/P_\infty) = \frac{M}{R\theta\rho}\left[\frac{2T}{r} - \frac{e^2}{8\pi k r^4}\right].$$

The latter term is negative in sign since the potential energy due to electrification decreases on increasing drop radius, while the potential energy due to surface tension increases with increasing drop radius.

Each of the above equations assumes that the surface tension is independent of drop radius; however, Thomson has pointed out that surface tension may vary with drop radius for drops of small radius. With this consideration the relation above becomes

$$\ln (P_r/P_\infty) = \frac{M}{R\theta\rho}\left[\frac{2T}{r} + \frac{dT}{dr} - \frac{e^2}{8\pi k r^4}\right].$$

On the basis of many experiments he concludes that the surface tension is zero at r equal to zero and then it increases with r, reaches a maximum value at a certain value of r and then diminishes again. On the basis of these assumptions, Thomson shows that the variation of

$$\ln (P_r/P_\infty) \text{ or of } \frac{M}{R\theta\rho}\left[\frac{2T}{r} + \frac{dT}{dr}\right] \quad \text{(uncharged)}$$

with r may be represented by the curves shown in Figure 2. Considering either curve, a drop located anywhere above the curve will be condensed upon, and one anywhere under the curve will exaporate, and one on the curve itself will be in equilibrium. Once a drop is formed, there will always be a drop, no matter what the supersaturation.

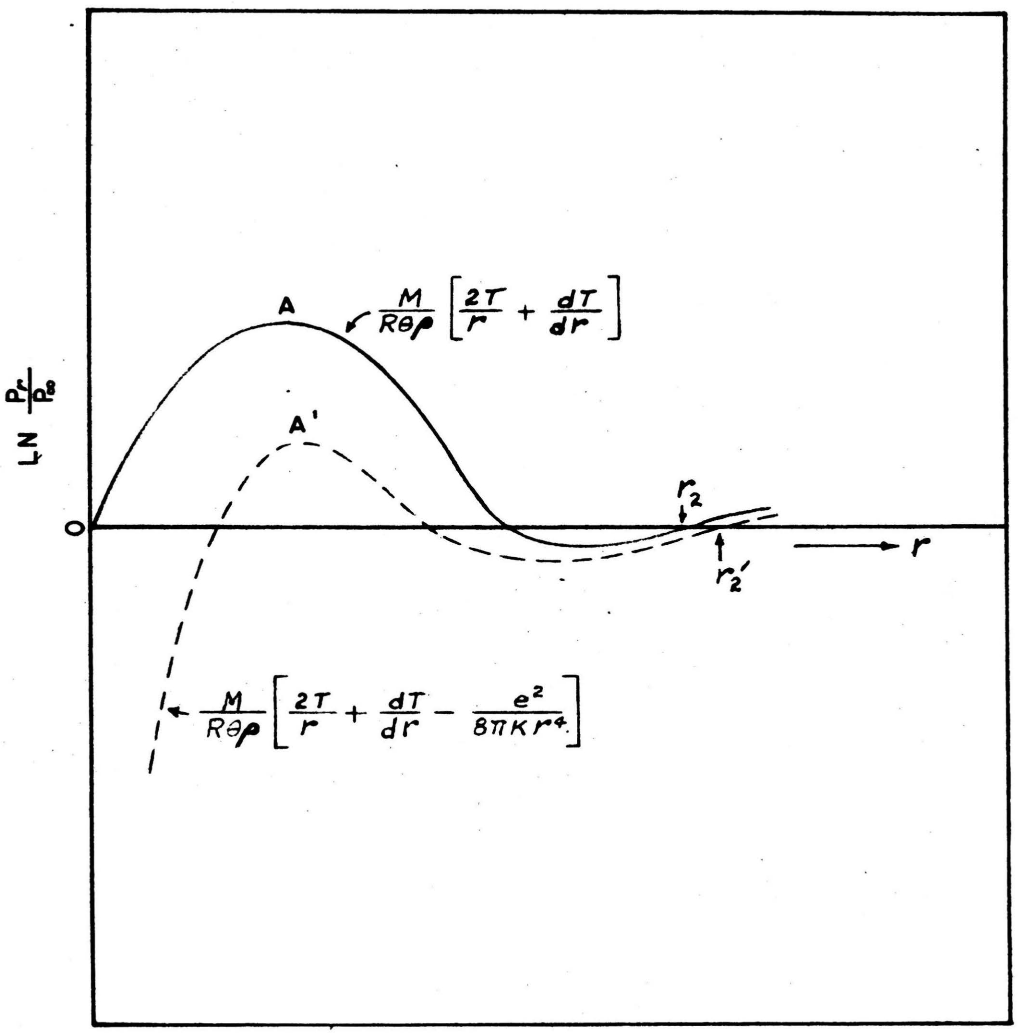


FIG.2 INFLUENCE OF THE VARIATION OF SURFACE TENSION ON THE SATURATION VAPOR PRESSURE OVER A DROP

If a drop were to grow to considerable size in the region above the curve, and then if the supersaturation were to fall quickly to zero, the drop would find itself below the curve and evaporate to a radius of r_2 at which point it would be in equilibrium and remain at that size. Then upon a small supersaturation it would again grow indefinitely. This equilibrium radius r_2 is believed to be greater than 10^{-7} cm[13] leaving nuclei which will appear as background in the following expansions.

In order to keep this type of nucleus from being present in the cloud chamber from expansion to expansion, it seems evident that one must maintain a sufficient supersaturation after the ion sensitive period to allow all drops formed to continue to grow and fall into the liquid before evaporation can take place.

Chapter II

THE CHAMBER AND ITS OPERATION

The Wilson cloud chamber constructed by Mettenburg[7] has been used for this study. The arrangement of associated equipment for operation and photographic observation is shown in Figure 3. Table I gives details for optimum operating conditions.

1. The Chamber. This study employs a long sensitive time cloud chamber (Figure 4) which uses a system of five expansion valves to achieve the long sensitive time. The orifice openings of the valves are variable and their operating times are flexible, being controlled by the electronic cycling units. The recompression is achieved using a sixth valve which is normally open between expansions and closed during the expansion so that greater regulation can be maintained. The recompression is relatively slow, its rate depending upon the cycle time, and complete recompression is always obtained about ten seconds prior to the expansion. The operating times for the various valves and a schematic representation of the optimum expansion curve are given in Table I and Figure 5 respectively.

2. Operating Devices. The control panel contains the electronic equipment controlling the cycle time and the method of expansion, as well as the operating times for the incandescent and flash tube lighting, the camera, the clearing field and other equipment which may be used in a particular experiment. This panel also contains the valve manifold which is used as the intermediate control between the line air pressure and the chamber. It is used to fill and empty the chamber in addition to regulating the air flow during the recompression cycle. Variations in the line pressure are regulated by the use of two reducers in series.

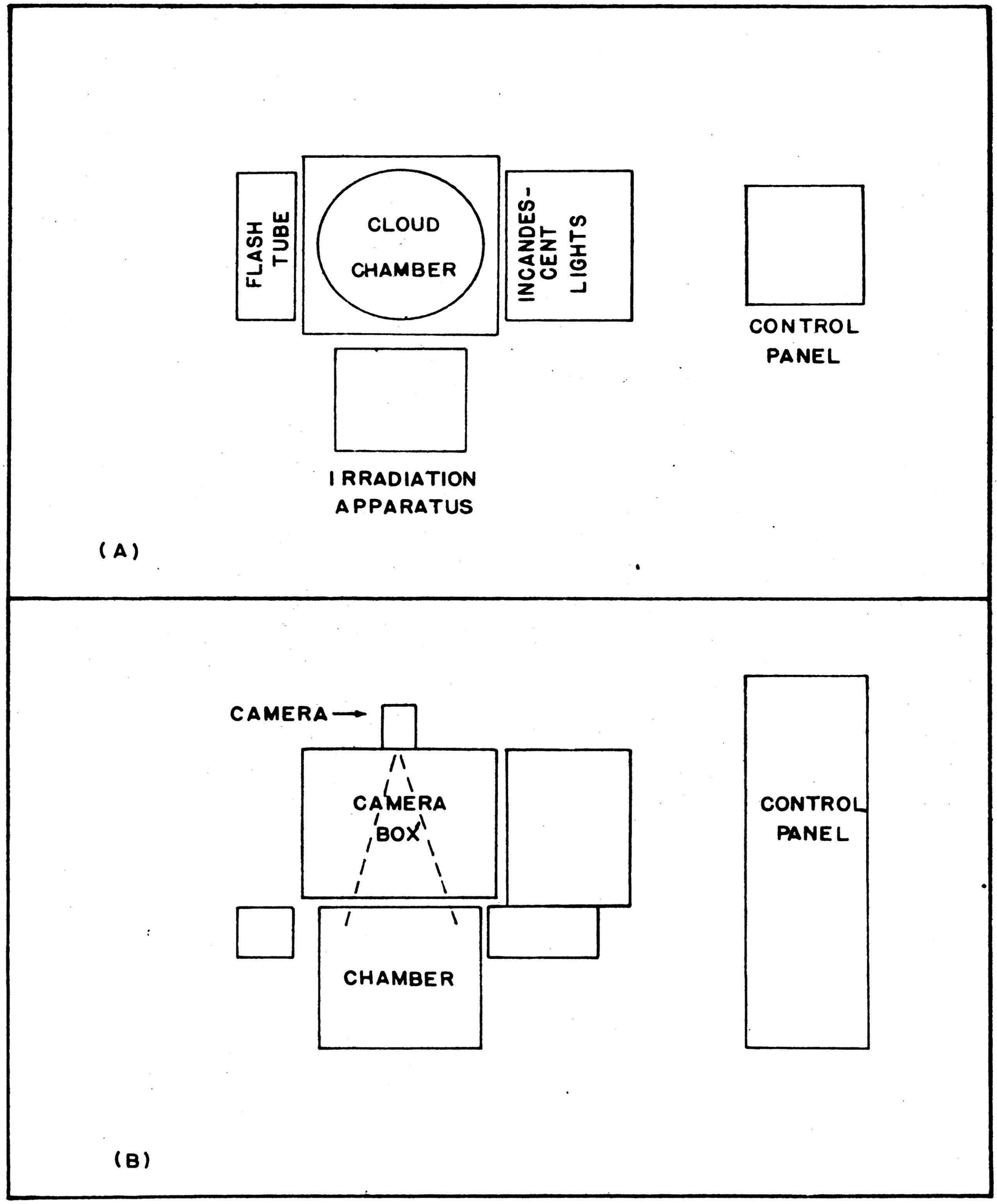


FIG. 3 (A) ARRANGEMENT OF CHAMBER AND CONTROLS
(B) SCHEMATIC OF CAMERA IN POSITION FOR PHOTOGRAPHY

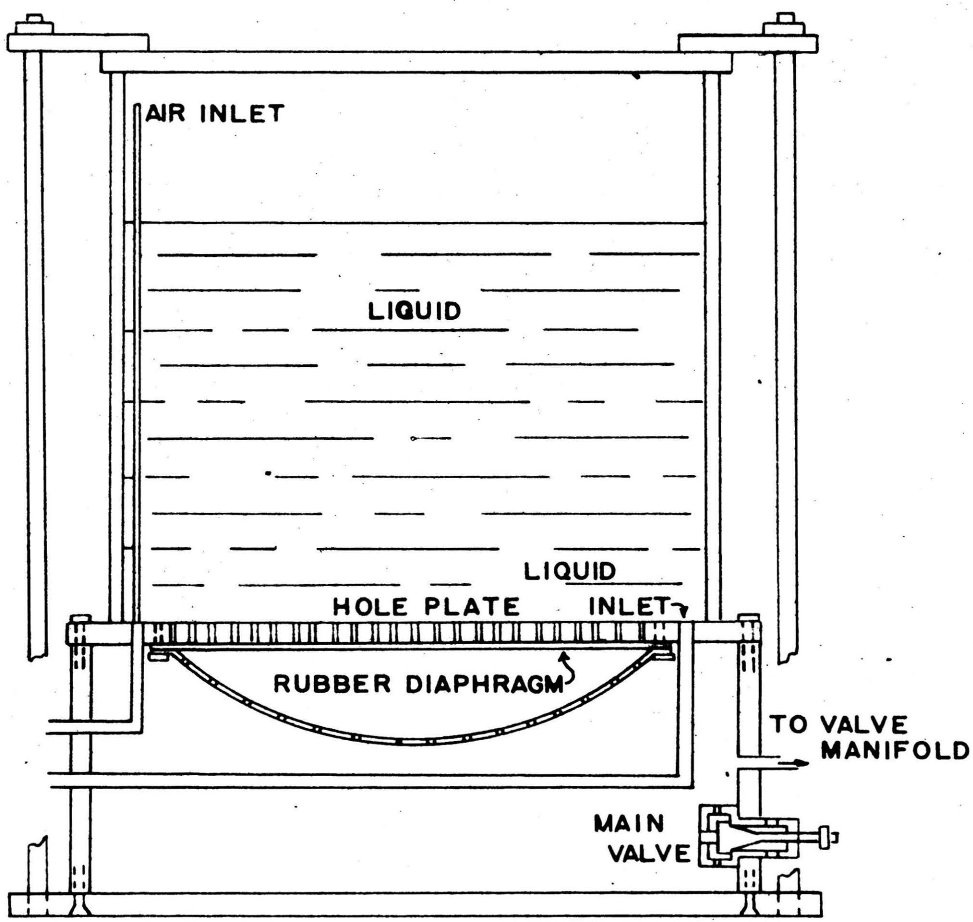


FIG. 4 THE CLOUD CHAMBER

TABLE I. Operating Conditions

1. Chamber Constituents
   Liquid: 2 parts ethyl alcohol to 1 part water.
   Solution blackened with Putnam Dye.
   Gas: air

2. Liquid Level
   Compressed position, 6 cm; expanded position, 8.2 cm.

3. Pressures
   Compressed, 7 psig; expanded, 5 cm Hg.

4. Clearing Field (applied between ring and metal base)
   Voltage, 708 volts DC; current, 0-7 microamperes.

5. Cycle Time 2 minutes 15 seconds.

6. Expansion Valve Settings (seconds)

Valve	Start	Stop
1	0.00	0.36
2	0.00	0.58
3	0.58	3.10
4	3.50	15.00
5	3.80	15.00
6	0.00	20.00

7. Room Temperature 72°F

8. Illumination
   Incandescent: 4 General Electric 200W clear lamps
   operating voltage, 200 volts
   ultraviolet filter, Kodak 2B
   Flash: 1/4 inch zenon flash tube, 11 inches long
   operating voltage, 1400 volts DC
   120 microfarad condensers
   ultraviolet filter, Kodak 2B

9. Camera
   35 mm De Vry Air Force Surplus movie camera
   lens opening, f/8 and f/11
   lens to chamber distance, 46 cm
   depth of focus, 7.4 cm
   camera framing rate, 10 per second
   magnification, 1/9

10. Film
    Kodak 35 mm Tri-X and Linagraph Pan

11. Development
    Kodak D-19 Developer at 72° F for 8 minutes

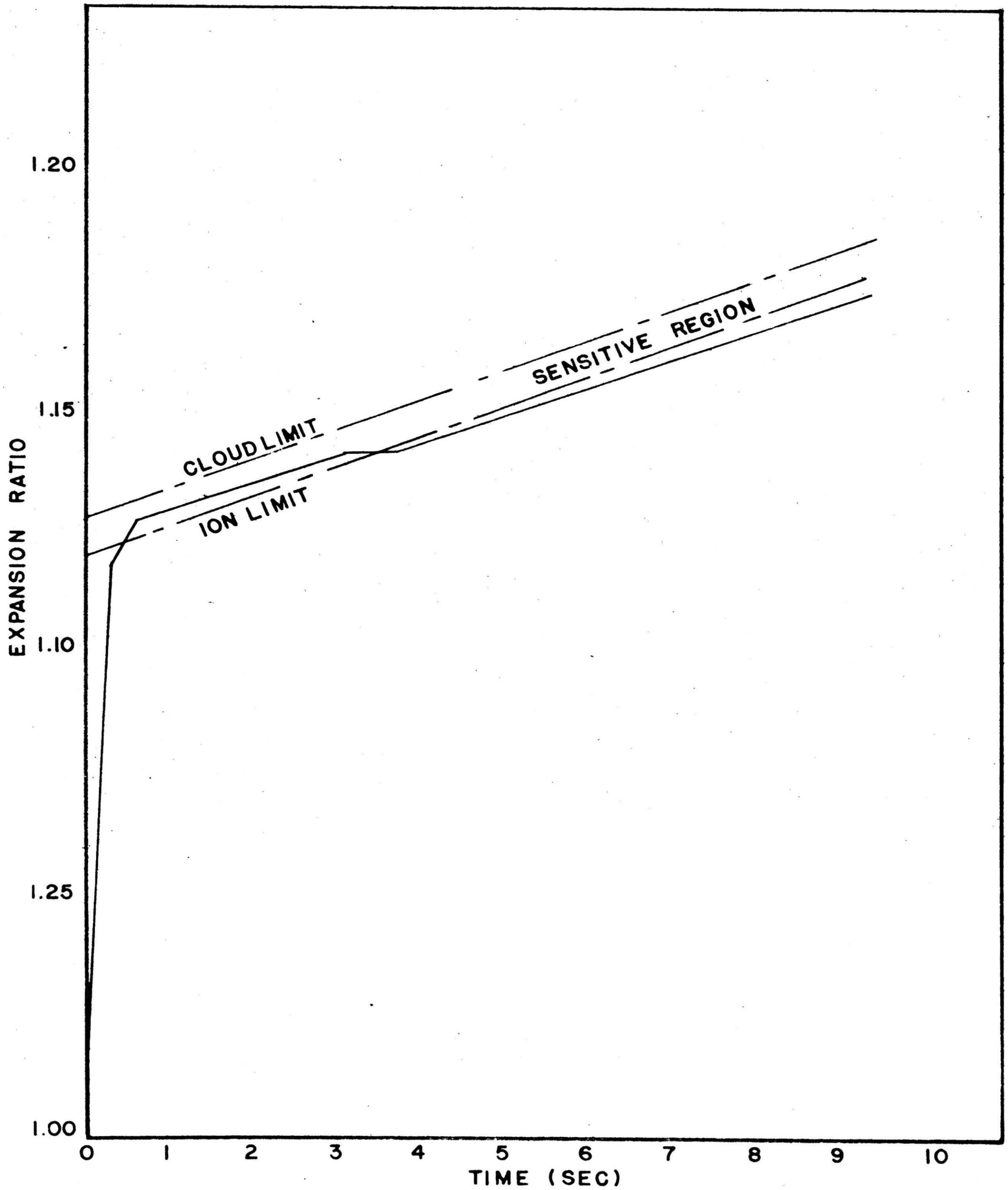


FIG. 5 SCHEMATIC OF OPTIMUM EXPANSION

The type of electronic control circuits employed are discussed by Mettenburg[7] and little need be said about them here. The complete schematic diagrams of the various control circuits for normal chamber operation are shown in Figures 6 and 7.

3. Illumination. An incandescent lighting system was employed for visual observation. The collimating system as shown by Mettenburg[7] proved to be sufficient for single frame photography at f/3.5. However, this system proved to be unsatisfactory for multiple photography because of the shorter exposure time.

The flash lighting system used for multiple photography is set up to allow twenty-two flashes per expansion. It was found that seven flashes at three tenths second intervals provided sufficient photographic information for this study. Figure 8 shows the entire flash system schematically. The system has worked satisfactorily for the conditions outlined in Table I.

4. Photography. The De Vry 35 mm Air Force Camera has been used for multiple photography by synchronizing the exposure interval with the flash system. The camera is oriented vertically above the chamber and is located 46 cm from the center of the sensitive region. For the counting of background droplets it is required that the maximum diameter of the diffraction pattern on the film be not greater than 40 microns. Using this criterion the depth of focus is calculated after Allen et al[1] where

$$d = \frac{2D^2 A\delta}{f^2} .$$

Here d is the depth of focus, D the object distance, A the aperture setting, f the focal length of the lens, and δ the diameter of the circle of least confusion. For our 5 cm focal length lens, D equal to 46 cm,

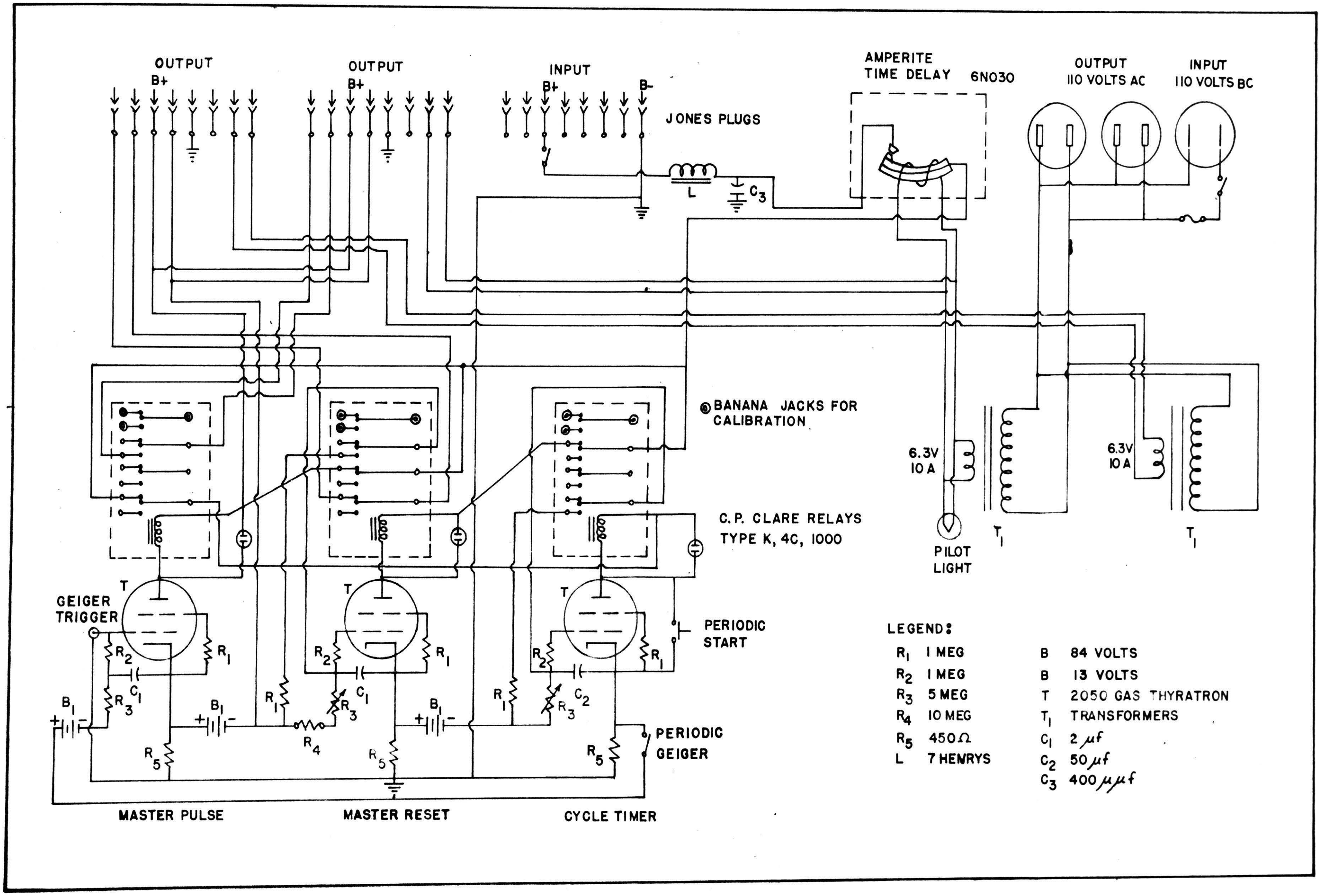


FIG. 6 CLOUD CHAMBER MASTER CONTROL TIMER

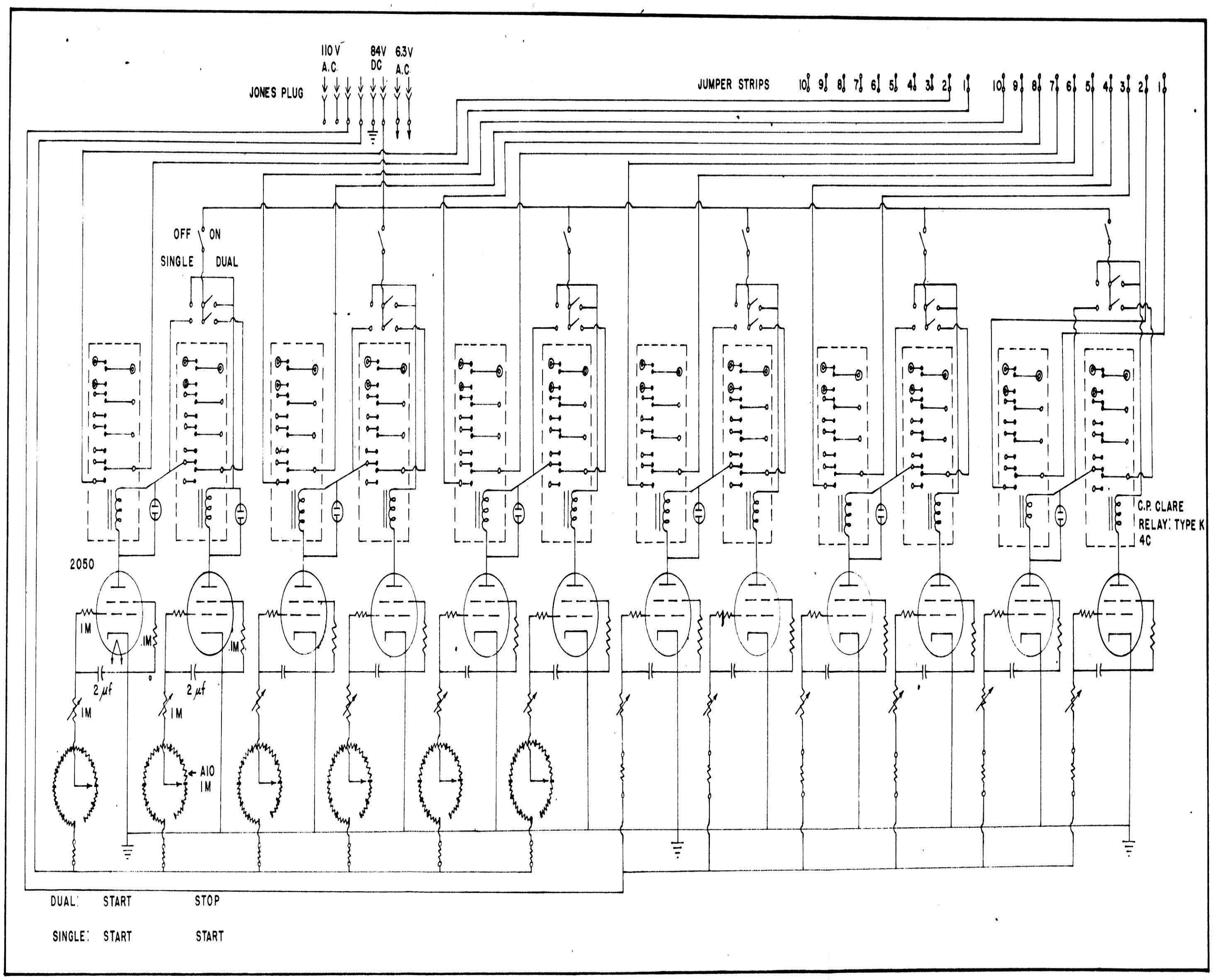
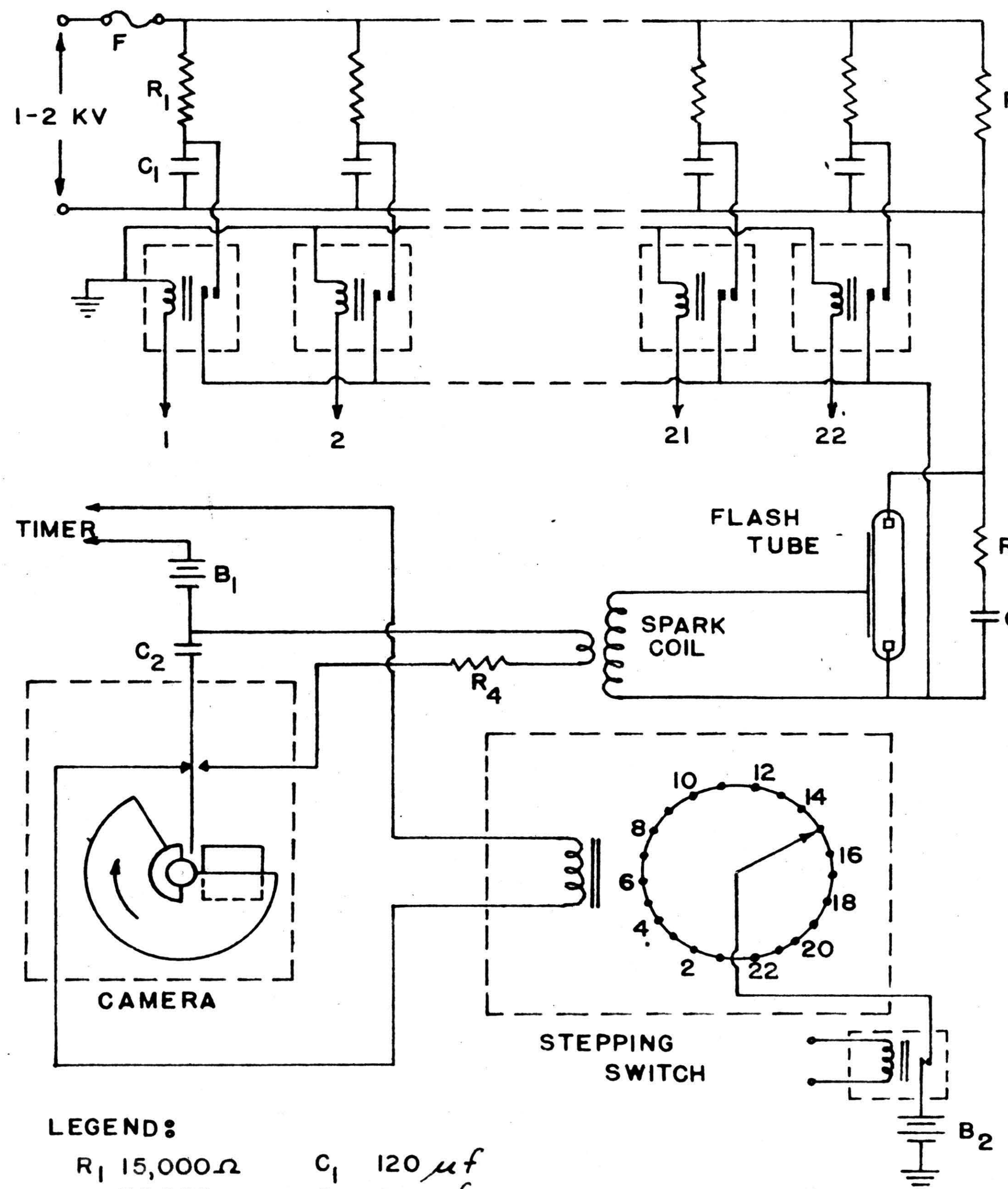


FIG. 7 CLOUD CHAMBER VALVE CONTROL CIRCUIT



LEGEND:

R_1	15,000 Ω	C_1	120 μf
R_2	30,000 Ω	C_2	50 μf
R_3	15 Ω	C_3	.02 μf
R_4	15 Ω	B_1	84 VOLTS
F	3.0A FUSE	B_2	60 VOLTS

FIG. 8 FLASH ILLUMINATION CIRCUIT

A equal to 11, and δ equal to 40 microns, the depth of focus is 7.4 cm.

It is noteworthy that according to Newth[8] this requirement on the diffraction pattern diameter is not stringent enough if we were to attempt to resolve droplets in a normal track for accurate drop counting. This is arrived at from the consideration of a track of minimum ionization which creates about 100 ions per cm of path in a track width of about 0.1 cm. Then we must have the inequality

$$0.1 \times m^2 > 100 \times 16 \times 10^{-6}$$

$$m > 1/8$$

where $16 \times 10^{-6} cm^2$ is the area of the drop image. Since the magnification, m, must be greater than 1/8 for proper drop resolution with a minimum of overlapping, and since our magnification is approximately 1/9, it is concluded that the 40 micron image diameter exceeds the limit for proper resolution. As pointed out, this does not apply to the counting of widely spaced background droplets.

In recording data on background from photographs, it is believed that a negligible error is incurred due to failure to photograph all drops in the sensitive volume. This conclusion is drawn from the known divergence of our light beam and the knowledge that it illuminates the entire sensitive region of the chamber, and that the depth of focus is as great or greater than the chamber depth at any time during the sensitive period. A careful study of individual photographs indicates that each drop is sufficiently illuminated to cause a sharp image to appear on the film.

Experiments in photographic technique were done in an effort to find the film best suited to our needs, in addition to calibrating the camera and flash system. It was found that Kodak Tri-X was best suited for our purposes, although its resolution is poorer than Linagraph Ortho or Linagraph Pan Film. Good results have also been obtained with Kodak Linagraph Pan film which has a slightly greater resolving power than that of the Tri-X, but is slightly slower. An f-stop had to be sacrificed when using the Linagraph Pan. Kodak Linagraph Ortho was also tested, but it was found that still another f-stop had to be sacrificed to obtain sufficient exposure. In the data taken, Tri-X and Linagraph Pan were used in approximately equal amounts.

5. Techniques of Operation. Since the primary concern in this study is to reduce background in the chamber to a minimum during the entire sensitive time, a great deal of time was spent in an effort to obtain the optimum operating conditions for this chamber. These conditions have been outlined in Table I, and it will suffice to mention here that the chamber is extremely versatile in that some of the conditions in Table I are not restricted to those values given for optimum conditions.

It was found that for the chamber depth given, the maximum usable sensitive time was 2.5 seconds. This does not indicate that 2.5 seconds is the maximum sensitive time the chamber can achieve (it could be twice that); however, after approximately three seconds from the initiation of the expansion, the turbulence currents become so great that it is impractical to attempt any greater sensitive time.

As mentioned in Chapter I, the chief source of background is re-evaporation nuclei. Mettenburg[7] has mentioned how it is planned to reduce this source of background to a minimum without the use of a series of intermediate expansions. Figure II shows the use of valves 4 and 5 to continue the expansion in such a manner that the supersaturation will be less than critical, but sufficient to allow all nuclei condensed upon during the sensitive period to grow in size and fall into the liquid before re-evaporation takes place, leaving no re-evaporation nuclei which may be condensed upon in the following expansion. A delay in the recompression has also been employed for a reason other than that stated earlier in this chapter. This delayed recompression has been found to be very valuable in the reduction of background, and has given evidence supporting the existence of re-evaporation nuclei. The results of the aforementioned modes of operation will be dealt with more thoroughly in Chapter IV.

It is noteworthy that another method of operation is now being used by some investigators[12]. This involves a rapid over-compression after the expansion, followed immediately by a slow expansion to the pre-expansion position. This technique is advantageous in two ways. First, it allows operation with a fast cycle time, the slow expansion after the over-compression accelerating the redistribution of vapor. Second, the slow expansion acts as a clearing expansion, reducing the background due to re-evaporation nuclei. It is hoped that this method can be incorporated with the present chamber in the near future.

Chapter III

EXPERIMENTAL PROCEDURES

At this point, procedures used in performing experiments in general will be discussed, and problems encountered will be pointed out. With this information, individual experiments and their results can be concisely dealt with in the following chapter.

1. General Procedures. Our first requirement before taking any photographic data was to be sure that all characteristics of operation had reached a steady state. Specifically, we required that the room temperature remain constant throughout the data taking period, as well as when preparations were being made. Constancy of room temperature proved to be one of our primary problems, and it was finally resolved by taking all data at night. This procedure was not entirely satisfactory, but sufficed for this particular work.

Visual observations were made of all experiments prior to taking photographic data. This insured that time and film would not be wasted and prompted us on the number of sequences of photographs which would be necessary to complete the experiment. In the case of some experiments, a programming device which operated in conjunction with the cycling unit was used to reduce the possibility for human error.

Some experiments required a mode of expansion which was other than that found for ideal chamber operation. In each of these cases 30 to 60 expansions were performed before data was taken. Experience indicated that this was certainly more than sufficient time for the chamber to reach a steady state for that mode of operation.

2. Recording of Data. A simplified method of recording background densities was used. The film was reprojected using a 35 mm film strip

projector. The screen was oriented such that the magnification relative to the actual size of the chamber was five, and the 11 x 11 cm square was divided into squares of one square centimeter of chamber at the screen. Replicas of this grid were made on data sheets so that drop counts for each square of interest could be recorded directly. The exact location of a drop in the chamber was of little interest to us; hence, stereoscopic photography was not employed. Eventually, statistical data could be obtained from these data sheets. All frames from expansions that were of particular interest were made into 2 x 2 slides and numbered for future reference.

3. Ultraviolet Irradiation Procedures. Preliminary irradiation studies were accomplished by simply using an unfiltered flash tube when taking photographs. The intensities of the wavelengths effective in producing photochemical nuclei were sufficient to estimate the resulting drop density distributions as a function of succeeding flashes for a single expansion.

A mercury lab arc was then set up near the chamber, and the sensitive region irradiated. This did not produce any reproducible results with respect to formation of photochemical condensation nuclei. On some occasions photochemical drops were observed, and later, under identical conditions, there were no drops observed. This was accounted for by taking a spectrogram of the emission spectra of the arc with a quartz spectrograph. The results indicated that the constancy of the emission spectra was extremely unreliable. It was also found that the cut off for the glass cylinder of the chamber is between 3500 and 3600A. Because of the above mentioned unreliability and the lack of proper apparatus, threshold measurements for the wavelengths causing the photochemical process were not made.

A quartz window was inserted in the wall of the chamber and the outer glass envelope of the mercury lab arc removed, leaving an all quartz irradiation system. A quartz lens was also used to collimate the light into the chamber. It was found that this system transmitted all radiation above 2200A. Using this arrangement, many observations were made on the characteristics of condensation on photochemical nuclei. These results will be pointed out in detail in Chapter IV.

Chapter IV

EXPERIMENTS AND DATA

In the present chapter each of the experiments performed will be discussed, the discussion including the experimental arrangement, data taken, and the results of the experiments.

1. Chamber Reproducibility. It was desired to determine the re-reproducibility of the chamber with regard to background density. In any experiment that might be done, it will be necessary to know what variation in background density can be expected from irregularities in the chamber operating mechanism. The chamber was operated in the manner outlined in Table 1 and single photographs were taken of 52 consecutive expansions. The photographs were taken 1.2 seconds after the beginning of the expansions, indicating, as seen in Figure 5, that the chamber was sensitive approximately .6 second prior to the time that data was recorded. Each photograph was reprojected and the following data was recorded on data sheets. All data was restricted to an 11 x 11 cm square in the center of the chamber.

(a) The number of tracks, whether new or diffuse.

(b) The number of background drops in each of 40 square centimeter squares. These 40 squares were picked at random, the only criterion being that a track not be within .5 cm of the square.

The data from (a) is recorded in Figure 9a as a histogram showing the number of expansions of the 52 for which each number of tracks appeared in the chamber. For example, there were 4 tracks in each of 14 expansions. Figure 9b shows the results of (b). Here the total number of drops in the 40 squares was determined for each expansion, then using a depth of focus of 5 cm, the volume density of drops was found. The resulting histogram is read in the same manner as Figure 9a.

For this experiment the most probable background density for an expansion was about one drop in 20 cm^3. This is considered to be a very clean chamber and one with which we could start a search for subionizers. The average number of tracks after a sensitive period of .6 second is about 6. It is interesting to note that only 3 of the 52 expansions had less than 4 tracks.

The same experiment was performed after lengthening the operating time of the first valve (Table 1) by .02 of a second. Visual observation indicated that the background was about the same; however, photography showed that the background density alternated between two values, the lower being about one drop in 10 cm^3 and the upper from 1 to 2 drops per cm^3. The background alternated between these two values from expansion to expansion in such a manner that it called for closer inspection than could be afforded by visual observation. It was found that the chamber was definitely over-expanding slightly into the fog region during the operation of the second valve in some expansions and not in others. The only reasonable conclusion was that the main valve (valve 1), which has a large orifice, was not remaining open for exactly the same length of time during each expansion. It is known that this is not due to the electronic time delay circuit so it must have been due to the operation of the soleniod and lever arm opening and closing the valve. This can only be corrected with a new arrangement for the operation of this valve.

2. Re-evaporation Nuclei. There is little doubt in the author's mind that re-evaporation nuclei do exist, but it is felt that they can be practically excluded from chamber background. It should be pointed out

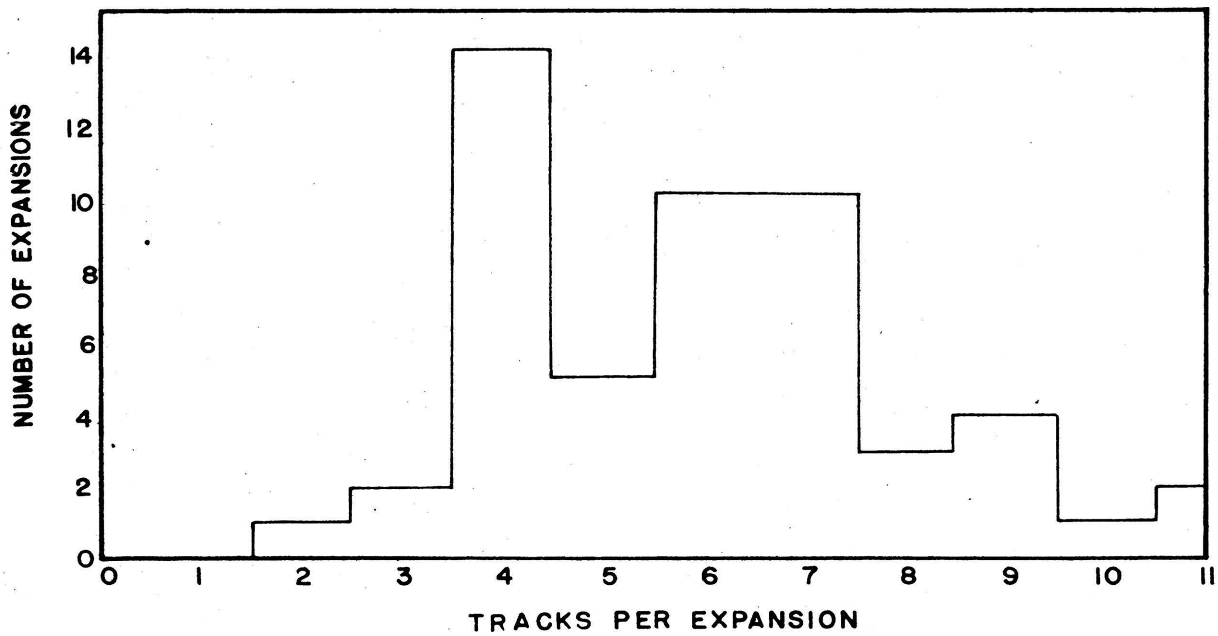


FIG. 9A HISTOGRAM OF TRACK DENSITY

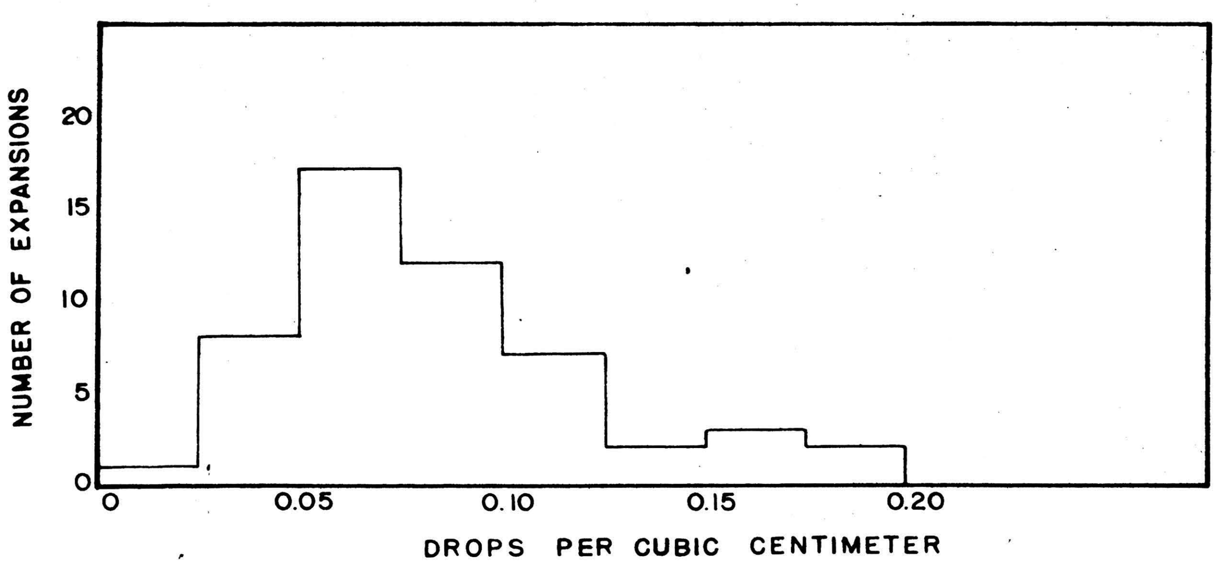


FIG. 9B HISTOGRAM OF BACKGROUND DENSITY

here that this chamber operates differently from most other chambers in two respects. First, the method of continued expansion as already pointed out, is being used, and second, the beginning of the recompression is being delayed until 20 seconds after the expansion begins.

In regard to continued expansion, much time was spent observing visually its effects on background density. Photography showed that under optimum conditions without the use of valves 4 and 5, the background density was one drop in 5 cm^3. As was seen in the previous section, with the use of valves 4 and 5, the background density was one drop in 20 cm^3. Hence, in a chamber depth of 8 cm (expanded) the background has been reduced by a factor of four. We believe that in a chamber of greater depth, 12 or even 16 cm, the value of a continued expansion at a supersaturation slightly less than critical would be even more significant. The reason for this belief is that more re-evaporation could take place on a greater number of drops since they have a greater distance to fall before reaching the liquid. Now the background would become greater without the use of valves 4 and 5, but if a great enough total expansion could be achieved, continued expansion would produce the same background aforementioned.

This type of experiment has not been performed since the total expansion of the chamber is limited by the two confining hole plates. Indeed, we have found that an expanded chamber depth of about 8 cm is our limit for optimum operation. This gives us a total expansion ratio of 1.33. A chamber depth of 12 cm would give a ratio of 1.20 and a depth of 16 cm a ratio of 1.14. The latter is just enough to reach the sensitive region using the constituents mentioned in Table 1. Here, a maximum sensitive time of .5 seconds can be obtained with, of course, no continued expansion.

It was of interest to determine whether or not the reduction in background by the use of valves 4 and 5 was actually due to the elimination of re-evaporation nuclei; that is, if they really exist, and also to determine the effectiveness of delayed recompression. An experiment was performed which, we believe, clearly answers each of these questions.

In duscussing the following experiment, we will refer to delayed recompression and immediate recompression. The former refers to recompression beginning 20 seconds after the expansion, while the latter refers to recompression beginning immediately after the chamber becomes insensitive to ions. Figure 10a shows schematically the use of the valves to accomplish the above. Valves 1, 2, and 3 are operating precisely as before. Continued expansion with valves 4 and 5 is not used. Valve 6 represents the recompression valve.

Considering first the delayed recompression, seven consecutive expansions were observed photographically. The first two expansions were normal as shown in Figure 10a and gave the background density (one drop in 4 cm^3). In the third expansion valve 4 was used to purposely over-expand the chamber well into the fog region, giving a drop density of over 200 per cm^3. On the following expansion, which was normal, the background was one drop in 2 cm^3, and on the fifth expansion the background was normal for this mode of operation. It is interesting to note that the chamber has almost completely cleaned itself in one expansion without intermediate expansions, whereas in some chambers this would require a number of hours of continuous operation.

The exact procedure was used for immediate recompression, the results for this and delayed recompression being shown in Figure 10b. Points of

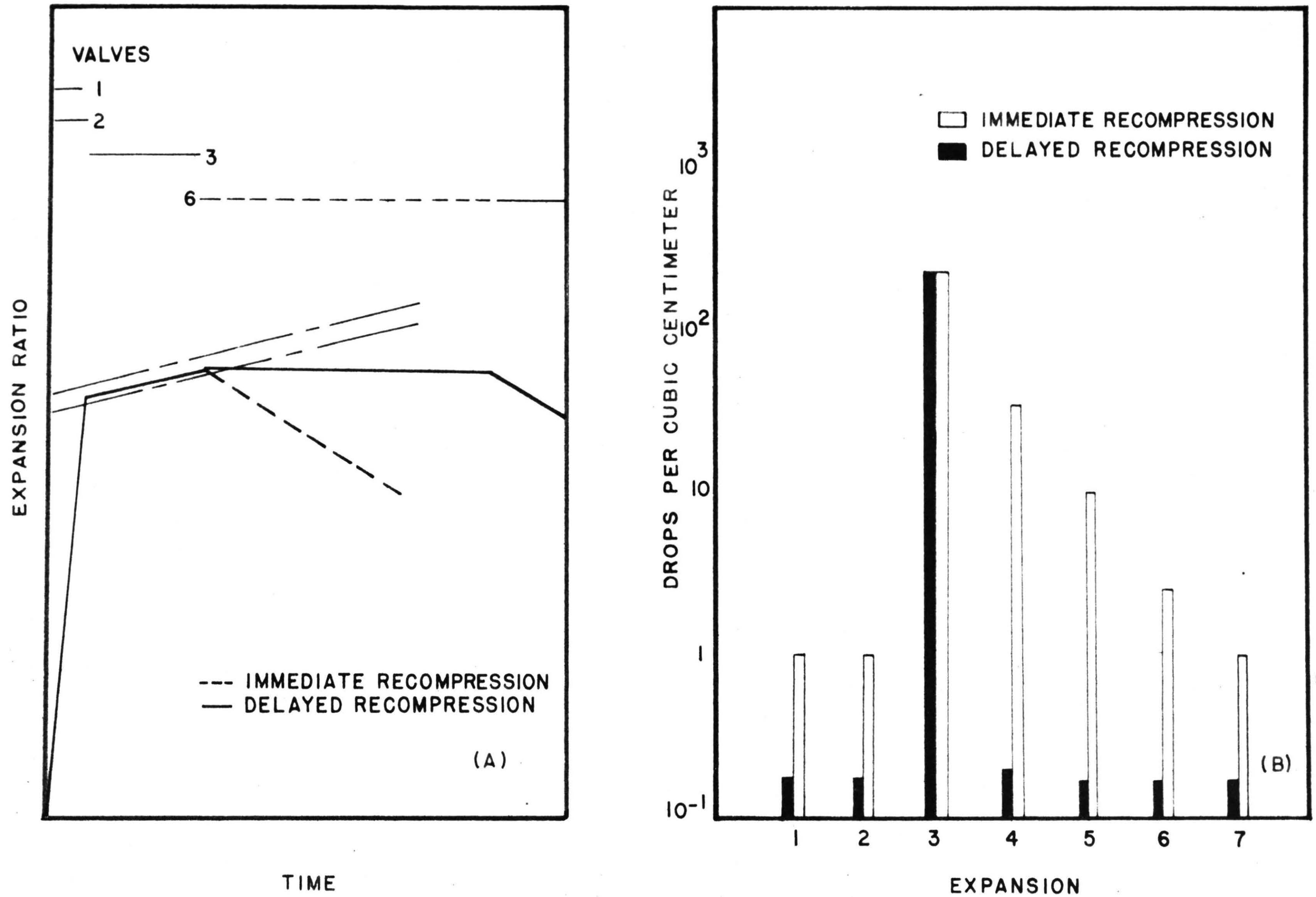


FIG. 10 (A) SCHEMATIC OF EXPANSION METHOD
(B) DATA ON RE-EVAPORATION NUCLEI

interest are the following:

(a) Normal background for immediate recompression is 4 times greater than that for delayed recompression.

(b) Expansion 4 showed a background of 40 drops per cm^3 for immediate recompression; expansion 5 showed 10, expansion 6 showed 2, and finally in expansion 7 the background was back to one drop per cm^3.

The above results surely indicate the value of delayed recompression and at the same time show strong evidence in support of the existence of re-evaporation nuclei. These results indicate that in the case of delayed recompression, the evaporation of the condensed vapor from the drops is slow enough so that almost all of the drops fall into the liquid before reaching an equilibrium size. However, in the case of immediate recompression, the evaporation process is accelerated and a large number of drops reach equilibrium size before contacting the liquid. These nuclei are then present to be condensed upon in the next expansion.

3. Background Characteristics. In the experiment mentioned above, multiple photography was used. Seven frames were taken of each expansion, the first frame being taken .6 second after the expansion began and all succeeding frames at intervals of .3 second. In this way we had data on background for two seconds during each expansion, the chamber being sensitive to ions throughout the period. Although only one frame from each expansion was used for data mentioned above, the same film was used to study the characteristics of the background distribution as the expansion progressed.

It was found that the background density in the center portion of the chamber is essentially constant throughout the sensitive period, while the background density along the walls increased several fold with time. The increase near the walls is attributed to the uplifting convection currents due to the heating effect of the walls. Accordingly, it was decided that only the 11 x 11 cm square already mentioned would be used in taking of data. This area was picked for convenience since the sweep field grid[7] is visible in the photographs and its center square is of this size.

It was also found that the turbulence in the center of the chamber suddenly becomes quite pronounced about three seconds after the expansion starts. This accounts for the time at which valve 3 is stopped (Table 1) allowing the chamber to become insensitive to ions. Attempting to retain sensitivity after this time in the expansion proves worthless and the remaining portion of the total expansion is expended using valves 4 and 5 in such a fashion that re-evaporation nuclei are eliminated.

4. Nuclei Produced by Unfiltered Flash Illumination. Figure 11 shows the variation of background density for each of seven unfiltered flashes taken at intervals of .3 second during one expansion. The variation is plotted as a function of increasing distance from the flash tube. The first flash shows the background density as it would appear if the illumination were filtered, since the droplets require a period of time to grow to photographable size. Each of the next four flashes indicates an almost linear increase in the background for any given position in the chamber. On the last two flashes, the background seems to have reached a maximum value. It seems reasonable to assume that a steady state has been reached between the rate of formation of the nuclei and the rate at which they are falling from the field of view. The decrease in density with increasing distance from the flash tube seems to indicate only the

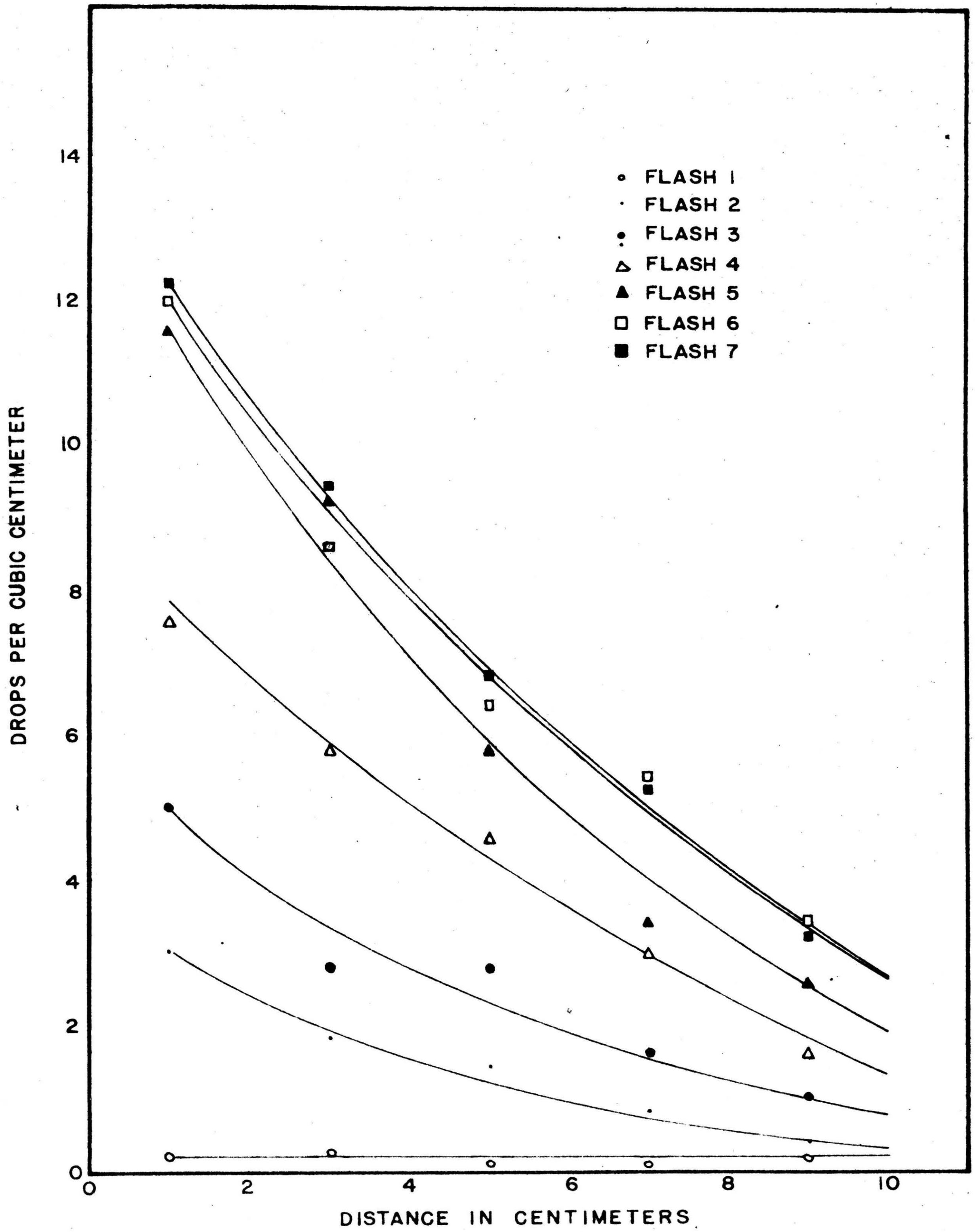


FIG. 11 BACKGROUND PRODUCED BY UNFILTERED FLASH ILLUMINATION

character of the illumination. This decrease seems reasonable in that the light beam is collimated by a cylindrical reflector[7].

Kassner[6] has indicated in private discussions that he has observed a much more dense formation of background with an unfiltered flash tube, the background being sufficiently dense to take the chamber several hours to return to normal. He inserted as much as 6 inches of plate glass between the flash tube and the chamber without appreciably changing the density. This surely indicates that the glass he was using did not appreciably diminish the wavelength or wavelengths of light causing the process to take place. On the other hand, the glass cylinder of the chamber used in this study may be absorbing some of the light causing the process. No proof has been found to substantiate the above.

5. Nuclei Produced by a Quartz Mercury Lamp. The quartz irradiation system mentioned in Chapter III was used to study the formation of photochemical nuclei. The following observations were made:

(a) These nuclei are insensitive to the electric clearing field.

(b) They will remain in the chamber to be condensed upon for at least 2 minutes after they were formed.

(c) There is no threshold supersaturation required to achieve the condensation. The degree of supersaturation required for condensation depends upon the intensity of the irradiation and the period of time during which the chamber is irradiated.

The statement (a) above agrees with Saltmarsh[11] and indicates that the nuclei formed are uncharged. The result of (b) is contradictory to Beck's statement[2] that the nuclei are unstable and that they probably have a short enough lifetime so that those formed but not condensed upon in one expansion will not be present to be condensed upon in the following expansion. This is certainly not the case.

The conclusion stated in (c) results from a series of observations in which the irradiation took place for a two minute period between expansions, the expansion ratio being changed for each observation. It was required that the chamber be completely free of drops in the expansion immediately prior to the irradiation period, except in the instance when the supersaturation was sufficient to effect condensation on ions produced by high energy particles. In this case the chamber was operating normally. Expansion ratios used ranged from 1.05 to 1.15. For an expansion ratio of 1.05 and an irradiation of 2 minutes prior to the expansion, drops appeared only near the quartz window in the chamber. The density of drops in this region was estimated to be about 100 per cm^3, while there were none outside the region. With increasing supersaturation during the same expansion, the area in which drops were formed increased, the density in the region remaining as it was in the first case cited. The constancy of droplet density is probably explained by the fact that the existing droplets have depleted the vapor density within the region sufficiently to greatly reduce the supersaturation in this region. Even though additional nuclei might exist in this region, they would not be condensed upon. The drop density outside the dense drop region continued to remain at zero. Finally, at an expansion ratio of 1.15, the dense cloud of drops covered the entire chamber.

The same type of observations were made keeping the expansion ratio at a value of 1.11 and varying the duration of the irradiation prior to the expansion. The irradiation period was varied from 10 seconds to 2 minutes and the character of the drop density was very similar to that mentioned above, the area of drop formation increasing with increasing irradiation time.

Now, keeping the above results in mind, it seems proper to refer again to C. T. R. Wilson's statement already mentioned in Chapter I. He was led to the conclusion that the nuclei in question were water droplets containing hydrogen peroxide, the amount of which, in each droplet, increased during prolonged exposure to ultra-violet light with a resulting increase in the equilibrium diameter of the droplet. If the above postulate were to be correct, this would indicate that, with adequate exposure to ultra-violet light, these nuclei would become quite large and act very much like dust particles as centers for condensation. The larger they would become, the smaller the supersaturation required to cause condensation.

The results of the experiments in question seem to agree with the ideas set forth above and could be in complete agreement with the conclusions drawn by Wilson. It should be recalled, however, that Saltmarsh[11] failed in her attempt to detect hydrogen peroxide in the experiment she performed. This certainly does not indicate positively that hydrogen peroxide was not being formed in the process, as pointed out in a discussion of Saltmarsh's paper[11].

6. Nuclei Produced by Clearing Field Electrode. It has been observed that if the clearing field ring is not properly coated, nuclei are formed near the ring and are condensed upon during the expansion. An explanation for this has been that at sharp points on the electrode, where the field could be quite high, ions are produced which may be a source of background in the chamber. Observations of this phenomena showed that drops were produced when the clearing field was left on after the expansion began; however, if the clearing field was turned off at the initiation of

the expansion they did not appear. It was also found that these nuclei are condensed upon at supersaturations less than that required for condensation on ions produced by high energy particles. An explanation for this is not obvious; however, a possible explanation is that a strong electric field in the vicinity of the corona point reduces the required supersaturation enough to cause condensation at slightly lower expansion ratios.

7. Other Field-Sensitive Nuclei. In the process of studying the production of photochemical drops at small supersaturations, it was found that there are nuclei which are swept out by an electric field, but, in the absence of one, are condensed upon at supersaturations less than that required for ions. It was established that these drops were certainly not the result of photochemical processes and that, with the field off, the density increased from expansion to expansion until an equilibrium density was reached. From time to time the population of drops in a particular area resembled the characteristics of a diffuse track. It should be pointed out that if the expansion ratio had been sufficient to effect condensation on ions, the entire chamber would have been filled with drops in the absence of the electric field. As in the case of the nuclei produced in the previous section, there seems to be no obvious explanation for this phenomenon.

Chapter V

CONCLUSION

The experiments performed and the results found have been discussed in detail. In this chapter these results will be summarized, and suggestions will be made for further work.

1. Summary. Following is a list of results which have been found that are of particular significance:

(a) The cloud chamber used is easily capable of operation with an average background of one drop in 20 cm^3.

(b) The effectiveness of delayed recompression and continued expansion at a supersaturation less than critical in the reduction of background has been established.

(c) Evidence supporting the existence of re-evaporation nuclei as the principal source of background has been presented.

(d) The production of field-insensitive photochemical nuclei has been verified, and it has been established that, if these nuclei are unstable, they have a reasonably long lifetime.

As a result of the many experiments performed, there are five classes of condensation nuclei which have been observed.

(1) Uncharged aggregates of molecules which are condensed upon at supersaturations greater than the critical supersaturation for ions.

(2) Ions formed by high energy particles.

(3) Field-sensitive nuclei produced by the clearing field electrode which may be condensed upon at supersaturations less than critical.

(4) Field-sensitive nuclei which are condensed upon at less than critical supersaturation and which appear randomly

and as fragments of tracks in the chamber in the absence of of an electric field.

(5) Field-insensitive photochemical nuclei which may be condensed upon at most any degree of supersaturation depending upon the period of time and intensity of ultra-violet irradiation.

Classes (3), (4), and (5) exist in the chamber under the conditions mentioned; however, processes responsible for these have not been established.

2. Suggestions for Further Work. A more thorough study of photochemical nuclei should be carried out. The most important determination to be made is the threshold wavelength for the process which will help establish the proper filter to use in the flash illumination system and give greater insight into the photochemical processes resulting in condensation nuclei which are energetically possible.

Further investigation should be made on classes (3) and (4) mentioned above in an effort to determine the type of charged nuclei being produced.

As has been pointed out, versatile as the chamber is in its operating characteristics, there are two changes which should be made in its design. The main valve should be changed in favor of one which will assure greater reproducibility in achieving the same expansion ratio for each expansion. In addition to this, the lower semispherical hole plate should be replaced with a larger one so that a larger total expansion can be achieved. This will facilitate operating the chamber with a greater height of sensitive volume and at the same time keep the background density as low, if not lower, than has been achieved in this study.

The suggestions mentioned here will give a still better insight into the causes of background and methods by which this background may be eliminated so that a proper search can be made for new particles in cosmic rays ionizing less than the minimum ionization of the electron.

BIBLIOGRAPHY

1. Allen, K. R., Lipsicas, M., Williams, W. F., and Fotheringham, D., "Stereoscopic Cameras for Use with a Wilson Cloud Chamber", R. S. I., 24, No. 7, p. 501 (1953).

2. Beck, C., "Optimum Liquid Combinations for Cloud Chambers", Rev. Sci. Instr., 12, p. 602 (1941).

3. Das Gupta, N. N., and Ghosh, S. K., "A Report on the Wilson Cloud Chamber and Its Applications in Physics", Rev. of Mod. Phys., 18, No. 2, p. 225, (1946).

4. Good, W. B., "A Search for Particles Ionizing More Lightly Than the Electron", Ph. D. Thesis, University of Alabama, 1956.

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

6. Kassner, J. L., Jr., "A Search for New Particles in Cosmic Rays with a Large Cloud Chamber", Ph. D. Thesis, University of Alabama, 1957.

7. Mettenburg, C. W., "An Improved Long Sensitive Time Wilson Cloud Chamber", M. S. Thesis, Missouri School of Mines and Metallurgy, 1958.

8. Newth, J. A., "Photography and Illumination", Nuovo Cimento II, Ser. 9, p. 302 (1954).

9. Rollefson, G. K., and Burton, M., Photochemistry and the Mechanism of Chemical Reactions, Prentice Hall, Inc., New York, 1939.

10. Ruark, A. E., "A Cloud Chamber Search for Free Magnetic Poles", A Proposal to the National Science Foundation (1953).

11. Saltmarsh, M., "Experiments on Condensation Nuclei Produced in Gases by Ultra-violet Light", Proc. Phys. Soc. (London), 27, p. 357 (1914-15).

12. Walker, J., Tagliaferri, G., Bower, J. C., and Hadley, D. W., "A Simple Fast-recycling Cloud Chamber", J. Sci. Instrum., 33, p. 113 (1956).

13. Wilson, J. G., The Principles of Cloud Chamber Technique, Cambridge Press, 1951.

VITA

Donald A. Rinker was born September 25, 1932, in Ottawa, Illinois, the son of Mr. and Mrs. Lloyd M. Rinker. He received his elementary education in the Grand Ridge and Ottawa, Illinois public schools, and was graduated from Streator Township High School, Streator, Illinois, in June, 1950.

In September 1950, he enrolled at Illinois Wesleyan University, Bloomington, Illinois, and received a B. S. Degree in Mathematics in June 1954. He entered the United States Army in September 1954, and was discharged in September 1956, at which time he enrolled in the Graduate School of the Missouri School of Mines and Metallurgy as a candidate for the degree of Master of Science, Physics Major.

A STUDY OF BACKGROUND IN A LONG SENSITIVE TIME WILSON CLOUD CHAMBER

BY

DONALD A. RINKER

AN

ABSTRACT

submitted to the faculty of the

SCHOOL OF MINES AND METALLURGY OF THE UNIVERSITY OF MISSOURI

in partial fulfillment of the work required for the

Degree of

MASTER OF SCIENCE, PHYSICS MAJOR

Rolla, Missouri

1958

A STUDY OF BACKGROUND IN A LONG SENSITIVE TIME WILSON CLOUD CHAMBER

A long-sensitive time Wilson Cloud Chamber has been built and tested. A usable sensitive time of 2.5 seconds has been achieved by the use of a system of five expansion valves, the first three of which are used to obtain the sensitive time and the final two to continue the expansion at a supersaturation slightly less than critical in order to allow all droplets formed to grow in size and fall into the liquid. This system of continued expansion, coupled with delayed recompression, has been proved to reduce the background density in the chamber to an average operating value of one drop in 20 cm^3.

Re-evaporation nuclei have been investigated and evidence has been given supporting their existence as well as their virtual elimination as a source of background in this chamber. The production and existence of photochemical nuclei has been studied, the primary results being that these nuclei are uncharged and that the supersaturation required for condensation depends upon the duration and intensity of ultra-violet irradiation.

Five classes of condensation nuclei were observed in the chamber, each of which present a potential source of chamber background. These are: (1) uncharged aggregates of molecules condensed upon at super-saturations greater than that required for ions, (2) ions formed by high energy particles, (3) field sensitive nuclei produced by the clearing field electrode which are condensed upon at supersaturations less than critical, (4) field-sensitive nuclei condensed upon in the absence of an electric field and requiring less than critical supersaturation, and (5) field-insensitive photo-chemical nuclei which may be condensed upon at most any degree of supersaturation depending upon the period of time and intensity of ultra-violet irradiation.

The low background and long sensitive time mentioned can be achieved easily due to the great versatility in operating conditions afforded by the expansion valve system and the electronic time delay and cycling units.