1961

# A systematic study of experimental parameters in a cloud chamber search for subionizers

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# A SYSTEMATIC STUDY OF EXPERIMENTAL PARAMETERS IN A CLOUD CHAMBER SEARCH FOR SUBIONIZERS

BY

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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 IN NUCLEAR ENGINEERING

Rolla, Missouri

1961



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Approved by

(Advisor)

ACKNOWLEDGEMENTS

The author wishes to express his sincere appreciation to Dr. James L. Kassner, Jr., Associate Professor of Physics, for the guidance and assistance extended by him during the course of this research.

Thanks are due to Mr. James Hornkohl for his assistance with the electronic equipment; to Mr. Sergio Lerda-Olberg, and Mr. Thomas Kemple for their assistance in carrying out the experiments; to Mr. Herbert Pruett for his help in the shop; and to Mr. Lee Anderson and the Mechanical Engineering Department for construction of the fast expansion valve.

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# CHAPTER I

## INTRODUCTION

1. General. There now exists some thirty so-called fundamental particles, most of which are unstable. Some have been discovered experimentally while the existence of a few had been predicted theoretically before they were detected and identified experimentally. So far, all the charged particles have charges equal to that of the electron, or to some integral multiple of the electronic charge e. As regards mass, almost all of these particles have masses greater than that of the electron with the exception of the neutrino, the rest mass of which is generally accepted to be zero. Further, all of the known charged particles are characterized by minimum specific ionizations which are larger than that of the electron. Little attention has been devoted to looking for possible particles producing specific ionizations intermediate to those of the electron and neutron. Such particles have been termed subionizers, and might be particles with sub-charge, free magnetic monopole, or electric dipole moment.

Since there is no theoretical basis for the quantization of charge, it is reasonable to consider the possible existence of particles having charges smaller than the electronic charge, or those having non-integral electron charges.

Dirac[1] has also predicted the existence of free magnetic monopoles. A relativistic pole of strength ne electromagnetic units causes specific

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[1]All references are in bibliography

ionizations of substantially the same amount as produced by a charge of ne electrostatic units. Thus a magnetic pole of strength less than e electromagnetic units would show ionization rates smaller than that of the electron.

Considerable interest has been shown in the concept of pole conjugation.[2,3] The inclusion of this symmetry condition would allow a particle to possess an electric dipole moment, which might possibly give rise to very small ionization rates. A number of investigators have looked among known charged particles for electric dipole moments, but none have been found.[4,5]

The Wilson cloud chamber appears to be the most suitable instrument for detecting subionizers since it is the most sensitive of ion detecting devices. It is capable of detecting a wide range of probable ionizations, almost all the individual ions of one sign and an appreciable fraction of ions of the other sign present being detected.

Previously, cloud chamber tracks with sub-minimum drop counts have been explained away as flukes due to recombination of ions before sensitivity, immaturity of the track, or other chamber artifacts. Since methods which would allow positive identification are not compatible with the usual cloud chamber techniques, the possibility that the above mentioned sub-minimum tracks were subionizer tracks cannot be ruled out with certainty. With the refinement of apparatus and techniques developed in this laboratory, it is now possible to differentiate chamber artifacts from true subionizers.

One typical cloud chamber track with a subnormal drop count was photographed by Rinker,[6] unfortunately without stereoscopy and multiple photography. Hence the possibility that the track is a chamber artifact cannot be ruled out with any degree of certainty.

An example of a chamber artifact observed in the author's work is shown in Plate 1. The filling gas is helium at a pre-expansion pressure of 43 cm Hg gage. The vapor supply is 2:1 ethyl alcohol-water. The print is full size. The lightly ionizing track may be seen passing through the center of the chamber. This track appears at the onset of sensitivity and only a few tracks appear in the remaining pictures of this sequence. Note that the drop count increases to about normal toward one end of the track. It may be concluded that the chamber underexpanded slightly so that the condensation efficiency was low.

2. Previous Work. Professor A. E. Ruark,[7] at the University of Alabama in 1953, initiated a program to search for subionizing particles using a Wilson cloud chamber. He first conceived of multiple photography as a technique useful with the Bearden chamber. The Alabama group employed incandescent lights for photography and found that considerable resolution was lost. They also established the advantage of the water floor chamber as a means of reducing background. They observed some tracks with low drop counts but were unable to identify them with any possible subionizer.

In 1957, Kassner, who worked under Ruark at Alabama, initiated a similar program at the University of Missouri School of Mines and

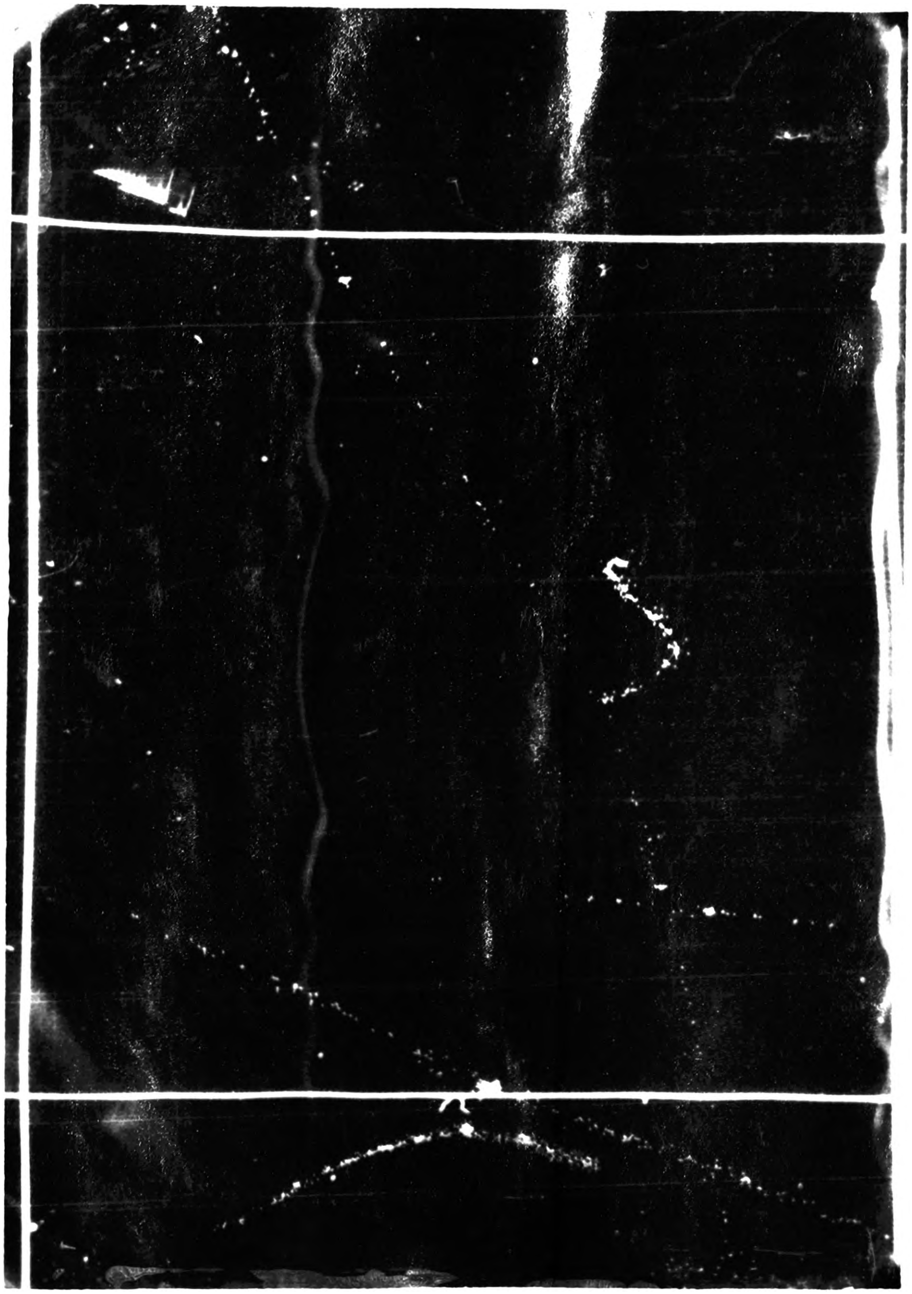


Plate 1. An example of a chamber artifact. Sub-normal drop counts are observed along most of the track while the drop count near the top of the picture indicates close to the normal minimum ionization. Examination of the other photographs of this expansion indicates the chamber failed to expand fully leaving the condensation efficiency low. The chamber gas is helium.

Metallurgy. Kassner and Mettenburg[8] pioneered a multiple valve expansion system as a means of lengthening the sensitive time. Mettenburg assembled the chamber in its original form and determined some operating parameters.

Kassner and Rinker[9] continued the development of the chamber by employing a continued expansion just below the sensitive region as a means of reducing background. This technique reduced the background caused by re-evaporation nuclei by suppressing their formation. Rinker also studied the other causes of background and verified the existence of photo-chemical nuclei as a source of background.

Kassner and Hughes[10] implemented a fast overcompression technique to reduce cycle time, and designed a workable high energy flash photography system and a special stereo-movie camera.

3. Scope of Present Work. At this point the apparatus was becoming useful as a detection instrument for subionizers. The author's problem was to make minor alterations in the equipment to improve reproducibility, systematically study the experimental parameters, and undertake the first serious search for subionizers.

## CHAPTER II

## DESIRED CONDITIONS FOR SUBIONIZER SEARCH

1. Selection of Apparatus. Pictorial tracking detectors offer a considerable advantage should the subionizer have a short lifetime or occur only rarely. The observation of a single subionizer by this method would carry considerably more weight than a single event in some other type of detector. Since the ionization rate of a subionizer might be quite low, the tracking device should be capable of detecting very low ionization rates; that is, the occurrence of accidental background should be quite low.

1.1 The Diffusion Chamber. The diffusion chamber might seem suitable because it is continuously sensitive; this would certainly increase the chance of observing very rare events. The continuous rain of background droplets is, however, a serious objection to employing the diffusion chamber for a subionizer search.

1.2 Nuclear Emulsions. Nuclear emulsions currently available are not sensitive enough to detect particles ionizing substantially more lightly than the electron.

1.3 The Bubble Chamber. The bubble chamber does not seem suitable for the detection of subionizers. The sensitive medium of the bubble chamber has a density comparable to that of the nuclear emulsion, which would lead one to believe that a very lightly ionizing particle might produce a sufficiently large number of bubbles in the detector to be recognizable as a particle trajectory. Glaser[11] has shown that a bubble carrying a single charge would collapse whereas a bubble carrying N charges may develop under suitable superheating conditions, and since ionization events due to a very lightly ionizing particle are likely to take place at considerable intervals, it is believed that sufficiently large groups of ions required to produce bubbles of N charges each would be unlikely to occur with sufficient frequency to make the bubble chamber suitable for the detection of subionizers.

1.4 Scintillation Counting Technique. Shuskus[12] developed an ingenious scintillation counting technique for a search for subionizers in the cosmic ray flux. He found that the minimum detectable subionizer flux would be at least 5% of the total cosmic ray flux. If subionizers occur with this frequency they would surely have been already detected. Even if the scintillation technique were to be developed further to make it more feasible, the data obtained from cloud chamber photographs would carry more conviction.

1.5 The Wilson Chamber. The Wilson cloud chamber appears to be best suited for the detection of subionizers; it is sensitive to individual ions and is capable of very low background levels, one drop in 20 $cm^3$ and less.[13] The desired conditions in a Wilson cloud chamber for a subionizer search will be discussed below.

2. Background. In carrying out a search for subionizers with a Wilson cloud chamber, a very low background is desired. A subionizer

might produce a track of very low density so that it would be very difficult, if not impossible, to look for, and identify a subionizer track if there was appreciable background.

2.1 Re-evaporation nuclei and drop fall-out. One of the major sources of background is re-evaporation nuclei. Re-evaporation nuclei are droplets which have insufficient time to grow and fall out before supersaturation ceases. These evaporate into nuclei which act as condensation centers in the following expansion producing background droplets. Background due to these re-evaporation nuclei is effectively reduced by suppressing their formation by a technique developed by Rinker.[14] This technique will be described in Chapter 3. Any means of insuring good drop fall-out will greatly aid in suppressing the formation of re-evaporation nuclei. This is accomplished (a) by maintaining a high degree of supersaturation (below the critical value) while the droplets are falling out, (b) by having a small height of sensitive volume, and (c) by using a gas of low viscosity. Further details will be given in the next chapter.

2.2 Photonuclei. It is well known that certain components of the light used to illuminate cloud chambers produce background. Photochemical nuclei or photonuclei are produced by certain ultraviolet components of the illumination. These nuclei add to the background density of the chamber unless effective filters are employed to prevent their formation.

2.3 Ion and Cloud Limits. In order to produce good tracks with minimum background, the chamber must be placed between the so-called ion and cloud limits. The ion limit is defined as the critical supersaturation required to produce condensation on ions. The ion limits for positive and negative ions differ in general for a particular gas-vapor combination. When as many as 20% of the negative ions are condensed upon, essentially all of the positive ions are effective as centers of condensation in air and alcohol-water mixtures. Small clusters of molecules become effective as condensation centers at supersaturations slightly higher than that required for condensation on ions; this is referred to as the cloud limit. The region between the ion limit and the cloud limit is quite narrow, and extremely accurate control devices are required to place the chamber between these limits initially and to maintain this situation for a few seconds. C. E. Nielson[15] found that the ion and cloud limits were not sharply defined so that if very high ion sensitivity and low background are simultaneously required, the operating range is considerably reduced. This places even higher requirements on the operating mechanism.

3. Sensitive Time. The length of time during which there is sufficient supersaturation to cause condensation on newly formed ions is called the sensitive time. A long sensitive time is desired since this would give a greater probability for observing subionizing particles which occur very rarely. A long sensitive time also permits multiple photography to be employed so that the growth of drops and tracks can be followed in each expansion. This prevents mistaking

remnants of old tracks and other chamber artifacts for true subionizers.

4. <u>Photography</u>. If subionizers occur in cosmic rays, velocities up to the velocity of light are possible. At any rate, the particle will traverse the chamber very quickly compared to the time required for condensation. About one tenth of a second is required for full development of the droplets formed on the ions left along the trajectory. The droplets begin to fall immediately, distorting the trajectory. Thus, a photograph is clearly necessary as a record of the trajectory which may be analyzed later.

4.1 <u>Multiple Photography</u>. To take advantage of the long sensitive time of the chamber multiple photography is highly desired. Multiple photographs of each expansion permit one to observe and follow track development so that remnants of old tracks, and insufficiently developed tracks may be recognized and disregarded. They also permit one to identify background droplets so that those present prior to the entry of a track may be neglected.

4.2 <u>Stereoscopy</u>. Close to the chamber surfaces the supersaturation and condensation efficiency are low; tracks formed in these regions have inherently low density. To recognize and identify such tracks their spatial position must be established. This is accomplished by taking the photographs stereoscopically. Stereoscopy also gives the spatial layout of a track so that interesting collision and decay phenomena may be analyzed.

5. Illumination. A uniform, well collimated beam of light is desired to prevent scattering from the liquid surface and top glass. The light should be of sufficient intensity to provide short exposures and enough resolution for photography of individual droplets throughout the sensitive volume. By recording individual droplets, tracks are easily distinguished from random background. Typically, background droplets form on neutrals and are therefore single, while ion-pairs are commonly seen along tracks.

6. Temperature Considerations. Temperature is one of the most important parameters in good cloud chamber work. The critical supersaturation limits depend on temperature.[16] The limits for ion and background condensation are reduced with increasing temperature, while at the same time the separation between them is also reduced. This requires that the temperature of the cloud chamber laboratory be accurately controlled. To obtain a fairly wide operating range, the chamber is best run at the lowest temperature convenient.

A temperature gradient is desired for stability. The lower part of the chamber must be cooler than the top. This temperature gradient is useful in two ways: it prevents the migration of liquid to unwanted places and it stabilizes the gas of the chamber.

7. Expansion. The gas in the sensitive volume of a cloud chamber becomes saturated with vapor during the waiting interval. A fast expansion then causes a sudden decrease in the temperature of the gas causing the vapor to become supersaturated. The supersaturated vapor

condenses on any particles which serve as condensation nuclei. The degree of supersaturation has to be closely controlled if condensation only on gaseous ions (left along the path of an ionizing particle) is to be achieved. Since the region between the ion and cloud limits, called the sensitive region, is very narrow, the expansion mechanism must be accurate.

A number of investigators have sought to increase the sensitive time of the cloud chamber. It is well known that supersaturation lasts longer in pressure-defined expansions than in volume-defined expansions. In the pressure-defined expansion, local heating of the gas by conduction from the walls or from condensing drops causes a further expansion of the gas volume. Since the expansion does not end abruptly the persistence of supersaturation lasts somewhat longer.

To achieve a longer sensitive time, a slow expansion must follow the main expansion so that the temperature of the expanded gas remains constant. Clearly then, for good reproducibility, accurate pressure control must be exercised in the operation of the chamber.

8. Recovery Time. A fast overcompression technique, first described by Gaerttner and Yeater,[17] is used to reduce the recovery or recycle time of the cloud chamber. After the fast initial expansion and subsequent continued expansion, the chamber is recompressed beyond the waiting or pre-expansion pressure. In conventional cloud chambers slow cleaning expansions are employed which lower the temperature of the gas further; a long period is then necessary to regain thermal equilibrium.

But, when the chamber is overcompressed the temperature of the gas is raised. This tends to hasten the redistribution of vapor throughout the chamber, and it also hastens the re-establishment of thermal equilibrium by allowing the rapid flow of heat out of the chamber to compensate for the heat that flowed in during the expansion. It is also thought that overcompression would bring the drops to ionic or near-ionic mobilities so that they may be removed by the electric clearing field. The application of this technique is made almost mandatory by the above mentioned expansion method.

Advantage is taken of the expansion to the pre-expansion pressure by using this expansion as an intermediate expansion. Any droplets that might have re-evaporated (due to getting caught in uplifting convection currents near the vertical walls of the chamber) stand another chance of being removed.

In this chapter the selection of an apparatus for a subionizer search has been discussed. The desired conditions for a subionizer search, using a long sensitive time Wilson cloud chamber, have been outlined. Details showing how these conditions are achieved with the apparatus will be presented in Chapter 3.

# CHAPTER III

## EXPERIMENTAL CONSIDERATIONS

1. The Apparatus. In searching for lightly ionizing particles, it is desirable to look for tracks which enter the chamber during the central portion of the sensitive period. This is achieved by using a long sensitive time Wilson cloud chamber and taking a series of stereoscopic pictures of each expansion. A xenon flash tube illumination system is capable of providing high intensity illumination of short duration for the greatest possible photographic resolution.

2. The Chamber. The chamber employed is a simple Wilson cloud chamber (Fig. 1) with a sensitive volume 12 inches in diameter and 4 inches high. A liquid piston is operated pneumatically by air in a separate lower chamber. The chamber is expanded by a system of six solenoid operated valves which release the air in the lower chamber. The orifice and operating time of each valve are independently controlled, yielding an extremely flexible expansion system.

3. The Chamber Cycle. One of the primary disadvantages of the Wilson chamber is its short sensitive time and long recovery time. In this chamber a novel use of the multiple valve expansion system permits us to extend the sensitive time considerably. The cloud chamber cycle is shown in Figure 2. A fast initial expansion, AB, brings the chamber to sensitivity as rapidly as possible; the next three valves are operated in a slow continued expansion to maintain

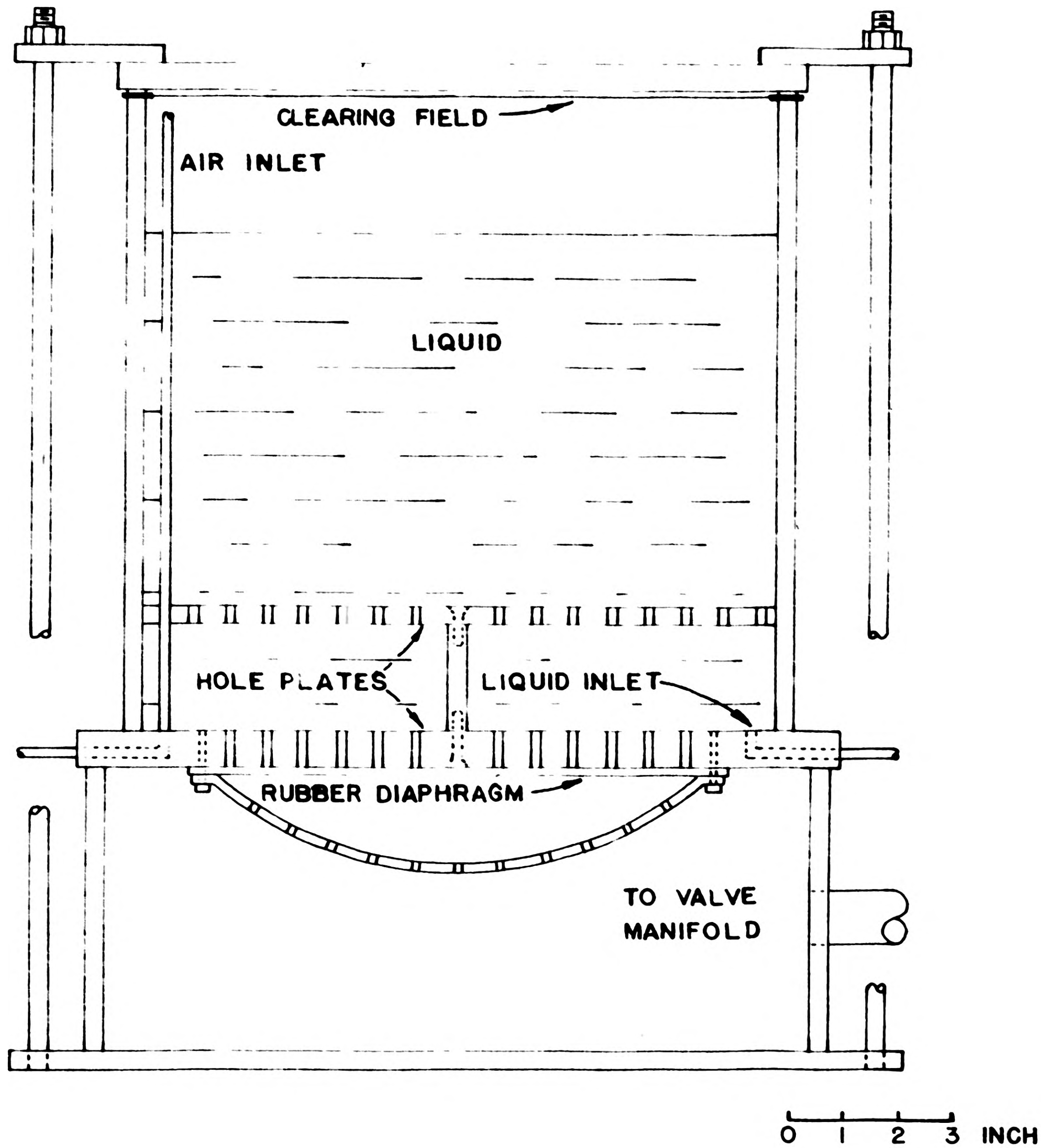



FIG. I THE CLOUD CHAMBER

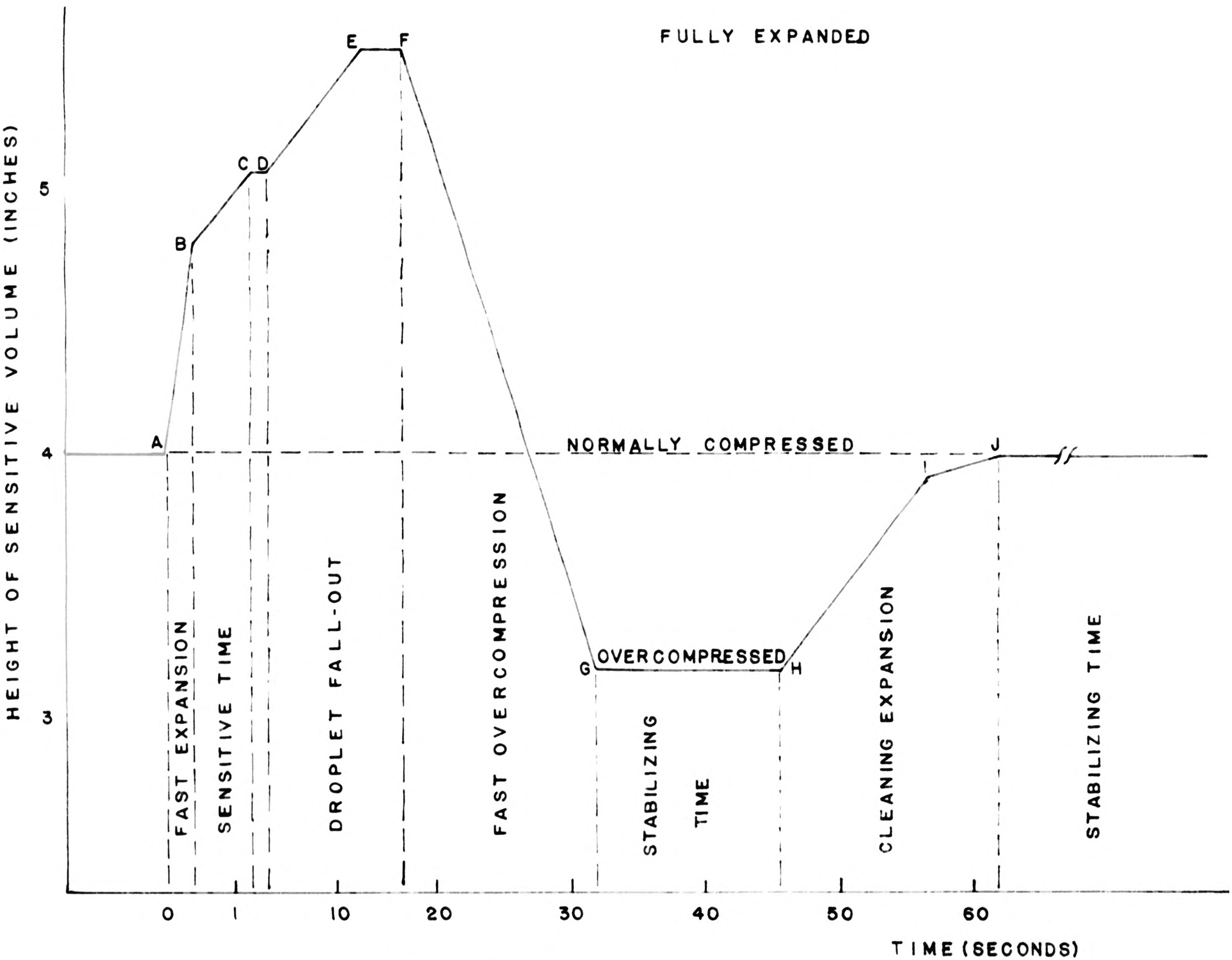



FIG. 2 CHAMBER CYCLE

sensitivity. The maximum obtainable usable sensitive time, BC, is limited by the development of convection currents. The expansion is interrupted momentarily, CD, and 's then allowed to continue slowly so that the chamber stays just below the ion limit but remains supersaturated enough to permit the droplets already formed in the chamber to grow to full size and fall out of the sensitive volume. This effectively suppresses the formation of re-evaporation nuclei. To decrease the recovery time at the end of the expansion, the chamber is recompressed beyond the pre-expansion pressure (FG). The chamber is held in this overcompressed condition for a short time (GH) to allow the chamber to stabilize itself. The expansion back to the pre-expansion pressure (HIJ) removes a considerable portion of any re-evaporation nuclei which might have formed in spite of the fall-out technique.

The fast initial expansion is carried out by a special solenoid valve designed and built at MSM. In the Gould solenoid valve used previously, the motion of the valve piston is transverse to the direction of air flow, is vibratory, and causes turbulence. Reproducibility was poor with the Gould valve. The new valve (Fig. 3) is designed to operate with the valve piston or stem moving in the direction of air flow which is now in streamline motion. Greatly improved reproducibility is achieved. Since the expansion quality is very sensitive to the amount of air escaping from the lower chamber, a rough adjustment is obtained by setting the aperture -- limiting the amount of travel of the valve stem. The fine adjustment is achieved by controlling the length of

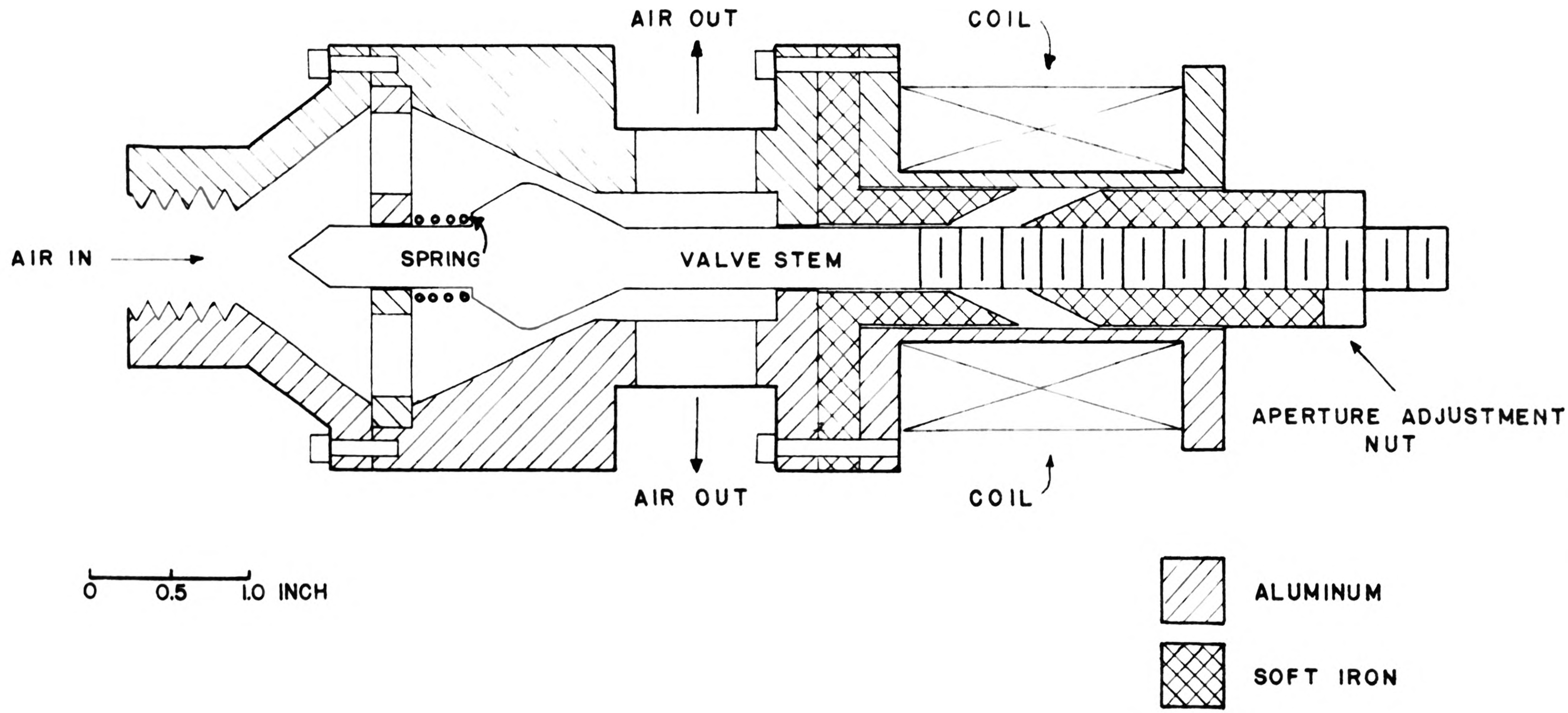



FIG. 3 FAST EXPANSION VALVE

time the valve stays open. This time is controlled to within ± 50 microseconds electronically.

4. Gas-Vapor Combinations. A number of experiments were carried out to determine the best possible gas-vapor combination to produce optimum operating conditions for the chamber. The gases used were air, argon, nitrogen, oxygen, and helium combined with pure water and with 66% ethyl alcohol-34% water mixture. Helium with the 2:1 ethyl alcohol-water mixture gave the longest sensitive time, approximately seven seconds, utilizing the available mechanical expansion ratio of the chamber. This long sensitive time is due to the low expansion ratio of the gas-vapor system, 1.085. The low viscosity of He retards the development of turbulence effects, which become noticeable only late in the expansion as compared with the situation for the other gases. Smaller turbulence currents make longer sensitive times usable for data taking purposes. The low viscosity is also a definite advantage in the clearing of old tracks by insuring rapid drop fall-out. The high thermal conductivity of helium is an advantage in regaining and maintaining thermal equilibrium.

Since a helium gas-water vapor mixture has a higher specific heat, it was expected to give a lower expansion ratio, but it was found experimentally that a vapor composed of ethyl alcohol and pure water gave a considerably lower expansion ratio than that obtained with a pure liquid. Pure alcohol is undesirable because of its high vapor pressure. Pure water has a high surface tension which raises the critical supersaturation thus requiring a higher expansion ratio. Pure water by itself is undesirable also because dust particles and impurities float on its surface whereas they settle down and sink to the bottom in a mixture which has a lower surface tension.

One tank of Matheson argon was found to contain a detrimental impurity which caused a dense background. Ordinary commercial grade Linde argon was found to be satisfactory.

5. Effect of Filters on Photonucleation. It was noticed by Hughes that the Kodak 2B filter did not effectively remove the harmful components of the light from the xenon flash tubes that were producing photonuclei. Mettenburg and Rinker did not notice this as they never operated the chamber with a full set of twenty-two flashes. The number of flashes used per expansion has been increased to twenty-two from the seven that Hughes employed. Thus, it was imperative that a more effective filter be found. A number of inorganic filters were tested as were a few commercial filters. The inorganic filters used were solutions of potassium nitrite, calcium nitrate, and copper nitrate. A Corning CS 3-73 filter, Kodak 2B, and Kodak 8K2 filters were also tested. The Kodak 8K2 filter was found to be the best as shown in (Table I). It provides the best filtering with a minimum loss of light in the longer wavelength regions.

TABLE I

EFFECT OF VARIOUS FILTERS ON THE BACKGROUND DENSITY CAUSED BY PHOTONUCLEI

| Filter | Background Density drops/$cm^3$ |
|---|---|
| None | 20.3 |
| Calcium Nitrate * | 15.0 |
| Copper Nitrate | 10.0 |
| Potassium Nitrate | 0.6 |
| Kodak 2B | 1.6 |
| Corning CS 3-73 | 0.2 |
| Kodak 8K2 | 0.1 |

*In the inorganic filters, 453 grams of the chemical are dissolved in 1000 cc of water.

6. Temperature Control. The chamber is operated in a room which is maintained at a steady temperature within ± 0.5°C. The temperature is kept at 20°C by an air conditioning unit. The cloud chamber is further enclosed to isolate it from air currents. A small heater located near the top of the chamber, keeps the chamber top slightly warmer than the bottom. This prevents the condensation of moisture and helps stabilize the gas in the sensitive volume. Some temperature gradient is required to help stop turbulence currents if short cycle times are to be employed.

7. Pressure Control. Pressure in the sensitive volume is controlled by controlling the pressure in the lower chamber with a

mercury manometer pressure control system (Fig. 4) which is an improved version of the same one used by Hughes. Arcing of the contacts in the mercury caused the formation of oxide producing a significant decrease in the accuracy of control. A layer of mineral oil on top of the mercury delayed the formation of oxide, but accuracy was still lost after long periods of operation. The problem of the oil draining down the walls of the tube further reduced its usefulness. A transistor amplifier circuit added to the pressure control system has appreciably reduced the current passing through the mercury contacts; arcing no longer occurs. During the waiting interval a slight trickle of air is fed into the lower chamber to compensate for leaks. Any excess pressure is released by a solenoid valve controlled by the mercury manometer. Pressure is now controlled to within a tenth of a millimeter of Hg which corresponds to about one part in ten thousand.

8. Illumination and Camera Control. Incandescent lighting is used for visual observation in adjusting the chamber for best operating conditions. The xenon flash tube illumination system described by Hughes is used exclusively for photography. Three flash tube reflector units like the one shown in Figure 5, are positioned on three sides of the chamber. The incandescent light unit occupies the fourth side. The flash tubes are 3/8 inch diameter, half aluminized tubular units rated at 50 watt-seconds manufactured by Amglo Corporation. The tubes are fired alternately, one for each frame taken by the stereo movie camera and synchronized by a microswitch in the camera. A system of

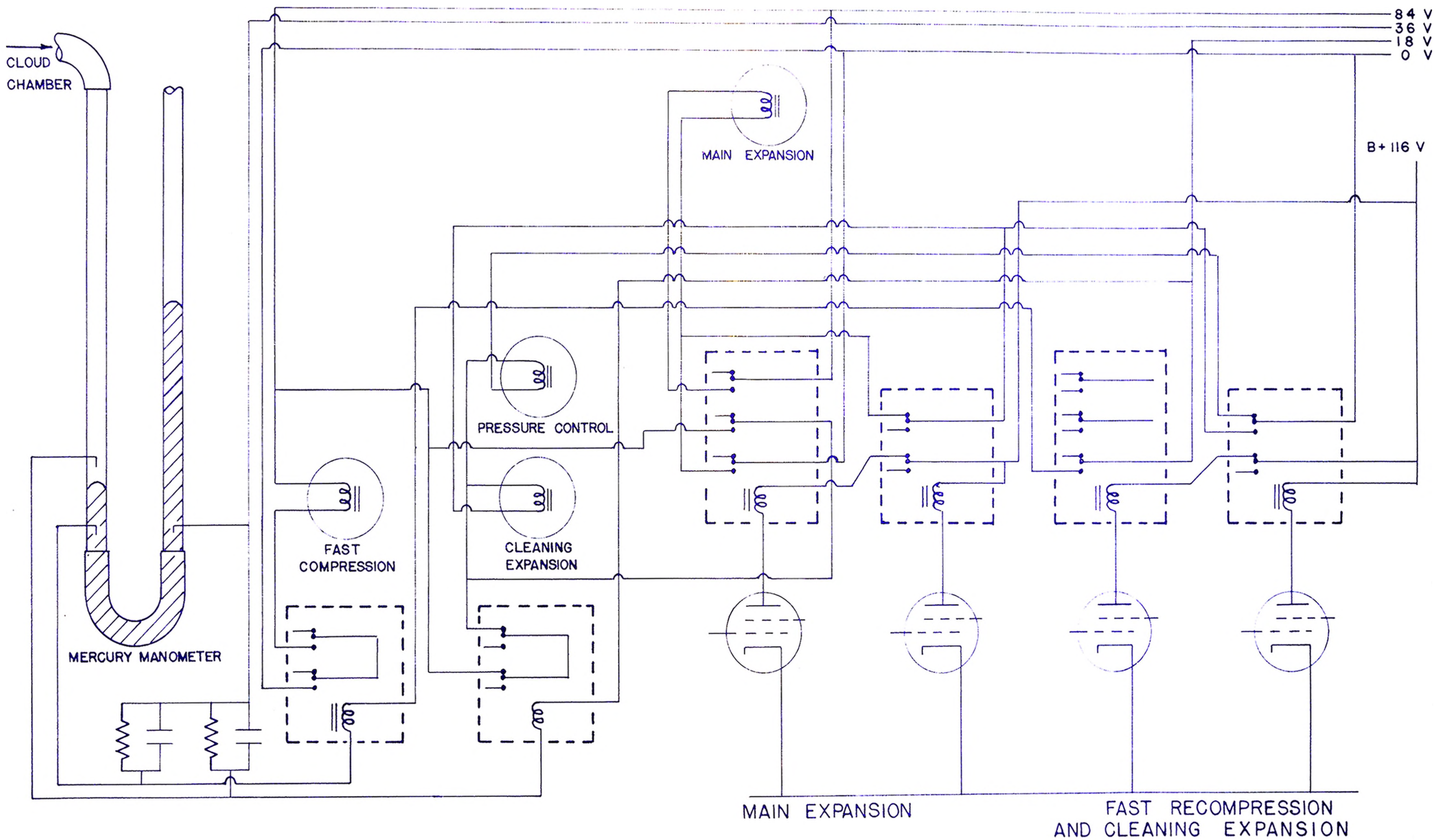
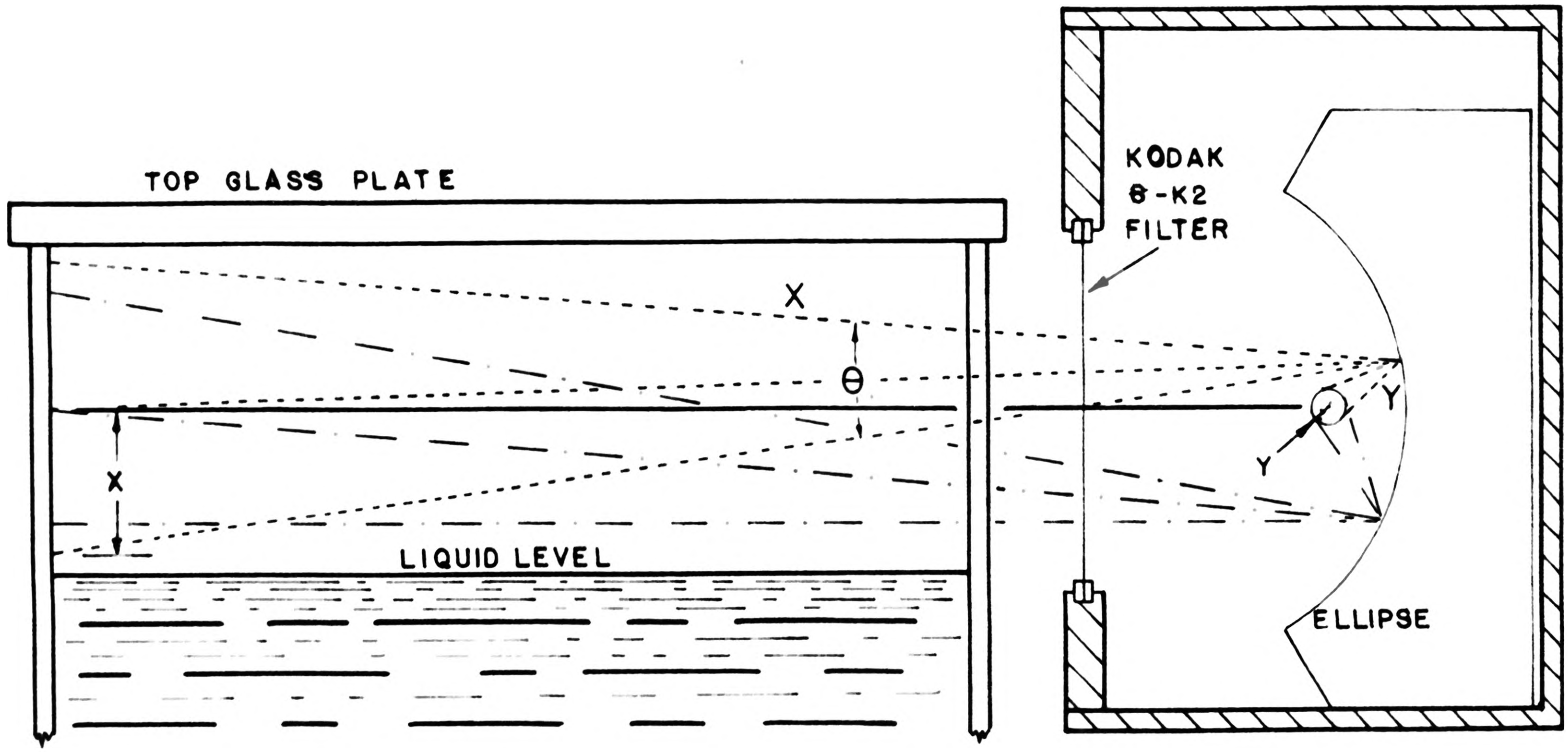



FIG. 4 PRESSURE CONTROL SYSTEM




$$\theta = \frac{x}{X} = \frac{y}{Y}$$

FIG.5 FLASH TUBE ILLUMINATION SYSTEM

twenty-two energy storage capacitors are charged up before each expansion when taking pictures. The ignitron switching circuit shown in Figure 6, fires the flash tubes in the desired sequence. Each flash has a duration of about 2 milliseconds and the peak current is slightly in excess of 500 amperes. Tight connections throughout the wiring of this circuit is a must if full light output is to be obtained. Periodic checks of all connections are desirable. It has been noticed that solder apparently disappears from soldered points in the course of time.

The motor of the movie camera is started 10 seconds before the initial fast expansion; this insures sufficient inertia in the motor and part of the gear train to make the geneva movement come up to normal operating speed in only a few frames after the magnetic clutch is activated. Table II shows the frame timing. A standard electric clock was photographed to obtain the data in the table.

9. Photography. Twenty-two stereo-pairs of pictures are taken per expansion with a special movie camera designed and built at MSM. The camera now uses 35 mm film but may be readily adapted for use with 70 mm film. In loading the camera care should be taken to see that there is sufficient slack in the film between sprockets to minimize jamming and breakage of film. A trip switch mechanism has been added to the camera which lights a small red lamp when the film tears, breaks, or runs out. The double lens system of the camera must be checked periodically to see that they are both in good focus and have the same apertures. The f-stop calibrations on the two lenses are not quite

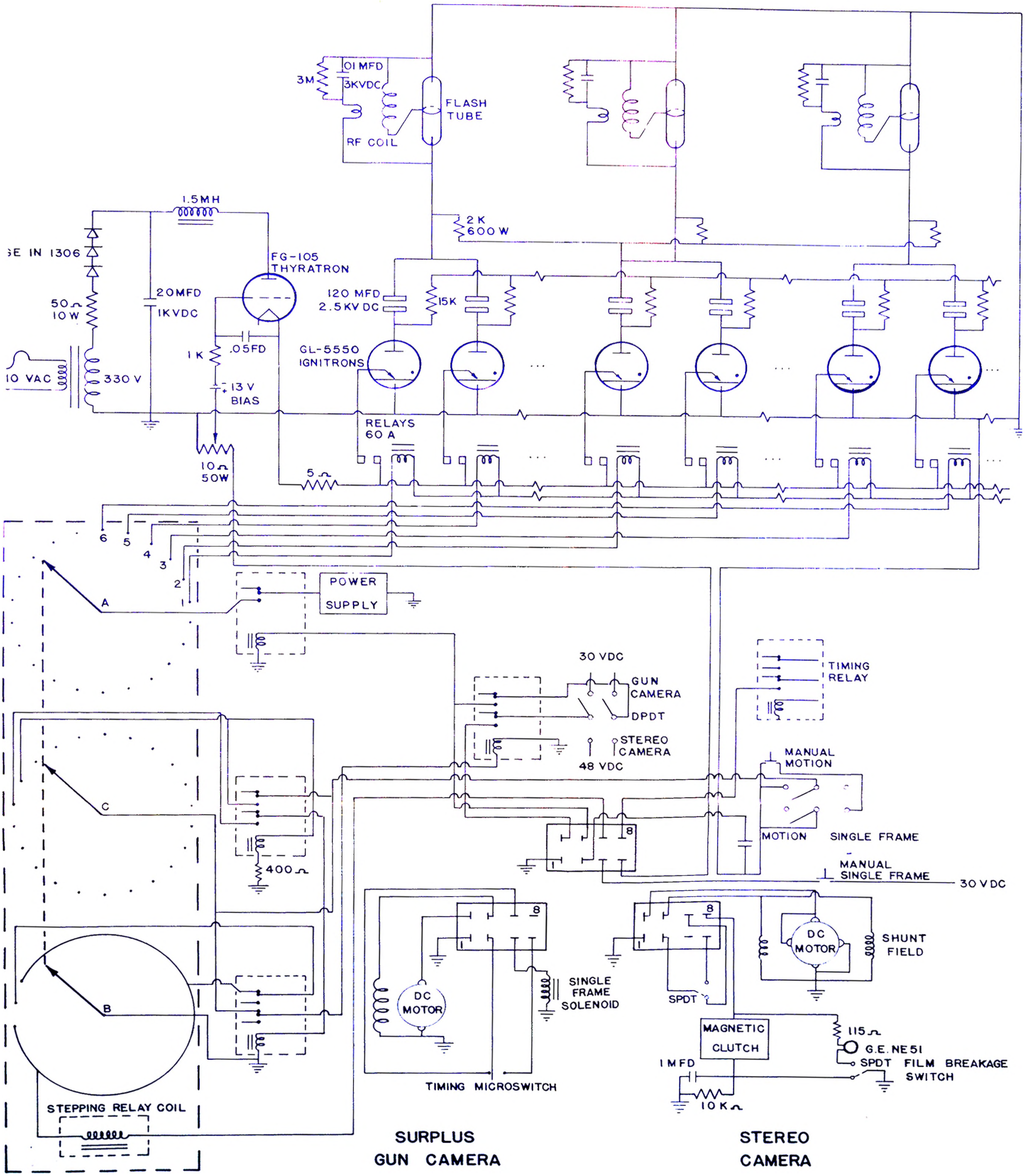



FIG. 6 ILLUMINATION & CAMERA SYNCHRONIZATION CIRCUIT

TABLE II

FRAME TIMING OF PICTURES

| Frame | Time* | Interval between frames |
|---|---|---|
| A | 0.32 sec. | |
| B | 0.40 sec. | 0.08 sec. |
| C | 0.49 sec. | 0.09 sec. |
| D | 0.58 sec. | 0.09 sec. |
| E | 0.66 sec. | 0.08 sec. |
| F | 0.74 sec. | 0.08 sec. |
| G | 0.82 sec. | 0.08 sec. |
| H | 0.91 sec. | 0.09 sec. |
| I | 1.00 sec. | 0.09 sec. |
| J | 1.08 sec. | 0.08 sec. |
| K | 1.16 sec. | 0.08 sec. |
| L | 1.24 sec. | 0.08 sec. |
| M | 1.32 sec. | 0.08 sec. |
| N | 1.40 sec. | 0.08 sec. |
| O | 1.49 sec. | 0.09 sec. |
| P | 1.56 sec. | 0.07 sec. |
| Q | 1.64 sec. | 0.08 sec. |
| R | 1.73 sec. | 0.09 sec. |
| S | 1.82 sec. | 0.09 sec. |
| T | 1.89 sec. | 0.07 sec. |
| U | 1.97 sec. | 0.08 sec. |
| V | 2.05 sec. | 0.08 sec. |

Framing Rate: 12 per second

*Measured from the beginning of the main expansion. The camera is on 42 volts DC.

identical. A slight difference in apertures (even when set on the same f-stops) will produce stereo pairs of unequal intensity.

The films used were Kodak Linagraph Pan, Tri-K Pan, and Ansco Super Hypan. The latter two gave quite satisfactory results when used with apertures f/8 and f/11. With the object distance employed, 49 cm, this gives a depth of focus of 3.1 to 4.2 cms. Faster films are desired to give good exposures at f-stop numbers 16 or 22 to obtain a greater depth of focus (See Table III). A greater object distance could be used but this would result in a net loss of resolution and light.

TABLE III

DEPTH OF FOCUS, IN CENTIMETERS

| Aperture | Object distance, cm | | |
|---|---|---|---|
| | 34.5 | 49 | 69 |
| f/8 | 1.5 | 3.1 | 6.1 |
| f/11 | 2.1 | 4.2 | 8.4 |
| f/16 | 3.1 | 6.1 | 12.3 |
| f/22 | 4.2 | 8.4 | 16.9 |

A stereo pair taken with the special movie camera is shown in Plate 2. Plate 3 shows a sequence of pictures taken in one expansion. Only one frame from each pair is reproduced. The sensitivity of the chamber is shown by the appearance of new tracks indicated by the arrows in Plate 3.



Plate 2. An Example of a Stereo-Pair

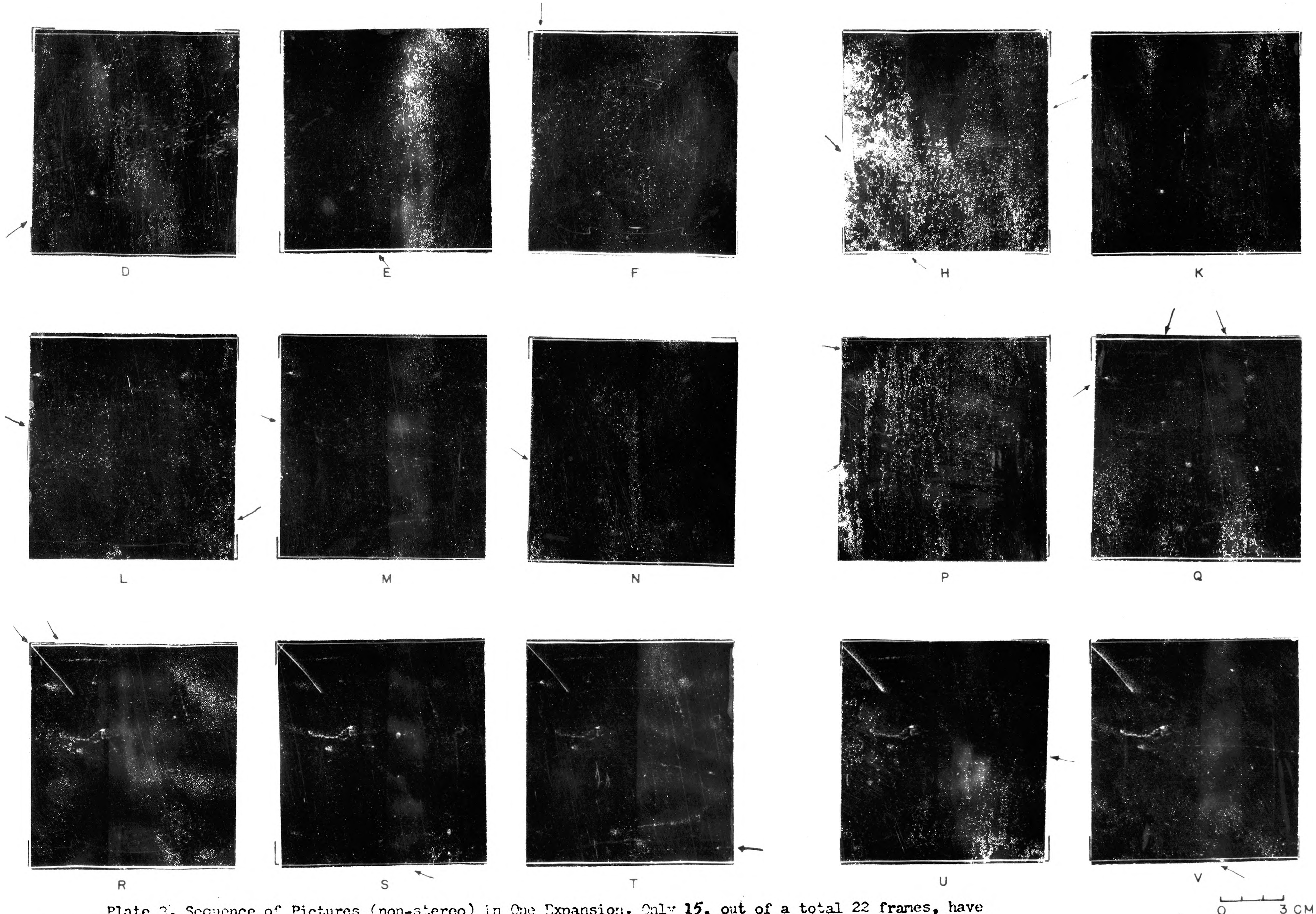



Plate 3. Sequence of Pictures (non-stereo) in One Expansion. Only 15, out of a total 22 frames, have been reproduced. The letter below each exposure indicates the actual sequence of frames. The arrows indicate the first appearance of new tracks. The interval between successive frames is approximately 0.8 sec for this series. Each exposure represents the central 11 cm x 11 cm portion of the chamber. Large images are dust particles on top glass of cloud chamber. A great reduction in resolution was encountered in printing.

10. Optimum Operating Conditions. The operating conditions are shown in Table IV. The relative operation times for the valves, camera, and clearing field are shown in Figure 7. In achieving an optimum expansion the most critical adjustment lies in the aperture and timing of Valve No. 1, the fast expansion valve. It is most convenient to set the aperture first to give tracks with the valve operating for about one quarter of a second. Then the fine adjustment, to obtain sharp tracks without background, is achieved by varying the opening time of the valve by very small amounts. Although this time is measured directly by the clock to only one hundredth of a second, a fine vernier adjustment on the control panel allows it to be varied to within about 50 microseconds. A variation of about 0.5 milliseconds either way from the optimum time is sufficient to cause the expansion to deviate noticeably from the desired condition. The slow continued expansion is carried out by valves 2, 3, and 4 whose operating times are set first. Needle valves are attached to all these solenoid valves, and the apertures are adjusted to make the chamber follow the desired expansion schedule (See Figure 8, Chapter IV). All settings are made by visual observation.

Some precautions in the operation of the chamber are in order. The top glass and clearing field wires should not be moist. A large clearing field current usually accompanies a moist top glass which stimulates the appearance of a cloud of droplets which emanate from the clearing field wires. It is found best to clean the top glass with a solution of the same composition as the chamber liquid using a squee-gee which does not leave any marks or lines on drying. Too short a waiting

TABLE IV

OPERATING CONDITIONS

1. Chamber Constituents
   Liquid: 2 parts pure ethyl alcohol to 1 part distilled water by volume. Solution blackened with Putnam black dye.
   Gas: Helium (Matheson Company)

2. Sensitive Volume Pressures at 20°C

| | |
|---|---|
| Overcompressed | 78 cm Hg |
| Normally Compressed | 43 cm Hg |
| Fully Expanded | 12 cm Hg |

3. Clearing Field, 708 volts DC, 015 microamperes

4. Cycle Time, 2 minutes 15 seconds

5. Expansion Valve Settings (Seconds)

| Valve | Start | Stop |
|---|---|---|
| 1 | 0.04 | 0.25 |
| 2 | 0.25 | 0.80 |
| 3 | 0.80 | 2.00 |
| 4 | 2.00 | 3.20 |
| 5 | 3.70 | 5.80 |
| 6 | 6.00 | 14.50 |
| 7 | 17.50 | (78 cm Hg in manometer) |
| 8 | 45.00 | (43 cm Hg in manometer) |

6. Room Temperature, 20°C

7. Illumination
   Incandescent: 4 G. E. 200W clear lamps
   Operating voltage, 200 volts AC
   Heat filter, water
   Flash: 3 Xenon flash tubes, 3/8 inch diameter
   Operating voltage, 2000 volts DC
   Ultraviolet filter, Kodak 8K2

8. Camera
   Stereo-movie camera, 35 mm
   Operating voltage, 42 volts DC
   Lens opening, f/8 and f/11
   Object distance, 49 cms
   Depth of focus, 3.1 to 4.2 cm
   Framing rate, 12 per second and 16 per second
   Magnification, 1/9

9. Film and Processing
   Kodak 35mm Tri-X and Linagraph Pan, Ansco 35mm Super Hypan
   Developer, Kodak D-19, 7 minutes at 20°C (1500 cc)
   Stop bath, Kodak SB-5, 1 minute at 20°C (1500 cc)
   Fixer, Kodak F-5, 30 minutes at 20°C (1500 cc)
   Washed in running tap water for 2 hours
   Each batch of developer, stop bath, and fixer is used on 100 feet of film only.

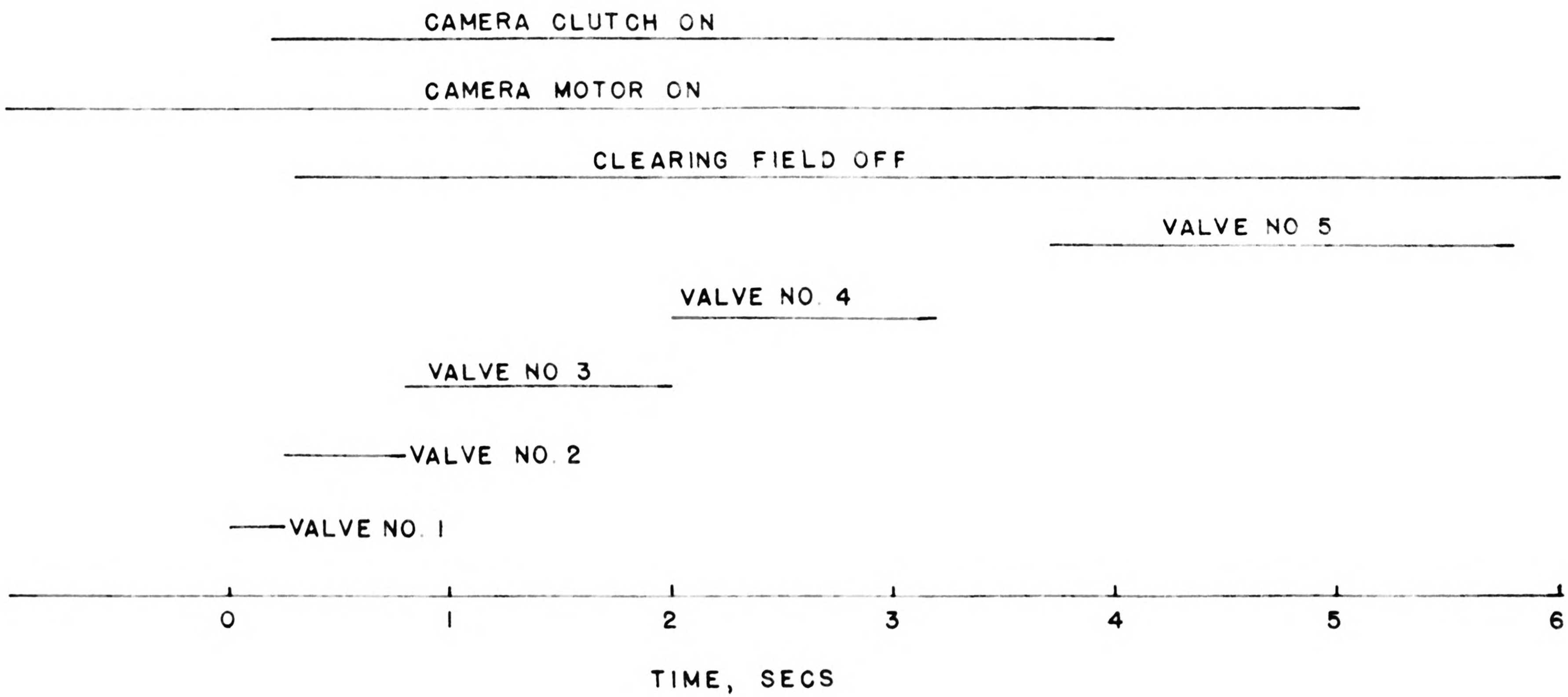



FIG. 7 RELATIVE CONTROL OPERATION TIMES

interval may lead to incomplete vapor redistribution and poor track quality. If the temperature gradient maintained across the sensitive volume is too great, the gas will be so stable that vapor redistribution will be appreciably slowed down. Too high a temperature gradient will also cause an appreciable difference in the condensation efficiencies at the top and bottom regions of the sensitive volume. Hence, care must be taken not to overstabilize the gas in an effort to eliminate condensation of moisture from the top glass.

## CHAPTER IV

## THE SEARCH

1. Introduction. In conducting a search for subionizers, data films are taken with the chamber operating in its optimum conditions. Since there are statistical fluctuations in the quality of the expansion due to the limitations of the expanding mechanism and the limitations of the operator in ascertaining what comprises optimum conditions, only the best photographic sequences are utilized for the actual search. The best expansions are those in which there is very little background throughout the expansion and in which well-formed tracks appear throughout the entire sensitive period. As a basis for selection, the expansions are classified into the following six categories:

(1) Class A: Good Expansion

(2) Class B: Delayed Underexpansion

(3) Class C: General Underexpansion

(4) Class D: Interrupted Expansion

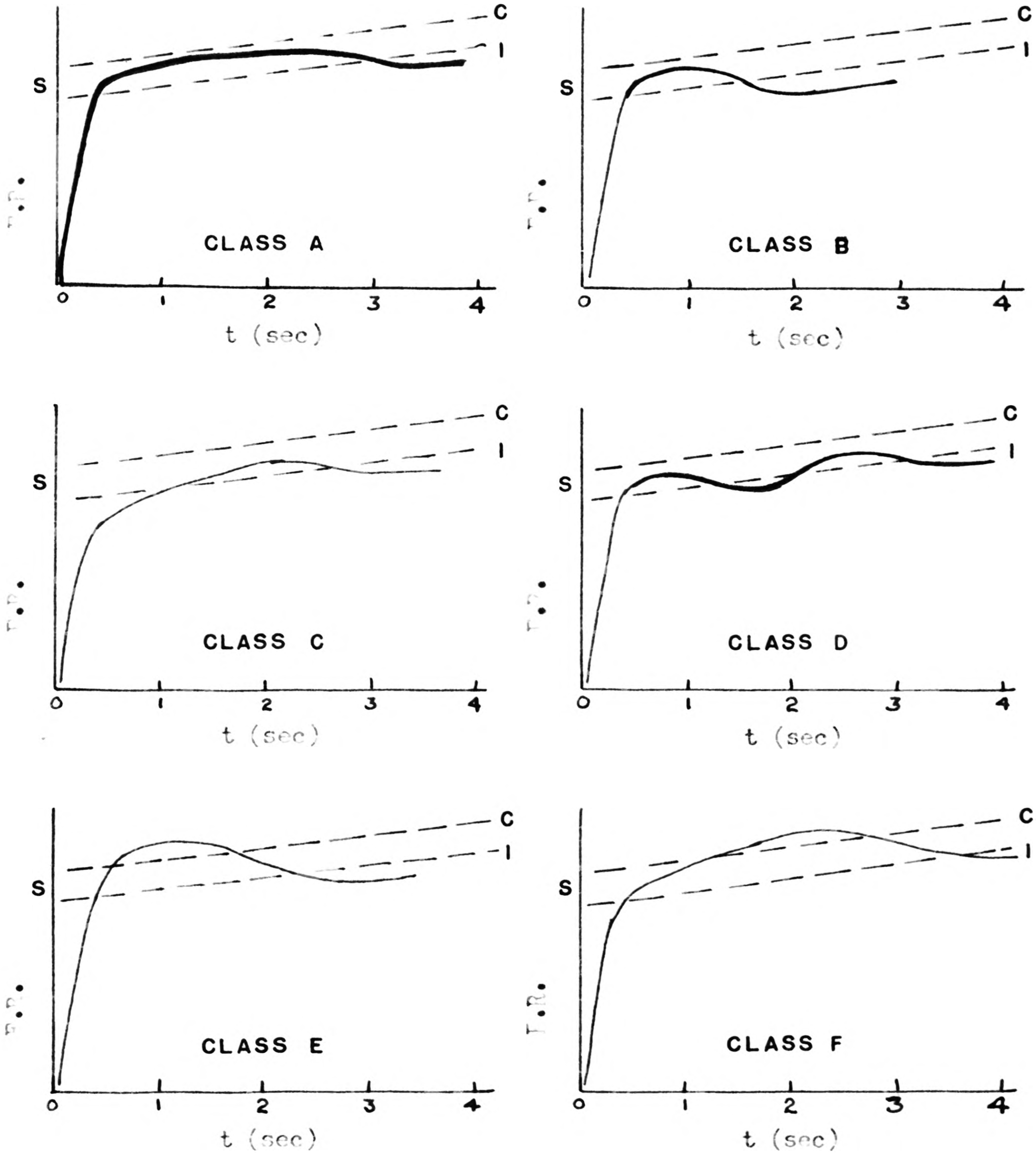
(5) Class E: Overexpansion

(6) Class F: Delayed Overexpansion

The conditions prevailing in the above classes of expansions are depicted in Figure 8, in which the expansion ratio is shown as a function of time.

2. Discussion of the Classification.

Class A. The chamber expands rapidly into the region S, and continues to expand slowly so that it remains in this region, giving a




S – SENSITIVE REGION; I – ION LIMIT; C – CLOUD LIMIT

FIG. 8 CLASSIFICATION OF EXPANSIONS

maximum possible sensitive time with a high degree of sensitivity throughout. There is little or no background throughout and well-defined tracks appear continuously as long as the chamber co tinues to be sensitive. The occurrence of ordinary, well-defined tracks as a function of the time is used to establish the sensitivity of the chamber. Sensitive times for this class of expansions are usually of the order of 2 seconds.

Class B. Since the sensitive region S is very narrow, slight variations in the operation of the expansion mechanism bring about changes in the sensitivity during the expansions. In Class B expansions, the initial fast expansion brings the chamber into the sensitive region S, but the slow continued expansion is such that the sensitivity falls below the required value. There is still little background, but the chamber becomes insensitive in a very short time. Appearance of new tracks is observed only in the first portion of the photographic sequence. Sensitive times in this class of expansions are usually about 0.5 to 1.0 second.

Class C. This class results from an insufficient initial expansion. Sensitivity is achieved only late in the slow continued expansion. Fairly well-formed tracks appear at about the 5th or 6th frame of the photographic sequence.

Class D. In this class, the chamber goes into an insensitive period in the middle of the expansion. As the complete expansion is carried out by five valves, a variation in the opening time or period of one of the middle valves may cause the expansion ratio to go below the sensitive region for a short time during the expansion; a large burst of tracks early in the expansion can cause the same effect. Tracks appear in the first four or five frames with little or no background. Then, for the next six frames or so, no new tracks appear signifying the absence of sensitivity in this period. Sensitivity is regained in the last few frames.

Class E. This class results when the chamber overexpands. Tracks and heavy background are present from the very beginning. The background density continues to increase completely filling the chamber. Few additional tracks appear.

Class F. In this class, the initial expansion brings the chamber into the sensitive region S, but the rate of expansion from then on increases taking the chamber above the sensitive region. Well-formed tracks appear in the beginning but background droplets also start to appear in the 5th or 6th frame; the background density may increase during the remainder of the expansion.

3. Details of the Search. Only the Class A expansions and a limited number of Class B expansions are employed for the actual search. The reason for this will be apparent by considering the rather strict requirements which we have set for observing a subionizer track. First of all, the track must appear during the central portion of the expansion. A light track may be seen in the early part of the expansion that would appear to have a sub-normal ionization rate; this could possibly be made

up of re-evaporation nuclei from droplets in the previous expansion that were neutralized and not swept away by the clearing field. Tracks appearing a short time before the onset of sensitivity may lose an appreciable number of ions due to recombination effects. Tracks appearing late in the expansion could also seem to have low ionization rates because the droplets have not had time to grow to sufficient size to make them individually photographable, giving an apparent low drop count.

The suspect track must show sub-normal drop count everywhere along its path. In Plate 1 (See p. 5), a lightly ionizing track is seen passing through the center of the chamber. The drop count increases to almost normal toward one end of the track. Examination of other photographs of this expansion indicates that the chamber underexpanded slightly so that the condensation efficiency was low.

The suspect track must not lie close to the chamber surfaces as the condensation efficiency in these regions of the chamber is usually low with a resultant tendency to give low drop counts.

The track must not be too close to a region where numerous previous tracks have formed, because the low drop count observed in such a case is most probably due to vapor depletion in that region. Diffusion processes are somewhat slower than the times involved here.

Thus, in searching for subionizer suspects utilizing selected expansions, tracks present at the beginning and those appearing toward the end of the expansion are eliminated from consideration. Only tracks appearing in the central portion of the chamber are considered. First, a simple search without stereoscopy reveals any tracks with drop counts between two drops per cm and the normal minimum ionization of the electron (13 ion pairs per cm in helium with alcohol-water vapor at approximately 1-1/2 atmosphere) which appear during the central portion of the sensitive period and which are readily observable above the background of the chamber. Although the Class A expansion is ideally defined to have no background, in practice there will be background present which is, however, of the order of one drop in 40 $cm^3$. The suspect tracks originating too close to the chamber surfaces are to be discounted; the position of the track in the chamber is to be established by stereoscopic viewing. However, the stereoscopic reprojection apparatus has not been completed yet and was not used in this search.

Under most favorable conditions of background and track load, the background droplets present initially can be followed throughout the sensitive period so that any new droplets appearing in the central portion of the sensitive period may be recognized. It will then be possible to look for drop counts less than two ion pairs per cm, but the droplets in this case must lie in a straight line, or along a continuous curve, to be considered a track.

4. Data. Photographs of more than 150 expansions are taken, but only those of 116 expansions are viewed, the remainder being eliminated for technical reasons such as mechanical and processing failures. The statistics of the search, referring to these 116 expansions, are as shown in Table V. Figure 9 shows the distribution of the expansions by classes.

TABLE V

CLASSIFICATION OF EXPANSIONS

| Class | Number of Expansions | Number of Tracks | Duration in Seconds |
|---|---|---|---|
| A | 31 | 614 | 46.2 |
| B | 37 | 563 | 35.5 |
| C | 20 | 304 | 17.0 |
| D | 12 | 220 | 9.7 |
| E | 12 | 182 | 13.5 |
| F | 4 | 67 | 5.0 |
| Total | 116 | 1950 | 126.9 |

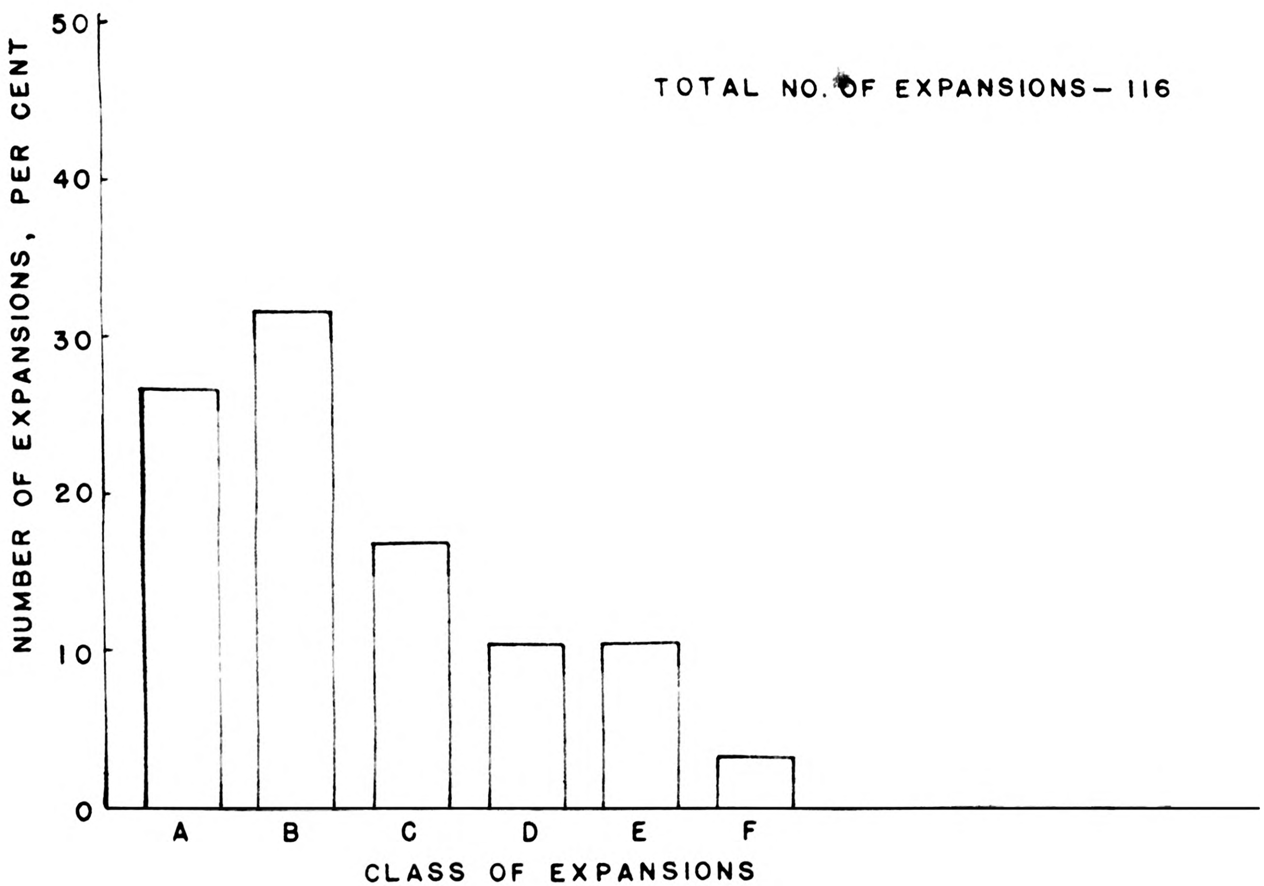



FIG. 9 DISTRIBUTION OF EXPANSIONS BY CLASSES

It may be mentioned that in most cases of Class B expansions the background densities are substantially low, although the usable sensitive times are short. Then, from the data presented in Table V, it may be stated that substantially background-free expansions are achieved in about 50% of the cases. Only the Class A expansions and a limited number of Class B expansions are utilized for the actual search. It must be remembered that the last portions of Class B expansions, during which period the chamber has low sensitivity, are eliminated from consideration. This yields a total sensitive time of about 54 seconds during which 797 electron and meson tracks are observed. No subionizer tracks were observed in this body of photographs.

The number of tracks appearing in a single expansion of Classes A and B is shown as a function of time in Figure 10. The number of tracks increases almost linearly at first, but becomes fairly constant towards the end when the number of new tracks balances the number of tracks that have developed to full growth and fall out of the sensitive volume. Note that for the Class B expansion, the total number of tracks decreases suddenly towards the end; this is where the chamber sensitivity drops so that no new tracks appear while at the same time tracks already observed fall out of the sensitive volume before the picture-taking sequence is completed.

Figure 11 shows the manner in which a track develops from the time it is first observed to the time it is fully developed to its probable ionization rate. Note that a time of about 0.2 to 0.4 seconds is required for the track to attain full growth.

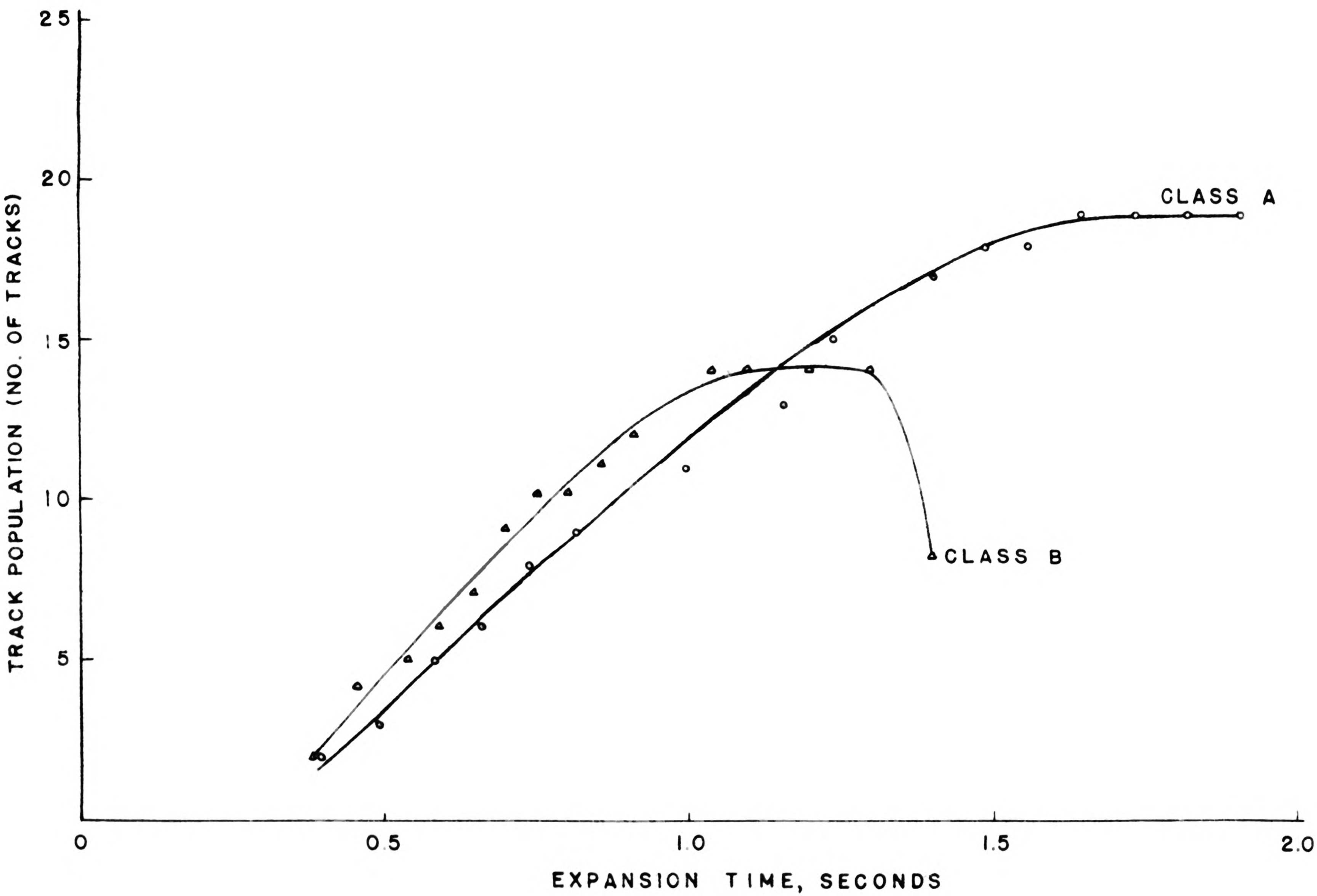



FIG. 10 TRACK POPULATION AS A FUNCTION OF EXPANSION TIME FOR EXPANSION CLASSES A AND B

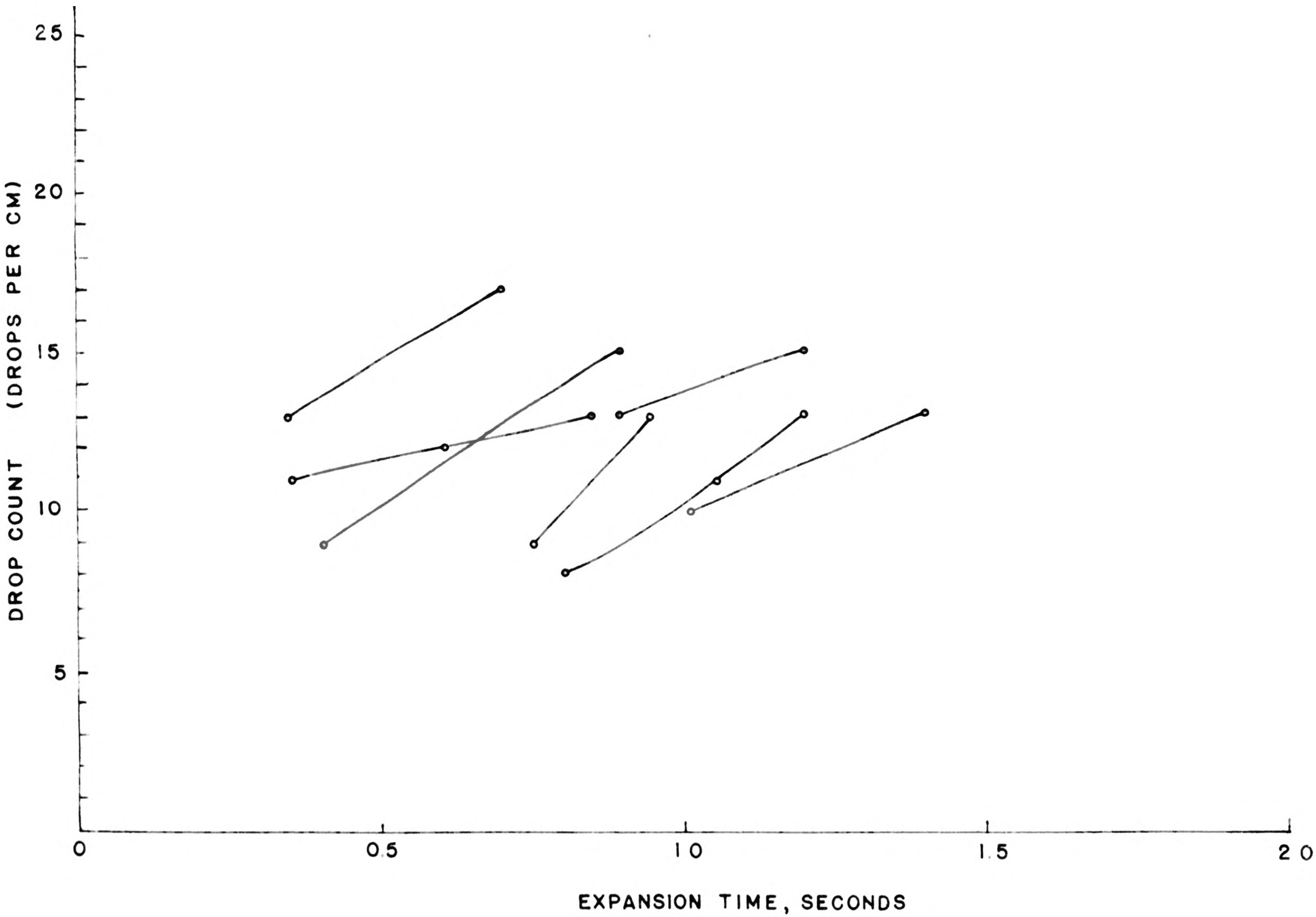



FIG. 11 TRACK DEVELOPMENT AS A FUNCTION OF EXPANSION TIME FOR CLASS A EXPANSIONS

A method of classifying expansions is now established. A technique for a systematic search for subionizers has been presented in which the criteria for observing a subionizer track are outlined. The data obtained from a limited search is presented. The results will be summarised and the conclusions drawn will be presented in the following chapter.

CHAPTER V

# CONCLUSION

1. Summary of Results. Helium with a 2:1 ethyl alcohol-water mixture is found to be the best gas-vapor combination investigated, and gives a long sensitive time with satisfactory conditions regarding background density and track development.

With the xenon flash tube illumination system employed, a Kodak 8K2 filter provides the best filtering with a minimum loss of light in the longer wavelength regions. This appreciably reduces the background caused by photochemical nuclei.

In a body of photographs representing 116 expansions, not less than 50% are found to be satisfactory as regards background density and sensitivity.

Forty-three expansions representing a sensitive time of approximately 54 seconds are utilized for the actual search. During this time in which approximately 800 electron and meson tracks are observed, no subionizer tracks were identified.

Data has been obtained showing the growth of track population as a function of expansion time. Track development during a single expansion has been shown; a period of about 0.2 to 0.4 seconds is required for a track to attain full growth.

The most probable value for the normal minimum ionization of the electron in helium with an alcohol-water vapor at approximately 1-1/2 atmosphere is found to be about 13 ion pairs per cm.

2. <u>Conclusions</u>. Evidence is presented that in a long sensitive time Wilson cloud chamber conditions can be achieved such that at least half of the expansions will be substantially free from background. Apart from statistical fluctuations, the number of background-free expansions that can be obtained depends essentially on the skill of the operator in visually observing and adjusting the chamber for optimum conditions.

A method of classifying the expansions as a function of (1) background density and (2) chamber sensitivity, is established. Employing the above method of classification, usable photographs are selected, and a technique is developed for carrying out a systematic search in which a subionizer could be positively identified.

Examination of photographs containing 1950 tracks of particles from cosmic ray flux and natural radioactivity reveals no tracks that can be attributed to charged relativistic subionizers with z-values in the range 1/6 to 1/2. From the data obtained in this experiment, a conservative statement is that subionizers with z-values in the range 1/6 to 1/2 are not present in cosmic rays and natural radioactivity to an extent as great as one subionizer per 800 ordinary cosmic ray tracks.

3. <u>Suggestions for Continuation of Work</u>. A system of mirrors in the camera box would permit visual observation of the chamber while the camera is taking pictures; any deviation from optimum conditions will then be detected at once, and adjustments may be made to regain them. This would appreciably reduce the number of unsatisfactory expansions recorded on film.

Accurate temperature measurements should be made. A closer control should be kept on the vertical temperature gradient. This temperature gradient was apparently more than 2°C in the present research which is sufficiently high to cause overstabilization of the sensitive volume. This is believed to be one of the factors causing the chamber to deviate from the optimum conditions. This would cause the observed non-uniformity of conditions throughout the chamber. Subsequent work by others in this laboratory confirms these conclusions. A vertical temperature gradient of not more than one tenth of a degree should be employed. No horizontal temperature gradient should be observed.

A temperature sensing device could be installed inside the chamber and an oscilloscope employed so that the chamber could be adjusted for constant temperature during the sensitive time. This would improve the continuity in the sensitivity as this cannot be reliably judged by purely visual observation, and might further aid in reducing the number of poor expansions.

A larger chamber should be employed. This would provide a greater sensitive volume and a larger space in which to look for subionizers; a lower limit of detectable z-values would be realized.

The overall track load should be reduced. The reason for the heavy track load is the high level of radioactivity from the radioactive minerals in the Geology Department directly above our laboratory. The whole chamber should be appropriately shielded or moved to another location. A much lower track load would reduce the number of old tracks encountered, and would increase the available space for looking for subionizers.

The statistics obtained from this research are low. The apparatus has now proved itself useful as a detection instrument for subionizers. More data films should be taken so that a more extensive search can be carried out using the completed apparatus, including the stereoscopic reprojection system.

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# VITA

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A SYSTEMATIC STUDY OF EXPERIMENTAL PARAMETERS IN

A CLOUD CHAMBER SEARCH FOR SUBIONIZERS

BY

ZIN AUNG

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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 IN NUCLEAR ENGINEERING

Rolla, Missouri

1961

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# A SYSTEMATIC STUDY OF THE EXPERIMENTAL PARAMETERS IN A CLOUD CHAMBER SEARCH FOR SUBIONIZERS

Since there is no theoretical basis for the quantization of electric charge, it is reasonable to consider the possible existence of particles with charges much less than the electronic charge 'e'. Such particles, if they exist, are expected to ionize more lightly than the electron. Similar remarks hold true for particles with electric dipole moments, and relativistic monopoles with strengths much less than 'e' electrostatic units. These particles have been termed subionizers.

The selection of apparatus for a subionizer search has been discussed. The desired conditions for such a search using a low background, long sensitive time Wilson cloud chamber have been outlined. The techniques by which the desired conditions are achieved are presented. A method of classifying the expansions as a function of (1) background and (2) chamber sensitivity, is established. The criteria for observing a subionizer track are outlined, and the techniques for a limited search were developed.

The apparatus has proved itself useful as a detection instrument for subionizers. Data obtained from a limited search is presented. No subionizers with z in the range 1/6 to 1/2 appeared in a body of photographs containing approximately 800 electron and meson tracks from cosmic rays and natural radioactivity.