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An improved long sensitive time Wilson cloud chamber

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AN IMPROVED LONG SENSITIVE TIME
WILSON CLOUD CHAMBER

BY

CLARENCE W. METTENBURG

A

THESIS

submitted to the faculty of the
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in partial fulfillment of the work required for the
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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 at the University of Missouri School of Mines and Metallurgy, Rolla, Missouri.

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INTRODUCTION

The discovery of numerous new particles in recent years such as mesons and hyperons causes one to speculate about the possible existence of still other particle types. Some very general facts concerning the known new particles are as follows:

(1) All of these new particles are unstable and decay into photons and other known particles.

(2) Ionization measurements indicate that these new particles have a charge equal to that of the electron, although ionization measurements are subject to many experimental difficulties.

(3) All of these particles have masses heavier than that of the electron.

(4) Only a few of these particles have any theoretical reason for existing according to present theories.

Thus it is reasonable to ask whether still other varieties of particles exist.

The following possibilities warrant further investigation:

(1) Particles with masses different from those already discovered,

(2) Particles (regardless of mass) with a charge less than that of the electron,

(3) Particles (regardless of mass) with non-integral multiples of the electronic charge,

(4) Dirac type isolated magnetic poles,

(5) Isolated poles of any conceivable description.

It is interesting to note that there is no theoretical resaon for charge being quantized, however, almost all experimental evidence favors the idea that charge is quantized.

Dirac(1) stated that due to symmetry in the field equations of electrodynamics in regard to electric and magnetic forces, isolated magnetic poles might possibly exist. Assuming that charge is quantized, Dirac's theory predicts the existence of isolated free magnetic poles whose unit strength in emu. is larger than the strength of the electronic charge in esu. Dirac gives no hint as to what the possible mass of these free poles might be so that a search for these particles could take various directions. It has been suggested by some that the discovery of the positron, which was also predicted by Dirac justifies experiments designed to detect free magnetic poles. Cole(2) and Bauer(3) have assumed a mass for the Dirac isolated pole and have calculated its rate of ionization in a cloud chamber so that it might be recognized. It is readily seen

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(1) Dirac, P.A.M., Phys. Rev., 74, 817, (1948)

(2) Cole, H.J.D., Proc. Cam. Phil. Soc., 47, 196 (1951)

(3) Bauer, E., Proc. Cam. Phil. Soc. 47, 777, (1951)

that the question of whether charge is quantized and whether free magnetic poles exist may well be related and offer a broad field of experimentation.

The quantization of electric charge can be studied by searching for either non-standard charges or free magnetic monopoles. It has been decided to begin by looking for particles ionizing less than the minimum ionization of the electron. Such particles have been termed subionizers and could include a variety of particle types as pointed out by Ruark (4) and Fitz (5). It is obvious that if these particles are unstable, they must be studied under dynamic conditions. This would rule out a modified oil-drop experiment.

A cloud chamber seems to be a most suitable means of detecting particles ionizing less than the minimum ionization of the electron because it is capable of detecting almost all the ions produced. The cloud chamber makes it possible to study not only a wide range of ionization but also many fine details of track structure which would go unnoticed by other means of detection.

Arthur E. Ruark (6) initiated a program to experimental-

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(4) Ruark, A.E., "A Cloud Chamber Search For Free Magnetic Poles", A Proposal to the N.S.F. (1953)

(5) Fitz, H.C., Jr., M.S. Thesis, Univ. of Alabama (1955)

ly search for isolated magnetic monopoles and sub-charges. As a continuation of this work James L. Kassner, Jr. has begun a similar program at the Missouri School of Mines and Metallurgy. This program will begin with the construction of a suitable cloud chamber and associated equipment for its operation.

In searching for a particle whose minimum ionization is less than that of an electron, one is hampered by the presence of an excessive number of tracks whose specific ionization will be greater than the minimum, and by background droplets.

The presence of these subionizers may have gone unobserved due to lack of interest in such particles, poor experimental conditions, their possible infrequent occurrence or any combination of these reasons. It stands to reason that a cloud chamber with very low background would be necessary to detect a particle producing very few ion pairs per centimeter along its path.

In addition to a relatively background-free cloud chamber, a long sensitive time and a large chamber would further enhance the possibility of photographing a rare occurrence. A long sensitive time would enable one to take more than one photograph of each expansion. The advantage of the latter will be explained in detail

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(6) Ruark, A.E., *op. cit.*

later.

Fitz(7) has offered some of the first information regarding the search for subionizers. He presents views on the apparatus and methods needed for a subionizer search and has generalized some of the pertinent equations to apply toward sub-charges and pole varieties. These equations give us the information necessary to enable us to recognize new particles in the above categories on observation.

Good(8) continued the search and achieved ideal background conditions plus a reasonably long sensitive time which enabled him to take motion pictures of each expansion. The water floor cloud chamber he used had a small sensitive volume making the probability of observing a rare event small. Inadequate lighting and long exposures may have prevented photography of individual droplets. Good's work indicates the advantages of multi-frame photography and water floor chambers. He also showed that slow expansions will lengthen the sensitive time considerably. His low background condition could be due to the small height of the chamber which would help insure fall out of droplets. This may indicate that the background present

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(7) Fitz, H.C., Jr., *op.cit.*

(8) Good, W.B., Ph.D. Thesis, Univ. of Alabama (1956)

in larger chambers is due to re-evaporation nuclei(9). Re-evaporation nuclei are droplets which have insufficient time to grow and fall out before supersaturation ceases. These evaporate into nuclei which can be condensed upon in the next expansion and appear as background. It is possible that Good's low background may be due to suppression of re-evaporation nuclei and that measures should be tried to achieve these conditions in larger chambers where background is usually appreciable.

Kassner(10) and others(11) have pointed out that relatively dry chambers with diaphragms and interior hole plates are undesirable. The dry, diaphragm type chamber would offer no permanent trap for dust and other drop producing contaminants which are removed from the sensitive volume by the "nucleation" and fall out process. The water floor of chambers similar to the Bearden(12) chamber seems to be an effective trap.

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(9) Wilson, J.G., "The Principles of Cloud Chamber Technique", Camb. Univ. Press, p. 13, (1951)

(10) Kassner, J.L. Jr., Ph.D. Thesis, Univ. of Ala. (1956)

(11) Blumenfeld, H., Booth, E.T., Lederman, L.M., R.S.I. 25, 1220, (1954)

(12) Bearden, J.A., R.S.I. 6, 256, (1935)

Kassner(13) noted in his work the frequency of so-called ghost tracks that were assumed to be composed of re-evaporation nuclei. With careful suppression of re-evaporation nuclei, the true nature and cause of these ghost tracks may be ascertained.

With the information and experience gained by the above investigators, the present status of the search is to make use of the information available and construct a cloud chamber suitable for such a program.

The author's contribution to this research program is the construction of a long sensitive time, low background cloud chamber with all control devices suitable for a search for subionizers. The author has also undertaken a possible means of reducing background due to re-evaporation nuclei.

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(13) Kassner, J.L. Jr., *op cit*.

EXPERIMENTAL AND THEORETICAL CONSIDERATIONS

Rapidly moving charged particles produce local ionization along their trajectory. The density of this ionization depends upon the density and atomic number of the medium, and the charge, mass and velocity of the incident particle. C.T.R. Wilson(14), who had developed a condensation chamber for studying meteorological phenomena, noticed that under certain conditions condensation occurred on ions giving what he called tracks. During the following years the cloud chamber was developed into an extremely versatile apparatus for detecting charged particles and studying their interaction with matter.

A chamber filled with a suitable gas-vapor mixture is allowed to expand approximately adiabatically. The lowering of the temperature of the gas-vapor mixture brought about by the expansion, produces vapor supersaturation provided that, under the original conditions, the gas was saturated with vapor. Wilson noted that relatively small supersaturations were required to cause condensation on dust particles and at higher supersaturations ions begin to serve as condensation nuclei. At slightly higher supersatura-

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(14) Wilson, C.T.R., Phil. Trans. Roy. Soc. 189, 265, (1897)

tions than that required for condensation on ions, the system is evidently so unstable that condensation can occur on practically anything such as aggregates of three or more molecules which might occur by chance. It is only within a relatively narrow region of supersaturations that well defined tracks of ionizing particles are obtained.

Most cloud chambers expand from an initial preset volume to a final preset volume; such chambers are said to be volume defined. In this case the supersaturation obtained is readily calculated from the expansion ratio, (E.R.), the ratio of the final volume to the initial volume.

$$E.R. = 1 + e = \frac{\text{Final Volume}}{\text{Initial Volume}} \qquad (1)$$

where e represents the charge in volume ratio. The supersaturation, S, attained by a given expansion is given by

$$S = \frac{P_1}{P_2} \left(\frac{1}{1+e} \right)^{\gamma} \qquad (2)$$

where P_1 and P_2 are the initial and final pressures and γ is the ratio of the specific heats of the gas-vapor mixture. The for the gas-vapor mixture may be obtained from the ${}_g$ of the gas and γ of the vapor by using a formula due to Richarz(15).

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(15) Richarz, F., Ann. d. Physik 19, 639, (1906)

$$\frac{1}{\gamma-1} = \frac{1}{\gamma_g-1}\,\frac{P_g}{P_t} + \frac{1}{\gamma_v-1}\,\frac{P_v}{P_t} \qquad (3)$$

where P_g and P_v are the partial pressures of the gas and vapor respectively and P_t is the total pressure. The relationship between the initial and final temperatures is given by

$$\frac{T_1}{T_2} = \left(\frac{V_2}{V_1}\right)^{\gamma-1}. \qquad (4)$$

The critical supersaturation, ion limit, is defined as the supersaturation required to cause condensation on ions. Although it will be found that the final temperature is frequently somewhat below freezing, the droplets will not freeze because the latent heat of vaporization, given up in the process of condensation, keeps them warm. In areas where the ionization is heavy within a cloud chamber, this heat of condensation is sufficient to produce peculiar local turbulence currents.

The very nature of the expansion process makes the acquired supersaturation an extremely temporary condition. If the expansion itself is not too rapid, it will only approximate a truly adiabatic process and as a result of the transfer of heat from the walls of chamber to the gas-vapor mixture, a slightly higher expansion ratio will be required to produce a given temperature change than is predicted by equation 4.

After the expansion ceases the transfer of heat from the walls to the gas gradually reduces the degree of supersaturation. If condensation takes place, two processes are active. Vapor is removed from a localized region around the droplet and the heat of condensation helps to raise the temperature thereby lowering the supersaturation throughout the chamber.

The length of time during which there is suffient supersaturation to cause condensation on newly formed ions is called the "sensitive time". A long sensitive time increases the probability of photographing a rare event.

The mechanism by which a warm surface reduces the degree of supersaturation is interesting. It is clear that the process is not one of straight conduction; otherwise, after an expansion, the center of the chamber would be the last to become insensitive to newly formed ions and this is not what is observed. The entire chamber becomes insensitive simultaneously. The relatively slow conduction process warms a thin layer of gas next to the warm surface. This layer expands compressing the entire volume. The compression wave travels at the speed of sound and the compression serves to equalize the temperature. An exact analysis of the process is not possible because it is far more complicated than this simple explanation indicates. The equilization of temperature due to the compression mechanism just mentioned is not complete but serves to expalain what happens at large distances from the walls and throughout the bulk of the chamber volume. The presence of this layer of warmer gas next to a vertical wall gives rise to turbulence currents, resulting in an up draft along the walls and a downdraft occurring somewhere farther out from the walls. These turbulence currents require time to reach noticeable velocities and set an upper limit to the usefullness of a long sensitive time.

The mode of operation has a considerable affect on the sensitive time and the recycle time. Chambers have been designed to operate:

(1) from constant initial pressure to a constant final pressure
(2) from constant initial volume to constant final volume
(3) from constant initial pressure to a constant final volume
(4) from constant initial volume to a constant final pressure
(5) and many other variations.

The differences in the sensitive times for these various modes of operation may be attributed to differences in the time rate of expansion.

Endt(16) has calculated the sensitive time and the recycle time for several of these modes of operation. He found that for a constant final pressure the sensitive time was considerably longer than for an expansion ending at a constant final volume. It is shown qualitatively why this should be expected in figure 1. When one is operating between volume defined limits it is customary to use a large enough upper chamber pressure (driving force) to obtain a rapid expansion. Pressure defined chambers usually operate from some positive initial gauge pressure to atmospheric pressure. The initial gauge pressure is limited by the desired expansion ratio so its very nature produces a slower expansion.

The mode of expansion ending at a constant final volume reaches the critical supersaturation faster but stops suddenly allowing the chamber to pass out of the sensitive region rather quickly. Note the discontinuity in the slope of the expansion curve inside the sensitive region. The exponential shape of the constant final pressure curve allows a curve fitting, resulting in an expansion that can be made to follow inside the sensitive strip for a longer period of time.

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(16) Endt, P.M., Physica 14, (1948), 16, (1950)

EXPANSION RATIO VERSUS TIME

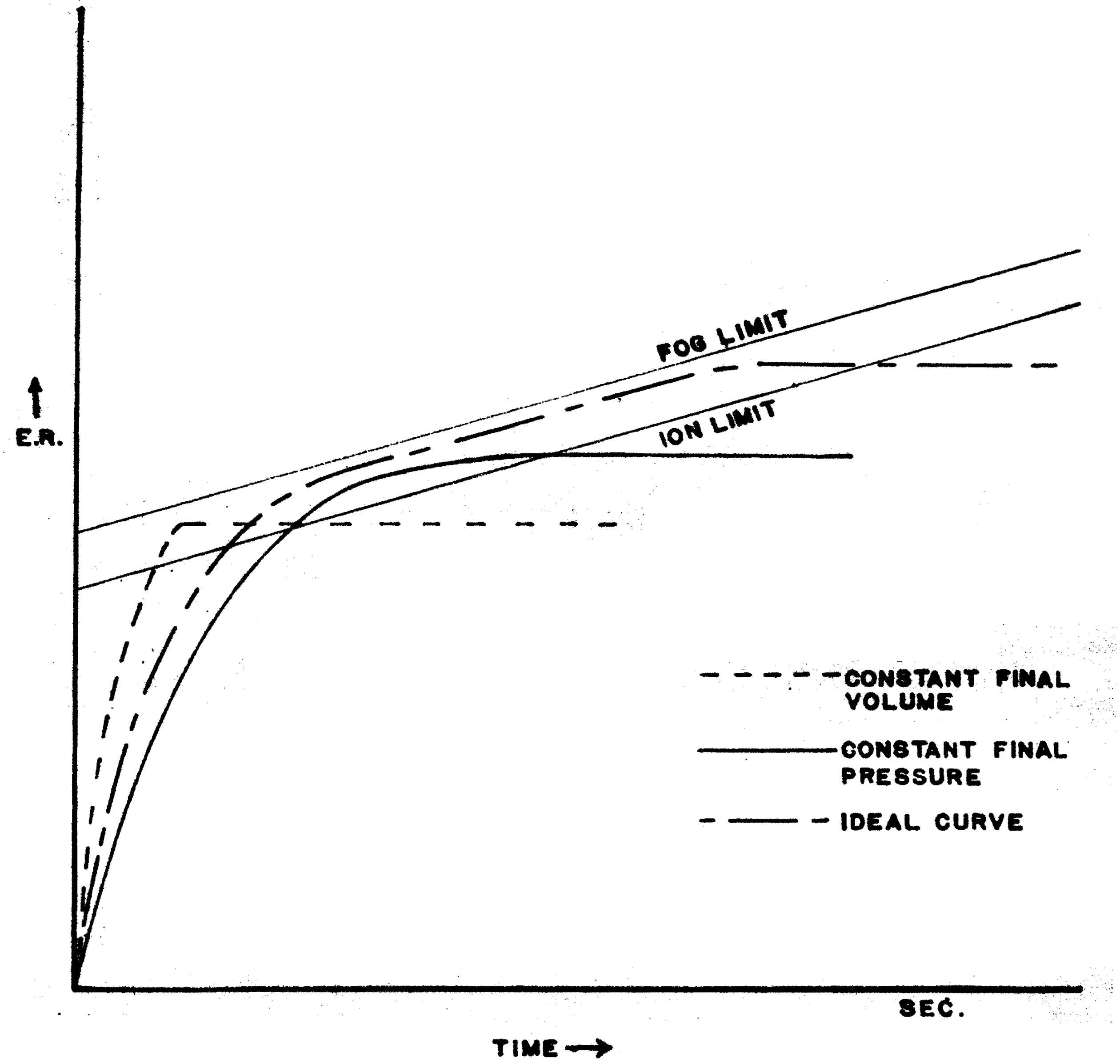

FIG. 1

It should be noted that the continuous rise in the ion limit and fog limit curves represents the additional expansion required to offset the transfer of heat from the walls. The sensitive time will depend upon the slope of the critical supersaturation curve, the width of the sensitive region between the ion limit curve and the fog limit curve, and the exact shape of the expansion curve (17).

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(17) Hazen, W.E., R.S.I. 13, 247, (1942)

It should be apparent to the reader that expanding to a constant final pressure is merely an expedient way to achieve a longer sensitive time. What is really required is to determine the shape of the ion limit curve and then provide for an expansion that will follow this curve for a specified length of time. The ion limit curve has been shown as a straight line for simplicity in figure 1.

Endt (18) found that for a constant initial volume the recycle time was less than for a constant initial pressure. The reason for this is apparent if it is remembered that the recycle time is necessary for the redistribution of vapor by diffusion (a relatively slow process) and turbulence processes. As long as

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(18) Endt, P.M., Ibid

the initial pressure is volume defined, a relatively fast recompression cycle is possible. If, however, the initial condition is pressure defined, the compression must take place at an ever decreasing rate. The compression curve is exponential in shape and the next expansion cannot take place until the relatively flat portion of the curve is reached if reasonable reproducibility is to be achieved. Thus the compression to final pressure requires a rather long time and little time can be spared for vapor redistribution. The compression requires a smaller fraction of the time between expansions for a constant initial volume type of operation than for a constant initial pressure type of operation. Thus more time is allowed for vapor redistribution under fully compressed conditions. If it were not for small turbulence currents, many times the observed recycle time would be required for adequate redistribution of vapor by diffusion processes alone.(19) It has been a common practice to operate a chamber with its top slightly warmer than the bottom.(20)

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(19) Wilson, J.G., "The Principles of Cloud Chamber Technique", Camb. Univ. Press, p.55, (1951)

(20) Fretter, W.B., Frieser, E.W., R.S.I. 26, 703,(1955)

If this temperature gradient is too large the gas will be too stable during the recycle period and an objectionable long recycle time will be required. This slight intentional temperature gradient is considered necessary to help stabilize the chamber after compression and stop turbulence currents before the next regular expansion without having to wait an undue length of time.

The recycle period is an important consideration in designing a chamber for a search for rare events since its data gathering speed is limited by this factor.

In order to obtain sharp tracks with a minimum of distortion a rapid expansion has been found to be necessary by the people working with fast magnetic chambers. Track distortion is caused by two main factors. The Geiger counter controlled chambers have the ions formed when the chamber is in the compressed position and the tracks are photographed in the expanded position. In order to be able to extrapolate back to find the original positions of the droplets an extremely uniform expansion is required. Any nonuniformity can produce large errors. Track distortion is also produced by turbulence currents whose magnitudes and directions are not known as a function of time. As has been mentioned, turbulence currents require some time to begin and a rapid expansion minimizes error from this source. In a preliminary search for subionizers, track distortion is relatively unimportant until some examples of suspected subionizers are actually found and their properties are to be studied. As a result a reasonable amount of track distortion can be tolerated.

When a chamber is freshly filled with gas, dense clouds of fog are seen during the first few expansions. Here condensation is taking place on minute dust particles. Once these have been precipitated, the gas-vapor volume is clean and ready for operation. However, in addition to tracks, background of varying densities is noted. This background comes from several sources.

Some background is produced by re-evaporation nuclei(21). These are produced when droplets get caught in the recompression cycle and are evaporated. The droplets fail to evaporate completely and a relatively large but invisible nucleus persists until the next expansion where it serves as a condensation center and appears as part of the background. It is possible that whole tracks caught late in the expansion are re-evaporated and may appear as so-called "ghost tracks". Ghost tracks are distinguished by their extent of

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(21) Wilson, J.G., op. cit.

diffusion, appearance at lower expansion ratio than that required for condensation on new ions. This effect deserves further study.

Re-evaporation nuclei undoubtedly play a major role as a source of background. In large vertical chambers the probability of a drop being evaporated before it falls to the floor of the chamber is high. It is possible to partially eliminate this type of background by allowing the majority of the droplets sufficient time to fall to the floor of the chamber. If the expansion curve is made to fall just below the ion limit curve and remain just below it for a long enough time for all the droplets to grow to a large size and fall out, the background should be somewhat reduced. See figure 2.

However, any droplets just beginning to form near the end of the sensitive time will evaporate without ever growing to visible size as soon as the expansion curve falls below the sensitive region. These nuclei would have to be brought down by an intermediate expansion, a partial expansion just sufficient to cause condensation on relatively large nuclei but not on ions(22).

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(22) Wilson, J.G., op.cit.

Condensation on aggregates of molecules, which is

EXPANSION RATIO VERSUS TIME

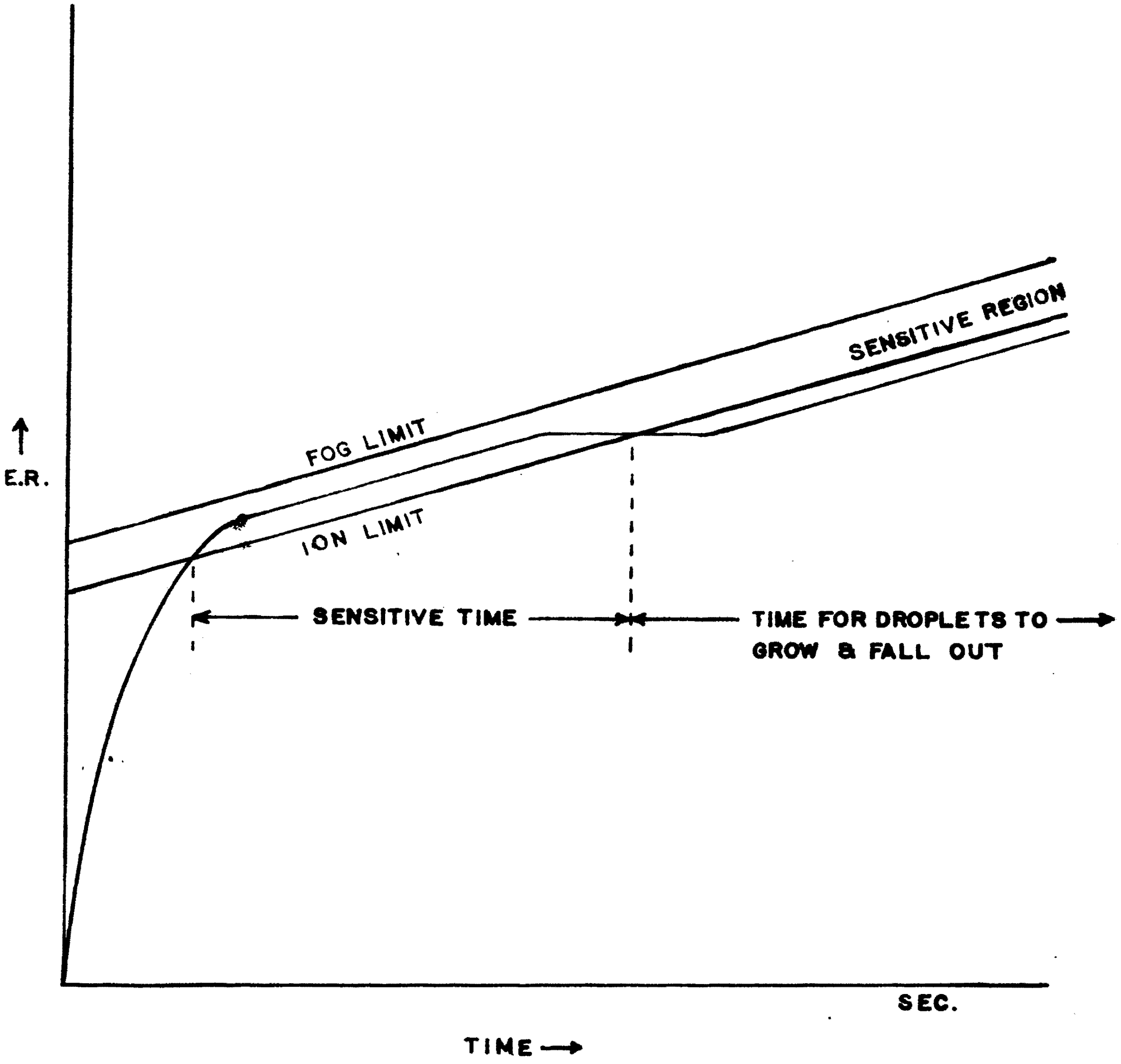

FIG. 2

thought to be the cause of the general fog, in the presence of a pure gas-vapor mixture, is thought to occur at an expansion ratio characteristic of that particular gas-vapor mixture. It is well known that the degree of supersaturation required for condensation on ions is also characteristic of the gas-vapor mixture (ion limit). Obviously, if general fog is to be eliminated and condensation on ions achieved, a gas-vapor system must be chosen which has a reasonable gap between the ion limit and the fog limit, the fog limit occurring at a higher expansion ratio than the ion limit.

Certain substances are known to be poisons to cloud chambers. The presence of nitric acid in extremely small concentrations has been found to appreciably increase the background level.

Photo chemical fog of condensation nuclei produced by light has been studied by Beck(23). His results show that wavelengths shorter than 3900 Angstroms were chiefly responsible for such fog. This type of background can be reduced by using appropriate filters.

Clearing field wires within the chamber may cause large areas of ionization due to corona from sharp points. Corona can be eliminated by coating the sharp edges with a non-conducting material such as rubber

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(23) Beck, C., R.S.I. 12, 602, (1941)

cement.

Friction will cause some stray ions although it is not one of the dominant sources of background. This form of background can naturally be reduced by reducing the movement of the gas-vapor mixture.

Bubbling and splashing will produce ions(24). Air bubbled through pure water will pick up a negative charge. Impurities will change the order of magnitude and the sign of the charge.

These several sources of random droplets cause the background which is detrimental to the subionizer search. Some can be eliminated completely, while others can only be reduce to some extent in particular situations.

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(24) Thompson, J.J., "Conduction of Electricity Through Gases", p. 287, (1933)

APPARATUS

Critical supersaturation in Wilson's early cloud chamber was obtained by allowing a volume of gas-vapor mixture to expand into a partially evacuated vessel. The lowered temperature supersaturated the volume of air causing condensation on ions produced by dynamic particles. The degree of supersaturation is important. In order to prevent general condensation on nuclei other than ions, the expansion ratio has to lie between certain definite limits.

The years following Wilson's discovery brought many modifications and developments. A few major developments were: 1) a diaphragm in place of pistons and other expansion devices, 2) automatically controlled periodic reproducible expansions. The diaphragm chamber had a rubber diaphragm between the sensitive volume and a rear chamber. Compressed air was forced into the rear chamber which in turn compressed the sensitive volume. Then the rear compressed air was allowed to escape causing the adiabatic expansion in the forward chamber and producing the critical supersaturation. The advent of the diaphragm eliminated small leaks around even the tightest fitting pistons helping to insure reproducibility.

In 1933 Wilson built a chamber using a rubber diaphragm to obtain the compression and expansion.

Bearden(25) a year later announced the development of a sylphon bellows type expansion chamber. The bellows type chamber was operated by a cam arrangement and had a relatively long sensitive time. Tracks in this chamber remained undistorted up to one and one-half seconds by using a slow expansion. This chamber was borrowed by the University of Alabama and used by Good(26) in a search for subionizers. The latter operated the chamber pneumatically obtaining sensitive times of the order of two seconds.

Maier-Leibnitz(27) constructed a cloud chamber and obtained a sensitive time of about one second. There have been other investigators who have designed and developed chambers with the object of increasing the sensitive time although very few have actually exceeded two seconds.

The chamber constructed by the author was designed by James L. Kassner, Jr. and is similar to the type introduced by Wilson in 1933. A rubber diaphragm is positioned by air pressure in a back chamber. It is

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(25) Bearden, J.A., *op. cit.*

(26) Good, W.B., *op. cit.*

(27) Maier-Leibnitz, H., Zeits. fur Physik 112, 569, (1

a relatively large chamber with the top glass cylinder measuring twelve inches in diameter and eleven and one-half inches in height.

The glass cylinder is on top of a circular aluminum plate. A circle ten inches in diameter, located in the center of the plate, has been filled with closely spaced five-thirty second inch holes to allow the passage of liquid through the plate. About 65 percent of the total area in the ten inch diameter region is cut away.

Attached to the under side of this aluminum plate is a one-sixteenth inch thick rubber diaphragm held in place by an aluminum ring. Also held in place by the aluminum ring is a hemisphere with numerous holes to allow the rubber diaphragm to position itself in this hemisphere when the chamber is in the expanded position. Thus the chamber is ultimately volume defined at both limits.

The aluminum plate is attached to a steel cylinder fourteen and one-half inches outside diameter, and six and one-half inches in height which forms the rear chamber. See figure 3.

An air inlet into the upper chamber passes through the aluminum plate down into and out of the side of the rear chamber. A liquid inlet is also passed through the aluminum plate down into and out of the rear chamber. The air inlet on top of the aluminum plate has a one-

CLOUD CHAMBER

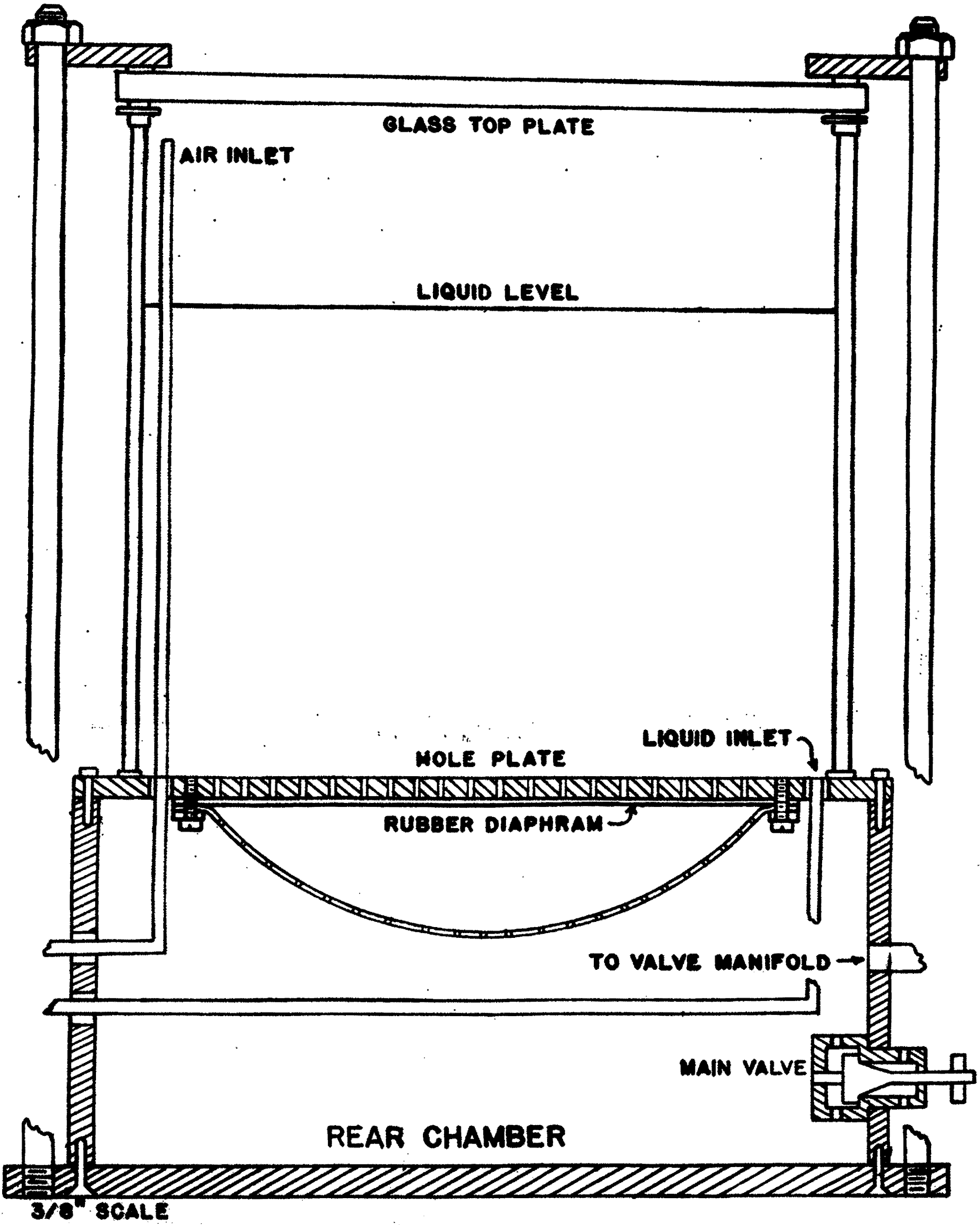

FIG. 3

eighth inch copper tube extending to the top of the upper chamber, allowing the air to escape when the chamber liquid is introduced.

The lower steel cylinder is attached to a one-half inch steel plate which serves as the base of the chamber. Four steel rods threaded on both ends are screwed into the bottom steel plate and extend upward above the glass cylinder. A thirteen inch diameter circular glass plate, one-half inch thick, forms the top of the upper chamber. Between the glass cylinder and the top glass plate, a thin circular aluminum ring holds the clearing field wires. Cromel P number 28 wire was used for the clearing field electrodes, attached to the aluminum ring as shown in figure 4. The clearing field grid is needed to produce as uniform a field as possible. The field is still far from uniform due to conduction along the walls.

A steel ring fits on the four steel rods and holds the glass cylinder and glass top plate to the aluminum hole plate. Seals were obtained with double layers of one-sixteenth inch soft rubber tape.

A large main valve is used to cause a very rapid expansion to reach the desired supersaturation in a minimum of time. The time this valve is open depends upon the liquid level and may range from 0.2 to 1.0 seconds. The valve opening is also adjustable. In addition to

CLEARING FIELD RING

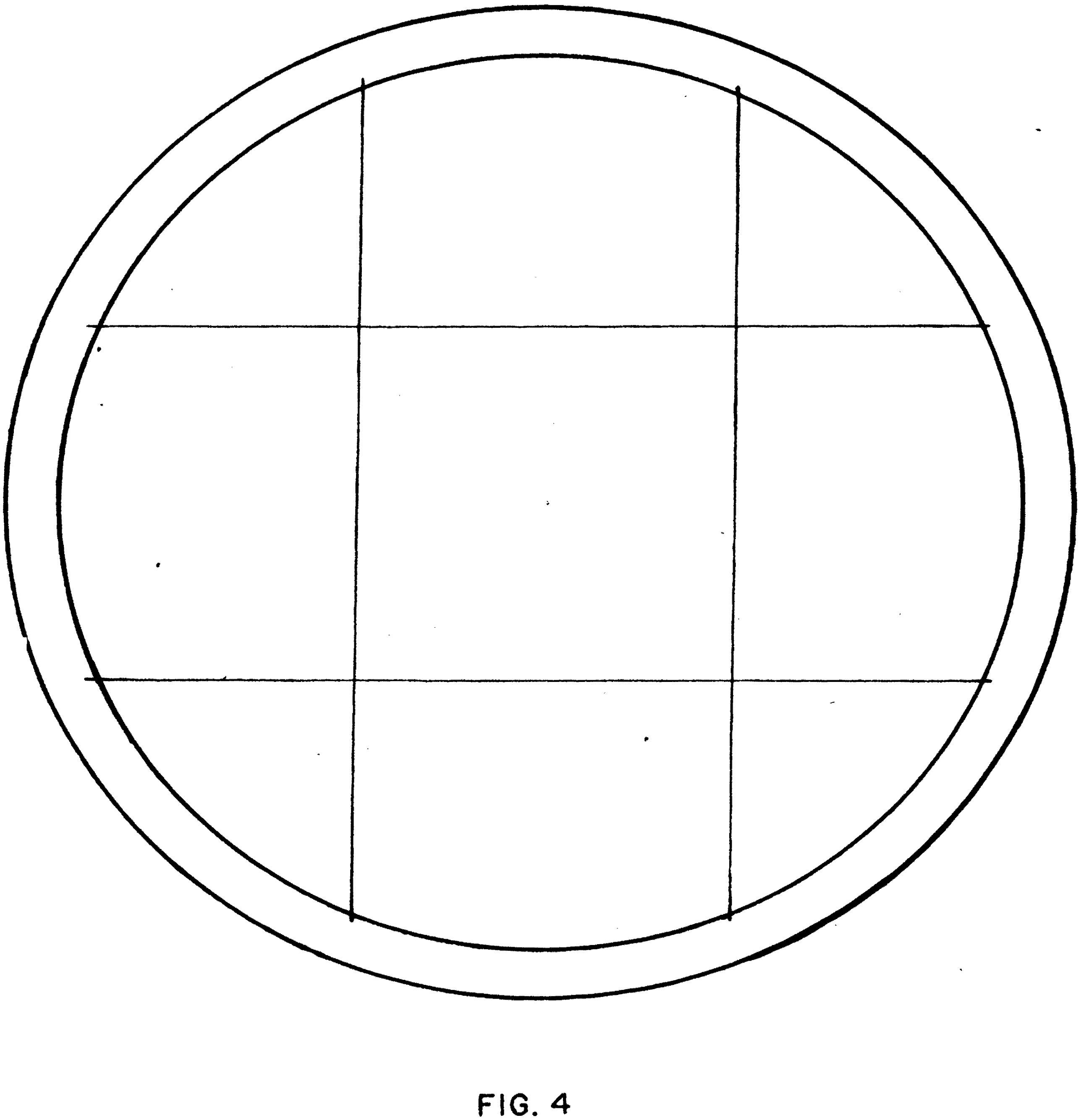

FIG. 4

this solenoid operated main valve, four smaller solenoid valves are located on a manifold connected to the rear chamber. See figure 3A. Also on this manifold is a solenoid operated inlet valve for stopping the flow of pressurized air into the lower chamber during the expansion. This eliminates variations in expansions due to the fluctuations of the flow of air into the lower chamber.

The four smaller solenoid valves on the manifold are used to continue the expansion once supersaturation has been achieved by the main valve. It is necessary to maintain a slow expansion after critical supersaturation has once been achieved due to the heat flow from the walls of the chamber and the heat liberated from the process of condensation. See figure 1. Each of these solenoid valves has a stop-cock valve connected in series with it to control the rate of flow of air through the unit.

The liquid inlet to the chamber is connected to a valve and a tee next to the chamber and then to a five gallon bottle. Two lines run into the bottle, one from the chamber and the other connected to the air pressure manifold. See figure 3 and 3A.

Beck (28) found an optimum liquid mixture containing

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(28) Beck, C., R.S.I. 12, 602, (1941)

CLOUD CHAMBER AND CONTROLS

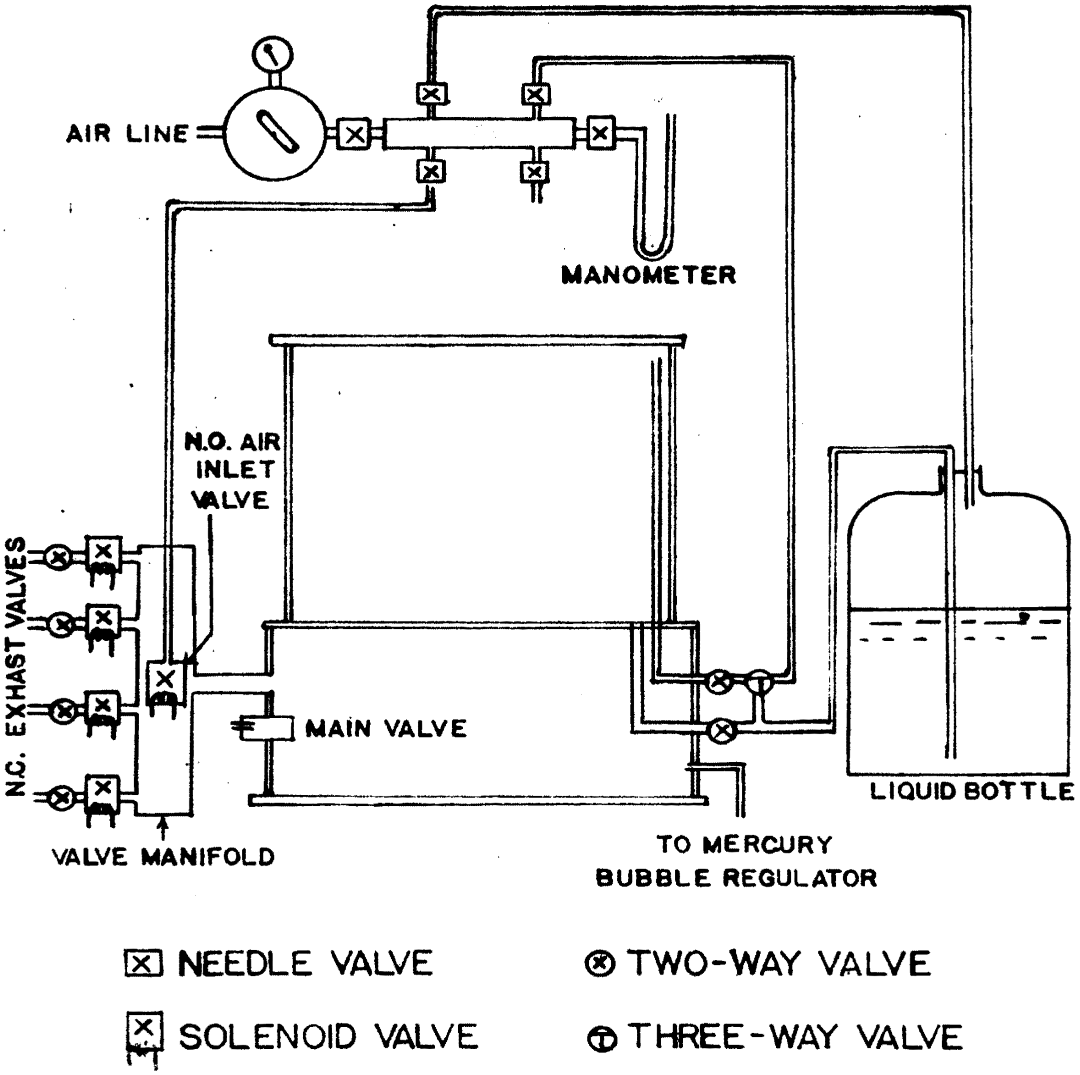

FIG. 3A

fifty percent normal propyl or ethyl alcohol, twenty-five percent acetone and twenty-five percent water. This mixture gave him excellent tracks and a clean chamber. For simplicity a reliable mixture used frequently by investigators in this field was used which contained 66 percent ethyl alcohol and 34 percent distilled water. Black Putnam Dye was added to the liquid to provide a dark background for photography.

The liquid is mixed and put into the five gallon bottle. The copper line from the chamber is passed to the bottom of the bottle. The air above the liquid in the bottle is compressed in order to force the liquid into the chamber. It is necessary to have the air inlet valves open in the line from the sensitive volume so that the volume of air in the chamber can escape during the filling of the chamber. Once a particular liquid level is reached the liquid valve near the chamber is closed. The pressure in the upper chamber is then measured with the manometer. The manometer is on the side of the panel rack and is connected to the air pressure manifold. The valves in the air inlet line are left open and the manifold is closed except to the manometer and the chamber air inlet line. A pressure of approximately five centimeters of mercury is necessary to cause the rubber diaphragm to position against the hemisphere reproducibly in the expanded position.

The upper pressure may be raised or lowered depending upon the desired operating characteristics.

The air inlet tube inside the chamber is then filled with liquid by pressurizing the liquid bottle, positioning the three way valve, and opening the air inlet valve next to the chamber very slowly. After filling the tube, the air inlet valve next to the chamber may be closed and the three way valve returned to an off position. The liquid in the air inlet tube prevents ionization and turbulence due to air flow out of the tube during the expansion.

In order to achieve good "reproducability" with the chamber, a mercury bubble air pressure regulator was connected to the lower chamber. This permitted good regulation of the pressure in the lower chamber thus causing less irregularity in the time rate of expansion.

Thyratron sequence timers, similar to the time delay circuit of Jones (29), were used to operate relays which in turn controlled the solenoid valves, clearing field, lighting, camera, and reset circuit. Banana jacks from the relay, which is operated by a thyratron tube, enable one to measure the delay and operation times very easily. Cams operated by a variable speed motor govern the

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(29) Jones, C.C., R.S.I. 8, 319, (1937)

over-all cycle time and provide the initial grid pulse for the expansion cycle. Time delay circuits are employed in the grid line of the thyratron circuit to delay the operation of any of the associate equipment from zero time. Other time delays were used to govern the time of each operation.

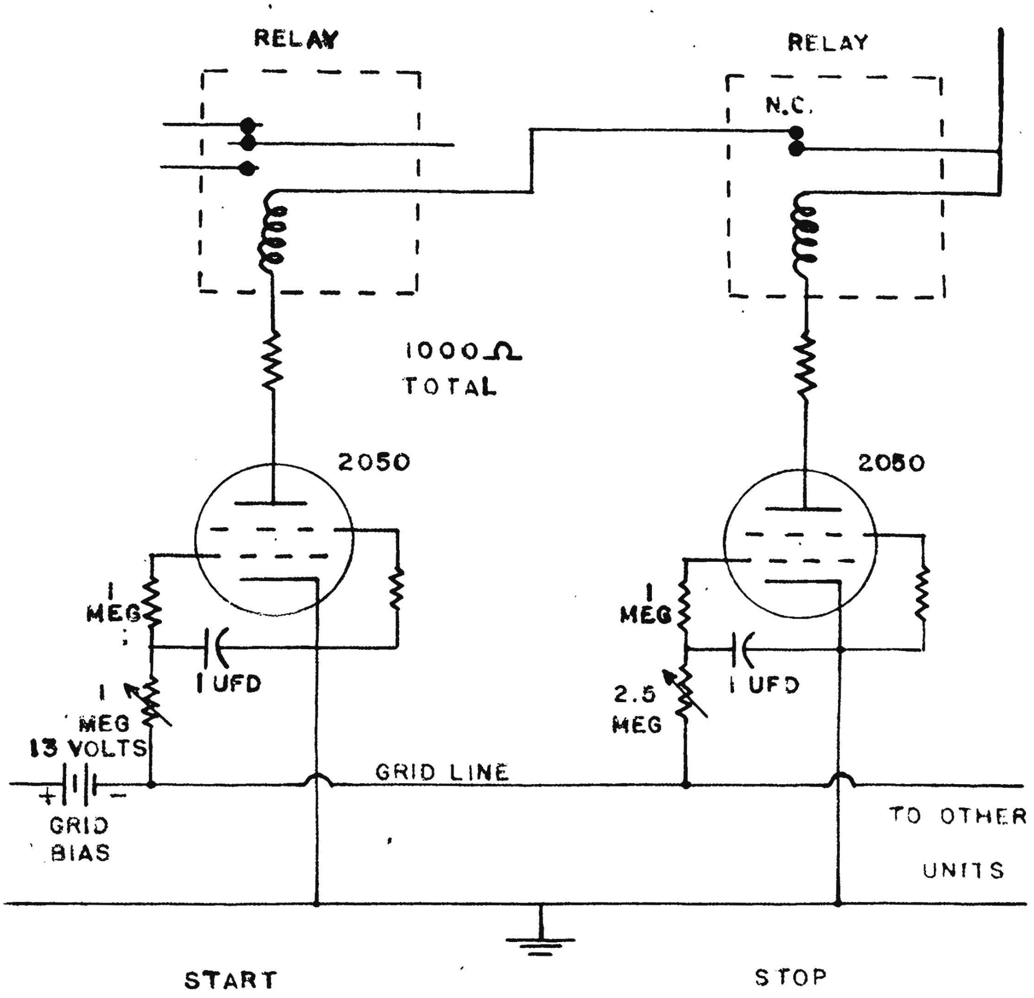
All solenoid valves, inlet and expansion, are controlled from an individual timer of twelve thyratron tubes. Each valve is operated by two thyratron tubes. One thyratron opens the valve at a preset time and the second allows the valve to close at a preset time. See figure 5.

Other operations are controlled from another thyratron timer. This timer has the variable speed motor, cam arrangement and seven thyratron tubes. It also contains the dry cell batteries for the clearing field. See figure 6.

The clearing field is cut off at zero time and back on at the reset time about seven seconds after zero time. A micro-ammeter gives the current in the clearing field circuit.

Incandescent lighting was obtained with the use of cylindrical elliptical reflectors. Straight line filament bulbs were positioned at one foci and a one-half inch slit at the other focal point. Four General Electric, clear, two hundred watt bulbs were used in each

SEQUENCE TIMING UNIT



RC TIME DELAY CIRCUIT, ONE UNIT ONLY

FIG. 5

THYRATRON TIMING CIRCUIT NO. 1

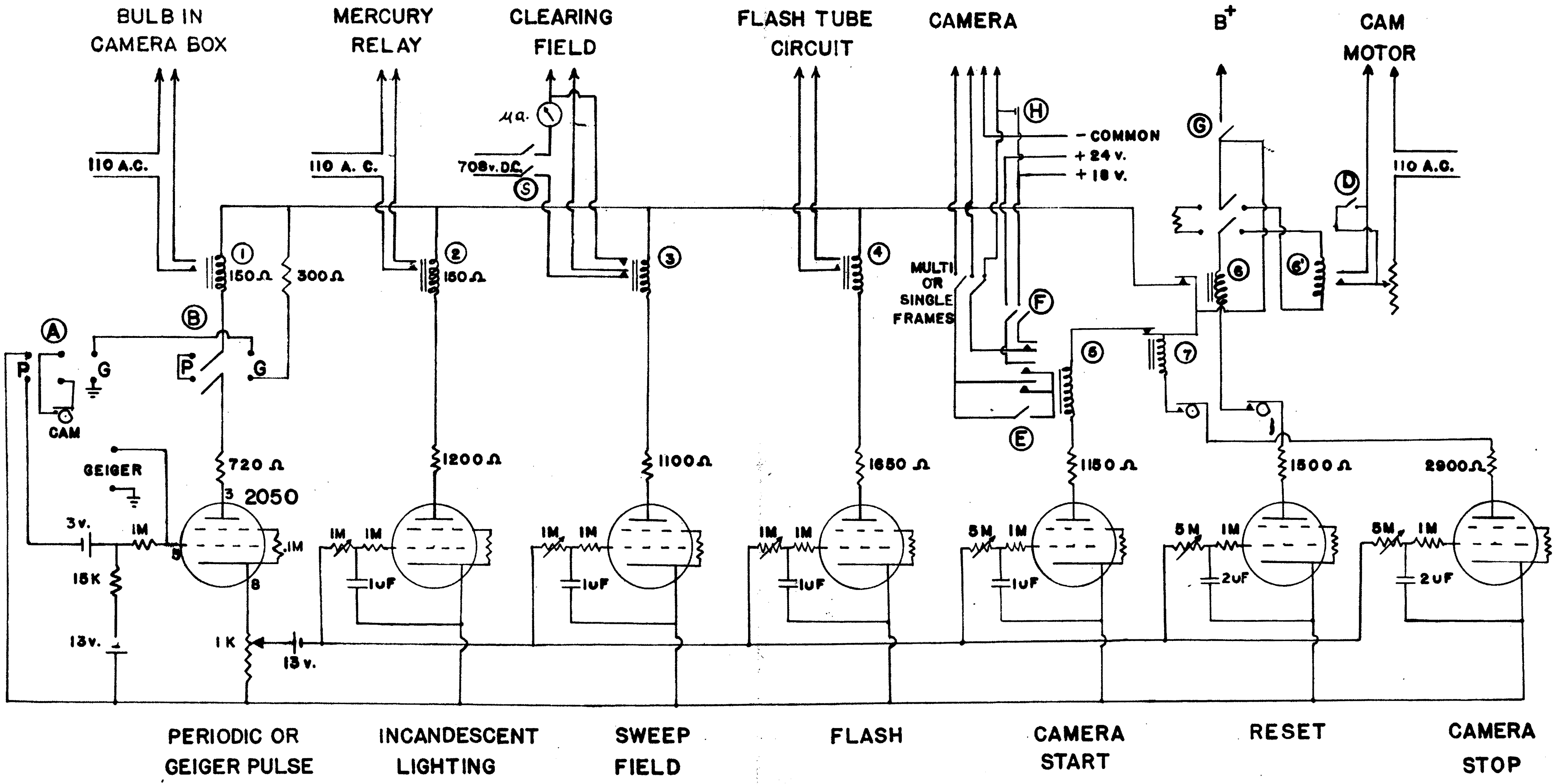


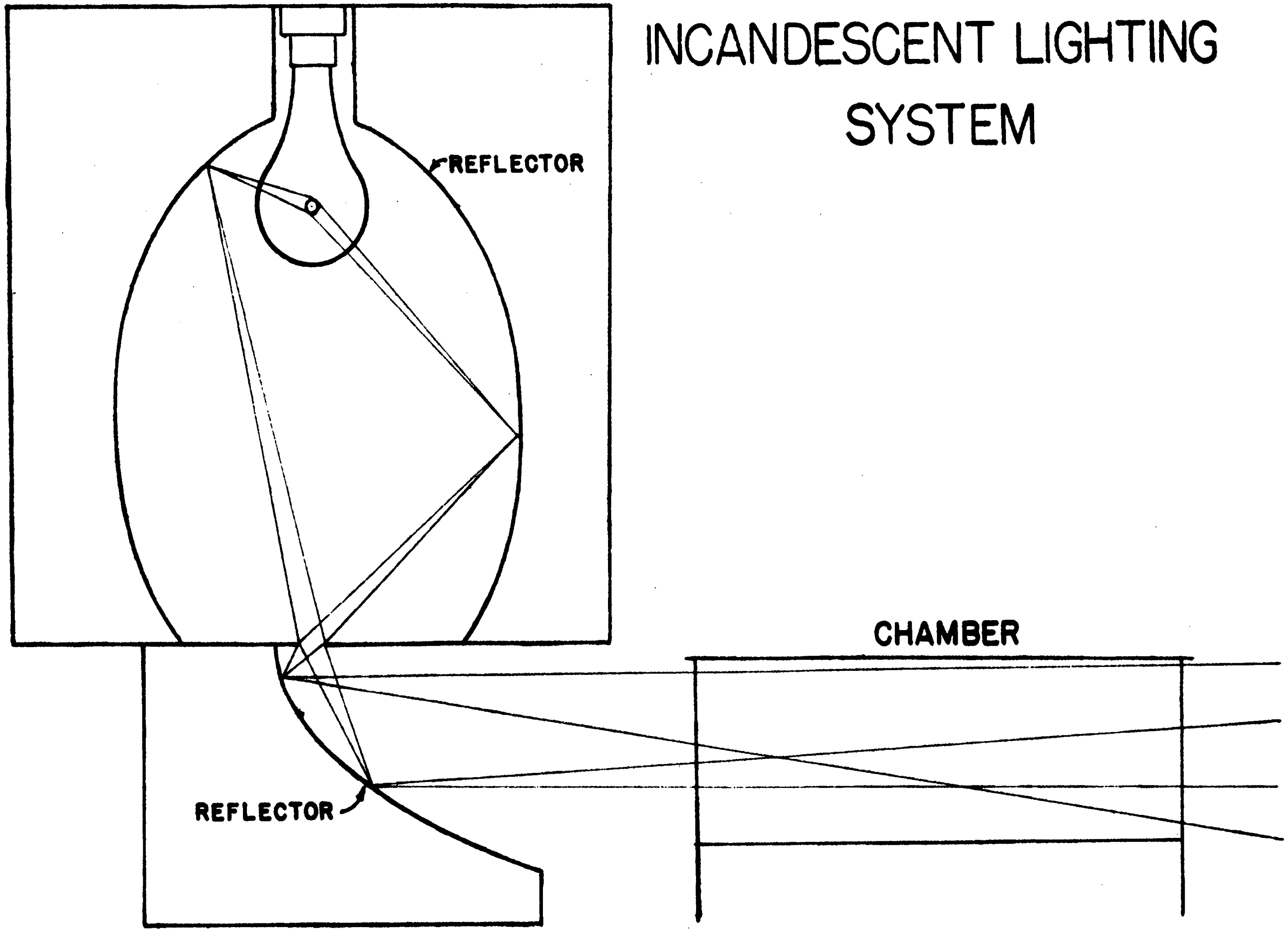
FIG. 6

light source. The slit of the elliptical reflector is positioned as the focus of another part of an ellipse that collimates the beam within boundaries of the chamber. Parallel light is not achieved but the light intensity is sufficiently uniform for our purposes. A parabola is undesirable for collimating since it collimates a beam only for a line source. Ferrotype, chrome plated, brass reflecting surfaces were used for all reflecting surfaces. Two of these sources were constructed using one-fourth inch mansonite for the reflector forms. See figure 7.

Flash tube lighting was also perfected. A three-eighths inch Xenon flash tube with a ten inch effective length was used in a cylindrical reflector. See figure 8.

Twenty capacitors of 120 microfarads each were wired in banks of two, providing ten banks for ten flashes. A stepping switch is employed to operate power relays which switch the flash tube from one condensor bank to another. A micro-switch operated by a cam connected directly to the shutter of the camera sends a pulse to a high voltage spark coil which in turn triggers the flash tube and stepping switch in proper sequence. These capacitors are charged to a potential of two thousand volts by a motor-generator. See figure 9. Note that the charging current of the

INCANDESCENT LIGHTING SYSTEM



1/4" SCALE

FIG. 7

FLASH TUBE ILLUMINATION SYSTEM

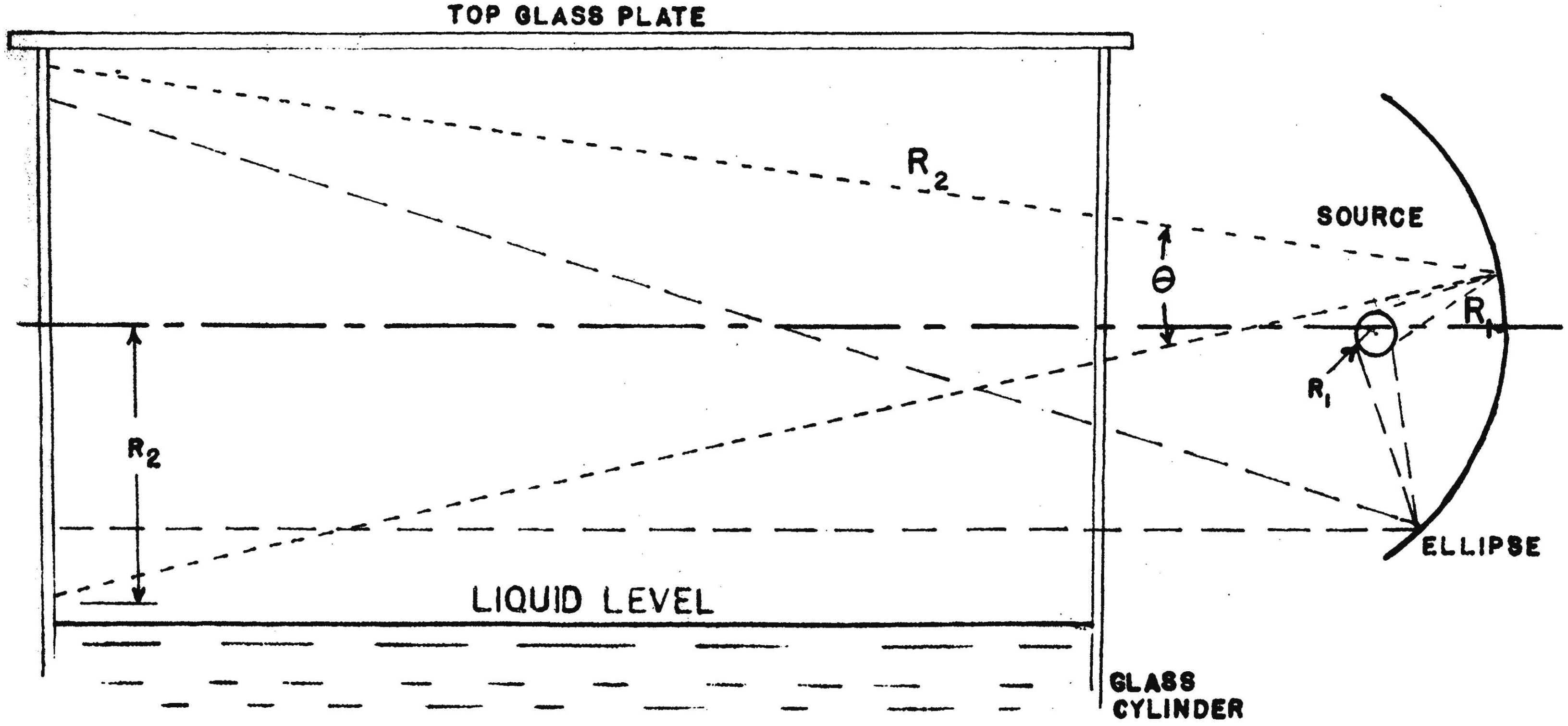


FIG. 8

FLASH TUBE CIRCUIT

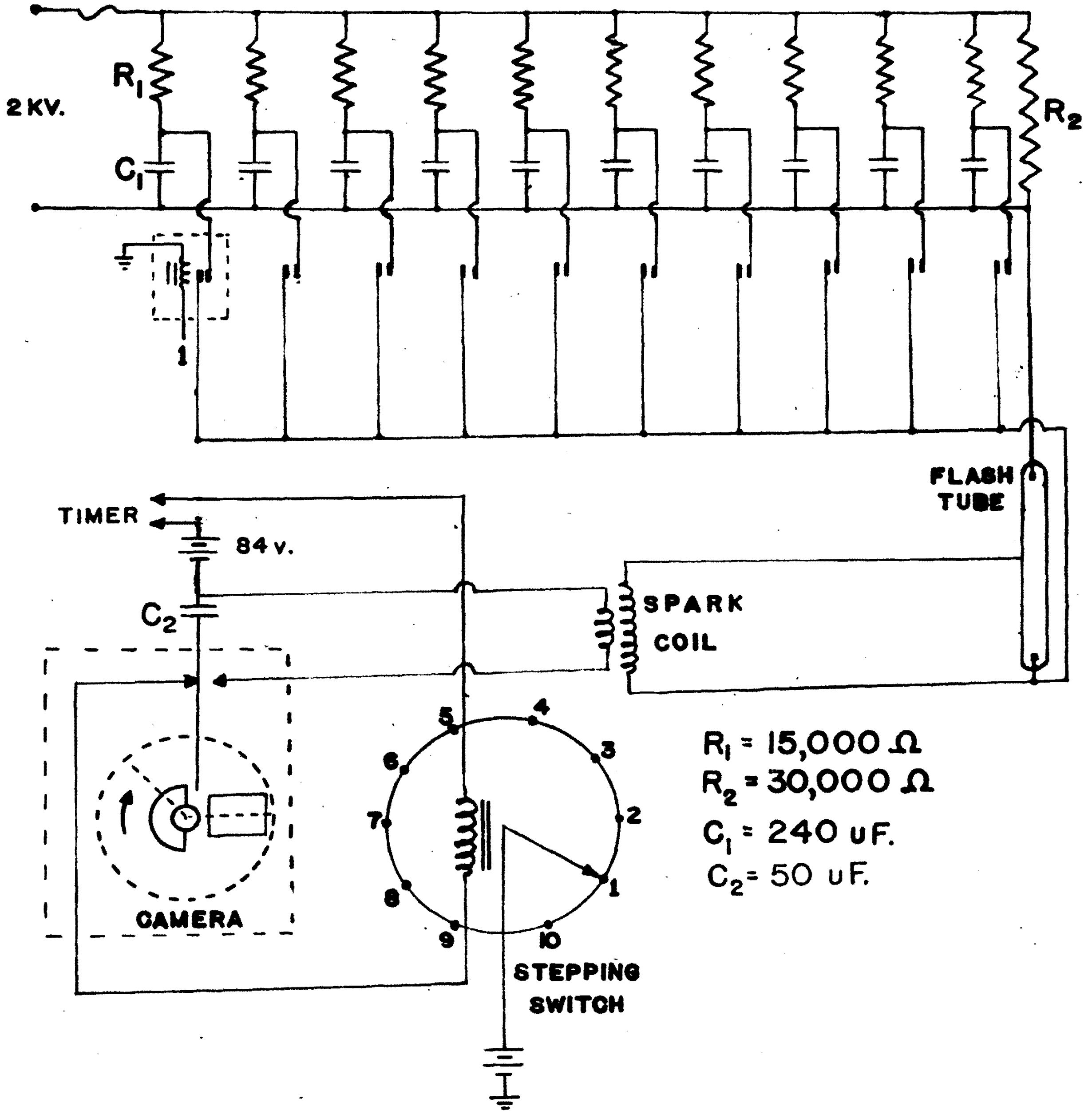


FIG. 9

capacitor is sufficient to operate the stepping switch in figure 9.

Two 35 mm. DeVry Air Force surplus aerial movie cameras are used with 50 mm. focal length lenses. One camera was reworked and wired so that single frames could also be taken completely automatically or manually. The relay operated by the thyratron tube on the timer in the camera circuit is a solenoid ratchet relay. This ratchett relay can be preset to take up to fifty single or movie runs of fifty consecutive expansions automatically. Separate voltages for the armature and field of the camera motor enables one to vary the framing rate on movie runs. The wiring diagram of this particular camera is given in figure 10. The second camera was wired with a cam operated micro-switch for synchronizing the multi-flash lighting system with the camera shutter. This camera is used only for movie runs. See figure 11.

Tri-X and Linagraph Pan film were used. Kodak D-19 developer, FB-5 stop bath and Kodak fixer were used in the developing process.

Sixteen photographs per foot of film were obtained in movie runs at a rate of approximately ten frames per second. A one hundred and twenty degree shutter provided an exposure of approximately thirty milli-seconds. The photographs were mounted in 2 1/4 by 2 1/4 slides and projected for viewing.

CAMERA NO. 1

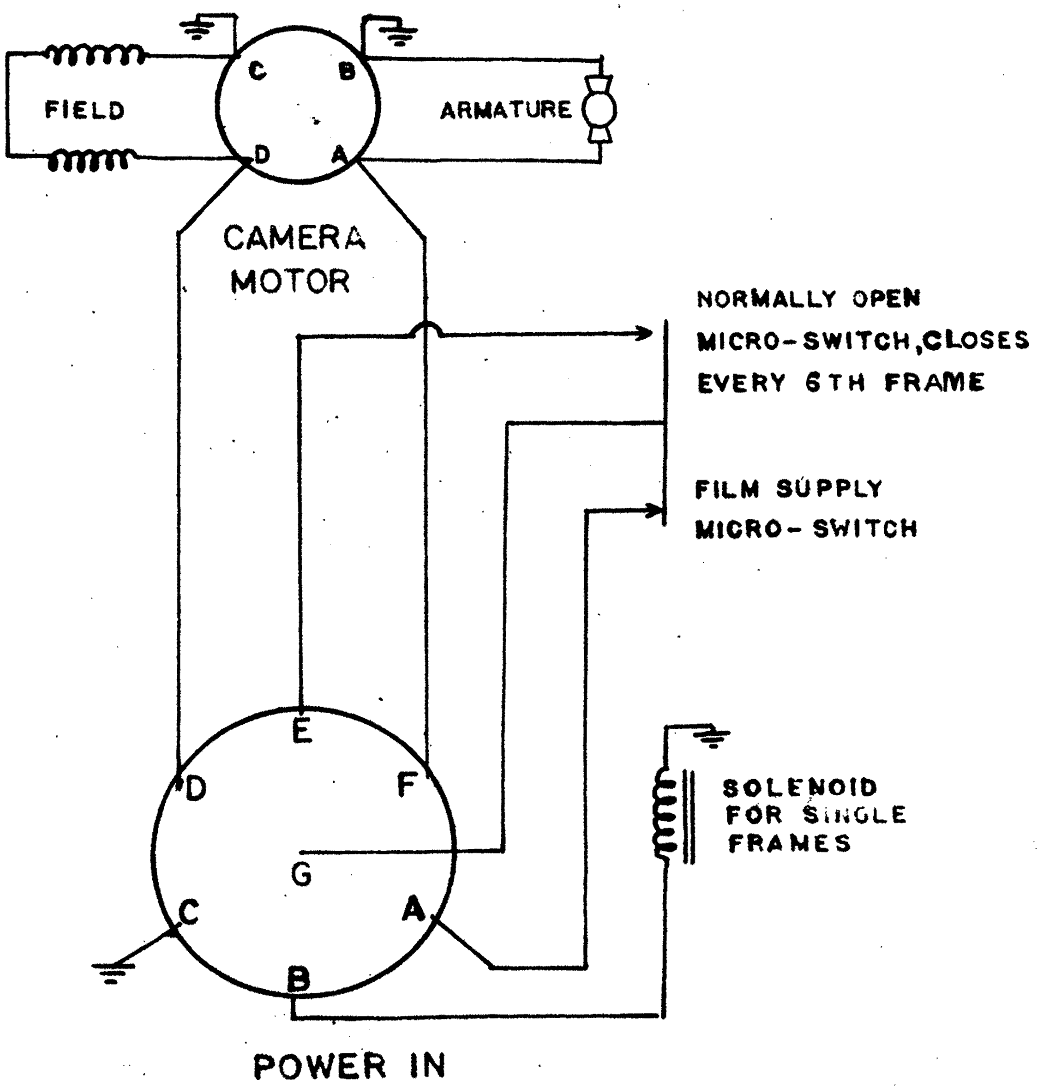


FIG. 10

CAMERA NO. 2

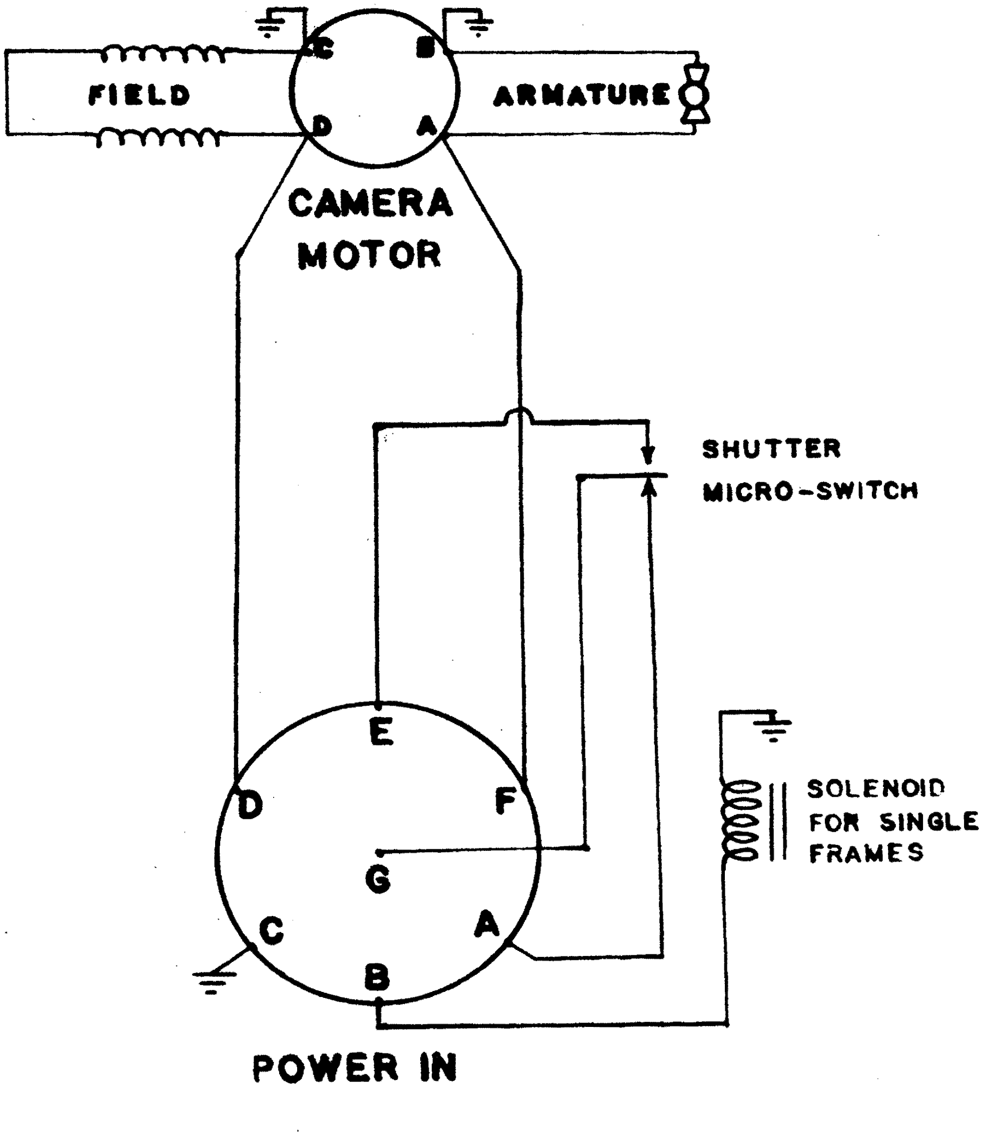


FIG. 11

The camera is located vertically above the chamber on a camera box. This camera box is fourteen inches square and twenty eight inches high. It contains a front surface mirror which gives a stereoscopic view and is also used for reprojection with the mirror removed. See figure 12. This is essentially the same method of obtaining stereoscopy originally employed by Jones and Ruark (30).

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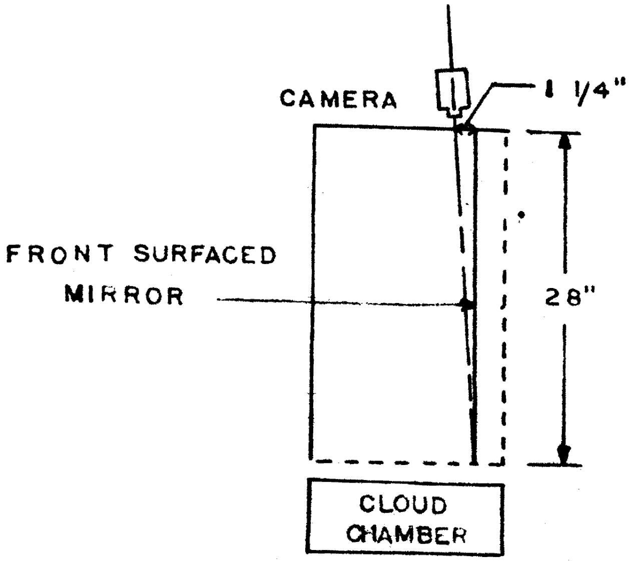
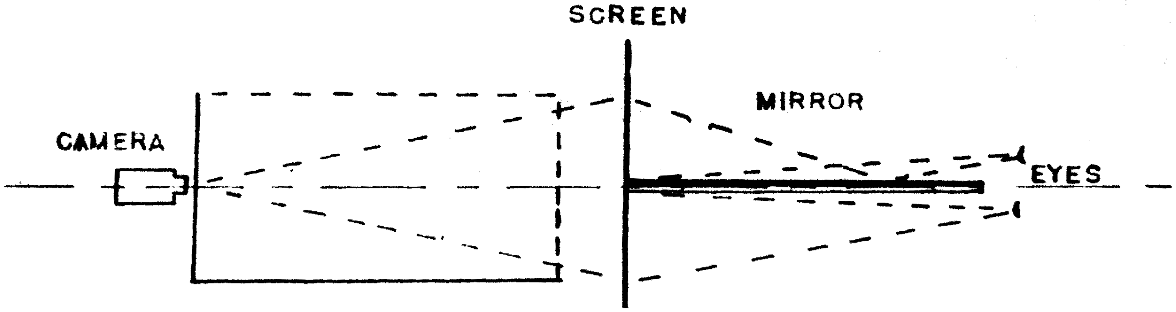
(30) Jones, C.C., Ruark, A.E., Am. Phil.Soc. Proc. 82, 333, (1940)



CAMERA BOX
POSITIONED FOR PHOTOGRAPHY



STEREOSCOPIC VIEWING SYSTEM

FIG. 12

EXPERIMENTAL PROCEDURE AND RESULTS

The characteristics of this particular chamber have been determined experimentally. It is desirable to know what maximum sensitive time can be obtained as a result of the multi-valve expansion system. It is also necessary to determine to what extent turbulence currents limit the usefulness of the obtained sensitive time. Preliminary results are given regarding background as a function of the liquid level.

The experimental conditions are numerous for chamber operation. A list of these conditions is given in Table I. A cycle time of approximately ninety seconds was commonly used. A means of varying the cycle time from 1/2 to 4 minutes is available.

An electric timer having a least count of one-hundreth of a second, provides an accurate means of determining the delay and operation times of the valves, camera, etc.

The sensitive time was lengthened by employing more than one valve. The main valve is used for a rapid expansion to get into the sensitive region, and the other valves are used to follow the sensitive region curves as is shown in figure 1. The following account relates to rather long sensitive times, of the order of three to four seconds. These observations were made visually. The sensitive time was ascertained as the time during which new sharp tracks appeared. At the beginning of the expansion the first tracks to be observed were rather diffused. The extent of the diffusion observed could be due to several causes:

1) They could be tracks that were just beginning to form at the end of the previous expansion. The tracks may have been caught in the recompression cycle and evaporated without ever producing droplets of visible size. These are commonly called ghost tracks.
2) An equally plausible explanation is that they are tracks coming into the chamber a second or two before the chamber becomes sensitive. It should be kept in mind that the rate of diffusion of ions is greater before condensation takes place. If the clearing field is on during this time these tracks should be separated into two distinct columns of droplets. It could not be determined visually whether the tracks were actually separated into two columns or not.

These diffused tracks coming in at the beginning of the expansion seem to be responsible for the majority of the background toward the end of the sensitive time. The spread of the droplets grew rapidly as the tracks fell out so that toward the end of the expansion, the track load and spreading were such that an almost continuous background was produced. This effect predominated when the height of the sensitive volume exceeded approximately four inches. This effect alone would prevent more than the first two seconds of the sensitive time from being used for data-taking purposes. This remark applies to the sensitive volumes of chambers approximately four inches or more in height.

The sensitive time exceeding the usable data taking sensitive time is useful in determining the shape of the sensitive region curve as a function of time. This enables one to drop below the sensitive region by providing a break in the continuous expansion curve and follow just beneath the ion limit long enough to insure the fall out of most of the droplets formed during the expansion. This should eliminate the major portion of the background due to re-evaporation nuclei. See figure 2.

Turbulence becomes noticeable about two seconds after tracks first appear and increases steadily until the chamber becomes insensitive. Recompression due to the heating effect of the walls begins as the chamber becomes insensitive. During this period the turbulence currents gradually subside. These turbulence currents predominate in a ring approximately two inches in width around the edge of the chamber. Turbulence currents inside this region seem to be mainly due to large concentrations of droplets in a small region. The heat liberated in the process of condensation is probably responsible. In all cases the turbulence has been noticed by observing the drift of the droplets.

Observations were made with smaller heights and longer usable sensitive times were obtained. This increase in usable sensitive time was due mainly to less turbulence and more rapid fall out of tracks, due to a smaller vertical distance in the sensitive volume. Smaller initial volumes require a smaller change in liquid level for the same expansion ratio, thus providing a longer possible expansion. It should be remembered that the maximum change in volume is a constant for this chamber. Smaller initial volumes require more accuracy in the time rate of expansion and makes it more difficult to follow the sensitive region.

The clearing field wires caused corona, which produced background. The wires were later coated with a rubber cement, reducing the corona, although some was still present due to sharp edges on the aluminum ring holding the wires. Corona can be eliminated during the expansion by making sure the clearing field is off throughout the entire expansion. Corona is observed as a continuous stream of droplets originating near the clearing field ring. This corona persists during elapsed time between expansions and is a potential source of background.

A curve of the expansion ratio versus time for a particular expansion is given in figure 13. This curve was obtained by a movie run simultaneously photographing a timer, the chamber, and the liquid level. The timer gave us the abscissa of the curve, the chamber view produced information in regard to the chamber sensitivity, and the liquid level provided the expansion ratio. Table I gives the information on the parameters for this particular expansion. The liquid level was obtained by placing a plexiglass rule on the side of the chamber. This was photographed with the use of a mirror and was illuminated more than sufficiently from the incandescent lighting source. A white piece of paper on the opposite side of the chamber gave better "definition" of the rulings. The higher intensity of the illumination of the liquid level was reduced with a pair of polaroids. The correct intensity was obtained when the polaroids were set at 70 degrees. Timer illumination was produced by a six volt galvanometer light. The intensity of the illumination was controlled by a power-stat.

Figure 13 shows a damped oscillation of the curve which is to be expected since the momentum of the water carries the expansion ratio past the value at the time

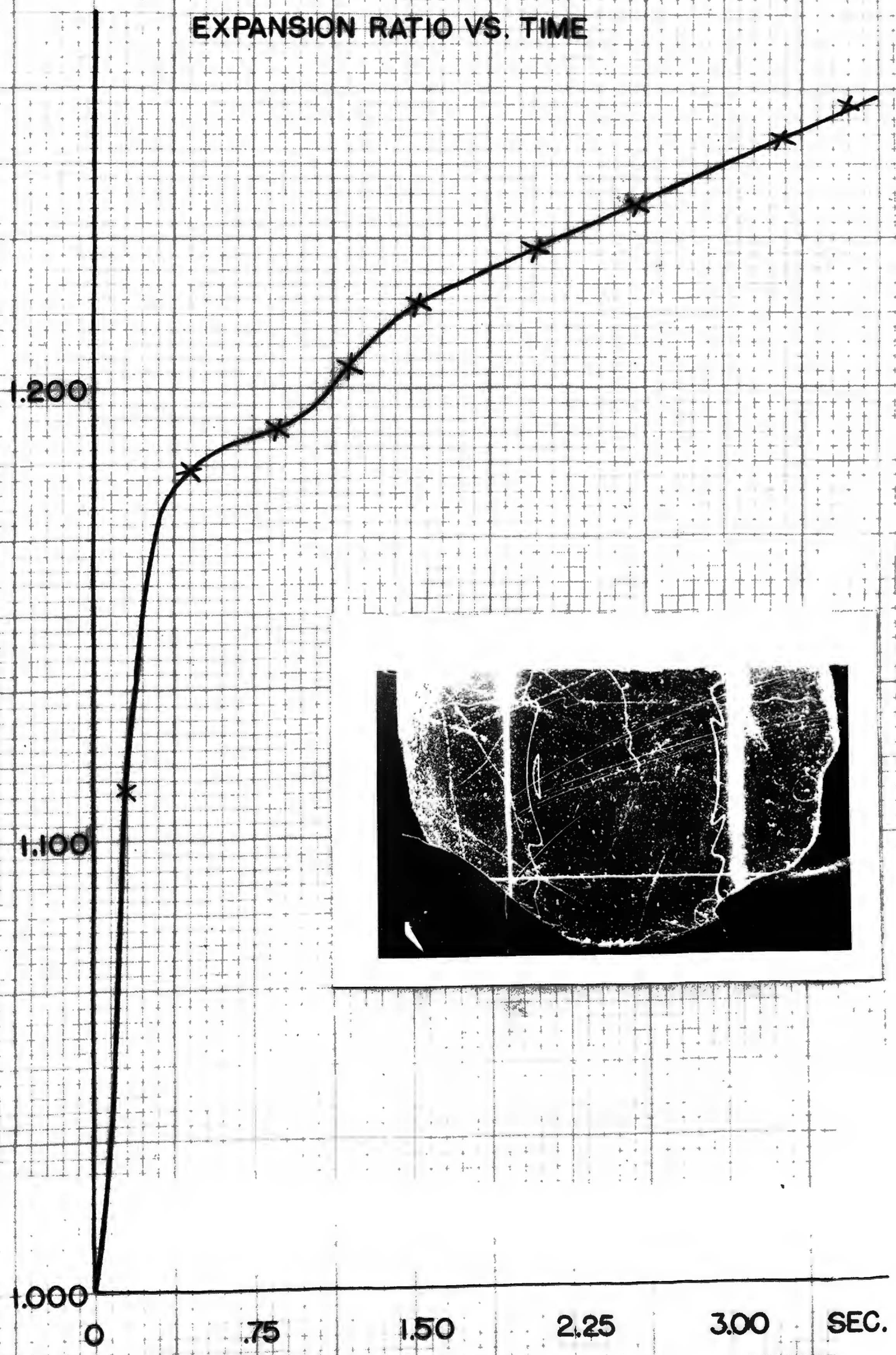


FIG. 13

TABLE I

Cycle time 90 sec.

Liquid level: compressed 8.3 cm., expanded 10.5 cm.

Upper pressure, expanded 5 cm. of mercury.

Lower pressure, compressed 6 3/4 p.s.i.

Clearing field: 708 volts 1/2 micro-amps.

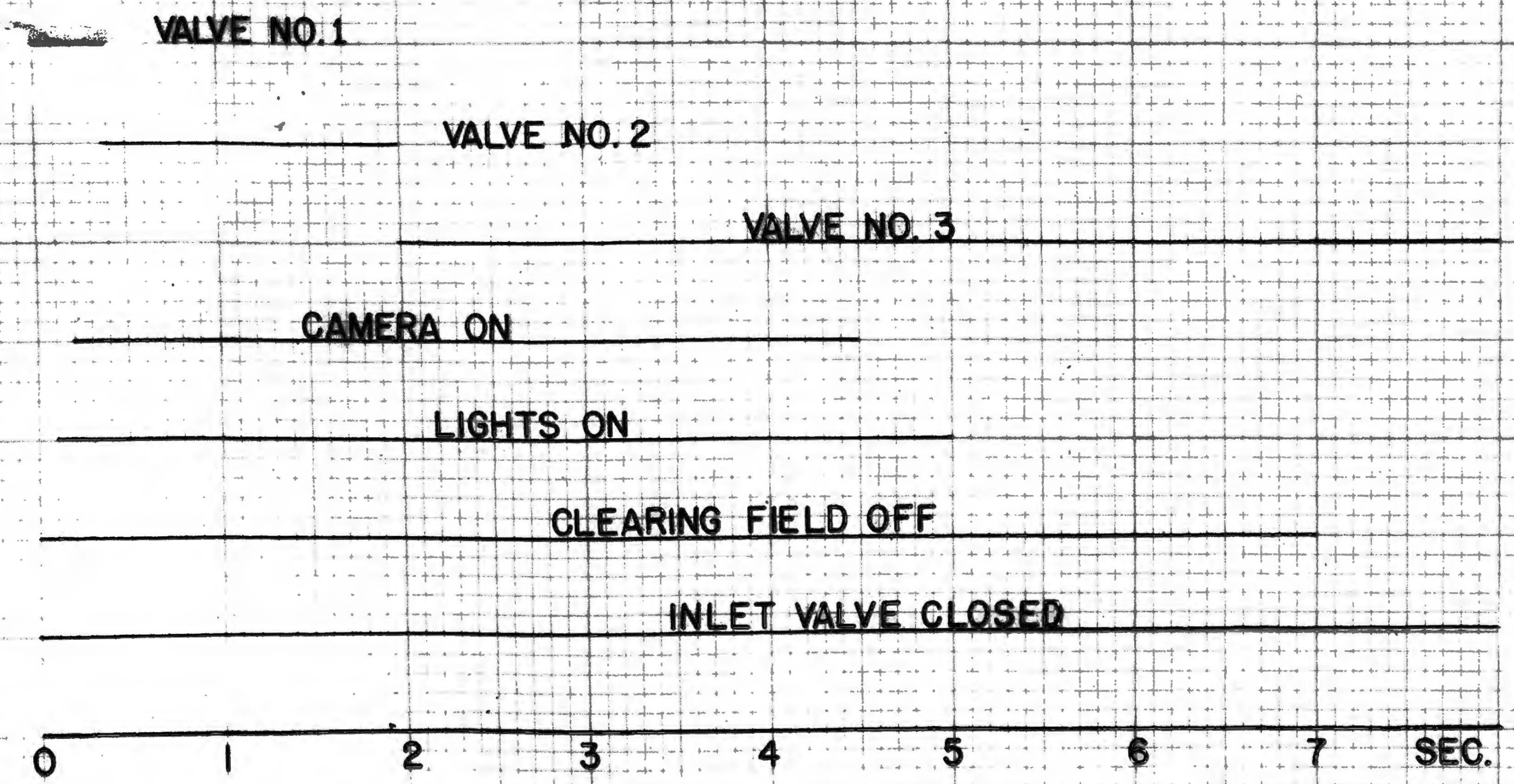
Camera No. 1 Lens No. 1 Film Tri-X

Cycle data:	start	stop
clearing field	0 (off)	5 (on)sec.
lighting, incandescent 200 volts.	0	4
Valves:		
1. Main 42 v.d.c.	0	.38
2. 110 volts a.c.	.35	5
3. Inlet, 84 volts d.c.	0	5

the main valve closes. The hole plate serves as the damping mechanism. Further evidence for this oscillation is provided by stray light hitting the clearing field wire. The photograph shows the wave motion of the liquid level, and was taken on Tri-X film at f/11. It shows the reflection of the clearing field wires on the liquid surface. This motion is more violent when the main valve is opened as wide as possible for a short duration of time and allowed to close abruptly. The wave motion will produce track distortion during the usable sensitive time and measures should be taken to eliminate this oscillation or to critically damp it.

With the use of several valves, a sensitive time of approximately three to four seconds was obtained. This particular sensitive time was reasonably reproducible and quite consistent for numerous successive expansions.

Figure 14 shows the delay and operation times of the associated equipment operated by the thyratron timer. The thyratron timer offered good control of all operations and eliminated mechanical fluctuations which cause variations in expansions.



RELATIVE CONTROL OPERATION TIMES

FIG. 14

SUMMARY

The cloud chamber constructed has a fairly long sensitive time compared to other long sensitive time cloud chambers. The sensitive time obtained with one valve was about two seconds. The use of more than one valve increased the sensitive time to approximately four seconds. The length of the usable sensitive time is limited by turbulence currents and background. Smaller vertical heights of the sensitive volume will reduce the amount of background and will also provide a longer possible expansion. This is due to the fact that the smaller initial volume requires less liquid level change to obtain a certain expansion ratio.

Photographs of the liquid level, timer and chamber provided measurements on the expansion ratio versus time. This provides information of the amount of continued expansion necessary to compensate for the heating effect of the walls and the heat from dondensation. With this information a possible means of eliminating re-evaporation nuclei by allowing sufficient time for droplets to grow and fall out was found.

The damped oscillation of the expansion ratio versus time curve in figure 13, can be eliminated by keeping the main valve from closing so rapidly and by the use of hole plates restricting the liquid flow within the upper chamber.

Background due to corona has been reduced but can be still further reduced by increasing the time delay which keeps the clearing field off. Although the clearing field at present stays off for seven seconds, the chamber is still expanding slightly and there may be sufficient supersaturation to cause condensation. A coating of non-conducting material on the entire clearing field ring would help eliminate corona from sharp edges.

Ethyl alcohol which is usually slightly acid, caused some chemical reactions which produced sediment in the chamber. The acidic condition reacts with the metal parts in the chamber and could be eliminated by neutralizing the acid in the ethyl alcohol with barium hydroxide. The metal parts of the chamber might also be coated with a suitable resin to prevent such reactions.

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Vita

Clarence W. Mettenburg was born October 16, 1933 in Fort Madison, Iowa, the son of Joseph and Mildred Mettenburg. He received his elementary education in the parochial school of Houghton, Iowa and was graduated from St. John High School in May, 1951.

In September, 1951, he enrolled in St. Ambrose College and received a degree from that same institution in January, 1956. In February, 1956, 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.