A CONTINUOUSLY SENSITIVE CLOUD CHAMBER

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A CONTINUOUSLY SENSITIVE CLOUD CHAMBER

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CHAPTER I

INTRODUCTION

In recent years the detection of particles ejected from the atoms of radioactive substances has become of major importance in nuclear physics and related fields. Several devices are in common usage which serve this purpose. For example, electroscopes and vacuum tubes have found extensive use in the detection of radiated particles. Several modifications of the electroscope and a variety of vacuum tube circuits have been used to accomplish this result. Among the vacuum tube circuits used are the familiar linear amplifier, the proportional counter, several modifications of the Geiger-Müller counter, and many other recording and counting devices. Discussions of these various instruments may be found in literature concerning nuclear physics and related topics. Pollard and Davidson[1] and Hoag and Korff[2] give excellent discussions of these devices in their books on atomic and nuclear physics. Another device which has been useful in the development of atomic and nuclear theory is the cloud chamber. A study of the electroscopes, vacuum

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[1] E. Pollard and W. L. Davidson, Applied Nuclear Physics, pp. 18-44.

[2] J. B. Hoag and S. A. Korff, Electron and Nuclear Physics, pp. 436-461.

tube circuits, and cloud chambers reveals that each depends fundamentally upon the detection of charged particles produced by the ionizing effect of the radiation being studied.

The cloud chamber is perhaps the most graphic of all the instruments mentioned. It is graphic in so much as the path of the particle and secondary effects of the particle may actually be observed with the eye. Essentially it depends upon the condensation of a supersaturated vapor on the ions created by the radiation under observation. In 1911, C. T. R. Wilson[3] developed such a cloud chamber. Until 1934, his chamber was used extensively almost without modification[4] even though it suffered from two major difficulties in its operation. First, its operation was intermittent, being sensitive to radiation for only a fraction of a second out of approximately one minute, and second, the chamber required mechanisms which were expensive and difficult to operate. Each of the difficulties was the direct result of the method used to obtain the supersaturated vapor. His method was to expand adiabatically a vapor in contact with the liquid producing it. The cooling due to the expansion caused the vapor to become supersaturated and sensitive to condensation. To accomplish this expansion the vapor and liquid were enclosed in a cylinder which was fitted with a piston in one end and

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[3] _Ibid._, pp. 452-460.

[4] J. D. Stranathan, _The "Particles" of Modern Physics_, p. 43.

a transparent window in the other. The liquid used was usually water or alcohol. The chamber was operated with the piston down so that the liquid was in contact with the piston and the vapor was in contact with the transparent top. The cooling process consisted of operating the piston to slowly compress the vapor and then suddenly expand it. The expansion cooled the vapor to the extent that it became supersaturated and would then condense on any dust particles or ions in its presence. When a radiated particle passed through the chamber during or immediately after the expansion, the ions it created formed nuclei upon which the vapor could condense. The condensed droplet could then be made visible by illumination with a fairly intense light beam passed through a window in the side of the chamber. Thus the ions created all along the path of the particle could be made visible and the entire track could be seen. After the expansion, which yielded vapor that was sensitive to radiation for a small portion of a second, it was necessary to wait for approximately one minute to allow the vapor to come to thermal equilibrium with the liquid before the next expansion could take place. A highly undesirable consequence of this time lapse is that many important events taking place in the substance producing the radiation and events subsequent to the radiation could easily be missed. Much research has been devoted to lengthening the sensitive time and shortening the recovery time for this type of cloud chamber; however, the expansion chamber is of necessity intermittent in its operation.[5] This not only causes important events to be missed, but also makes photography difficult since the exposure would have to be made at exactly the correct time after the expansion. Cooling the vapor to supersaturation by this method requires expensive, precise instruments and intricate timing devices for operations which follow the expansion.

Another difficulty experienced by those who have used the expansion type cloud chamber is that dust which is present in the vapor will also act as nuclei for the formation of droplets. As long as it is present to any appreciable extent, the entire track cannot be observed because the available vapor is used up in condensing on the particles. Often many repeated expansions were necessary to free the chamber of undesirable dust. A minor difficulty which has arisen due to the necessity of illuminating the tracks is the convection currents in the vapor. The heat produced by the light source causes motion of the vapor which tends to break up the tracks and make photography difficult.

The two major difficulties encountered by those who have used the expansion type chamber make it immediately obvious that a chamber of simple construction and continuous operation would be very desirable, and if at the same time some of

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[5] A. Langsdorff, Jr., "A Continuously Sensitive Diffusion Cloud Chamber", The Review of Scientific Instruments, X (March, 1939), 91.

the other difficulties could either be alleviated or lessened, a very desirable and useful instrument would indeed be the result. Several notable attempts to construct such an instrument have been made. The earliest attempt was made by Langsdorff[6] in 1938, but his apparatus was never widely accepted for practical use due to its complexity and the intervention of World War II which prevented the necessary simplification. Other independent attempts were made during the same period by Hoxton and Vollrath.[7] Work on the continuous cloud chamber was discontinued until the close of World War II. At this time a surprisingly simple continuous diffusion cloud chamber was constructed by Needels and Nielsen.[8] A much more elaborate continuous chamber, yet still simple as compared to the expansion chamber, was constructed and studied by Cowan[9] in 1950 with satisfactory results. Langsdorff, Cowan, and Needles and Nielsen constructed chambers which utilized the diffusion of a vapor from a warm to a cooler region. This diffusion process allowed the vapor to become supersaturated upon reaching the cooler region. Hoxton's chamber utilized warm air passed over water and thence into a chamber cooled by a water jacket. Vollrath's chamber operated on the

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[6] Ibid. [7] Ibid.

[8] T. S. Needels, and C. E. Nielsen, "A Continuously Sensitive Cloud Chamber," The Review of Scientific Instruments, XXI (December, 1950), 976-977.

[9] E. W. Cowan, "Continuously Sensitive Diffusion Cloud Chamber," The Review of Scientific Instruments, XXI (December, 1950), pp. 991-996.

principle of interdiffusion of two vapors which became supersaturated with respect to both components. Of these various models, the ones which use the principle of diffusion from a warm to a cooler region appear to give the more sensitive vapor and are somewhat more stable and easily operated than other types.

As was previously pointed out, one advantage of the continuous chamber over the expansion chamber is immediately evident. A continuous cloud chamber of sufficiently practical design would yield much more data in a given time and thereby improve some types of experiments which have been previously performed by the expansion type chamber. A continuous chamber which is inexpensive to operate would be ideal for classroom demonstration since a large class could observe cloud chamber phenomena in a short time, a feat impossible with the older expansion type chamber. Also, the likelihood of obtaining photographs of tracks without expensive timing devices would be increased. It is also within the realm of possibility that the time required to free the chamber of dust could be shortened. With these facts in mind, it seems that a continuous cloud chamber would be a valuable asset to laboratory work in nucleur and atomic physics. For this reason the construction and investigation of a continuously sensitive diffusion cloud chamber has been undertaken. It is the purpose of this paper to report the design and operating characteristics of such a chamber.

CHAPTER II

GENERAL CONSIDERATIONS AND THEORY

The basic components of all the cloud chambers which have been previously constructed are a chamber proper, a vapor source, a refrigerating system, and a source of light. If a diffusion cloud chamber is to be constructed, an investigation of the functions and desirable characteristics of each component should be made.

The chamber proper is the region in which a supersaturated vapor will be created to condense on ions which form tracks. This region must be provided with a means of keeping it relatively dust-free or the vapor will condense on the dust. It should be easily accessible from the outside so that sources may be changed readily. A means of observing the tracks from the outside must be provided. The entire sensitive region should be clearly visible so that all the tracks can be observed. There must be a means of illuminating the tracks after they are formed. A light source can be placed outside the chamber for this purpose. Cowan has constructed a square chamber, but difficulty in keeping it air tight has been encountered. It has been suggested by Langsdorff that a glass cylinder be used as a chamber proper. A top and bottom can be made to keep out the dust. Visibility can be through the wall of the cylinder or through the top. The top could be made removable to allow a source to be introduced into the chamber.

The vapor source should supply an amount of vapor sufficient in quantity to condense on all the ions in the chamber and should supply this vapor continuously. The source should be designed so that different vapors can readily be used. Langsdorff's chamber utilized a vapor source external to the chamber and connected in such a way that the vapor entered the chamber through small holes in the top. A more convenient method was used by Cowan. A heavy velvet pad was attached to a thin metal sheet, saturated with the liquid used to produce the vapor, and clamped in place at the top of the cylinder by means of rods which pressed the top and bottom tightly against the cylinder. Having several such pads available would make a simple matter of changing liquids. A saturated pad should supply enough vapor to operate the chamber continuously for over an hour.

If the vapor source is placed in the top of the chamber, refrigeration must be applied to the bottom. The purpose of this refrigeration is to cool the vapor to a suitable degree of supersaturation to allow condensation on ions. All that is required to do this is that the floor be kept at a temperature below that necessary for condensation, about minus thirty degrees Centigrade for methyl alcohol.[1] Langsdorff's method was to pass a cold liquid between two

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[1] Cowan, op. cit., p. 993.

glass plates which formed the bottom of the chamber. Cowan and Needles and Nielsen used dry ice as a refrigerant for the bottom of their chambers. This appears to be the most practical method. If dry ice is used, it must be clamped tightly to the bottom to maintain the necessary low temperature.

Illumination can be produced by any reasonably intense light source placed outside the chamber. If it becomes desirable, a fairly weak source might be placed inside the chamber. It might be necessary to provide a reflector for the source if an ordinary incandescent light bulb is used.

After considering the basic components of a diffusion cloud chamber, the most practical combination seems to be a glass cylinder for the chamber proper, a felt or velvet pad to hold the liquid which produces the vapor, dry ice applied to the floor as a refrigerant, and a strong light source placed outside the chamber. The top for the chamber could be made of glass, plexiglass, or metal. A hole, covered with a transparent material and sealed, will have to be provided for visibility from above if a metal top is to be used. A hole will also have to be cut in the absorbent pad to fit the hole in the top. The bottom should be black to provide a contrasting background for the tracks. A means of keeping the dry ice clamped securely to the bottom can be provided by a system of springs. These components can be clamped together with stove bolts as shown in Figure 1.

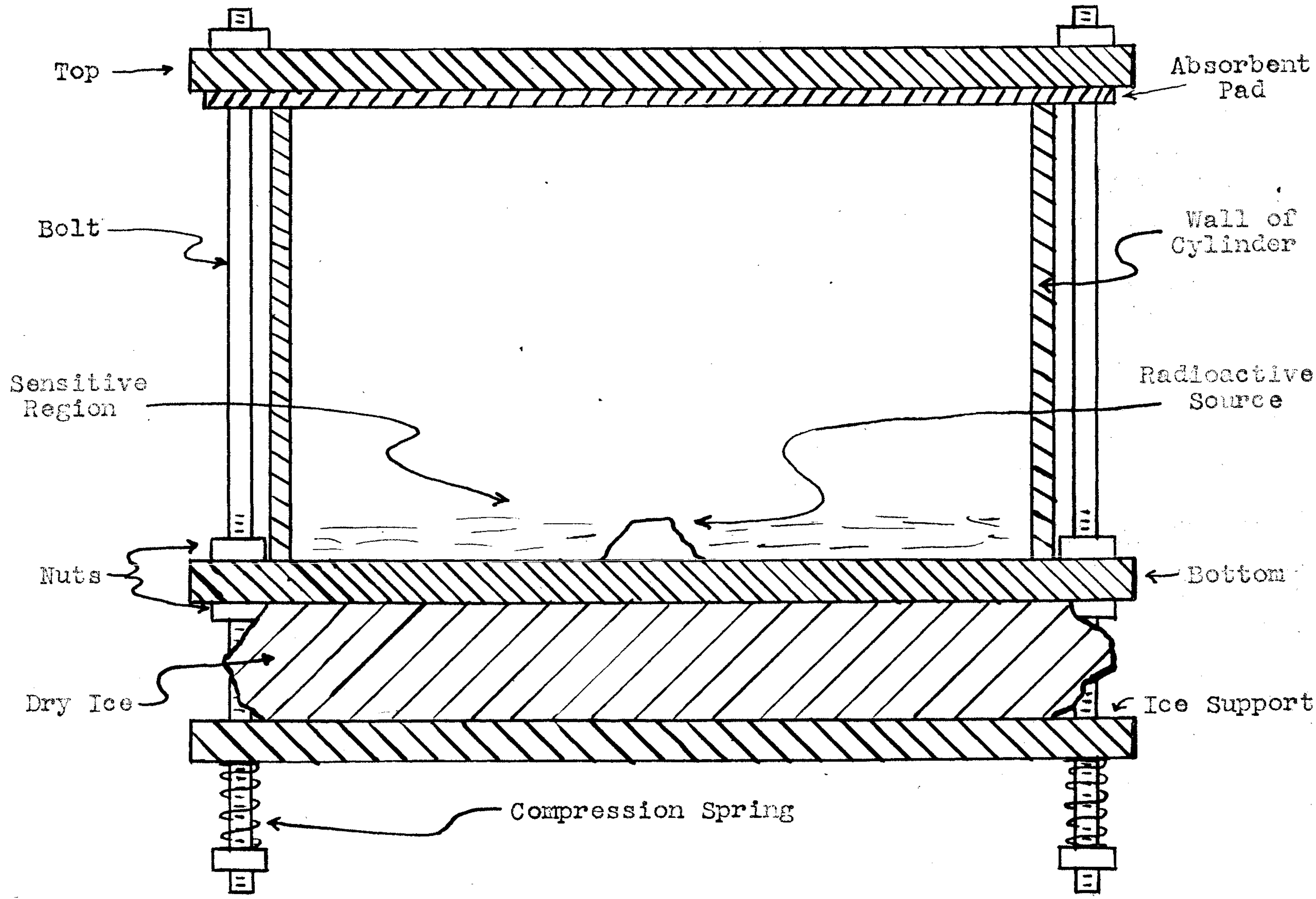

Fig. 1.--The basic cloud chamber

With this arrangement, tracks from cosmic and other background radiations can be observed. Needles and Nielsen discovered that such a chamber will operate satisfactorily with a source of radiation inside. If this is possible, it will not be necessary to provide a mount for the radiation source. In some cases the source may require a suitable container before it can be lowered into the vapor.

It has been noted previously that all detecting devices actually detect the ionization produced by a particle. In the cloud chamber, the ions produced are the nuclei upon which condensation takes place. For these reasons the processes of ionization and condensation on ions should be considered.

The process of ionization is well accounted for by the theory of the atom. Suppose that an electron of fairly great energy is allowed to enter a gas or other medium. The mutual repulsion between the electron and the electrons of the atom is greater than the mutual attraction between the electron and the nucleus. Thus the electron and the atom experience a mutual force of repulsion. When the electron passes near an atom, it imparts some of its energy to the atom due to these forces and may eventually lose all its energy and become absorbed. On the other hand, if the electron comes very close to an atom, the possibility that a planetary electron would be dislodged from its nucleus is great. The mutual force of repulsion between the electron and the planetary electrons would be great enough to accomplish this.

This process is known as ionization. The dislodged electron is the negative portion of an ion pair, while the positive portion is composed of the nucleus and the remaining electrons of the atom.

Condensation is a process which has been observed and experimented with for many years. A well known fact is that, in order to grow, a drop must start with a finite size; it therefore requires a nucleus for condensation. Thus vapor will condense readily in the presence of dust, ions, or molecules; but without such particles vapor can not condense. If a supersaturated vapor is allowed to form in a dust-free region, a degree of supersaturation will finally be reached which is great enough to allow the vapor to condense on the molecules of the surrounding medium. However, this degree of supersaturation is greater than that which is required for condensation on ions.[2] Thus in a dust-free region it is possible to maintain a supersaturated vapor which will condense on any ions in its presence. The condensation process liberates heat which will cause convection currents in the chamber.

The operation of a diffusion cloud chamber depends upon the principle that a vapor will diffuse from a warm to a cooler region. This is the result of the random motion of the vapor molecules which will eventually cause molecules to move to the cooler region where they lose some of their energy

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[2]Stranathan, _op. cit._, p. 42.

to the ice. The mean free paths of the cool molecules are less in the cool region than in the warm region and, consequently, the molecules will tend to stay in the cool region, forming a supersaturated vapor there.

A mathematical analysis of the conditions inside a diffusion cloud chamber has been carried out by Langsdorff. Some very interesting conclusions have been drawn from the results. His analysis shows that there should be an optimum range of chamber height which must be determined experimentally for each set of operating conditions. The upper limit on this optimum range of height is reached when a favorable balance between vapor available from the source and vapor removed by condensation on excess ions occurs. The lower limit occurs when the liquid is cooled sufficiently to prevent evaporation or when the warm liquid raises the temperature of the vapor sufficiently to prevent condensation. A chamber of this type should be very sensitive to temperature conditions. In fact, a change of a few degrees might be enough to prevent operation. If the supersaturation is in any way lowered, the sensitive layer will decrease in thickness. In the case of methyl alcohol a vapor flux of the order of 10^{-6} grams per square centimeter per second is necessary to maintain condensation on ion tracks. It should be pointed out that the use of the cloud chamber is not limited to the detection of particles. It may be used to determine the range of particles in different gases which is a measure of the energy and type of the particles. If the radiation is in the form of a beam, the deflection of the beam by an electric field may be observed. The energy of particles is information of value to the physicist. The action of a constant magnetic field on a charge moving with constant velocity is such that it causes the particle to move in a circular path. If the mass m, the charge q, the magnitude of the magnetic field B, and the radius of the path r are known, the energy of the particle E is given by electromagnetic theory as

$$E = \frac{(rqB)^2}{2m}$$

Subsequent calculations with this equation reveal that the magnitude of the magnetic field necessary to bend an electron of average energy in a circle of measurable radius is approximately 1000 gauss. This calculation is based on the assumption that an "average" energy is four million electron volts and a measurable radius of curvature is six centimeters.

In order to measure the radius of curvature of the trajectory of the particle, a record of the path must be made. The most common method of recording tracks is the photograph. If a photograph is to be made, the axis of the camera must lie along the lines of force of the magnetic field. This requires that the camera be placed at one of the poles of the magnet, a condition difficult to fulfill since a fairly large field is required. A large field can be produced with a large permanent magnet, an iron-core electromagnet, or a many-turned electromagnet.

Ions are formed by radiation throughout the vapor, and these ions drift into the sensitive region to form random, undesirable droplets. This not only decreases the amount of vapor available for condensation, but also forms an undesirable mist in the sensitive region. These ions may be removed by an electric field applied between the top and the bottom of the chamber. Suppose that an electric field exists throughout the chamber. Ions in the chamber will experience a force in an upward or downward direction depending on the nature of the charge. Thus half of the undesirable ions will be attracted to the top while the other half will be pulled through the sensitive region near the bottom. A track formed in the sensitive region will also be affected by such a field. The effect will be a tendency to slow down the fall of half the track and speed up the fall of the other half. However, this effect should not be prohibitively great if the field is not too large. Any tracks formed just above the sensitive region will have half its ions pulled into the sensitive region where they can be made visible. The overall effect of such a field will be to create more tracks and eliminate about one-half of the undesirable mist. This should be an improvement over operation without an electric field. If the field described above tends to break up the tracks to an undesirable extent, the field may be applied between electrodes above the sensitive region. The top can act as one electrode and a ring or grid wire system placed just above the sensitive region as the other. In this manner more than half the undesirable ions can be captured without disturbing the tracks in the sensitive region. This method would not create additional tracks as was the case with the previous method. Another method of applying the field will be to utilize a third electrode placed just above the sensitive region (see Figure 3). The third electrode can be held at a positive potential while the top and bottom of the chamber can act as the ground electrodes. Essentially this will be a combination of the first two methods and will probably be the most satisfactory.

CHAPTER III

CONSTRUCTION AND OPERATION OF CLOUD CHAMBERS

The purposes of the first cloud chamber constructed were to test the basic components suggested previously and to provide a means of experimenting with various vapors and radiations.

The chamber proper consisted of a glass cylinder which was a section cut from a reagent bottle. The cylinder was five inches in diameter and three inches high with a wall thickness of one-eighth inch. A piece of paper was rolled around the bottle to provide a straight edge as a marker for a groove cut with a triangular file. A high resistance wire was placed in the groove and a current passed through it to produce heat which expanded the glass and caused it to break smoothly along the groove. The edges were then sanded until smooth on an ordinary disc sander using a very fine grade emery cloth. The edges had to be smooth to provide an air-tight seal at the top and bottom of the chamber. A top five inches square was made of plywood and a piece of felt was bradded to the bottom side. The liquid used could then be poured directly onto the felt until it was saturated. The vapor source was formed by placing this top on the cylinder. No arrangement for heating the liquid was provided since most of the liquids used evaporated readily at room temperature. A pan of hot water placed on the top appeared to give only slightly more satisfactory results than allowing the liquid to evaporate without external heat, but might be advantageous when operating the chamber at low room temperatures.

The bottom was made of a sheet of black, phenolic bakelite five inches square. Dry ice was pressed firmly to the bottom by a piece of plywood supported by compression springs. A hole was bored in each corner of the top, bottom, and plywood support to allow the components to be bolted together with three-sixteenths inch stove bolts, six inches in length as shown in Figure 1. The bolts were threaded one-half inch on one end and three inches on the other.

The light source was a 200-watt lantern-slide projector with the slide-holding mechanism removed in order that it could be placed close to the chamber. Best results were obtained with the light source on a level with the sensitive region and inclined slightly to allow light to fall on the bottom. The sensitive region was found to be just above the bottom and approximately one-fourth inch deep.

The first vapor used was that of ordinary duplicator fluid which was very nearly pure methyl alcohol. When the chamber was first set up, a very dense mist formed throughout the chamber. The process of setting up the chamber consisted of saturating the felt with liquid, placing a piece of dry ice between the bottom and the ice support, and tightening all the nuts to seal the chamber and to press the ice to the bottom. As the vapor in the chamber condensed on the dust particles, they were eliminated since they fell out due to gravity. The chamber began to clear except for a region near the bottom which appeared to be subject to a diffuse rain of particles. After about ten minutes, tracks began to form on cosmic and background radiations. These tracks ranged in length from about one to six centimeters. Some were very thin, while others were heavy, depending on the characteristics of the radiation involved.

The diffuse mist which remained in the chamber after the dust had settled out was caused by ions which drifted down through the sensitive region. If this had not been the case, a tightly sealed chamber would have eventually become free of this mist.

Under the influence of gravity, the ions created by particles that passed through the chamber became heavy with condensed vapor and drifted downward fairly rapidly. It was observed that the ion tracks experienced a side-wise drift which tended to break them up as soon they were formed. This effect was reduced by leveling the chamber so that the tracks drifted straight down in the center of the chamber. Convection currents created by heat from the external light source and from the heat of condensation of the vapor caused considerable turbulence in the mist. Their action caused the vapor to drift slowly outward from the center of the chamber even when the chamber was level. This effect was undesirable because it tended to break and deform the tracks. Sealing the cylinder to the bottom with a felt gasket did not affect these currents in any way.

With this apparatus, observations were made through the glass cylinder. The glass was not of uniform thickness and created considerable distortion, and the view through the side of the chamber was not advantageous. To give a better view of the tracks, a six-inch by six-inch by one-fourth-inch plexiglass sheet was substituted for the plywood top. A small hole approximately two inches in diameter, was cut in the felt to allow a view from the top. With this arrangement the tracks were more clearly visible and there was no distortion.

Several different sources of radiation were tried by placing the source inside the chamber. Each source gave satisfactory results by producing many tracks which were easily observed; however, when a very active radium-beryllium source was brought in the vicinity of the chamber, no tracks of any kind could be observed. With this strong source, the chamber was overloaded and the available vapor condensed out on scattered particles leaving a deficiency of vapor for tracks. The diffuse mist became quite dense under these conditions. This characteristic limited the usefulness of the chamber to the weaker sources of radiation. A pan of warm water was placed on top of the chamber to vaporize the liquid more rapidly, but the dense mist still prevailed. An undesirable tendency of the chamber was to produce larger droplets rather than more droplets as the vapor supply was increased.

Among the sources tried were an isotope of cobalt (C_o^{60}) as a gamma source, radioactive carbon (C^{14}) as a beta source, and uranylacetate as an alpha source. All three produced tracks of good quality. The alpha particle produced a heavy, smooth, straight track. The beta particle's track was light, spotty, and sometimes bent quite drastically. Gamma particles produced an irregular path slightly heavier than the beta particle. Tracks of gamma particles gave the appearance of great ionization over a fairly large region as compared to great ionization over a small region by the alpha track.

Collision phenomena have been observed with beta and gamma sources. This occurred when a particle came sufficiently close to an atom either to cause a nuclear reaction or to be deflected and give energy to the atom. When this occurred a track appeared to break up into two tracks at the point of collision.

Several vapors were tried with satisfactory results. A mixture of ether and alcohol increased the thickness of the sensitive layer to a small extent. Pure ether also gave a better layer than alcohol, but evaporated so rapidly that its use was not practical for this particular chamber. Very good results were obtained with a mixture of thirty per cent water and seventy per cent alcohol. Acetone worked fairly well but did not appear to be as sensitive as other vapors tried. From these results, the conclusion was drawn that most volatile solvents will give fairly satisfactory results.

As pointed out in Chapter II, in order to perform quantitative measurements, a means of deflecting the particles must be available. To deflect the particles the method of applying a magnetic field described before was attempted. All three of the suggested magnets were investigated. Since the field strength decreases as the distance between the poles increases, another chamber of smaller height was constructed.

The second chamber constructed was exactly like the first except that the chamber proper consisted of a lucite cylinder six inches in diameter and only two inches high. Concentric circles of radii differing by one centimeter were cut on the bakelite to give a scale for estimating the length and curvature of the tracks. The same sources and vapors tried in the first chamber were also tried in the second and each produced satisfactory results. The very short chamber height caused the sides and top to become cool and difficulty was experienced with condensation of moisture in the air. This condition was improved by heating the top and sides with a small laboratory hot plate. Most of the vapors that were tried produced a thinner sensitive layer in this chamber than in the first; however, this chamber allows a heavier ion load because of fewer excess ions. Methyl alcohol produced a vapor that appeared to give results as good as any other liquid and since it was easily obtained, it was used in the following experiments.

An easily portable permanent magnet would be the most desirable method of producing the necessary magnetic field for a demonstration cloud chamber. A magnet of this type was tried, but the field was not strong enough to produce appreciable curvature of the tracks. The magnet used gave approximately 200 gauss with the pole pieces separated by six centimeters. The permanent magnet method was discarded in favor of an air core electromagnet which allowed a camera to be mounted above the chamber. In any case the permanent magnet was impracticable since a camera could not be placed in the correct position to obtain photographs suitable for quantitative study. Pole pieces large enough to permit a camera to be mounted inside have been constructed but they are impractical from a financial standpoint.

The first air core electromagnet consisted of two coils of wire separated by six centimeters. In this manner the chamber could be placed between the coils and photographs made from the top. Each coil, six inches in diameter, consisted of 140 turns of number seventeen copper wire. An arrangement such as this gave approximately 400 gauss for intermittent use. The effects of the field were visible on some very low-energy particles but the tracks were not suitable for measurement. As pointed out previously, the minimum field necessary is of the order of magnitude of 1000 gauss, a value much greater than was obtained with such coils. Since a larger field was necessary, the next step was to experiment with an iron-core electromagnet. A magnetron magnet was available which produced the order of 1500 gauss for intermittent use or 1000 gauss for steady operation. This magnet consisted of many turns of wire wound on two pole pieces. These pole pieces were mounted in such a way that the distance between them could be varied conveniently. This arrangement allowed a maximum magnetic field to be produced by adjusting the separation of the pole pieces to a minimum. Such a magnet required a high voltage power supply which was available from other apparatus. The cloud chamber was set up and placed between the poles. The pole pieces were adjusted for minimum separation, and a current passed through the coils. A current of fifty milliamperes produced no deflection, but upon increasing the voltage until the current was about 100 milliamperes, deflection became noticeable. The field thus created was not sufficient so the current was gradually increased to 250 milliamperes. Sharper bending became noticeable as the current was increased. With this field, the tracks were clearly circular. Some of the low-energy particles were bent into a complete circle of about two or three centimeters radius. Photographs were not attempted since the view from the side was very limited. Two factors which limited the view were moisture on the walls and the small chamber height. After several minutes of operation, it was noticed that the wall of the chamber began to clear up. This was due to the heating effect in the upper coil. The heat thus available served two very convenient purposes: first, it cleared away the undesirable moisture, and second, it created more vapor which gave a greater load limit and enlarged the sensitive region.

A quantitative measurement of the magnetic field of this magnet was made to determine the validity of previous calculations. The magnetic fields for various values of current were measured and a graph of the results was made as shown in Figure 2. These measurements were made with a General Electric Flux meter, Model Number 32C248. The current was measured with a Model 260 Simpson multi-meter. The search coil was mounted on a lucite rod and hinged to a rigid support so that it could easily be passed through the field along the same path for each measurement. The field was measured at approximately the center of the region between the pole pieces where the sensitive region would be if the chamber were in place. Since the flux meter measured the average flux density, the values obtained were averages over the entire sensitive region. The chamber was set up using alcohol to produce the vapor and an isotope of cobalt (C_o^{60}) as a radiation source. This source was chosen because the gamma radiation it produced caused secondary radiation of widely varying energies of the order of those encountered in the laboratory. The chamber was placed between the poles of the magnet and the following qualitative observations were made. In a field of approximately 500 gauss, occasional bending of low energy particles was noticeable. A few were bent to a radius of curvature of six centimeters. The average radius of curvature was greater than this, estimated to be about eight centimeters. Many tracks appeared to be unaffected.

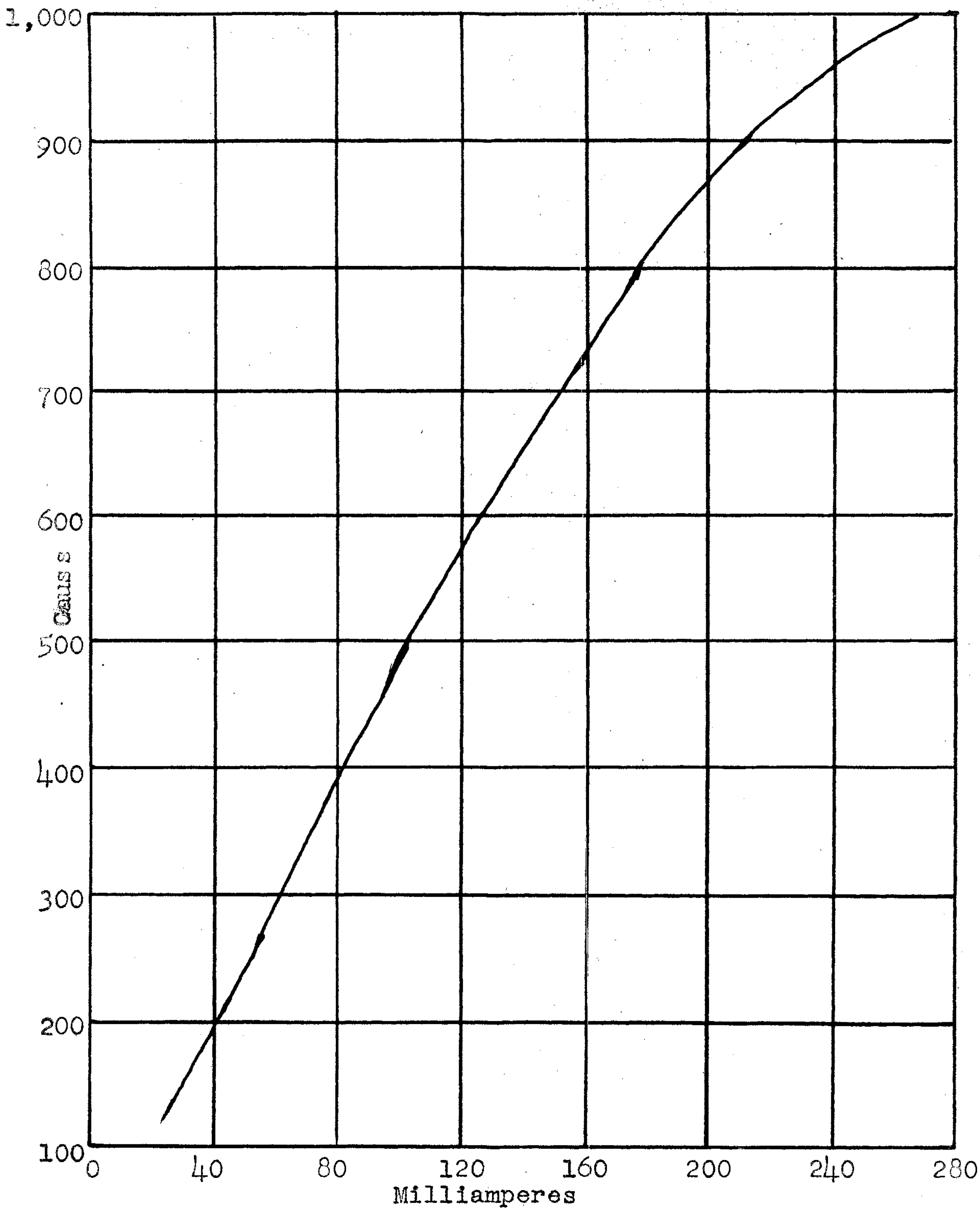

Fig. 2.--Magnetic field as a function of current

Those which were bent the most did not appear to be perfect circles. This was probably due to convection currents, collisions, varying velocities, and a non-uniform magnetic field. A field of 600 gauss altered the situation somewhat but not to any great extent. The average radius of curvature was estimated to be about seven centimeters. Upon increasing the field to about 700 gauss, the average radius was approximately six centimeters. Even with a field of this strength, a few tracks were virtually unaffected. A field of 800 gauss brought the estimated average radius of curvature down to about five centimeters. With this field, the effect could definitely be seen on all but a very few tracks. This might be the minimum tolerable field for laboratory work, but a few were still not curved enough to allow accurate measurement. A few tracks were bent into almost complete circles. A field of 900 gauss gave an average radius of approximately five centimeters. Some tracks formed complete circles of radius not more than two centimeters. Tracks were observed which had a radius of seven or eight centimeters. A field of approximately 1000 gauss produced measurable bending of all tracks except those formed by the alpha particles from uranylacetate. It seemed that the average radius was about four centimeters. At this point the coils were carrying a current greater than their rating and became too hot for further operation. These observations substantiate, to a small extent, the conclusion that a field of 1000 gauss would be about the least field required if the chamber is to have wide applicability.

An air-core solenoid was available, but calculations showed that it would produce a field of only 200 gauss so it was not used. A solenoid of radius just great enough to accommodate the chamber would be very desirable, but from a constructional standpoint it was impractical at that time.

Photographing the tracks was the next problem encountered and proved to be the most difficult. The first chamber constructed was used for the first attempt at photography. The camera used was a thirty-five millimeter Argus reflex. The procedure was a straightforward one of focusing the camera on a small object placed on the floor for that purpose. The focus was set for the shortest possible object distance and the camera moved until the object on the floor was in focus. The only results achieved by this procedure were blurred pictures of the top of the chamber. It was noted that even if the pictures had been successful, the portion of the floor that would appear in the picture would have been only slightly larger than the hole in the top. For this reason a taller chamber was constructed. It was thought also that a taller chamber would increase the depth of the sensitive region and be more advantageous for classroom demonstration.

The third chamber was constructed in the same manner as the second except that the chamber proper was six inches high. The results of the first test operation were disappointing.

The sensitive region was increased in depth, but it was not nearly as sensitive as was the case in previous models. In this chamber the sensitive region was almost one-half inch deep. Tracks were formed, but many appeared not to be complete and they were very sparse as compared to the number obtained before. Actually, it was found later, the primary source of trouble was that the available ice was not sufficient in quantity to cool the floor adequately. A second test with more ice proved to give more satisfactory results. Even then the number of tracks was not comparable with those observed previously. It should be pointed out that in all chambers the temperature of the floor is critical. Dry ice will maintain this temperature only if it is pressed firmly to the bottom. Vapors which had proved satisfactory in previous models produced satisfactory results with this chamber.

An electric field was tried with good results. A simple arrangement of applying a field between the top and the bottom was tried. To accomplish this, a brass top was made with circular hole two inches in diameter in its center. The hole was fitted with plexiglass and sealed. Insulators were made of lucite in such a way that the top could be electrically insulated from the rest of the chamber. The other electrode consisted of a sheet of aluminum small enough to be slipped between the ice and the bottom of the chamber. The instant the field was turned on, a very noticeable change occured in the number and quality of the tracks formed. The number of the tracks was increased almost two-fold. The field tended to break the tracks into two parts. One part drifted down very rapidly, while the other tended to float down more slowly. Occasionally a track settled gently on the condensed liquid on the floor and remained for several seconds. With this arrangement, fields ranging from 200 to 350 volts were tried with very little difference in performance being noted between the two extremes. A third electrode was made of copper screen wire. It was placed between the two-inch and the six-inch cylinders used previously as shown in Figure 3. A two-inch hole was cut in the center of the wire to allow the floor to be seen from above. In this case, the screen-wire grid was held at 300 volts and the other two electrodes used in the third chamber were held at ground potential. This arrangement appeared to give the same results as the two-electrode field. The primary objection to such an arrangement was that the grid obscured a portion of the floor and became covered with condensed vapor which dropped off on the floor, causing a considerable disturbance. The nature of this disturbance was very similar to track formation and suggested the possibility of using a similar chamber for a study of the hydrodynamics of particle motion.

With the third chamber operating satisfactorily, another attempt at photography was made. The six-inch chamber with two electrodes was used and the camera was an Eastman studio type mounted on a tripod and loaded with Isopan film. The focusing procedure was the same as in the previous attempt.

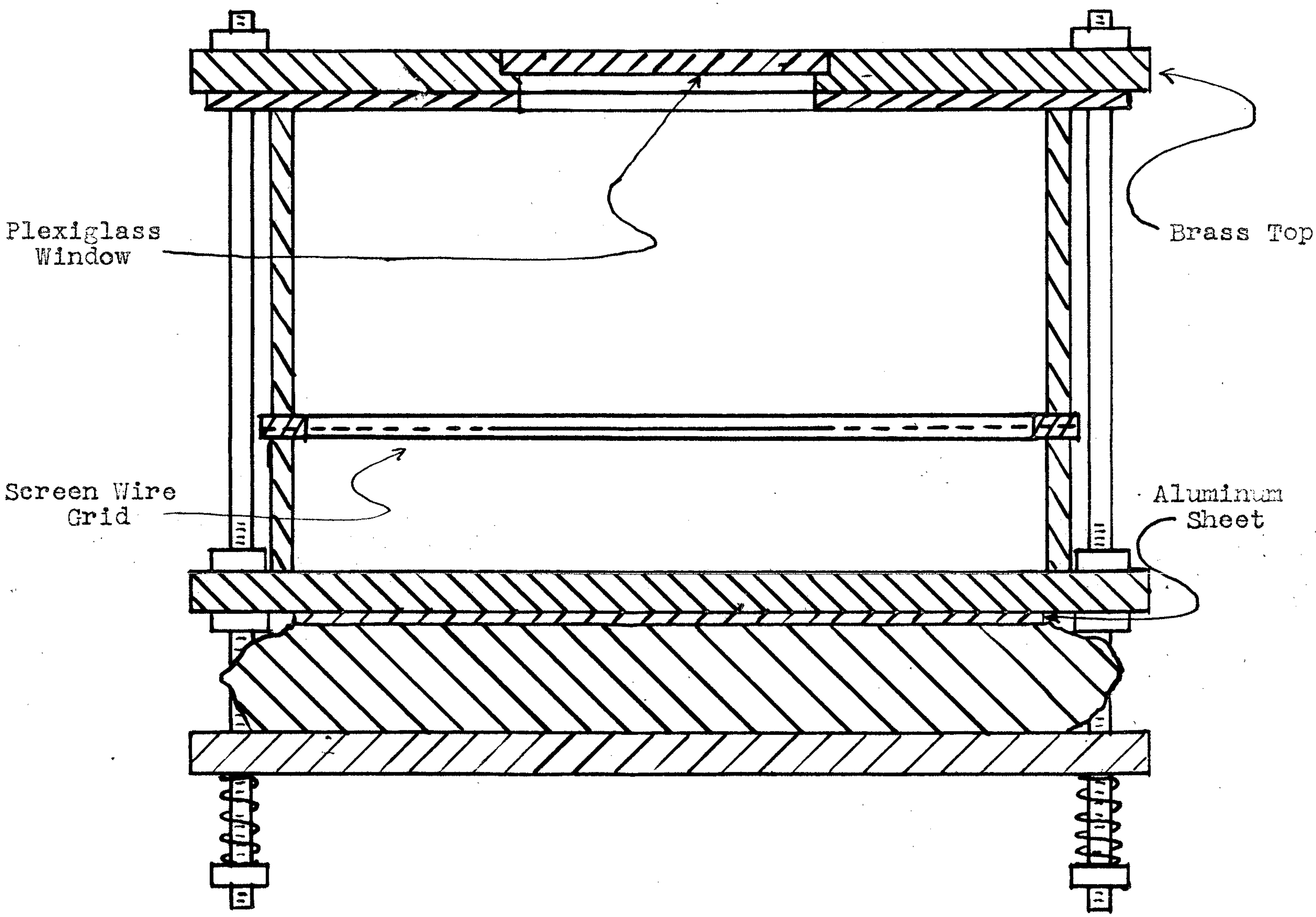

Fig. 3.--The three-electrode cloud chamber

Eight pictures were taken with this apparatus with various times and apertures for the exposure. The results were again of no value; however, more of the floor was visible in these pictures than before and fair photographs of the radiation sources were obtained.

A camera with a special lens system for taking close-range pictures was obtained. The two-inch chamber was set up without the electric field electrodes, using alcohol as a vapor source and uranylacetate and radioactive carbon (C^{14}) as radiation sources. This chamber was used because the camera would take actual size photographs with an object distance of four inches. A ringstand was used to mount the chamber so that its position relative to the camera could be easily adjusted. The film used was a 35 millimeter Kodak Panatomic-X, ASA Tungsten 20. The field of view of this camera with the special purpose lenses in place was very small, making it difficult to obtain photographs of desirable tracks with random exposures. Seventeen exposures were made ranging in time from one twenty-fifth to one-half second, and apertures ranging from f 2.9 to f 4.2. Five photographs of tracks were obtained, two of which are shown in Figures 4 and 5. Figure 4 was obtained with a one-tenth second exposure at f 4.2. Figure 5 was taken with one-fifth second exposure at f 5.6. These photographs were enlarged approximately four times. The enlarging paper was Kodabromide. Since the camera gave photographs which were actual size, the entire track near the center of the photograph in Figure 5 is approximately 1.3 centimeters long.

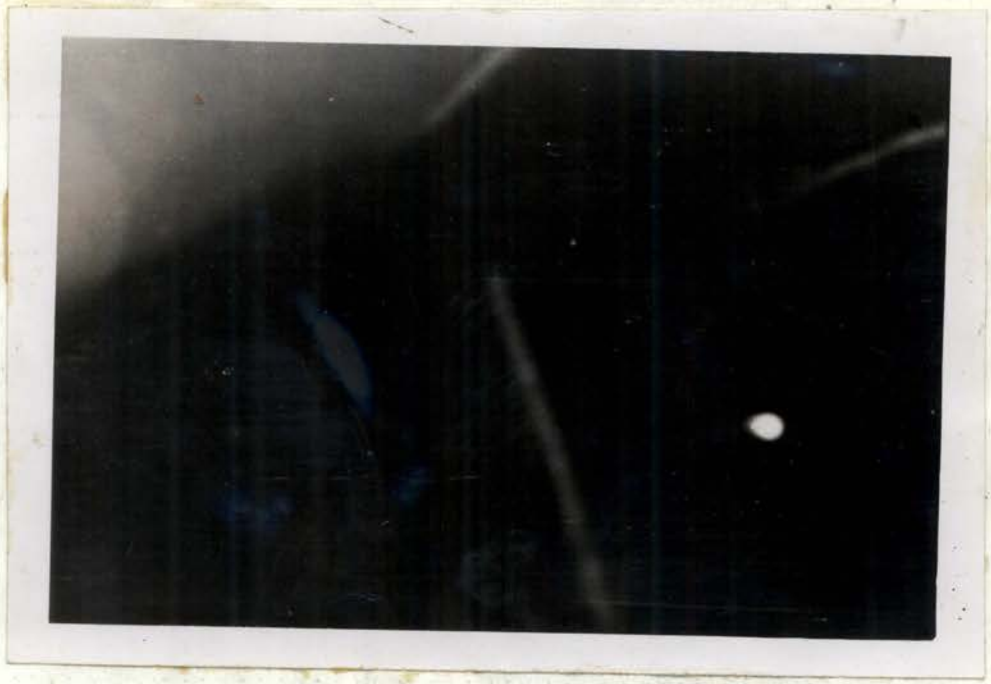

Fig. 4.--Photograph of three alpha tracks

Fig. 5.--Photograph of an alpha track

There are portions of three tracks in the photograph in Figure 4. The blurr in the upper left-hand corner is the felt pad. The radiation source may be seen at the right edge of Figure 5. These tracks were created by alpha particles from the uranylacetate. They are much heavier than beta or gamma particle tracks (not visible in the pictures) because the alpha particles ionize much more than the other particles. Beta tracks obtained in this chamber were extremely thin and, consequently, were difficult to illuminate sufficiently for photography. Since none of the beta tracks present at the time of exposure were evident in any of the photographs, no further attempt was made to obtain photographs of such tracks. It seems that such photographs could be obtained with a more sensitive, higher contrast film. This special purpose equipment was not readily available.

For demonstration purposes the third chamber constructed was more satisfactory than the others. When weak sources were used, the electric field was not necessary. Three sources were placed in the chamber simultaneously to demonstrate the three kinds of tracks. Commercial laboratory sources for beta and gamma particles were available and uranylacetate made an excellent alpha source. This arrangement made a convenient demonstration unit which an entire class could observe simultaneously.

To make the chamber more portable, an attempt was made to build a light source in the chamber proper. A six-watt, 110 volt bulb was soldered to a headphone jack. The jack was bolted to the top of the chamber in such a way that the light bulb very nearly touched the floor. A reflector was made of sheet aluminum and attached to the bulb. The phone plug was connected to a 110-volt outlet plug. The chamber was set up and the light connected. Tracks were visible in the immediate region of the light, but they were immediately broken up by swift convection currents caused by the heat of the light. Since a stronger light would only cause more convection currents and a weaker light would not illuminate the tracks sufficiently, no further attempt was made to place the light source inside the chamber.

To add to the convenience of operation, a circular groove, five inches in diameter, was cut through the brass top. Small holes were bored in the bottom of this grove. Liquid was added to the felt pad by filling this groove. The holes in the top apparently did not affect the operation of the chamber to any appreciable extent even though some dust entered through these holes. It appeared that an air tight seal at the top was not necessary, but a leak at the bottom produced drastic effects. A swirl of condensed vapor could be seen at any leak at the bottom. This practically eliminated all track formation. A good seal at the bottom was facilitated by pouring some liquid on the bottom. This liquid also improved the background for the tracks.

CHAPTER IV

SUMMARY AND CONCLUSIONS

Three continuously sensitive diffusion cloud chambers have been constructed. Each chamber had its own particular advantages in application. The two-inch chamber was more satisfactory for the application of a magnetic field and did not require an electric field for reasonably good load capacity. Photographs of alpha tracks were obtained using this chamber. The top and sides of this chamber had to be heated to clear away condensed moisture. The three-inch chamber was an experimental model to test the basic components of a diffusion cloud chamber and sources of vapor and radiation. The six-inch chamber was best for demonstration, but for best results, an electric field applied between the top and the bottom was required. Good results were obtained using a 300-volt d-c power supply to create this field.

All the chambers constructed gave satisfactory results with several volatile liquids furnishing the vapor. Good tracks were obtained with all the available commercially prepared radioactive sources except the radium-beryllium source which overloaded all the chambers to such an extent that no tracks could be observed. Photographs of alpha tracks were obtained using a special purpose camera designed for short-range photography. Fairly sensitive film and developer were used, but more sensitive contrast would have given better results. The cloud chambers constructed were not suitable for quantitative study; however, it appeared that they will find applicability in studying the weaker radioactive sources.

An accurate quantitative chamber can be made with the proper camera and magnetic field. The most desirable method of applying the field would be with an air-core electromagnet. This would allow a camera to be mounted above to take pictures suitable for quantitative study. Such a magnet would be expensive but within economic boundaries. If the desirable field of 1,000 gauss is to be obtained, calculations have shown that the product of the number of turns of wire and the current in amperes must be approximately 20,000. For example, this would correspond to 20,000 turns of wire capable of carrying a current of one ampere. This can be achieved without great expense and difficulty. A chamber four or five inches high and four inches in diameter could be placed inside such a solenoid. A window which will permit light to enter the solenoid must be provided. A camera suitable for mounting above the chamber would have to be obtained. The camera would probably be the most expensive part of a quantitative cloud chamber.

The work which has been done clearly indicates that the continuously sensitive diffusion cloud chamber is excellent for demonstration purposes. A useful quantitative chamber can be constructed which is within the economic means of most small laboratories.

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