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ON A DIFFUSION CLOUD CHAMBER TO BE USED FOR THE
EXPERIMENTAL DETERMINATION OF THE HALF-LIFE OF THE NEUTRON

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On a Diffusion Cloud Chamber to Be Used for the Experimental
Determination of the Half-Life of the Neutron^o

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1. INTRODUCTION

The operation of a diffusion cloud chamber continuously sensitive to ionizing radiations was considered for the first time by Langsdorf¹ in 1939. Since then various² authors have considered the same problem, both experimentally and theoretically, and diffusion cloud chambers have been used in many experiments.

A diffusion cloud chamber is a closed vessel containing a gas such as air, CO₂, helium, etc. An organic liquid, such as methyl, ethyl, propyl alcohol, etc. is contained in a suitable trough, kept near room temperature in the upper region of the chamber. It evaporates and diffuses toward the bottom of the chamber, which is maintained at a temperature of approximately -60°C. In a region 2 or 3 inches deep near the bottom of the chamber, condensation of the vapor occurs on the ions produced by ionizing particles.

In an ordinary Wilson cloud chamber, the saturated vapor becomes supersaturated when the temperature drops suddenly because of an expansion. In a diffusion chamber, the alcohol which is saturated at room temperature near the top of the chamber becomes supersaturated as it goes down to regions at lower temperatures.

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* On leave of absence from Comitato Nazionale per le Ricerche Nucleari, Rome, Italy.

¹ See reference 1 (Bibliography).

² See references 2-19 (Bibliography).

At the Argonne National Laboratory, we recently have built a diffusion cloud chamber to be used in an experiment to determine the half-life for neutron decay by detecting the electrons arising from the decay in a beam of thermal neutrons from the CP-5 reactor.

The necessity of keeping the electron background as low as possible suggested that the chamber should be built of 61-S aluminum alloy, which may be worked fairly easily and at the same time has a low macroscopic cross section for radiative capture of thermal neutrons. The necessity of minimizing the electron background, which might have resulted from the scattering which occurs in the entrance and exit windows, also required a chamber of unusual shape, with two long arms for the windows through which the neutron beam enters and leaves. The necessity of avoiding (n, p) reactions with slow neutrons in nitrogen required a vacuum-tight diffusion chamber. Furthermore, consideration was given to the possibility of using the chamber with gases, such as helium, having low Z and small cross sections for thermal neutrons. It is known that good conditions of stability with such light gases may be reached either by working at fairly high pressures or by keeping both top and bottom temperatures low. For this reason the chamber was built to stand a few atmospheres pressure.

In Sec. 2 we describe the diffusion chamber and in Sec. 3 the heat exchanger used to cool the bottom plate of the diffusion chamber. Section 4 will contain a few remarks on the operation of the diffusion chamber, and Sec. 5 will describe the photographic system.

2. THE DIFFUSION CHAMBER

The chamber works by downward diffusion of methyl alcohol vapor in a gas such as air, CO₂, helium, etc., from a warm region (at about 35° C) to a horizontal cold surface (at $\sim$ -60° C) which is cooled by a flow of acetone which circulates through a heat exchanger in a mixture of acetone and dry ice. Near the cold surface a continuously sensitive layer $\sim$ 2 inches deep is obtained. Tracks are photographed through the top window of the chamber.

Our diffusion chamber consists of three main parts:

1. the bottom with its cooling coils;
2. the cylindrical body with the windows for the illumination and for the neutron beam;
3. the conical region, with the methyl alcohol source and the coils for circulation of warm water.

Figure 1 is a drawing of the chamber. A photograph of the general assembly is given in Fig. 2.

The bottom is made of two circular plates, in one of which is milled a system of circular grooves. The two plates are welded together at the periphery to obtain a system of two coils in parallel to be used to circulate the refrigerating acetone. Two coils in parallel, instead of one, are used to get a more uniform temperature distribution on the bottom of the chamber and to avoid any effects, such as turbulent motions, radial gas currents, etc., which could arise if the temperature distribution were too non-uniform.

In the original design, the bottom plate had a hole to drain off the methyl alcohol which condensed there. However it was eliminated later because the amount of condensate collected during 4 or 5 hours of operation is not enough to prevent good performance of the chamber.

The joint between the bottom plate and the cylindrical body of the chamber is sealed by an O-ring made of compound #7474-70 obtained from Linear, Inc. It is not affected by alcohol and stands the low temperature of the bottom.

The cylindrical body of the chamber is of aluminum 3/8 in. thick. The neutron beam enters and leaves the chamber through bismuth windows 0.5 cm thick at the ends of two arms of the chamber³. The chamber has

³ The two windows are of bismuth because bismuth will be used in the neutron half-life experiment as a filter of the γ -rays in the neutron beam.

Fig. 1. The diffusion cloud chamber.

Fig. 2. General assembly.

three windows for illumination, the large one for continuous illumination for visual observation and the other two for the flashes used in the photography. The lucite which was initially used for these windows was attacked by the methyl alcohol; so it was replaced by polystyrene.

The cylindrical body is attached to the conical section by a micarta flange and screws provided with insulating micarta rings, so as to insulate electrically the top from the bottom of the chamber and have the possibility of providing an electrical sweeping field.

The alcohol which acts as the source of vapor is contained in an annular aluminum trough supported by the conical body. The heat to evaporate the alcohol comes from water circulated at constant temperature through a small aluminum tube welded underneath the trough.

The conical region is kept at constant temperature by circulating water through a coil welded around the outside of the conical body. A thermostatic switch controls the temperature both in this coil and in the parallel loop to the alcohol trough. In our chamber the alcohol trough may be moved up and down over a range of about 2 inches to obtain as deep a sensitive layer as possible.

A plate of black glass on the bottom of the chamber provides a background for the photography.

Also a polystyrene cylinder of a diameter a little smaller than that of the cylindrical body, 1/4" thick and about 4" high, is used to insulate the sensitive region from the outside walls and to provide, by means of a tape heater just below the micarta flange, the right temperature distribution along the boundaries of the sensitive region. The tape heater is wrapped all around the top of the polystyrene cylinder. It has a resistance of 13 ohms and is operated at about 10-12 volt ac.

The polystyrene cylinder has two openings for passage of the neutron beam. To prevent turbulent motions because of them, these

large openings are closed by lead foils 1 mil thick. A thicker foil would cause unnecessary scattering of the neutrons.

The chamber is blackened inside by means of black scotch tape which, over a period of more than two months, seems to work satisfactorily and sticks fairly well against aluminum or polystyrene, methyl alcohol having no appreciable effect on it.

3. THE HEAT EXCHANGER

The bottom plate of the diffusion chamber is cooled by circulation of acetone cooled by thermal contact with a mixture of dry ice and acetone.

In Fig. 3 is a drawing of the heat exchanger. The acetone to be circulated is contained in a steel cylindrical container 4 in. in diameter and 26 3/4 in. high. This cylinder is concentric with a steel cylinder, 2 ft. in diameter and 28 3/4 in. high, which contains the mixture of dry ice and acetone.

From the bottom of the inner cylinder the acetone flows to a mechanical pump, divides between two coils consisting of 25 turns of 3/8 inch copper tubing outside the inner cylinder in the heat exchanger, then goes to the refrigerating coils in the bottom of the diffusion chamber, and comes back to the inner cylinder of the heat exchanger. The pump used to circulate the acetone is an Easy Industries 1/3 hp 115/230/60/1 A. C. Class I Group D Explosion Proof (Oil Type) 1725 rpm Ball-Bearing unit coupled to a pump with a bronze casing and stainless steel gears. It can operate at temperatures as low as -90°C . The tank for the mixture of dry ice and acetone is insulated by about 6 in. of rock wool. The amount of dry ice required is about 200 pounds per 8-hour day.

With this type of heat exchanger the circulating acetone is cooled twice per cycle: in a preliminary cooling inside the inner cylindrical container and in a final cooling when it divides through the two coils inside the heat exchanger itself.

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Fig. 3. The heat exchanger.

4. REMARKS ON THE OPERATION OF THE DIFFUSION CHAMBER

The diffusion chamber has been operated with methyl alcohol in air, in CO_2 , in helium, and in a mixture of helium and CO_2 . Other alcohols than methyl have been used, but methyl alcohol seems to give the best results. Operation in air at atmospheric pressure or in CO_2 in the range 0.5 - 1 atmosphere is satisfactory, when the temperature of the bottom is about -60°C and the temperature of the conical body and of the alcohol trough is $\sim 35^\circ\text{C}$.

On the other hand, continuous convection currents in the chamber prevent proper operation with methyl alcohol vapor in pure helium gas at total pressures below about 2 atmospheres. These convective motions are mainly the result of the negative specific-gravity gradient between top and bottom of the chamber in a mixture of helium and alcohol vapor at these pressures. Nevertheless the addition of a small amount of CO_2 to the helium stabilizes the chamber and gives very satisfactory conditions of operation. We get a sensitive layer about 2 in. deep, working at ~ 2 atmospheres of helium and ~ 4 psi of CO_2 at the temperature specified above.

The polystyrene cylinder and the tape heater in the cylindrical body of the chamber proved to be very useful for a good performance. Without them the main temperature drop along the side boundaries is across the micarta flange. The conical region is almost at uniform temperature and the temperature drop along the side walls of the cylindrical body is very small. Under these conditions we have observed a sensitive layer a few centimeters deep just below the micarta flange, but no sensitive layer was usually present in the region about 3 in. thick between the lower boundary of this sensitive layer and the bottom plate. The sensitive layer observed under these conditions showed a heavy general fog and poorly-defined tracks.

This type of behavior may be explained as follows. As the warm vapor from the source enters the very cold region immediately below the

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micarta flange, its supersaturation becomes so great that condensation occurs as a heavy general background of fog as well as on the tracks of charged particles. Thereafter the descending vapor is no longer sufficiently supersaturated to permit condensation on ions. In a very few cases, another sensitive layer a few millimeters thick has been observed very close to the bottom plate, where the temperature presumably is so low that even after depletion by condensation in the region below the micarta flange the vapor again becomes sufficiently supersaturated that it condenses on ions.

The performance of the chamber with the polystyrene cylinder and the tape heater is completely different. No matter what the temperature distribution along the aluminum walls of the chamber, the temperature distribution along the polystyrene cylinder is almost linear. Under these conditions, a sensitive layer $\sim 2''$ deep is produced just above the bottom plate. If the current in the tape heater is too large (> 1.5 amp), observation of ionizing particles is often prevented by dense clouds which first appear near the polystyrene cylinder and then move toward the center of the chamber.

In our diffusion chamber, as already mentioned, the alcohol trough can be moved up and down, with a total excursion of $\sim 2''$. We found that, working with methyl alcohol in air or in CO_2 or in a mixture of helium and CO_2 , the best performance is obtained when the alcohol trough is just above the micarta flange.

To increase the surface of evaporation of the methyl alcohol we have tried to use a wick of black velvet all around the alcohol trough. Although this wick may increase the thickness of the sensitive layer slightly, it may also give rise to some troublesome and persistent clouds.

The electric sweeping field is obtained with a voltage of 300 volts between top and bottom of the chamber. The tracks are sharpest about 3 or 4 seconds after the electric field is switched off.

Among the drawbacks of having the chamber made of 61-S aluminum is the fact that after a few weeks of continuous operation, the aluminum seems to be slightly corroded. However this seems to be of minor importance since it has not to date interfered with operation. The white powder produced on the aluminum surface by this corrosion process may be very easily removed by cleaning the surface with acetone.

5. THE PHOTOGRAPHIC SYSTEM

To take pictures of the events occurring in our diffusion chamber we use a Varitron Beattie Camera, Model DR-2, which is supposed to take pictures on 35-mm film at repetition frequencies of 1, 2, 4, 5 and 8 frames per second.

The light for a photograph is provided when a 200 μ f battery of condensers charged to 1500 v is discharged through two linear GE Model FT-126 flash tubes. Fairly well collimated beams of light are obtained using cylindrical lucite lenses. The film used is Kodak Tri-X. The camera lens is a Baltar, 50 mm, f/2.3, of the Bausch & Lomb Optical Co.

It seems to be necessary in the neutron half-life experiment to be sure whether or not an electron track comes from the bottom plate of the diffusion chamber. For this reason stereoscopic pictures of the interesting events must be taken. An important thing to know about a point of an electron track, for instance its origin, is its height z above the bottom plate of the chamber. To determine it, a beam splitter and a single camera are used to get two pictures, on the same frame, of the particular event to be recorded. Then we project the image with an ordinary projector and measure on the screen the distance between the two points corresponding to the same point of the recorded track. From this distance we are able to deduce the height of the particular point under consideration.

Let us consider Fig. 4. The point under consideration is point A, on the axis of the lens. The distance from the camera lens to

Fig. 4. Sketch of the stereo-photographic arrangement.

Fig. 5. $\Delta = \frac{af}{(d+a-f)^2}$ as a function of a , for a distance $d = 35$ cm and a focal length $f = 5$ cm.

A is d . The distance between the two mirrors on the same side of the beam splitter is $\underline{a}$.

Points A_1' and A_2' are the two images of A formed on the film by the beam splitter and the camera lens, and f is the focal length of the lens. The distance K between A_1' and A_2' is

$$K = \frac{2 a f}{d + a - f}$$

Projection magnifies this distance by a factor n , so the distance h between the corresponding points A_1'' and A_2'' on the screen is given by

$$h = n K = \frac{2 a f n}{d + a - f}$$

An obvious measure of the sensitivity of the method is

$$\left| \frac{\partial h}{\partial d} \right| = \frac{2 a f n}{(d + a - f)^2} = 2 n \Lambda,$$

where

$$\Lambda = \frac{a f}{(d + a - f)^2}$$

The useful upper limit of n is determined by the fact that points A_1'' and A_2'' are actually spots having a finite diameter which increases with n . It is then clear that an increase in $|\partial h / \partial d|$ must be accomplished mainly by increasing Λ .

In Fig. 5 we give the curve Λ versus $\underline{a}$ for a distance $d = 35$ cm and a focal length $f = 5$ cm. For small values of $\underline{a}$ ($0 < \underline{a} \lesssim 15$ cm), the sensitivity of this method increases strongly as $\underline{a}$ increases. As $\underline{a}$ increases further, Λ rises gradually to a broad maximum and then decreases. Thus the small gain in sensitivity in going from, say, $\underline{a} \approx 10$ cm up to values of 25 or 30 cm probably does not justify the excessively large top window which this would require.

The values of $|\partial h / \partial d|$ calculated for $n = 10$, for the focal lengths of $f = 8$ cm, 5 cm and 3.5 cm, and for different values of d and $\underline{a}$, are shown in Figs. 6, 7 and 8.

Figs. 6,7,8. Sensitivity of the method $|\partial h/\partial d|$, calculated for the focal lengths $f = 8$ cm, 5 cm and 3.5 cm, for different values of d and a , and for $n = 10$.

Fig. 9. $|\partial h/\partial d|$ as a function of the focal length, for a distance $a = 7.5$ cm, $d = 45$ cm and for $n = 10$.

On the basis of these considerations our beam splitter and camera have been arranged so as to have $\underline{a} = 7.5$ cm, $d = 40$ cm with $f = 5$ cm.

Under these conditions we have taken pictures of a mockup made with graph paper stuck against an aluminum plate, whose height above the bottom plate has been varied from 0 to 1, 2, 3 and 5 cm. The distance $h = A_1 A_2$ between points on the screen corresponding to the same point A on the graph paper has been measured for various heights of the graph paper and for various points on it. From these data the value of $|\partial h / \partial d|$ has been found, under the above conditions, to be equal to 0.52 ± 0.02 , and independent of the particular position of the point A on the graph paper. A magnification factor $n \approx 10$ has been used in projection.

Once the distance h is known for any point on the bottom plate, the height of any other point may be obtained easily from the known value of $|\partial h / \partial d|$.⁴

Under the above conditions ($d = 40$ cm, $\underline{a} = 7.5$ cm, $f = 5$ cm) the depth of focus in the chamber for an aperture of $f/5.6$ is at least 2 in. It has been determined using pictures of electron tracks obtained when the chamber was working with a sensitive layer about 2 in. deep. The beams of light provided by the two linear flashes are also 2 in. thick.

Other things being equal, $|\partial h / \partial d|$ increases as f increases (Fig. 9), but the depth of focus decreases as f increases. A good compromise between the conflicting requirement of big $|\partial h / \partial d|$ and big depth of focus seems to be $f = 5$ cm.

To illustrate the behaviour of the diffusion chamber we give in Figs. 10 and 11 two pictures we got without the beam splitter and with the beam splitter, respectively.

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Of course, an additional simple processing of the data is necessary in order to determine the x and y coordinates of the particular point under consideration.

Fig. 10. Photograph of electron tracks.

Fig. 11. Stereo-photograph of electron tracks.

CONCLUSIONS

In conclusion we wish to add the following remarks:

1. With suitable arrangements it is possible to have a good performance in a diffusion chamber of an unusual shape, which may be required by the necessity of minimizing the consequences of the interaction of the beam with the material used at the entrance and exit windows of the chamber itself.

2. The permanent conditions of instability which result in operating with light gases such as helium, at a few atmospheres pressure and with the top of the chamber at about room temperature, may be avoided by adding to the filling mixture a few psi of a heavier gas, such as CO_2 .

3. It seems difficult to build a diffusion chamber which is able to provide a sensitive layer much thicker than in the usual chambers by merely making the methyl alcohol vapor diffuse toward a fairly deep region kept at a very low and uniform temperature. This is mainly a result of the vapor depletion occurring at the top of the cold region.

4. In the design and operation of our chamber, we have sought working conditions as close as possible to those described by Argan et al. in problems 2 and 3, which seem to be the best among the various possibilities they have considered in their theoretical work.⁵ In particular, the micarta flange of our chamber is such as to provide the required uniform temperature distribution in the top region. The other possibilities considered in the theory of Argan et al. have not yet been checked systematically.

5. The photographic arrangement we use seems to be fairly simple, relatively cheap, and adequate to our purposes.

⁵ See references 18 and 19 (Bibliography).

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