# Operation of a diffusion cloud chamber with 23 atm of deuterium

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[*Paper received* 23 *August*, 1956]

The successful operation of an 18 in. diameter diffusion cloud chamber filled with deuterium at a pressure of 23 atm is reported. The importance of the tritium and oxygen content are discussed. An account of the apparatus for the manufacture and transfer of the deuterium is given.

The diffusion cloud chamber has been used with success in high energy nuclear physics for a study of the interactions between elementary particles, especially those involving the production of $\pi$-mesons. The main advantage of this apparatus over the expansion cloud chamber is that it is continuously sensitive when filled with light gases at high pressure. This makes it suitable for operation with accelerators such as the Birmingham proton synchrotron, which provides a pulse of 1000 MeV protons every ten seconds. The use of such a chamber in conjunction with the synchrotron, when filled with hydrogen at a pressure of 25 atm, has already been described.[1]

The cloud chamber has now been operated successfully at a pressure of 23 atm of deuterium. This paper describes the source and production of the deuterium, and operating conditions for satisfactory chamber performance. Since the amount of vapour available for track formation in a diffusion chamber is limited, the presence of quite small amounts of tritium may seriously affect the performance because of its radioactivity. A hydrogen-filled diffusion cloud chamber has been used[2] to measure the tritium content of ordinary water, from which the hydrogen is produced chemically.

## APPARATUS

The cloud chamber[1] has a volume of fifty litres and an operating pressure of about 300 lb/in.$^2$ was intended. Since deuterium is not available commercially in England it was necessary to produce it in the laboratory. Fig. 1 illustrates the apparatus for its manufacture, storage and transfer. The deuterium was obtained by electrolyzing 99·5% heavy water, produced at Norsk Hydro, Norway, and purchased through the Atomic Energy Research Establishment, Harwell. Electrolysis was considered the method most likely to result in the production of pure deuterium. The electrolyte used was caustic soda at an initial concentration of 3%. This would result in a hydrogen content of at most 1% in the deuterium. The use of $Na_2O_2$ was not possible because of the slow evolution of oxygen.

The cells, one of which is shown in Fig. 1, are enlarged versions of one in use on a similar but smaller aparatus at the

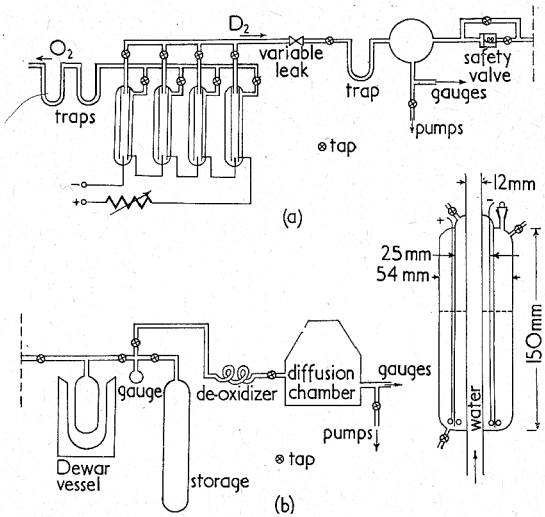


Fig. 1. (*a*) Deuterium generator and (*b*) storage vessels

Clarendon Laboratory, Oxford. Each was made from two coaxial glass tubes, with the heavy water inlet and drain and the outlet for the oxygen in the outer tube (54 mm diameter), and the outlet for deuterium at the top of the inner tube (25 mm diameter). The inner tube is supported in the outer one with a small (2 mm) clearance at the bottom for the ion current. The electrodes are helices of nickel wire mounted close to and one each side of the inner tube 2 mm from its end, supported from tungsten–glass seals at the top of the cell. A third central tube, 12 mm in diameter, is used for water cooling. Smooth operation is obtained for currents up to about 8 A, the resistance of each cell being about 3 Ω. Sheet nickel electrodes were much less satisfactory because of the formation of large bubbles of gas. The oxygen passed to the atmosphere through two liquid air traps, one to remove atmospheric moisture and the other to collect heavy water lost from the quite warm cell. A further trap was placed between the outlet for the deuterium and the pumps and storage vessels.

The deuterium was collected continuously in a Vibrac steel cylinder of four litres capacity (by Vickers Armstrongs Ltd.), filled with activated charcoal, and immersed in a large Dewar vessel filled with liquid air. A variable leak permitted the deuterium pressure in the cell to be maintained near atmospheric pressure, fine control being obtained by varying the current through the cell. If the cylinder was filled to atmospheric pressure when cold, and sealed, a pressure of about 900 lb/in.$^2$ was obtained at room temperature. The deuterium was then transferred to the storage cylinder (30 l.) and the process repeated. About 1050 g of heavy water were electrolyzed, the process taking about a hundred hours. It was therefore necessary to ensure that the air leak rate into the system was low. The charcoal was degassed at 300° C for twelve hours and the heavy water pumped for several minutes to remove all air before electrolysis was commenced. Glass and metal taps and vacuum and pressure gauges allowed control of the apparatus.

Deuterium was transferred to the cloud chamber and back with the assistance of the activated charcoal. The chamber was carefully evacuated and the deuterium inserted slowly through a spiral of copper tubing four feet long packed with copper granules and maintained at a temperature of 400° C. This ensured the removal of all oxygen, the importance of which is mentioned below. The constitution of the gas was investigated in the Chemistry Department of the University with a mass spectrometer. Initially it was found to contain 94·9% $D_2$, 3·1% HD, 0·35% $N_2$ or CO, 0·06% $O_2$, and small amounts of methyl alcohol and water vapour. The HD percentage was unaltered after a hundred hours operation of the cloud chamber. This confirmed the absence of any exchange reaction between the hydrogen atoms in the $CH_3OH$ molecule, and the deuterium, a fact previously established by heating a sample mixture to 160° C for sixteen hours.

## OPERATION OF THE CLOUD CHAMBER, AND DISCUSSION

A theory of the diffusion cloud chamber has been given by Shutt,[3] and it is essentially in agreement with experiment. Shutt has shown that the temperature gradient $dT/dx$ required for successful operation depends only on a parameter $\beta$, which is related to $\mu_0$ the viscosity of the gas at 0° C, $D_0$ the diffusion coefficient of the vapour within the gas at N.T.P., $P$ the gas pressure, $n_0$ the number of ions per cm$^2$ per second which would be produced in air at N.T.P. by the radiation within the chamber, $\tau$ the number of atoms per molecule of the gas, and $Z$ its atomic number. The equation for $\beta$ is, for temperatures below about 260° K,

$$\beta = \mu_0 D_0^{-1/3} P^{1/3} [n_0 \tau z P + f(t)]^{4/3} \qquad (1)$$

where $f(t)$ is a function of the temperature $t$ of the vapour source, and takes account of the removal of vapour by the growth of droplets on large molecular aggregates of methyl alcohol. The assertion that $dT/dx$ depends only on $\beta$ has been verified experimentally by Bevan[4] for a variety of gases under various conditions in a particular chamber.

The maximum temperature of the vapour source for good performance is set by the fact that instability of the gas-vapour mixture occurs when the density of the mixture at the source exceeds that near the top of the sensitive layer. The chamber is then no longer uniform, but sensitive in patches. To ensure the best sensitive depth and shortest flash delay times, it has been the practice to operate at temperatures as close to this limit as possible. Care is necessary, for during a long experiment the settings of the heater elements on the chamber wall are dependent upon ambient conditions. These vary considerably because of the pulsed magnet in which the chamber is located.[1] The main parameters for good operation with both hydrogen and deuterium are summarized in the table. These are typical approximate values used during an experiment. The temperatures at which instability occurs, 30 and 45° C respectively, are rather lower than those calculated,[4] but differ by approximately the calculated amount.

*Operating parameters at 24 atm*

| | *Hydrogen* | *Deuterium* |
|---|---|---|
| Maximum source temperature (°C) | 30 | 45 |
| Source temperature (°C) | 22–25 | 38–42 |
| Base temperature (°C) | −55 | −50 |
| Sensitive depth (cm) | 6·0 | 4·5 |
| Temperature at top of sensitive depth (°C) | −17 | −15 |
| $n_0$ (ions cm$^{-3}$ s$^{-1}$) | 5 | 14 |
| $dT/dx$ (°C/cm) | 6·4 | 7·9 |
| $3{\cdot}3 \log_{10} \beta + 8{\cdot}2$ (°C/cm) | 7·1 | 9·8 |
| Flash delay time (s) | 0·12 | 0·20 |

The table shows that a sensitive depth noticeably less than that for hydrogen, but nevertheless satisfactory, has been obtained with deuterium. The quality of the tracks is evident from Fig. 2, which is a photograph showing a beam of 950 MeV protons from the synchrotron. The large number of blobs of ionization is due to the decay electrons of mean energy about 8 keV from the tritium present in the gas. These are the main reason for the higher values of $dT/dx$ and source temperature used for deuterium. Satisfactory operation with deuterium has not been achieved at the source temperature used for hydrogen. The effect of the factor $\mu_0 D_0^{-1/3}$ is relatively small, and for the purpose of this paper the term $f(t)$ has been neglected. The value for this term used by Bevan is approximate and it is not evident from his communication to what extent his empirical relation $dT/dx = 3{\cdot}3 \log_{10} \beta + 8{\cdot}2$ (°C/cm) depends on $f(t)$. At the source temperature of 40° C used for deuterium, his expression for $f(t)$ suggests that it would easily be the larger term in equation (1), whereas it is evident in practice that although the background is important, this is not so.

For cosmic radiation the value generally used for $n_0$ is two. Further, about fifteen high energy proton tracks and the associated background are passed through the chamber each ten seconds; these are equivalent to a further 3 ions cm$^{-2}$ s$^{-1}$

in air at N.T.P. In the case of deuterium about 800 tritium decays are found on each photograph. Assuming each remains visible for 1·5 s, the number of decays per cubic centimetre per second is about 0·065, and the corresponding number of ions is nine. Since it is known that the use of beam intensities several times greater than mentioned results in local vapour depletion, causing gaps in tracks as well as a substantial reduction in the sensitive depth, it is evident that

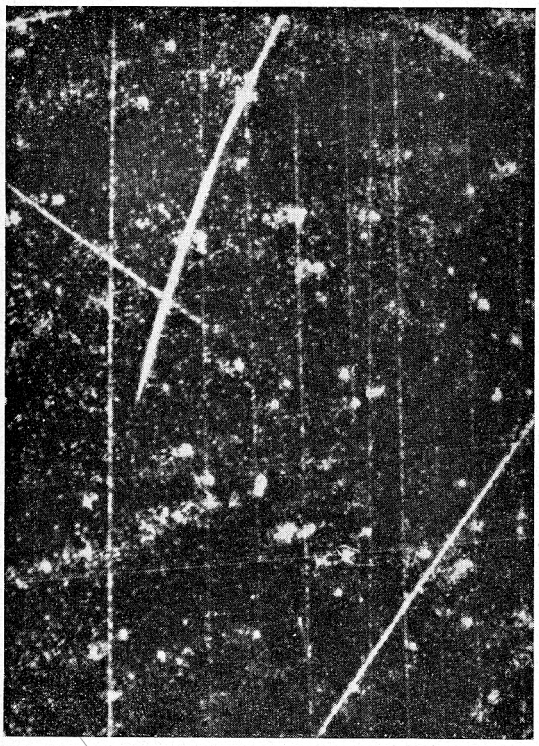

Fig. 2. Typical photograph showing 950 MeV proton tracks and background blobs due to tritium decays

the tritium decays will influence chamber performance considerably. The values of $\beta$ for hydrogen ($n_0 = 5$) and deuterium ($n_0 = 14$) are 0·45 and 2·95, the ratio of the factors $\mu_0 D_0^{-1/3}$ being 0·62 only. The corresponding values of $dT/dx$ according to Bevan are 7·1 and 9·8° C/cm whilst the values used were 6·4 and 7·9° C/cm respectively. The differences in source temperature used arise from the differences in $dT/dx$. Thus the chamber performance with deuterium can be approximately accounted for by the theory. A higher temperature gradient is required for deuterium because of the lower sensitive depth, but cannot be achieved because of the limit to the source temperature.

To obtain a better sensitive depth with deuterium it would be necessary to use a gas with a substantially lower tritium concentration. The ratio $T/H$ in ordinary rain water in Norway is about $10^{-18}$,[5] although it may be considerably higher elsewhere.[6] In producing 99·5% $D_2O$ from ordinary water by electrolysis, as is done at Norsk Hydro, the tritium ratio T/D is expected to increase to about $5 \times 10^{-14}$.[5] For 0·065 decays per cubic centimetre per second and a half-life of 12·4 years the observed concentration may be shown to be $3{\cdot}0 \times 10^{-14}$, in reasonable agreement with that expected. For lower concentrations the use of very old heavy water, or glacial water with a lower initial tritium content,[2] would be necessary. Less tritium would also result in improved photographs, for the blobs of ionization cause gaps in the tracks owing to local vapour depletion, and also by their presence may occasionally result in uncertainty in the interpretation of events.

A longer flash delay time than that normally employed for hydrogen is necessary to obtain satisfactory photographs in deuterium (see the table). Hazen[7] has shown experimentally with expansion chambers that for a given degree of supersaturation for nitrogen and hydrogen, the rate of increase of surface area of a drop is approximately proportional to the diffusion coefficient of the vapour in the gas. In the present case the ratio of the flash delay times used is not inconsistent with the ratio of the coefficients $D_0$, which is 1·66. There is, in addition, the effect of local vapour depletion just mentioned.

The initial oxygen content in the deuterium was 0·06%. The pulsed magnetic field applied to the cloud chamber is quite non-uniform, and, moreover, changes in uniformity as the field strength increases to its maximum value of 13 kG. This causes gas motions as a result of the paramagnetism of the oxygen, and, for the concentration stated, velocities of about 1 cm/s may be achieved. These make the measurement of track curvature quite impossible. It is, therefore, essential to remove all traces of oxygen from the deuterium as described above. No evidence for significant gas motions has been observed with commercial hydrogen stated to contain not more than ten parts per million of oxygen. These observations emphasize the need to evacuate the cloud chamber thoroughly before the insertion of any gas. The question of accurate momentum measurements in a diffusion cloud chamber is discussed by Culwick[8] in another paper.

A study of the interaction of 950 MeV protons with deuterons is in progress, and will be reported elsewhere. Since this paper was written, two preprints describing experiments with diffusion chambers filled with deuterium to a pressure of 17 atm have been received. L. M. Lederman, K. C. Rogers and R. Rockmore of the University of Columbia have investigated the scattering of 85 MeV positive pions in deuterium,[9] and V. P. Kenney of the Brookhaven National Laboratory has studied meson production in deuterium by 1400 MeV negative pions.[10]

ACKNOWLEDGEMENTS

We are grateful to Prof. P. B. Moon for his interest in this work, and to Prof. Sir Francis Simon for advice on the deuterium generator. Dr. J. C. Robb has been kind enough to analyse several samples of deuterium. Two of us (A. P. B. and B. B. C.) wish to thank the Department of Scientific and Industrial Research for maintenance grants, and one of us (H. B. K.) is indebted to Norges Teknisk Naturvitenskapelige Forskningsraad for a research grant, and to J.E.N.E.R., Norway, for a year's leave of absence.

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