SOME FEATURES OF THE BRITISH NATIONAL HYDROGEN BUBBLE CHAMBER

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(presented by W. H. Evans)

1. INTRODUCTION

In May 1957 a meeting of physicists from several institutions was convened in London by C. C. Butler to consider the desirability of constructing a large hydrogen and deuterium bubble chamber in the United Kingdom. It was suggested that the chamber should be built for use with the 25 GeV proton synchrotron at CERN and with the 7 GeV proton synchrotron under construction at the Rutherford Laboratory of the National Institute for Research in Nuclear Science at A.E.R.E., Harwell. As a result, a working party, consisting of members of the physics departments at Birmingham University, Imperial College, London, Liverpool University, Oxford University and the Rutherford Laboratory, Harwell, was formed to prepare the basic designs. Most of the main design features of the chamber were settled by the summer of 1958 and financial approval for the project was granted in the autumn of 1958.

The first problem studied was the size of the chamber. The final decision was influenced by many factors, for example, engineering feasibility and economic considerations, as well as by the physics problems to be tackled in the future using the new high-energy accelerators. By the autumn of 1957 it was decided to design a chamber 150 cm long, 50 cm high and 45 cm deep provided with a modest magnetic field, certainly greater than 10 000 G. The first one third of the chamber length may be regarded as a target for producing interactions by beam particles. The remaining length is reasonably adequate for studying secondary phenomena, such as decays and interactions of particles produced in the target zone. For the highest-energy primary interactions the decay paths will be rather long and, consequently, a still larger chamber would be desirable but this was not considered feasible for engineering and financial reasons.

The chamber has the following principal features, some of which are described in detail in later sections :

(i) The chamber will have vertical glass windows and a metal top and bottom, thus permitting good temperature control.

(ii) Two windows are used, one for illumination and one for photography. This arrangement enabled a high quality optical system, with several novel features to be designed. A detailed description of this system is given in Section 2.

(iii) The chamber will be expanded upwards. A special effort has been made to ensure a uniform expansion free of gross turbulence in the fluid. A vapour expansion system, using many liquid-vapour interfaces will be used; a description is given in Section 3.

(iv) The temperature of the chamber will be controlled by refrigeration loops, following the practice used in the 72″ chamber at Berkeley.

(v) The chamber will be suspended in a large stainless steel vacuum tank, the dimensions of which were fixed before the design of the electromagnet was completed. The vacuum tank is large enough to permit the expansion system to be redesigned or modified in future years.

(vi) A 300 ton electromagnet, with a large coil separation, will provide a magnetic field of at least 11 000 G across the chamber for a power consumption of 4 MW. Some efficiency in magnet design has been sacrificed in order to allow space for possible modifications in chamber and expansion system designs.

Features (i), (ii) and (iii) require the use of a horizontal magnetic field across the chamber. It is realised that this arrangement may sometimes lead to difficulties when feeding beams of particles, particularly low-energy beams, into the chamber. It is felt, however, that these difficulties can be largely overcome by elaborations to the beam arrangements. Furthermore, the disadvantages of the system adopted will probably be completely outweighed by the advantages gained in the quality of the bubble chamber photographs.

The design problems have been divided among the members of the consortium as follows: magnet — Birmingham University; chamber vessel, hydrogen and nitrogen shields, expansion manifold system, vacuum tank and pumps — Liverpool University; illumination and photographic system, glass windows and gaskets, test equipment, gas expansion and electrical compressors, hydrogen gas purifiers, safety arrangements — Rutherford Laboratory, Harwell. It is hoped that the equipment will be completed and ready for test at the end of 1960.

At present the University groups consist of nine part-time and five full-time physicists and engineers. Seven full-time draughtsmen and technicians are employed and some work is being carried out in the University workshops. In addition, there are several engineers and draughtsmen working on the buildings and plant arrangements at the Rutherford Laboratory.

Throughout this paper pressures are given in units of pounds per sq. in. absolute (p.s.i.a.) or pounds per sq. in. gauge (p.s.i.g.). For convenience it may be noted that: 1 atmosphere = 14.7 p.s.i.a. = 1.033 kg. cm^{-2} = 1.013×10^6 dynes cm^{-2}.

2. THE PHOTOGRAPHIC AND ILLUMINATION SYSTEMS

It is natural to conjecture that, in order to achieve an optimum optical design for the bubble chamber, it would be necessary to begin by a consideration of photographic film characteristics. Fortunately this is not the case; it is possible to design an optimum illumination system which will serve any photographic arrangement, for example, a wide range of film sizes may be used. Before this illumination system can be designed, however, it is necessary to fix the number and positions of the camera lenses.

2.1. The location of the camera lenses

The working distance of the camera lenses is not determined by consideration of film size but a lower limit is given by the maximum field angle of the camera lenses available. For the comparatively small aperture camera lens required this angle may safely be taken as 30° half-angle. The area to be photographed may be taken as a rectangle 150 cm × 50 cm at the camera side of the chamber which is 45 cm deep, thus the maximum working distance from chamber centre to lens is about 160 cm. Although lens distortions will decrease if a greater working distance is chosen, this is of no great importance since these are fixed and can be allowed for in reconstructing the tracks from the stereoscopic photographs. Increasing the working distance has the serious disadvantage that a worthwhile stereo-angle cannot be maintained without making the electromagnet design extremely costly.

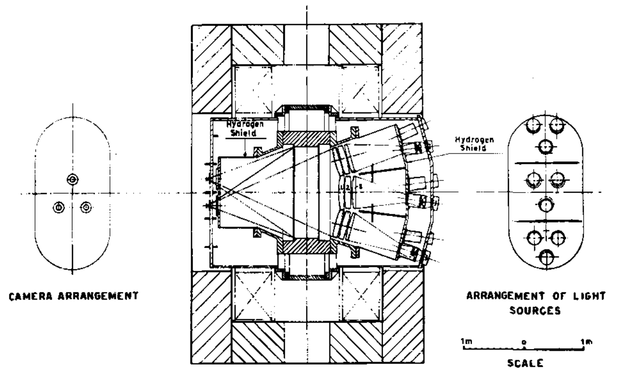

Fig. 1 Plan view of bubble chamber and magnet. (The figure is only schematic; it shows the chamber vessel, the windows, the hydrogen shields and an outline of the vacuum tank. The nitrogen shield is omitted.)

Assuming the working distance of the camera lens to be the minimum value of 160 cm, the spatial arrangement of the camera lenses can be fixed. The greatest distance between lenses in the vertical plane is 46 cm if vision is not to be blocked by the chamber walls. For economy, it is considered reasonable to use three cameras, spaced as shown on the left-hand side of Fig. 1. The average stereo-angle is about 18° in air, or 17° in liquid hydrogen.

2.2. The illumination system

An attempt has been made to design an illumination system which will produce sufficient and uniform light for the bubbles to be photographed very soon after they are formed. It is hoped that the delay between the injection of the beam of particles and the flash of the lights may be somewhat less than 1 msec. The bubbles will then be small and will not have coalesced. Thus their positions can be determined with high accuracy and bubble densities along tracks determined. Also the shorter the time between the beam and taking the photographic record the smaller will be the distortion of the tracks due to the motions of the liquid. It is also necessary to illuminate the chamber uniformly so that the photographic conditions will be uniform throughout the volume.

To give uniform illumination of the chamber it is essential that the illuminating source should be focused in the plane of the camera lenses. Detailed considerations show that a single axis optical system is impracticable since the total thickness of the condenser lenses would be too great, consequently it is necessary to divide the chamber optically. It is convenient to do so into three parts, so it is necessary to consider separately the illumination of three spaces 50 cm × 50 cm × 45 cm deep.

Spherical and parabolic mirror systems suffer from the serious disadvantage that they require a strongly diverging cone in the magnet polepiece and, in addition, need either a glass window for the vacuum tank even larger than the chamber windows, or light sources operating in the vacuum, both of which are highly undesirable propositions. Sources at a finite distance and simple condenser lenses are, however, a feasible arrangement. A 2 : 1 system, which has a reasonably good light collecting power, has been chosen for the present chamber. This magnification has the practical advantage that considerable adjustment of the source to image distance is possible by a small movement of the source.

In practice, it is found that the condenser lenses have to be somewhat larger than 50 cm square since they cannot be mounted in contact with the chamber windows. The 2 : 1 system needs a total condenser thickness at the centre of 25 cm; it is convenient to split such a lens into three components. The spatial

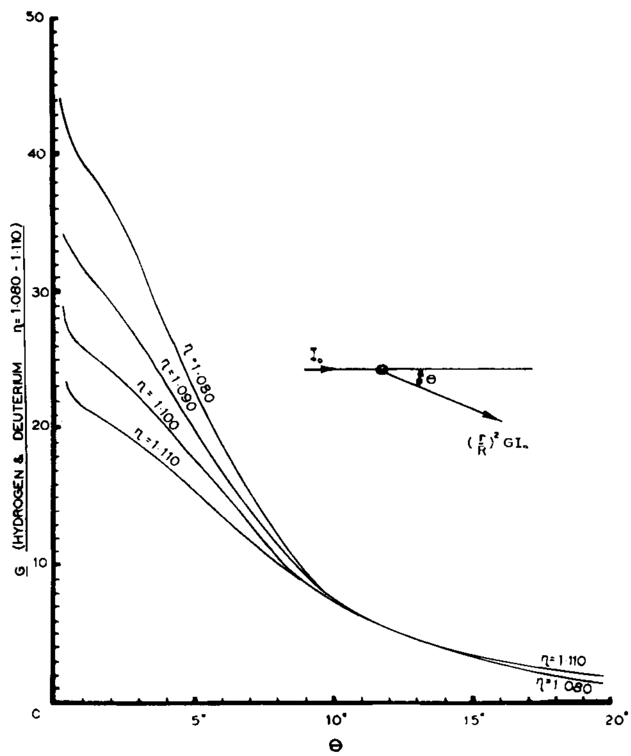

Fig. 2 The intensity of light scattered by a bubble in hydrogen or deuterium as a function of the angle of scatter.

disposition of the nine lenses is shown in Fig. 1, which is a plan view of the bubble chamber and magnet. (The figure is schematic, for simplicity the nitrogen shield is omitted). Details of the individual condenser lenses are given in Section 4.

If only three sources were used, to give a single image equidistant from the three camera lenses, the light would have to be scattered by the bubbles through about 11° in order to reach the lenses. The significance of this angle of scatter can be seen from Fig. 2 which shows the intensity $I(\theta)$ at a distance R from a bubble of radius r, illuminated by light of initial intensity I_0, as a function of the scattering angle θ. The relationship is $I(\theta) = G(\theta)\, I_0\, (r/R)^2$, where G is a scattering function derived from geometrical optical theory. The function has been calculated for a range of refractive indices of fluid encountered in liquid hydrogen and deuterium bubble chambers. The relative change of light intensity with scattering angle is shown in Fig. 3.

It may be seen at once that, in order to photograph bubbles as soon as possible after they are formed, it is desirable to use scattering angles of less than 11°. In addition to intensity of scattered light, it is important to achieve uniformity of brightness of the bubble images over the whole chamber, since this allows the photographs to be underexposed. The underexposed pictures will have smaller images than normally exposed pictures, since only the peaks of the Airy

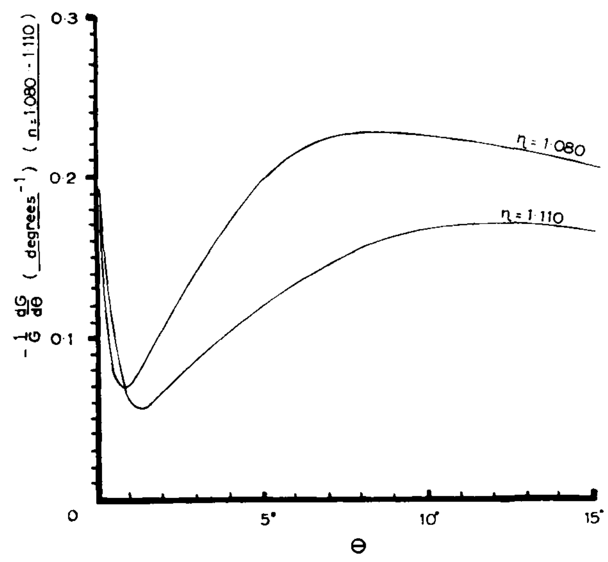

Fig. 3 The relative change of scattered light intensity with scattering angle.

discs will be recorded. Non-uniformity can arise from aberrations in the condensing system causing deviation of the rays from the correct angle, so that the scattering angle varies. Non-uniformity also arises from the fact that the scattering angle varies between the front and back of the chamber since the camera lenses are at a finite distance from the chamber. Thus it is desirable that the relative rate of change of scattered intensity with scattering angle should be as small as possible. A serious non-uniformity from front to back of the chamber arises from the fact that the illumination beam is convergent and thus the same light flux is spread over a smaller area at the camera side than at the source side. There is also a similar error, operating in the same direction, due to the variation in solid angle subtended by the camera lens apertures throughout the chamber. These effects are inherent in any small angle illumination system and will probably be overcome by setting the best focal plane of the cameras nearer one window than the other.

Smaller angles of scatter than 11° can be used if separate images are formed near each camera lens. Each condenser system must then have three sources spaced so that they produce images near each of the three cameras, i.e. 9 sources in all. If a scattering angle of only 2° can be used then the light intensity is increased by a factor of three over the 11° arrangement and also the sensitivity to errors in the image position is reduced by a factor of 3 (see Figs. 2 and 3).

Unfortunately, chromatic aberrations in condenser systems of the size proposed are liable to give variations in angle of the order of 3° across the condenser aperture. It is impracticable to achromatize the system so it becomes essential to use roughly monochromatic light. Assuming a bandwidth of about 300 A the light intensity from a condenser discharge lamp is then reduced by a factor of about 10. This rough monochromaticity is also desirable if efficient anti-reflection coatings are to be used, as pointed out below. If, in addition, one component of each condenser triplet is aspherized to eliminate spherical aberration the total angular spread due to condenser aberrations can probably be reduced to about 0.2-0.3° in the worst parts of the field. The angular spread due to the depth of the chamber will be of about the same magnitude. To obtain even greater uniformity and lack of sensitivity to alignment errors, it is planned to use ring sources of 7 cm diameter, 3 for each condenser, to give image rings of 14 cm diameter round each camera lens. The arrangement of the sources is shown in Fig. 1 (right-hand side). It is necessary to use small windows in the hydrogen shield (to avoid the risk of breakage inherent in large windows), consequently the ring sources are imaged just inside the hydrogen shield by sets of precondensers as shown schematically in Fig. 1.

The energy required for the light sources has been estimated provisionally as follows. The energy needed to blacken (density 0.8) one square cm of fairly fast film is about 3×10^{-9} J. With the present system for the 150 cm bubble chamber the light energy required to pass through the chamber is 0.06 J. Allowing a factor of 1/10 for monochromatizing and 1/20 for conversion of electrical energy it follows that about 70 J per lamp must be expended. It may not be practicable to use lamps in the form of 7 cm diameter rings; in this event, it is intended to simulate optically the form of the ring source.

The use of a monochromatic system with a band-width of only about 300 A will permit the use of efficient anti-reflection coatings on all the glass surfaces. A reflection coefficient as small as 0.1% can be achieved in monochromatic light, using a double-film coating. The problem of multiple reflected source images is very much simplified by the use of these high efficiency coatings.

2.3. Photographic arrangements

Lenses of the kind used for aerial survey work will be used: these operate at apertures of F/11 or smaller and have a nominal field coverage of $\pm45°$, but vignetting and aberrations increase rapidly above 30°, hence the more conservative angle given in 2.1. Two film sizes have been considered, namely unperforated 35 mm (magnification 1/16) and unperforated 60 mm (magnification 1/9). The camera apertures can be determined using the conventional depth of focus theory and an estimate can then be made of the diameter of the recorded image. In making the latter calculation it is assumed that a recorded bubble image will have a diameter half that of the first dark ring of the Airy diffraction disc. This is a reasonable assumption since the film will be underexposed. The results of the calculations, for a chamber depth of 45 cm are as follows :—

(i) 35 mm film, magnification 1/16. Aperture f/27. Diameter of recorded image 19μ.

(ii) 60 mm film, magnification 1/9. Aperture f/45. Diameter of recorded image 34 μ.

Thus if a film resolution of better than 20 μ is possible using the proposed illumination system, then the only advantage to be gained from 60 mm film is the greater relative accuracy with which it can be analysed. However, until further experimental work establishes the relevant film characteristics in detail, it is considered wise to plan for the use of the larger film for high accuracy positional measurements and bubble counting.

It is possible, moreover, that much smaller bubble images will be obtained if a proposal for using annular apertures in the camera lenses is adopted. It may be noted that cloud chamber drops have been recorded on fast film as excellent images of 10 μ diameter, when an underexposure technique was adopted. It is therefore reasonable to conjecture that recorded bubble images of diameter 10 μ will be obtainable. Such an image would be obtained with an aperture of about f/15 using either film size, although the depth of focus would be inadequate. However, since the depth of focus can be increased by the factor $1/(1-\rho^2)$ by stopping out a proportion ρ of the aperture diameter, without affecting the image size, an adequate depth of focus can be obtained for both film sizes. Using this technique there is every indication that substantial advantages accrue from using the larger film, particularly for bubble counting experiments.

Two sets of cameras will probably be made, one using $3\frac{1}{4}''$ focal length lenses and 35 mm film, and one using 6″ lenses and 60 mm film. The former set would be used for experiments involving momentum measurements only, the latter for bubble-counting experiments. Alternatively, an arrangement with two 35 mm cameras and one 60 mm camera might be used. The cameras will be independent with separate film spools.

3. THE EXPANSION SYSTEM

The overriding consideration in the choice of the expansion system has been reliability and with this in view a gas phase system similar to that employed at Berkeley has been adopted. All the moving parts are outside the vacuum tank and can be maintained and repaired without emptying the chamber. In alternative designs, employing pistons or bellows in the liquid phase system, a considerable amount of dismantling is necessary to repair faults which may develop and much time is wasted since the chamber must necessarily be brought up to room temperature.

In order to avoid distortion of the tracks the expansion system should produce uni-axial flow of the liquid in the chamber under transient conditions and should cause the minimum thermal disturbance to the liquid.

One of the difficulties associated with gas-phase systems is the inherent instability of large gas-liquid interfaces subjected to sudden pressure changes. This effect is minimised by sub-dividing the surface into 48 regions which are held at a controlled height in 48 tubes, each with a bore of 5 cm, using heat exchangers supplied by a refrigeration system.

The pipes are uniformly distributed in a 3-bank array of 16 pipes each (see Fig. 4). A smooth transition is made from the circular sections of the pipes to

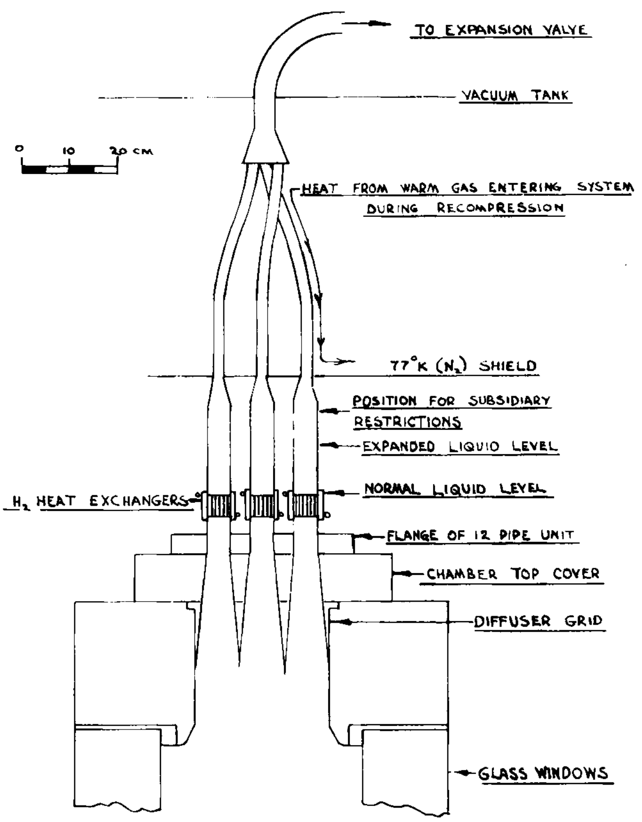

Fig. 4 Schematic transverse section of expansion system.

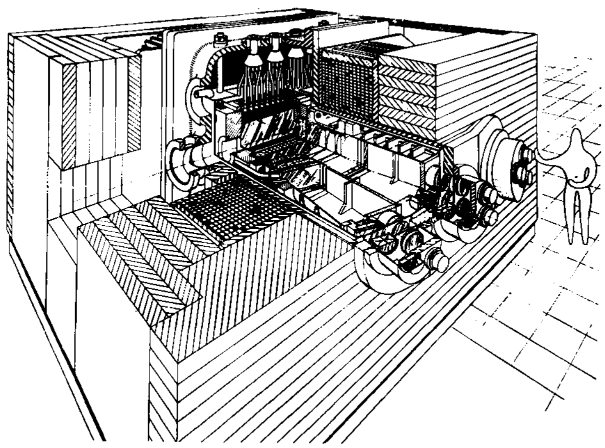

Fig. 5 Schematic projection of bubble chamber and magnet, showing expansion system.

rectangular sections covering the top area of the chamber. The position of the expansion pipes in relation to other parts of the chamber can be seen in Fig. 5 which shows two schematic elevations of the chamber, vacuum tank and magnet.

An important feature of the chosen expansion system is the inertial control exercised by the liquid columns in the pipes. This effectively isolates the chamber liquid from small irregularities in the rate of pressure change of the gas throughout the system. It is important to ensure that the pressure pulses arrive simultaneously at all gas-liquid interfaces both during expansion and recompression. The pipes are so arranged that the path length between the expansion valve and each liquid surface is constant, thus ensuring that no transverse pressure gradients are set up in the chamber. These could produce cumulative circulation in the liquid which would be serious at high repetition rates.

The control exercised by the large number of pipes should enable gross distortion in the expansion of the chamber liquid to be avoided. If remaining small-scale distortions should prove troublesome a free piston will be used, moving vertically at the top of the chamber to give linear expansion in the visible volume of the liquid. Provision has been made for mounting such a piston.

The pressure of the hydrogen gas in the tubes is lowered from about 90 p.s.i.a. by allowing the gas to expand adiabatically into an expansion chamber. When the pressure in the bubble chamber is at its operating value of about 40 p.s.i.a. the liquid surface has risen approximately 10 cms from its rest position in each pipe. The liquid rise is calculated on the basis of a 2% increase in the liquid volume for the required pressure drop.

The main refrigeration to the chamber is applied at the liquid surfaces and removes the heat of condensation at this point on heat-exchanging elements in the individual pipes. Each heat exchanger will be 5 cm high constructed from copper strip 0.1 cm thick and spaced by 0.5 cm. The surface area of each exchanger is 700 cm^2. The heat exchanger design will be tested in a dynamic model of one of the expansion pipes.

In the design of the expansion system it is important to ensure that the liquid pressure can be smoothly reduced from the initial to the final pressure in a time of the order of 20 msec and that the operating pressure can be steadily maintained for at least 5 msec to allow for irregularities in beam timing.

The simplest expansion arrangement would consist of an expansion valve through which the gas was suddenly allowed to expand into an expansion chamber. Unless controlled by a suitable impedance the gas flow is likely to be too rapid, causing appreciable " flashing " at the liquid surface, and producing a large acceleration of the liquid columns which, due to their inertia, cause a large " overshoot " of chamber pressure. The main gas restriction is placed adjacent to the expansion valve and provision is made for subsidiary restrictions to be placed in each pipe a short distance above the highest liquid level attained during expansion. Subsidiary impedances cannot be accurately calculated and their value will be determined experimentally in a model representing one section. The system will be pre-assembled as 4 units each comprising 12 pipes on a common flange bolted to the chamber. A single pipe leads from each unit to the expansion valve.

The heat input to the chamber due to pulsing cannot be calculated very accurately. A rough estimate has been made of the several contributing factors giving a figure around 1000 W at 10 pulses per min exclusive of effects due to flashing at the liquid surface. It is assumed that the heat carried in by warm gas entering on recompression is removed at liquid nitrogen temperature (Fig 4).

The design of the expansion line has not yet been completed in detail. It is hoped that a new type of valve currently under development will prove satisfactory for both expansion and recompression of the chamber. In essence this valve consists of a cylindrical spool ground and highly finished to a precision sliding fit within a honed sleeve of the same material. The fit is such that no lubricant is required and gas leakage between the sleeve and spool is unimportant. The spool, in sliding through the sleeve, opens ports in the sleeve wall and allows gas to flow axially along the sleeve and escape through the ports. The valve being of all metal construction should operate quite cold. The design also lends itself readily to the automatic sensing of misoperations such as failure to open or close. It can thus contribute important information to the interlock system of the expansion line.

The main expansion and recompression valves will be operated pneumatically (by hydrogen) using pilot valves of the same general design which are available commercially. The primary electro-pneumatic conversion will be performed by a moving coil actuator, similar to a loudspeaker movement, operating directly on the spool of a pilot valve. With this system the delay associated with solenoid operated devices is avoided.

An expansion valve which runs cold can be positioned in the expansion line nearer the chamber end of the line than if a valve with inferior low temperature characteristics were used. The expansion line volume can thus be reduced somewhat, as can the sizes of the expansion and recompression tanks.

The cold gas boil-off from the chamber nitrogen shield, even under static conditions, represents a considerable refrigerator capacity which is available for pre-cooling of the recompression gas if desired.

The gas circuit is completed by the low pressure hydrogen compressors, Corblin A4V diaphragm machines having been selected. These offer the advantage that they in no way contaminate the gas with oil or other foreign matter and are therefore ideally suited to deuterium operation. Initially three such compressors will be used to pump 160-190 s.c.f.m. of hydrogen from an inlet pressure of 25-30 p.s.i.a. to 175 p.s.i.a. Provision is being made for the installation of two further machines of the same type should more compressor capacity be needed to deal with a high repetition rate.

4. SUMMARY OF PRINCIPLE DESIGN FEATURES

4.1. The main cryostat

(i) The chamber vessel

Machined from an aluminium forging material Mg 3 containing 3% magnesium. Finished weight 2.9 tons. The working stress is 2 tons per sq.in. Deflection at the centre of the bottom at 60 p.s.i.g. is calculated to be 0.005 in.

(ii) The window flanges

Machined from aluminium forgings (Mg 3). Considerable care has been taken to minimise trouble due to opening up of the gaskets between the chamber vessel and the flanges.

(iii) The glass windows

Borosilicate crown glass. 6¼″ thick, maximum stress 1000 p.s.i. Faces and edges highly polished to avoid trouble from cracks spreading from the edges.

(iv) Window gaskets

Inflatable window gaskets of a slightly modified Berkeley design are being constructed for test purposes.

(v) Hydrogen shields

Each glass window is protected by a hydrogen shield fabricated from forged and sheet Mg 3 aluminium. The shields have only very small windows. The shields will safely withstand a pressure of 50 p.s.i. which is expected to be the pressure developed if the main windows fail. They will be cooled to liquid hydrogen temperature using one loop of the refrigeration unit (see 4.2 below).

(vi) The nitrogen shield

A copper shield with pipes circulating liquid nitrogen will surround the chamber and hydrogen shields.

(vii) Expansion and suspension arrangements

The chamber will be expanded as shown in Figs. 4 and 5. The chamber will be suspended by a system of stainless steel tubes. Detailed design work is still in progress on this part of the project.

(viii) The vacuum tank

The tank will be fabricated from stainless steel sheet (Firth-Vickers F.C.B.), total weight 23 ton. The tank has to withstand some overpressure if a major spill of hydrogen should occur, for example, through a beam window. Plastic deformations set in at about 100 p.s.i. but the chamber would not break unless an internal pressure of 300 p.s.i. develops. The volume of the tank is 8000 litre.

(ix) Vent line

If the vacuum in the main vacuum tank is destroyed and the pressure rises above 15 p.s.i.a then the tank is connected automatically via a vent line 10″ in diameter and about 100 ft long to a dump tank. It is estimated that the pressure rise in the vacuum tank will be about 50 p.s.i.g. during the venting of the 500 litre of liquid hydrogen. The dump tank volume is 4600 cu.ft.

4.2. Refrigeration system

A refrigeration system similar to that used on the Berkeley 72″ chamber is being installed. It is being manufactured by Cryenco Ltd. of Denver, Colorado, to the designs of the National Bureau of Standards Cryogenic Laboratory at Boulder. The refrigerator will have four independently controlled refrigeration loops. Two four-stage hydrogen compressors, each rated at 200 s.c.f.m., will feed the refrigeration unit. Using both compressors, the unit is expected to remove at least 3 kW at liquid hydrogen temperature. A hydrogen storage and purification system, following the basic design used at Berkeley, is being installed.

4.3. The optical system

a) Condenser lenses

Numbering the surfaces consecutively starting from the source side the radii of curvature are as follows:

Surface	1	2	3	4	5	6
Radius, cms	plane	178.5	274	123	plane	85

The thicknesses are 5.2 cm, 10.0 cm and 10.0 cm and the glass is hard crown. The sixth surface has a large curvature in order to ensure that the rays do not touch the chamfered abutting surfaces; thus the join between the three systems will not show up bright. This sixth surface is aspherised to eliminate spherical aberration, the departure from the best-fitting spherical shape being about 2 mm.

b) Camera lenses

For 35 mm film 3½″ lenses at 1/16th magnification, giving a frame 31 mm × 93 mm; for 60 mm film, 6″ lenses at 1/9th magnification, giving a frame 56 mm × 167 mm. The lenses will have annular stops with outside diameter giving resolution equivalent to F/15.

4.4. The pneumatic and electric controls

Some features of the control system have been described in section 3. Detailed design work has not yet been completed.

4.5. The electromagnet

The electromagnet has been designed in two halves to enclose the vacuum tank. The power supply was fixed to be 4 MW at 500 V before the magnet was designed. The main design parameters are as follows:

Magnetic field	11 800 G
Effective air gap	137 in.
Amp — turns	3.36×10^6
Number of turns	420
Water flow	450 gallons per min.
Water pressure	300 p.s.i.
Temperature rise	35° C
Conductor cross-section	1.74×1.74 in.
Water hole diameter	1.180 in.
No. of pancakes	2×14
Weight of copper	40.2 ton
Weight of yoke	240 ton
Total weight	300 ton

The magnet will be provided with a hydraulic jacking system to bring the centre line to the beam height of the Rutherford Laboratory's 7 GeV accelerator. The mounting employs approximately 400 ball castors running on hardened steel sheets. The floor loading does not exceed 20 ton per sq. metre.

Acknowledgements

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DISCUSSION

PEYROU: I want to comment about your requirement of not building any pressure gradient in the chamber. There might be a difficulty; even if you have the same length of pipes, you are not at all sure to have the same gradient of temperature, and since the velocity of sound in gaseous hydrogen varies by a factor of 3 from 300°K to 25°K you are not sure that all the tubes will evacuate at the same rate. On the other hand, I don't believe that these pressure gradients are very important because essentially you put the beam into the chamber when the expansion is finished.

EVANS: Are you saying in actual fact that the distortions of the bubble chamber are entirely independent of the design of the expansion system?

PEYROU: Not entirely independent.

EVANS: Well, how dependent are they on the design of the expansion system? This is the real point, isn't it? If they are relatively independent, onecan be very loose about the design.

PEYROU: I think that, if you have less than one millisecond difference for the time the pressure waves need to travel to different parts of the chamber you are quite safe, but I am not sure.

VILAIN: I see some trouble in getting the levels at the same height in all the pipes, the reason being that you get separate heat exchangers. Now, either you put the loops in series or in parallel. If you put them in series, the ones at the end of the loop will be warmer, and if you put them in parallel, it is quite difficult to know if you get equal flows in all of them. So unless you make a rather complicated structure where your refrigerating liquid flows evenly round all the pipes, it is quite possible that the levels will not be at the same height at all, depending on the geometry of the refrigeration coils.

EVANS: You could even get away with it with a double-pipe system. The liquid is passing in opposite directions in the two pipes. This usually gives you a very good average figure for the whole lot.

VILAIN: Yes, if you have a completely symmetrical system or something like that.

HILDEBRAND: I would like to ask the same question I have asked about the other big chambers. How did you decide what dimensions to use? I notice that your magnetic field is lower than for the other big chambers. For the same cost one could presumably have a larger field and a somewhat smaller chamber.

EVANS: The length of the bubble chamber was the first thing to be settled. We made this the maximum we thought we could construct with the personnel available. The magnetic field at that time was 15 kG which is not very much different. It is very easy to fall into the tub of designing the chamber for a given magnet size, that is, weight of iron and copper, and cost, if one can get a certain field. When you start putting in the dimensions, the thicknesses necessary for the material in the chamber, it starts pushing itself out, quite markedly. In our particular case the addition of the hydrogen shields meant we had to move the magnet out quite a considerable amount. So this is the reason why the magnetic field has gone down a little below the others. The rest of the answer is exactly the same as you got from Shutt. We regard the first third of the chamber as a target; this is very loose, I admit; the other 2/3 is the part we actually do the measurements on. Now we feel 40″ is necessary in order to do the measurements with the accuracy that we want.

PEYROU: Since Hildebrand is going to ask me his usual question, I might answer immediately that I don't know why our chamber is exactly two metres long. You can put forward reasonably rational arguments why a narrow chamber is an instrument well adapted to high energy physics. If you are exceedingly rational you could say that the ratio length to width should be of the same order of magnitude as the γ of the centre of mass in the collision of a particle of the primary beam with a proton. This is the first point. The second point is that in the quarrel between small chambers with high field and low field large chambers I believe that the low field large chamber is better as a general purpose instrument, because I believe the kind of information you get from a bubble chamber depends very much on how much you let secondaries make secondary or tertiary interactions as the geometrical mean free path in hydrogen is 4 metre. So any chamber shorter than 4 metre is certainly too short.

O'NEILL: In the operation of the British chamber, the arrangement is to be such that the bubble growth is very fast, much less than 1 ms. I would suppose that it would take of the order of 10 to 20 ms for the chamber to go from no sensitivity to full sensitivity; in this time there is a reasonable chance of getting at least one cosmic ray μ meson into so large a chamber. Is there any difficulty, because with this fast bubble growth there is a good chance that some tracks were started in this way much sooner than the beam pulse has been turned on?

EVANS: The bubble growth is no faster than in other chambers. The delay between the entry of particles and the flash can be made short.

SOME FEATURES OF CERN HYDROGEN BUBBLE CHAMBERS

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The purpose of this paper is not to describe in detail the hydrogen bubble chambers in existence or projected at CERN. I would prefer to discuss some speculations and describe some experiments that we have performed, most of them in order to foresee the future performances of the CERN 2 metre bubble chamber.

There exist in CERN two hydrogen bubble chambers which have been used with the 600 MeV Synchrocyclotron, a 10 cm and a 30 cm one. The 10 cm one was built and used in order to acquire experience in the field. The 30 cm one is now finished and produced tracks for the first time at the beginning of May 1959. It will be placed inside a magnet giving a field of 15 000 G.

30 CM CHAMBER

Fig. 1 shows the chamber schematically. The diameter is 32 cm, the depth 15 cm, giving a total volume of 15 l. The chamber body is made of stainless steel. Tempered glass is used for the windows. The gaskets are made of rings of hard copper, which have a circular section, and are covered with indium.

This system of gaskets is used in metal—metal joints as well as in glass—metal joints. These gaskets are very satisfactory. The copper provides a gasket which does not flow and is tight after several cooling and warming cycles; and the indium takes care of possible small scratches. The chamber is expanded by a piston of stainless steel, 11 cm in diameter. The piston movement is forced and not due to the pressure of the liquid. The piston can be demounted without dismantling any part of the chamber inside the vacuum tank.

The temperature of the chamber is controlled by means of a pressurized bath working in closed circuit and transferring heat to a reservoir of hydrogen boiling at atmospheric pressure [1]. The bath sur-