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ABSTRACT

Bright-field illumination using a beaded reflective screen is accomplished in the 30-inch heavy liquid bubble chamber by using separate light sources for each lens. The resolution obtainable is about four times as great as with dark-field illumination.

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Bright-field illumination for bubble chambers usually involves use of a mirror to reflect the light into the lenses if straight-through illumination is not used. The largest chambers using this type of illumination are those at Brookhaven National Laboratory.[1] The principle involved is that of a back-silvered concave mirror with a ground upper surface (ground surface diffuses the reflections in the mirror so as to avoid the confusion of clear reflected tracks). Both of these chambers require an expensive mirror of considerable thickness as well as a special ground surface to avoid reflections. Separate light sources are used for each view, extended sources to reduce reflections from the top glass.

Although attempts had been made to use the retrodirective properties of beaded reflective screening such as "Scotch Lite" (made by the Minnesota Mining Company) and others, no satisfactory reflective coatings have been obtainable until now.

Mr. Melvin L. Johnson of the Minnesota Mining Company sent us a sample of an experimental beaded reflective screen which has all the desirable properties, namely, small angular width to the reflected light, small falloff in intensity away from the normal, extremely fine grain (so that no graininess in the surface is apparent in the photographs), and high reflecting power.

Unlike most beaded reflective sheets, these sheets have the beads very uniformly spaced and closely packed. Whereas on the usual sheets there are various spots where six or seven beads are missing, this sheeting is notable for not having such groups of missing beads. Only single beads are missing. The beads are about 20 microns in diameter, and no graininess shows in the photographs. The sheet has a yellowish cast, but this causes no difficulty with the red light used for these photographs.

Figure 1 shows the track of a cosmic ray photographed against a composite background of two types of reflective screen. The successful screen is on the right. Small spots are actually tracks of particles from a radioactive source and not defects in the screen. The crosses are fiducial marks spaced 5 cm apart.

The cosmic ray goes out the bottom of the chamber, where any shadows would be most apparent, and it is obvious that shadows are no problem, since they lie directly under the tracks.

The illumination system consists of ring flash tubes surrounding each lens and shining down through the 2.25-in.-diameter glass windows.

Figure 2 shows a window with its light and lens. A glass cylinder, C, 2-1/8 in. in diameter and 2 in. tall, rests on top of the sealing window, S. Microscope objective oil is placed between the two pieces of glass so that there is no change in index and therefore no reflection at the interface. Two smaller glass cyclinders, G, G, are placed directly in front of the lens. They are sealed to the 2-1/8-in. diameter glass with balsam, again to reduce reflections. The outer edges of the three cylinders are blackened with Apiezon black wax to avoid reflections.

A ring-shaped flash tube, T, is placed around the small glass cylinders and covered with a reflector R. Since a diffuse source is most desirable, a ring of tracing paper is placed between the tube and the glass to diffuse the light. This reduces the intensity of reflections from the top and bottom glasses of the inner chamber. The camera looks through the center of the ring light at the chamber. The small glass cylinders have optical surfaces and are useful in keeping scattered light away from access to the camera lenses.

The inner chamber is supported by clear mineral oil, as before.[2] The index of refraction of the oil is 1.47 and that of the glass sealing window 1.51, and this makes the reflection of the oil-glass surface negligible.

The inner chamber has a glass top and a glass bottom. The reflective sheeting came in 12-in. widths. This was fastened to a 1/16-in. aluminum plate by its own adhesive and placed under the bottom of the bottom glass of the chamber as shown at P in Fig. 3. The sheets were overlapped in the middle, and this line shows in the pictures.

The reflective sheeting is in the mineral oil surrounding the inner chamber. The glass beads of the coating are completely submerged in a plastic which has a glossy surface. This plastic has an index close to that of the oil, and therefore gives no specular reflection from its surface.

The light from any given ring light is returned by the reflective coating to its own camera lens. If one light fails only that view is missing. The reflective sheeting is sufficiently retrodirective so that there is no blackening of the negative in the other views. As a result of this property Polaroid pictures can be made through a special lens with its own light without fogging the other pictures, and the chamber can be viewed with a steady light at the Polaroid lens with only very slight fogging from scattered light.

The photographs are taken through an Eastman 25A (six times) red filter on Eastman Shellburst film at f 32. The lights are run with 250 μF at 420 V.

The images of single bubbles appear to be slightly smaller than the diffraction pattern of the lens, which corresponds to 0.34 mm in diameter when reprojected to full size or to less than 45 μ on the film with the 4-3/8-in. focal length lenses on our camera.

Contrast is very easily controlled by controlling the size of the bubbles.

The usual Freons and propane have indices of refraction around 1.18, and therefore there will appear on the film a reflection of each light from the liquid-glass interfaces at the top and bottom of the chamber. Only the top reflection obscures a track. This effect was reduced to a negligible amount by coating the glass with a quarter-wave-length thickness of magnesium fluoride suitable for the red light used. The reflections are just visible in the dark background.

The illumination is sufficiently uniform so that no steps were taken to improve it. At larger viewing angles (i.e., farther from the normal) it would pay to curve the reflective coating so as to be more nearly normal to the line of sight. This would reduce the effect of the inverse-square law. It would also be possible to direct the light toward the edges so as to make up for this loss.

Tracks cast shadows on the reflective sheet. These shadows are parallel to the tracks, close to tracks that leave the bottom glass of the chamber, and further away and very diffuse when tracks are high in the chamber. The shadows are nearly always invisible for tracks at minimum ionization, and never strong enough, even for heavily ionizing tracks, to cause difficulties.

Approximately 300,000 exposures were made with the conditions above. It became apparent that the bubbles could be diminished greatly in size and still be photographed. In order to increase the resolution in the midplane of the chamber the lenses were opened up to f 23. The track images for minimum ionization corresponded to 0.1 mm in the chamber, a reduction by nearly a factor of 4 from track diameters usually photographed. Thirty thousand pictures were made in this way. By varying the chamber operating conditions, the number of bubbles per centimeter was increased from 12 to about 30. Heavily ionizing tracks appeared to be 0.2 to 0.3 mm in diameter. It was possible to detect ionization changes quite well.

This method of operation permits very high resolution, photographically, of tracks in a large chamber, about four times as good as has been possible in the past.

The theoretical diameter of the first ring for the diffraction pattern of a point source corresponds to 0.0247 cm in the chamber 56 inches away from the lens with an aperture of 0.188 in. and light of the 6800-Å wavelength used. The images of minimum tracks were 14 μ in diameter on the film, equivalent to 0.01 cm in the chamber. This corresponds to a point on the diffraction pattern of a bright source at which the intensity is 65% of the intensity at the middle. The exposure was chosen so that this point gave a just perceptible decrease in the darkening of the film. The film was much more transparent, of course, at the center of the bubble. Images of heavily ionizing tracks were as wide as 40μ, corresponding to 0.3 mm in the chamber.

Other major modifications were made in the chamber and are shown in Fig. 3. The depth of the liquid was doubled from 6 in. to 12 in. The lights and water tubes that formerly were under the inner chamber were removed, as well as the Venetian blind. This allowed the bottom of the inner chamber to be lowered 3 in. The reflective sheeting, P, was placed under the bottom glass. A 3.5-in.-high ring, R, extended the sides of the pressure vessel. The magnet coils were placed closer together, their spacing reduced from 12 in. to 3 in. This change raised the magnetic field to 15,000 gauss, whereas before it was 13,000 gauss.

Electric heating pads, H, were attached to the cylindrical walls and the bottom of the chamber for heating. A propeller S, driven by a 1/4-hp motor, stirred the supporting oil to achieve uniform temperature. The water tubes, O, in the upper cone were used when cooling became necessary on two hot days. The heating pads were thermostatically controlled by four thermocouples attached to the steel under the pads. Freon (C_3F_8) was used, operating at 36 ± 1 C°. With propane at 61°C the water tubes would not be necessary. For part of the run the chamber was operated with nine chromium-plated copper plates which were placed at such angles that they were viewed edge on by the lenses of two of the cameras. The illumination was unaffected by the presence of the plates, since they are oriented edge on with respect to the lights surrounding the lenses. The third view did not look between the plates.

Figure 4 shows an enlarged section of a picture of the very fine bubbles.

In addition to the changes mentioned, a three-view camera was constructed with all three views on one film.

Eastman Shellburst emulsion was used for two thirds of the run, Dupont 140E for one third. Both films gave very similar results, the Shellburst showing slightly more contrast and the Dupont 140E slightly less but having a wider latitude of exposure which was advantageous at the edges of the pictures where the illumination was slightly less.

There is every reason to believe that this illumination system would work for hydrogen chambers. The reflective sheeting does not deteriorate in oil. In Freon it remains unchanged until the Freon is removed; then the liquid Freon that has penetrated the plastic expands into a gas again and blows the glass beads off the screen.

Some Optical Properties of the Reflective Screen

The optical properties of the reflective screen were measured by with a spectrometer having a slit 0.5 mm wide and 3 mm high. A half-silvered mirror at 45 degrees reflected the light returned by the reflective screen into the telescope. The eyepiece was replaced by a second 0.5×3-mm slit. The reflected light was measured with a good photometric photocell properly calibrated and linear. The reflected peak had a full width at half maximum of 1.7 degrees. This tailed off to quarter maximum at 3 degrees and to eighth maximum at 4.2 degrees. The spectrometer system gave a width of 7 minutes of arc, so that no correction was needed for the width of the slits.

For oblique rays there was a 4% drop in light intensity at 50 degrees from the normal, a 33% drop at 60 degrees, and a 66% drop at 70 degrees. At exactly normal incidence there is a specular reflection from the smooth glossy surface of the plastic containing the glass beads. The specular reflection doubles the intensity of the peak over a very narrow angle. When the reflective screen is submerged in the oil the reflection no longer occurs.

The angular spread of light with this sheeting was compared directly with the spread caused by mirrors such as used in the Brookhaven chambers.[1] The angular spread of the light reflected from the beaded reflective screen was found to be approximately half as great as that from the mirrors. Plunging the reflective screen into liquid nitrogen causes no change in its optical properties. If the reflective screen resists deterioration in liquid hydrogen, also, then all its characteristics are suited to operation in hydrogen.

REFERENCES

1. A. G. Prodell and Jack Steinberger, Rev. Sci. Instr. 33, 1327 (1962); also private communication.

2. W. M. Powell, W. B. Fowler, and Larry O. Oswald, Rev. Sci. Instr. 29, 874 (1958).

FIGURE LEGENDS

Fig. 1. A cosmic ray passes out of the bottom of the chamber. It starts at the upper left-hand corner, where it is above an older type of beaded reflective screen. The new reflective screen is to the right. The large symmetric cross is on the bottom glass of the chamber. The unsymmetric cross is on the top glass. The spacing between fiducial marks is 5 cm.

Fig. 2. The illumination system.

S sealing glass window
C glass cylinder
O location of tracing paper diffuser
W steel wall of outer chamber
T ring flash tube
R reflector
G glass cylinders

Fig. 3. The modified chamber

H electric heating pads
P reflective sheeting
B bottom glass
R 3.5-in. extension ring
O water tubes
S propeller stirrer

Fig. 4. A τ decay of a K^+ coming to rest in liquid C_3F_8. The two π^+ mesons decay into μ^+ and e^+. The μ^+ from the backward π^+ has a range of 1.43 mm and is at right angles to the line of sight. The positron is dipping at an angle of 20 degrees and should appear to be 1.07 times minimum. The other positron is at 68° and should appear to be 2.7 times minimum. The pair on the right is horizontal and should appear to be minimum. The large cross is on the bottom of the chamber. The dark ring around the cross comes from reflections, from the top and bottom glasses, of the light surrounding the lens. The lens is directly over the cross. The diagonal track crossing the center of the picture is very close to the bottom of the chamber. It is less clear for two reasons; it is out of focus, and the shadow on the reflective screen shows slightly. The faint straight line at the lower right-hand corner is the overlap of the reflective screen.

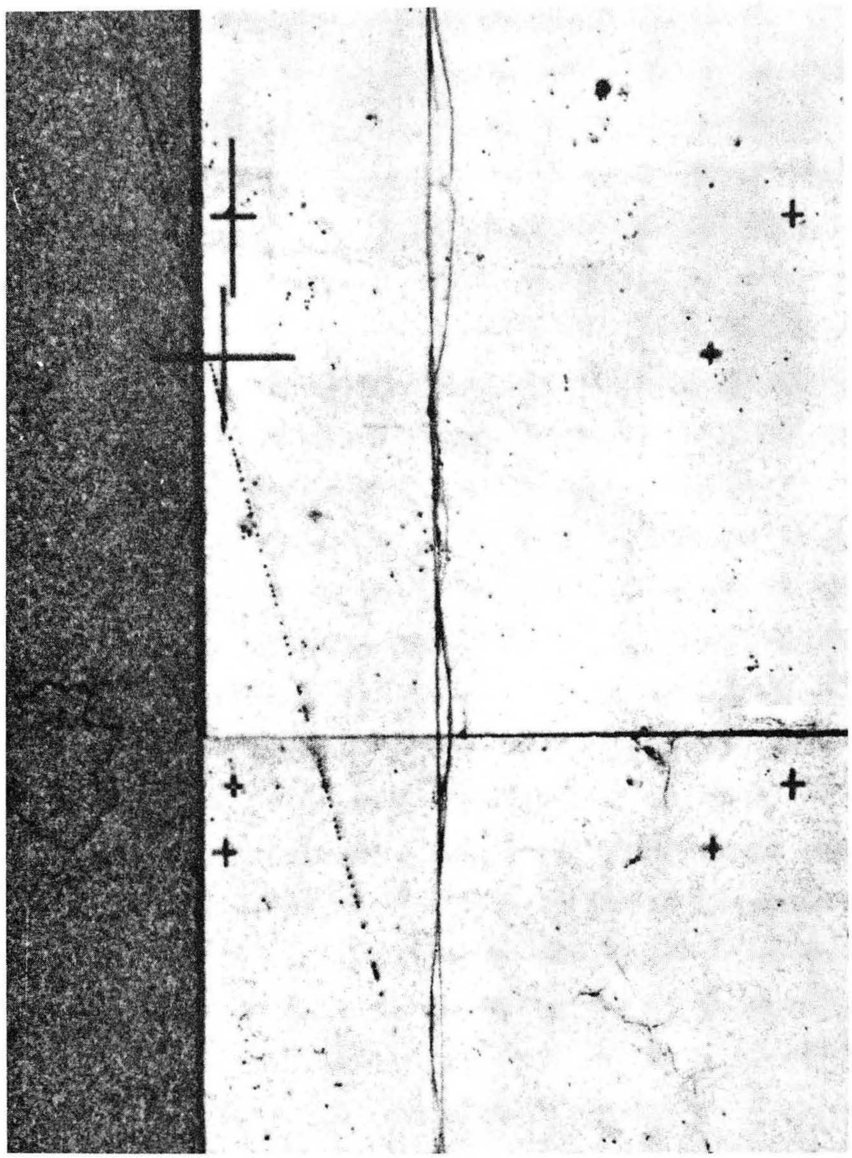

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Fig. 1

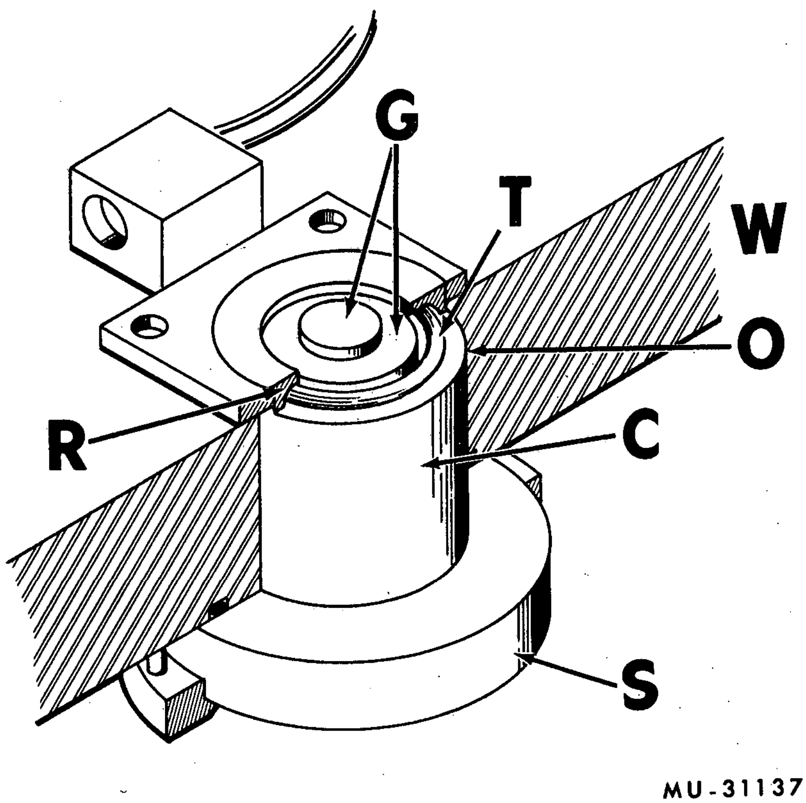

Fig. 2

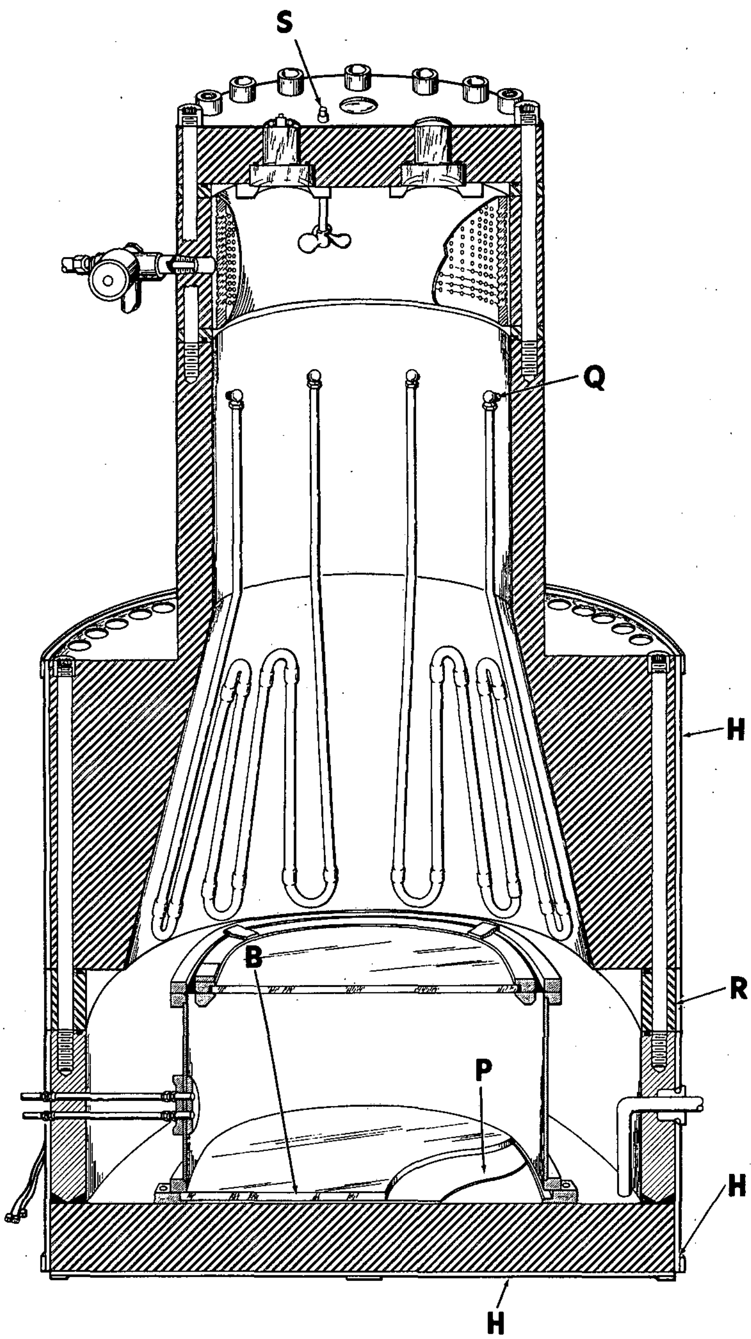

Fig. 3

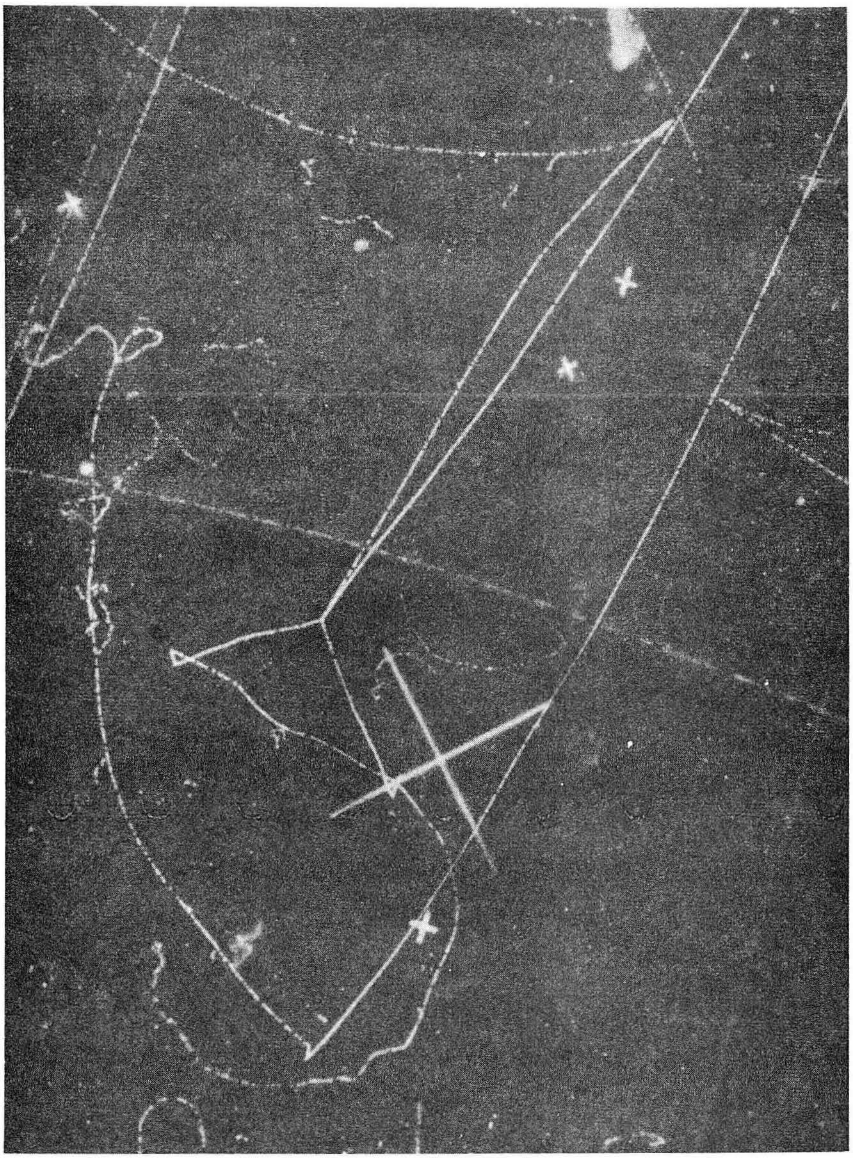

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Fig. 4