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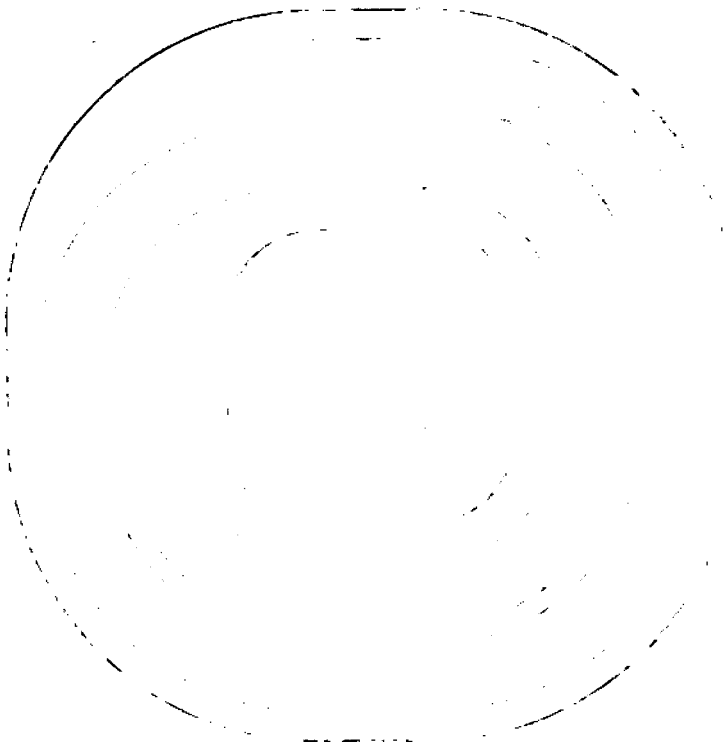
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A LARGE LIGHTWEIGHT MIRROR FOR USE IN CHERENKOV COUNTERS*

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April 19, 1971

ABSTRACT

The construction is described of Cherenkov counter mirrors of dimensions 120 cm x 120 cm, presenting on average 0.7 gm/cm^2 to penetrating particles, yet with optical qualities adequate to allow a simple light collection system.

Spherical mirrors made from aluminized acrylic sheets have been employed for some time in gas threshold Cherenkov counters, especially those operated at atmospheric pressure. An important advantage of mirrors constructed of this material is the comparatively low mass in the path of penetrating particles. They are also inexpensive to fabricate although this tends to be offset by asphericity of the surface and consequent unpredictability of the optics of the counter. The specifications of thickness and distortions are also dependent strongly on the size of the mirror and the support needed for the plastic sheet. On the other hand the use of several small mirrors to cover a larger area has been attended by efficiency loss near the common boundaries of adjacent mirrors.

The experiment for which the mirrors to be described were developed was a search for the rare decay modes $K_L^0 \rightarrow \mu^+ \mu^-$, $e^+ e^-$, $\mu^+ e^-$, carried out

at the Bevatron during 1969 and 1970.¹ The mirrors were the primary reflectors of threshold gas counters used at atmospheric pressure to detect electrons. Because of a possible high background from K_{e3} decays, which can kinematically resemble the $K_{\mu\mu}$ mode, a high detection efficiency was necessary for trajectory angles up to 50 mrad from the mean, over the entire active area of the counter, a minimum of 1.0 m square.

The counter design centered around the use of a single spherical mirror of 254 cm radius of curvature. This reflected the Cherenkov light from a two meter path length in the gas into the mouths of collecting cones approximately 140 cm from the center of the mirror, Figure 1. The spun copper cones, which were buffed, laquer dipped and aluminized, were of the Winston-Hinterberg type² with collecting apertures of 25.4 cm diameter. The photomultipliers used were RCA 4522 type with 11.5 cm diameter photocathode.

A single row of three intersecting cones, with axes 21.6 cm apart, was used in the experiment of reference 1, but for only 10% of trajectories were the side cones necessary. The electron detection efficiency over the specified phase space was $99.6 \pm 0.1\%$ measured with Freon 12 as the radiating gas. In many applications the quality of the primary mirror would give a high efficiency with a single collecting cone.

Black acrylic is normally used for mirrors of this type to eliminate difficulties with Cherenkov light emitted in the mirror material. Previous experience of casting such mirrors indicated that a square reflective area of up to 125 cm side could probably be obtained from a single sheet of 3.2 mm nominal thickness. On the other hand severe problems of distortion within about 8 cm of the edges demanded careful treatment of this aspect. Distortions caused by the use of epoxy resins in attaching

the mirror to its backing had also been noted. A further complication was the tendency of some of the plastic samples to develop a fine grain, likened to orange peel, on the surface after heating. It was found this occurred only in samples from certain manufacturing plants.³ A temperature cycle test on a sample is indispensable.

The equipment and experience developed at this laboratory remain available for the makers of any future mirrors. The forming and mounting technique consisted of the following steps.

Slumping Over a Female Mandrel

The mandrel is a machined concave steel dome finished to 1.6 microns with holes for the extraction of air near the perimeter. Steel was chosen because of its relatively low coefficient of thermal expansion. The spherical radius of curvature is 254 cm, and the reflecting area of the mirror to be formed is limited to a maximum diameter of 183 cm. The mandrel is fitted with a clamping ring to constrain the plastic sheet.

The acrylic,³ cleaned with trichlorethane, was evenly heated for 15 minutes in a horizontal position on the mold in a heavily baffled hot air oven at 165°C. When the consistency of the borders of the plastic on all sides felt "floppy" - experience seems to be the only guide to the best consistency - the space between the mandrel and the acrylic was evacuated to 250 mm Hg, and the mirror gradually allowed to cool in a protected environment outside the oven. While the hardening process was commencing it became necessary to unclamp and free the mirror from the steel, to allow the plastic to shrink. In the case of an unsatisfactory shape caused, perhaps, by a dust grain between the plastic and the mold, it was found possible to reform the same piece two or three times before irreversible imperfections appeared. The distortion of the spherical surface could be observed optically as the mirror cooled. The small

scale aberrations noted below appeared only when the temperature dropped to a few tens of degrees above room temperature. It has not so far been possible to suppress this rippling.

Annealing Over a Male Mandrel

This mold is also a steel dome, but its convex surface is covered by a thin layer of flocking⁴ to protect the concave mirror surface. On this the acrylic was trimmed to the required size, covered by a rubber diaphragm, and uniformly constrained to the mold by evacuating the air from under the rubber. The annealing temperature was 80°C held for 12 hours, followed by cooling for 24 hours in the oven.

Mounting

The acrylic reflecting sheet was held rigid by supporting it on a layer of cellular plastic which was held around the edges by an aluminum frame. This structure was prepared before the annealing of the acrylic sheet. An old rejected mirror was held down on the male mandrel and covered with a thin layer of mylar as a parting agent. The aluminum side frame, cut to the shape of the mirror, was placed on this and very slowly filled with the liquid mixture⁵ which set to the cellular backing in a markedly exothermic reaction. To obtain a good match for the acrylic surface it was necessary to remove distortions from the face of the foam backing with sand paper fixed to the face of the dummy mirror. This operation resembles the rough grinding of telescope mirrors.

When the annealing of the reflecting sheet on the mold was complete, the vacuum was resealed by tape around the edges of the mirror, and the foam backing was fixed to it with a matrix of 3 mm diameter spots of epoxy resin⁶ spaced about 5 cm apart. After the resin was cured, the mirror was released from the mandrel.

Aluminizing

Apart from gentle cleaning with alcohol no preparation of the plastic surface was necessary. The foam backing was a burden on the pumping system of the aluminizing tank, but it was found that about four hours' pumping using pumps with 7000 l/sec capacity, and a glow discharge at 8×10^{-2} mm Hg for one hour allowed a good aluminum surface to be transmitted to the mirror at 8×10^{-5} mm Hg. No protective overcoat was used.

Maintenance of Optical Performance

The condition of one of the mirrors used in the experiment for 20 months, mostly in an atmosphere of Freon 12, has been examined. It has changed little over its period of service. The reflectivity has been measured in the range 3400-6000 Å to be $(88.1 \pm 0.5)\%$, which compares with a value of $(89.7 \pm 0.5)\%$ obtained for a small aluminized glass mirror, the angle of reflection being 15° from the normal in both cases.

The focusing properties were examined by photographing the mirror with a pinhole camera at the center of curvature. Between the camera and the mirror was a strongly illuminated wire grid. The relative positions of the grid and its mirror image on the photographic plate (Fig. 3) gave the information that the severest distortions occur within about 10 cm of the edge of the mirror. It is these regions which are responsible for the light outside the principal image spot in Fig. 2. This latter was an exposure in the image plane close to the spherical center of curvature with a small light source 5 cm from the center of the image spot.

Only in patches beyond a radius of about 55 cm from the mirror center does the measured angle of the mirror normal exceed 20 mrad deviation from the nominal. Discrepancies of up to 40 mrad occur beyond 60 cm from the center towards the corners of the mirror, the surface

tending to flatten out before curling in again close to the edge. Superimposed on these larger distortions which typically occur in areas of ~ 10 cm radially and ~ 25 cm azimuthally, there is a small scale irregular rippling affecting areas ~ 3 cm in dimension, producing deflections of the surface of less than 4 mrad.

The technique is flexible enough to allow considerable freedom in the choice of parameters. In particular it is believed that considerably thinner but smaller mirrors can be produced without sacrificing optical quality. A requirement for non-spherical mirrors can also be met if suitable steel molds can be machined.

ACKNOWLEDGMENT

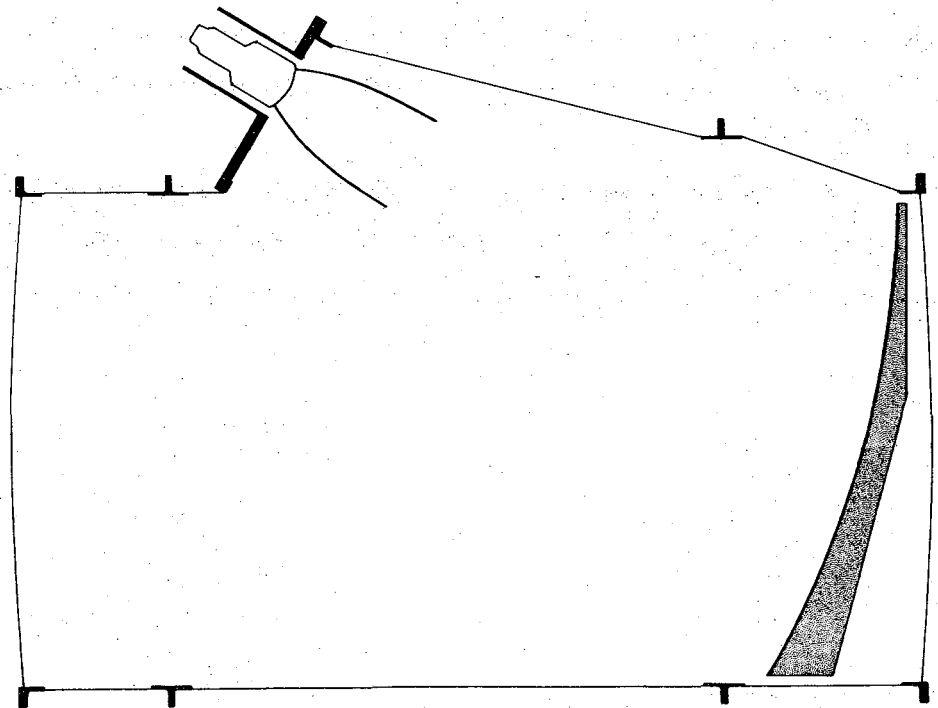
We wish to record our appreciation of the work of Mr. Gordon Steers on the aluminization process and of Mr. John Gustinis for help with the optical measurements.

REFERENCES

- * This work was done under the auspices of the United States Atomic Energy Commission.
1. A. R. Clark, T. Elioff, R. C. Field, H. J. Frisch, R. P. Johnson, L. T. Kerth, W. A. Wenzel, *Phys. Rev. Letters* (to be published) (UCRL-20289).
 2. R. Winston, T. H. Hinterberg, *Rev. Sci. Instr.* **37**, 1094 (1966).
 3. Acrylic plastic sheets, 1/8" thick, black opaque mirror quality material; Rohm and Haas plexiglas No. 2025, from Bristol, Pa. plant. The Knoxville, Tennessee, plant produced the material whose surface distorted on heating.
 4. Rubber suede flock; Ohio Flock-Cote Co., East Cleveland, Ohio.
 5. Polycel 420; Olin Mathieson Chemical Co., Baltimore, Md.
 6. Epon 820 (Shell Chemical Co.) mixed with Versamid 140 (General Mills Inc.).

FIGURE CAPTIONS

1. Elevation section of Cherenkov counter showing relative position of primary reflecting mirror and collecting cone.
2. Image of small light source near spherical center of curvature of mirror.
3. Photograph of 1.27 cm grid mounted one third of the distance between pinhole camera and mirror, and its reflection. The camera was sited close to the spherical center of curvature, 252 cm from the mirror.



50 CM

XBL 714-622

Fig. 1

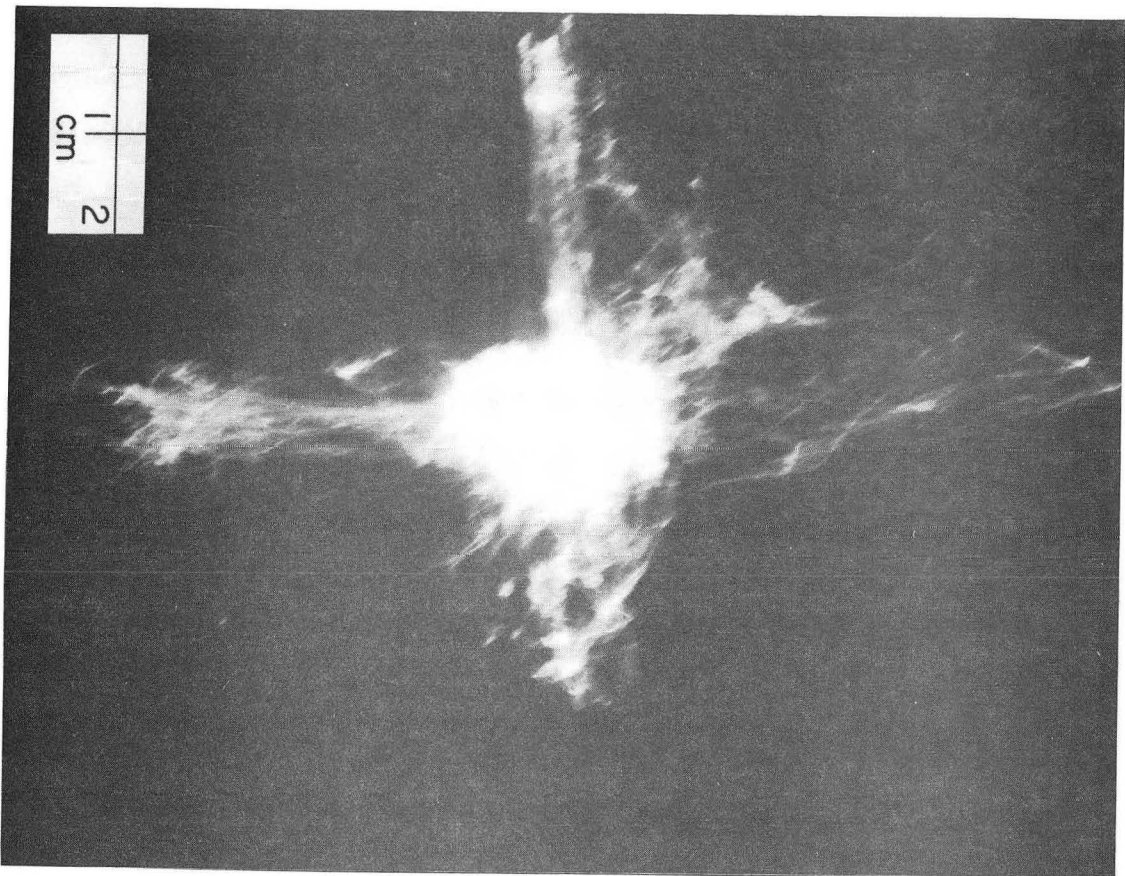


Fig. 2

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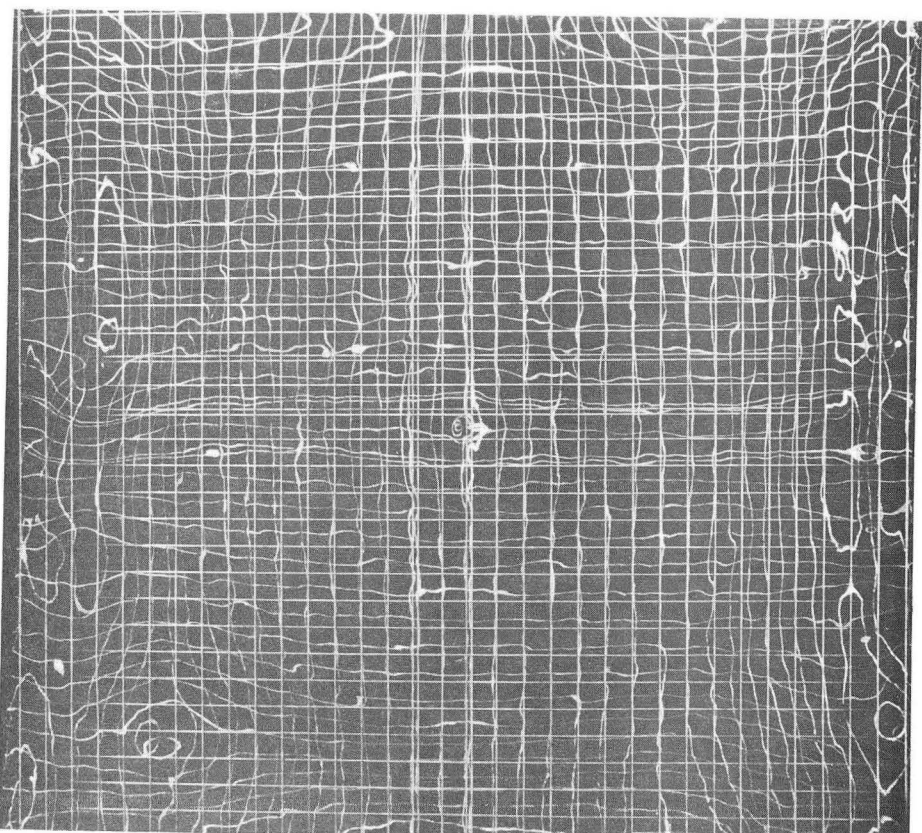


Fig. 2

XBB 713-1177

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