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ENHANCEMENT OF PHOTOMULTIPLIER SENSITIVITY BY TOTAL INTERNAL REFLECTION

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A good semitransparent photocathode should be very thin to permit escape of a large fraction of the electrons set in motion by the incident light. In addition, a good cathode should be sufficiently thick to absorb most of the incident light. A study was begun in March of 1964 to determine whether these apparently contradictory requirements could be harmonized without sacrificing the high electron collection efficiency and other favorable features of conventional end-window photomultiplier tubes.

Various schemes were used to pass the light through the cathode two or more times by means of total internal reflection. One of the simpler arrangements is shown schematically in Fig. 1. A Dumont 6292 photomultiplier tube, 5.08-cm diameter with S-11 cathode, was used for experiments. It was desired to add the quarter-circle glass structure to the tube face to accept light equally at different directions from the normal. To compensate for the tube window thickness, approximately 3 mm was cut from one of the edges of a glass quarter circle of 12-mm thickness and 18-mm radius. The resulting glass chip was placed in optical contact with the tube face so that the chip together with the tube face approximated a quadrant, as indicated in the figure. A 3-mm diameter beam of

[redacted]

light normal to the curved surface of the quadrant struck the photocathode near the center of the end window. The same small incandescent filament bulb was used for white light, blue light (Corning 5-59 filter, $3600 \lesssim \lambda \lesssim 5200$ A) and red light (Corning 2-62 filter, $\lambda \gtrsim 6000$ A). A different dynode supply voltage was used with each color so that the photomultiplier output currents were of the same order of magnitude. The experimental data have been normalized to unity at $\theta = 0^{\circ}$ for each color.

At near normal incidence some of the light passed through the cathode down into the tube, and the small peak at 25° is a result of reflection of some of this light from part of the tube structure. Near $\theta = 41^{\circ}$ total internal reflection occurred at the cathode-vacuum interface and sensitivity increased abruptly. This angle is determined by the index of refraction of the glass and is independent of that of the cathode material. For $\theta \gtrsim 50^{\circ}$ the increased sensitivity was observed to diminish, presumably due to reflection at the glass-cathode interface.

A prediction of the fraction of the incident light internally reflected at the cathode-vacuum interface has been normalized to the blue-light data at $\theta = 0^{\circ}$. The predicted curve, shown as a solid line in Fig. 1, was fitted to the data at $\theta = 45^{\circ}$. The dotted line is also theoretical and is based on the variation with angle of both the reflection coefficient at the glass-cathode interface, and the number of "bounces" before the light reaches the edge of the tube. Uncertainties in this calculation permit more than the observed difference between prediction and data. However, it does give an indication of light loss at the side wall of the photomultiplier as a function of incident light angle. Another mechanism which could diminish sensitivity as θ increases is the dependence of electron collection efficiency on position of electron emission.

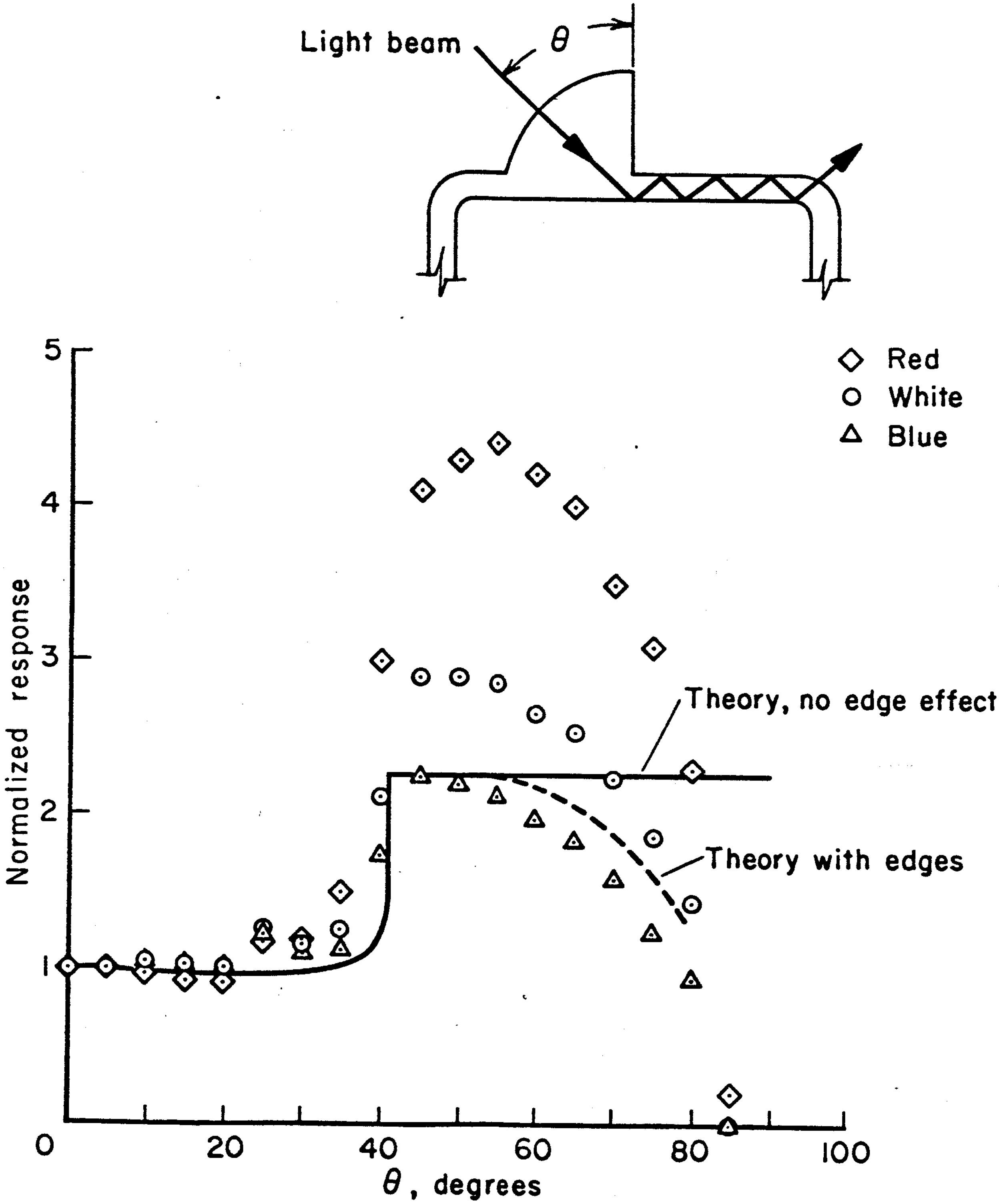
As expected, the relative increase in sensitivity is greater for red light than for blue light. This is due to the fact that the Cesium-Antimony cathode transmits red light more readily[1] and usually wastes a higher proportion of the red than of the blue light. Although substantial increases in sensitivity are thus shown to be possible for existing tube types, even greater increases should be possible by making special tubes with ultra-thin cathodes and using total internal reflection and multiple passes to maximize absorption of the light.

Reference

1. E. Wallis, Ann. Physik 6, 17, 401 (1956).

Figure Title

Fig. 1.- Variation of photomultiplier response with angle of incident light.



Light beam
θ
Red
White
Blue
Theory, no edge effect
Theory with edges
Normalized response
5
4
3
2
1
0
20
40
60
80
100
θ, degrees