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# Tests of 5-Inch Venetian-Blind-Type Photomultiplier Tubes

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# TESTS OF 5-INCH VENETIAN-BLIND-TYPE PHOTOMULTIPLIER TUBES

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ABSTRACT

Test results are described on three inexpensive 5-inch photomultiplier tubes of Venetian-blind construction to be used for collection of Cherenkov light produced by electromagnetic showers in lead glass. Parameters evaluated include photoelectron collection efficiency, pulse-height resolution, amplitude and rate stability, and linearity.

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## I. INTRODUCTION

As part of the design of a $\pi^{\circ}$ spectrometer,[1] we tested three 5-inch photomultiplier tubes: EMI 9618KR, EMI 9530KR, and RCA 4525. In this application the tubes will be optically coupled either to 15- by 15-cm faces of total-absorption lead-glass Cherenkov counters for the detection of photons of energy $E_{\gamma}$ = 70-500 MeV, or to thin (2.5cm) pieces of lead glass positioned in front of the total-absorption counters to be used as active converters of the $\gamma$ rays. A typical $\gamma$-initiated shower is expected[2] to result in 1.4 photoelectrons per MeV in the photocathode of the total-absorption detector. A typical event in the 2.5cm lead-glass converters will result in approximately 10 photoelectrons. These calculations further indicate that the contribution to the energy resolution of each arm of the spectrometer from photoelectron statistics is about 20% FWHM at $E_{\gamma}$ = 100 MeV. In view of the small numbers of photoelectrons, high quantum efficiency in the appropriate wavelength region is an important characteristic for our application. On the other hand, since each shower event has a sizeable transverse spread, and since the counting rates will be restricted by other components of the spectrometer (MWPC's), photocathode uniformity and time resolution of the photomultiplier (PM) tubes are less important.

## II. TUBE SELECTION CRITERIA

The initial selection of phototubes for testing was based on calculations for the expected relative number of photoelectrons from Cherenkov light produced by electromagnetic showers in various types of Pb glass. Using a model where Cherenkov light enters one end of a 14-radiation-length ($x_0$) glass block and is collected at the opposite end by a phototube of radiant sensitivity $S(\lambda)$, a maximum value of the integral

$$N = \int_{300\text{nm}}^{700\text{nm}} \left(\frac{1}{\lambda^3}\right) T(\lambda)\ S(\lambda) d\lambda$$

was sought. The Cherenkov light intensity between wavelengths $\lambda$ and $\lambda+d\lambda$ is $dI \propto d\lambda/\lambda^3$.[3] Thus, high transmittance $T(\lambda)$ in the short wavelength region is a desired charateristic of the glass, and various glass-phototube combinations were considered. Transmittance through $14X_0$ for glass types used in recent nuclear and particle physics applications are shown in Fig. 1.[4] F2 glass was used in the study of Sober et al.[5] and SF5 glass in those of Holder et al.,[6] Heusch et al.,[7] and Dibon et al.[8] LF5 has been selected for use in the $\pi^0$ spectrometer due to its greater transmittance. Fig. 1 indicates that a phototube with high spectral sensitivity in the region 340-700nm is desirable.

Values of N were computed for various types of spectral functions available in 5-inch phototubes:[9-11] S-11(RCA 8055, EMI9618B), "Super" S-11 (EMI9618KB), bialkali type-D (Amperex XP 2041), bialkali type-118 (RCA 4522), and bialkali type-115 (RCA 4525). Typical curves of quantum efficiency ($QE = 1249\ S(\lambda)/\lambda$) are shown in Fig. 2. The low wavelength cut-off in these curves is determined by the cathode window material. Since typical pyrex windows reach maximum transmission near 340mm, which is the expected lowest wavelength to be detected (Fig. 1), tubes with quartz windows are not required. Comparing the "Super" S-11 with bialkali cathodes, it is seen that the former has a broader response, with higher QE for $\lambda > 450$nm, but has a lower maximum QE (23% vs 25%). The calculations of N showed the broader response to be more important, giving an increase of 10-15% in the relative number of photoelectrons. Of course, it is well known that fluctuations in S(λ) for individual tubes are easily as large as 10-15%. If the advantage seen in the calculations is to be maintained, it is important that the tubes be selected for high cathode sensitivity. In terms of the catalogue values,[9,10] this would mean ≥ 85μA/lm for the EMI-9618KR and ≥ 67μA/lm for the RCA 4525.

Based on these calculations, as well as some phototube tests performed by an LBL group with electromagnetic showers in Pb glass initiated by 100-500 MeV electrons,[12] three tube types were tested: EMI9618KR, EMI9530KR and RCA 4525. Manufacturer's specifications are listed in Table I. The principal difference between the two EMI tubes is the external focusing grid on the 9618KR model. The RCA 4525 also has an external focusing grid.

## III. TESTS AND RESULTS

All tests were performed at the manufacturer's recommended average operating voltage of -1500V. The cathode-to-first-dynode voltage was 450V for the EMI tubes and 300V for the RCA tube. Tests were made for two tubes of each type having a cathode sensitivity for tungsten light of 70 and 73 μA/lm (RCA 4525) and 95 and 105 μA/lm (EMI9618KR).

Pulse height as a function of the photocathode-to-focusing-grid voltage was measured for the EMI9618KR and RCA 4525 tubes. Variations of up to a factor of two were observed for different grid voltages. All of the following tests were performed with grid voltages set for maximum photoelectron collection efficiency, and the results are summarized in Table II. While this may not be the best setting for timing or photocathode uniformity, collection efficiency is more important for our application. Hence, time resolution and uniformity of photocathode responses were sacrificed for better photoelectron statistics, and the tests were performed with the maximum photoelectron efficiency condition imposed.

### A. Photoelectron Collection Efficiency, Gain, and Pulse-Height Resolution

A $^{207}$Bi source (electron line of 1044 keV) was used to scintillate a piece of 2cm-thick by 7.5cm-diam plastic scintillator, optically coupled to the tube face and wrapped with aluminum foil. Relative pulse heights and pulse-height resolutions (PHR) were recorded. The relative pulse heights for the EMI9618KR, EMI9530KR, and RCA 4525 were 1.0, 0.5, and 0.75, respectively. Pulse-height resolutions were 10%, 15%, and 17%, respectively. These results indicate the advantage obtained by the extra focusing grid in the EMI9618KR compared to the otherwise similar EMI9530KR. Tests performed by a Berkeley group to determine PHR of several tubes yielded similar results.[12]

In a second test, each photocathode was illuminated by a green LED,[13] triggered by a variable amplitude pulser whose output width was small compared to the phototube time constants. Measured pulse-height resolution vs pulse height is shown on a typical log-log plot in Fig. 3. The results indicate that the observed PHR is dominated by photoelectron statistics since the resolution varies as (pulse amplitude)$^{-\frac{1}{2}}$. Hence, we conclude that our tests were sensitive to the photoelectron collection efficiency of the tubes, and probably were not very sensitive to the inherent PHR of the tubes.

B. Stability

Two types of stability were tested. Amplitude stability is important for a long-term operation and is measured by observing pulse-height variations with an identical input signal over a long period. Rate stability is a measure of the output pulse-height variations as a function of input rate. It turns out, however, that the latter characteristic is limited by the voltage divider design.

1. Amplitude Stability: After exposing the photocathode to light, the tubes were kept in the dark box under high voltage for about 48 hr before the tests were performed. Then the pulse height was recorded every 1-2 hr for 48 hr. The input signal was generated by either a $^{207}$Bi source or a green LED. The LED was pulsed at a rate of 2kHz. The results were similar for both the $^{207}$Bi source and the LED, with all tubes proving stable to ±1% within the 48 hr period. When similar tests were carried out with an initial waiting period of 2 hr the stability was only ±5%.

2. Rate Stability: To simulate beam conditions at LAMPF, the light pulser which triggered the LED was gated on for a duration of 500 μs every 8 ms, and the pulse rate was varied. To further simulate realistic conditions, the LED light output was adjusted such that it resulted in approximately 1000 photoelectrons (determined from the PHR), and the phototube output was about -1V into 50 Ω. Pulse height as a function of rate was recorded until about a 1% decrease in pulse height was observed. Both EMI tubes were stable up to instantaneous rates of 0.65 MHz. (The RCA tube was

not tested.) These tests were repeated with a higher current voltage divider, and 1% stability was recorded up to an instantaneous rate of 1.5 MHz. Some details of the voltage dividers are given in Sec. III.F.

### C. Linearity

The linearity tests used a green LED pulsed at a rate of 2 kHz to illuminate the photocathodes. Kodak wratten gelatin neutral density filters[14] were used to transmit a known percentage of the LED light. These tests determined the linear range of the tube's performance and the linearity within this range. At the above rate, the EMI9618KR was found to be linear to ±1% for output pulses of ~-850 mV. A typical linearity curve is presented in Fig. 4.

### D. Timing

Since the maximum rate at which the spectrometer will operate is determined by other components, the time constants of the phototube are not critical. However, Cherenkov counters often encounter high-rate background pulses, each giving a low signal. If the average time between these pulses is short compared to the dynode chain integration time, a pileup of these pulses can integrate to a signal having the same order of magnitude as a real event. Hence, time characteristics cannot be completely ignored.

Timing tests were made using LED's whose time constants are short compared to those of the phototube. These tests included measurements of risetime, FWHM of pulses, and delay required between two consecutive pulses to avoid distortion of the single-pulse shape. All tubes were found to be similar in their timing characteristics. Typical results for risetime, FWHM and delay required between two consecutive pulses were 18 ns, 42 ns, and 100 ns, respectively. The results are presented in Table II.

### E. Photocathode Uniformity

Each shower within the lead-glass blocks is expected to have a significant transverse spread.[2] In addition, the Cherenkov light bounces back and forth in the block an average of 10 times before hitting the photocathode. As a result, the Cherenkov light from each event will be averaged over a large area of the photocathode.

Thus we do not expect photocathode uniformity to be a significant factor.

Photocathode uniformity tests were made using an LED embedded in a small (2 x 2cm) piece of plexiglass. The plexiglass was wrapped in aluminum foil and was optically coupled to different places on the phototube face. Pulse height was recorded as a function of the photocathode coordinates illuminated. All photocathodes were uniform to ±10% under the standard conditions. As already mentioned, while not necessarily the best settings for photocathode uniformity, these are overall realistic conditions for operation. Results for a typical test are given in Fig. 5.

F. Voltage Divider Considerations

Two voltage divider designs were considered for the EMI9618KR and 9530KR tubes. The difference between the two designs was that at an operating voltage of -1500V one drew a current of approximately 0.65 mA, and the second drew approximately 2.4 mA. Under extreme conditions (long operation in a light-tight box), the high-current base overheated and became temperature-unstable. However, because it drew more current, the tube was stable at higher rates (see Sec. III.B.2.). For our application the rate stability obtained with the low-current base was sufficient, and it was selected. The circuit diagram for the EMI9618KR tube is shown in Fig. 6.

## IV. TESTS WITH POSITRON BEAMS

The pulse-height resolution achieved with a 100-MeV $e^+$ beam incident on a $0.6x_o$ F2 glass converter ($C_2$) and $10x_o$ F2 total absorption block ($C_3$) is shown in Fig. 7. Light from the converter was collected on one edge (2cm x 15cm) via a 3-strip light guide coupled to an EMI9618KR phototube with a rated cathode sensitivity of 95 μA/lm. Light from $C_3$ was collected with a second such tube, rated at 105 μA/lm, coupled directly with Dow Corning Q2-3059 optical coupling compound to the back face (15cm x 15cm) of the block. The positrons entered $C_2$ in a 5cmx 5cm region centered on the $C_2$ - $C_3$ axis. The light of $C_2$ and $C_3$ were added in a linear fan-in and gave a pulse-height resolution of 30% FWHM, shown in Fig. 7a. Since the $e^+$ beam resolution was previously measured to be 14%, the Cherenkov light resolution contribution is 26.3%. When $C_2$ was physically removed, the resolution of $C_3$ was 27%, giving 23% for the light resolution. The best value achieved by Holder *et al.*[6] for 1 GeV $e^-$ in $15x_o$ of SF5 glass was 8.6%(FWHM). Scaling this by $E^{-\frac{1}{2}}$ gives 27% at 100 MeV. To our knowledge, the value of 23% is the best ever achieved for total absorption Cherenkov counters.

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TABLE I

MANUFACTURER'S SPECIFICATIONS GIVEN FOR 5-IN. PHOTOTUBES

| Type and Manufacturer | EMI 9618KR | EMI 9530KR | RCA 4525 |
|---|---|---|---|
| Photocathode diameter (in.) | 4.37 | 4.37 | 4.38 |
| Type of photocathode | Super S-11 | Super S-11 | Bialkali |
| Quantum efficiency at maximum response | 0.22 | 0.22 | 0.25 |
| Number of stages | 11 | 11 | 10 |
| Dynode shape | Venetian blind | Venetian blind | Venetian blind |
| Dynode surface | CsSb | CsSb | CuBe |
| Typical rated gain | $1.8 \times 10^6$ | $2 \times 10^6$ | $4 \times 10^5$ |
| Anode pulse risetime (ns) | 15 | 15 | 18 |
| Anode pulse FWHM (ns) | 30 | 40 | -- |
| Transit time (ns) | 60 | 120 | 110 |
| Focus option | yes | no | yes |

TABLE II

SUMMARY OF RESULTS OBTAINED BY PRESENT WORK

| Type and Manufacturer | EMI 9618KR | EMI 9530KR | RCA 4525 |
|---|---|---|---|
| Relative photoelectron collection efficiency + gain (hv = -1500 V, $^{207}$Bi source) | 1 | 0.5 | 0.75 |
| PHR ($^{207}$Bi source) (FWHM) | 10% | 15% | 17% |
| Amplitude stability (over 48 h) | ±1% | ±1% | ±1% |
| Rate stability under beam condition[a] | 650 kHz[b] | 650 kHz[b] | not tested |
| | 1.5 MHz[c] | 1.5 MHz[c] | not tested |
| Linearity | ±1% | ±1% | not tested |
| Timing (ns) | | | |
| risetime | 18 | 15 | 18 |
| FWHM | 44 | 40 | 42 |
| delay required between consecutive pulses | 110 | 90 | 100 |
| Photocathode uniformity | ±10% | ±10% | ±10% |

[a]Instantaneous rate--average rate is 6% of tabulated values.

[b]Low-current base.

[c]High-current base.

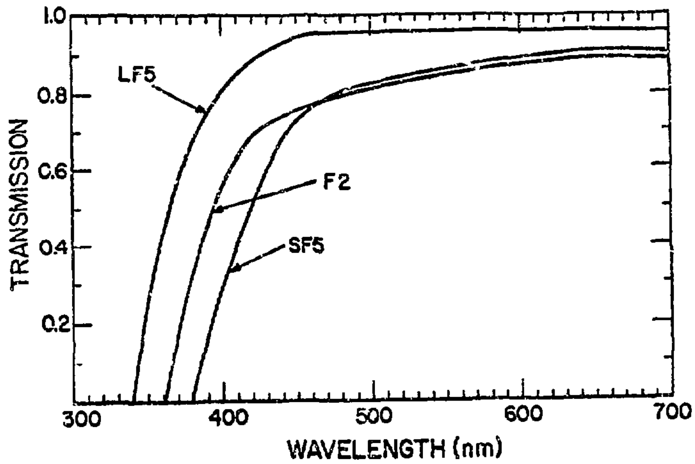


Fig. 1. Transmission vs wavelength for three types of Pb glass commonly used for total absorption Cherenkov counters.

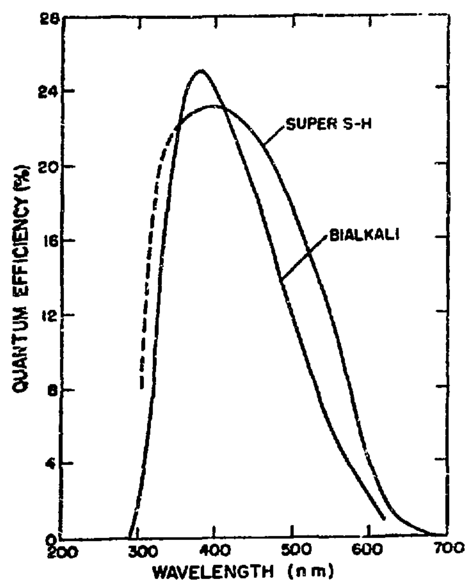


Fig. 2. Spectral response of the photocathodes which were tested.

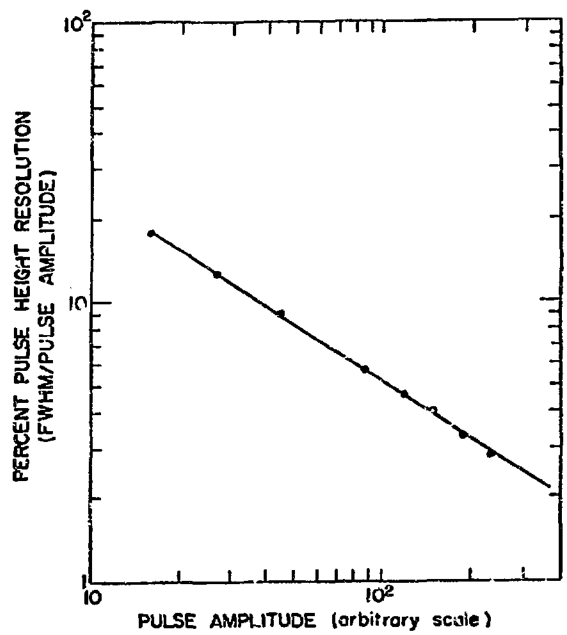


Fig. 3. Pulse-height resolution vs. pulse-height (for EMI9618KR). The straight line is a plot of $kE^{-\frac{1}{2}}$.

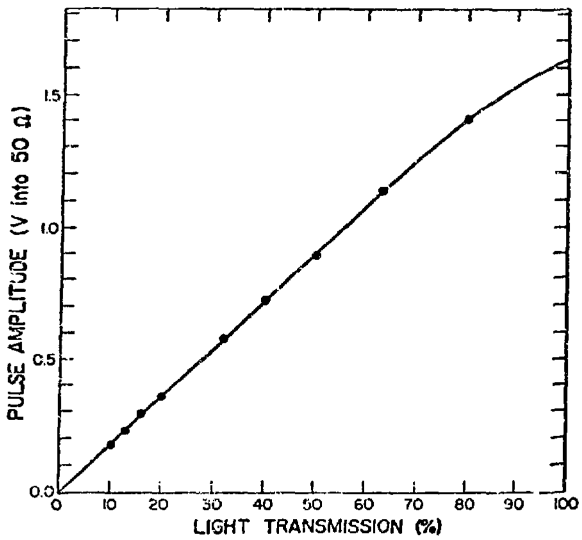


Fig. 4. Linerarity curve obtained for EMI9618KR.

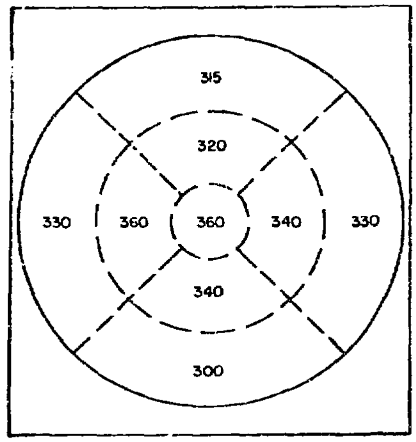


Fig. 5. Pulse-height (mV) obtained by illuminating different sub-areas of the photocathode (EMI9618KR). The solid line is the outline of the photocathode, and the dashed lines demarcate the areas measured.

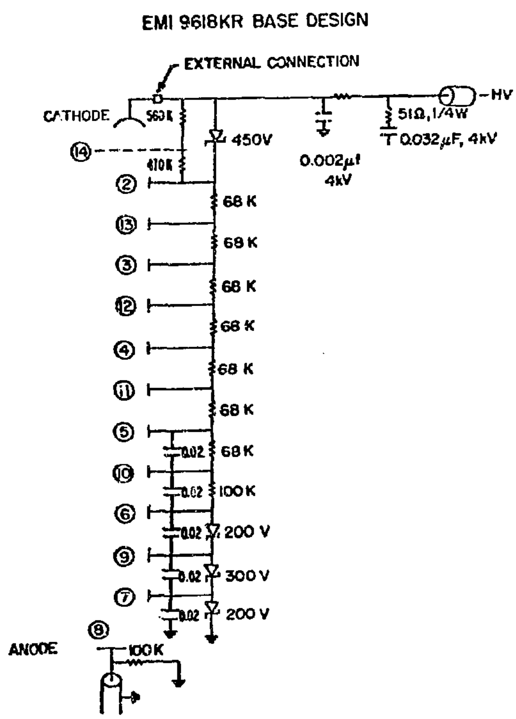


Fig. 6. The voltage divider chain used for the EMI9618KR phototube (Ref. 12).

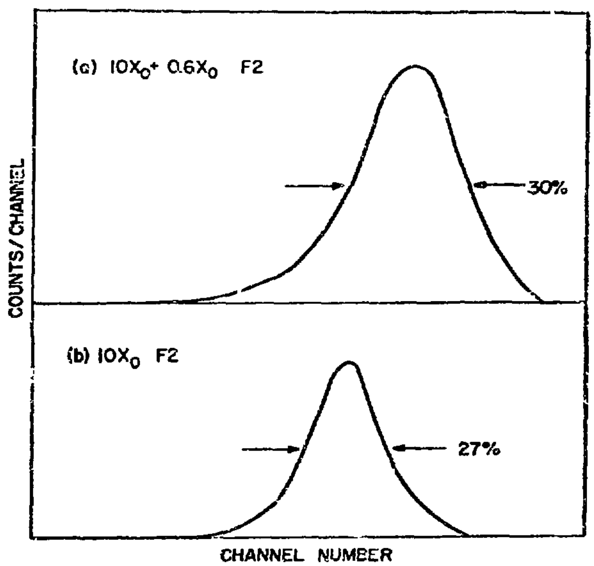


Fig. 7. Pulse-height distribution for Cherenkov light produced by 100 MeV $e^+$ beam incident on $10X_0$ of F2 glass (b) and added light from $0.6X_0$ (converter, F2) + $10X_0$(a).