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ELECTRONIC DEVICES FOR NUCLEAR PHYSICS

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PART I

Multi-alkali Photocathodes

A. X-Ray Studies

In the last report it was mentioned that work has been started to study the composition of photocathodes by the x-ray diffraction method. The technique employed consists of scraping the photoelectric material off the glass and transferring it into capillary suitable for x-ray work. The main purpose of this investigation is to look for a relationship between the high photoelectric sensitivity of "multi-alkali" photocathodes and their crystal structure.

Before examining "multi-alkali" photocathodes by this method, a preliminary experiment was made with the simpler (single-alkali) SbCs$_3$ cathode. The structure of the SbCs$_3$ compound in bulk has been established previously (see Quarterly Report No. 16), but there exists the possibility that a thin evaporated layer of the compound is not crystalline at all or does not have the same crystal structure as the bulk material. The experiment with the SbCs$_3$ photocathode, using the scraping technique, produced the required evidence that the photocathode has the same structure as the SbCs$_3$ compound in bulk.

On the basis of this result, several photocathodes of the Sb-K-Na type were examined by the same method; it was expected that either the known SbK$_3$ and SbNa$_3$ patterns would be found side-by-side or that a specific new compound, such as SbKNa$_2$, would manifest itself by a previously unknown pattern.
So far, the interpretation of the pattern obtained with these cathodes has been ambiguous owing to lines which are probably due to impurities. In one case, there was definite evidence for the presence of SbK₃, but strangely enough no indication of the Na-compound. These experiments will continue.

B. New Cathodes with Low Red Response

Originally the main purpose of the work on photo-cathodes for use in scintillation counters was to find a cathode which combines the high quantum efficiency of the SbCs₃ cathode in the 4000 Å range with a lower thermionic emission (and red response) than that of the SbCs₃ cathode. The development of the "multi-alkali" cathodes led unexpectedly to cathodes of higher red response but the systematic investigation of different combinations of alkali metals indicated that at least two types of cathode may be useful for the original application.

These cathodes are represented by the general formulae Sb-K-Li and Sb-Rb-K. The color response of these cathodes is shown in Fig. 1 in comparison with a standard SbCs₃ cathode. It is apparent that both cathodes have a cut-off at shorter wavelengths than the SbCs₃ cathode. Comparing the Sb-Rb-K cathode with the Sb-K-Li cathode, the first has the advantage of higher quantum efficiency in the relevant part of the spectrum, while the second has a shorter cut-off wavelength. In practice the activation process of the Sb-Rb-K cathode proved to be simpler and it was therefore decided to concentrate efforts initially on developing a multiplier tube with such a cathode.
As reported previously, unexpected difficulties were encountered in obtaining dynodes with high secondary emission factors in multipliers containing "multi-alkali" photocathodes. The best tube with an Sb-Rb-K cathode and 10 silver-magnesium dynodes had a total multiplication of approximately $10^5$ at an overall voltage of 2500 volts. This is still well below the factor obtained in multipliers with SbCs$_3$ cathodes, but the tube can be used to investigate whether the absence of Cs leads to the improvements in performance which were expected, i.e., higher work function which should reduce thermionic emission at room temperature, and greater stability at high voltages due to the lower vapor pressure of Rb and K in comparison with Cs. These experiments are now in progress.

In view of the consistently low dynode performance in "multi-alkali" tubes, it has been decided to discontinue temporarily the construction of complete multiplier tubes and to study instead the effect of Rb and K on secondary emission in special experimental tubes. The following section will deal with this work.

C. Secondary Emission Experiments

Experiments have been started with a tube which is shown diagrammatically in Fig. 2. Instead of the conventional thermionic cathode, a photocathode P was used as a source of primary electrons in order to avoid the danger of surface contamination by evaporation from the hot oxide cathode. The secondary emission target T consists of a disk which can be
rotated by a magnet so that each surface can be made to face either the cathode or the evaporator E. (The rotation also permits measurements of secondary emission as a function of angle of incidence.) Secondary electrons emitted from T are collected by the ring C which is painted on the inner glass wall.

Before trying any new substances, a control experiment was made with a conventional SbCs$_3$ target. A secondary emission factor of the order of 10 was obtained which indicated that the design of the tube is satisfactory for the intended experiments, i.e., that there is no need for additional focusing electrodes. In a second experiment, the disk was made of the silver-magnesium material used for dynodes in many commercial multipliers. In this tube Sb was evaporated from E onto one side of the target disk and the disk was then exposed to Cs. In this way it was possible to compare in one single tube the secondary emission factors of SbCs$_3$ and Ag-Mg-Cs surfaces. In confirmation of earlier work, it was found that higher factors are obtained with SbCs$_3$ than even with cesium-activated Ag-Mg.

A third tube is now being prepared which is identical with the second one, except for the fact that cathode and target will be activated with K and/or Rb instead of Cs. It should then be possible to establish in which stage of the activation process the alkali metals have an unfavorable effect on the secondary emission factor and whether the process with one of the surfaces can be modified to increase secondary emission without affecting the photocathode sensitivity.
It is also planned to use this type of tube to investigate the performance and activation of copper-beryllium alloy as a secondary emitter. From published results it appears that this material has a lower secondary emission factor than silver-magnesium, but that it also has less tendency to fluoresce under electron bombardment and may therefore reduce the after-pulse effects in multiplier tubes.
PART II

Photomultiplier Development

A. High Current Photomultiplier (Type H-6687)

Development of this type was completed during the preceding report period, but two more tubes were constructed, No. 4 and No. 5. Measurement of peak saturated output current vs. overall voltage is in progress. The output is essentially the same as for the previous tubes, that is, in the vicinity of 1 amp. peak for 4000 to 4500 volts.

The ionization gauges attached to these tubes supply useful information in providing a continuous monitor of gas pressure in the tube. When excessive voltages are experimentally applied to the multiplier, the ionization gauge generally indicates impending breakdown before a spark-over occurs. The gas evolved in this way effectively demonstrates the pumping capabilities of the ionization gauge, which will repeatedly pump from $10^{-5}$ mm Hg back down to $2 \times 10^{-7}$ mm.

B. Central Potential Photomultiplier

Design work has been started on a photomultiplier intended primarily as a high speed multiplier in which the transit time dispersion, and hence the minimum output pulse width, is expected to be substantially less than in existing high-gain tubes. The presently obtainable minimum for a 16-stage type H4646 structure operated at normal voltages of about 200 volts per stage, is about $3 \times 10^{-9}$ sec. pulse width.
In the new tube, the transit time, and therefore the dispersion in transit time, will be reduced by employing the equivalent of a single high potential accelerating electrode placed along the center-line of the multiplier, between the odd and even numbered rows of dynodes. When this electrode is slotted to permit passage of electrons between dynodes, the central electrode is broken into a number of smaller accelerator strips which may then be more favorably oriented to control focusing between dynodes. See Fig. 3. While this arrangement may not resemble a single central strip in a geometrically obvious way, the potential distribution along the center-line of the structure reflects the basic notion of a single high potential electrode. A potential of 3000 v to 6000 v is planned for the accelerating electrodes. This potential may be available from an electrode in the photocathode-to-first-dynode input lens system, reported under "High Speed Multiplier Tubes."

The electron optics of the region of current flow between dynodes will also exhibit the characteristics of a cylindrical lens having a high potential saddle point in the central region between dynodes, such that the emission from each dynode converges most rapidly at first, forming a moderately small beam which then passes the saddle point at high velocity. The beam decelerates as it approaches the bombarded dynode, without much change of beam width.

A major feature of this tube will be high current output, obtained by using the design principle of the H6687 "High Current Photomultiplier," in which space-charge saturated
peak current is increased by the use of accelerating electrodes to form high field gradients between dynodes. The new tube, however, will differ from the H6687 in that every dynode will now be exposed to high gradient, and the accelerating potential will be about an order of magnitude greater. At least 1 amp. peak output is expected.

The objective of increased current output is seen to be very closely related to that of reduced transit time dispersion, as both may be accomplished by increasing the gradient between dynodes. These aims are also closely related in terms of tube use, in that higher output current may avoid the necessity for amplification of millimicrosecond pulses, thereby making possible some scintillation counter applications involving maximum time resolution of nuclear events.

C. High Speed Multiplier Tubes

Tube No. H6791-1 was delivered and tested. The outline of the tube was shown in the last Quarterly Report as Fig. 8. It is repeated in this report as Fig. 4 for convenience in following the description. In testing this first tube, the following facts emerged. The beam current in the primary electron gun, which should be of the order of 30 µa, is only of the order of 1 µa. Experimentation showed that over 300 µa could be drawn by G1, if G1 was a few volts positive with respect to the cathode. This latter figure is of the proper order of magnitude. The conclusion was then that the side walls of the cathode were well activated but that the small face, which is responsible for almost all of the beam current was for some reason inactive.
This behavior in cathodes has been observed before, and it was not considered profitable to pursue an investigation as to the cause and cure of this behavior, mostly because the cathode was sufficiently active for this particular experiment.

Tracing the beam further through this tube, the beam strikes the first dynode of the multiplier under test. As the primary beam is moved across the aperture in front of dynode 1, it is desirable that those primary electrons that strike the first dynode should do so in essentially the same place. If the primaries strike the first dynode at many places, there is the possibility that some extra transit time dispersion is introduced. In tube H6791-1, this question of additional transit time dispersion is aggravated by the fact that the path of the primary electrons, shown by the dashed line in Fig. 4, is very close to the curved edge of d, much closer than is shown in the drawing. The effect of this is that the primary beam can be carefully aimed so that it goes through the aperture, but grazes the first dynode and is collected by the back of the third dynode. This defect introduces inconveniences but does not make the device inoperative.

Going further, the beam of primaries enters the secondary emission multiplier, which in this case uses the L-16 dynodes. (This type of dynode is used, for example, in tubes C7189 and C7165, both of which are made by RCA at Lancaster.) These dynodes can be made to have secondary emission ratios of the order of 4 at 125 volts/stage. The particular dynodes in this tube, however, have gains close to unity even at 150 volts/stage. In fact
the total multiplication factor is only 6.

The output current is extracted in the form of a circular beam which is directed at the phosphor on the face of the tube. This particular tube produces a round spot on the phosphor which is about 1/2" in diameter. The size of this spot is large but the fraction of electrons from d_6 that appear in the spot is also large ~50%. The fact that such a high percentage of the output electrons can be formed into a beam is expected to be useful in future photomultiplier work. As far as this experiment is concerned, however, it is felt that it is not strictly necessary to collect such a large fraction of the output. The reason is that the secondary electrons will have been sufficiently mixed by the successive multiplication processes so that any fraction of the output will be as representative of transit time dispersion as any other fraction. This idea will be tested experimentally.

It is felt that it is desirable also to have a tube in which the output can be focused into a small spot. The advantages of this would be that more resolution would be available for a given level of rf and that a greater signal is available at the probe wire.

Because of the aforementioned defects in tube H6791-1 and of the desirability of having a tube with a small focused output spot, a second tube is being built. This tube is identical in design with the first one except that it has an 1/8" limiting aperture in l_3. This tube will be ready for testing in the early part of May.
In an additional experiment with tube H6791-1, audio voltage was applied to D_{1,2}. The deflection sensitivity was of the order of 50 volts/inch at \( V_p = 1300 \) volts (\( V_p \) being the primary voltage). This value is of the correct magnitude.

**Photoelectron collection system**

While this device to test high speed multipliers is being built, work is being done to develop suitable multipliers. The electron optics of the inter-dynode region can be tested experimentally with an H6791 tube; the optics from the photocathode to first dynode, however, has to be tested separately. It would be possible to test these optics for speed experimentally, but it is felt that an equally satisfactory result can be obtained by calculating the paths and transit times.

The simplest way of decreasing the transit time dispersion would be to decrease the average transit time in the cathode-to-first-dynode region by raising the first dynode voltage until the transit time is small enough. The disadvantages of this method are that a current will be drawn by this high voltage (necessitating a rugged supply) and that the voltage will be too high to produce optimum secondary emission ratio at the first dynode. A better solution would be to devise an inverse focus type of lens. It is a characteristic of this type of focus that the lens element between the cathode and first dynode is at a higher potential than the first dynode. Thus the photoelectrons are accelerated by a high potential (perhaps 5000 volts) for half of their journey to the first dynode and are decelerated for the second half. The total transit time, however, is the same as
it would be if the first dynode itself were at that high potential.

Several tubes were in existence which looked as if they might be capable of inverse focus operation. Schematic outlines of two of these tubes are shown in Figs. 5a and b. Each of these tubes has a photocathode, an accelerating element and a willemite target. Both tubes could be operated with inverse focus operation. If the phosphor in tube #1 is at 200 volts with respect to the cathode, central illumination produces the smallest spot of light on the phosphor at $a_1 = 18$ volts and at $a_1 = 5000$ volts. In tube #2, when $a_2 = 500$ volts, the smallest spot occurs at $a_1 = 66$ volts and at $a_1 = 5000$ volts. It should be noted that the "smallest spot" does not correspond to a focus, but rather to a crossover or exit pupil in the electron beam. The results with tube #2 were so encouraging that an equipotential map of the tube in a direct focus condition and in the inverse focus condition were prepared. These maps were conveniently obtained from the resistance network and are shown in Fig. 6. Several electron paths have been plotted but they have not yet been analyzed.

D. Nine-inch Cathode Multiplier (H6699)

A report from Los Alamos on the first tube of this type indicated, as had been expected, that the performance was poor because of the extremely low photocathode sensitivity. Therefore, a modified tube was constructed (see Fig. 7) in which the exposure of evaporated antimony to air, the cause of low sensitivity in the previous tube, was avoided. This tube has a good photocathode (50 $\mu$A/l), but the multiplier failed on test, owing to an internal short circuit. Another tube is in preparation.

5/25/55
Sensitivity in arbitrary amounts (corrected for absolute energy)

I Sb-Cs
II Sb-Rb-K
III Sb-Li-K

Fig. 1 Color Response of Photocathodes
Fig. 2 Experimental Tube for Secondary Emission Measurements
Fig. 5a Equipotentials in Inverse Focus Case
Fig. 5b  Equipotentials in Direct Focus Case
Fig. 6  Outline of Tubes Capable of Inverse Focus Operation
Fig. 7  9-Inch Cathode Photomultiplier