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THE STUDY OF NOISE PULSES AND A LIQUID SCINTILLATOR

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ABSTRACT. Analysis of noise pulses of RCA photomultiplier 5819 has been made with about 350 volts between photocathode and first dynode. The differential distribution of noise pulses has been studied at different voltages and temperatures. Two distinct distributions are apparent in these curves. One has been interpreted as due to thermal noise and the other due to after-pulses caused by ion feedback. Response of stilbene in xylene liquid scintillator has been studied for Co^{60} gamma-rays with high collection efficiency and at low temperature. From the differential distribution of these pulses, the Compton edge due to Co^{60} gamma-rays is clearly indicated.

I. INTRODUCTION

It is well known that the collection efficiency between the cathode and the first dynode increases at high voltages between the two (Engstrom *et al.*, 1952). But at these high voltages the noise in the photomultiplier also goes up considerably. The pulse height distribution of these noise pulses is of considerable importance especially when the genuine pulses are of small size, as for example, in liquid scintillators.

The origin of these noise pulses has been the subject of analysis by many workers (Engstrom, 1947; Rodda, 1949; Morton and Mitchell, 1949; Curran, 1953 and others). From these investigations it appears that the main causes of the noise may be summarised as (i) amplified thermionic emission from the photocathode, (ii) positive ion feedback, (iii) the generation of photons inside the photomultiplier and (iv) ohmic leakage. In the early work of Engstrom, Rodda and others only the integrated effect of the noise pulses *i.e.* the noise current was studied. Morton and Mitchell made some studies of differential distribution of the noise pulses. Later Mueller (1952), Harrison (1952) Davison (1952), Lanter and Corwin (1952) and Breitenberger (1955) studied the after-pulses which are mainly produced by the feedback of ions created by the electrons of the main pulse.

A systematic study of pulse height distribution of the noise pulses was therefore essential to analyse the pulses from the liquid scintillator. This also helps one to understand the origin of the noise pulses

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2. EXPERIMENTAL

For the study of noise pulses, RCA photomultiplier 5819 was mounted in a light-tight chamber. The assembly which contained the 5819 tube with Mu-magnetic shield, associated voltage dividing resistance network, and cathode follower (scintillation head), was enclosed in a thermostatically controlled cabinet. The temperature in the cabinet could be varied from 30°F to 75°F.

The voltage between the cathode and the first dynode was about seven times the voltage between the other dynodes in order to get very high collection efficiency. The pulses from the cathode follower were fed to the Atomic's linear amplifier model 204C and the pulse height analysis was made by Atomic's pulse height analyser model 510, after which the pulses were scaled and recorded.

Stilbene in xylene (3 gms/litre) introduced by Kallmann and Frust (1950) is our liquid scintillator, whose response was studied for Co^{60} gamma-rays. A thin-walled glass cell (diameter 4.8 cm and length 11 cm) was filled with the scintillator liquid solution and was covered from sides with aluminium to serve as reflector. The cell was fixed to the photomultiplier with silicone grease, with a perspex piece in between to provide a flat surface and to act as a light pipe.

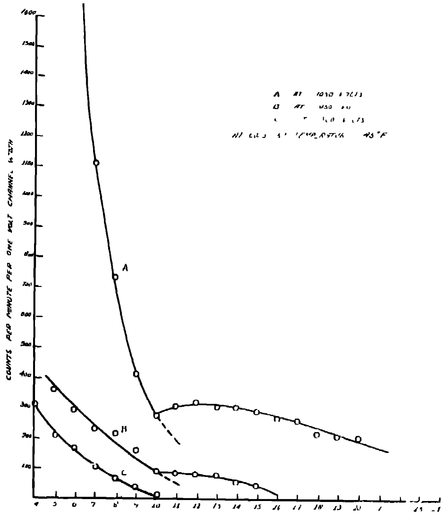

Fig. 1 Differential pulse height spectrum of noise pulses at various total voltages applied to the photomultiplier when the temperature of the photomultiplier was kept constant at 45° F.

For attaining a particular temperature the system was left in the cabinet for about $1\frac{1}{2}$ hours to attain the equilibrium, which was checked by observing the counting rate at a particular pulse height which remained constant with time.

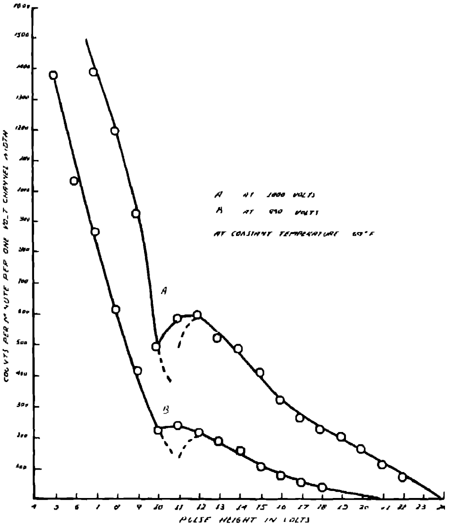

Fig. 2. Differential pulse height spectrum of noise pulses at various total voltages applied to the photomultiplier when the temperature of the photomultiplier was kept constant at 69°F.

3. OBSERVATION AND RESULTS

Figures 1 and 2 show the curves of differential distribution of noise pulses at different voltages, keeping the temperature constant, while figures 3 and 4 show the curves at different temperatures keeping the voltage constant Voltages were varied from 900 to 1050 volts while the temperatures were kept at three different settings, 37°F, 56°F and 69°F.

An interesting feature of these curves is that each curve appears to consist of two parts, the first part coming down smoothly and the second part having a maximum Also it is clear from the curves that the total noise is decreased at lower temperatures and lower voltages.

Figure 6 gives the distribution of the pulses from the liquid scintillator for Co^{60} gamma-rays, after substracting the background. Peak due to Compton edge is clearly visible. It was noted that only xylene without stilbene did not give any pulse above 4 volts.

4. DISCUSSION

Though the first part of the curves for the noise pulses more or less resembles the trend of the curves reported by a number of workers, (Morton and Mitchell, 1949 and others), the second part with a hump seems to be a peculiarity of these curves. Comparatively very high voltage applied between the cathode and the first dynode appears to be the main difference between this experiment and that of other workers.

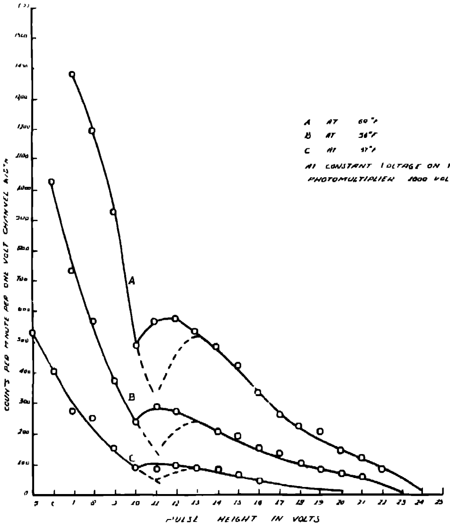

Fig. 3. Differential pulse height spectrum of noises at various temperatures of the photomultiplier when the total voltage on the photomultiplier was kept constant at 1000 volts.

In our conditions, the gain of the photomultiplier could be taken roughly as 4×10^4, the total stray capacity at the anode as 10 pf and the gain of the linear amplifier as 8000. One electron from the photocathode, therefore, gives pulse of about 4 to 5 volts.

The pulses due to ohmic leakage are known to be small in size as discussed by Morton and Mitchell (*loc, cit*), Engstrom (1947), Rodda (1949) and others. They are expected to be around or below 5 volts Therefore in the analysis of these curves, we need consider only thermionic noise and ion feedback, as the main contributing factors. According to the above authors also, these two effects contribute most to the noise in the region of our interest.

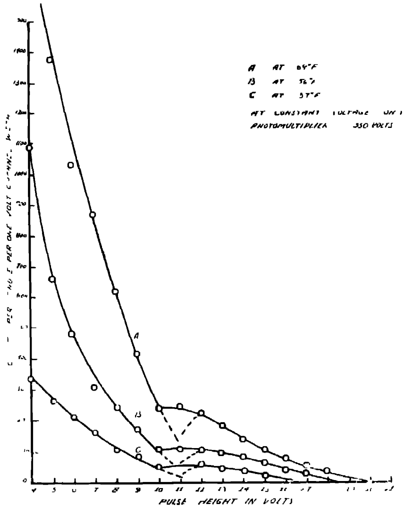

Fig 4 Differential pulse height spectrum of noise pulses at various temperatures of the photomultiplier when the total voltage on the photomultiplier was kept constant at 950 volts.

As mentioned above, the hump portion in our curves appears to be related with the high voltage between the cathode and the first dynode. This is borne out by figure 1, where at an overall voltage of 900, when the voltage between the cathode and the first dynode is 335 volts this portion disappears, while at overall voltage of 1050, when the voltage between the cathode and the first dynode is 390 volts, this portion is very dominant The fact that the pulse height, in this portion are comparatively high, rules out the possibility of its arising from any other dynode, except from the cathode. It also appears that this is due to some secondary effects, connected with the initial electrons starting from the photocathode. It is well known that the thermal electrons, which are the only primary

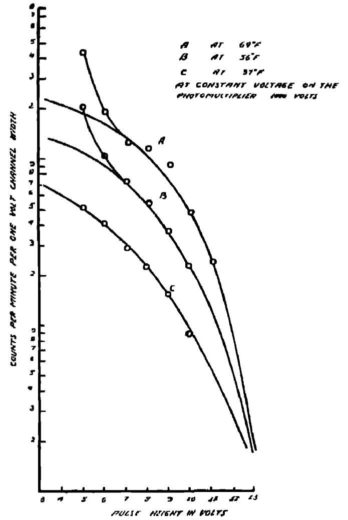

Fig. 5. Differential pulse height spectrum of noise pulses at various temperature of the photomultiplier when the total voltage on the photomultiplier was kept constant at 1000 volts (Semilog graph).

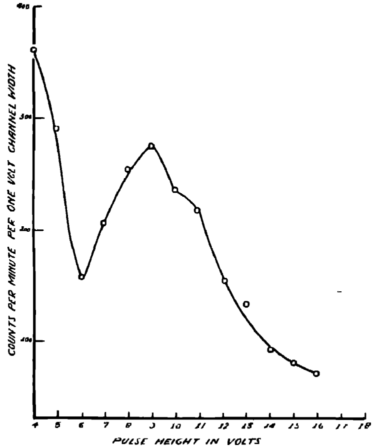

Fig. 6 Differential pulse height spectrum of pulses from stilbene in xylene liquid scintillator due to Co^{60} gamma rays.

electrons from the cathode in our case, give noise pulses whose pulse height distribution curve comes down smoothly following some sort of distribution law. Most of the curves of noise pulses found in the literature bear this out They are normally taken at comparatively low voltages between the cathode and the first dynode where the positive ion feedback effect will not be dominant and therefore the curves may be assumed to be wholly due to thermal noise. Normally change of voltage is expected to change the number and the pulse height but the general trend of the curves due to thermal electrons should remain the same.

The most predominant secondary cause of noise pulses is the positive ion feedback The primary electrons starting from the cathode may ionize the atoms of the residual gas, which on reaching the cathode may release further electrons, to give one more pulse. These pulses are expected to be delayed with respect to the primary ones Though this effect should be present even at comparatively low voltages, its probability of occurrence shoots up at higher voltages. This is borne out by Huxford (1939) who ploted γ, the average number of electrons released by each positive ion falling on Cs-Ag-O photo-surface, versus the field through which positive ion moves It appears from his curve that while γ remains constant at a value of about 0.5 for fields less than 150 volts per cm, at higher fields the value of γ goes up quite steeply so that at 250 volts/cm, γ is about 4 and if the trend of the curve is assumed to remain the same even for little higher fields, γ for 350 volts/cm or so may be still higher. The trend of this curve for γ suggests that it is feasible that after a certain field between the cathode and the first dynode, the pulses, due to positive ion feedback may attain heights, to deviate appreciably from the curves due to the primary electrons. The above arguments therefore, suggest that the humped portion may be attributed to the positive ion feedback.

Photons produced inside the photomultiplier due to de-excitation of the residual gas may be ruled out as the cause of this part of the curve, because the efficiency for electron emission for photons is extremely small It requires about 25 photons in the photo-sensitive region to emit one electron

Pulses due to positive ion feedback which are delayed with respect to the primary pulses, have been studied by Harrison, (1952) Davison, (1952) Mueller *et al.*, (1952) Lanter and Corwin (1952), and Breitenberger. (1951) According to Harrison the amplitude and the distribution of these is consistent with their being caused by single positive ions, produced by the electrons of the main pulse. Mueller *et al.* observed that after-pulses which are produced by the initial pulses due to the single electrons, are of the same height or slightly taller than the main pulses. Lanter and Corwin, however, observed that at higher gain the maximum height of the after-pulse corresponds to more than one photoelectron and depends on the height of the main pulse. It appears from the oscillograph traces given in this paper that the after-pulses follow some sort of distribution law in heights. But according to Davison, the number, but not the amplitude of the after-pulses seems to be related to the amplitude of the main pulse. Further, he observed that the visual comparison of the after-pulses produced by a single electron seems to indicate that the pulse height distributions of the two are identical

At the low voltage between the cathode and the first dynode the value of γ as given in the curve of Huxford is of the order of 0 5, which may be interpreted that the after-pulses will be mostly due to one electron This seems to be borne out by the experiments of the workers mentioned above. However, at comparatively high voltages at which the present experiments were carried out, probability of emission of more than one electron is appreciably high. It is even possible that the most probable number of electrons emitted by a single positive ion at high voltages may be five or six etc in which case one should expect a sort of pulse height distribution with a maxima corresponding to the average value of γ This explains the hump in our curves.

In figure 5 the first part of the curve of figure 3 is replotted on a semilogarithmic graph Two interesting facts emerge from these curves, firstly, these curves follow more or less a parabolic shape and secondly, at higher temperatures and higher voltages a deviation from the parabolic shape is observed. It seems that these deviations are due to preponderance of small pulses caused by ohmic leakage or certain effects arising from dynodes. The parabolic shape confirms our conclusion that the first portion of these curves is mostly due to thermionic emission from the photocathode.

It is further clear from the curves in figures 1 to 4, that (1) the number of noise pulses decreases at low temperatures. (2) the number of pulses at higher pulse heights decreases more slowly with temperature than the number at the smaller pulse heights, (3) the number of small pulses seems to go up very rapidly with higher voltages and (4) in general, the structure of the curves remains the same.

5. RESPONSE OF STILBENE IN XYLENE LIQUID SCINTILLATOR

Luminescence efficiency of liquid scintillator is much less as compared to NaI(TL) crystal. It should, therefore, be quite interesting to study their response under our conditions of extraordinary high collection efficiency.

The scintillators containing atoms of low atomic number, like the one in this experiment, respond to gamma-rays of about 1 Mev, mainly through Compton effect. Co^{60} emits two gamma-rays of energies of 1.17 Mev and 1 33 Mev. Under very good conditions the two Compton edges due to Co^{60} gamma-rays have been clearly indicated by McIntyre and Hofstadter (1950) using NaI(TL) crystal as detector.

Figure 6 gives the differential distribution of pulses from stilbene in xylene liquid scintillator with Co^{60} gamma-rays This spectrum was taken with 390 volts between the cathode and the first dynode and at a temperature of 37°F. These conditions increase the collection efficiency and decrease the noise pulses. This curve was drawn after substracting the noise pulses of the type mentioned earlier.

The peak at 9 volts may be interpreted as due to Compton edge At 11volts also there is an indication of an edge If the peak at 9 volts is taken to be due to Compton edge of 1.17 Mev. gamma-rays and if the scintillator is assumed to be linear, the Compton edge due to 1.33 Mev gamma rays should come out to be at 10.6 volts However, one should be cautious in attributing the Compton edge at 11 volts due to 1.33 Mev. gamma-rays, because the primary pulses from the scintillator are also expected to give after-pulses which will have their maximum at about 12 volts These after-pulses cannot be subtracted. Though their number is expected to be small still it can not be ruled out that the edge at 11 volts may be mostly due to them Also because of low luminescence efficiency the scintillator is not expected to be good enough to resolve the two Compton edges. Peak at 9 volts is, of course, definitely due to Compton edge of Co^{60} gamma-rays

A comparison was made of pulse heights produced in NaI(TL) and stilbene in xylene by the same energy gamma-rays under the same conditions This gave the ratio of photoelectron yield of our liquid scintillator and NaI(TL) as 0.0045 for gamma-rays of Co^{60}

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