A STUDY OF THE SCINTILLATION PHOTO-MULTIPLIER
FOR NUCLEAR PARTICLE COUNTING

by

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INTRODUCTION

Statement of the Problem

The work done on the scintillation detector is divided into two categories:

(1) the design and construction of a photo-multiplier scintillation detector together with the associated electronic circuits to provide a sensitive and efficient counter of gamma radiation,

(2) an analysis of the performance of the various circuits of the counter and a discussion of the experimental results obtained with a naphthalene scintillating phosphor.

The preliminary design of the counter was carried out through the use of articles published in the journals of Physics and Electronics. Improvements were made on these circuits and a complete counter was constructed. Measurements were made of the operating characteristics of the circuits and the scintillation detector. The quantitative results establish the maximum counting rate at which the instrument is capable of operating. Recommendations are made regarding experimental work that may be done when additional sources of radiation are obtained. Possible cir-
cuit improvements are also discussed.

Review of the Literature

Scintillation detectors, consisting of a photo-multiplier tube to measure the light emitted by a fluorescent screen, were rapidly evolved during the years that followed the development of the atomic bomb. At first mainly intended as gamma radiation detectors, their use has been extended to the measurement of beta particles, alpha particles, protons and neutrons. Improved high frequency circuits made possible the registration of individual quanta of all these radiations as pulses rising above the noise level of the photo-multiplier "dark" current.

Marshall and Coltman(1) reported the use of such a detector at the Montreal meeting of the American Physical Society in 1946. They found that it compared favorably in sensitivity with the best Geiger counters and was much faster in its response. Gamma ray energies from 25 KEV were successfully detected at efficiencies approaching 100%. Slow neutrons were detected by introducing Boron to the phosphor.

(1) H. Marshall and J. Coltman
The Photomultiplier Radiation Detector
Phys. Rev., Vol.72, p.528, 1947
These results were confirmed by Deutsch(1) who used naphthalene crystals prepared from melt. He reports that Beta particles were mounted substantially without loss at room temperature if their energy loss in the phosphor was greater than 0.15 MeV. Cooling the photo-tube to dry ice temperature resulted in a three-fold sensitivity increase.

P. R. Bell(2) using the same type of detector found that anthracene crystals were more sensitive in scintillation counters. Satisfactory crystals of anthracene were difficult to prepare since they were formed by slow cooling from the melt in an atmosphere of nitrogen. Using phosphor samples of about the same size, he found that gamma rays from Co60 produced pulses about three times as large in anthracene as in naphthalene. Some experiments with low energy Beta rays showed that the sensitivity of the anthracene counter corresponded to that of a thin mica window Geiger counter. Fast Neutrons were counted by the recoil protons produced in anthracene at 10% efficiency.

A number of experiments were conducted by

(1) M. Deutsch
High Efficiency, High Speed Scintillation Counters for Beta and Gamma Rays

(2) P. R. Bell
The use of Anthracene as a Scintillation Counter
Phys. Rev., Vol.73, p.1405, 1948
R. J. Moon(1) using a variety of inorganic crystals. Several of them were found to be efficient gamma ray detectors. Calcium tungstate and calcium fluorid produced the largest scintillation pulses.

L. F. Wouters(2) and G. B. Collins(3) measured the rise and decay characteristics of scintillation pulses and found them to be of the order of $10^{-8}$ microseconds. Their procedure involved the operation of the phototubes at 150 volts per stage so that direct connection could be made between the anode and cathode ray tube deflection plates. Cooling to liquid nitrogen temperatures was employed to reduce spurious noise impulses.

Alkali Halide crystals were used by R. Hofstadter(4) who measured their light output in contact with photographic films. The greater densities and higher atomic number of

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(1) R. J. Moon
*Inorganic Crystals for the Detection of High Energy Particles and Quanta*
Phys. Rev., Vol. 73, p. 1210, 1948

(2) L. F. Wouters
*Pulse Characteristics of Anthracene Scintillation Counters*

(3) G. B. Collins
*Decay Times of Scintillations*

(4) R. Hofstadter
*Alkali Halide Scintillation Counters*
Phys. Rev., Vol. 74, p. 100, 1948
these crystals make them better detectors of alpha particles and protons. NaI (Tl) is a particularly efficient detector of all types of radiation\(^1\).

The efficiency of a number of fluorescent materials was measured quantitatively by H. Kallman\(^2\) who distinguished between two characteristics of the phosphors - the light yield, that fraction of the absorbed energy transformed into light, and the practical light yield, the amount of light obtained at the phototube from a given intensity of radiation. Although the inorganic sulfide phosphors have a higher light yield, their practical output is lower because they are opaque to their own radiation. Naphthalene and anthracene are much better in this respect. The wavelength of the naphthalene radiation is 3600Å which is especially useful when this phosphor is used in conjunction with the 931-Å photo-multiplier.

Accurate measurements of the relationship between scintillation pulse heights and proton energies have been made by

\(\text{(1) R. Hofstadter}
\)

\text{The Detection of Gamma Rays with Thallium Activated Sodium Iodide Crystals}

\text{Phys. Rev., Vol. 75, p. 796, 1949}

\(\text{(2) H. Kallman}
\)

\text{Quantitative Measurements with Scintillation Counters}

H. B. Frey, et al. A smooth curve of pulse height versus proton energy was obtained when the source was the M.I.T. electrostatic generator whose output was monoenergetic.

(1) H. B. Frey, et al
Response of an Anthracene Scintillation Counter to Protons
CHAPTER I

Experimental Results and Counter Characteristics

Description of Circuits

The completed scintillation counter consists of a group of electronic circuits arranged on four separate chassis units and utilizing 36 vacuum tubes in all. These circuits include the scintillation detector, a nine-stage pulse amplifier, an amplitude discriminator, a scale of 64, audio output and register driver circuits, together with the power supplies required to furnish the operating voltages.

A block diagram, Fig. 1, shows the functional arrangement of these various component circuits. The different chassis units are separated in the block diagram by a dashed line and are named according to their major function. These are

1. the low voltage power supply,
2. the high voltage power supply,
3. the detector and preamplifier chassis,
4. the counter chassis.

The scintillation detector is a type 931-A photo-multiplier which with the scintillating phosphor is mounted on the front panel of the detector and preamplifier chassis in
a light-tight shield. The function of this circuit is the conversion of the scintillations produced by the interaction of charged particles with the phosphor to electrical impulses.

A three-stage preamplifier follows the detector. In construction, the wiring is so arranged that leads are short and that adequate shielding is provided in order to prevent the pickup of spurious signals. The output of the preamplifier is fed through a resistance voltage dividing network to the main pulse amplifier, which is separated into two three-tube sections. The first of these is located on the detector chassis and the other on the counter chassis. In addition to the voltage divider there is also a control to vary the amount of feedback in the first amplifier section. Connection between the two halves of the pulse amplifier is made through a short coaxial cable.

At the counter chassis the incoming signal may be switched to the input of the amplitude discriminator whose function is to select pulses above a given amplitude and provide at the output pulses fixed in amplitude and duration. These standard pulses then actuate the trigger circuits and the mechanical register. A speaker on the panel of the counter provides an audible indication of the counting, and terminals on the back of the chassis are provided for external counting circuits or for visual presentation
of the pulses on an oscilloscope.

The low voltage power supply provides the d.c. voltages for the amplifier and trigger circuits, while the high voltage supply furnishes a high negative potential to the photo-multiplier.

**Experimental Results**

Fig. 2 is a graph of the detector counting rate in counts per minute plotted against discriminator bias in volts. These data were obtained using a naphthalene scintillating phosphor with a 1 milligram radium sample located 25 cm. from the detector. The background counting rate as a function of the bias voltage is also shown. The difference between the two represents the actual counting rate for \( \gamma \)-radiation from the radium source.

The pulses at the output of the amplifier were observed on an oscilloscope and a photograph of a typical pulse waveform as displayed on the cathode ray tube is shown in Fig. 3. The rise time (from 10% to 90% of peak) is approximately 0.5 microseconds. This represents the rise time of the amplifier rather than actual pulse shape at the scintillation detector output. The decay time constant of these pulses is of the order of 2 microseconds. Apparently this time constant depends upon the shunt capacitances at the output of the detector, since the minimum clipping time constant of the amplifier is 8 microseconds.
These results are compared with those of Wouters\(^1\) and Collins\(^2\), who measured the rise and decay characteristics of scintillation pulses from naphthalene and directly found them to be on the order of \(5 \times 10^{-9}\) and \(6 \times 10^{-8}\) microseconds respectively.

The operation of the scintillation counter is dependent upon the choice of photo-multiplier tube. The background counting rate is almost wholly due to the emission of random electrons at the photo-cathode. These are amplified and will give rise to false counts if, during a short interval of time, a sufficient number of them are emitted. For most of the photo-multipliers tested, this background was so great as to completely mask the \(\gamma\)-radiation counts.

It was observed that the background counting rate was definitely related to the temperature of the photo-multiplier. A measurably higher rate was observed during the middle of the day as compared with the background in the early morning or late evening.

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\(^1\) L. F. Wouters
Pulse Characteristics of Anthracene Scintillation Counters

\(^2\) G. B. Collins
Decay Times of Scintillations
COUNTING RATE VS. DISCRIMINATOR BIAS
FOR RADIUM GAMMA RADIATION ON
NAPHTHALENE

STATISTICAL ERROR ≈ 3 %

FIG. 2.
Naphthalene exposed to sunlight and then enclosed in the light-tight shield with the phototube was observed to emit a relatively large number of photons in bursts. This radiation was observed to decay to a negligible value within a few hours.

The background counting rate and the sensitivity of the detector are both functions of the voltage applied to the stages of the photo-multiplier. As the voltage is reduced a small amount, the background and the γ-counting rates drop sharply. A 5% reduction in the voltage results in a 15% reduction in the measured count.

**Performance of Circuits**

The maximum rate at which the counter will record pulses, whose occurrence is random, is a function of the speed of the amplifiers and, more important, of the dead time of the amplitude discriminator and trigger circuits.

The resolving time of the amplitude discriminator is estimated on the basis of an analysis of the output waveform. These pulses had a decay time of approximately 5 microseconds. On the basis of similar observations made of the waveforms at the first scale of 2, the dead time of the counter is of the order of 10 microseconds. Less than 1% error in the recorded count is to be expected for random impulses up to 1000 counts per second. Sketches of these critical waveforms are shown in Fig. 4.
CRITICAL WAVEFORMS

DISCRIMINATOR OUTPUT

30 V

MICROSECONDS

0 1 2 3 4

TRIGGER INPUT

40 V

0.1 SECONDS

0 0.5 1

INPUT TO REGISTER DRIVER

80 V

FIG. 4.
The maximum counting rate is also dependent upon the limiting speed of the mechanical register and its driver circuit. Manufacturer's data indicate that the maximum rate to be expected from the Mercury Register is 20 counts per second. The actuating pulse, however, decays in approximately 0.06 seconds placing an upper limit of 16 counts per second. Even when randomly occurring pulses are being counted, the output of the scale of 64 shows a considerable "smoothing" effect. As a result, a negligible error is introduced when the register is only slightly faster than is required for regularly spaced pulses at the same counting rate. Therefore, counting rates up to 1000 pulses per second can be handled by the instrument without appreciable counting losses.
CHAPTER II

Design and Analysis of the Circuits

The circuits employed in this equipment are of conventional design, but incorporate a few innovations which warrant a brief discussion of their design and operating characteristics. The following circuits are considered in the analysis which follows:

(1) The low voltage and high voltage power supplies, both of which are electronically regulated,

(2) The pulse amplifier,

(3) The amplitude discriminator,

(4) The trigger circuits,

(5) The mechanical register and driver circuit.

Power Supplies

In addition to providing a relatively stable d.c. voltage, an electronically regulated power supply provides a low source impedance and the regulating circuits effectively filter out the ripple voltages. A comparison between different power supplies may be made on the basis of these three quantities, defined as follows:
(1) The Stabilization factor

\[ S = \frac{E_o}{E_s} \frac{dE_s}{dE_0} = \frac{E_o}{E_s} \frac{E_s}{E_0} \]

where \( E_s \) is the supply main's voltage and \( E_0 \) is the stabilized d.c. voltage.

(2) The output impedance

\[ R_0 = - \frac{dE_0}{dI_0} = - \frac{E_0}{I_0} \]

where \( I_0 \) is the load current.

(3) The smoothing factor

\[ Q' = \frac{dE_0}{dE_l} = \frac{E_0}{E_l} \]

where \( E_l \) is the voltage at the output of the rectifier-filter circuit preceding the voltage stabilizer.

The basic circuit of the low voltage power supply is given in Fig. 5a. It consists of a standard rectifier-filter supply followed by a series triode in the positive supply lead. A fraction, \( Q' \), of the output voltage is compared with the fixed voltage of a voltage regulator tube. The

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(1) Elmore and Sands; *Electronics*, National Nuclear Energy Series, McGraw-Hill, 1949
difference between the two voltages is amplified by a difference amplifier whose gain is $G$ and applied so as to bias the series triodss to give degenerative compensation for any change in load or supply-main's voltage.

The plate-load resistor of the amplifier stage is returned to the unstabilized side of the power supply. This enables the potential of the grid of the series triode to approach that of its cathode without causing the current through the amplifier to become small and the gain to become reduced. For the same reasons, the screen grid of the amplifier is maintained at a fixed potential above the cathode. As a result, the low voltage supply may be operated over a large range of output voltages.

![Diagram](image)
The equivalent circuit of this supply is indicated in Fig. 5b. $r_p$ and $U$ are the plate resistance and amplification factor of the series triode.

These conditions may be assumed for practical voltage stabilizers.

$$\frac{dE_s}{E_s} \approx \frac{dE_l}{E_l} \quad \text{and} \quad \beta G \gg 1.$$  

The grid to cathode voltage of the series triode is given by

$$e_g = -e_0 - \beta G e_0 = -e_0 (1 + BG).$$

---

(1) \quad S = \frac{E_0}{E_s} \frac{dE_s}{dE_0} \approx \frac{E_0}{E_l} \frac{dE_l}{e_0} \quad \text{or} \quad \frac{E_0}{E_l} \frac{dE_l}{e_0} \approx S.$$

$$e_0 = \mu e_g + e_l = -\mu (1 + GB) e_0 + e_l.$$

$$e_l = e_0 (1 + \mu (1 + GB)).$$

$$e_l \approx e_0 \mu GB.$$

$$S \approx \frac{E_0}{E_l} \mu GB.$$
(2) \[ R_0 = - \frac{dE_0}{dI_0} = - \frac{e_0}{I_0} \]

\[ i_0 = \frac{e_1 + \mu \text{gb} - e_0}{r_p + R_1} \]

\[ i_0 \approx \frac{e_1 - \mu \text{gb} e_0}{r_p + R_1} \]

For all practical stabilizers, \( e_1 \ll \mu \text{gb} e_0 \).

\[ i_0 \approx - \frac{\mu \text{gb} e_0}{r_p + R_1} \]

\[ R_0 \approx \frac{r_p + R_1}{\mu \text{gb}} \]

(3) \[ \alpha' = \frac{dE_0}{dE_1} = \frac{e_0}{e_1} \]

\[ e_1 \ll e_0 \mu \text{gb} \]

\[ \alpha \approx \frac{1}{\mu \text{gb}} \]
For the stabilizer of the low voltage supply, the values are

\[ S \approx 160, \]
\[ R_0 \approx 0.12 \text{ ohms}, \]
\[ \alpha \approx 40 \times 10^{-3} \] for ripple voltages.

The circuit of the high voltage power supply and its electrical equivalent are shown in Fig. 6. Two tubes are employed in series in order that the plate voltage may be reduced to a reasonable value. The additional tube serves only to couple the control tube to the high voltage lead and to drop the voltage across the control tube. Its internal resistance is simply added to the plate resistance of the control tube.

Fig. 6
For the analysis of the high voltage power supply it is assumed that

\[
\frac{dE_s}{E_s} \approx \frac{dE_l}{E_l}.
\]

and that

\[Gm_\phi R >> 1.\]

(1) \[S = \frac{E_0}{E_s} \frac{dE_s}{dE_0} \approx \frac{E_0}{E_l} \frac{e_1}{e_0}.
\]

\[e_0 = e_1 - i_0 R = e_1 - (i_0 + Gm_\phi e_0) R,
\]

\[= e_1 - (i_0 + Gm_\phi e_0) R.
\]

\[e_0 \approx e_1 - Gm_\phi R e_0.
\]

\[e_1 \approx e_0 (1 + Gm_\phi R),\]

\[e_0 \approx Gm_\phi R.
\]

\[S \approx \frac{E_0}{E_l} Gm_\phi R.
\]
(2) \[ R_0 = - \frac{\partial E_0}{\partial I_0} = - \frac{e_0}{I_0} \]

\[ i_0 = \frac{e_1}{R} - Gm e_0 = \frac{e_1}{R} - GmB e_0 \]

\[ \frac{e_1}{R} \ll GmB e_0 \]

\[ i_0 \ll GmB e_0 \]

\[ R_0 \approx \frac{1}{GmB} \]

(3) \[ \alpha = \frac{\partial E_0}{\partial e_1} = \frac{e_0}{e_1} \]

\[ e_1 \ll GmB R e_0 \]

\[ \alpha \approx \frac{1}{GmB R} \]

For the stabilizer of the high voltage supply, the expected values are: \( S \approx 35 \),
\( R_0 \approx 2000 \) ohms,
\( \alpha \approx 2 \times 10^{-2} \).

**Pulse Amplifier**

The nine-stage pulse amplifier consists of three three-stage feedback amplifier loops. A typical three-stage feedback loop is shown in Fig. 7.
Pulse inversion occurs at the output of the second loop so that the amplitude discriminator input signal is positive in sign.

Each loop consists essentially of two amplifying stages followed by a cathode follower; a fraction of the output voltage is fed back into the cathode of the first tube. The output impedance of such an arrangement will be on the order of 10 ohms. This feedback circuit affords several conveniences in design because the feedback resistances can be chosen to give the proper cathode bias values.

Because of the form of the pulses present at the detector output, pulse shaping in the amplifier is necessary. If the input signal were to be faithfully transmitted to the counter, the individual impulses in the signal would be
too small to be measured accurately. To avoid this difficulty, the low-frequency response of the amplifier is so chosen as to drop the output signal to zero following the rapid rise of each pulse. The simplest method of accomplishing this is to use a short time constant coupling in the amplifier. The value of this time constant is referred to as the "clipping time" of the amplifier.

The rise time of the pulse amplifier is made as short as possible consistent with the amplification required and the permissible signal to noise ratio. The duration of the pulses at the output is determined both by the clipping time of the amplifier and by the interelectrode capacities of the amplifier stages. Too short a duration results in unreliable operation of the amplitude discriminator, while a long duration causes counting losses due to pulse pileup and amplifier overloading. Very short pulses may be stretched by loading a portion of the circuit with a capacitance.

To prevent transient overshoot on steep impulses, a small capacitance on the order of a few micromicrofarads is connected across a portion of the feedback path. This method of reducing the width of the bandpass increases the stability of the amplifier risetime since the high frequency cut-off is determined by a property of the feedback path rather than by the parasitic capacitance in the amplifying portion of the loop.
There is one important precaution that must be taken in using a three-stage feedback loop. The cathode follower furnishing output voltage will alter the high frequency response of the amplifier if it is loaded by a capacitance. For this reason any load on the loop should be primarily resistive, and if coaxial cables are used, they should be properly terminated.

The upper half power frequency of the amplifier used is about 700 kilocycles per second. The relatively large feedback capacitance used in the second feedback loop stabilizes the rise time of the amplifier and limits the high frequency response.

Two controls permit a variation in the amplification up to a maximum of approximately $10^6$. The short time constant is provided by the coupling capacitance and voltage divider circuit at the input to the second feedback loop. The clipping time in microseconds is given by

$$T = 8 \times 10^{-3} \, C,$$

where $C$ is in micromicrofarads.

**Amplitude Discriminator**

The amplitude discriminator has the property of providing a standard pulse whenever it receives an input pulse whose amplitude is greater than some minimum value. Almost any monostable trigger circuit has this property but most
of them do not possess these properties which are desired in a reliable amplitude discriminator:

1. A discriminator should be able to discriminate reliably between pulses differing in amplitude by only a small fraction of a volt.

2. It should be able to accept narrow pulses.

3. It should present a high impedance to the signal source.

4. It should not overload on a pulse whose amplitude is much greater than the critical amplitude.

5. It should have an easily adjustable discrimination voltage.

A circuit which, in practice, meets these requirements satisfactorily is a modification of the Schmitt trigger circuit. (See Fig. 8) This circuit can be considered as a voltage comparison device. It gives an output signal whenever the input voltage becomes approximately equal to the voltage at the grid of T-2. A circuit of this type is triggered when the potential at point A goes above some critical value, say 100 volts, and returns to its original state when the voltage falls a little below 100 volts.

If the value of the potential at A is adjusted to +80 volts, the circuit will be triggered when an input sig-
nal greater than +20 volts is impressed on the input grid. The circuit remains in the new state as long as the signal is above +20 volts, and returns to its original state when the input signal falls a little below this value. If an input signal is less than +20 volts, no output signal is obtained. The output signal is always a rectangular wave with an amplitude approximately 40 volts and a duration equal to the time spent by the input signal above the 20 volt level. The magnitude of the signal that will just trigger the discriminator is called the bias voltage of the discriminator. For the circuit shown the bias voltage can be adjusted by potentiometer $R_1$. By means of the variable resistors $R_2$ and $R_3$ it is possible to adjust voltages in the circuit to make the dial read the bias voltage of the discriminator directly.

A difficulty that may be encountered with this type of circuit is a false count due to pulses having too short a rise time. This will give no trouble if the risetime of pulses from the amplifier is sufficiently great.
The trigger circuits used in the scale of 64 are symmetrical vacuum tube networks that possess two stable operating conditions. A sufficiently strong transient voltage deliberately applied from an external source will momentarily drive the circuit out of a particular state of equilibrium. The voltages will rapidly swing to the other set of equilibrium values. The circuit is initially set at one of the stable operating conditions and the successive transitions from one stable state to the other take place in sequence. Any stable set of voltages is held for an unlimited time changing only on the arrival of the next trigger impulse from the external source. The operation of the trigger circuit is essentially a switching action.
A schematic diagram of one of these scales of two is shown in Fig. 9. The triggering impulse is fed to the junction of the plate load resistors. The output signal is taken from the plate of the second triode. This particular circuit will discriminate against positive pulses and triggering operation takes place when a negative signal is applied.

Six identical trigger circuits are cascaded to provide the scale of 64. Neon interpolation lamps are connected through isolating resistors to the plates of the output triodes. The circuits may be forced into the "lamp off" stable condition by the insertion of a large series resistance in the cathode leads of the input triodes. This provides a large bias voltage at these cathodes and the output triodes fall into the conducting state. In practice this is accomplished when the counter is reset.
The particular circuit shown (1) has many advantages over the conventional scale of two. No clipping diodes are required between the successive counter stages to discriminate between positive and negative pulses. Because the shunt capacities are low, the dead time of this scale of two is lower than that of comparable counter circuits. Fewer parts are required and the power dissipated is appreciably less; furthermore, the operation of the circuits is reliable over a wide range of supply voltages and is not at all critical with regard to component values.

Register and Driver

A mechanical register is the final indicating device of the counter, therefore, the final function of the counter circuit is to produce a pulse suitable for driving an electromechanical register.

The Mercury Register used here is a ratchet-operated mechanism whose speed is limited to 20 counts per second by the mechanical inertia of the mechanism. Energy is supplied by means of a current through a coil. This register has an inductance of 16 henries and a resistance of 6000 ohms, and it requires a current of 15 ma for reliable oper-

(1) R. J. Blume,
Predetermined Counter for Process Control Electronics, Vol. 21, p. 88, Feb. 1949
The register driver circuit operates by differentiating the rectangular pulse that appears at the plate of the final scale of two. The problem is one of supplying a sufficiently high voltage across the register until it closes, and then removing this voltage to enable the register to recover for the next count.

The input triode of the driver, shown in Fig. 10, is normally operating at zero grid bias. A large negative pulse from the final scale of two rapidly drives this tube beyond cutoff and the rising voltage at the plate of this triode causes the output tube to conduct heavily, actuating the register. As the charge leaks from the input coupling capacitor, the circuit returns to its quiescent operating condition. The duration of this decay is approximately 0.6 seconds. The register cannot operate again until the circuit has returned to normal.

![Fig. 10](image-url)
CHAPTER III

Conclusions and Recommendations

The results obtained using the scintillation counter show that such a device is an efficient detector of γ-radiation. Because only a radium source was available, no measurements could be made of the relative counting efficiency for other types of nuclear particles. It seems safe to assume, on the basis of work done by others in this field, that good results are to be expected for α and β particle counting. The few experiments performed give little indication of the actual usefulness of the scintillation detector for quantitative measurements.

Some interesting topics for future experimentation with this instrument are

(1) the duration of the light emission process,
(2) the amount of light per incident energy of the ionizing radiation,
(3) the sensitivity of the various phosphors in distinguishing between the energies of different monoenergetic rays or particles.

The scintillation counter should prove to be particularly useful as a proportional device to measure the energy of the incident particles. When other sources of radia-
tion become available to the Department of Physics, a set of experiments utilizing the counter should be performed to gather information about the detector pulse amplitude as a function of the incident particle energy.

Other phosphors, particularly those composed of elements having higher atomic number, should prove to be more efficient than the naphthalene used in these experiments. In particular, the counting efficiency of naphthalene and some of the other organic phosphors in detecting protons and $\alpha$ particles has been found to be low. The use of inorganic phosphors such as calcium tungstate or calcium fluoride may increase the efficiency of the heavier particle counting. A solution to this problem may also be found in the use of liquids containing suitable elements in solution.

One of the difficulties encountered with scintillation counters is that when light flashes of small intensity are recorded, the counting rate is limited by the number of noise pulses of comparable size occurring in the multiplier tube itself. One crystal of a scintillating phosphor when operated with two or more photo-multipliers in a coincidence circuit should eliminate these noise pulses to a large degree. Two and three fold coincidence circuits offer many interesting possibilities toward the reduction of background noise.
Accurate measurements of the pulse amplitude and duration depend upon the speed of the associated amplifier circuits. In the present equipment, a definite limitation is placed upon the results obtainable by the rise time of the amplifier. Circuits having a much lower rise time have been designed.

(1)

If changes in the present circuits are planned or if new equipment is to be constructed, a change in the location of the various component circuits might be advisable. For example, the photo-multiplier and its preamplifier could be mounted on a smaller separate chassis. With the pulse amplifier and amplitude discriminator together on one chassis, all of the counter and indicating circuits could be mounted on a third.

This arrangement has several practical advantages. The counter circuits do not require stabilized voltages, while both the amplitude discriminator and the pulse amplifiers do. Smaller power supplies could then be built on the same chassis. A second advantage is found in the elimination of any interconnecting cables between portions of the pulse amplifier and the amplitude discriminator. Because the signal requirements between the amplitude discrimi-

inator and the first scaling unit are less stringent, a relatively long connection may be made here.

While the existing scintillation counter can provide the basis for a number of experiments, it is recognized that, because of its inherent limitations, it is a rather crude instrument. The experience gained through the construction and use of this counter will, however, prove valuable when the need is felt for more refined apparatus.
Operating Instructions

General

The equipment consists of a group of electronic circuits located on four separate chassis. These are so designed that the counter may be operated with all of them mounted in a standard 19 inch relay rack, or with the individual chassis separated. Interconnecting cables up to six feet in length may be used without impairing the operation of the counter.

The four chassis are

1. the low voltage power supply, delivering +300 volts regulated and +480 volts unregulated to the amplifiers and counter circuits,
2. the high voltage power supply, delivering -700 volts regulated to the 93l-A photo-multiplier tube,
3. the detector and preamplifier chassis containing the 93l-A scintillation detector and a six tube pulse amplifier,
4. the counter chassis with final pulse amplifier, amplitude discriminator, trigger circuits and count register.

The circuits are grouped in this way for convenience in construction and because this arrangement permits of greater flexibility when circuit changes and additions are contemplated.
Function of Controls

Some of the operating controls are located on the front panels for easy access, while others, not normally requiring adjustment, are located on the chassis in back of the front panels. These are grouped as follows:

1. On the low voltage power supply, front panel controls are the power switch and the voltage control. The power switch operates the low voltage power supply only. The voltage control will vary the regulated output over a range from ±150 to ±325 volts. The unregulated output voltage depends upon the current drawn from the supply.

2. The only front panel control on the high voltage supply is the power switch controlling both the -700 volt output and the 117 v A.C. to the other chassis. This is transformed to supply filament power to the amplifiers and counter circuits. In addition, the voltage control located on the chassis varies the output voltage from -600 to -750 volts.

3. On the front panel of the detector and preamplifier chassis are the gain and feedback controls. Their settings determine the amplification of pulses from the scintillation
(4) The operating controls of the counter chassis are located on the front panel. A three-position switch controls the input to the amplitude discriminator. In the OFF position, no pulses reach the input grid; in the TEST position a 60 cycle signal is impressed on the grid to permit a rapid check of the discriminator and counter circuits; in the ON position the pulses from the scintillation detector (or other source) are fed to the grid of the amplitude discriminator. With the switch in this position, the pilot light on the front panel is lighted indicating that the equipment is "counting." The DISC. BIAS control varies the grid potential of the discriminator in such a way that only pulses above a certain amplitude will actuate the counter circuits. The RESET switch in the up position extinguishes the neon interpolation lamps. The VOLUME control permits the operator to make adjustments in the loudness of the "clicks" heard in the loud speaker. On the chassis are the DISC. ZERO and DISC. SLOPE controls.
These require adjustment only when tube and component aging change the operating characteristics of the amplitude discriminator. Their settings permit the calibration of the DISC BIAS control directly in volts.

**Normal Operation**

With the four chassis mounted in a relay rack or spread out in a more convenient arrangement and the interconnecting cables all in place, the power may be turned on and a few checks made to insure normal operation. The following step-by-step instructions will assist the operator in making these preliminary adjustments.

1. The power switch on the high voltage power supply is turned ON. This applies voltage to the 931-A photo-multiplier and energizes the filmaments of the amplifier and counter tubes.

2. The low voltage power supply should be turned on after 10 seconds. Normally, the front panel meter will not indicate any voltage for about 30 seconds due to the warmup time of the regulator tubes. Proper operation of the amplitude discriminator requires that the regulated voltage be set
accurately at +300 volts. If the meter reading is not 300 volts, the VOLTAGE CONTROL should be adjusted.

(3) The operating switch on the counter chassis may be set to the TEST position. As the DISC BIAS control is rotated counter clockwise, a critical position between 0 and I is reached at which the interpolation lamps on the counter will operate in regular sequence. The register will click over once approximately every second. The operating switch should be thrown to the OFF position.

(4) The interpolation lamps on the counter chassis are extinguished by momentarily moving the RESET switch to the up position. A 10 to 15 minute wait for the equipment to warm up and for the circuit components to stabilize is advisable. A slight re-adjustment of the VOLTAGE CONTROL on the low voltage power supply may be necessary. The counter is now ready to operate.

(5) Final adjustments of the GAIN and FEEDBACK controls depend upon the conditions of the experiment. Rotation of either control
in the clock-wise direction increases the sensitivity of the instrument. The setting of these controls is determined primarily by the permissible background counting rate and is best determined by experiment.

**Discriminator Calibration**

Although the circuit components and tubes in the amplitude discriminator circuit are reasonable stable, an occasional adjustment of the **DISC. ZERO** and **DISC. SLOPE** controls will be necessary for accurate calibration of the **DISC. BIAS** control in such a way that 1 corresponds to a pulse height of 10 volts, 2 to 20 volts, etc. up to 10 to 100 volts.

Some source of calibrating pulses is necessary for this adjustment. Conveniently these may be supplied by the circuit illustrated in Fig. 11. In any case the pulses should be of short duration in comparison to their repetition period.

![Fig. 11](image-url)
The pulse generator output should be connected to the input of the pulse amplifier through the coaxial cable connector. The amplitude of the pulses at the input of the amplitude discriminator may be observed by connecting an oscilloscope to the terminal provided at the rear of the counter chassis.

(1) With the pulse height adjusted to 100 volts peak and the DISC. BIAS control set at 10, the DISC. SLOPE control should be adjusted so that the counter will just count.

(2) With the pulse height reduced to 10 volts peak and the DISC. BIAS control at 1, the DISC. ZERO control is adjusted so that the counter will just count.

(3) Steps (1) and (2) should be repeated until no further adjustment of the DISC. SLOPE and DISC. ZERO controls is necessary.

(4) The operation of the discriminator at several other settings of the DISC. BIAS control should be checked. A slight readjustment of the DISC. SLOPE and DISC. ZERO controls may be necessary.

Servicing

The following illustrations and tables will be helpful
when equipment servicing is necessary. The tube location chart and table of operating voltages indicating normal operating conditions will permit rapid identification of the defective circuit. A complete set of circuit diagrams is included, but where a detailed description of the circuit operation is needed, the reader is referred to the following texts:

(1) **Crufte Electronics Staff:**

(2) **Elmore and Sands:**
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<thead>
<tr>
<th>Type</th>
<th>Function</th>
<th>Pin 1</th>
<th>Pin 2</th>
<th>Pin 3</th>
<th>Pin 4</th>
<th>Pin 5</th>
<th>Pin 6</th>
<th>Pin 7</th>
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<td>V-6</td>
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<td>V-7</td>
<td>6SN7 Difference amplifier</td>
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<td>220</td>
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<td>V-8</td>
<td>OA3 Voltage regulator</td>
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(All voltages measured to chassis with Vacuum Tube Voltmeter)

**TABLE OF TUBE VOLTAGES**

**LOW VOLTAGE POWER SUPPLY**
<table>
<thead>
<tr>
<th>Type</th>
<th>Function</th>
<th>Pin 1</th>
<th>Pin 2</th>
<th>Pin 3</th>
<th>Pin 4</th>
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<th>Pin 6</th>
<th>Pin 7</th>
<th>Pin 8</th>
<th>Pin 9</th>
<th>Pin 10</th>
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<td>V-13</td>
<td>6C3 Voltage regulator</td>
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<td>V-14</td>
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<td>V-15</td>
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<td>6SJ7 Pulse amplifier</td>
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<td>V-20</td>
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(All voltages measured to chassis with vacuum tube voltmeter)

**TABLE OF TUBE VOLTAGES**

**HIGH VOLTAGE POWER SUPPLY**

**DETECTOR AND PREAMPLIFIER CHASSIS**

* FEEDBACK CONTROL position 0.
<table>
<thead>
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<th>Type</th>
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<th>Pin 5</th>
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<td>V-22</td>
<td>6AG7 Pulse</td>
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<td>6AC7 Cathode</td>
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<td>300</td>
<td>70</td>
<td>74</td>
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<td>V-26</td>
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<td>6SN7* Trigger</td>
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<td>120</td>
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</table>

(All voltages measured to chassis with vacuum tube voltmeter)

# Pin 4 voltage depends on setting of DISC. BIAS control.

* Interpolation lamps extinguished.

**TABLE OF TUBE VOLTAGES**

**COUNTER CHASSIS**
LOW VOLTAGE POWER SUPPLY

HIGH VOLTAGE POWER SUPPLY

DETECTOR AND PREAMPLIFIER CHASSIS

COUNTER CHASSIS

TUBE LOCATION GUIDE

FIG. 15.
FIG. 16.
FIG. 17.
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