0
UNCLASSIFIED

NYO-3048

**Construction and Calibration of a Fast Neutron
Scintillation Spectrometer**

by

G. L. Guernsey, G. R. Mott, B. K. Nelson and A. Roberts

**University of Rochester
Department of Physics**

AT(30-1) -875

April 4, 1952

This document is
PUBLICLY RELEASABLE

H. Kinsler

Authorizing Official

Date: *10/20/09*

To be submitted to the Review of Scientific Instruments

**Individual copies will be supplied as long as the
supply lasts**

This report has been photostated to fill your requests as our supply of copies was exhausted. If you should find that you do not need to retain this copy permanently in your files, we would greatly appreciate your returning it to TIS so that it may be used to fill future requests from other AEC installations.

UNCLASSIFIED

W-294-1

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

Construction and Calibration of a Fast Neutron
Scintillation Spectrometer

by

G. L. Guernsey*, G. R. Mott**, E. K. Nelson*** and A. Roberts
Department of Physics, University of Rochester, Rochester, N.Y.

ABSTRACT

A quadruple coincidence scintillation counter telescope has been constructed for neutron studies with the University of Rochester 130" synchro-cyclotron. A calibration of pulse height vs. proton energy has been obtained for the fourth crystal of the telescope. The response of this crystal to monoenergetic protons has been found to be in fair agreement with calculations for the distribution of energy loss for protons, made using the method developed by K. R. Symon. The instrument covers the range from about 50 to 240 Mev. in recoil proton energy.

I. INTRODUCTION

The need for a high energy neutron spectrometer arose from the desire to perform experiments with the neutron beam from the University of Rochester 130" synchro-cyclotron. Such experiments call for an instrument which indicates neutron energies and intensities in the region from about 50 to 250 Mev, and are described elsewhere¹.

The spectrometer to be described is based simply upon detection and energy measurement of the recoil proton in a neutron-proton elastic collision. Since, for this type of scattering, a knowledge of the proton energy and the scattering angle implies knowledge of the neutron energy,

one can measure the energy of protons counted at any convenient scattering angle and immediately refer the proton distribution to a neutron energy scale. If, in addition, one knows the n-p cross section as a function of energy for that angle a neutron energy spectrum can be obtained.

In previous work²⁻⁵, the recoil proton energy has been obtained from range measurements. In the present apparatus, it is measured by observing the energy lost by the proton in passing through the fourth telescope crystal. Observation of the pulse height spectrum thus gives the neutron spectrum over a considerable energy range, at one time.

II. GENERAL DESCRIPTION OF APPARATUS

In brief, the spectrometer consists of the following basic elements:

(see Fig. 1)

Quadruple coincidence counter telescope - to detect and define the direction of the recoil protons. The pulse height from the fourth counter of this telescope can be calibrated in terms of proton energy.

Two radiators - one of polyethylene and one of carbon, with the same number of carbon atoms per cm². These are placed alternately in the neutron beam to be investigated, and the polyethylene-carbon differences are taken to obtain the effect of the hydrogen in the polyethylene.

Coincidence amplifier - which amplifies and mixes the outputs of the four counters and selects the multiplicity of the coincidence.

Gated linear amplifier - which amplifies the output pulse from the fourth counter whenever it is turned on by a trigger from the coincidence amplifier (usually set to respond to four-fold coincidences).

Pulse height analyzer - to sort according to height and record in one of 24 channels the pulse output of the gated linear amplifier.

III. COUNTER TELESCOPE

A photograph of the counter telescope and scatterers appears in figure 2. The entire array is mounted on a rotatable table with radiators affixed to a circular frame capable of rotation by selsyn remote control. A detent mechanism locates the radiators, which are $3/4$ in. square, in a position such that the axis of rotation of the counter table passes through the center of the scatterers. The polyethylene used is 0.500 inches thick and the carbon 0.222 inches.

The counters themselves employ RCA 5819 photomultiplier tubes, which are magnetically shielded by three concentric iron cylinders for use in the fringing magnetic field of the cyclotron. The shielding ratio was measured to be approximately 1500 to 1 when the shields were placed in a field of the order of 200 gauss. These magnetic shields also housed the preamplifier for each 5819 output and served as light shields for the photomultipliers.

In the case of the first three counters anthracene crystals were used as scintillators. Their dimensions are given in Table 1.

TABLE 1

Dimensions of Anthracene Crystals for Counter Telescope

Counter	Height, in.	Width, in.	Thickness, cm.
C1	0.768	0.735	0.484
C2	0.750	0.750	0.381
C3	0.713	0.713	0.381
C4	0.846	1.083	1.090

They were mounted directly on the ends of rectangular, polished lucite light pipes 8 1/4" long. The light pipes hold the crystals 4 inches away from the iron shield in order to reduce the effects of scattering from the shields.

The light pipes were perfectly satisfactory for the first three counters, whose function was only one of detection. When used with the fourth crystal, which also served as a proportional counter, a light pipe was found to impair the pulse height resolution as measured with the Cs¹³⁷ internal conversion line. The fourth crystal was therefore mounted directly on the face of the fourth photomultiplier tube to obtain the best possible resolution. This precaution, as will be seen later, turned out to be unnecessary.

Of the scintillators available at the time of construction, NaI(Tl), anthracene and stilbene were considered as useful possibilities. Although the work of Franzen, Peelle and Sherr⁶ indicated that the organic phosphors depart from linearity in the region of high density of ionization, their greater ease of handling, faster response, and smaller nuclear absorption per unit energy loss has favored the organic over the inorganic phosphors in our application. The crystal which has been most used is a 1.09 cm. thick anthracene phosphor held mechanically to the face of the 5819 by a covering of aluminum foil taped to the glass envelope. This gave about 15% pulse height resolution for 193 Mev. protons, as will be described in the last section of this paper.

Use of Counters in a Magnetic Field

An additional factor affecting the resolution of the counters is connected with their use in a magnetic field. The dynode structure in the RCA 5819 is essentially cylindrical. In the presence of a magnetic field the axis of this cylinder should be perpendicular to the direction of the

field, so that any deflection moves the electrons along rather than across a dynode.

Now in order to space the fourth crystal sufficiently close to the third crystal so that the latter defines the angular acceptance (see Fig. 3) it was necessary that the face of the fourth counter tube be only 1 1/2 inches from the face of its magnetic shield. This condition, and the necessity of a 1 1/2 inch diameter hole in the face of the shield, allowed some magnetic leakage inside the shield at the position of the tube elements. Consequently, the half-width of the Cs^{137} internal conversion line increased from about 10% half-width at half maximum to being completely unresolved when the axis of the dynodes was rotated from perpendicular to parallel to the field. However, with the dynode axis perpendicular to the field (in a fringing field of approximately 100 gauss), only a 6% increase in pulse height was observed when the cyclotron magnet was turned completely off and there was no detectable change in resolution.

Counter Geometry

The geometry of the counters and scatterers is indicated in Figure 3. The particular geometry shown results in a solid angle of scattering for a proton in the scatterer of 1.81×10^{-3} steradians and a maximum spread in the laboratory proton angle of 5° full width at the base. The angular resolution window is essentially triangular in the approximation that $\tan \delta\phi = \delta\phi$ and that the widths of the scatterer and counter 3 are equal. This geometry has been used as a somewhat arbitrary compromise between reasonable counting rates and good angular resolution. A pulse height distribution for the protons, representative of the neutron energy spectrum, could run at 7.5° with $\pm 10\%$ statistical error at the maximum in about 2 hours. This time applies

for an incident neutron flux of the order of 5×10^5 neutrons per cm^2 per sec. of energy between 120 Mev and 245 Mev.

IV. ELECTRONICS

Proportional Pre-Amplifier

Tests with a cathode follower pre-amplifier in the proportional counter channel indicated that greater gain stability against changes in supply voltage was necessary. Stabilization of heater voltage and regulated B supplies did not reduce fluctuations and drifts to values sufficiently low to permit the desired precision in pulse-height determination. To correct this situation, a wide band (20Mc) unity-gain feedback amplifier triple was built. This 2-stage amplifier has a rise time of approximately 2×10^{-8} second, nearly unity gain, and better gain stability than a cathode follower with respect to change of the characteristics and change of supply voltages. The output of the amplifier consists of a triode-connected 6AQ5 serving as a cathode follower, permitting signals up to 3 volts peak to be fed into the 93 ohm cable.

Coincidence Analyzer

A block diagram of the coincidence analyzer is shown in Figure 4. The signals from each counter are amplified by an inverse feedback amplifier "triple" of approximately 20 Mc bandwidth and gain of about 20, then limited in a pentode stage driven to plate current cutoff. The plates of the four limiters are common and are connected to a shorted 160-ohm delay cable 1.5×10^{-8} seconds long one way. This cable differentiates the limited pulse and produces a fast signal of 6×10^{-8} sec. full width at the base.

and of constant height for an amplifier input in excess of 0.2 volts. The limiters are followed by a diode discriminator which can be set to pass signals with amplitudes corresponding to 1, 2, 3, or 4 channels in coincidence. The output of the discriminator operates a univibrator, whose output served as the trigger supplied to the gated amplifier.

This simple addition type of coincidence amplifier has proven quite satisfactory at low single counting rates. At high single counting rates ($10,000 \text{ sec}^{-1}$ or higher peak rates) the thresholds for discrimination begin to change, and discrimination between, say, triple and quadruple coincidence become progressively worse as the rates increase. This is probably due to bias changes in the limiters, and can only be improved by going to different circuits.

Gated Amplifier

A block diagram of the gated amplifier is shown in Figure 5. This circuit consists of four sections: input triple, gated stage, final amplifier, and gate generator. The overall gain is about 500.

Input Triple - This amplifier is a well stabilized circuit with a rise time of about 4×10^{-8} second with a gain of 80 and 20 db of feedback. Negative input pulses up to 0.1 volt are amplified in a linear fashion. Non-linearity begins between 0.1 and 0.2 volt input and for signals close to 0.3 volt complete saturation results. This circuit was kept moderately fast to minimize pile-ups before the gated stage.

Gated Stage - The gated stage is preceded by a conventional phase inverter providing essentially unity gain for the phase inverter and gated stage combination.

The gated stage itself consists of a 6AS6 tube with the gating signal impressed on the suppressor and the gated signal on the control grid. The output of this stage consists of the gated pulse rising out of a "pedestal" caused by the turning on of the dc plate current by the gating pulse. A large part of this undesired pedestal is removed by a biased diode clipping circuit which follows the 6AS6. It is often convenient not to remove all the pedestal, so that it can still be counted in the output if desired.

Final Amplifier - The output amplifier consists of a 6AG7 amplifier stage with cathode degeneration feeding a 6AG7 cathode follower. This combination has a gain of 5, output linear up to 50 volts, with nonlinearity beginning in the 50 to 100 volt region. Output saturation limits usefulness above this value. The bandwidth of this stage is about 3 Mc since speed is not required after gating.

In normal operation of gated amplifier and pulse height analyzer, a total range of input pulse heights of about 10:1 may be accommodated, the first half of this range being handled in a relatively linear fashion, while the onset of saturation provided appreciable departure from linearity over the upper half of the range. Many spectra observed occupied such a small range of pulse heights compared to the widths of the pulse height analyzer channels that the details of the shapes were not apparent. To allow for a closer inspection of these details, provision for expanding the scale of the pulse heights was incorporated into the gated amplifier. This was accomplished by raising the bias of the 6AL5 clipping diode to the point of removing not only the pedestal but about half the amplitude of the maximum pulse. By changing

the attenuator in the proportional channel. any desired portion of a spectrum may be placed in the region of input pulse height corresponding to pulses above the clipping level but below the onset of saturation. This range of pulse heights is then amplified by the final amplifier so that it covers the range examined by the pulse height analyzer. The usefulness of the 24th channel analyzer is considerably extended by such "clipped" operation.

Gate Generator - The gate generator consists of a conventional blocking oscillator followed by a pulse shaping circuit. The positive trigger from the coincidence circuit is transferred to the blocking oscillator by a 6AQ5 amplifier. The blocking oscillator output is clipped at the 20 volt level providing a rectangular pulse whose length can be adjusted from 0.25 to 1.0 μ sec.

Pulse-Height Analyzer

The 24-channel pulse-height analyzer was designed by H. Logemann, chief electrical engineer. It is patterned after the one described by Wilkinson⁷. Equality of channel widths, and stability of channel edges, are achieved by converting pulse height to pulse duration in a Miller circuit, gating a free-running oscillator and counting the number of pulses from the oscillator to determine the channel in which to register the incoming pulse. It is a "slow" machine, with a dead time of about 3 milliseconds. Since the Rochester f-m cyclotron output consists of beam pulses of duration .25 milliseconds, repeated 110 times per second, the analyzer will respond to only one pulse per f-m cycle, and would have to be much faster to respond to more than one. Since the average incoming pulse rate seldom exceeds 1 per second, a faster device would be of no advantage.

The major difference from Wilkinson's analyzer is the use of 2D21

thyratrons rather than relays to operate the registers. The individual registers are not preceded by scalars, and the maximum recording rate in any one channel is therefore about 15 per second. The instrument has proven to be simple and reliable in operation, with no critical adjustments required.

Electrical Calibration

An overall calibration of the electronics must be made to furnish a pulse height scale for subsequent measurements. This process consisted of introducing a test pulse into the input of the proportional pre-amplifier and measuring the pulse height corresponding to each channel of the pulse height analyzer. The shape of the test pulse was adjusted so that the output of the proportional pre-amplifier was indistinguishable from that produced when it was responding to anthracene scintillation pulses from the photomultiplier. To perform the calibration, the test pulse was fed into the preamplifier and the coincidence circuit set to trigger for singles. Thus, the test signal was measured in the same way as pulses from the photomultiplier.

In the test pulser, a small condenser is charged to a measured d.c. voltage and discharged by a relay-operated mercury switch through a resistive load of size adjusted to give the proper time constant into a 93 ohm line. The repetition rate is 5 pulses per second. Since the mechanical registers of the pulse height analyzer could operate at rates no faster than about 15 per second, this rate insured both proper operation of the analyzer and the attainment of full charge by the test pulser condenser. The value of the measured d.c. voltage was used as a measure of the amplitude of the test pulse, and is

W-294-11

referred to as "relative pulse height". Precision of 0.2% in pulse height is readily attained.

Gain Stability

In order to achieve the full gain stability afforded by inverse feedback amplifiers, it is necessary that the spectrum of the amplified pulses lie mainly in the frequency region well below the upper limit of the amplifier pass-band. Frequencies near the upper limit have little or no gain stabilization. It is therefore advisable to slow down the rise of pulses from organic scintillators. We have recently done this with a series resistance in the grid of the first preamplifier stage, with an improvement in overall gain stability. This change necessitates another, however. In order to obtain fast 4-fold coincidences, a prompt response from counter 4 is necessary. We have therefore added a second preamplifier in parallel with the proportional channel on counter 4, which provides the fast-rising pulse needed.

Stabilization of Photomultiplier Gain

The attainment of very good gain stability with electron multipliers is difficult, since in the usual operating region a 0.1% change in multiplier voltage produces about 1% gain change, and gain stability to 0.2% is desirable. Even a carefully made electronically regulated power supply is difficult to hold to 0.02% stability over long periods of time. We have recently found a solution to this problem by installing a regulator circuit which stabilizes the multiplier gain against high-voltage changes, thus easing considerably the requirement on the power supply stability. This circuit is adapted from one designed by Sherr⁸, and is shown in Figure 6. It provides a gain "plateau" about 80 volts wide (see Fig. 7).

With this circuit, and the slow pulse rise-time, we have found that over-all pulse heights from a monochromatic proton beam remain constant within $\pm 0.5\%$ or better over a whole day's run.

V. OVERALL SYSTEM PERFORMANCE

Calibration with Protons

The response of the entire system to protons of various energies must be calibrated.

Protons of a single energy were obtained by using the cyclotron magnetic field and a collimator as a momentum spectrometer. Certain of the protons scattered in the forward hemisphere from a cyclotron target have a trajectory that takes them through the collimator, as indicated in Figure 8. The telescope was aligned with the collimator, and the response to these protons observed. Two targets were used, giving two different energy groups. The beams are contaminated by deuterons, which can be removed by an absorber, but are actually useful in calibration also.

The energy of the protons was determined by measuring their range in copper, and in the case of the higher energy group, as an independent check, also by the calculation from their known trajectory in the cyclotron field. The energies obtained by these two methods agreed within 1%. Their ranges were 1.623" and 0.328" in copper, indicating energies of 193 and 77 Mev. The range was measured by inserting the absorber in the telescope immediately ahead of the last crystal, so that these energies are those of the protons incident on the last crystal.

Additional proton energies were obtained by inserting various thicknesses of absorber in the proton beam.

Resolution

At the same time as the pulse height data are obtained, the width of the pulse height spectrum for monochromatic protons is also obtained. This resolution must be known, of course, to analyze properly the continuous spectrum of proton recoils obtained from a continuous neutron spectrum.

Ordinarily, scintillation spectrometers have a resolving power (defined as pulse height/full width at half maximum) which is proportional to the square root of the pulse height. This is because, with electrons, the full energy of the electron is lost in the crystal; the number of photons produced is thus proportional (or nearly so) to the energy lost, and the average number of electrons at the output of the photomultiplier is proportional to the number of photons. The fluctuations in pulse height are then due to shot noise in the multiplier, and therefore increase as the square root of the number of electrons.

For fast particles that are not stopped in the crystal there is a more important source of pulse height spread. This is the fluctuation in energy loss by the particle in passing through the crystal, and it depends on the mass and energy of the particle as well as the energy loss. The fluctuations are essentially due to changes in the small number of collisions in which a fairly large amount of energy is lost to a single electron; such collisions are infrequent, but cause considerable fluctuations in the energy lost.

This problem has been treated theoretically by Landau⁹ and by Symon¹⁰ and the fluctuations have been observed for fast μ -mesons^{11,12}. It turns out that, while a 6 Mev proton stopped in a 1.1 cm anthracene crystal might be expected to give a resolution width of, say, 4% due to multiplier shot noise, a 240 Mev proton losing 6 Mev in the same crystal will give a resolution width

of about 15%. Consequently shot noise plays only a minor role in determining the observed width; thus the use of less efficient phosphorous is also possible without sacrificing resolution, and it is not even necessary to be careful about collecting the maximum possible light from the crystal. This conclusion has recently been verified by the observation (by J. Rosenthal, M. S. and W. F. Cartwright) that a crystal mounted on a 6" lucite pipe has the same resolution for protons as when it is directly mounted on the multiplier tube face. The difference in light collection is a factor of about two. The resolution of the Cs^{137} internal conversion line under these circumstances is of course considerably impaired.

We have measured pulse heights and resolution widths for various proton energies, using either a 1.09 cm anthracene¹³ or a 2.2 cm stilbene crystal. The results are shown in Figures 9 and 10. Figure 9 shows the measured pulse heights vs. energy, compared with those calculated from the Symon "small-thickness" approximations. The marked deviation of the observed pulse heights, for both stilbene and anthracene, from the theoretical values, indicates either an inadequacy of the theory or departure of the light output from strict proportionality to the energy loss. The latter seems more likely, from previous work by Franzen, Peelle and Sherr⁶.

Figure 10 shows the resolution for monochromatic protons observed with the same crystals, compared with the predictions of Symon's theory. The agreement is somewhat better here, but not too good. The anthracene crystal is poorer, the stilbene better than the prediction.

A sample curve showing the actual pulse height data obtained with the 2.2 cm crystal for 131 Mev and 121 Mev protons is given in Figure 11.

Both the resolution and the dispersion are poorer at higher energies, as one sees from Figs. 9 and 10. The specific ionization of protons is only twice minimum at 240 Mev, and this energy seems to be a practical upper limit for obtaining reasonably good resolution and dispersion. Making the last crystal thicker will improve the resolution somewhat, but above one inch we are in a region where nuclear absorption of protons in the crystal has an appreciable probability (five percent or more) of introducing erroneous pulse heights into the spectrum. The nuclear absorption is even larger in sodium iodide, which therefore is not as suitable as are the organic crystals for this use.

Double-Valued Pulse Height Spectrum

In measuring a neutron spectrum, there is some value of neutron energy for which the proton recoils have just enough energy to penetrate the fourth crystal. For protons of lower energy the pulse height will be smaller, as of course it will also for faster protons. The pulse-height spectrum is thus double-valued; appropriate precautions and corrections are therefore required, especially for thick crystals.

The calibration data were of course obtained from the equipment in the form of a channel spectrum. The transformation to a pulse height spectrum is made via the data of the electronic calibration, already discussed.

Backgrounds

The most significant contribution to background comes from those cases in which a random count occurs in counter No. 4 during the interval that the gate is open. This small effect is readily measured by removing the delay in the fourth channel preceding the gated amplifier. The spectrum thus observed can then be subtracted, if desired. Since this spectrum is identical

with carbon and polyethylene radiators, the subtraction is obtained automatically when the polyethylene-carbon differences are taken. Random openings of the gates can occur in many ways. The counter geometry is such that all protons traversing the counters 1-3 must traverse 4 unless they stop or are scattered or absorbed in 3. Quadruple coincidences due to such protons with a random count in 4 are rare under operating conditions. The insertion of delays, or the withdrawal of a counter from the recoil proton path, permit measurement of the various contributions. With the neutron beam intensities available, none of these contributions has been significant in experiments thus far performed.

VI. ACKNOWLEDGMENTS

This work was supported by the Atomic Energy Commission. We have had helpful discussions with Mr. H. Logemann, chief electrical engineer, on the circuit designs, with assistance from Messrs. R. Mortensen, James Dungan and L. Momo in mechanical designs. The cooperation of the electronics shop under Mr. Braun and the cyclotron crew under Mr. F. Palmer, and the assistance of Mr. William Spry in taking data and in improving the operation of the equipment are gratefully acknowledged.

REFERENCES

- * Now at Project Lincoln, M.I.T., Cambridge, Mass.
- ** Now at Strong Memorial Hospital, University of Rochester
- *** A.E.C. pre-doctoral fellow; now at Project Lincoln, M.I.T., Cambridge, Mass.
- 1 G.L. Guernsey, G.R. Mott and B.K. Nelson; G.R. Mott, G.L. Guernsey and B.K. Nelson; B.K. Nelson, G.L. Guernsey and G.R. Mott, Phys. Rev. (in press).
- 2 J. Hadley, E. Kelly, C. Leith, E. Segre, C. Wiegand, and H. York, Phys. Rev. 75, 351 (1949).
- 3 H. E. Taylor, T. G. Pickavance, J. M. Cassels and T. C. Randle, Phil. Mag. 42, 20 (1951).
- 4 R. Fox, C. Leith and L. Wouters, Phys. Rev. 80, 23 (1950).
- 5 D. Bodansky and N. F. Ramsey, Phys. Rev. 82, 831 (1951).
- 6 W. Franzen, R. W. Peelle, and R. Sherr, Phys. Rev. 79, 742 (1950).
- 7 D. H. Wilkinson, Proc. Cam. Phil. Soc. 46, 508 (1949).
- 8 R. Sherr, private communication (to be published, R. S. I.). The present circuit differs from Sherr's only in the substitution of a 5651 regulator tube for the battery.
- 9 L. Landau, J. Phys. U.S.S.R. 8, 201 (1944).
- 10 K. R. Symon, Thesis, Harvard Univ., 1948.
- 11 W. L. Whitmore and J. C. Street, Phys. Rev. 76, 1786 (1949).
- 12 F. X. Roser and T. Bowen, Phys. Rev. 82, 284 (1951).
- 13 G. Guernsey, G. Mott, B. Nelson, Phys. Rev. 83, 873 (1951).

CAPTIONS FOR FIGURES

1. Elements of the fast neutron scintillation spectrometer. Recoil protons from a polyethylene radiator (not shown) produce quadruple coincidences in four scintillation counters. The quadruple coincidence opens a gated amplifier, and the height of the pulse produced in the fourth scintillation crystal is then recorded in a 24-channel pulse-height analyzer.
2. The quadruple coincidence scintillation counter telescope. The fourth crystal is inside the magnetic shield and is not visible.
3. Typical arrangement of counter geometry.
4. Coincidence amplifier. Pulses in each channel are amplified, limited, clipped and added. A discriminator then selects the multiplicity of coincidences desired.
5. Gated amplifier. The diode clipper may be set to pass part of the pedestal generated by the gating pulse and the entire superposed signal; or, in the "clipped" position, to pass only the signals above a certain clipping level. In the latter position, a portion of the pulse-height spectrum may be amplified and examined by the 24-channel analyzer.
6. Gain stabilization of 5819 photomultiplier (adapted from Sherr, reference 8). Terminal numbers refer to pin connections at socket. The resistor R is adjusted to set the value of gain at which the "plateau" in gain occurs, as shown in Fig. 7. Varying R from 110 to 140 K will move the plateau about 200 volts. Sherr's circuit uses a battery instead of the 5651 and therefore gives somewhat greater flexibility.
7. Gain "plateau" observed for circuit of Fig. 6.
8. Typical set-up for calibration with monochromatic protons. The magnetic

field of the cyclotron allows only particles of a single momentum from target T_4 or T_2 to traverse the collimator and telescope. Other collimator positions can be used to obtain different energies.

9. Calibration of pulse height response of a 1.09 cm anthracene (circles) and a 2.2 cm stilbene crystal (crosses). The anthracene data are normalized to unit pulse height at 193 Mev, the stilbene data to the anthracene at 173 Mev. The dotted curve shows the theoretical most probable energy loss from Symon's theory.
10. Pulse-height resolution width of a 1.09 cm anthracene and a 2.2 cm stilbene crystal. The curves show the values predicted from Symon's theory.
11. Pulse-height spectrum obtained with a 2.2 cm stilbene crystal as counter No. 4. The crosses indicate the data obtained with 131 Mev protons incident on the last crystal. The peak at 85 volts is due to deuteron contamination. The circles indicate the spectrum obtained when sufficient absorber is introduced to slow the protons to 121 Mev.

20

Physics Department
University of Rochester
Rochester, N. Y.

UNCLASSIFIED

NYO-3048

The enclosed figures are to be added to the paper "Construction and Calibration of a Fast Neutron Scintillation Spectrometer" by G.L. Guernsey, G.R. Mott, B.K. Nelson and A. Roberts - NYO-3048.

W-294-21

21

Fig-1.

FIG. 1

FIG. 3

W-294-26

26

FIG. 7

EXPERIMENTAL ARRANGEMENT

PULSE HEIGHT OR ENERGY LOSS RATIO

3.0
2.5
2.0
1.5
1.0

40 50

100

150

200

PROTON KINETIC ENERGY - MEV

FIG. 9

FIG. 10

W-294-30

30

Fig. 11.

FIG. 11

W-294-30