BNL-I-7

November 1, 1948

DETECTION OF NEUTRONS WITH SCINTILLATION COUNTERS

by

ROBERT HOFSTADTER

Princeton University, Princeton, N. J.
Consultant at Brookhaven National Laboratory

Brookhaven National Laboratory [redacted]

Electronics and Instrumentation Division

DISCLAIMER

DETECTION OF NEUTRONS WITH SCINTILLATION COUNTERS

It has occurred to many investigators that the scintillation counter may offer a new means for detection of neutrons.[1,2,3] There is room for improvement of conventional neutron detectors with respect to:

(a) obtaining higher efficiencies
(b) improved geometry of detectors, i.e. smaller size
(c) faster counting.

It has also been suggested that the crystal conduction-type counter (e.g. Ag Cl) may be useful in detecting neutrons. There appears to be a good possibility that such a counter can be developed, in view of the unpublished experiments of K. A. Yamakawa on mixtures of Li Br and Ag Br. However, the relative difficulty of working with conduction-type counters, which require annealing and low temperatures, makes it reasonable to begin a search for a neutron detector with the easier technique of the scintillation counter.

A possibility exists that pure boron crystals may be used as conduction-type counters, since pure boron has many properties similar to diamond. Presumably, if such crystals count, low temperatures would not be necessary. Unfortunately, it has not been possible to obtain pure boron crystals.

These considerations have suggested than an attempt be made to detect neutrons by means of the scintillation counter technique. As is well known, neutrons can be detected by the production of gamma rays following capture by certain nuclei, or by the production of heavy charged particles, or lastly by the production of recoil nuclei. In this work all of these methods have been briefly examined experimentally. The problem divides itself into a study of slow neutrons and fast neutrons.

Methods of Investigation

To detect slow neutrons two methods have been employed, as follows:

1. (a) Detection of single gamma rays following capture by cadmium or mercury.

   (b) Detection of more than one gamma ray by observing coincidences after capture.

2. Detection of heavy charged particles after capture in lithium or boron nuclei.

Method 1

In the method of 1 (a) one places a cadmium or mercury sheet nearby a scintillation counter and records the additional gamma rays due to the neutrons. One takes advantage of the high efficiency for detecting gamma rays with the solid scintillation counter. This feature is, of course, a disadvantage

at the same time, for neutrons are always accompanied by some gamma rays. In fact, the problem of making a neutron counter is more difficult than merely detecting neutrons, for one must discriminate against gamma rays at the same time. Method 1 (b) may perhaps do this, as well as Method 2.

The idea behind Method 1 (b) is that since Cd emits on the average three gamma rays after slow neutron capture, two coinciding gamma ray counts in the scintillation counters may be obtained, depending on the efficiency of the crystal-photomultiplier combination for gamma counting and the solid angle subtended by the counters.

Method 2 (Phosphor Selection)

Phosphors were prepared, having boron or lithium constitutents or impurities, for use with slow neutrons. In this method the alpha particles released by neutron capture will give large pulses while gamma rays will not. One, therefore, distinguishes neutrons from gamma rays in a natural way.

Results

1. (a) The method suggested in 1 (a) has been found to serve moderately well for neutron detection. However, since the neutron count has to be obtained by taking difference readings with and without a slow neutron absorber in the neutron beam, the method is limited only to those cases where gamma ray background is small.

As an example of the counting rate and efficiency, the following case is about what may be expected. A twenty-gram sodium iodide (thallium) scintillation sample enclosed in a quartz bottle, 1" wide by 3/8" thick and 1" high, was placed so that the wide face of the bottle was adjacent the window of the multiplier. The face of the bottle, opposite the window side, was covered with a cadmium sheet 1/32" thick. Counting rates were measured with a boric acid absorber and a gamma ray-equivalent thickness of aluminum.

In these experiments, the total number of slow neutrons emerging in all directions from the polonium-beryllium source is in the neighborhood of 10^5 per second, as determined by measurements with a BF_3 counter. The average counting rates were:

without absorber	896 ± 50 counts per minute
with boric acid absorber	619 " " "
with aluminum absorber	852 " " "
background	110 " " "

The number of neutron counts is, therefore, about 233 per minute or about four per second. Since the neutron source was 30 centimeters from the counter, the number of neutrons striking the cadmium sheet (effective estimated area 9.0 cm^2) per second is about 80. The counting efficiency is therefore of the order of 5%. Since it is difficult to estimate the effective area of both the scintillation counter and the cadmium sheet, this figure is probably not more accurate than within a factor or two.

1.(b) Method 1 (b) has not been pursued in any detail since the number of coincidences, for the source strength used, is only of the order of one every five seconds. Coincidences have been observed visually on an oscilloscope screen but no attempt has been made to measure the rate as distinguished from the random coincidence rate.

2. Various (potential) phosphors have been prepared in an attempt to incorporate boron or lithium in the fluorescent material. The following phosphors have been tried:

(1) Zinc borate, ZnB_2O4 (Kabakjian, Phys. Rev. 51,366,1937)
(2) Lithium chloride with thallium impurity
(3) Sodium iodide with 10% (and also 1%) lithium chloride plus thallium impurity
(4) Sodium iodide with 10% boric acid plus thallium impurity
(5) Sodium iodide plus sodium tetraborate plus thallium
(6) Fused boric acid and ZnS (Ag).

Various other lithium compounds have been fused with thallium impurities. Most of the results obtained thus far, with the exception of (6) above, have been negative. In most cases the reason has been that the addition of impurity makes the fused mass practically opaque, whereas the pure compounds produce transparent or translucent polycrystalline masses. Another reason for negative results, particularly with lithium compounds, is that the quartz tubes, in which the samples are prepared, crack under the strains produced in solidification from the melt. Since the lithium materials are hygroscopic they are soon turned to liquid. Another difficulty is that the quartz is etched by most of the lithium compounds and it is not possible to obtain good light transmission through such etched surfaces. Quartz has been necessary since the melting temperatures are high and also because good ultraviolet transmission is necessary for the lithium halides. Boron compounds show a tendency to combine with quartz and also crack the quartz tubes.

A possible way out of these difficulties is to grow single crystals which, after production, can be cleaved to present a good surface to the photomultiplier. Such an attempt could not be made in the time available and therefore must be postponed until an opportunity for crystal growing arises, perhaps at Princeton.

Method (6) is successful in that it permits neutrons to be detected with hardly any competing background. Slow neutrons have been detected with a phosphor prepared by fusing boric acid in the bottom of a quartz or alundum crucible or boat and adding zinc sulfide (Ag) powder on the glassy surface when cool. Reheating fixes the powder in intimate contact with the fused boric acid. With this arrangement, and the usual Po-Be source, about 20 neutrons/ min have been detected over an effective area of about 3 cm^2. This type of detector has an efficiency of roughly 1% and is therefore somewhat comparable with the cadmium detector of 1 (a). However, this detector has the advantage that it has only small sensitivity to gamma rays.

Further improvements might be made by adding several layers of ZnS (Ag) or perhaps by a better mixing process. One must protect the surface of the boric acid glass because it rapidly "frosts up" in a humid atmosphere.

Although a definitely successful slow neutron detector has not been developed thus far, it appears that the possibilities favor its eventual development; perhaps along some of the paths indicated above.

Fast Neutrons

Dr. H. Poss and the author have studied the possible use of anthracene for counting fast neutrons. The curves of Fig. A show that fast neutrons are, indeed, detected but only as a difference between two large numbers — one due to neutrons (through recoil protons) plus gamma ray background, and the second to gamma ray background. Thus, for neutrons in the range about 1.0 Mev, the use of anthracene is not particularly good, although higher energy neutrons may produce better results. Dr. Poss expects to continue these studies with 14 Mev neutrons.

References
(1) R. J. Moon, Phys. Rev. 73, 1210 (1948)
(2) P. R. Bell, Phys. Rev. 73, 1405 (1948)
(3) R. Hofstadter, Phys. Rev. 74, 100, (1948)

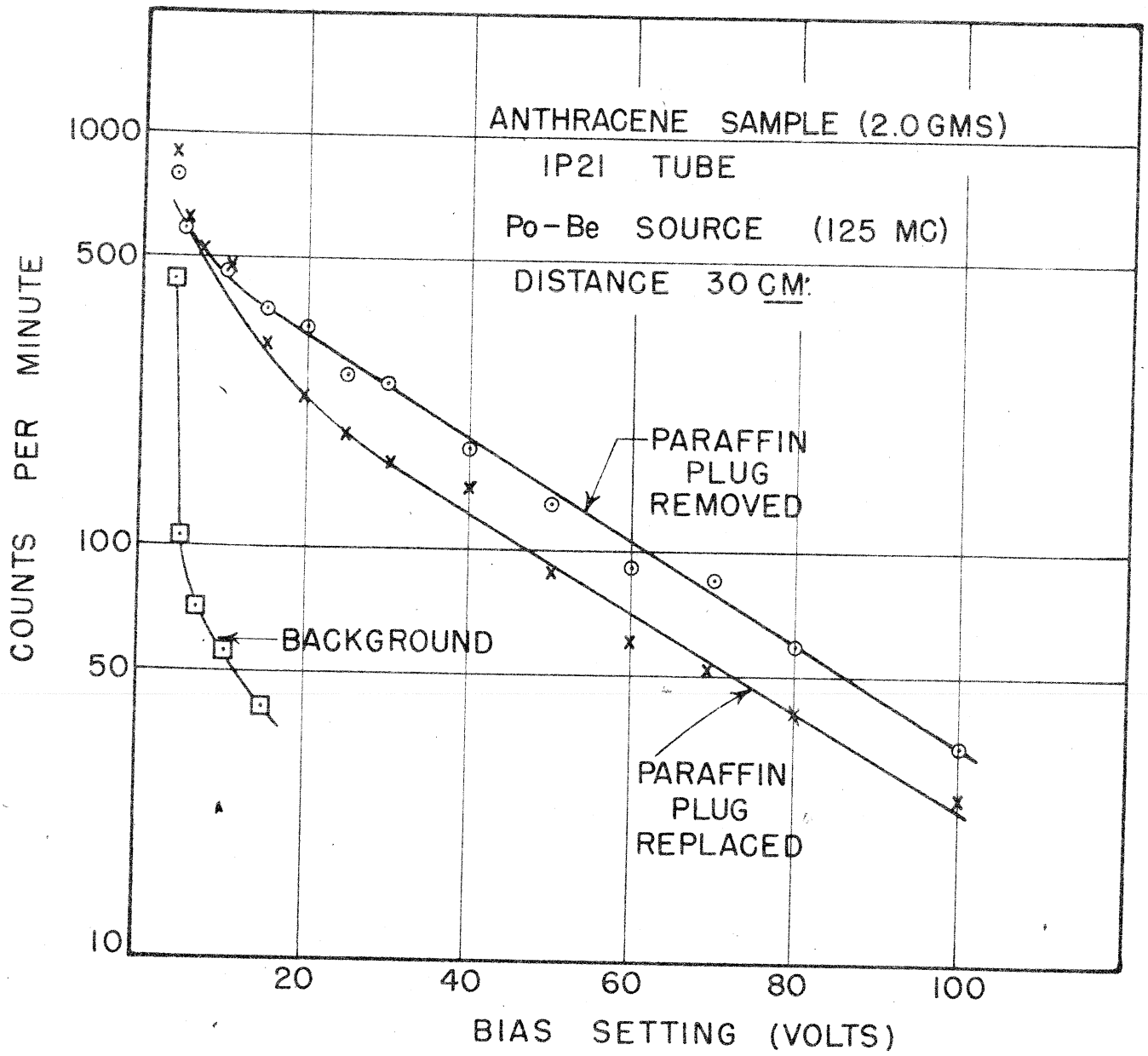
ANTHRACENE SAMPLE (2.0 GMS)
IP21 TUBE
Po-Be SOURCE (125 MC)
DISTANCE 30 CM.
PARAFFIN PLUG REMOVED
PARAFFIN PLUG REPLACED
BACKGROUND
COUNTS PER MINUTE
1000
500
100
50
10
20
40
60
80
100
BIAS SETTING (VOLTS)

FIGURE A