The Total Neutron Cross Section and Measurement of the Nuclear Radius

EQUIPMENT NEEDED FROM EG&G ORTEC	
113 Scintillation Preamplifier	ACE-2K MCA System including suitable IBM PC (other EG&G ORTEC MCAs may be used)
266 Photomultiplier Tube Base	Oscilloscope
Bin and Power Supply	1- to 3-Ci Am-Be neutron source
556 High Voltage Power Supply	1 each AlRd-3, FeRd-1, CuRd-1, PbRd-1, PnRd-1 absorbers (see Appendix)
480 Pulser	High Transmission Stand, HTS-1
575A Amplifier	ORC-16 Cable Set
905-5 Fast Plastic Scintillator and PM tube	

Purpose

In this experiment the total cross section, σ_T, and the fundamental nuclear radius, R_0, will be determined for several elements: aluminum, iron, copper, and lead.

Introduction

This experiment is based on the use of the 1-Ci Am-Be source, probably the most common of the neutron sources. The measurement of total cross section of an element is quite similar to the mass attenuation coefficient measurement made in Experiment 3. In this experiment (written in greater detail in ref. 5) the data for calculations will be obtained by measuring the intensities of the neutrons from the source both without an absorber and with an absorber placed between the source and the detector. Figure 16.1 shows the experimental arrangement of the source, absorber, and detector for this measurement.

The distance from the source to the detector should be ~100 cm, and the absorbers will be introduced, one at a time, at about the midpoint between the source and the detector. Handle the Am-Be source cautiously; 1 Ci of this material produces over 1 x 10^6 neutrons/s. It can be positioned by handling it with tongs at least 3-ft long or by a long string. Instructions for the safe handling of the neutron source are supplied by the manufacturer of the source. These instructions should be read carefully before using the source.

Figure 16.2 is a typical neutron source spectrum that was measured with a ^{3}He neutron spectrometer. It is obvious that the neutron spectrum from this source is rather complicated. For this experiment an electronic bias will be set on the neutron detector in order to eliminate response to neutron energies below ~7 MeV. The average neutron energy from 7 MeV to the end of the spectrum is ~8.5 MeV. A detailed analysis of the mathematical treatment of the neutron spectrum, as well as the total cross section, can be found in refs. 5 and 6. In this experiment the total neutron cross section will

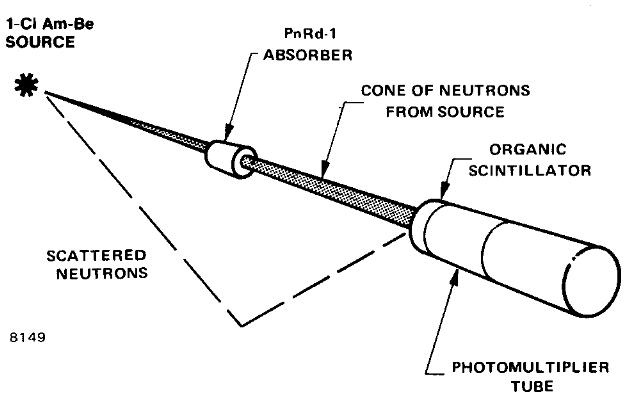

Fig. 16.1. System for Measuring Total Neutron Cross Section.

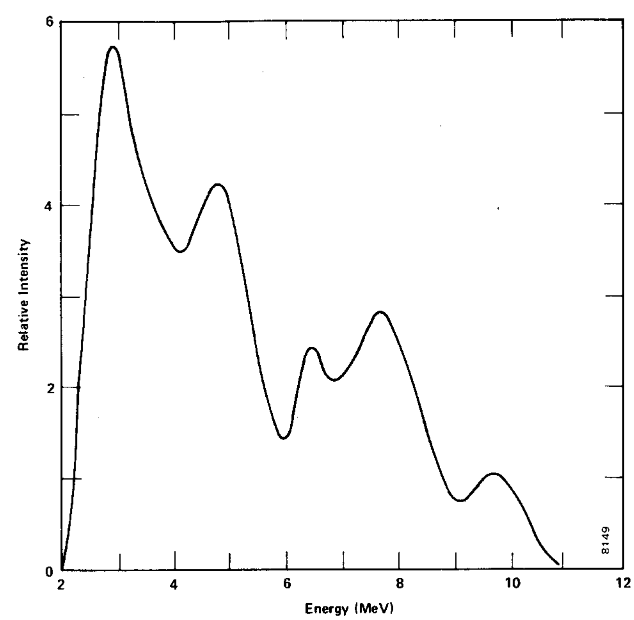

Fig. 16.2. Typical Neutron Source Spectrum Measured with a ^{3}He Semiconductor Spectrometer.

be measured for the several elements and for an average neutron energy of 8.5 MeV. The experimental values can then be compared with the accepted cross sections listed in ref. 1.

The Total Neutron Cross Section (TNCS)

The TNCS measurement is a transmission measurement. In Fig. 16.1 the number of neutrons, dN, that are removed from the initial beam by the absorber is given by

$$dN = \mu_t N dt\ , \tag{1}$$

where

μ_t = linear absorption coefficient,
N = initial number of neutrons without the absorber,
dt = thickness of the absorber (in this case it is the length of the absorber in cm).

Hence, as for I_0 in Experiment 3,

$$N = N_0 e^{-\mu_t t} \tag{2}$$

The total cross section, σ_T, is defined from μ_t as

$$\sigma_T = \frac{\mu_t}{n}\ , \tag{3}$$

where n = number of nuclei/cm^3 of the absorber.

If we substitute Eq. (3) back into (2), the following is obtained:

$$N = N_0 e^{-\sigma_T n t}\ . \tag{4}$$

Since N/N_0 is equal to the transmission T,

$$T = e^{-\sigma_T n t}\ , \tag{5}$$

and the total cross section, σ_T, is given by

$$\sigma_T = -\frac{\ln T}{nt}\ . \tag{6}$$

The samples to be used as absorbers are cylinders that are ~6 cm in diameter by a length, (t), of ~7 cm. The nt values for Eq. (6) can be calculated for each sample. These nt values are the number of nuclei/cm^2 for each absorbing sample. The transmission in Eqs. (5) and (6) is simply a ratio of the neutron counts with and without the absorber.

From the Optical Model Theory in ref. 4 the total cross section can be expressed:

$$\sigma_T = 2\pi (R + \lambda\!\!\!^{-})^2\ , \tag{7}$$

where

R = $R_0A^{1/3}$,
R_0 = fundamental nuclear radius (~1.3 x 10^{-13} cm),
A = atomic weight of scattering sample,
$\lambda\!\!\!^{-}$ = the de Broglie wavelength/2π for 8.5 MeV neutrons (ref. 4).

Equation (7) can be written in two other forms:

$$\sigma_T = 2\pi\ (R_0 A^{1/3} + \lambda\!\!\!^{-})^2\ , \tag{8}$$

and

$$\sqrt{\sigma_T} = \sqrt{2\pi}(R_0 A^{1/3} + \lambda\!\!\!^{-})\ . \tag{9}$$

The fundamental nuclear radius, R_0, is therefore

$$R_0 = \frac{\sqrt{\sigma_T/2\pi} - \lambda\!\!\!^{-}}{A^{1/3}} \tag{10}$$

If the $\sqrt{\sigma_T/2\pi}$ is plotted as a function of $A^{1/3}$ for the absorber, the slope of the line is R_0. The purpose of this experiment is to measure σ_T for aluminum, iron, copper, and lead and to determine R_0 from the analysis derived above.

Procedure

1. Set up the electronics as shown in Fig. 16.3, and position the source and detector as shown in Fig. 16.1 separated by ~1 m and located on a common optical axis. The high transmission stand (HTS-1) that will hold the sample and the shadow bar should be placed half-way between the source and the detector. The source, stand, and detector can be aligned on axis with a tight string, or if available, a small laboratory laser. Do not put an absorber in the stand at this point.

2. Adjust the controls on the instruments as follows: set the 556 high voltage to the value that is recommended for the 905-5 detector; set the amplifier gain for a maximum bipolar output amplitude of ~5 V.

3. Accumulate a spectrum on the MCA. It should look like Fig. 16.4.

4. Set the Lower Level of the MCA so that it cuts out all pulses below the location marked E in Fig. 16.4. This corresponds to an energy level of ~7 MeV. Many of the pulses from the detector that represent energies below this level are gammas rather than neutrons, but most of the pulses for energies ~7 MeV represent neutrons only. The 7-MeV point in the spectrum can be determined by a linear extrapolation since the end point of the spectrum will be ~11 MeV.

5. Clear the analyzer to zero. Accumulate a spectrum in the MCA until there are ~3000 counts in the active portion of the spectrum.

EXERCISES

a. Compare the spectrum with the portion of Fig. 16.4 above the 7-MeV level. Record the number of counts and the accumulation time, t_0, in Table 16.1. Use the first line for "No absorber."

b. Place the aluminum absorber in the stand (on the axis) as shown in Fig. 16.1 and repeat the measurement made in

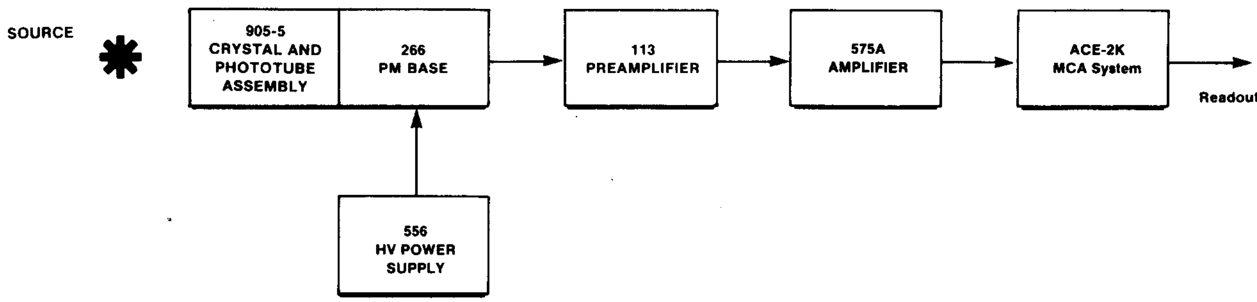

Fig. 16.3. Electronics for Total Neutron Cross-Section Measurements.

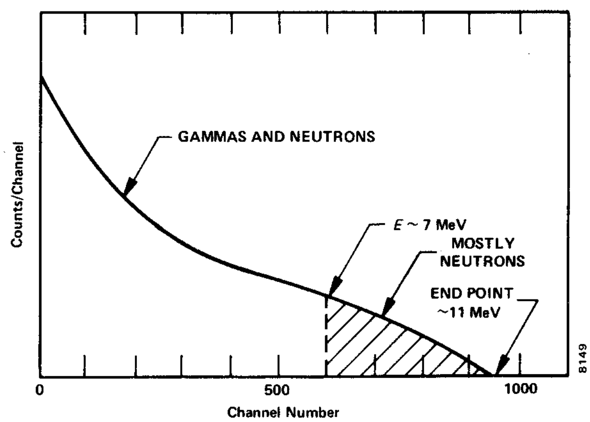

Fig. 16.4. Typical Neutron Spectrum Taken with an EG&G ORTEC 905-5 Detector.

step **5** for the same time, t_0. Record the counts in Table 16.1. Repeat for each of the other absorbers and for the shadow bar. The shadow bar effectively attenuates all of the direct neutrons from the source, and any counts that are accumulated when it is in position will be those scattered from the floor or other surroundings into the detector. This is background, and the number of counts taken with the shadow bar must be subtracted from each of the other counts in Table 16.1 before these data are used.

c. Calculate σ_T from the corrected data in Table 16.1, using Eqs. (4), (5), and (6). Record these values in Table 16.1 as σ_T (measured). Look up the accepted values for $E_n = 8.5$ MeV in ref. 1 and record these in the last column of Table 16.1. Compare the measured values with the accepted values.

d. Plot $\sqrt{\sigma_T/2\pi}$ versus $A^{1/3}$ on linear graph paper and determine R_0 from the plot. Figure 16.5 shows some typical data that were measured by this method.

Additional Note: The conventional neutron long counter that is found in many laboratories could have been used to count the neutrons in this experiment. These counters can be set so that they are relatively insensitive to gammas, and the system can be operated to measure a wider portion of the spectrum than just the part from 7 to 11 MeV. The gamma

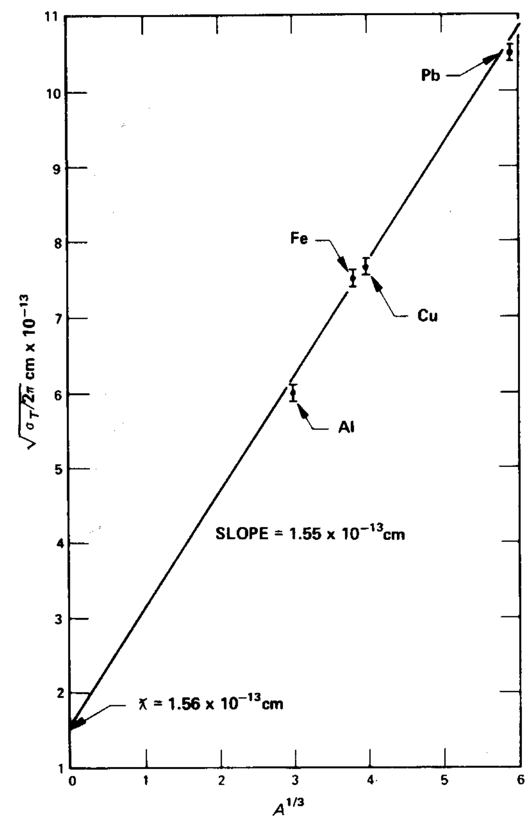

Fig. 16.5. Plot of $\sqrt{\sigma_T/2\pi}$ versus $A^{1/3}$ for Am-Be Neutron Energies (Electronic Bias at 7 MeV).

Table 16.1

Sample	Counts	Time, t_0	σ_T Measured	σ_T Accepted (from ref. 1)
No absorber				
Aluminum				
Iron				
Copper				
Lead				
Shadow Bar				

problem can also be solved by using pulse shape discrimination with, for example, an organic scintillator and an EG&G ORTEC 458 Pulse Shape Analyzer.

References

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