Modern Physics Lab PHYS 3704L
Neutron Flux of a Pu-Be Howitzer[1]
Experiment 9

Neutron activation analysis can be used to determine the half-lives of isotopes created by exposure to neutrons or to determine the activity of the incident neutron beam. The source of neutrons for our experiment is housed in the basement of the Biology wing of Ward Beecher Hall. It is a mixture of plutonium and beryllium (a Pu-Be "howitzer"). The reaction that produces neutrons in the source is

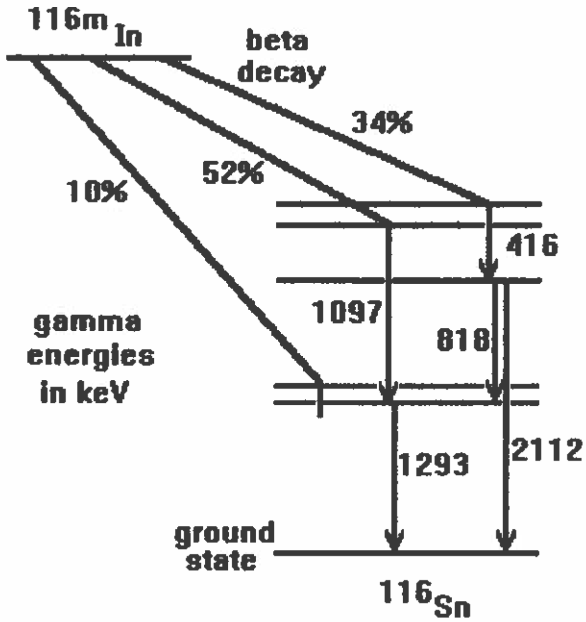
$$^{9}Be+\alpha \rightarrow n+^{12}C+5.704MeV,$$

where the 5.704 MeV is the energy resulting from the conversion of mass to energy in the reaction shown above. It is the difference between the masses of the beryllium and helium nuclei and the masses of the neutron and the carbon nucleus. Since the incoming alpha particle has an energy of about 5.5 MeV (from the plutonium decay), there is about 11 MeV available to the neutron and carbon nucleus after the reaction. By momentum conservation, the neutron could get 12/13 of the available energy in a linear reaction but the actual amount can vary considerably with angle. In addition, ^{12}C could be left in an excited state, and the energy of the incoming alpha could be lost in collisions in the source before the reaction occurs. For these reasons, only an upper limit of about 11 MeV can be assigned to the neutrons coming from the howitzer.

The howitzer is surrounded by paraffin which helps to "moderate" the neutrons. The ideal way to slow high energy neutrons is to cause them to collide with something their own size. Since using another neutron would only give the energy to another neutron, this choice is not very productive in that it simply excites more neutrons. Protons are the next choice. High energy protons are easily stopped after the collision through Coulomb forces, and paraffin is an excellent source of protons. Slow neutron reactions are usually of the type

$$n+^{x}A\rightarrow ^{x+1}A+\beta+\gamma,$$

where the excited nucleus ^{x+1}A beta decays followed by gamma emission. Our target nucleus is indium. The stable isotope of indium is ^{115}In. We will expose a metal foil of ^{115}In to slow neutrons to form ^{116}In that decays into ^{116}Sn with a half-life of approximately 54 minutes followed by gamma ray emission (0.416MeV, 1.097MeV, 2.112MeV, & 1.293MeV). Our goal is to determine the activity of the source (through the paraffin obstruction in howitzer chute #2). At the same time, we will determine the decay half-life for ^{116}In. A partial energy level diagram for these decays is shown in the figure on the following page.[2]



The activity of the sample in disintegrations per second at time t=0 (the instant the sample was removed from the howitzer) is given by

$$A_0 = \frac{\sigma m \eta \phi \alpha S}{w},$$

where

A_o = number of disintegrations per second at the time of removal of the sample from the howitzer
N = cross section of the reaction in cm^2
m = mass of target element (^{115}In) in grams
5 = Avogadro's number
P = neutron flux in neutrons/(cm^2sec)
K = fraction of target isotope in the sample
S = saturation factor for activation, $1-e^{-9t}$ where 9=0.693/$T_{½}$
(t is the activation time in the howitzer)
$T_{½}$ = half life for the reaction
w = atomic weight of the element

It is possible to look up all of the above values except A_o, P, and S. We can experimentally determine S by noting the activation time t, A_o and $T_{½}$ by fitting the exponential decay of ^{116}In. Ideally, one can fit the exponential decay of individual peaks in the gamma energy spectrum for redundant measures of $T_{½}$ and A_o.

The Maestro software in Dr. Carroll's lab can be used to automatically collect data for this experiment. It should be run for at least 3 or 4 lifetimes. If you collect data for 3.5

hours, saving each 30 minutes, you should have ample data. If you select a region of interest that encloses one of the decay peaks and consider the total numbers of counts (area) under the peak collected in a certain time period as a function of time, you should easily be able to plot an exponential decay that can be fitted for $T_{1/2}$ and A_o (even with EXCEL).

The sequence of steps to run the program will be shown to you in the XEL laboratory in the engineering building. Note that the Indium foils need to be exposed to neutrons for a time period long enough to cause some saturation of the excitation (about 3 or 4 hours also). You will need to time each step of the experiment. In addition, you must make sure that the germanium detector has been cooled with liquid nitrogen 5 to 6 hours before you can collect data. It is probably a good idea to load the howitzer with an indium foil at the same time the detector is first cooled.

[1]Modified from Ortec Application Note, second edition. Ortec Inc., 1976.
[2]Assembled from information in *Table of Isotopes*, Vol I, J. Wiley and Sons, 1996.