

Physics 1040L Laboratory

LAB 12: RADIOACTIVE DECAY OF NUCLEI

OBJECT: To study the time dependence of radioactive decay. To find half-life time for a given material.

APPARATUS: Geiger-Mueller counter, stage, sample holder, with computer interface, radioactive source.

THEORY: The nuclei of many artificially created and of a few naturally occurring *isotopes* are unstable and spontaneously change into other nuclei by the emission of α -particles, β -particles and γ -ray photons in the process of radioactive decay.

The rate at which decays occur, or number of decays per unit time, is called the *activity* of the radioactive source. The *half-life* of a radioactive substance is the time required for its activity to be reduced by one half. The intensity of the radiation detected depends on the distance between the detector and the source (via the inverse square law **SEE Lab 1**) as well as the activity of the source itself.

The probability of nuclear decay is determined by the interactions among the various components within the nucleus, and because the forces among the nuclear particles are so strong, external forces do not usually play a role. Consequently, the probability of decay is independent of external circumstances, such as the number of other nuclei present, and the number of nuclei of the original, or *parent* isotope is a decreasing function of time. For example, if 100 million nuclei were present in a sample, we might expect 100 of them to decay in the next second. If only 50 million nuclei were pre-sent, we would then expect 50 to decay in the next second. At each moment, the activity of the source, A , is proportional to the number of parent nuclei, N , remaining at that time:

$$A = \frac{dN}{dt} = -\lambda N \quad (1)$$

where λ is called the decay constant. The negative sign indicates that the number of parent nuclei decrease with time.

Integration of equation (1) leads to the result that

$$N = N_0 e^{-\lambda t} = N_0 e^{-0.693 \frac{t}{\tau}} \quad (2)$$

Where N_0 is the initial value of N and τ is the half life. Moreover, since the activity of the sample is proportional to N , we can also write

$$A = A_0 e^{-\lambda t} \quad (3)$$

Where A_0 is the initial activity. The half-life, $t_{1/2}$, of a radioactive isotope can be derived from equation (3) by setting

$$\frac{A}{A_0} = \left(\frac{1}{2}\right) \quad (4)$$

The primary objective of this experiment is to determine the half-life of Iodine-128.

Note: Because of the statistical nature of radioactive decay, there is an uncertainty inherent in every count that is obtained. Repeated counts, under identical conditions, follow a Poisson distribution. Furthermore, the standard deviation of the Poisson distribution is equal to the square root of the average number of counts. Consequently, the error in any single count is taken as the square root of that count. Therefore, it is advantageous to maximize the number of counts in order to reduce the error. To illustrate this, note that if 100 counts were obtained, the uncertainty would be 10 counts — or 10%. If 10,000 counts were obtained, the uncertainty would be 100 counts — only 1 per cent.

Units: An activity of one disintegration per second is called a Becquerel (Bq). An older unit of activity still in use is the curie (Ci), equal to 3.7×10^{10} disintegrations per second. A common subunit is the micro curie: $1 \mu\text{Ci} = 37,000 \text{ Bq}$ and $1 \text{ Bq} = 2.7 \times 10^{-5} \mu\text{Ci}$.

Iodine-128: The ^{128}I sample in this experiment is not pure, but is part of the molecule potassium iodate (KIO_3). The iodine in a normal KIO_3 molecule is ^{127}I , which is stable and, therefore, not radioactive. The KIO_3 sample used in this experiment is activated by placing it in a neutron howitzer, which contains an Americium-241 source and a Beryllium-9 target. Americium-241 decays to Neptunium-237 by emission of an α -particle (the nucleus of a helium atom). This is written as: $^{241}\text{Am} \rightarrow ^{237}\text{Np} + ^4\text{He}$.



Figure 1 Neutron Howitzer

The α -particles hitting the Beryllium target fuse with it to form Carbon-12. In this process a neutron (n_0) is given off (${}^4\text{He} + {}^9\text{Be} \rightarrow {}^{12}\text{C} + n_0$). The Iodine-127 in the howitzer absorbs this neutron and in the process is transformed into Iodine-128 (${}^{127}\text{I} + n_0 \rightarrow {}^{128}\text{I}$). Iodine-128 is a radioactive isotope which decays to Xenon-128 by emitting an electron (β^-): (${}^{128}\text{I} \rightarrow {}^{128}\text{Xe} + \beta^-$)

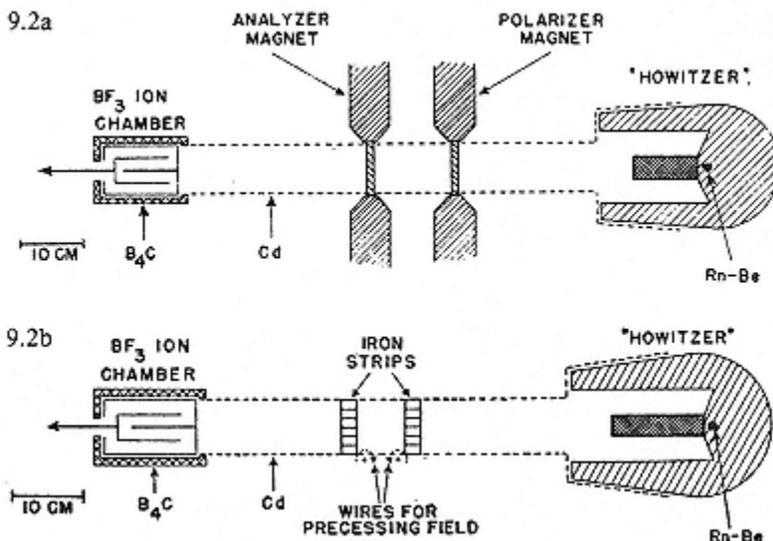


Figure 2 Schematic diagram of Neutron Howitzer

Geiger-Müller Tube: The detector in this experiment consists of a Geiger-Müller (G-M) tube connected to a pulse counter. A G-M tube is a cylindrical tube with a thin membrane on one end containing a low-pressure gas (Argon). A wire through the central axis of the tube is held at a high positive potential. When ionizing radiation enters the tube, the electrons freed through ionization are attracted to the positively charged central wire. As they move toward the wire, the electrons ionize other atoms through collisions, thus freeing more

electrons which are also attracted to the central wire and which in turn ionize other atoms. The resulting cascade of electrons produces a small electrical pulse that is amplified and counted by a scalar-timer.

Caution! The membrane covering the front of the G-M tube is rather thin and fragile. The tube is expensive to replace.

Background radiation arises from radioactive isotopes that occur naturally in the environment and from cosmic ray events. The background count allows you to correct the source counts for these extraneous sources.

Caution! The radioactive sources used in this experiment are not strong, but they should be treated with respect. After you have completed the background count, Mr. Pitkin will place the activated sample in the top slot of the stage. **NO FOOD OR DRINK IS ALLOWED IN THE LAB**

When the experiment is done leave the sample alone

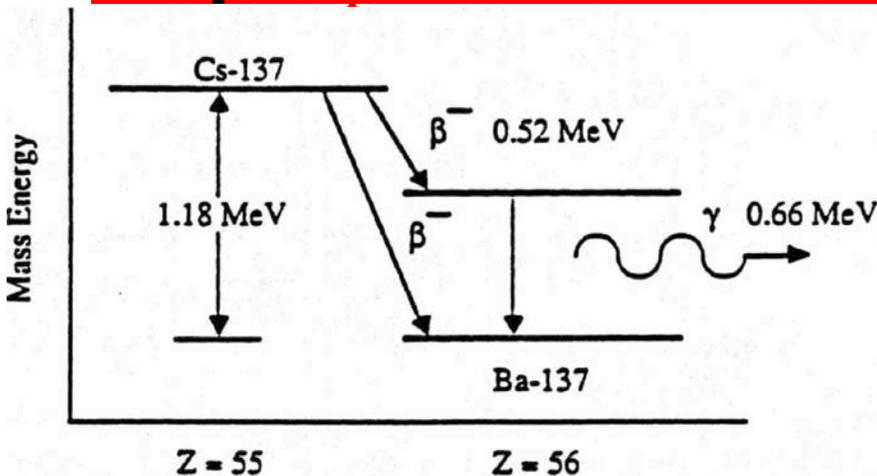


Figure 3. Radioactive decay schemes of Cs-137 and Ba-137

The diagram above gives the decay process Cesium 137. Cesium has a radioactive isotope, a 30 year half life that beta decays to an excited state of barium (Ba-137), as shown in the figure 3. This excited state has a half life of a few minutes and is easily measured.

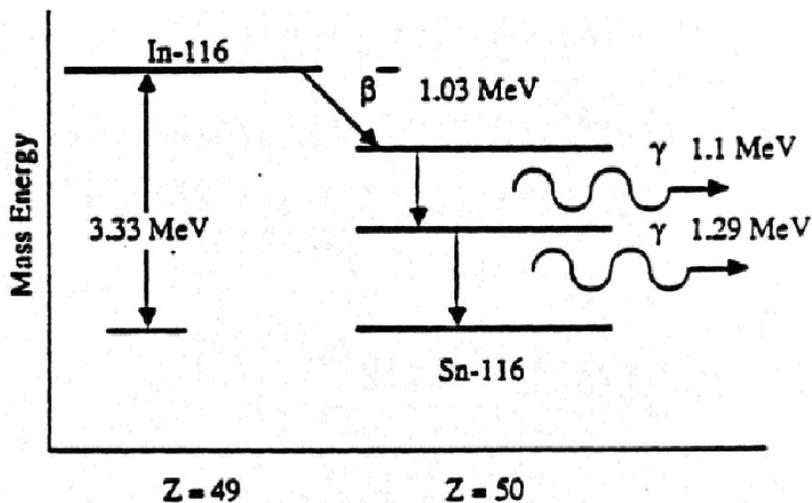


Figure 4. Radioactive decay scheme of In-116.

Indium metal (^{49}In , atomic number of 49) as found on the surface of the earth is 95.72 % mass 115 and 4.28% mass 113. (Using the nuclear masses of 114.9041 and 112.9043 instead of the number of nucleons, 115 and 113, the chemical weight of 114.82 can be calculated.) If the indium is placed where there are many free neutrons with kinetic energies, on the order of 0.03 eV, both isotopes In-115 and In-113 will absorb neutrons, and become radioactive nuclei, In-116 and In-114, respectively. Because there are so few In-113 atoms compared to In-115, and because In-115 has a much larger probability (cross section) to capture a neutron, neutron irradiated samples of indium contain primarily In-113, In-115, and In-116 nuclei. The decay of In-116, sketched in figure 4, involves the prompt emission of two gamma rays after the nucleus beta decays to become tin, Sn-116.

Procedure

1. To find the background count set the time on the counter to 300 sec, number of runs to 0 runs.
2. Record the number of counts for 300 seconds.
3. Divide the number of counts for 300 seconds by 5 to get background counts in **counts per minute**.
If the background counts in counts per minutes gives a decimal number round the number up if the decimal part of the number is ≥ 0.5 c/min and down to nearest whole number if is < 0.5 c/min.
4. Set the time on the counter to 60 seconds.
5. Set the number of runs to 90 runs
6. Obtain a sample of radioactive material from your lab instructor.
7. it will immediately placed in the top slot of the stage (2cm distance from G-M tube) by your instructor.
8. Start the GM counter and record the number of counts occurring in 90 sixty-second intervals.
9. Save your data as a *.tsv file.

10. Open this file in Excel.
11. Record your background radiation in this file.
12. Save it as Excel file.
13. Put it on a USB flash drive or e-mail it to yourself.

DATA ANALYSIS

YOU WILL PLOT YOUR DATA USING TWO DIFFERENT GRAPHS

Organize your data in the Excel file in the following way:

1. Background radiation for 300 s. Calculate background radiation for 1 minute
2. Subtract the background radiation in c/min from your raw counts in c/min, and put the results in a second column.
3. Calculate natural logarithm of corrected counts and place the results in a third column (next column).
4. Your time is based on your run number in minutes (next column).
5. Plot Ln of adjusted counts as a function of t.
6. This should be a linear function.
7. The slope of the line will be equal to the decay probability constant, λ (see equation 2). The half-life time of the sample can be calculated as

$$\tau = 0.693/\lambda = (\ln 2)/\lambda \quad (5)$$

8. Find the decay constant and the half-life time.
9. Compare your half life time with the given data. Is the material as predicted?
10. For your second graph you will plot the corrected counts in counts per minute vs. the time in minutes.
11. You will fit your data to an exponential function $Y = A*\exp(-Ct)+ B$.
12. Find the half life of you Radioactive Nuclide from this fitted data. **Refer to the RC Time Constant Lab, if you have forgotten how to do this.**
13. Using a search engine on your browser, search for “Chart of the Nuclides” and find the correct value of τ for your sample. Find and look at the decay scheme for our sample.
14. Make sure you list the web site where you found this information in the results section of your report.

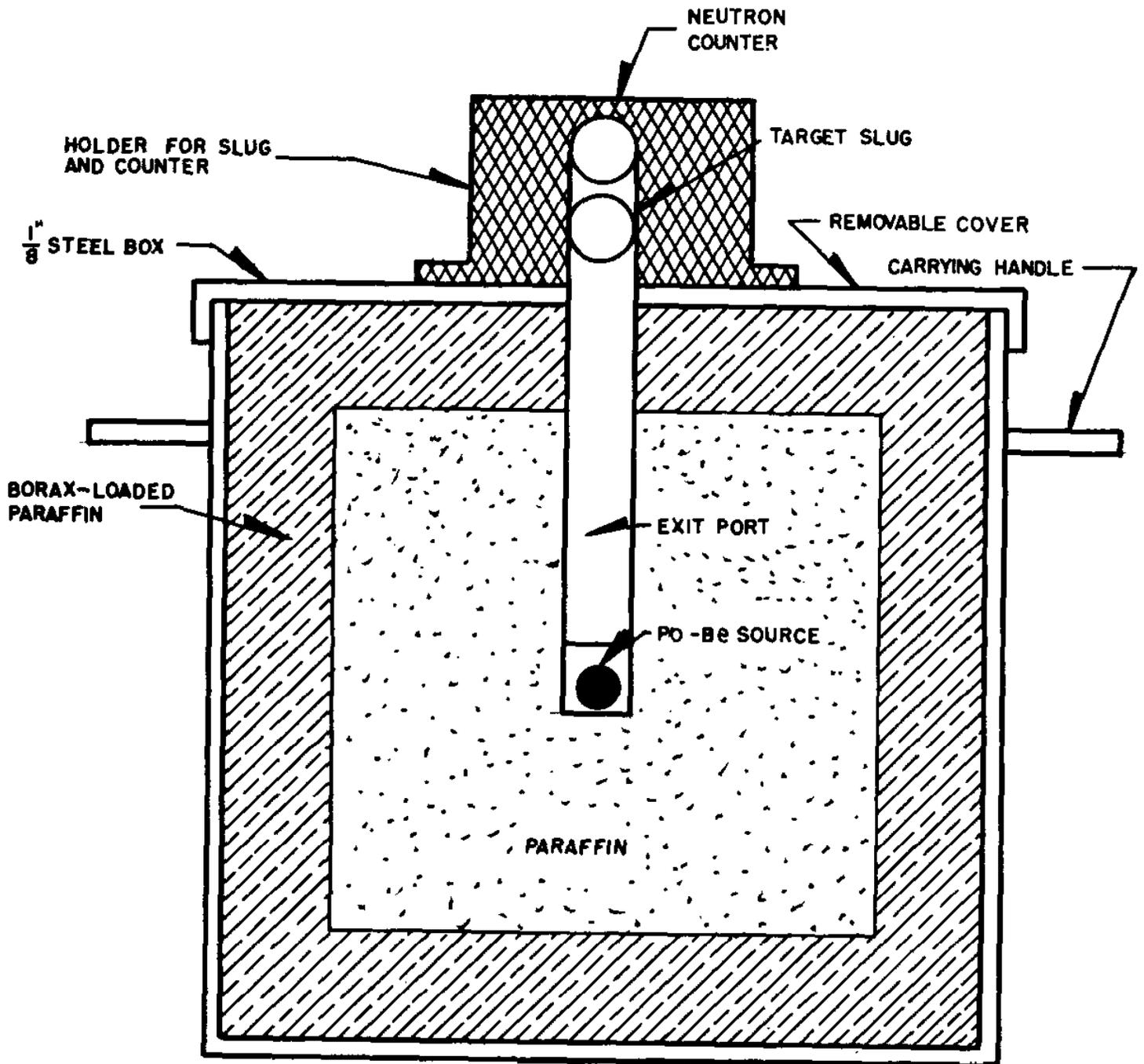


Figure 5 Cross section image of another Neutron Howitzer

Example of how to set up Excel Spread Sheet.

RUN NUMBER	TIME (min)	Raw Counts (c/min)	Corrected Counts (c/min)	Ln Corrected counts	
1	1	45,058.0	45,023.0	10.714	
2	2				
3	3				

Background counts in counts/min = 35 c/min