Neutron Activation Analysis

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1 Introduction and Theory

A neutron is an electrically neutral particle, generally located in atomic nuclei. Neutrons can also exist freely outside the nucleus, and have a half life of 15 minutes. A free neutron will decay according to the β^- decay scheme:

$$n \rightarrow p + e^- + \bar{\nu} \tag{1}$$

A neutron has many properties which we can exploit in order to learn more about the atomic structure and the properties of materials. Firstly, a neutron has an intrinsic magnetic dipole moment. This means that a neutron can behave as a small magnet, and that the neutron can interact with matter through its magnetic moment. The existence of the neutrons magnetic moment indicates that the neutron is not an elementary particle. For an elementary particle to have an intrinsic magnetic moment, it must have both spin and electric charge. The neutron has spin 1/2, but it has no net charge and thus it must have an internal structure. This was explained using the quark model; the neutron consists of three quarks; one up and two down. It also indicates that the internal charge distribution of the neutron must be such that the negative charge is concentrated on the periphery. The existence of the magnetic monopole means that microscopic magnetic structures can be investigated.

The De Brogile wavelength of slow moving neutrons are comparable with interatomic distances, and the energies of slow moving neutrons are comparable with the energies of nuclear and molecular movements. As neutrons are electrically neutral, they will not interact with the electronic electron shells of atoms, but only with the nuclei.

Neutrons can be used to induce nuclear reactions via a process called nuclear activation, which is investigated in this experiment. This process involves the formation of a compound nucleus as a result of free neutron capture by a stable nucleus. The free neutron usually impacts with an atomic nucleus, and forms a nucleus of atomic number $A + 1$. The captured neutron shares its kinetic energy with the nucleus, and the nucleus enters an excited state due to the increase in kinetic energy and the increase in mass. As a result, the nucleus will no longer be stable and will decay via the following channels: emission of an α-particle, of two or more nucleons, of γ-ray photons or by undergoing nuclear fission. Thus the process of neutron capture often involves the formation of an unstable activation product. Neutron activation is the only common way that a stable material can be induced into becoming radioactive. All naturally-occurring materials can be induced (activated) by neutron capture into some amount of radioactivity as a result of production of neutron-rich radioisotopes.

Neutron activation is used in this experiment in order to induce radioactivity in a strip of natural metallic silver. This is achieved by placing the strip which contains two stable isotopes; ^{107}Ag and ^{109}Ag into a canal connected to a chamber containing a neutron source. The cross sections for thermal neutron capture are 30b and 80b, respectively. The neutron source (Pu-α-Be) is placed in a paraffin block so the neutrons can be moderated, i.e. slowed down, as the cross section for thermal neutrons is much higher than that of fast moving neutrons. Three channels are available for the insertion of the silver strip, all at a sufficient distance

from the source to allow complete thermalisation of the neutrons generated by the source. As a result, the canals contain optimum conditions for the activation of nuclei by neutron capture.

2 Experimental Method

Figure 1: Experimental setup.

Before the experiment is run, it is ensured that all apparatus is correctly connected; the neutron source is placed in a lead protection shell where the three available chambers for the insertion of the silver strip are visible. A cascade of geiger counters are protected by a lead jacket, and contain a slit into which the activated silver strip can be inserted. This is connected to a high voltage power unit which is in turn connected to a counter device. The power supply on the high voltage power unit was turned on and the voltage set to 400V. The counting device was switched on and the following settings were specified; the pulse counting channel B was chosen, as was the button N. 10 second time intervals were selected. This set up resulted in number of counts over the 10 second interval being displayed on the counter.

Under the supervision of an adviser, the holder containing the sample of silver was lowered into the canal of the neutron source and left there for just over 15 minutes. While the sample was being activated, the background count was measured. The automatic measurement was started, and the counter measured the count over 10 second intervals. The counter saved 20 values and an average background count, n_f, was obtained. The memory was cleared, and after the appropriate 15 minutes, the activated sample was removed from the channel linked to the neutron source and placed in the canal of the lead container of the geiger counter set up. The measurement of the count for 10 second time intervals was started immediately, and consecutive measurements were taken until the count approached n_f. All measurements were noted in the lab notebook. The high voltage power supply was turned off, as was the counter device, and the sample was removed from the channel of the geiger counter.

Once the data was recorded, it remained to plot the dependence of the count rate on time. The background count n_f was subtracted from each reading, and they were then divided by the time interval $\tau = 10$s in order to find the activity, N. By plotting $\ln N$ as a function of time, the behaviour of the activity of the sample can be observed. More specifically, the different behaviours at different times suggests that there are two individual activities, N_1 and N_2, present, which represent the activity of the shorter and longer nuclides, respectively. Assuming these activities are described by the equations

$$\ln\left(N_i\left(t\right)\right) = \ln\left(N_i\left(0\right)\right) - \lambda_i t, \quad i = 1, 2 \tag{2}$$

then the decay constants λ_i and hence the half lives of the radioactive nuclei can be determined.

3 Results and Analysis

The data was recorded and is represented in the graph below. A curve of exponential decay was fit through all of the data points, and a straight line can be fit through the latter half of the points which represents $\ln N_2$. The equation obtained for this was $\ln(N_2(t)) = 0.92163 - 0.00296t$, giving us values of $\ln(N_2(0)) = 0.92163$ and $\lambda_2 = 0.00296$. Using this equation, the activity was determined to be $N_2 = \exp(0.92163 - 0.00296t)$, which was used to determine N_1. Since $N = N_1 + N_2$, N_1 was determined using

$$\ln(N_1) = \ln(N - N_2), \tag{3}$$

where the expression for N_2 was previously determined and the values for N could simply be used from the recorded data. By obtaining values for $\ln(N_1)$ at two different times, two points were obtained, and hence the linear expression was determined: $\ln(N_1) = 3.64618 - 0.016818t$, giving values of $\ln(N_1(0)) = 3.64618$ and $\lambda_1 = 0.016818$. By using

$$T = \frac{\ln(2)}{\lambda}, \tag{4}$$

half-lives of $T_1 = 41.21$s and $T_2 = 234.17$s were obtained for the short living and long living isotopes.

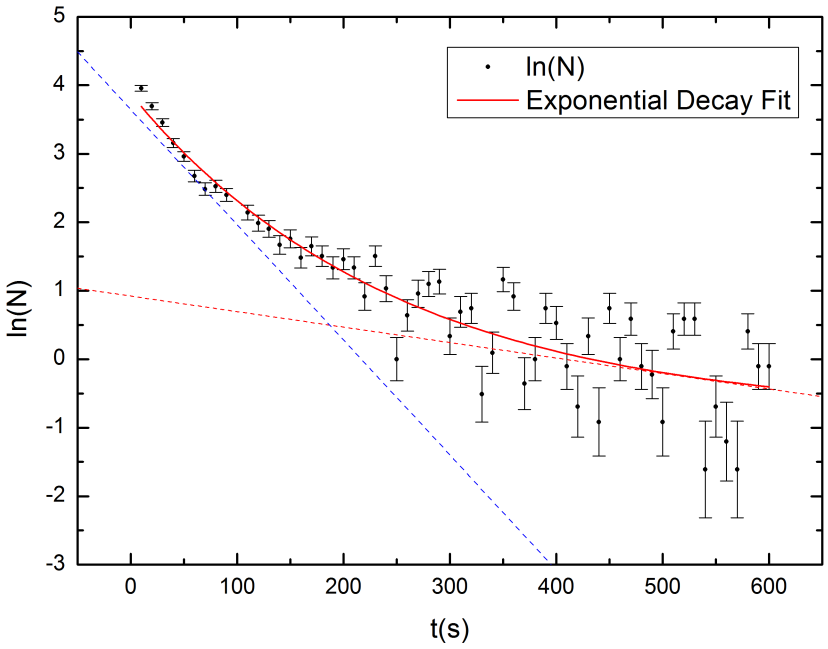

Figure 2: Dependence of the counting rate on time. The counting rate of the long living nuclides is represented by the dashed red line and the count rate of the shorter lived nuclides is represented by the dashed blue line.

4 Discussion and Conclusions

Half-lives of $T_1 = 41.21$s and $T_2 = 234.17$s were obtained for the short living and long living isotopes. These results make sense in the sense that the longer lived isotope has a larger half life than the shorter lived one. Assuming the isotopes in question are ^{108}Ag and ^{110}Ag, then the obtained values for the half lives are of the same order, but differ from the accepted values of 24.6s and 2.37min. One possible reason for this is that the experiment was only preformed once. By repeating the experiment multiple times and taking average values, the accuracy of the half lives obtained could be improved. Also, it was difficult to determine when the count approached the background count, so taking a much larger range of measurements would also have contributed to improving the accuracy of this experiment.