The Determination of the Half-Lives of Silver and Indium

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(Dated: September 6, 2022)

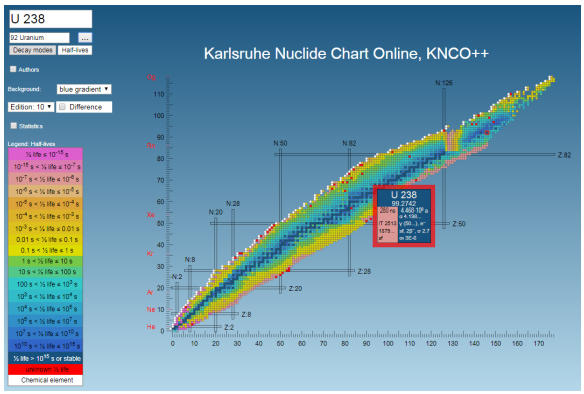

FIG. 1. Chart of nuclides.

I. Introduction

Purpose

The purpose of this experimentation is to (i) to understand the irradiation of silver and indium and (ii) to measure the half-lives of Silver-108, Silver-110, and Indium-116.

Radiation and Radioactive Decay

There are three primary forms of natural radioactive decay: alpha decay (α), beta decay (β), and gamma decay (γ). Alpha decay occurs when a radioisotope emits a particle that is equivalent to a doubly ionized Helium atom, i.e., an atom with two protons, two neutrons, and no electrons. Beta decay is normally associated with the loss of an electron and an increase in atomic number; however, although this is the end result, this raises the question of how the loss of an electron affects the number of protons. What actually occurs to produce the ejected electron is the decay of a neutron into a proton, an electron, and an antineutrino[1]. The last of the primary types of decay is gamma decay. Gamma decay is unique compared to alpha and beta decay in that the atomic mass and the atomic number are conserved, at the expense of an ejected high energy photon. Gamma decay typically occurs after alpha and beta decay, since both decays leave the nucleus in a high energy state. Thus, gamma decay occurs to bring the nucleus to a lower energy state.

When radioactive materials decay, they do so in a specified amount of time. Depending on the identity of the radioisotope, the time it takes for a sample to decay will vary, with decay times ranging from seconds to hundreds of thousands of years. Figure 1 is a Karlsruhe Nuclide chart, which provides information on the half-lives of different radioisotopes[2]. Each radioisotope has an associated lifetime, during which the sample continuously decays. The lifetime arises from the first-order, linear differential equation and its solution:

$$\frac{dN}{dt} = -\lambda N$$
$$N(t) = N_0 e^{-\lambda t},$$

meaning that the rate of change of nuclei with respect to time decreases proportionally to the number of nuclei present, which means that radioisotopes decay exponentially. In the above equation, N is the number of nuclei as a function of time, N_0 is the initial number of nuclei, and λ is the parameter that characterizes the lifetime of the radioisotope. The larger the λ, the faster the sample decays and the shorter the sample's lifetime. There are two definitions of the lifetime of a sample: the *mean life* and the *half-life*. The mean life is defined as

$$\tau = \frac{1}{\lambda}, \tag{1}$$

which is the average lifetime of all isotopes of one

[1] Berkeley Labs. (2009, February). *Neutron beta decays.* http://www.particleadventure.org/npe.html.

[2] See footnote 4.

atomic species[3]. The second definition of the lifetime of a radioisotope is the half-life, which is the time it takes for a sample to decay to half of its original composition, given by

$$t_{1/2} = \frac{\ln(2)}{\lambda} = \tau \ln(2). \tag{2}$$

II. Data Acquisition

Materials and Neutron Activation

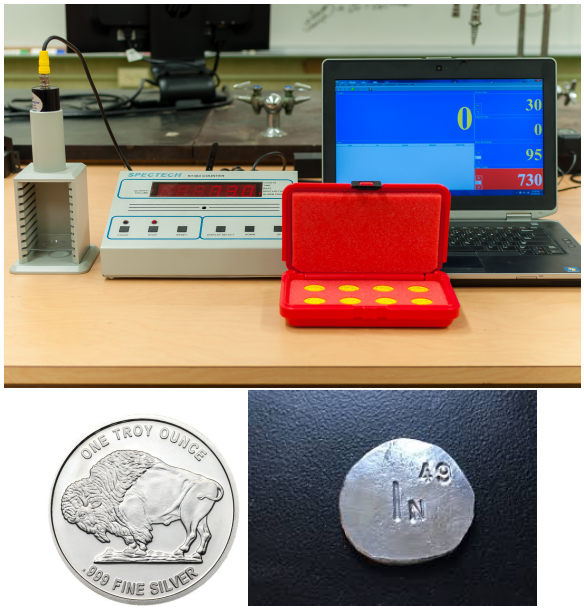

FIG. 2. (top) The experimental setup. (bottom) The sources used in experimentation.

The materials used to perform this experimentation, from left to right according to Figure 2, are: the GM 35 Probe, the GMS 35 Stand, the source tray, the BNC cable, the ST360 Counter, the USB connector, the laptop with the appropriate Spectrum Techniques software, a silver coin, an indium coin, and a radioactive neutron source, not listed in the figure. The purpose of the neutron source is to irradiate both silver and indium, for both elements have stable isotopes. So, in order to observe the lifetime, and thus the half-life, of both species, they both needed to be irradiated. The process by which this occurred was *neutron activation*. Neutron activation is the process of irradiating a species by placing it in the presence of a neutron activation in order to produce radioactive nuclei from stable ones. The process by which neutron activation occurs is through neutron capture,

$$^{A}_{Z}X + \, ^{1}_{0}n \longrightarrow \, ^{A+1}_{Z}X^{*},$$

where the above equation conveys that a species with atomic number Z and atomic mass A increases in size with neutron capture, while maintaining its chemical identity. In order to accurately determine the half-lives, it is good to irradiate the sample so as to irradiate it more than the expected half-lives, but it is best to perform this process for at least a day to ensure that decent data will be obtained, especially for silver. The isotopes of Ag-108 and Ag-110 have half-lives of 24.6 seconds and 2.382 minutes, respectively, and In-116 has a half-life of 54.29 minutes[4].

Procedure and Methods

In order to measure the half-life of silver, the silver coin was first irradiated with a neutron source for two days. Then, the coin was quickly removed from the neutron source and placed on the first slot of the GMS 35 stand, whose counts were measured with the Geiger-Muller (GM) counter with the optimum voltage of operation of 925 volts. Each run was ran for four seconds and the experiment was performed until the graph behaved asymptotically. This process was performed twice for both the silver and indium coins.

III. Analysis

Because radioactive decay processes are exponential in nature, the best form of analyses for the silver and indium coins would be models for exponential decay. For both Ag-108/110 and In-116, the data that was obtained was plotted with the x-axis being the time and the y-axis being the number of counts. Because silver has two different lifetimes, the model used to fit the data for silver was the superposition of decaying exponentials with the addition of a background term,

[3] The Editors of Encyclopedia Britannica. (2015). Mean life. In *Encylcopedia Britannica*. Retrieved from https://www.britannica.com/science/mean-life.

[4] http://www.nndc.bnl.gov/nndc/nudat/

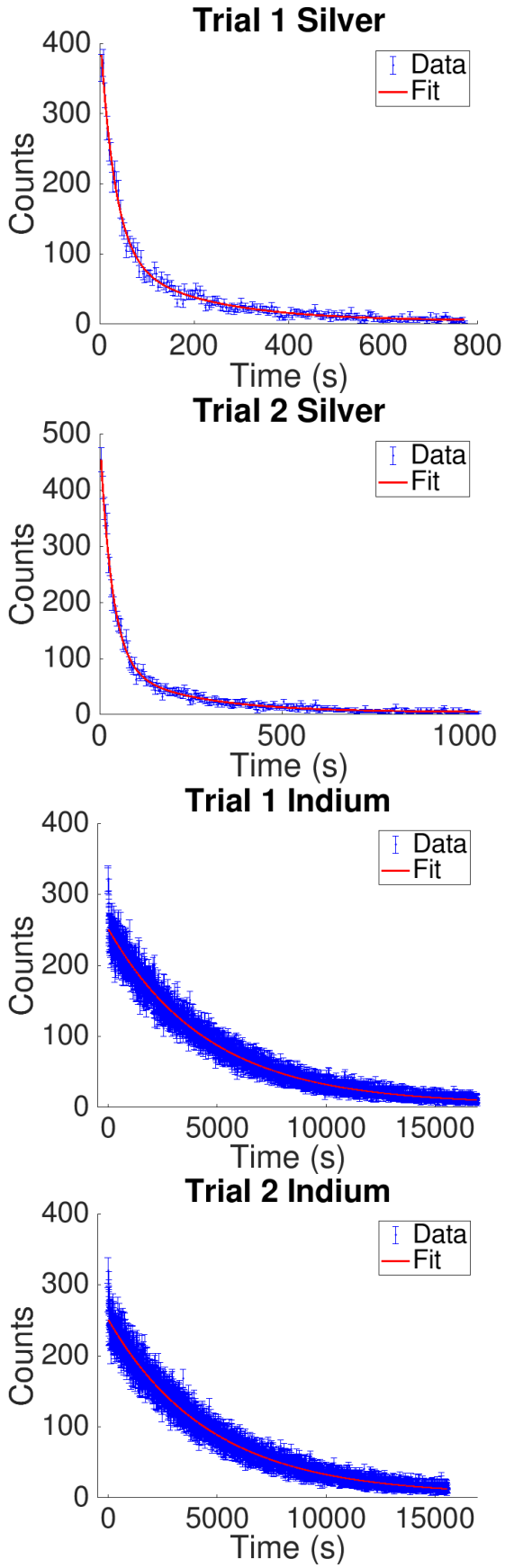

FIG. 3. The plots for the decays of the irradiated silver and indium coins.

$$y = C_1 e^{-\lambda_1 t} + C_2 e^{-\lambda_2 t} + b,$$

where y is the number of counts, C_1 and C_2 represent the initial number of counts, b is the number of background counts, and $\lambda_{1,2}$ are the values for the lifetimes of Ag-108 and Ag-110, respectively. Using this model, the data for both trials of silver were fit, and the determined parameters $\lambda_{1,2}$ were fit within a 95% confidence interval, using the standard deviation of the data instead of the square root of the number of counts of each run. The fits for the data are depicted in Figure 3. Then, the half-lives for the silver isotopes and for indium were calculated using equation (2). To obtain the random uncertainty in the lifetime, general error propagation was used for equation (1), such that

$$\begin{aligned}\delta\tau &= \sqrt{\left(\frac{\partial\tau}{\partial\lambda}\delta\lambda\right)^2} \\ &= \sqrt{\left(-\frac{\ln(2)}{\lambda^2}\delta\lambda\right)^2} \\ &= \pm\frac{\ln(2)}{\lambda^2}\delta\lambda \text{ seconds},\end{aligned}$$

because decay processes are random and independent events. For the systematic uncertainty of the GM counter, because each run was four seconds, then the systematic error would be half of the shortest time, which is two seconds. Afterwards, the weighted average was taken for each value obtained in order to obtain the best measured value for the half-lives of both silver isotopes. This process was repeated for both trials of In-116. However, because the decay of only one isotope was observed, the model used for In-116 was

$$y = Ce^{-\lambda t} + b.$$

Further, for indium, the decay in seconds was converted into minutes. Lastly, the data was also fit so as to exclude the background counts as a parameter that needed to be fit. This was done so as to understand the difference in the models with and without the background parameter.

IV. Discussion

The measured values for the half-lives of Ag-110, Ag-108, and In-116 were 22.4 ± 2.6 s, 2.4 ± 0.2

min, and 53.5 ± 0.5 min, respectively, which agree very well with the accepted values of 24.6 s, 2.382 min, and 54.29 min, for the model of the fits including the background parameter, utilizing two trials. For the decay of the silver coin, the discrepancies between the measured and known values of the half-lives for both Ag-110 and Ag-108 are 2.2 seconds and 0.018 min, respectively. Further, the percent uncertainty for the measured Ag-110 and Ag-108 are 12% and 8.3%. The percent uncertainty is much greater for Ag-110 because the addition of the two second systematic uncertainty[5] in the measurement. Thus, because the units of time are smaller, in addition to the added systematic uncertainty, the percent uncertainty for Ag-110 is greater than that for Ag-108. Because the discrepancy for both measured values is less than twice the uncertainties, it is reasonable to suggest that the measured values are consistent with the known values, suggesting that the exponential fitting was good and the data collection was a success. This confirms that the two silver isotopes that decayed were Ag-108 and Ag-110. For the fits excluding the background data fit for silver, the values obtained for Ag-110 and Ag-108 are 24.2 ± 2.9 s and 3.2 ± 0.2 min and the discrepancies are 0.4 seconds and 0.818 min, respectively. The low discrepancy for the Ag-110 isotope suggests that the fit without the background parameter is better than the fit including the background parameter. However, the discrepancy for the Ag-108 isotope is four times the uncertainty, meaning that the fit is quite poor, compared to the fit including the background counts. This conveys that the background counts have a much greater affect for the Ag-108, which could be due to the fact that the half-life is longer. As a result, the background counts have more time to affect the overall data. As was seen earlier, the percent uncertainty for Ag-110 is greater than that for Ag-108, having values of 12% and 6.3%. What is different, though, is that the percent uncertainty for Ag-108 without the background parameter is less than that for the fit of Ag-108 with the background parameter. This is merely a consequence of the mean value for the half-life being larger for the fit without the background parameter. This, however, does not negate how poor the half-life is for Ag-108 without the background parameter.

For indium, the discrepancy is 0.79 min, which is less than half the discrepancy, suggesting that the fit and data collection was adequate for the model including the background counts parameter. Further, the percent uncertainty is 0.93%. This establishes the half-life of indium. In comparison, the model excluding the background parameter has a half-life of 56.8 ± 0.2 min with a discrepancy of 2.51 min, which is 12.55 times greater than the uncertainty. The percent uncertainty, though, is 0.35%, which is lower than that for the model including the background parameter, only due to the fact that the half-life is larger. Even still, the estimate for the half-life of indium is poor with the exclusion of the background counts as a parameter because the number of background counts influences the data. Interestingly, both silver and indium models that excluded the background parameter produced poorer results than those that included the background parameter of the fit.

Two trials were performed in the obtention of the data, for each irradiated coin. In performing multiple trials, assuming that the procedure and data collection can be replicated without interrupting the apparatus and without anomalous occurrences, the determination of the half-life would be better. However, performing multiple trials could be disadvantageous because of time, especially for samples that have longer half-lives. This would mean that the sample would have to be irradiated and the experiment would have to run longer than the half-life for decent measurements. The advantage of performing a small number of trials is that time is not completely an issue, depending on the identity of the radioisotope. Yet, with a smaller number of trials, there will not be much variability in the measured half-lives, and the random errors, uncertainties, and effects of uncontrolled variables will not be minimized. Thus, the identity of the sample and the conditions of experimentation will determine the desired number of trials to perform, despite having more trials being ultimately more beneficial.

In this experimentation, the primary sources of uncertainty were the dead time of the GM counter, background radiation, the natural uncertainty in the activity of the radioisotopes, and the distance from the detector. These uncertainties have a direct effect on the counts observed. The dead time produces uncertainty because when the GM counter is quenched, the counter is unable to detect additional electric pulses. Of course, this is an instrumental limitation, which cannot be minimized. The background potentially contributes extra counts to the GM and can be reduced by subtracting potential background radiation from collected data. In this case, the back ground data that was present was

[5] The two second systematic uncertainty has a negligible effect on the half-lives calculated for Ag-108 and In-116.

used as a parameter in the exponential model fits. Because activities can not be measured precisely, there will always be a natural uncertainty with the activity of a radioisotope, which too cannot be minimized. Further, if the GM counter was not at a sufficient distance close to the source, than there would not be enough counts detected, producing a lower number of counts than expected.

V. Conclusion

To conclude, the obtained values of the half-lives for Ag-110, Ag-108, and In-116 were 22.4 ± 2.6 s, 2.4 ± 0.2 min, and 53.5 ± 0.2 min, respectively, which are in good agreement of the accepted values of 24.6 s, 2.382 min, and 54.29 min, for the model of the fits including the background parameter. The discrepancies are 2.2 seconds, 0.018 min, and 0.79 min for Ag-110, Ag-108, and In-116, respectively. The values of the half-life obtained from the models excluding the background parameter are 24.2 ± 2.9 s, 3.2 ± 0.2 min, and 56.8 ± 0.2 min with discrepancies of 0.4 seconds, 0.818 min, and 2.51 min for Ag-110, Ag-108, and In-116, respectively. The half-lives obtained for Ag-108 and In-116 from the fit with the background parameter were consistently better than the from the model without the background parameter; however, for Ag-110, the half-life obtained from the model without the background parameter was slightly better than the model including the background parameter. The errors present were a combination of random, independent errors, and systematic errors present in the GM counter.

VI. References

1. Berkeley Labs. (2009, February). *Neutron beta decays.* http://www.particleadventure.org/npe.html.

2. The Editors of Enyclopedia Britannica. (2015). Mean life. In *Encylcopedia Britannica.* Retrieved from https://www.britannica.com/science/mean-life.

3. http://www.nndc.bnl.gov/nndc/nudat.