

Irène Curie, Frederic Joliot and Artificial Radioactivity

Introduction

After Henri Becquerel's discovery of radioactivity in 1895, many leading European physicists experimented with radioactive materials. Marie Curie coined the term "radioactivity," invented apparatus to measure very small amounts of radioactivity and discovered several previously unknown elements (polonium, radium). Curie and her husband, Pierre, also defined the half-life, or time required for half of a radioactive substance to decay (see below). Ernst Rutherford and others realized that various radioactive substances emit three different kinds of radiation (α , β and γ rays), differing in their penetrating power and electric charge, and that in radiating, substances are transmuted into other elements or isotopes which themselves may also radiate and decay until a stable isotope is reached. All of these processes of radioactive transmutation and decay seemed related to the structure and behavior of atomic nuclei.

In 1932 James Chadwick identified neutrons with the very penetrating radiation that appeared after beryllium was bombarded with α -particles. Neutrons have a mass approximately equal to that of protons, are electrically neutral (hence their name), and if not in the atomic nucleus, are unstable. Following the discovery of the neutron, experimenters possessed a much more powerful tool to explore the nucleus (why would a neutral particle make a more powerful probe?). Using neutrons, Curie's daughter, Irène and her husband, Frederic Joliot discovered in 1934 artificial radioactivity. That is, they created new radioactive isotopes not found in nature, and then measured their decay back to stable isotopes.

Some months ago we discovered that certain light elements emit positrons [particles with the mass of electrons but positive charge] under the action of α -particles. Our latest experiments have shown a very striking fact: when an aluminum foil is irradiated on a polonium preparation, the emission of positrons does not cease immediately, when the active preparation [i.e., the stream of α -particles] is removed. The foil remains radioactive and the emission of radiation decays exponentially as for an ordinary radio-element. We observed the same phenomenon with boron and magnesium. The half life period of the activity is 14 min. for boron, 2 min. 30 sec. for magnesium, 3 min. 15 sec. for aluminum.... These radio-elements may be regarded as a known nucleus formed in a particular state of excitation; but it is much more probable that they are unknown isotopes which are always unstable [Joliot and Curie, "Artificial production of a new kind of radio-element," *Nature*, 10 Feb 1934, quoted in Emilio Segrè, *From x-rays to quarks: Modern physicists and their discoveries* (Berkeley 1980) 198].

For this discovery, Curie and Joliot won the Nobel Prize in chemistry in 1935 (like mother, like daughter ... Irène's mother, Marie, had won the Nobel Prize in physics in 1903 for the co-discovery of radioactivity).

In this lab, you will repeat Curie's and Joliot's work--although for a different element, silver. You will make a stable silver sample radioactive and study how the radioactivity of the sample changes with time using a modern version of a Geiger counter.¹

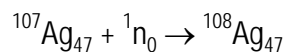
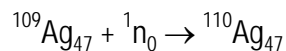
Preparing the Radioactive Silver Sample

The goal of this lab is to observe the decay and measure the half-life of a radioactive sample. We chose silver for this lab for two main reasons. First, the radioactivity is easy to detect with a modern Geiger counter. Second, the radioactive silver atoms you will make have short half-lives, so you will be able to see how the atoms become less radioactive during the course of the lab. However, because the silver atoms you will use have short half-lives, we cannot store them (why not?). To make the radioactive silver atoms, you will activate two stable isotopes of silver (Ag, from *argentum*, the Latin word for silver or money) by neutron bombardment. Natural silver consists of two stable isotopes²: about 51% is $^{107}\text{Ag}_{47}$ and about 49%

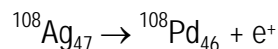
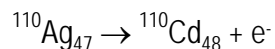
¹ Working with Ernest Rutherford, Hans Geiger developed a vacuum tube that could be used to detect α -particles. Geiger and one of his graduate students, Walther Mueller, improved the tube so that it could detect all kinds of ionizing radiation.

² Isotopes are nuclei of the same chemical element that have different masses. $^{107}\text{Ag}_{47}$ and $^{109}\text{Ag}_{47}$ are examples of isotopes. Both have 47 protons (as do all silver atoms), but $^{109}\text{Ag}_{47}$ has (109-47) or 62 neutrons, whereas $^{107}\text{Ag}_{47}$ has only 60 neutrons.

is $^{109}\text{Ag}_{47}$. When a nucleus of either of these isotopes either of these captures a neutron, a new isotope is formed:



Both of these resulting isotopes are unstable and transmute via β -decay. The reactions are shown below:

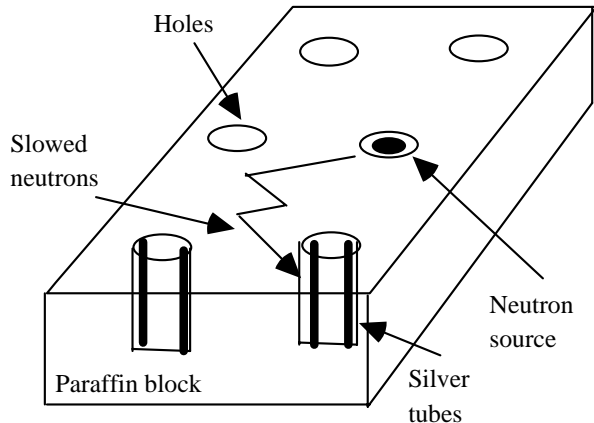


The $^{110}\text{Ag}_{47}$ atom emits an electron and becomes an atom of a new element. $^{108}\text{Ag}_{47}$ emits a positron (a particle very similar to the electron, except that it is positively charged). Check your understanding:

- There are several rules that govern possible nuclear decay reactions. Can you figure out two of these rules from the reactions above by comparing the two sides of each reaction?
- The two reactions also suggest neutrons and protons are the things that are decaying. Can you figure out what decays in each reaction and what it turns into?]

You will be measuring the half-lives of the two reactions above. The resulting isotopes of cadmium and palladium above are stable (not radioactive).

To create the unstable silver atoms for our experiment, you need neutrons of a specific energy range. Neutrons that are going too fast (or too slow) will not activate the silver. Our neutron source ejects neutrons that are far too energetic³ to be captured by the silver atoms, so you will use a paraffin block to slow the neutrons down before they get to the silver (see diagram). When fast neutrons collide with the protons (mostly in the carbon atoms) in the paraffin, the neutrons lose energy (and the protons in the paraffin gain energy). By the time the neutrons reach the silver atoms, many will have the right amount of energy to activate the silver. (Notice that humans also have lots of carbon. **Free neutrons interact strongly with humans!**)



³ The neutrons ejected by our source range in energy from a few keV up to a maximum of 11 MeV. Neutrons with around 100 eV of kinetic energy are the most likely to activate the silver.

Modeling Radioactive Decay

Radioactive decay of individual atoms is a random process, much like rolling dice. To do the following activity, you need a large number of dice (>100). If you do not have a large number of dice, you will find it helpful to roughly predict what the results might be instead.

Let's suppose that an atom of an isotope has a 1 in 6 chance of decaying in any one minute. You can simulate this by throwing a die representing the atom; if a six comes up, you can say that the atom has decayed. Now with 100 or more dice you have a model of a (very small) sample of radioactive isotope. Each time you shake the dice assume that another minute of the sample's life has passed. In this time more 'nuclei' have decayed – the ones that came up six.



Here's the basic procedure. Shake the dice. Count and remove the sixes. Repeat the procedure, completing a table like table below, until all the dice have 'decayed'.

Time/min	No. of 'active' nuclei, N (i.e. no. of dice thrown)	No. of decays (i.e. no. of sixes)

Interpret the results: (A spreadsheet program like Excel will be very helpful for all the analysis in this lab).

- Plot the results. Two graphs will be helpful: Number of active nuclei vs. time and number of decays versus time.
- Early researchers in radioactivity used the **half-life** concept. The half-life $T_{1/2}$ is the amount of time it takes for half of the sample's atoms to decay.
 - What is the half life of the sample of dice?
 - How many dice will likely be left after two half-lives? three half-lives? n half-lives?
 - Try to figure out the mathematical relationship between number of remaining atoms and "time."
- What would happen to the half-life of this system if you increased the chance for decay (say, by removing fives and sixes each round)? Explain.
- In the real world, you cannot measure the number of radioactive atoms remaining (as we can with dice in this example). You can only measure the number of decays per unit time (this is called **activity**). Compare your graph of activity versus time to the graph of remaining atoms versus time. How are they similar/different? How can you measure the half-life from the activity versus time graph?

Note: Your TA may want to collect the results of all groups and combine them. The combined results will 'smooth out' the results and point out some of the differences between small and large samples of dice.

Modeling a more complex system:

The real system you will study consists of two types of atoms. Each type of atom has its own decay constant. You can represent this situation using mixture of two types of dice (e.g. six-sided dice and twenty-sided dice). Try the experiment on the previous page again, but this time with a mixture of two types of dice (about 100 of each). Again, if you do not have dice (or do not feel like rolling dice), try to predict approximate results.

Note: You'll get quickly interpretable results if you remove all six sided dice reading five or six and all twenty sided dice that read twenty. (Why?)


Time (min)	# active d6 'nuclei'	# d6 decays	# active d20 'nuclei'	# d20 decays

Interpret the results:

- At early times, which species has more activity? At much later times, which species is more active? How would the answers to these questions change if you had much more of one kind of dice than the other?
- In the lab, you can only measure total activity. Unlike with the dice, there's no way to tell how many of the decays are of which type. Develop a strategy to use just the Geiger counter information (i.e. total number of decays per time interval) to find out the half-life of each reaction in the actual experiment. **Check your plan with a TA.**

Cool applet: <http://www.walter-fendt.de/ph14e/lawdecay.htm> (The applet simulates a group of atoms decaying. You can start and stop the process and create a graph)

Measuring radioactive decay

<p>SAFETY!</p>  <p>RADIOACTIVITY</p>	<p>Our radioactive sources can be dangerous if you are overexposed to them.</p> <ul style="list-style-type: none"> • Minimize the time the neutron source is unshielded! Free neutrons travel easily through air (but not paraffin) and are damaging to humans. • You must wear a safety badge during this entire lab session. The badge will record your level of exposure. <i>The badge offers no protection from radiation!</i> Record your name, social security number and birth date on the badge checkout list. At the end of lab, turn the badge in to your TA. A bio-safety company will determine use the badges to determine your exposure level.
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Measure the background radiation in the room. Radioactivity occurs naturally. The total amount of radiation in this experiment is small enough that you must account for the naturally occurring radiation in the room when you analyze your data.

Prepare for data taking. The purpose of this experiment is to see how the radioactivity of the sample decreases with time. Set the Geiger counter counts the total decays for ten seconds and then displays the result for two seconds. Check the settings with the stopwatch provided. You will record data for about 10 minutes, so plan accordingly.

Your TA will activate the silver. Your TA will place the neutron source in the paraffin moderator for about 10 minutes. Remember that the free neutrons are dangerous. While you wait, practice taking data with the Geiger counter. (You will not have meaningful data until the activation is over and the neutron source has been removed).

When the silver is sufficiently activated, the TA will transfer the neutron source back to its container. As the TA removes the source, hold the RESET button on the counter. As soon as the neutron source is away, release the button and start taking data.

If needed, take a second set of data. Your TA will need to reactivate the silver.

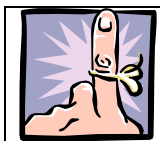
Analyze the data. Some things you might want to do:

- Compare the results from the real radioactive sample to the results from the dice rolling. (You may find graphs useful).
- Develop a strategy for figuring out the half life for each of the two radioactive decay reactions in your sample.
- Use the data to figure

Some things to keep in mind:

- The Geiger counter is idle (i.e. not counting) while it displays its result.
- There is background radiation, so not all of the activity recorded by the Geiger counter comes from the silver sample.
- The silver atoms decay via two different reactions. One of the decays is fast (short half life) and the other is relatively slow (longer half life).

Check your analysis with a TA. Once you have done some preliminary analysis, check your ideas and analysis with a TA. The TA will ask you some questions to help you refine your analysis.



Remember to sign out with your TA! Your TA will collect your **radiation badge** and mark the sheet to show that you returned your badge.

Post-lab Assignment

Write an abstract (200 to 400 words) that synthesizes the experiment: what was done, how the data were collected and analyzed. Compare and contrast the dice 'experiments' with the actual radioactive decay experiment. Report the values you obtained for the two half-lives and you found them. You may include graphs or other diagrams. (A picture may be worth a thousand words, but it does not affect the word count).