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The following lessons were created by Arnie Chamberlain, a teacher participating in a National Endowment for the Humanities Summer Institute for Teachers entitled Touch the Past: Archaeology of the Upper Mississippi River Region.

# Half-Life Lab

Objective: Using the hole punchouts from the paper hole puncher, shake the punchouts out onto a flat surface. Compare the rate of retention of the coins that land dark side up to the rate at which a radioactive substance decays to a new substance.

Materials: 2 containers, 200 punchouts (one side white and one side black, 2 containers to hold punchouts

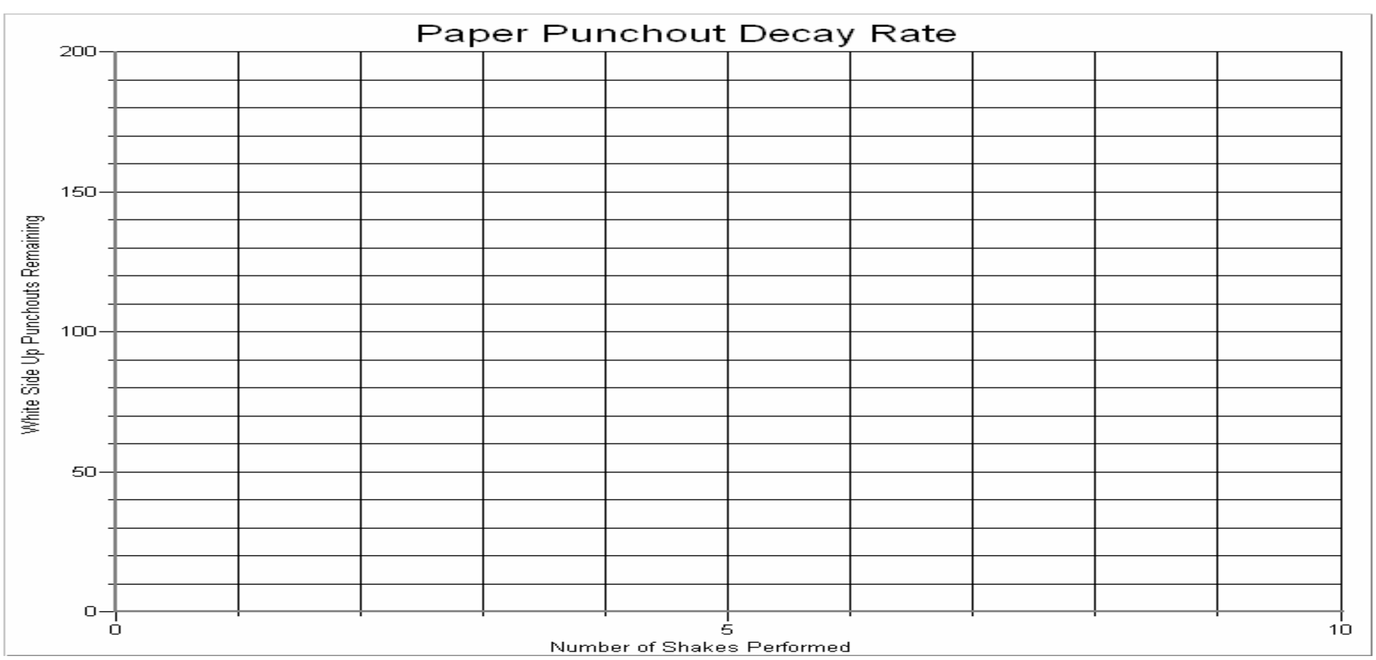
Procedure:

1. Count out exactly 200 punchouts and put them into a container.
2. Hold the container about one meter from a flat, horizontal surface and gently pour the punchouts onto the surface.
3. Count the number of punchouts that land dark side up. Record this number in the blanks below. Assume dark side up punchouts to be unchanged and white side up puNchouts to be changed.
4. Put the dark side up punchouts back into the container so they may be poured out again and put the white side up punchouts into the other container.
5. Continue the series 2 – 4 until all the punchouts have landed white side up or until you have completed 9 shakes.

| Shake | White Side Up Punch-outs Left |
|---|---|
| 0 | |
| 1 | |
| 2 | |
| 3 | |
| 4 | |

| Shake | White Side Up Punch-outs Left |
|---|---|
| 5 | |
| 6 | |
| 7 | |
| 8 | |
| 9 | |

Graph Your Data



Analysis

1) If you were dealing with the decay of radioactive Carbon-14 to the stable Nitrogen-14

   a) Which element would the punchouts that landed white side up represent? ____________________

   b) Which element would the punchouts that landed dark side up represent? _____________________

2) After 2 shakes, about what fraction of your paper disk sample had decayed? _____________________

3a) Was the rate of decay change of light side punch-out to dark side putout uniform from shake to shade always the same? ________________

3b) What is it about your graph that caused you to answer question 3a as you did?

______________________________________________________________________________________

***** IF EACH POURING OUT OF YOUR PAPER DISK ELEMENT TOOK 87 DAYS*****

6) How many days would it take for ½ of your paper disk element sample to decay? _______________

7) What, in this case, is the half-life or your paper disk element? _______________

8) Define the term half-life _________________________________________________________________

______________________________________________________________________________________

9) An old piece of cotton cloth is found to contain .0000156 grams of C-14 in it. A sample of new cotton cloth of equal mass, is determined to contain .00200 grams of C-14. How old is the old cotton cloth? (The half like of C-14 is 5730 years.)

# Teacher's Guide to Half Life Lab

**BACKGROUND**

The number of protons present determines an element's identity. Two protons are always associated with Helium. Eight protons are always associated with Oxygen. However, atoms of the same element may differ in the number of neutrons they contain. An oxygen atom with eight protons may have eight neutrons whereas a different oxygen atom may contain nine neutrons **Atoms of the same element that differ in their neutron number are termed isotopes.**

For example: Hydrogen occurs in three different forms. All the different forms of Hydrogen contain 1 proton. Having 1 proton is what gives an atom the identity of Hydrogen. However, each of the forms of Hydrogen differs in its number of neutrons.

**Table of Hydrogen Isotopes**

| Proton # | Neutron # | Total Mass | Name | Designation | | |
|---|---|---|---|---|---|---|
| 1 | 0 | 1 amu | Hydrogen | H-1 | or | 1-H-1 |
| 1 | 1 | 2 amu | Deuterium | H-2 | or | 1-D-2 |
| 1 | 2 | 3 amu | Tritium | H-3 | or | 1-T-3 |

While Deuterium and Tritium differ from the standard form of Hydrogen due to their additional neutrons, they can still react with substances just as Hydrogen does. Thus it is possible to produce water with Deuterium taking the place of Hydrogen. The resulting compound, Deuterium Oxide (formula $D_2O$) has the common name of "Heavy Water". Deuterium and Tritium occur naturally, but are both unstable. Nonetheless, any sample of pure water will have a little Deuterium Oxide and an extremely small amount of Tritium Oxide in it.

Although it is not fully understood, we are fairly certain that the neutrons act as a glue to help hold all the nuclear particles together. Without this glue, all the positive protons would repel each other and fly off in all directions. However, the gluing together function of neutrons works best with just the right number of neutrons. If too many neutrons or too few neutrons are present, the atomic nucleus becomes unstable and releases both particles and energy in getting to a stable form. We say that the unstable atom undergoes atomic nucleus decay (AKA atomic decay).

**DETERMINING ATOMIC STABILITY**

The easiest way to determine whether an isotope is stable or not is to look at the Periodic Table listing for that particular element (see the P. Table listing below). The larger number in each square is the atomic

| |
|---|
| 42 |
| Mo |
| 95.94 |

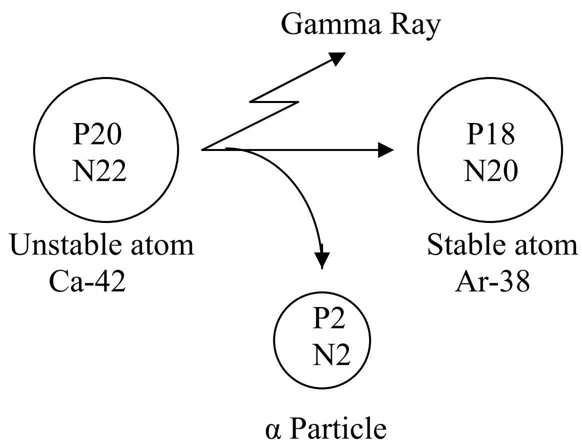
mass number. This number represents the average atomic mass of all the elements of that element. This includes both the stable as well as the unstable forms. As is usually the case with averages, they tend to center themselves around the most numerous value in the sample. In the case of atoms, the average atomic mass is usually closest to the stable form of the atom. In the case of Molybdenum, one can determine that a sample of Molybdenum must contain a lot of Molybdenum atoms with 96 AMUs of mass in that the average is very close to 96. One would call this isotope of Molybdenum, Mo-96. However, there must also be some Molybdenum atoms with less than 96 AMUs of mass in that the average is less than 96. We assume that all the atoms are created in the same amounts, but some of the atoms decayed where as some did not. Clearly the Molybdenum atoms with 96

AMUs of mass did not decay whereas the others did. By analysis of the Periodic. Table mass, one can determine that a combination of 42 protons and 54 neutrons that produce Mo-96 is stable and that most other combinations are unstable. In a similar manner, one can determine that Hydrogen with 1 proton and 0 neutrons (H-1) is a stable isotope of Hydrogen and Deuterium (H-2) and Tritium (H-3) are not .

**DECAY MECHANISMS**

The process by which an unstable isotope decays to become a stable isotope is called transmutation. There are essentially two decay mechanisms which result in transmutation. They are Alpha Particle Decay and Beta Particle Decay. Examples of each with appropriate notes are listed below:

**α Particle Decay**




α = Greek Letter Alpha

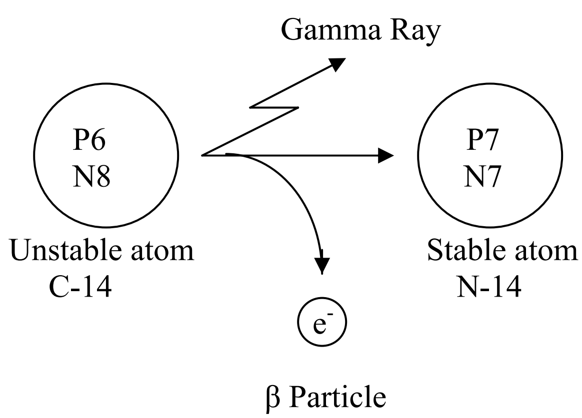
An α particle is lost from the original nucleus (an α particle is the same as a Helium nucleus)

A new material is formed

A Gamma Ray (very short wave form of electro magnetic radiation) is released

The decaying atom has its proton number and neutron number reduced by two.

**β Particle Decay**




β = Greek Letter Beta

An β particle is lost from the original nucleus (an β particle is very similar to an electron)

A new material is formed

A Gamma Ray (very short wave form of electro magnetic radiation) is released

A neutron is converted to a proton, the β particle must be lost so that the neutral neutron can be converted into the positive proton.

The decaying atom's proton number increases by one and its neutron number decreases by one.

**DESCRIPTIONS OF DECAY MATERIALS**

An α particle is very big. It is the same size and virtually indistinguishable from a Helium nucleus. Because of its size it can be easily stopped by something as thin as a piece of paper.

A β particle is very small. It is more like the size of an electron. Because of its size, it can penetrate matter more easily. It would take a sheet of metal or a very thick stack of paper to stop a β particle.

A Gamma Ray is virtually all energy and is very light like. It goes through virtually every thing. When it does hit something it is very destructive, however, due to its extremely small size it is very unlikely to hit anything.

**A HANDY REMINDER**

One can keep the two types of Decay Mechanisms straight by remembering the following statements:

***He, He, He. You can't catch me in my Alfa Romero.***

The He represents the Helium nucleus which is lost. An Alpha Romero is a type of car.

In your best Italian voice say, ***"I beta you one electron, that I canna change a neutron into a proton!"***

**THE CONCEPT OF HALF LIFE**

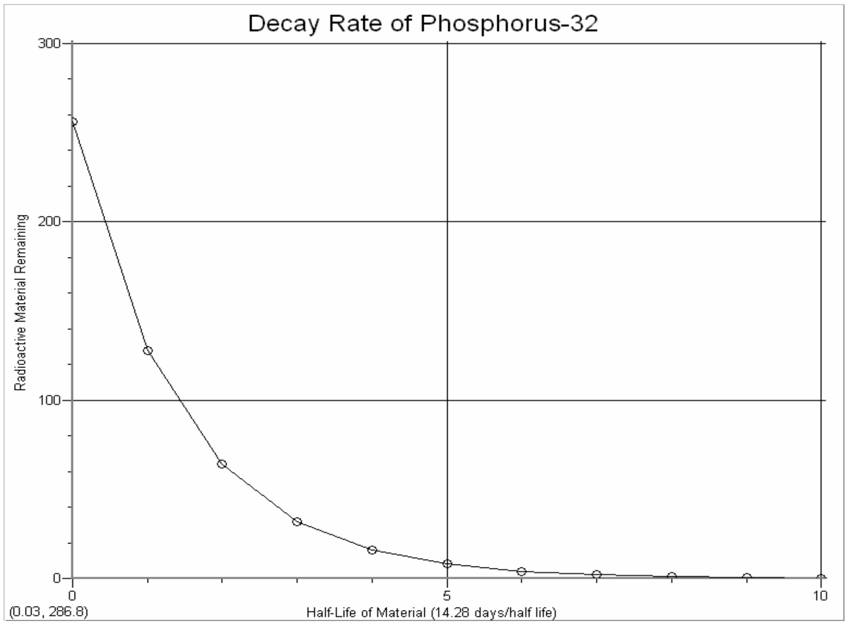
A radioactive element does not decay at a steady, constant rate. The rate of decay varies based on how much of the material is present. When a lot of radioactive material is present, decay rates are high. When little radioactive material is present, decay rates are small. If an object contains radioactive atoms, we can use the rate of decay of this material to determine the age of the item.

To do this we use the concept of half-life. The half-life of a radioactive material is the amount of time it takes for one half of the radioactive material to decay to its stable form. The half-lives of many different materials have been determined. The table below lists the half-life times for some radioactive materials.

| Element | Half-life | Element | Half-life |
|---|---|---|---|
| Uranium-238 | $4.4 \times 10^9$ **years** | Carbon-14 | $5.73 \times 10^3$ **years** |
| Potassium-40 | $1.3 \times 10^9$ **years** | Phosphorus-32 | 14.28 **days** |
| Uranium-235 | $7.1 \times 10^8$ **years** | Magnesium-27 | 9.46 **minutes** |
| Iodine-129 | $1.7 \times 10^7$ **years** | Magnesium-20 | 0.6 **seconds** |

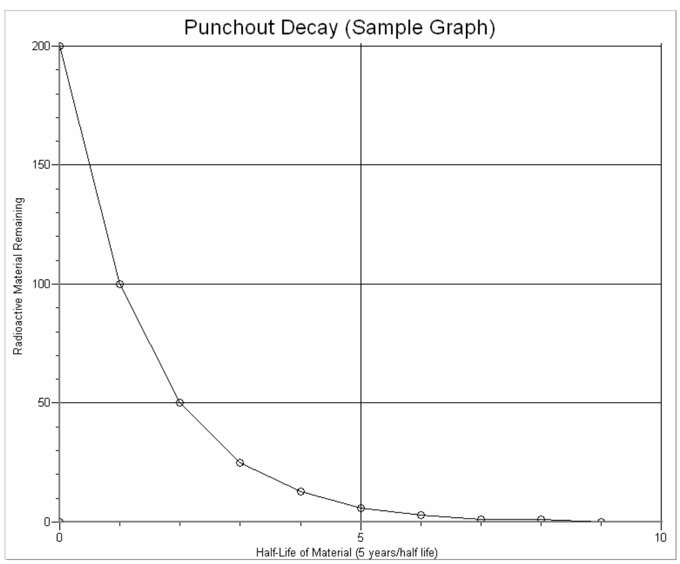
For example: Phosphorus-32 is radioactive. It undergoes Beta decay in which one of its neutrons get changed into a proton as it emits a Beta particle. This changes the radioactive element of Phosphorus-32 into the stable element Sulfur-32. The half-life of Phosphorus-32 is 14.28 days. If you were to start with 64 grams of Phosphorus-32. You would find that only half of the 64 grams (32 grams) would be present after 14.28 days had elapsed. In the next 14.28 days, one half of the remaining 32 grams would decay. You would now have only 16 grams left. After an additional 14.28 days, half of the remaining 16 grams would decay to a stable form leaving you with only 8 grams. This process continues until you get down to one atom, at which point it decays and you are left with none of the radioactive material remaining!

The following graph represents the decaying of Phosphorus-32.




Note that the above graph is NOT a straight line. As the Phosphorus-32 decays, less and less of it is left to decay. As a result, the rate of decay diminishes. This is represented by the curving nature of the graph.

Below is a simulated Decay Rate Graph of your punch-out element.




Note how the graph of your simulated punch-out element emulates the graph of the actual Phosphorus-32 element.

**HALF-LIFE AND CARBON-14**

Carbon-14 is produced by the action of ultraviolet light on the stable carbon atoms in the carbon dioxide in our atmosphere. Carbon-14 is radioactive and breaks down through Beta decay to the stable element of Nitrogen-14. However, over time, the ratio of stable carbon-12 atoms to radioactive carbon-14 atoms attains an equilibrium. When plants take in the carbon dioxide from the atmosphere during the process of photosynthesis, both the radioactive carbon-14 and the stable carbon-12 are taken from the air to be used in making sugar molecules. The ratio of radioactive carbon-14 to the stable carbon-12 is the same in the sugar as it was in the atmosphere. This is true as long as the plant is alive. If the plant is eaten by some other organism, the carbon in the sugars of the plant is assimilated into the tissues of the consumer. The carbon in the tissues of the consumer will also be in the same ratio of carbon-14 to carbon-12 as was found in the carbon in the sugars, which was also the ratio that was found in the carbon atoms in the atmospheric carbon dioxide. Seeing as nutrients are passed along in a food chain, all organisms in a food chain will have a ration of carbon-14 to carbon-12 equal to the equilibrium value that is found in the atmosphere. This is true as long as the organism is alive and taking in carbon.

When the organism dies, it no longer is taking in carbon and the equilibrium of carbon-14 to carbon-12 can no longer be maintained. The carbon-14 that breaks down through radioactive decay is not replaced by carbon from the atmosphere and the amount of carbon-14 diminishes. The carbon-14 breaks down so that only half of the original amount is left after 5730 years. After an additional 5730 years, half of the remaining amount (or ¼ of the original amount) remains. This reduction by ½ every 5730 years continues until none is left. Functionally, it will get to such a small amount that we can not reliably measure the amount of carbon-14 remaining in the organism and at that point we can no longer use this technique to determine the age of a object. Based on our estimate of the amount of carbon-14 in the carbon dioxide of our atmosphere many years ago and the minimum amount of carbon-14 we can detect through chemical means, the use of carbon-14 for dating objects is only reliable for about 40000 years. Other materials have longer half-lives and can be used in a similar fashion to date other items.

**DRAWBACKS OF CARBON-14 DATING**

In carbon-14 dating, there are two assumptions that are made that can lead to errors. We assume that the rate of solar radiation reaching the planet and the amount of carbon dioxide in the atmosphere today has been the same through out time. These are not true statements. Because of this, many skeptics refute the dates determined by carbon-14 dating. To solve this problem, scientists have developed a method to correct this problem. The bristlecone pine grows to be very old, well in excess of 4000 years old. We have samples of bristlecone pine trees that go back to nearly 8000 BC! By taking samples of wood from various rings of the bristle cone pine a correlation can be made between the amount of carbon-14 remaining in the wood and the age of the wood. These correction factors are then used to adjust the chemically determined carbon-14 date ascribed to an object.

Another drawback of carbon-14 dating is that it can only be used on organic items. In order to be used the material to be dated must contain carbon from the products of photosynthesis. Not everything does this; Most notably, rocks and minerals. When working with these materials, other radioactive elements with differing half-lives are used.

# ***LAB NUANCES***

This is an easy lab to set up. Divide your students into small groups. Each group will need the following materials:

- 200 punchouts that are white on one side and black on the other.
- two containers

**Tips to ease setup of lab.**

**PRELAB:**

*Discussion and Practice*

Make certain that students understand what the term half-life means. Define it and discuss it. The misconception with the term is students will think the term means ½ of some time unit. Emphasize that the time unit involved is static and that it is the amount of material that is being reduced in half.

Review the techniques of graphing that you expect to be used when the students are making their graph. If students have never graphed data before, you could do the graphing portion of the lab as a demonstration.

Work some sample problems on the board and give some drill and practice work on age determination before assigning the lab (see appendix for sample problems)

*Making the punchouts*:

Go to your copier. Make several copies with not paper on the document holder and the cover up so that the copy light shoots out into the copy room. This will produce copies that are black on one side and white on the other. Put several of these sheets together and use a handheld paper punch to produce the punchouts.

**PERFORMING THE LAB**

<u>Obtaining 200 punchouts</u>

Give the students a random amount of punchouts and have them count out 200 of them. If you have a particularly unruly group of students, change the number of punchouts at the start from 200 to 2000. It might take a couple days to complete the lab, but at least they will be busy doing something!

<u>Shaking out the Punchouts</u>

Paper tends to take on static electrical charges as the surface of one punch-out rubs across the surface of a neighboring punch-out. This is exacerbated if the punchouts are placed into a plastic container. Use either metallic or glass containers. Metallic containers will work best. Make certain that students SLOWLY shake out the punchouts for if they go to fast they will fall out of the shaking container all at once and their odds of landing either black side up or white side up will not be randomized. Ideally, the punchouts should individually flutter down to the desktop. If the shaking container is held a long way above the surface the punchouts will be landing one will maximize the randomness of their landing side, but they may miss the desk top as they flutter to its surface. This contributes to poor results, and wasted time as the students have to both retrieve the punchouts from the floor and count them.

# APPENDIX

Sample Problems:

1) ***Element A has a half-life ($t_{1/2}$) of 3 days. If you start with 100 grams of element A, how much will be left after 18 days?***

*In this problem, you will have to determine how many half-lives occur in an 18 day time span and then divide the original amount of element A in half that many times.*

*In 18 days, their will be 6 half-lives as there is 1 half-life every 3 days. Thus to answer this problem, you will need to divide the 100 grams of material in half 6 times.*

| Grams of Material Remaining | Half-lives Elapsed |
|---|---|
| 100 | 0 |
| 50 | 1 |
| 25 | 2 |
| 12.5 | 3 |
| 6.25 | 4 |
| 3.12 | 5 |
| 1.56 | 6 |

*So after 6 half lives (18 days), 1.56 grams of the original sample is left*

2. **Element B has a half live of 45 years. When object A was made many years ago and when it was made it had 306 grams of Element A in it. Today object A was analyzed and found to contain .2988 grams of element B. How many years ago was Object A made?**

*In this problem, you must determine how many times the mass of element B has been reduced in half as each of these represents one half live. Multiple the number of half lives by the number of years per half life to get the age of the object.*

| Grams of Material Remaining | Half-lives Elapsed |
|---|---|
| 306 | 0 |
| 153 | 1 |
| 76.5 | 2 |
| 38.25 | 3 |
| 19.125 | 4 |
| 9.5625 | 5 |
| 4.78125 | 6 |
| 2.39062 | 7 |
| 1.19531 | 8 |
| 0.59766 | 9 |
| 0.298828 | 10 |

*One must divide 306 grams in half 10 times to reduce its amount to .2988 grams. Therefore element B has undergone 10 half-lives. If each half-life takes 45 years to complete, object A was made 450 years ago.*
*(10 half-lives x 45 years / half-life)*