# Name Date Per.



RADIOACTIVE DATING PROBLEM SET!

**Background**: Scientists use a technique called **radioactive dating** to determine the age of rocks and fossils.

Here’s how it works: Rocks are made up of different elements. Some of these elements are **RADIOACTIVE**,

which means they decay (break down) into nonradioactive elements at a steady rate. The rate of radioactive decay is measured in a unit called a **HALF-LIFE**; it is the length of time required for half of the radioactive atoms in a sample to decay.

Each radioactive element has a different half-life (see Table 1 below). For example, potassium-40 has a half-life of 1.3 billion years. During that time, one half of the potassium-40 atoms in a rock sample decay to argon-40 (see Table 2). Geologists can measure the amounts of potassium-40 and argon-40 present in a rock sample. By determining how much argon has been produced by decay since the rock was formed, and by knowing the half-life of potassium, the rock sample’s age can be determined.

**Dating with Carbon-14**

Many collectors buy art and objects made by ancient people. In some cases, clever forgeries of ancient material have been made by individuals eager to cheat unsuspecting collectors or museums. But scientists have a way to date these artifacts and protect people from making expensive mistakes.

A common radioactive element, carbon-14, is often used to date fossils that are younger than about 60,000 years old. Carbon-14 has a half-life of about 5730 years. After about 60,000 years, or approximately ten half-lives, there is too little carbon-14 left to measure with accuracy.

Scientists use carbon-14 to date material that was once alive, such as a human bone, or to date an object that contains some living material.

For example, a pottery bowl or statue often contains a bit of straw that was used to hold the clay together when the bowl or statue was made. The straw contains enough carbon-14 to make radioactive dating possible.

Because it is present in the atmosphere, all living things take in carbon-14 while they are alive. The carbon-14 present in the body decays into nitrogen-14 at a fixed rate. In the case of the pottery bowl or statue, scientists can analyze the small amounts of once-living material, like straw, that are contained in the clay. They can then compute the ratio of carbon-14 to nitrogen-14 in the straw and determine how long ago the straw died. They assume, of course, that the straw was alive until shortly before it was used in the construction of the pottery.

Thus carbon-14 can be used to catch thieves and forgers of ancient art. Radioactive materials can make a pottery bowl or statue confess its true age.

# TABLE 1: Half-Lives of Radioactive Elements TABLE 2: Decay of Radioactive Element with a Half-Life of 1 Million Years in a Fossil

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Element** | **Half-Life** |  | **Time** | **Amount of Radioactive Element** | **Amount of Decay Element** |
| Rubidium-87 | 50 billion years |  | 4 million years ago, when fossil formed | 1 kg | 0 kg |
| Thorium-232 | 13.9 billion years |  | 3 mya | 0.5 kg | 0.5 kg |
| Uranium-238 | 4.5 billion years |  | 2 mya | 0.25 kg | 0.75 kg |
| Potassium-40 | 1.3 billion years |  | 1 mya | 0.125 kg | 0.875 kg |
| Uranium-235 | 713 million years |  | Present | 0.0625 kg | 0.9375 kg |
| Carbon-14 | 5730 years |  |  |  |  |

**Questions from background / readings:**

1) What are **radioactive elements**?

2) What is meant by “**half-life**”?

3) **DESCRIBE** how geologists can determine the age of a rock using **potassium-40**? (summarize steps involved)

4) a) What is carbon-14’s half-life?

b) What is the maximum age of a fossil that can be accurately dated using carbon-14?

5) If a fossil is older than your answer from 4b, what happens to the accuracy of a carbon-14 test? Why?

**Using Tables 1 and 2 on the previous page, answer the following questions.**

6) Which element has a half-life of 713 million years?

7) What is the half-life of Rubidium?

8) Looking at Table 2, what does the abbreviation “mya” stand for?

9) For the element described in Table 2, how much of the original amount of the radioactive element has decayed into the “new” element (decay element) after 4 million years? (i.e. at the present day?)

**RADIOACTIVE DATING / HALF-LIFE PROBLEMS:**

1) Suppose you were given $1000 and told that you could spend one-half of it in the first month, one-half of the remaining balance in the second month, and so on. One month thus corresponds to the half-life of the $1000.

a) If you spent the maximum allowed each month, at the end of what month would you have $31.25 left?

b) How much would be left over after 10 half-lives (i.e. 10 months)?

2) A person is attempting to reach a parked car, which is 512 meters away. Assume that the person covers half this distance (256 meters) in the first minute, half the remaining distance (128 meters) in the second minute, half the remainder (64 meters) in the third minute, and so on. In other words, the half-life for this moving process is one minute.

a) If the person never moves more than half the remaining distance in each one-minute interval, at the end of how many minutes would they be within 2 meters of the parked car?

b) How far would the person be from the parked car after 11 half-lives (i.e. 11 minutes)?

3) Nitrogen-13 decays to carbon-13 with a **half-life of 10 minutes**. Assume that you are given a starting mass of 12.0 grams of nitrogen-13.

a) How long (minutes) will it take for four half-lives to pass?

b) How many grams of nitrogen-13 will remain after four half-lives?

4) Manganese-56 has a **half-life of 2.6 hours**. Assuming you start with a sample of 10.0 grams of manganese-56, how much will remain after 10.4 hours? (HINT: think about how many half-lives have elapsed in this time!)

5) The mass of cobalt-60 in a sample is found to have decreased from 10.0 grams to 2.5 grams in a period of 10.6 years. From this information, calculate the half-life of cobalt-60. (HINT: think about how many half-lives must have occurred in that time period)

6) A patient is administered 20.0 milligrams of iodine-131. How much iodine-131 will remain in the patient’s body **after 40 days** if **the half-life of iodine-131 is 8 days**? (HINT: think about how many half-lives have elapsed in this time!)

7) Suppose you have a sample containing 800.0 grams of a radioactive substance. If after one hour (60 minutes) only 50.0 grams of the original compound remain, **what is the half-life of this isotope (in minutes)**? (HINT: think about how many half-lives must have occurred in that time period)

8) You are an archaeologist and you have discovered the remains of an ancient civilization. In one of the human bones that you find, you determine that of the original 600.0 grams of carbon-14 present in the bone, only 75.0 grams remain. Knowing that the half-life of carbon-14 is about 5730 years, what do you determine is the age of this bone (and thus this civilization)? (HINT: think about how many half-lives must have occurred in that time period)

9) You are a famous paleontologist and an expert in radioactive-dating techniques. One day, two visitors to your laboratory present you with two different fossils. One fossil is a dinosaur footprint, the other a human jawbone. Both were found at the bottom of a deep valley cut by a stream through cliffs of sedimentary rock. Your guests are very excited. Because they have found these fossils next to each other near the stream bed, they feel they have found conclusive evidence that humans and dinosaurs lived at the same time. You are asked to date the samples to confirm their claims.

a) You first test the human jawbone. You determine that it now contains 1/16 the amount of carbon-14 it contained when alive. How old is the jawbone? (HINT: think about how many half-lives must have occurred in that time period)

b) You next examine fossil footprint. You discover that the fresh mud that the dinosaur stepped in had just been covered with a thin layer of volcanic ash. You study the amount of potassium-40 and argon-40 in the ash. The ratio shows that **1/10 of one potassium-40 half-life** has passed since the footprint was made. How old is the footprint? (**see Table 1** on page 1 of this handout for half-life of potassium-40)

c) Were you visitors’ conclusions about these fossils’ ages correct? Explain.

d) If they were not, how could you explain the fact that they were found together at the bottom of the valley? (HINT: what geologic processes might have occurred in the time elapsed…?)