Carbon Dating Activity
It's a Puzzle!

Introduction

Archaeologists and geologists have been able to reconstruct some of the ancient history of the Earth by "dating" artifacts—determining when an artifact was made. The predictable process of nuclear decay can be used to date objects made of wood or cloth based on the amount of radioactive carbon-14 contained in the object.

Concepts

- Cosmic rays
- Half-life
- Radioactive decay
- Isotope ratios

Background

Cosmic rays continually bombard the upper atmosphere of the Earth. Collisions with gases produce neutrons which, in turn, can collide with nitrogen atoms to produce carbon-14.

$$^{1}_{0}n + ^{14}_{7}N \rightarrow ^{14}_{6}C + ^{1}_{1}H \qquad \textit{Equation 1}$$

Carbon-14 is radioactive and decays to nitrogen-14 by beta decay.

$$^{14}_{6}C \rightarrow ^{14}_{7}N + ^{0}_{-1}e \qquad \textit{Equation 2}$$

The half-life, $t_{1/2}$, of carbon-14 is 5730 years. The amount of carbon-14 in the atmosphere is approximately constant over time because the rate at which carbon-14 is produced is approximately equal to the rate at which it decays.

Plants take up carbon-14, along with the much more abundant isotopes carbon-12 and carbon-13, in the form of carbon dioxide during photosynthesis. The carbon-14 is incorporated into starch molecules in plants. The plants are then consumed by plant-eating animals, which are, in turn, consumed by carnivores. Over time, therefore, living organisms achieve a steady-state ratio of carbon-14 to carbon-12, which remains constant until the organism dies. At the time of death, the level of carbon-14 is approximately the same as atmospheric carbon-14. After death, however, the number of carbon-14 atoms decreases due to radioactive decay. The carbon-14 to carbon-12 ratio therefore decreases after an organism has died. If the ratio of carbon-14 to carbon-12 is known for a similar living organism, the age of an artifact can be determined by measuring the amount of carbon-14 in similar size samples of both the living organism and the artifact.

As time passes, the amount of carbon-14 in an artifact decreases according to the decay rate equation;

$$ln(^{14}C_t/^{14}C_0) = -kt \qquad \textit{Equation 3}$$

where $^{14}C_0$ = initial amount of carbon-14
$^{14}C_t$ = amount of carbon-14 after time t
k = rate constant for carbon-14 decay.

The rate constant for radioactive decay is related to the half-life:

$$k = 0.693/t_{1/2} \qquad \textit{Equation 4}$$

For carbon-14 ($t_{1/2}$ = 5730 yrs), the value of the rate constant is

$$k = 0.693/5730 \text{ yrs} = 0.000121 \text{ yrs}^{-1}$$

Rearranging Equation 3,

$$t = \frac{-ln(^{14}C_t/^{14}C_o)}{(0.000121 \text{ yrs}^{-1})} \qquad \textit{Equation 5}$$

Since the radioactivity of carbon-14 is directly related to the number of carbon-14 atoms, radioactivity (A) can be substituted into Equation 5. Equation is then simplified to Equation 6:

$$t = -8270 \ ln(A_t/A_o) \text{ yrs} \qquad \textit{Equation 6}$$

By measuring the carbon-14 activity in the same sample size of organic material of both the current organism and the artifact, the age of the artifact can be calculated.

After approximately six half-lifes have passed (6 × 5730 or 35,000 years), the activity of carbon-14 is reduced to near background radiation levels. Unless very sophisticated instrumentation is used, this limits the dating of artifacts by carbon-14 measurements to those less than 35,000 years old. To date objects of much greater age, a different naturally occurring radioactive isotope with a much longer half-life is used. One such isotope that is used for rocks and minerals is potassium-40. Potassium-40 decays by beta emission to argon-40, with a half-life of 1.3×10^9 years. Since argon is a noble gas not found naturally in rock formations, the only source of trapped argon in minerals would be the result of potassium-40 decay. By determining the ratio of argon-40 to potassium-40, the age of a rock, and everything deposited around it, may be determined.

Activity Overview

The purpose of this activity is to solve a carbon-14 dating puzzle by arranging a set of story tiles and picture tiles in a logical sequence to explain the process of carbon-14 dating.

Materials

Story tiles, sheet

Picture tiles, sheet

Blank paper, 4 pieces

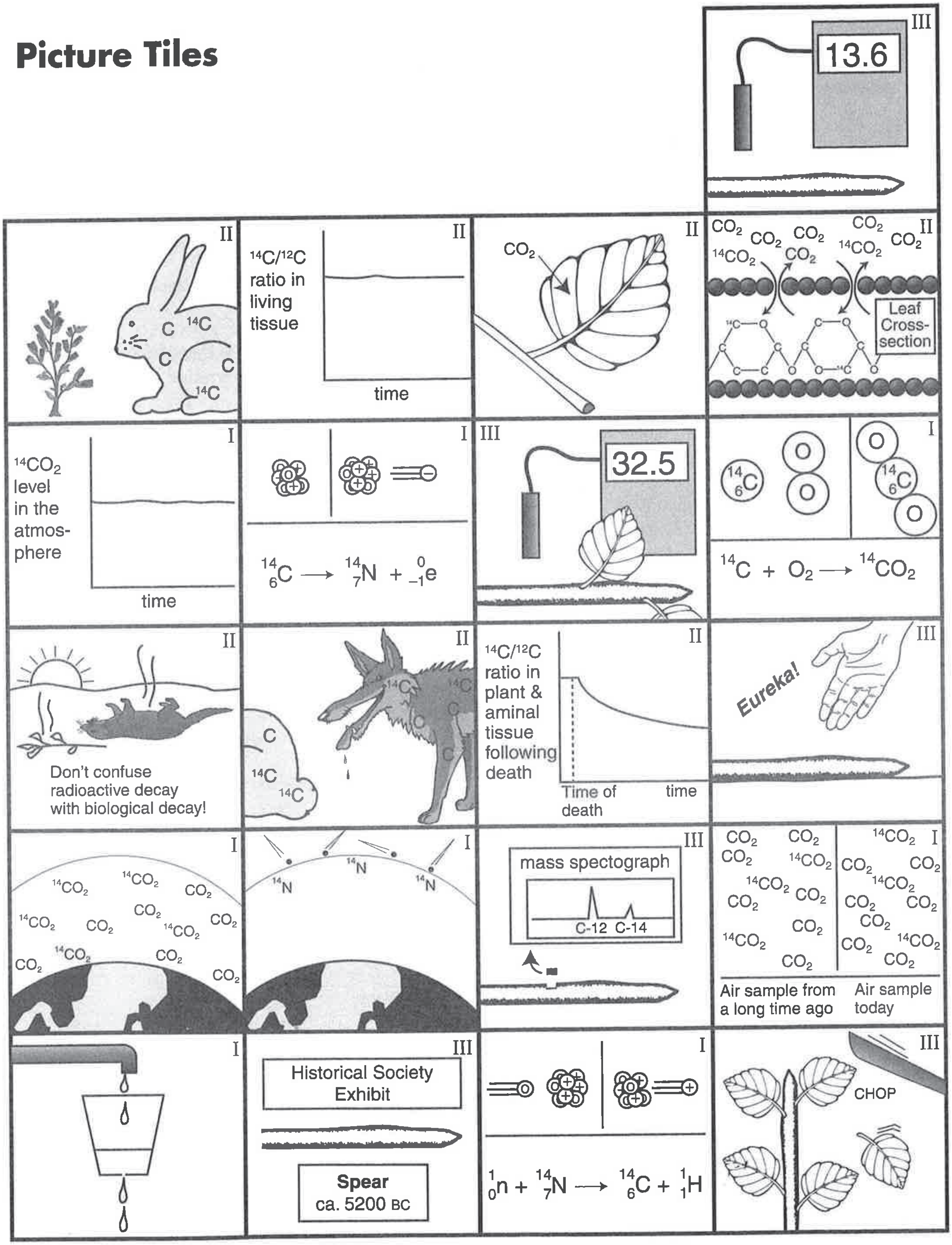
Tape, glue or glue stick

Scissors

Procedure

1. Take four sheets of blank paper and connect them in a landscape direction using the glue stick. Make a one inch overlap for each seam. This will be the "story board."
2. Cut out the 21 story tiles and the 21 picture tiles.
3. Read each story tile, then arrange the story tiles in a logical sequence to create a story-line that explains the process of carbon-14 dating. *Hint:* The story line has been divided into three parts (I, II and III), and each tile has been labeled to show where it belongs.
4. Once the sequence has been determined, use the glue stick to attach the story tiles in order to the 40-inch paper "story board."
5. Match the picture tiles to their corresponding story tiles and glue them to the "story board" just below the story tiles. The result should resemble a narrative "comic strip."
6. Use the story line and the background data to answer the Post-Lab Questions.

Picture Tiles



Story Tiles

			An ancient ancestor cut down a tree and carved it to make a spear. III
Carbon dioxide is evenly distributed throughout the entire atmosphere, even at ground level! I	Modern methods of ^{14}C dating utilize mass spectrometry, which detects the number of ^{14}C and ^{12}C atoms. III	Using a Geiger counter, the radioactivity of the artifact can be measured. From this, the ratio of $^{14}C/^{12}C$ in the artifact can be calculated. III	The $^{14}C/^{12}C$ ratio in carbohydrates produced during photosyntheses is equivalent to the ratio of these two isotopes in the atmosphere. II
As long as an organism consumes carbon-containing materials, it will maintain a constant $^{14}C/^{12}C$ ratio. II	Because ^{14}C is constantly being produced (by bombardment) and depleted (by decay), it reaches a steady-state concentration in the atmosphere. I	Carnivores eat herbivores and incorporate the ^{14}C stored in herbivores into their own tissues. II	The $^{14}C/^{12}C$ ratio in dead tissues decreases over time because ^{14}C decays but ^{12}C does not. II
An herbivore eats plants. It incorporates some of the carbon atoms from starch and carbohydrates into its tissue and exhales some carbon atoms in the form of carbon dioxide. II	The collision of high energy neutrons with ^{14}N produces ^{14}C atoms. A proton is also ejected in the process. I	By knowing how much this ratio has decreased, we can determine how old the artifact is. This is known as carbon-14 dating. III	An archeologist discovers a spear or a similar carbon-based artifact. III
High energy neutrons from space collide with atoms in the Earth's upper atmosphere. I	The radioactivity can then be compared with the activity level in comparable living tissue. III	This equilibrium is comparable to pouring water trickle into a cup which has a small hole in it. The water would reach a constant, stable level in the cup. I	The ratio of ^{14}C to ^{12}C in atmospheric carbon dioxide remains fairly constant over time. I
Plants consume atmospheric carbon dioxide (CO_2) during photosynthesis. II	The ^{14}C in the CO_2 decays back into ^{14}N by emitting a beta particle. This decay process is rather slow since ^{14}C has a long half-life (5730 years). I	Carbon reacts with oxygen in air to produce carbon dioxide. Both $^{14}CO_2$ and $^{12}CO_2$ are produced. I	Organisms die and decay through natural processes. Any decrease in the total amount of carbon due to decomposition will not affect the $^{14}C/^{12}C$ ratio. II

Name: ______________________________

Class/Lab Period: ______________________

Carbon Dating Activity Worksheet

Post-Lab Questions *(Use a separate sheet of paper to answer the following questions.)*

1. How and where is C-14 produced?
2. How is C-14 different from C-12? Give two differences.
3. If more and more C-14 is constantly being produced, why doesn't its concentration keep increasing?
4. Explain the "cup" analogy used in the puzzle.
5. How does C-14 get into us? Explain the entire pathway.
6. If we are constantly taking in more and more C-14, why does its concentration in us not increase?
7. As far as C-14 is concerned, what is the significance of death?
8. For each of the following, decide whether or not C-14 dating could be used.
   ___ To determine the age of a wooden axe handle, believed to be 10,000–13,000 years old.
   ___ To determine the age of the oldest living pine tree believed to be 5,000–10,000 years old.
   ___ To determine the age of an animal skin, believed to be 3,000–4,000 years old.
   ___ To verify the age of a man claiming to be 6,493 years old.
   ___ To determine the time of death of a murder victim who was found last Tuesday.
   ___ To determine the age of a wooden spear, believed to be 100,000–120,000 years old.
9. If a newly cut piece of wood gives a Geiger tube reading of 124 cpm (counts per minute) and an artifact gives a reading of 31 cpm, how old is the artifact?
10. C-14 is not the only isotope used for "radioactive" dating. List some others and explain why they might be better suited in some cases.
11. *(Optional)* In the puzzle, the spear is labeled 5200 BC. Show the exact math that gives this number.