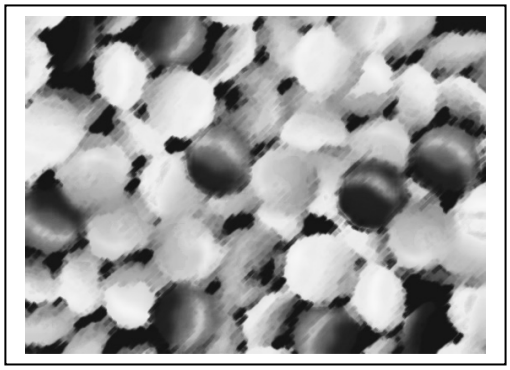
Carbon-14 Dating

or, How Old Are Those M&Ms?



One of the tools available to scientists who study ancient climates is called carbon-14 dating (also known as carbon dating or radiocarbon dating). This method is used, within limits, to determine the ages of certain types of objects. Carbon dating makes use of the fact that some atoms – radioactive atoms – change over time into other types of atoms in a natural process known as *radioactive decay*.

The decay of radioactive atoms occurs in a predictable way: After a length of time has elapsed, exactly one-half of the original atoms will have changed, leaving the other half unchanged. The length of time it takes for half of the atoms to decay is called a *half-life*. Each type of radioactive element has a distinct half-life different from all other elements. The half-life of a radioactive element does not vary.

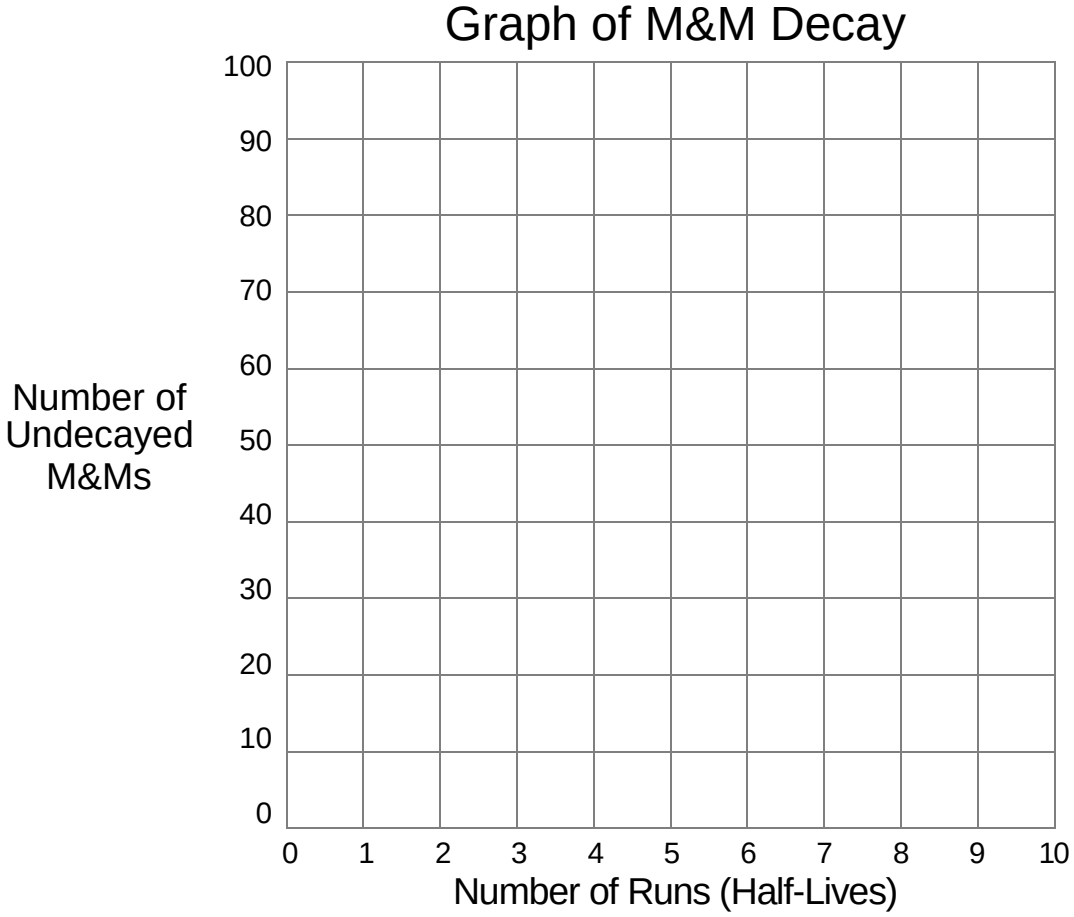
Warm-Up Activity

Before reading more about carbon-14 dating, do the following activity to see how the concept of half-life may be described mathematically.

1. Put exactly 100 M&M candies into a paper cup (do not eat them yet – you will need all 100!). The 100 M&Ms represent carbon-14 atoms before decay.
2. Shake the cup and empty it onto a clean sheet of paper. For this activity, each shake of the cup (each run) represents one half-life.
3. Remove the M&Ms that have the label up – these are the atoms that have "decayed." (Now you may eat the removed M&Ms!)
4. Record the number of remaining, undecayed, M&Ms in the table below under *Run 1*.
5. Repeat this procedure with several more runs until all M&Ms are gone or until there is only one left.
6. Graph each of the data points and connect them to form a line graph.
7. Obtain the class average for each run and plot the data to make a second line on the graph.
8. Finally, calculate the theoretical half-life values for all runs and graph them as a third line. The theoretical values are based on the assumption that label-side-up and label-side-down are equally probable – for example, the theoretical value is 50 after the first run.
9. Label the three lines on the graph.

Number of Undecayed M&Ms

	Start	***Run 1***	***Run 2***	***Run 3***	***Run 4***	***Run 5***	***Run 6***	***Run 7***	***Run 8***	***Run 9***	***Run 10***
Individual or Group Value	100										
Class Average	100										
Theoretical Value	100										



In mathematics, a smooth, declining curve of the type just drawn is called, not coincidentally, *exponential decay*.

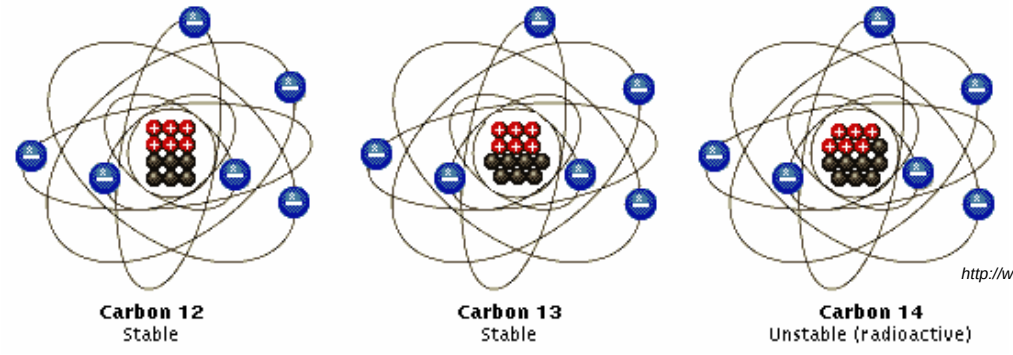
Discussion points: Which graph line – the individual or class average – most closely follows the theoretical line? Why?

The declining number of M&Ms after each succeeding run is like the radioactive decay of atoms after each half-life has passed. Eventually, the number of remaining atoms from the original quantity approaches zero, as almost all of the atoms have decayed into a different atomic form.

Why Carbon-14?

Carbon dating is performed on objects containing bits of organic matter, carbon-based substances that were once included in the bodies of living plants and animals. Not all carbon atoms are alike. Approximately 99 percent of carbon atoms have atomic nuclei with six protons and six electrons, giving them an atomic mass of 12. About one percent of carbon atoms have an extra neutron in the nucleus, giving them an atomic mass of 13. A very small number of carbon atoms – about one in every trillion – have two additional neutrons, giving them an atomic mass of 14. These different types of carbon atoms are called *isotopes* (see figure on next page).

The carbon-14 atoms are unstable and will disappear, or decay, on their own in time. This fact is central to understanding how carbon dating is used to establish the age of an object.



http://www.academic.rccd.cc.ca.us/~freitas/

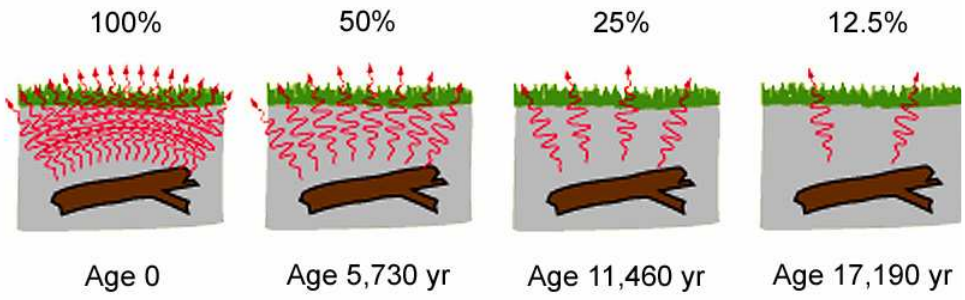
Because all living things are made from organic molecules, they must have a carbon source in order to exist. For most organisms, that source is carbon dioxide (CO_2) in the atmosphere. The carbon atoms in the atmosphere include the three isotopes in the proportions stated above. The same proportions are found in the organisms that obtain their carbon from the atmosphere. Those proportions will stay the same in their bodies for as long as they are living, because the carbon in living organisms is continuously being replenished.

When an organism dies, however, the carbon is no longer replaced. It remains there until it is eventually returned to the ecosystem through decomposition processes. The radioactive carbon-14 in the dead organism decays in a known way, similar to the decay curve for M&Ms.

Imagine a pollen grain that is picked up by the wind and carried aloft. After traveling hundreds of miles, the pollen grain settles onto a glacier and becomes buried under many annual snowfalls. Thousands of years later, a geologist removes an ice core from the glacier and finds that same pollen grain in his sample of ice. Can he determine the age of the pollen grain? If so, he will also know how old that part of the glacier is.

Shallow ice core drilling, Greenland
http://www.glaciology.gfy.ku.dk/ngrip/billeder01_eng.htm

Using carbon dating, the geologist can closely estimate the age of the sample. By measuring the ratio of carbon-14 to all carbon atoms in the pollen grain, he will know how much carbon-14 decay has occurred. The extent of decay will reveal the age of the pollen grain.



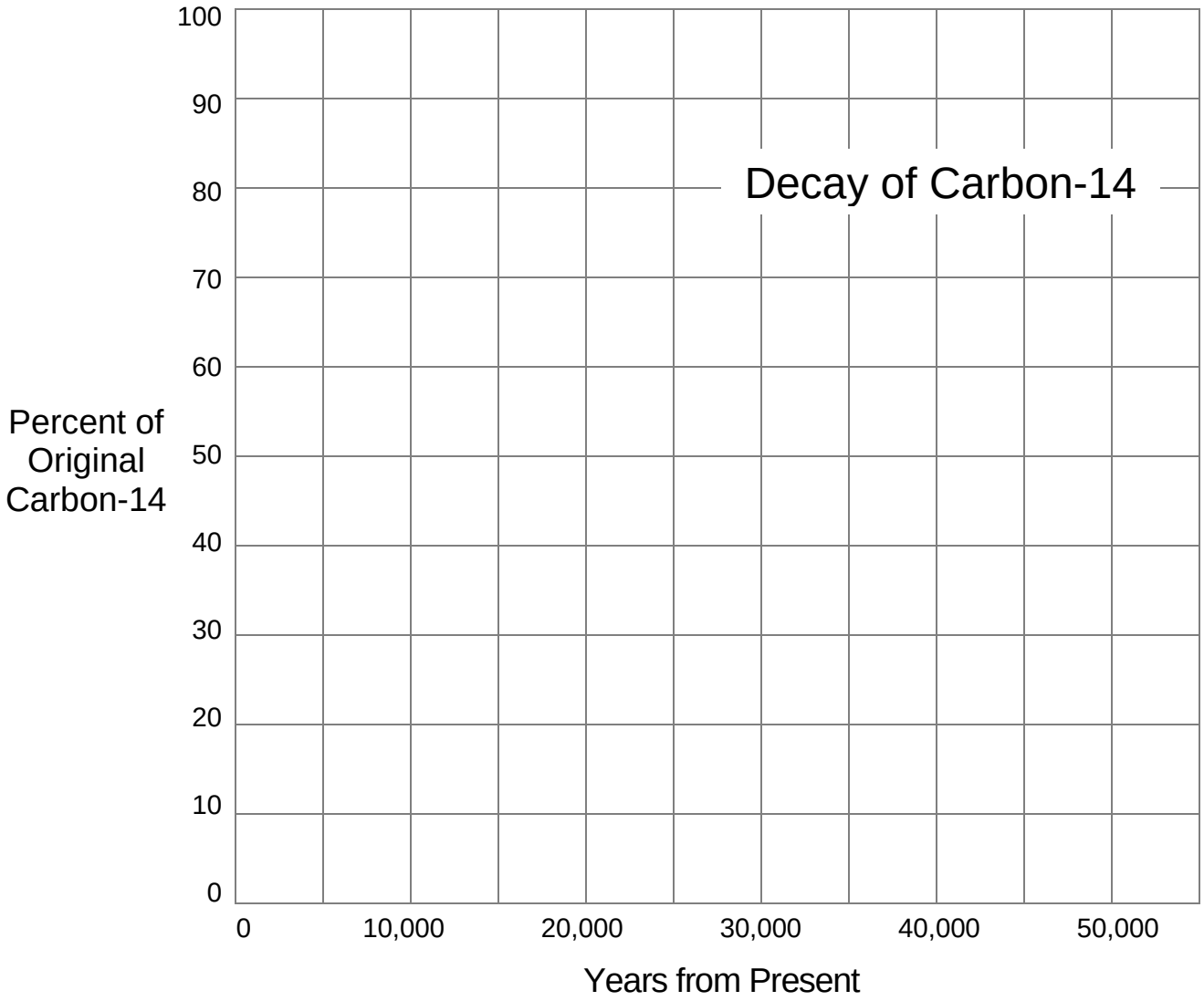
Radioactive decay of carbon-14
http://hyperphysics.phy-astr.gsu.edu/hbase/nuclear/cardat.html

Graphing the Decay of Carbon-14

Knowing that the half-life of carbon-14 is 5,730 years, it is easy to construct a decay curve like the one for M&Ms. Complete the following table and make a line graph of the data on the chart provided. The result should be a smooth, curving line through all points.

Decay of Carbon-14

Years from Present	0	5,730	11,460	17,190	22,920	28,650	34,380	40,110	45,840	51,570
Percent of Original C14 Remaining	100									



Carbon dating is generally useful for dating objects up to about 50,000 years old. Why is this method limited for objects of greater age? Fortunately, for scientists who need larger "measuring sticks," there exist other elements whose radioactive isotopes have half-lives greater than that of carbon-14 and can be used in a similar manner as dating tools.

Applying the Concepts

Use the graph of carbon-14 decay to solve the following real-life puzzles.

1. In 1991, hikers in the Tyrolean Alps of Europe made a remarkable discovery. They found an almost perfectly preserved body of a prehistoric man, whom scientists named Ötzi. The discovery was made possible because recent warming of the atmosphere had caused glaciers in the region to retreat, exposing objects that had been buried under the ice for millennia. Ötzi's fate was matched by a variety of well-preserved plant and animal species that were found close by. As discoveries of such quality are rare, the event was a genuine treasure trove for scientists. They reasoned that Ötzi and the other organisms must have been trapped by a sudden snowfall and virtually "flash frozen." This singular event was followed immediately by an extended cold period that preserved the specimens until the present glacial retreat. Carbon dating of samples from the site established the time of Ötzi's demise at approximately 5,300 years ago. What percentage of the original carbon-14 in Ötzi's body was remaining in 1991?

   → Many websites tell the history and science of Ötzi. This one is a good place to start: http://www.explorenorth.com/library/weekly/more/bl-iceman.htm

2. Scientists have been rethinking the nature of past climates. A 1998 study provided evidence that the tropics were much colder during the last glacial maximum than previously thought. Prior understanding had been that tropical regions were mostly unaffected by past ice ages. Constructing an accurate history of ancient climates is important, since the knowledge gained may have relevance to global climate change today. In the study just mentioned, investigators used a solar-powered drill to bore through the ice cap at the summit of an extinct Bolivian volcano named Sajama. They retrieved two ice cores at the bottom of the glacier, more than 132 meters (433 feet) deep. Trapped within the cores were insects and bark fragments from local trees. Carbon from organic material near the bottom of the cores dated to the coldest period of the last ice age. If those samples had 5.5 percent of their original carbon-14, approximately how many years ago did the glacier atop Sajama begin to form?

   → Read a more detailed description of the Sajama investigation at this website: http://researchnews.osu.edu/archive/sajama.htm

3. The authenticity of the Shroud of Turin had long been debated. In 1988, scientists received permission to remove small samples for carbon dating. Three different laboratories in Arizona, U.S.; Oxford, England; and Zurich, Switzerland analyzed the samples. All three laboratories came to the same conclusion: The shroud had lost about 8 percent of its carbon-14 atoms to radioactive decay. Given this result, what was the approximate date of origin of the Shroud of Turin? (Note: Despite these and other scientific investigations, the origin and date of the Shroud of Turin remains a subject of controversy.)

   → For a detailed account of the carbon-14 dating of the Shroud of Turin, visit this website: http://www.shroud.com/nature.htm

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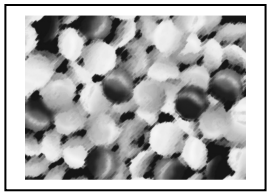

Teachers' Notes

Objectives: Students will learn how radioactive isotopes are used to establish the age of ancient objects and the location of events in geologic time. They will calculate and draw the exponential decay curve for carbon-14 and will apply that information to find ages and dates of past events as described in published reports.

Grade Level: Middle/High

NSES: A3, A4, A5, A6, B4, B7, B8, C12, C13, D8, D9, G3, G6

NHSCF: 1a, 2c, 3c, 4b, 5b, 6a, 6b, 6c

Key Concepts

Carbon-14 dating is familiar to many people because of its widespread use in archaeology. It is applicable, as well, to many other scientific disciplines where the ages to be measured are no greater than 50,000-100,000 years, depending on the analytical method selected. For older objects, isotopes of other elements must be used for radiometric dating.

While the ages of ancient objects may be intrinsically interesting, it is their context that has the greater scientific value. It is impossible, for example, to measure directly the time at which a glacier began to form. But it is entirely possible, by means of carbon-14 dating, to determine the age of organic material in an ice core sample from a glacier. The geologist or climatologist conducting such an investigation acts much like a police detective using the tools of a forensic laboratory to solve a crime.

In the warm-up activity with M&Ms, a question was asked about the three graphed lines. (Note: Variations on this introductory activity can be found at a number of websites. The activity presented here closely follows the description given at http://www.ucmp.berkeley.edu/fosrec/McKinney.html.) Based on probabilities, it is expected that whole-class results rather than individual results would more closely follow the theoretical curve. Liken this situation to flipping a coin. As the number of flips increases, the ratio of heads to tails more nearly approaches the familiar 1:1 relationship. In the case of radioisotope dating, the number of atoms involved will always be greater than trillions, so the radioactive decay curve will always match the theoretical values.

A second question asked students about the limits of the carbon-14 method. In simplest terms, the precision of any age estimate becomes less and less reliable beyond 50,000 years because the ratio of carbon-14 to all carbon atoms is a very low percentage, approaching zero – thus the need to use radioisotopes whose half-lives are longer than carbon-14's.

An important consideration in any carbon-14 testing is the possibility of contamination. Objects containing "old" carbon can be contaminated with newer material through both natural processes and human error in sample collection, handling, or analysis. Scientists have several ways to avoid errors in carbon dating, including such methods as multiple sample points, sample replication, and parallel measurements using alternate analytical procedures.

Visit these websites for more information about radiocarbon dating:

http://www.c14dating.com/
http://hyperphysics.phy-astr.gsu.edu/hbase/nuclear/cardat.html
http://www.101science.com/Carbon14.htm

Extension Activity

Many students will be familiar the water cycle (hydrologic cycle). Some may also have knowledge of the carbon, nitrogen, and oxygen cycles. It is one of the most fundamental principles of environmental/Earth science that these substances are continuously moving, in various forms, within and between the atmosphere, biosphere, and geosphere.

The science of radiocarbon dating is directly dependent on the transfer of carbon through the carbon cycle. However, the carbon cycle is so interconnected with the movement of oxygen that a more complete picture is presented by describing the carbon-oxygen cycle. Students can learn about the carbon-oxygen cycle from a wide array of print materials and online resources. One way to demonstrate their knowledge of this subject is to create a poster of the carbon-oxygen cycle. A good version of the poster assignment (including written component) can be found at the website listed below. This website also provides a list of suggested links for students' reference.

http://www.saskschools.ca/curr_content/biology20/unit2/UNIT2MODULE1LESSON3.htm

ANSWER KEY

Decay of Carbon-14

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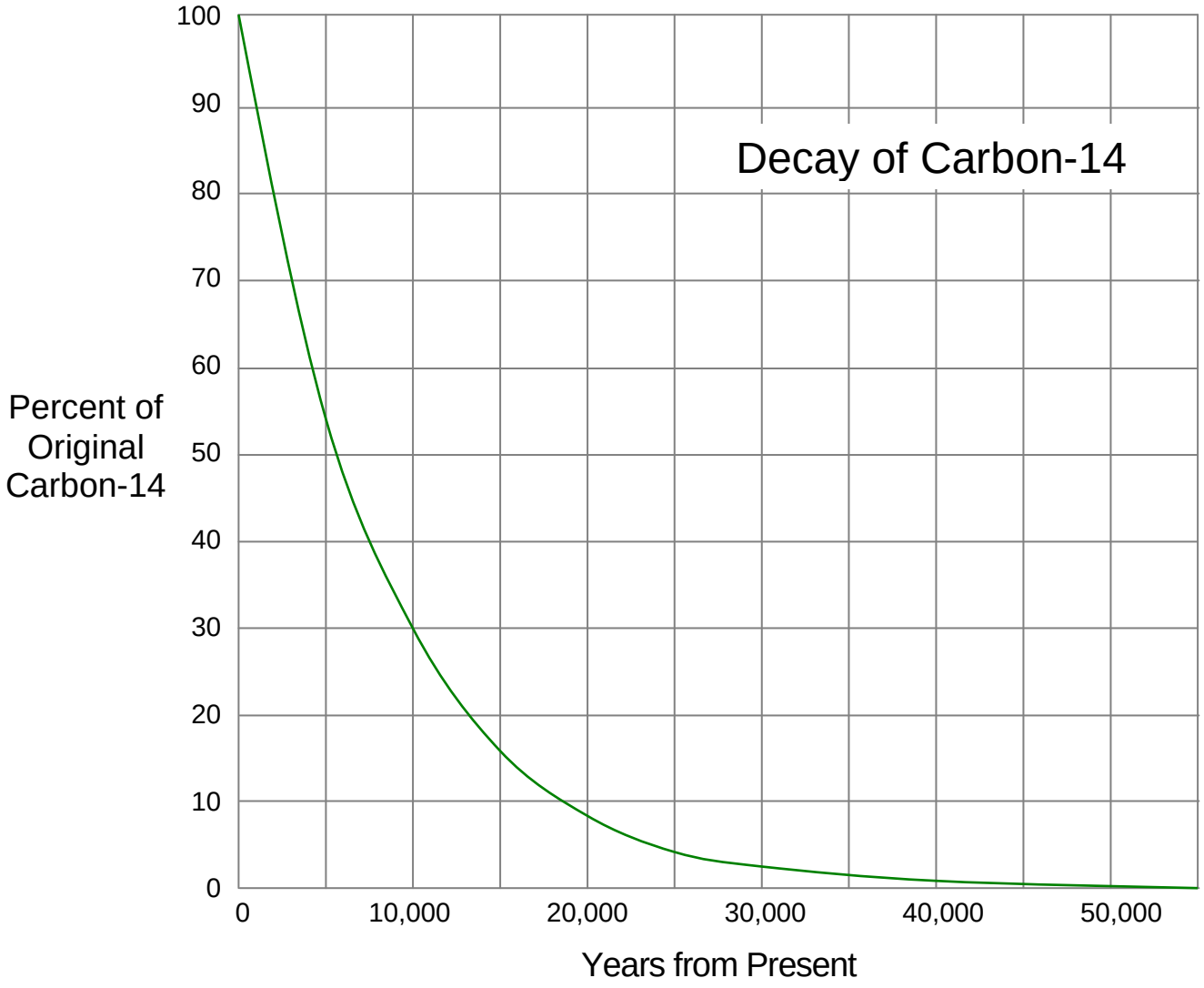
Percent of Original C14 Remaining	100	***50***	***25***	***12.5***	***6.25***	***3.13***	***1.56***	***0.78***	***0.39***	***0.20***



ANSWER KEY

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   53± percent

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   24,000± years

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   the year 1300±