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CARBON-14 DATING

I. Introduction

One of the tools available to scientists who study ancient history (natural and human) is carbon-14 dating (also known as carbon dating or radiocarbon dating). This method is used, within limits, to determine the ages of objects (bone, charcoal, plant material, etc.) that contain carbon. 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 radioactive element (or isotope) has a distinct half-life different from all other elements. The half-life of a radioactive element does not vary.

II. Half lives

The following activity shows how the concept of half-life may be described mathematically.

1. Put exactly 100 M&M candies into a 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 1 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.

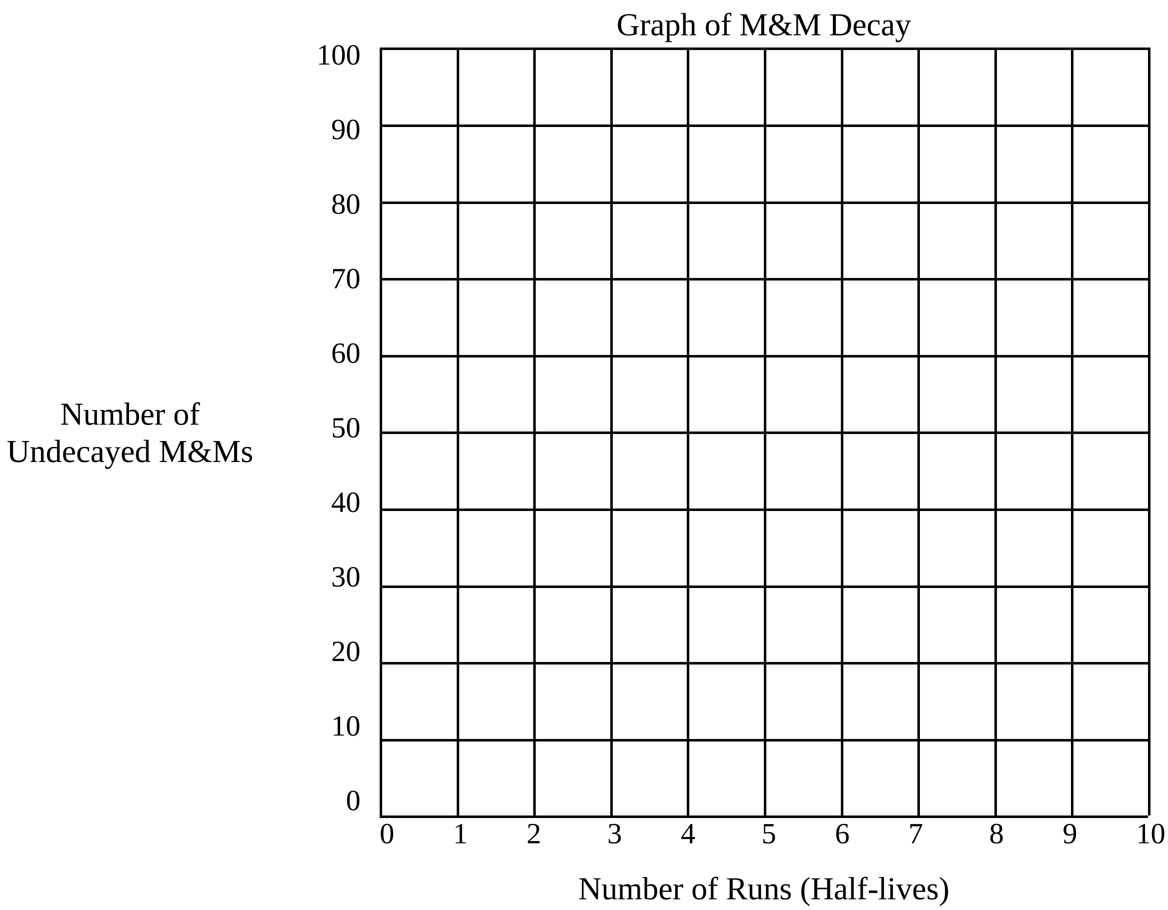
7. Obtain the class average for each run and plot the data to make a second line on the graph.

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.

Table 1. Data for M&M experiment

	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*.

1. 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.

III. 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* (Fig. 1).

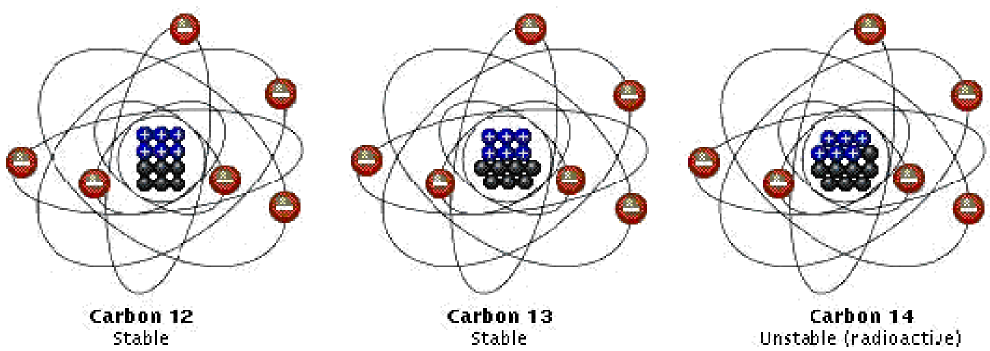


Figure 1. Three different types (isotopes) of carbon atoms.

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.

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 (CO2) 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.

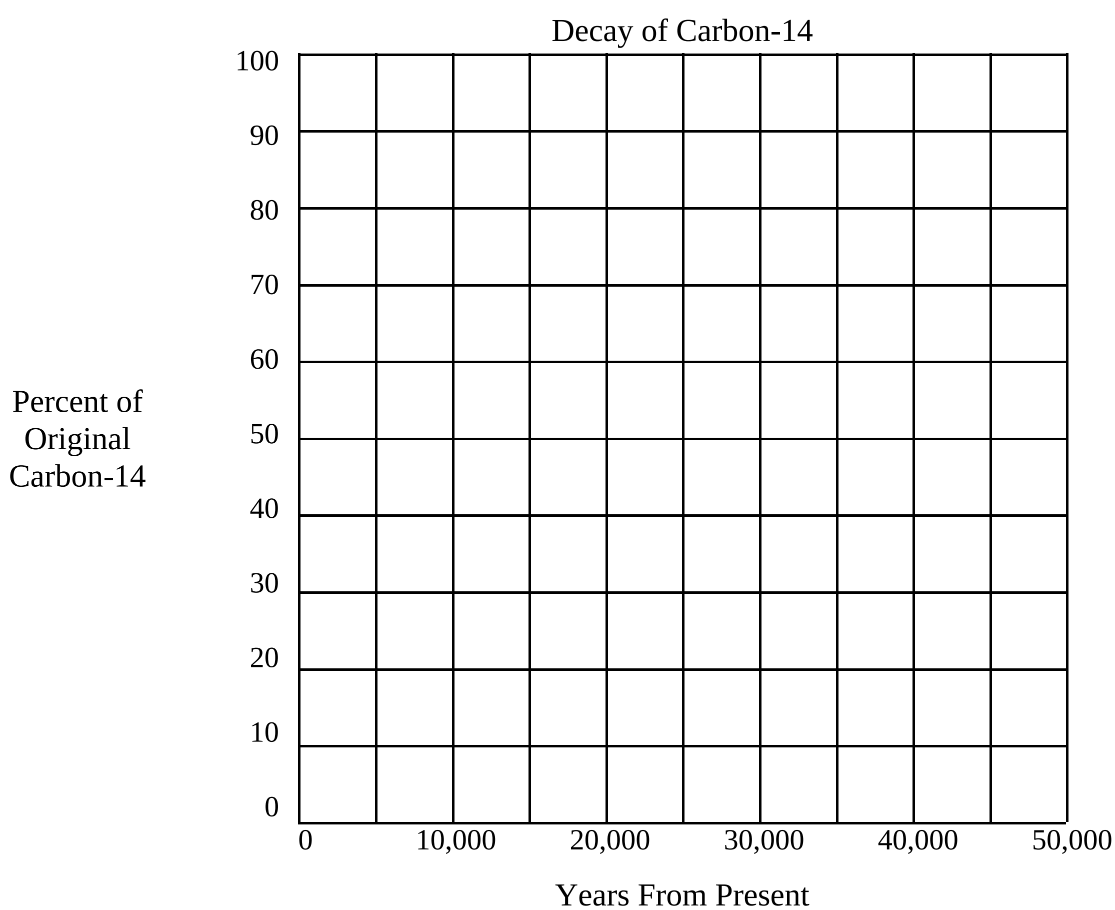
Using carbon dating, the geologist can closely estimate the age of the sample. By measuring the ratio of carbon-14 to all carbon atoms in the pollen grain, he will know how much carbon-14 decay has occurred. The extent of decay will reveal the age of the pollen grain

IV. 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.

Table 2. 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 C-14 Remaining	100									



2. 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.

V. Forensic applications of C-14 dating

3. 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. Samples collected from the site had an average of 53% remaining carbon-14. When did Ötzi die?

4. 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 C-14 atoms due to radioactive decay. Given this result, what was the approximate date of origin of the Shroud of Turin? Could the Shroud of Turin covered Christ’s body? Explain.

5. Check the ages you estimated from your graph using the C-14 dating spreadsheet. How well do the ages you estimated from the graph correspond to these precisely calculated ages?