CARBON-14 DATING

Radio-carbon dating is a **method of obtaining age estimates on organic materials**. The word "estimates" is used because there is a significant amount of uncertainty in these measurements. Each sample type has specific problems associated with its use for dating purposes, including contamination and special environmental effects.

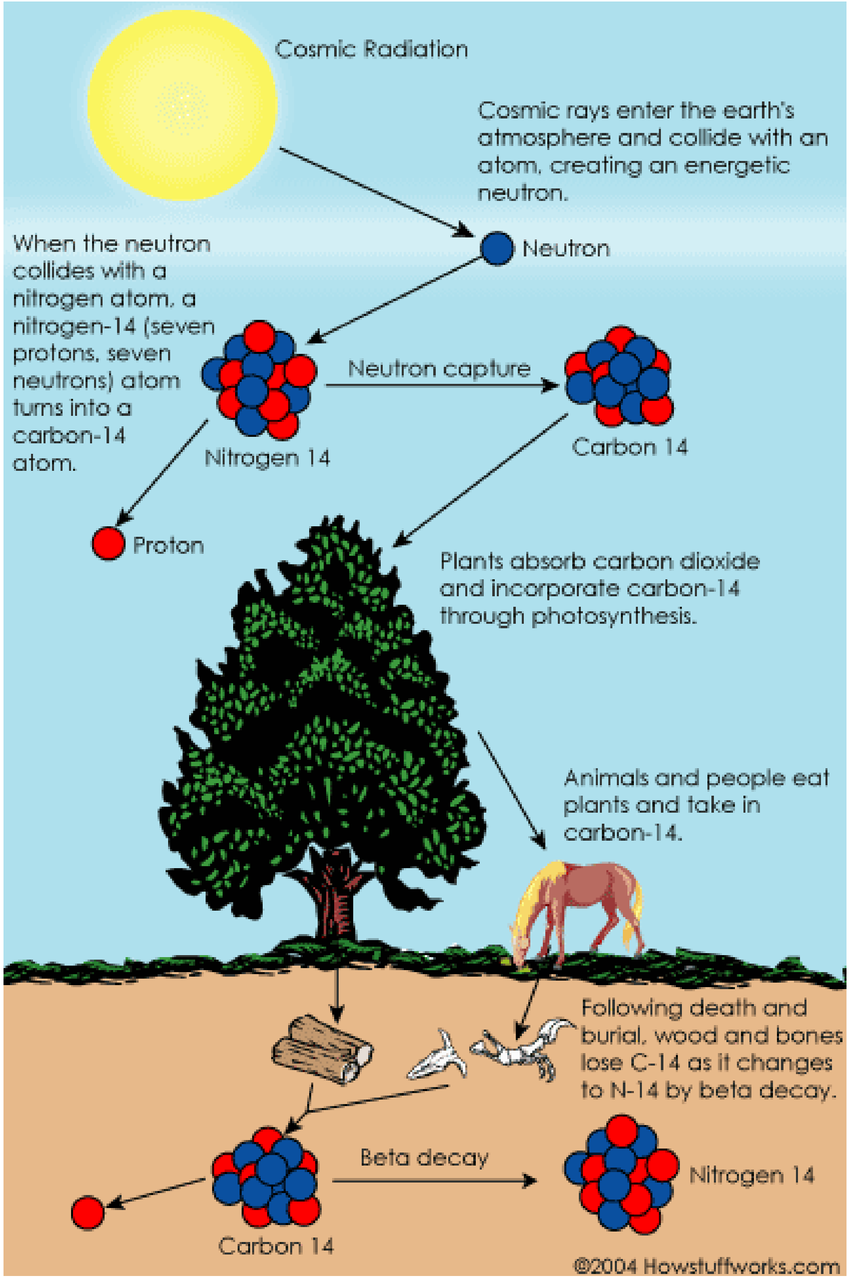
The method was developed immediately following World War II by Willard F. Libby and coworkers and has provided age determinations in archeology, geology, geophysics, and other branches of science. Radiocarbon dating estimates can be obtained on wood, charcoal, marine and freshwater shells, bone and antler, and peat and organic-bearing sediments. [1]

Cosmic rays enter the earth's atmosphere in large numbers every day. For example, every person is hit by about half a million cosmic rays every hour. It is not uncommon for a cosmic ray to collide with an atom in the atmosphere, creating a secondary cosmic ray in the form of an energetic neutron, and for these energetic neutrons to collide with nitrogen atoms. When the neutron collides, **a nitrogen-14** (seven protons, seven neutrons) **atom turns into a carbon-14 atom** (six protons, eight neutrons) and a hydrogen atom (one proton, zero neutrons). **Carbon-14 is radioactive, with a half-life of about 5,700 years.**

The carbon-14 atoms that cosmic rays create combine with oxygen to form carbon dioxide, which plants absorb naturally and incorporate into plant fibers by photosynthesis. Animals and people eat plants and take in carbon-14 as well. **The ratio of normal carbon (carbon-12) to carbon-14 in the air and in all living things at any given time is nearly constant.** Maybe one in a trillion carbon atoms are carbon-14. The carbon-14 atoms are always decaying, but they are being replaced by new carbon-14 atoms at a constant rate. At this moment, your body has a certain percentage of carbon-14 atoms in it, and all living plants and animals have the same percentage.

As soon as a living organism dies, it stops taking in new carbon. The ratio of carbon-12 to carbon-14 at the moment of death is the same as every other living thing, but the carbon-14 decays and is not replaced**. The carbon-14 decays with its half-life of 5,700 years, while the amount of carbon-12 remains constant in the sample. By looking at the ratio of carbon-12 to carbon-14 in the sample and comparing it to the ratio in a living organism, it is possible to determine the age of a formerly living thing fairly precisely.**[2]

[1] NDT Education Resource Center, The Collaboration for NDT Education, Iowa State University, www.ndt-ed.org.
[2] HowStuffWorks, Inc. - How Carbon-14 Dating Works; http://www.howstuffworks.com/



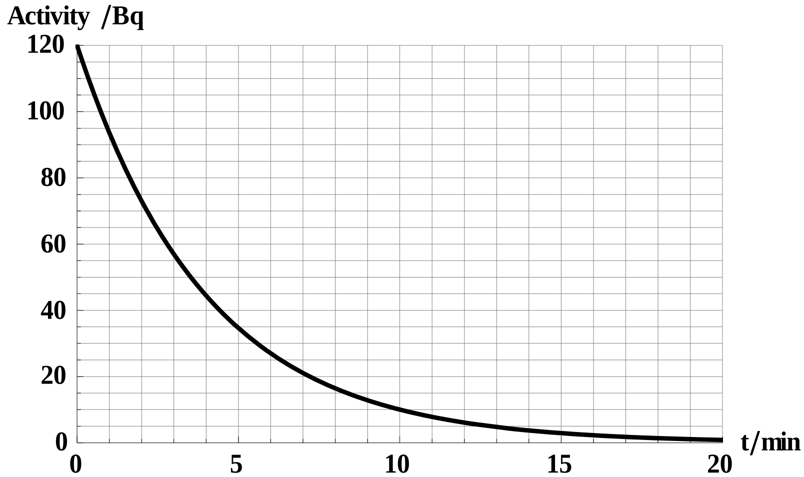
THE MATHS

The exponential function y = e^x plays a significant role in many areas of physics. The activity (number of decays per unit time) as a function of time behaves as

$$A = A_0 e^{-\lambda t}$$

, where λ is known as the decay constant and is related to the half-life as $\lambda = \frac{1}{t_{1/2}}$. Now consider these data:

Time, t/min	Activity/Bq
0	120
1	93
2	73
3	57
4	44
5	35
6	27
7	21
8	16
9	13
10	10



The graph for this data is on the right. To get a linear graph we have to take a natural logarithm of the formula for the nuclear decay:

$$A = A_0 e^{-\lambda t}$$
$$ln\,(A) = -\lambda \cdot t + \ln\,(\,A_0)$$

A graph of ln(A) on the y-axis and time on the x-axis will be a straight line, and the slope of this line will be equal to the decay constant λ. The y-intercept on the other hand will give us the value of the natural logarithm of the initial activity (To get A_o you have to exponentiate this number as in $e^{\ln(\text{y-intercept})} = A$).

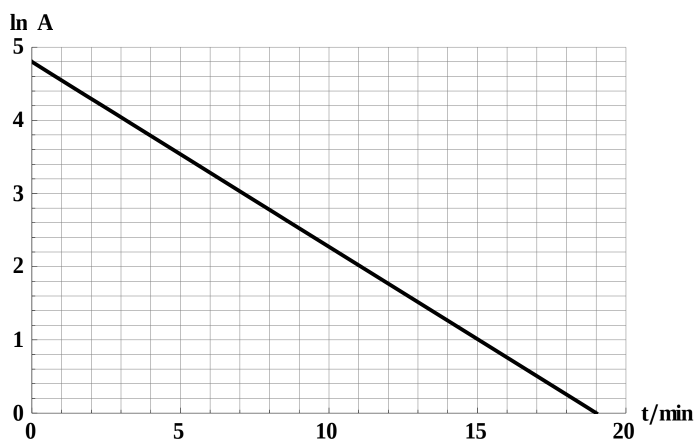
Finding the slope we get:

$$\lambda = slope = -\frac{4.8}{19} \approx -0.25\,min^{-1}$$

The vertical intercept is equal to 4.8 so:

$$\ln(A_0) = 4.8$$
$$A_0 = e^{4.8} \approx 120\,Bq$$

So we now know that the formula for the decay of this element is:



$$\boxed{A = 120e^{-0.25t}}$$

Problem 1.
Assuming the suspected relationship between the variables $y = c \cdot e^{a*x}$, plot the data in order to get a straight line and then find the values of a and c.

x	1.0	2.0	3.0	4.0	5.0	6.0
y	2,97	4,01	5,41	7,30	9,86	13,31

Problem 2.
Assuming the suspected relationship between the variables $y = c \cdot e^{a*x}$, plot the data in order to get a straight line and then find the values of a and c.

x	0.0	1.0	2.0	3.0	4.0	5.0	6.0	7.0
y	4.20	11.42	31.03	84.36	229.31	623.34	1694.40	4605.86

Problem 3.
Assuming the suspected relationship between the variables $y = c \cdot e^{a*x}$, plot the data in order to get a straight line and then find the values of a and c.

x	0.15	2.52	3.44	6.32	7.35	11.22
y	2.825	1.095	0.758	0.239	0.159	0.034

A formula to calculate how old a sample is by carbon-14 dating is:

$$\boldsymbol{t = [\, ln \left(\frac{N_f}{N_0}\right) / (-0.693) \,] \cdot t_{1/2}}$$

, where ln is the natural logarithm, N_f/N_0 is the percent of carbon-14 in the sample compared to the amount in living tissue, and $t_{1/2}$ is the half-life of carbon-14 (5,700 years).

So, if you had a fossil that had 10 percent carbon-14 compared to a living sample, then that fossil would be:

t = [ln (0.10) / (-0.693)] x 5,700 years

t = [(-2.303) / (-0.693)] x 5,700 years

t = [3.323] x 5,700 years

t = 18,940 years old