Carbon dating

Introduction

This activity looks at radioactive decay and how it is used in particular for carbon dating archaeological remains.
The use of TI-Nspire and the very quick and straightforward way that appropriate data can be inserted into a 'Lists & Spreadsheet' page and a suitable curve can be fitted to the data, could help to make this topic much more accessible to younger students. They can make of use the graph and 'Graph trace' to find useful information without needing to worry about the meaning of 'exponential 'or interpreting the equation shown.
There are possibilities for extending the activity to look at more advanced mathematics such as the form of the exponential regression function and the theory behind exponential decay, including topics such as integration, exponential functions and logarithms.

Background information

The 'How stuff works' website at http://science.howstuffworks.com/carbon-14.htm has several pages of useful information about carbon dating and also a video clip which could be used as an introduction to class discussion. There is a summary here and further information from this and other websites in the Additional information section at the end of the activity. Also included in the additional information is a section containing further mathematical details and some solutions which could be used depending on the age and background of the class.

> Cosmic rays enter the earth's atmosphere in large numbers every day. 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 fibres 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.
>
> **Important note:**
>
> Because the half-life of carbon-14 is 5,700 years, it is only reliable for dating objects up to about 60,000 years old. However, the principle of carbon-14 dating applies to other isotopes as well. Potassium-40 is another radioactive element naturally found in your body and has a half-life of 1.3 billion years. Other useful radioisotopes for radioactive dating include Uranium -235 (half-life = 704 million years), Uranium -238 (half-life = 4.5 billion years), Thorium-232 (half-life = 14 billion years) and Rubidium-87 (half-life = 49 billion years).

The Activity

Half life is defined as the time taken for the activity of a given amount of a radioactive substance to decay to half of its initial value. The lifetime of an individual radioactive atom is unpredictable but for a large number of similar atoms the average lifetime is quite predictable. For carbon-14 with a half life of approximately 5700 years this means that if something had been dead for 5700 years, you would expect the proportion of carbon-14 atoms to be 50% of that found in any living animal or plant specimen. This information can be used to date archaeological remains such as animal and human skeletons or wooden objects such as boats. For really old remains such as some fossils, this method cannot be used because the number of carbon-14 atoms remaining after this time is too small. There are other radioactive isotopes in the human body which could be used instead such as Potassium-40 which has a half-life of 1.3 billion years.

The Task

How could you set up a TI-Nspire so that you could use it to:-

- find the percentage of carbon-14 atoms remaining in specimens of different ages or
- find the age of a specimen if you knew the percentage of carbon-14 atoms remaining

When you have set your graph up and can trace values from it, try setting your own questions and using the graph to answer your questions or those of others. For example:-

- How many years will it be before approximately one third of the carbon-14 atoms have decayed?
- What percentage of carbon-14 atoms are likely to remain after 60 000 years?

Getting started

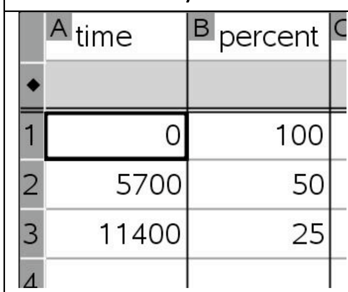
Try to put more information into the columns in this table for carbon 14 (Half life 5700 years)

year	0	?		
Percentage of carbon-14	100%	50%		

Now try to enter this information into a 'Lists & Spreadsheet' page of TI-Nspire.

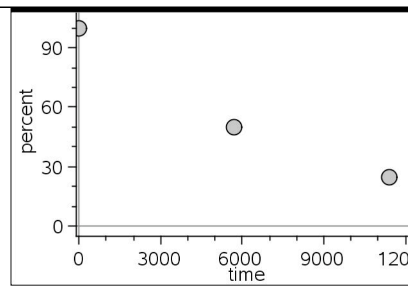
1. Set up the spreadsheet

Instructions to set up a spreadsheet page are given in the introduction to this booklet. There is also a sample file already set up for this activity.



2. **Insert a 'Data & Statistics' page**,

- from menu 2 select 'Add X variable' and select 'time'
- from menu 2 select 'Add Y variable' and select percent
- This will give you a Scatterplot.

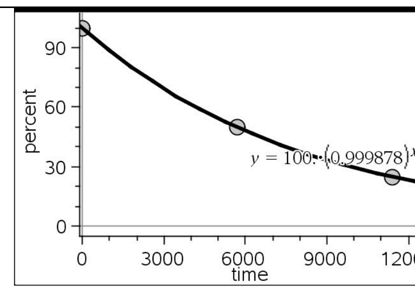


3. Fit a curve to the data

- From menu 4 choose 'regression' and select 'show exponential'

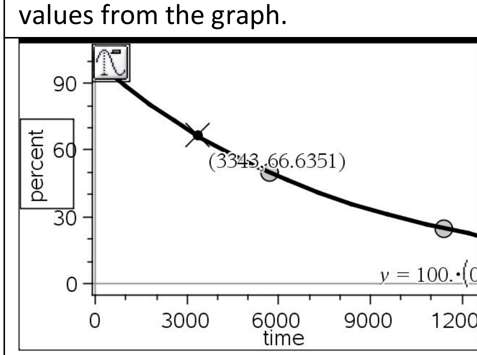
Don't be put off by the term 'exponential' or the equation shown. What you want is a curve that is a good fit to the points.

- You may prefer to drag the equation out of the way.



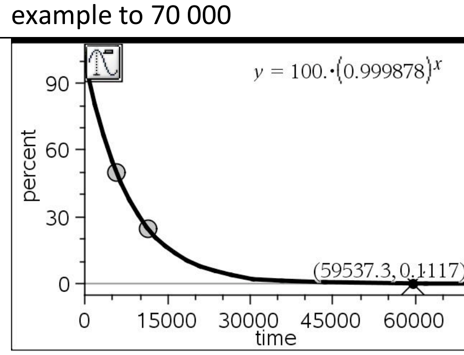
4. **Reading from the graph**

To read off values from the graph go to menu 4 and 'Graph Trace'. You can grab the point and move it along the graph so that you can read values from the graph.



5. Changing the graph scales

If you wish to go beyond the values shown you can change the window setting by going to menu 5; select 'window settings' and change maximum x value for example to 70 000



- You could also change the window settings (menu 4) to zoom in for greater accuracy or to zoom out.

Extension Activities Radioactive decay

Students could use a similar method to set up tables and graphs and look at the half life for other radioactive substances. They could compare the graphs that they get and look for similarities and patterns in the functions for the exponential regression curves.

Form of the regression function

Ti-Nspire gives exponential regression functions in the form $k*a^x$

For this activity the regression function gives the percentage of the isotope remaining as $100*a^x$ where a is a constant which varies with the half life of the isotope.

Students could investigate the relationship between the value of the constant and the half life.

- Choose a suitable range of half lives to work with (Note: Half lives of 1 year or half a year give interesting results). There are a large number of websites giving information about the half lives of radioactive isotopes such as
  http://www.buzzle.com/articles/list-of-radioactive-elements.html or
  http://www.iem-inc.com/toolhalf.html and some examples are listed below.
- Repeat the steps 1-3 above with different half lives. For each one note the constant (a) in the regression function $100*a^x$
- Complete a second spreadsheet with columns for the half life and the constant and look for possible patterns and rules.
- Look for possible functions that might fit the data. This time you will need to use 'plot function' on menu 4.

- **Can you derive this relationship by considering the theory behind exponential decay?**

These are a few examples of half lives

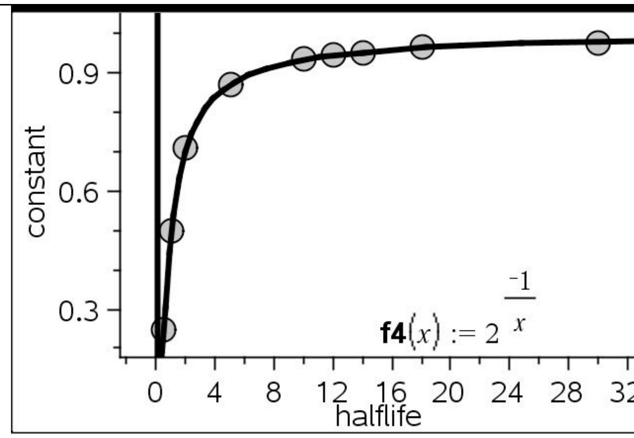
isotope	Half-life		isotope	Half-life		isotope	Half-life
Uranium 238	4.5 billion years		Strontium 90	28 years		Tritium (Hydrogen 3)	12 years
Uranium 235	700 million years		Cobalt 60	5 years		Curium 242	163 days (approx ½ year)
Uranium 234	245 000 years		Iodine 125 and 131	8 days		Curium 243	35 years
Plutonium 239	24 300 years		Americum 241	450 years		Curium 244	18 years
Caesium 137	30 years		Ruthenium 106	1 year		Antimony 125	2 years
Thorium 232	14 years		Xenon 137	4 minutes			

Notes for teachers: Possible solutions

These are some examples of the constants in the regression equation for different half lives. They have been entered into a new spreadsheet

The inclusion of half lives of 0.5,1 and 2 makes it easier to spot a possible connection as shown in the screen shot below.
Possible formulas could be tested by inserting into the formula cell in the next spreadsheet column.

	A isotope	B halflife	C constant
◆			
1	curium242	0.5	0.25
2	ruthenium106	1	0.5
3	antimony125	2	0.707107
4	cobalt60	5	0.870551
5	krypton85	10	0.933033
6	hydrogen3	12	0.943874
7	thorium232	14	0.951695
8	curium244	18	0.962224
9	caesium137	30	0.97716



Further theory

If N is the number of atoms at time t, the rate of decrease of *N* is proportional to the number of atoms remaining.