Investigating decay chains

Part 1

Radioactive materials decay by several mechanisms. The most common types of decay involve emission of either alpha, beta or gamma radiation. This activity concentrates on alpha and beta decay.

In the case of alpha decay a nucleus of a radioactive isotope releases an alpha particle. This consists of two protons and two neutrons — a helium nucleus. In doing so the mass number of the element is reduced by four, and the atomic number is reduced by two. For example when uranium-238 decays by alpha emission it produces thorium-234. The nuclear equation that represents this process is:

$^{238}_{92}U \rightarrow {}^{234}_{90}Th + {}^{4}_{2}He$ ($^{4}_{2}He$ is an alpha particle)

In the case of beta decay a neutron from the nucleus of a radioisotope is converted into a proton and an electron. The high-energy, negatively-charged electron is ejected from the nucleus. By releasing the electron, the mass number of the parent element remains constant but the atomic number is increased by one. For example, when uranium-240 decays by beta emission, neptunium-240 is produced. The nuclear equation that represents this process is:

$^{240}_{92}U \rightarrow {}^{240}_{93}Np + {}^{0}_{-1}e$ ($^{0}_{-1}e$ is a beta particle or electron)

- Locate and open the learning object *Decay chain explorer*. Select **Start** to display the **Decay chain builder** screen.
- Test your understanding of alpha and beta decay by following instructions on the screen.

1. Start with **U-238** and follow its decay series through to stable **Pb-206**.

   To check you have made the correct series, select **Next** to go to the next screen — **Decay chain explorer**. Select **U-238**. The uranium-238 decay series will be shown.

2. For more practice, return to the previous screen (**Decay chain builder**) and select a different radioisotope to repeat the process.

Extension

3. Write nuclear equations for each decay chain you create.

Part 2

Decay chain explorer contains information on 11 isotopes of uranium. For each isotope you can explore the decay chain that results from the decay of uranium and its radioactive daughter products. Other isotopes of uranium exist, but the most important isotopes are listed here.

- Locate and open the learning object *Decay chain explorer*. Select **Start** then **Next** to display the screen headed **Decay chain explorer**, and answer the following questions.

4. Use information about the uranium isotopes to list their half-lives in the table below.

uranium isotope	half-life
U-240	
U-239	
U-238	
U-237	
U-236	
U-235	
U-234	
U-233	
U-232	
U-231	
U-230	

5. Study the list of half-lives in your completed table. Which uranium isotopes would you expect to naturally occur on Earth, and why?

   Hint: Assume that the Earth is about 4.5 billion years old and that a wide range of uranium isotopes were present when Earth was formed.

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6. What are the stable daughters of radioisotopes U-234, U-235 and U-238? Do any of them share any intermediate daughters?

U-234 stable daughter .....

U-235 stable daughter .....

U-238 stable daughter .....

- The age of some rocks and minerals can be determined using the radioactive decay of uranium. The ratio between the stable daughter product and the parent uranium isotope is measured: in young rocks it will be small as little daughter product will be present. In older rocks the ratio will increase as the uranium isotope decays.

7. To date rocks, scientists use two different ratios between a daughter product and a parent isotope of uranium. These are based on the decay of different uranium isotopes. What do you think these two ratios are?

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8. If a mineral contains a small amount of uranium, but no lead, when it is formed, how old will it be before the ratios from question 4 equal 1.0? (The answer is different for each ratio)

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Part 3

Uranium-235 and uranium-238 are both radioactive isotopes that decay in stages through several intermediate daughter isotopes before finally reaching a stable state. U-235 decays in 11 stages to Pb-207; and U-238 decays in 14 stages to the isotope Pb-206.

This simulation illustrates, using a bar graph, what happens to the number of uranium nuclei and the number of daughter nuclei as U-235 and U-238 radioisotopes decay.

- Locate and open the learning object *Decay chain explorer*. Select **Start**, then **Next**, then **Next** again to display the screen headed **Uranium decay explorer**.
- Select the **Arithmetic** scale and the **U-235** decay series.
- Before selecting **Start** on this screen, answer questions 9 – 14 below:

9. Once the simulation has begun how many bars do you expect to see?

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10. Give a brief description of what you expect will happen to the bar graph when you select **Start**.

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11. What is the ratio **Pb-207 / U-235** when the elapsed time (t) is zero?

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12. When will the ratio **Pb-207 / U-235** be equal to one?

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13. During the decay process will **Pb-207** increase or decrease?

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14. During the decay process will **U-235** increase or decrease?

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Extension questions

Given that the Earth is 4.5 billion years old, the half-life of U-235 is 0.7 billion years, and the half-life of U-238 is 4.5 billion years, answer the following questions.

20. How many half-lives has U-235 been through since the Earth was formed?

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21. How many half-lives has U-238 been through since the Earth was formed?

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Extension activity

U-235 decays to stable **Pb-207** through a series of daughter products. This decay series and the half-life of each daughter product is listed in the table below.

If a logarithmic timescale is used then intermediate daughter products with reasonably long half-lives appear on the graph as they decay. This is different from the arithmetic scale, which shows only initial and end products.

isotope	half-life
U-235	0.704 billion years
Th-231	23.52 hours
Pa-231	32.76 thousand years
Ac-227 *	21.772 years
Th-227	18.68 days
Ra-223	11.43 days
Rn-219	3.96 seconds
Po-215	1.781 milliseconds
Pb-211	36.1 minutes
Bi-211 *	2.14 minutes
Ti-207	4.77 minutes
Pb-207	stable

* only the main decay path for these isotopes is listed.

- Select the **Logarithmic** scale and the isotope **U-235**. Before selecting **Start**, complete your predictions for questions 22 – 25 below.

22. Once the simulation has begun, how many bars do you expect to see?

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23. Give a brief description of what you expect will happen to the bar graph when you select Start.

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24. What is the value of the ratio **Pb-207 / U-235** when the elapsed time (t) is zero?

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25. When will the ratio of parent isotope to stable daughter product equal one?

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- Select **Start** on the *Uranium decay explorer*. Review your responses to questions 22 – 25 and modify them where necessary.

26. Can the half-life of **Pa-231** be calculated from the graph? If so, how would you do it? If not, explain why it can't be calculated.

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27. Observe the ratio **Pb-207 / U-235** (bottom-right corner of screen). What is the ratio when elapsed time is 0.704 billion years?

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28. Is this ratio consistent with what you would expect if the half-life of U-235 is 0.704 billion years? Explain.

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29. Calculate the ratio of the intermediate daughters **Ac-227 / Pa-231** at any stage of the decay.

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30. Repeat the calculation for two other stages of the decay chain.

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31. Compare the ratios calculated in questions 29 and 30 above and comment on the comparison.

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32. Change the isotope to **U-238** decay series and run until the time elapsed shows 4.5 billion years. This is approximately the age of the Earth. What is the value of the ratio **U-234 / U-238** at this time?

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33. Is this ratio constant over time? Calculate the ratio for two other values of time to confirm your answer.

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