Isochron Dating

As we discussed last time, we can express the radioactive decay equation in two ways:

$$[X] = [X]_i\, e^{-\lambda t} \qquad\qquad [X] = [X]_i\, (½)^{(t\,/\,t_{1/2})}$$

Where we have expressed the values in terms of concentrations [X] instead of number of atoms N. The problem is that we rarely know the initial concentration $[X]_i$ offhand. However, we can often figure it out by measuring the amount of decay *product* that accumulates.

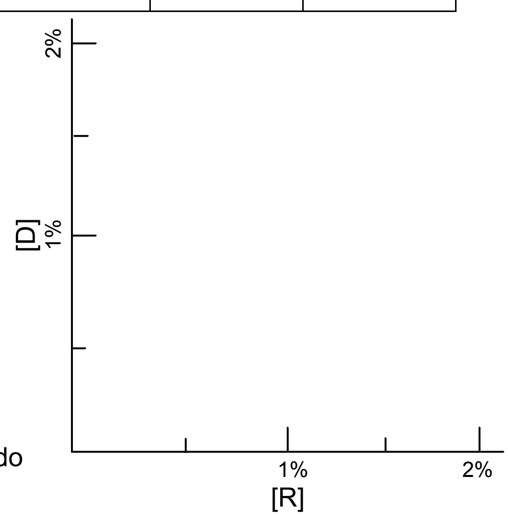
1. Suppose we have a sample that contains a concentration $[R]_i$ of some specific radioactive isotope *at its formation*. What is the concentration [R] after time t has elapsed?

2. Radioactive atoms don't disappear completely when they decay; they turn into other atoms, of some "daughter" elemental isotope. What is the concentration [D] of this daughter isotope at time t, if the sample had a concentration of $[D]_i$ to begin with at t=0?

3. Suppose a given sample has (at its formation) $[R]_i$ = 1% and $[D]_i$ = 0.5%; and the half-life of the radioactive element (as measured in a laboratory) is known to be 1 billion years. Use the table below to figure out how [R] and [D] change with time.

t	0	1 billion yr	2 billion yr	3 billion yr	4 billion yr	5 billion yr
[R]						
[D]						

4. Now plot these on the graph at right, labeling the points with their ages.



5. Suppose you pick up a rock in the field and measure [R] and [D] (their values today), and you find that in one region of the rock, [R] = 0.5% and [D] = 1%. Can you figure out its age?

6. Suppose now that some other sample had initial concentrations of $[R]_i$ = *1.5%* and $[D]_i$ = 0.5%. How do [R] and [D] change with time now?

t	0	1 billion yr	2 billion yr	3 billion yr	4 billion yr	5 billion yr
[R]						
[D]						

7. Plot this new data on the same graph as the old. Using a ruler (or drawing by eye if you can draw straight lines well), draw a line through each pair of points with the same age and extrapolate to the left side of the graph. What information does this give you? (These lines are called "isochrons".)

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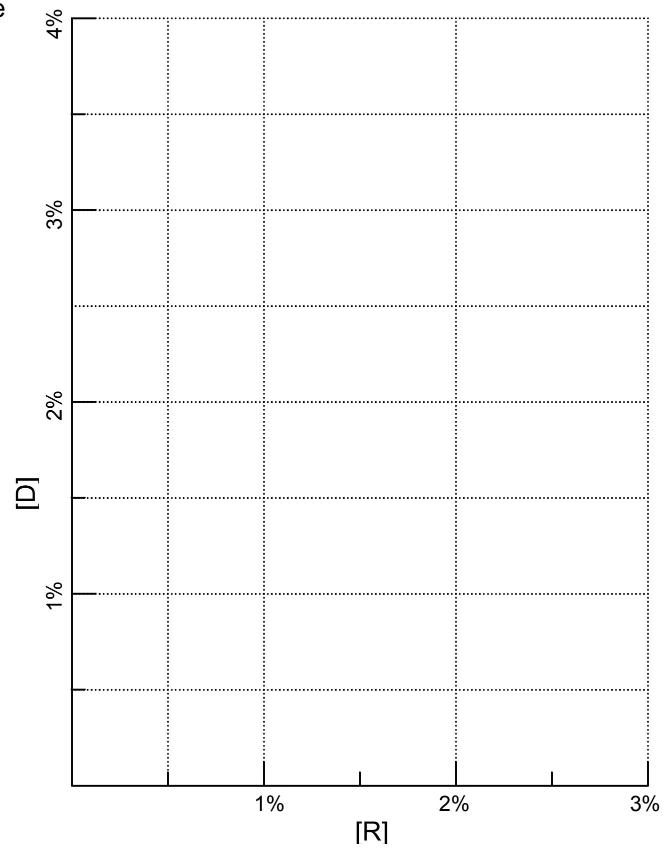
8. Now let's start calculating some real ages! Suppose we find a rock, and measure the concentrations [R] and [D] in a bunch of different areas:

	[R]	[D]	[D_{iso}]
region "A"	1.0%	4.0%	1%
region "C"	0.1%	1.3%	1%
region "F"	0.5%	2.5%	1%
region "G"	0.4%	2.2%	1%
region "L"	0.4%	1.7%	0.5%

Plot these at right. (Ignore the D_{iso} column for now.)



9. What was the initial concentration $[D]_i$ in this rock? Use the technique from (7), and ignore point L for now.

10. Now that you know $[D]_i$, draw an isochron for t=0, when we assume [D] was constant everywhere.

11. Draw an isochron for after 1 half-life has elapsed (t = 1 billion years), and after 2 half-lives (2 billion years). How old is the rock?

12. What would happen to the t=0 isochron line if $[D]_i$ were not a constant – that is, different regions of the rock had different values of [D] as well as of [R]? What about at other times?

Region "L" doesn't fit the pattern. You might suspect (and you'd be right) that this has something to do with its different value of [D_{iso}], which refers to the concentration of some alternate isotope of the same element as the daughter product. As it turns out, there is no reason to expect that the concentration of any isotope should be the same in different regions of the sample – this is why we are able to get different measurements for [R] in different places, and we expect this to happen as well [D]: there is no single initial value $[D]_i$ as we imagined in (9).

Fortunately, we can correct for this, knowing the abundance of some other isotope of the daughter element, [D_{iso}]. As it turns out, if some region of a rock happens to be depleted in one isotope of some element, it will be depleted in *all* isotopes of that element by the same fraction. So we can *divide* all our concentrations by this alternate isotope fraction [D_{iso}] to convert everything to a unit system in which the points really do begin on a line, since [D]/[D_{iso}] is constant.

13. "Correct" for the fact that region L was depleted in the daughter element to begin with by dividing its values (both [R] and [D]) by [D_{iso}]. Does it fit the pattern now?