EENS 211	Earth Materials
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Radiometric Dating	

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Prior to 1905 the best and most accepted age of the Earth was that proposed by Lord Kelvin based on the amount of time necessary for the Earth to cool to its present temperature from a completely liquid state. Although we now recognize lots of problems with that calculation, the age of 25 my was accepted by most physicists, but considered too short by most geologists. Then, in 1896, radioactivity was discovered. Recognition that radioactive decay of atoms occurs in the Earth was important in two respects:

1. It provided another source of heat, not considered by Kelvin, which would mean that the cooling time would have to be much longer.
2. It provided a means by which the age of the Earth could be determined independently.

Principles of Radiometric Dating

Radioactive decay is described in terms of the probability that a constituent particle of the nucleus of an atom will escape through the potential (Energy) barrier which bonds them to the nucleus. The energies involved are so large, and the nucleus is so small that physical conditions in the Earth (i.e. T and P) cannot affect the rate of decay.

The rate of decay or rate of change of the number N of particles is proportional to the number present at any time, i.e.

$$\frac{dN}{dt} \propto N$$

Note that dN/dt must be negative.

The proportionality constant is λ, the decay constant. So, we can write

$$\frac{dN}{dt} = -\lambda N$$

Rearranging, and integrating, we get

$$\int_{N_o}^{N} \frac{dN}{N} = -\lambda \int_{t_o}^{t} dt$$

or

$$\ln(N/N_o) = -\lambda(t - t_o)$$

If we let $t_o = 0$, i.e. the time the process started, then

$$N = N_o e^{-\lambda t} \qquad (1)$$

We next define the half-life, $\tau_{1/2}$, the time necessary for 1/2 of the atoms present to decay.

This is where $N = N_o/2$.

Thus,

$$\frac{N_0}{2} = N_o e^{-\lambda t}$$

or

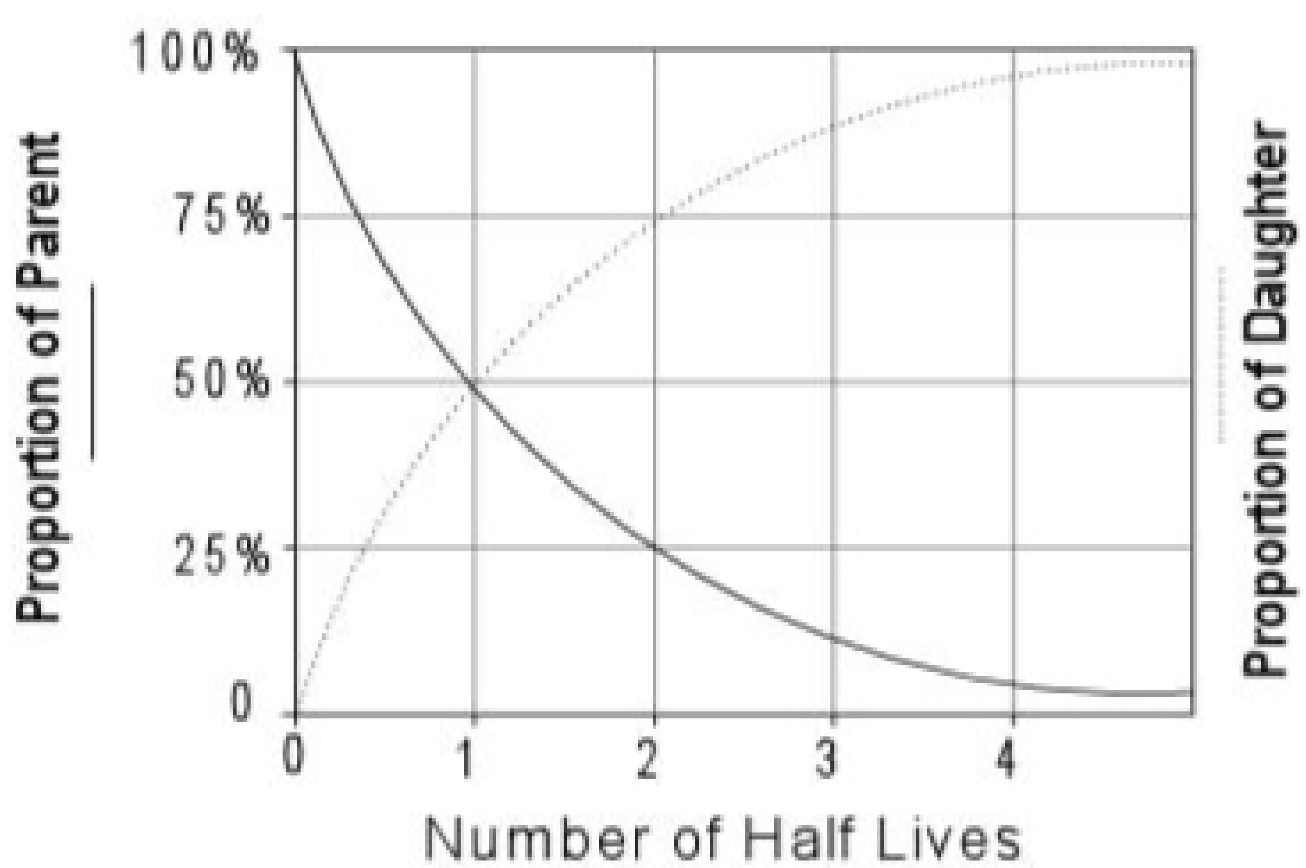
$$-\ln 2 = -\lambda t,$$

so that

$$\tau_{1/2} = \frac{\ln 2}{\lambda}$$

The ***half-life*** is the amount of time it takes for one half of the initial amount of the parent, radioactive isotope, to decay to the daughter isotope. Thus, if we start out with 1 gram of the parent isotope, after the passage of 1 half-life there will be 0.5 gram of the parent isotope left.

After the passage of two half-lives only 0.25 gram will remain, and after 3 half lives only 0.125 will remain etc.



Knowledge of $\tau_{1/2}$ or λ would then allow us to calculate the age of the material if we knew the amount of original isotope and its amount today. This can only be done for ^{14}C, since we know N_0 from the atmospheric ratio, assumed to be constant through time. For other systems we have to proceed further.

Some examples of isotope systems used to date geologic materials.

Parent	Daughter	$\tau_{1/2}$	Useful Range	Type of Material
^{238}U	^{206}Pb	4.47 b.y	>10 million years	Igneous & sometimes metamorphic rocks and minerals
^{235}U	^{207}Pb	707 m.y		
^{232}Th	^{208}Pb	14 b.y		
^{40}K	^{40}Ar & ^{40}Ca	1.28 b.y	>10,000 years	
^{87}Rb	^{87}Sr	48 b.y	>10 million years	
^{147}Sm	^{143}Nd	106 b.y.		
^{14}C	^{14}N	5,730 y	100 - 70,000 years	Organic Material

To see how we actually use this information to date rocks, consider the following:

Usually, we know the amount, N, of an isotope present today, and the amount of a daughter element produced by decay, D*.

By definition,

$$D^* = N_0 - N$$

from equation (1)

$$N = N_o e^{-\lambda t}$$

So,

$$D^* = Ne^{\lambda t} - N = N(e^{\lambda t} - 1) \qquad (2)$$

Now we can calculate the age if we know the number of daughter atoms produced by decay, D* and the number of parent atoms now present, N. The only problem is that we only know the number of daughter atoms now present, and some of those may have been present prior to the start of our clock.

We can see how do deal with this if we take a particular case. First we'll look at the Rb/Sr system.