7. Determining the Ages of Things

Geochronology

When a radio-active element decays we have a parent (P) producing a daughter element (D) with a half-life $T_{1/2}$, itself at the same time obviously losing the same number of atoms.

To use this for dating one needs $T_{1/2}$ to be a suitable length of time, measurable quantities of the daughter element, and of the parent. You need also to be able to estimate the amount of the daughter element originally there. There should be no loss or gain of the parent and daughter substances through, for example, diffusion, recrystallization, metamorphosis or contamination (the latter including during analysis).

There are several suitable candidate elements:

```
    P(arent)    D(aughter)   T₁/₂(x10⁹ yrs)

     U²³⁸        Pb²⁰⁶          4.7
     U²³⁵        Pb²⁰⁷          0.71
     Th²³²       Pb²⁰⁸         13.9

     Rb⁸⁷        Sr⁸⁷          49.8

     K⁴⁰         Ar⁴⁰          11.8
     also        Ca⁴⁰          1.47
```

The Lead decay has the added complication that it is usually added to the Lead that is already there. Fortunately non-radiogenic lead contains Pb^{204} and the proportions:

```
    Pb²⁰⁸   +   Pb²⁰⁷   +   Pb²⁰⁶   +   Pb²⁰⁴
     26%        21%         52%         1.4%
```

are independent of time. You can therefore use the amount of Pb^{204} to estimate the amount of non-radiogenic Lead.

in the Rubidium-Strontium decay the SR^{87} is added to non-radiogenic Sr^{87}, but we can get this latter from:

$$(Sr^{87}/Sr^{86})_{non-radiogenic} = 0.7$$

Similarly the Ar^{40} in the Potassium-Argon decay will be added to the Ar^{40} in the air, but, for the non-radiogenic component:

$$(Ar^{36}/Ar^{40})_{air} = 0.00337$$

We need also the fact that $(K^{40}/K_{total}) = 0.000119$

Decay to a single daughter element

When a simple one-to-one decay takes place we have daughter element D produced to the extent:

$$D = P_0 - P_0 e^{-Lt} = -P_0(e^{-Lt}-1)$$

where D=amount of daughter element, P of parent element and P_0 is the original amount of the parent. L here is lambda, the decay rate. Of course by this definition $L = \ln 2 / T_{1/2}$.

```
  if      Pₙ (= P now) = P₀e⁻ᴸᵗ
```
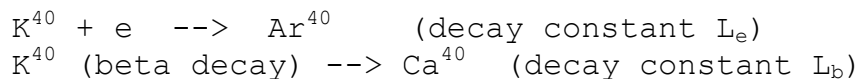
```
then    D = Pₙ(eᴸᵗ -1)
```

```
  so
       t = (1/L)[/SUP> -1)
  so
       t = (1/L)[ln(1 + D/Pₙ)]
```

Decay to two products

Things become more complex if we have more than one decay product. Thus for example with the the Potassium decay where we have two pathways, K^{40} can go to Ar^{40} after electron capture, or two Ca^{40} after beta decay:

```
       K⁴⁰ + e  -->  Ar⁴⁰     (decay constant Lₑ)
       K⁴⁰ (beta decay) --> Ca⁴⁰  (decay constant L_b)

  D = P₀ - P₀e⁻⁽ᴸᵉ⁺ᴸᵇ⁾ᵗ
```

```
so
    D = Pₙ(e⁽ᴸᵉ⁺ᴸᵇ⁾ᵗ-1)
```

```
so
   t = [1/(Lₑ+L_b)] ln [1+D/Pₙ]

    D = Dₑ + D_b = (1 + D_b/Dₑ) Dₑ
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so
   Dₑ = D/[1+D_b/Dₑ] = D/[1+L_b/Lₑ] = DLₑ/(Lₑ+L_b)
```

```
   so
   D = Dₑ(Lₑ+L_b)/Lₑ
   and
   t = [1/(Lₑ+L_b)] ln[1 + (Lₑ+L_b)Dₐ/LₐPₙ]
```

```
Now  Lₑ = ln 2 /Tₑ 1/2
```

Typically we might get amount of Ar^{40} per gm = 13.6×10^{15} atoms and amount of $K^{40} = 77 \times 10^{15}$ atoms. This will give a t of around 1.86×10^{9}.

Rubidium-Strontium Method

```
       Sr⁸⁷
       Sr⁸⁷_obs = 0.7 Sr⁸⁶_obs + Rb⁸⁷_obs(eᴸᵗ-1)
```

```
(SR^87/Sr^86)_obs = 0.7 + (Rb^87/Sr^86)_obs(e^Lt-1)
```

Rubidium substitutes for Potassium, K, with the same valency 1 and similar radii, 0.13 - 0.15 nm.

The method used for this dating technique is to take a rock sample, a solid source, then vaporise it to pass it through a mass spectrometer to obtain the ratios of the elements. Plotting the ratios should give an interrupt of 0.7 as a check on the answer, while the slope gives t.

The Potassium and Rubidium methods can be used together and often are as checks on one another.

The Uranium Method

The main problem with the Uranium method is that Uranium is not very commonly occurring. It does not substitute for the common ions in a mineral and so is "left out" when crystallization occurs, and is amongst the last of the rocks to crystallise. This means crystallisation takes place over a long time period, and so the crystals will be large. (Don't, therefore, look for U in a fine-grained area!)

To find Uranium we look for coarse grained granites and giant-grained granite(Pegmatite). Uranium and Thorium are found together as they substitute for each other and Zirconium. Uraninite is UO_2 and Zircon is $ZrSiO_4$

on_4

one further complication is that lead diffuses so $D_{obs} = e_{ta}D_{produced}$, where e_{ta} is the proportion that has not diffused away. You can eliminate e_{ta} by taking the ratios for U^{238} and U^{235} decay:

```
so:
        Pb^207/Pb^206 = [U^235(e^L235t-1)]/[U^238(e^L238t-1)]
```

This gives t. Compare this with the values from U^{238} --> Pb^{206} and U^{235} --> Pb^{207}. If they are the same (i.e. same ages) they they are said to be 'concordant' and of high accuracy. Usually they are 'discordant'. Usually Thorium in the same rock gives a further estimate - i.e Th^{232}/Pb^{208} is also used.

Oldest rocks found

The oldest rocks found are from Russia (3.5 x10^9 years and South Africa (3.2 x10^9 years). Many rocks are 1.0-1.8 x10^9 years old. There have been "quiet" times for rock formation as rocks between 0.5-0.9 x10^9 and 2.0-2.3 x10^9 are infrequent.