Types of Radioactive Decay

The two common kinds of radioactive decay that transmute a nucleus into another nucleus of a different element are, as we have seen,

alpha decay

and beta decay.

Let's look at these in a bit more detail.

Types of Radioactive Decay

Alpha Decay

Let's examine this by considering a particular example in detail.

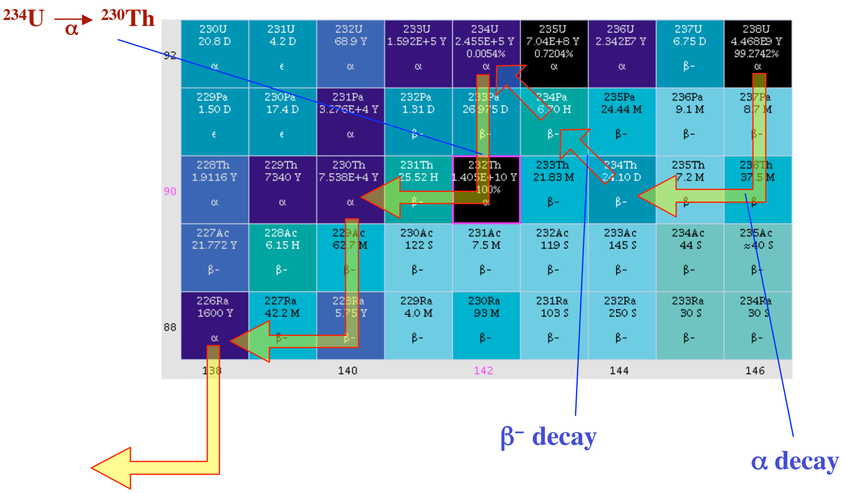
$$^{234}U \xrightarrow{\alpha} {}^{230}Th$$

Original nucleus — α particle emitted — Residual nucleus

This is one of the decays in the natural ^{238}U decay chain.

Alpha Decay

Nuclide chart, showing part of the ^{238}U decay series



Alpha Decay

To gain some insight into what is happening we consider the *original nucleus* to be made up of the *residual nucleus* and an α particle, initially together, and we consider the potential energy as seen by the α particle as it leaves during alpha decay.

Thus the system can be considered to be an alpha particle, with an energy equal to the energy released in the decay, that is inside a potential well given by the Coulomb potential between the alpha particle and the residual nucleus ^{230}Th.

It turns out that, in order to understand a decay, it is necessary to use the ideas of quantum mechanics, particularly barrier penetration or tunnelling.

Alpha Decay of ^{234}U into ^{230}Th.

$$^{234}_{92}\mathrm{U} \rightarrow ^{230}_{90}\mathrm{Th} + \alpha$$

The first step is to calculate the separation energy – the energy released in the decay.

We know that this is given by:

$$E_s = m\left(^{234}_{92}\mathrm{U}\right) - \left[m\left(^{230}_{90}\mathrm{Th}\right) + m\left(^{4}_{2}\mathrm{He}\right)\right]$$

with masses expressed as energy (MeV)

(As we discussed previously, if you use atomic masses then the electron masses balance out.)

$$E_s = \{234.04093933 - [230.03312683 + 4.00260305]\} \times 931.494$$
$$= 4.853 \text{ MeV}$$

So when the α particle has been expelled from the nucleus (and is far away), it will have an energy (that is *kinetic energy*) of 4.853 MeV.

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Alpha Decay of ^{234}U into ^{230}Th.

Next we consider that ^{234}U can be considered as ^{230}Th together with an α particle.

We then examine what the potential energy (P.E.) of this system looks like as a function of the distance between the ^{230}Th nucleus and the α particle.

We set the zero on the energy scale to be the P.E. of the system when the α particle is far away.

As we have calculated, when the α particle is inside the nucleus it has an excess energy of +4.85 MeV.

If it were *just outside* the nucleus (and beyond the attraction of the strong force) the α particle would have to have a very high P.E. – given by the Coulomb repulsion between the α particle and the residual nucleus.

In order to calculate this we need the radius of the ^{230}Th nucleus and the radius of the α particle.

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Alpha Decay of ^{234}U into ^{230}Th.

We use $r = 1.2 \times 10^{-15} A^{1/3}$ m to calculate this.

This gives r(^{230}Th) = 7.352x10^{-15} m and r(^{4}He)= 1.905x10^{-15} m.

So when these nuclei are just touching the distance between their centres is 9.26x10^{-15} m. We call this R_0

At this distance the strong force ceases to have an effect and the potential energy is given by the Coulomb potential between the nuclei.

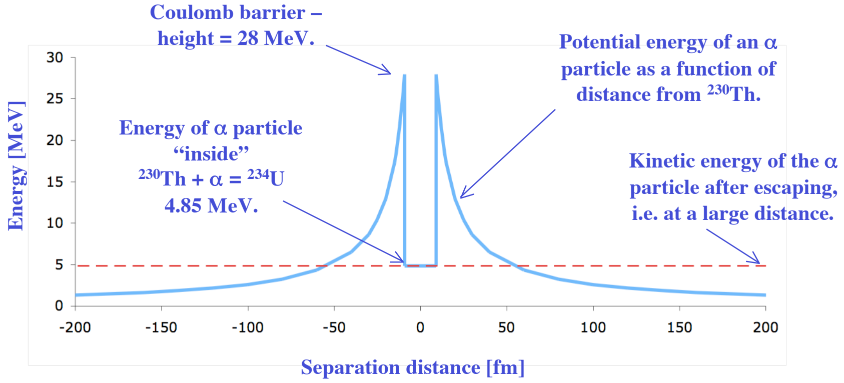
This is calculated from Coulomb's law which gives for the potential energy:

$$U = k_e \frac{q_1 q_2}{R_0}$$

$$= 8.99 \times 10^9 \frac{90 \cdot 1.60 \times 10^{-19} \cdot 2 \cdot 1.60 \times 10^{-19}}{9.26 \times 10^{-15}} \cdot \frac{1}{1.60 \times 10^{-19}} \text{ eV}$$

$$= 28.0 \text{ MeV}$$

Energy vs Separation for Alpha Decay of ^{234}U into ^{230}Th.



In this situation a classical particle would never escape.
It would not be able to penetrate the potential barrier.

But quantum mechanically we can have *tunnelling* – barrier penetration.

Exercise 21

1. ^{226}Ra undergoes α decay. What isotope is produced?

   Calculate the energy emitted in this decay.

   Calculate the height of the Coulomb barrier seen by the α particle.

   Sketch the potential seen by the α particle in this case.