Binding Energy and Nuclear Forces

Forces in the Universe

The most important force in the stars and galaxies and in the solar system is *gravity*. *Gravity* also keeps us on the earth and it keeps the earth together.

The *electromagnetic force* is an important force in the world around us.

It produces chemical binding between atoms and it is responsible for the behaviour of the materials that we use every day.

At the nuclear level there are two additional important forces: the, so-called *strong* force and the so-called *weak* force.

It is the *strong* force that is responsible for the *binding* between the *nucleons* in the nucleus as we have described.

Protons and neutrons

The *weak* force is important in *radioactive beta decay* (and in the nuclear reactions that take place in the sun, for example).

See later

Forces between nucleons

The strong force has a very short range. For it to be effective the nucleons, or nuclei must approach each other very closely.

When this happens a nuclear reaction occurs.

Nuclear Reactions

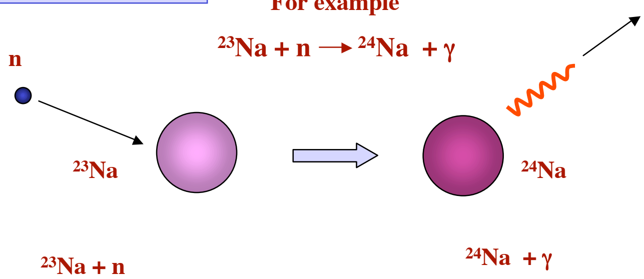
Nuclear Reactions

When a particle interacts with a nucleus, this is called a *nuclear reaction.*

This kind of reaction is called "neutron capture"

For example

$^{23}Na + n \longrightarrow {}^{24}Na + \gamma$



This can also be written in the form: $^{23}Na(n, \gamma)^{24}Na$

Target

Incident particle

Product

Outgoing particle

Nuclear Reactions - Neutron Capture

In *neutron capture* the incident particle is a *neutron* and the outgoing particle is a *gamma-ray*.

The product is the isotope of the same element with one more neutron.

It is neutron-rich.

Another example is: $^{27}Al(n, \gamma)^{28}Al$

and $^{238}U(n, \gamma)^{239}U$

and many others.

Neutron capture reactions can have very large *cross-sections* for *thermal neutrons*

Nuclear Reactions with Radioactive Products

In the particular case of ^{23}Na(n, γ)^{24}Na, for example, the product, ^{24}Na, is *radioactive*, and undergoes beta decay.

$$^{24}\text{Na} \xrightarrow{\beta^-} {}^{24}\text{Mg}$$

But remember - this is radioactive decay. It is *not* a nuclear reaction.

The product of a nuclear reaction could be stable or radioactive.

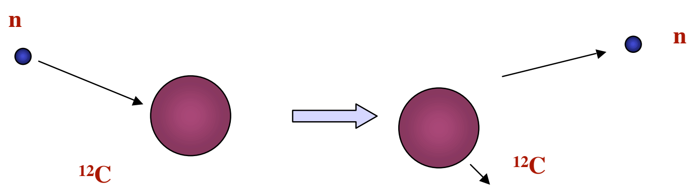
Note: Neutron capture is usually the most probable reaction when thermal neutrons interact with a nucleus.

Nuclear Reactions

When the incoming particle is a neutron we talk about *neutron-induced* reactions

When the outgoing particle is another neutron we call the reaction *neutron-scattering*.

When the outgoing particles have the same energy as the incoming particle we call it *elastic-scattering*



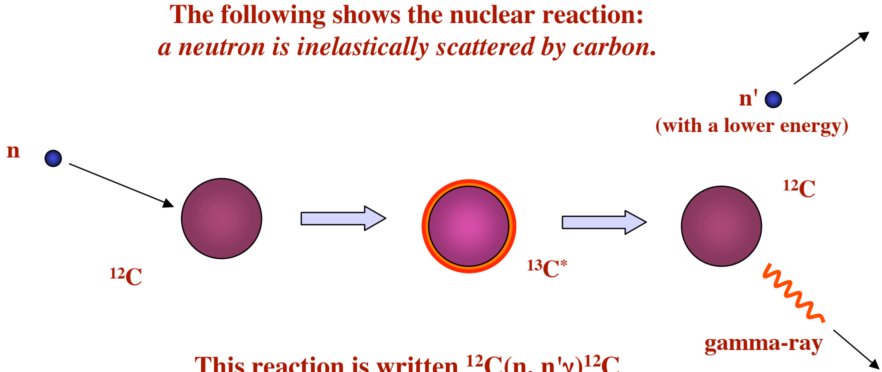
Kinetic energy and momentum are conserved

This reaction is written ^{12}C(n, n)^{12}C

Nuclear Reactions

When the outgoing particle is of the same type as the incoming particle but has a lower energy, then we call it *inelastic-scattering*.

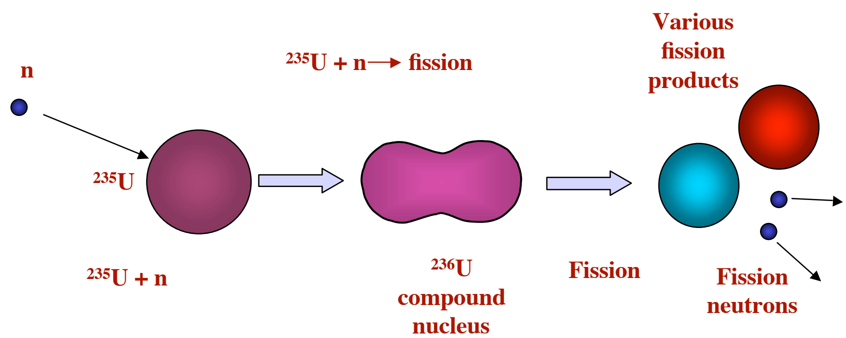
The following shows the nuclear reaction:
a neutron is inelastically scattered by carbon.



This reaction is written $^{12}C(n, n'\gamma)^{12}C$

Nuclear Reactions

Fission is also usually a neutron-induced nuclear reaction.



This can also be written in the form: $^{235}U(n,f)$.

Nuclear Reactions

Review of different kinds of neutron-induced reactions.

Neutron capture: $^{55}Mn(n, \gamma)^{56}Mn$.

Neutron elastic scattering: $^{12}C(n, n)^{12}C$.

Neutron inelastic scattering: $^{12}C(n, n'\gamma)^{12}C$.

Neutron reactions with an out-going charged particle: e.g. $^{27}Al(n, p)^{27}Mg$, $^{27}Al(n, \alpha)^{24}Na$.

Neutron induced fission: $^{235}U(n,f)$.

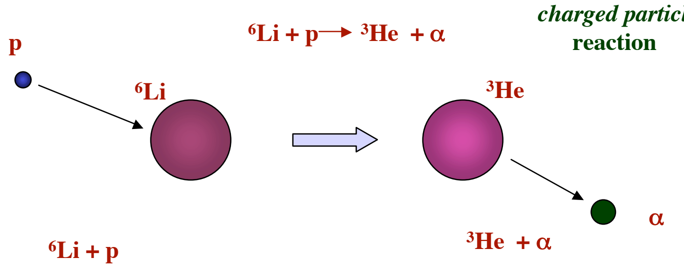
Nuclear Reactions

The incoming and outgoing particles could be of many types, for example they could both be charged.

Another example

$^{6}Li + p \rightarrow {}^{3}He + \alpha$

This is a *charged particle* reaction



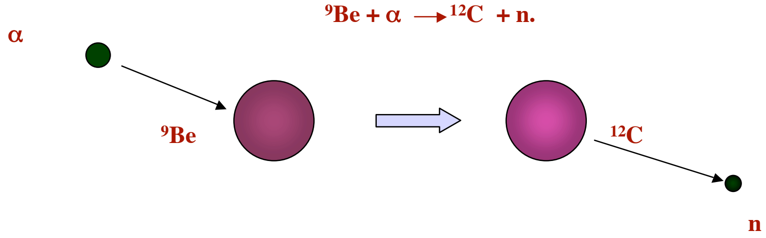
This can also be written in the form: $^{6}Li(p, \alpha)\,^{3}He$.

Nuclear Reactions

Another type of charged particle reaction is used as a *neutron source.*

For example the sources used by Enrico Fermi (see later), many laboratories today and sometimes for the start-up of nuclear reactors are of this type.

$^{9}Be + \alpha \rightarrow {}^{12}C + n.$



This can also be written in the form: $^{9}Be(\alpha,n)^{12}C$.

Where does this alpha particle often come from?

Nuclear Reactions and *Q* values

Energy is either produced or absorbed in a nuclear reaction.

This can be calculated from the masses of the particles on the left compared with those on the right, i.e. the total *initial* mass compared with the total *final* mass.

If the total mass of the products (the final mass) is *less* than the initial mass, then energy has clearly been *released.*
In this case the reaction has a positive *Q* value.
It is *exoergic.*

If the total mass of the products is *greater* than the initial mass, then energy has been *absorbed.*
The reaction has a negative *Q* value.
It is *endoergic.*

(Where does this energy come from?)

Exercise 18

1. **Calculate the *Q* value for the nuclear reaction: $^{9}Be(\alpha,n)^{12}C$.**

   Is it endoergic or exoergic?

   What do you think the *approximate* maximum energy of the neutrons produced is likely to be if the alpha particle has an energy of 4 MeV?

   Comment on why this value is *approximate*.