

## NUCLEAR ENERGY

In nuclear reactions, mass is converted into energy. The equation for the conversion is

$$E = mc^2$$

If only one gram of matter is converted into energy, it could produce

$$E = 0.001 \text{ Kg} \times (3 \times 10^8 \text{ m/s})^2$$

$$E = 9 \times 10^{10} \text{ J} \quad \text{or} \quad 2 \times 10^{10} \text{ Kilocalories}$$

Not all the matter present in a sample is converted into energy in a nuclear reaction, only a small part, the nuclear “glue” called the nuclear binding energy is consumed.

## NUCLEAR BINDING ENERGY

The force holding the particles in the nucleus together is called the “**nuclear binding energy.**”

This short-ranged force is extremely strong which allows the natural repulsive forces between protons to be overcome.

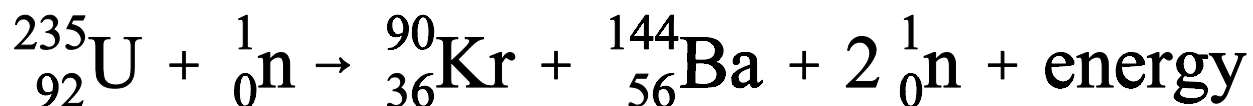
Another measure of the stability of atoms is the nuclear binding energy per nucleon.

The most stable elements in the universe are in the middle of the periodic table (iron and nickel).

## FISSION REACTIONS

**Fission** - The type of nuclear reaction where heavy nuclei such as uranium and thorium are split into two parts called fission fragments after being bombarded by neutrons.

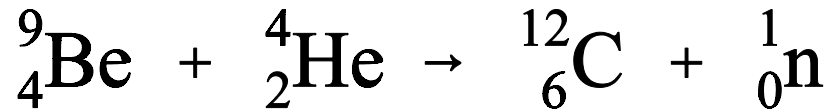
A typical fission reaction is:



Fission reactions produce large amounts of energy.

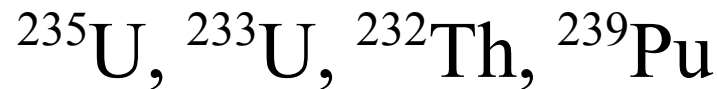
Fission reactions are also called chain reactions.

When the alpha particles from uranium bombard beryllium, neutrons are produced.



## FUELS

Only certain isotopes are fissionable and therefore may be used as fuels. They are



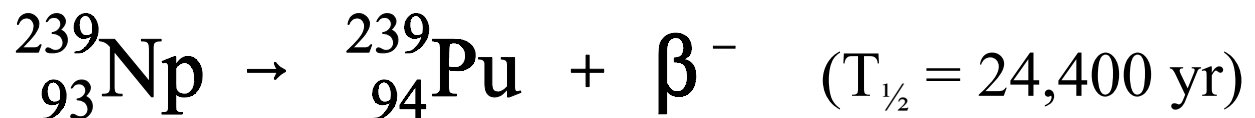
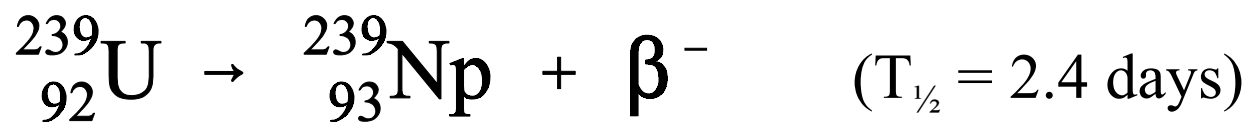
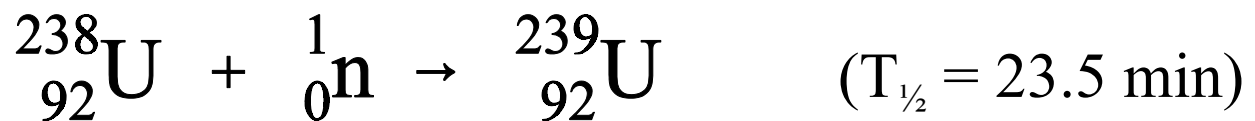
Natural uranium contains mostly (99.3%) uranium-238 and 0.7% uranium-235.

Only  ${}^{235}\text{U}$  is fissionable and can be used as a nuclear fuel.

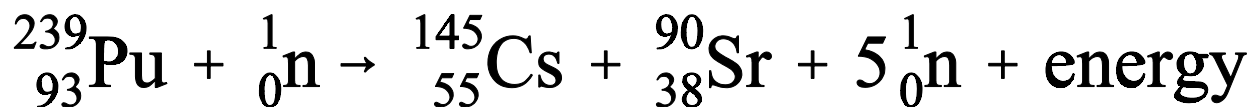
To use  ${}^{235}\text{U}$ , it must be separated from  ${}^{238}\text{U}$  by a process called enrichment. The result is a product called “enriched uranium” which contains 3-4%  ${}^{235}\text{U}$ .

## BREEDER REACTORS

Uranium-223 and plutonium-239 are produced in breeder reactors. Breeder reactors produce more fuel than they consume.



Plutonium-239 can then undergo fusion to produce energy. A typical reaction is



## MODERATORS

Moderators are necessary to slow down the speed of neutrons.

If the kinetic energy of a neutron is too great, the neutron will simply bounce off the nucleus without fusing.

Neutrons are slowed most effectively with a head-on collision with particles of similar mass.

Water, heavy water, beryllium, and graphite are commonly used as moderators.

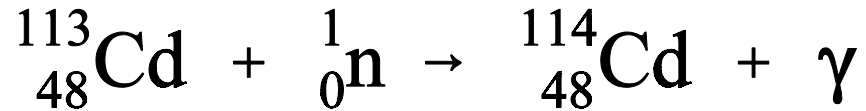
Water has the advantage that it can be used as a coolant as well as a moderator.

Other coolants are heavy water, air, helium, carbon dioxide, molten sodium, and molten salts are examples of reactor coolants.

## CONTROL RODS

The control rods control a nuclear fission reaction by absorbing neutrons.

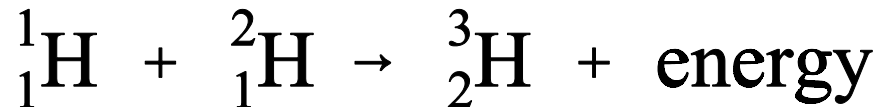
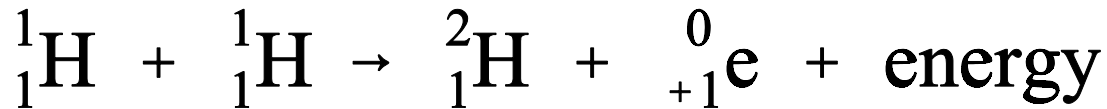
Boron and cadmium are commonly used in control rods by absorbing neutrons.



## FUSION REACTIONS

Fusion is the process of combining light nuclei to form heavy nuclei.

Fusion reactions are the nuclear reactions occurring on the sun.



Proton-proton cycle occurs on relatively cool stars such as our sun. (temperature .  $10^7$  °K)

Heavier elements are synthesized on hotter stars (temperature .  $10^8$  °K) with use carbon as their fuel.