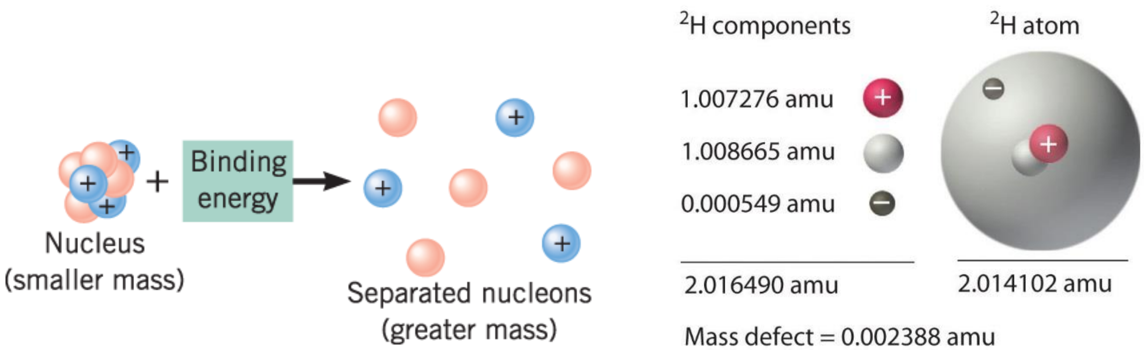
NUCLEAR FISSION AND FUSION

Mass Defect & Einstein's Equation

The mass of the nucleus is actually about 1% smaller than the mass of its individual protons and neutrons. This difference is called the mass defect.

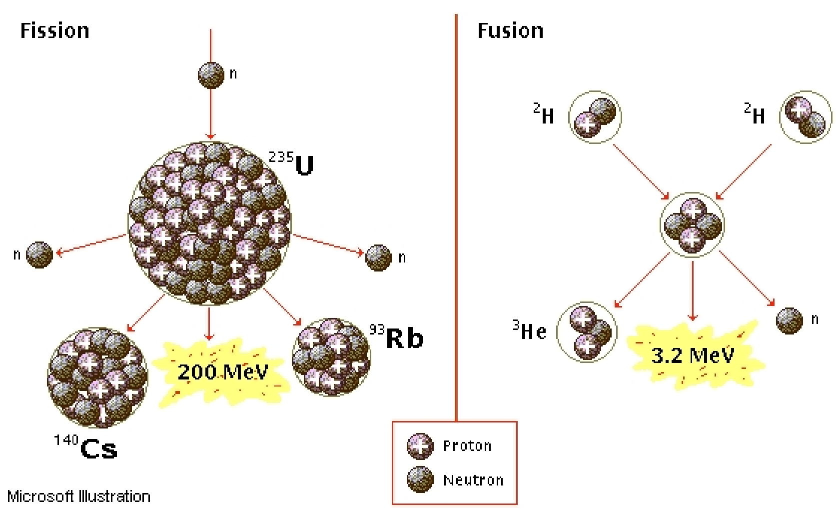


The mass defect results from the energy released when the protons and neutrons bind together to form the nucleus. This energy is called the nuclear binding energy.

The binding energy determines which nuclei are stable and how much energy is released in a nuclear reaction. The higher the binding energy, the more stable the nucleus.

Very heavy nuclei and very light nuclei have low binding energies. This implies:

1. a heavy nucleus will release energy when it splits apart (what we call fission)



2. two light nuclei will release energy when they join (what we call fusion).

The mass defect and binding energy are related by Albert Einstein's formula, $E = mc^2$ which shows that matter and energy are interchangeable.

This equation states, mass (m) can be converted into an amount of energy (E), where c is the speed of light.

Because the speed of light is a large number and thus c squared is huge, a small amount of matter can be converted into a tremendous amount of energy.

NUCLEAR ENERGY

FORMULA

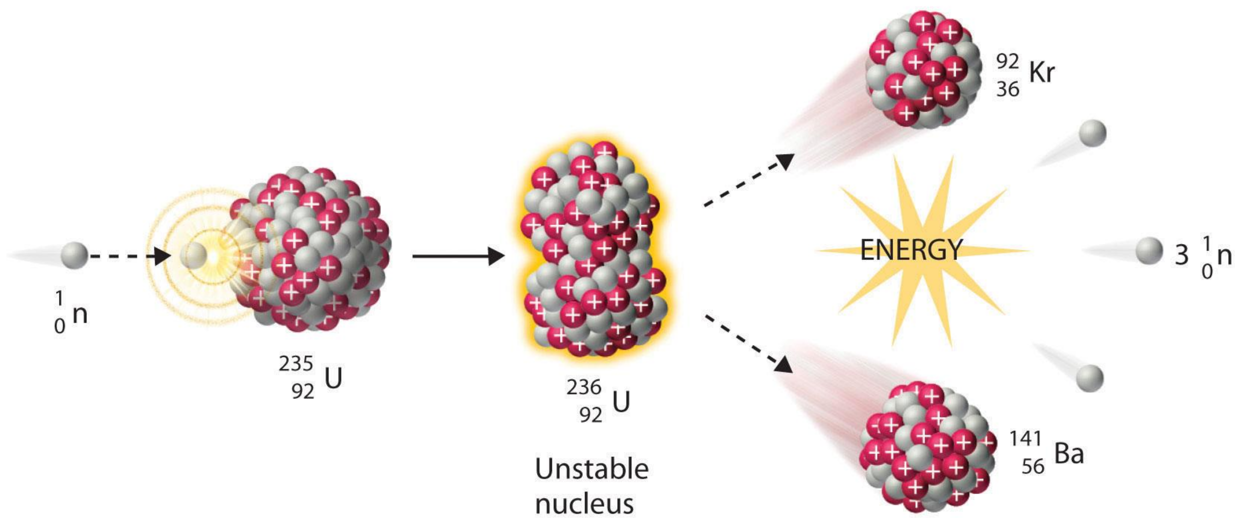
$$E = mc^2$$

E = Energy release,J or eV
m = mass defect,kg (*Always in positive number)
c = speed of light = $3 \times 10^8\ ms^{-1}$

This equation is key to the power of nuclear weapons and nuclear reactors.

Nuclear Fission

Very large nuclei (mass number greater than 230) tend to be unstable and can split into two or more parts. This is called fission.



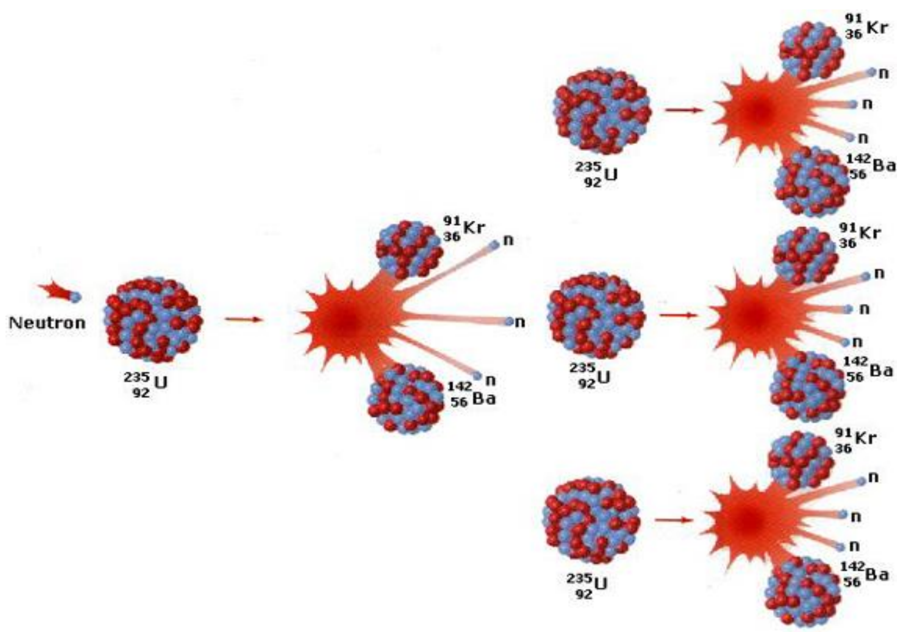
- Fission is not a spontaneous process. It can only occur when a slow moving neutron strikes an unstable nucleus.

- In this decay process, the nucleus will split into two nearly equal nuclei and release several free neutrons and huge amounts of energy.

- These nuclei are isotopes of more stable elements. If left alone, they decay radioactively by emitting alpha or beta particles.

- On average, three neutrons are released. These can go on to be absorbed by other nuclei if they are slowed down by a moderator (a medium, such as graphite, heavy water, and beryllium that causes the neutrons to travel more slowly).

- If these neutrons are absorbed by other nuclei, this causes a chain reaction.



- For the chain reaction to occur, there has to be a critical mass.
  - For uranium, this is about the size of a tennis ball. The critical mass has a mass of about 15 kg (uranium has a very high density, 19 g/cm^3). Anything less, the neutrons escape without setting off a chain reaction.

- If the chain reaction is not controlled, a nuclear explosion will occur.

Here is a typical fission equation:

$$^{235}_{92}U + ^{1}_{0}n \rightarrow ^{90}_{36}Kr + ^{143}_{56}Ba + ^{1}_{0}n + ^{1}_{0}n + ^{1}_{0}n$$

Notice:
1) The mass numbers balance (235 + 1 = 90 + 143 + 3).

2) The atomic (proton numbers) balance (92 = 36 + 56).

3) Three neutrons on average are released.

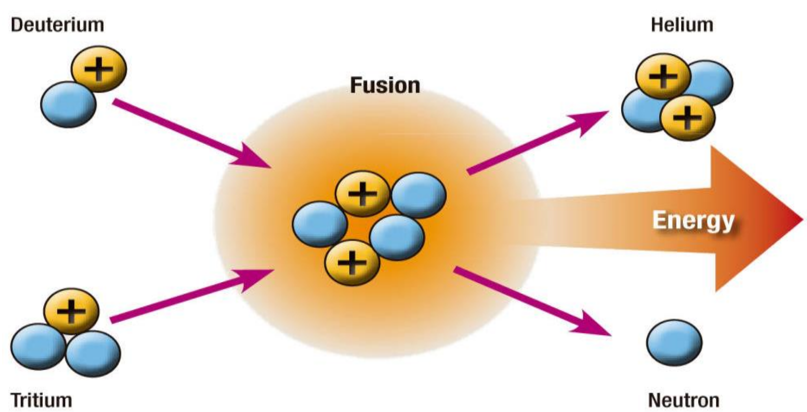
Example:
Complete the fission decay equation when uranium-235 splits into xenon-144 and strontium-90.

Solution:

$$^{235}_{92}U + ^{1}_{0}n \longrightarrow ^{144}_{54}Xe + ^{90}_{38}Sr + 2\,^{1}_{0}n$$

Nuclear Fusion

Very light nuclei can combine to form heavier atoms in a process known as fusion.



- When fusion happens, the products have a larger binding energy than the reactants. The mass defect results in the release of huge amounts of energy.

- Actually produces <u>more energy per gram of products than fission</u> and produces no by-products

- Why isn't it used yet then for energy production?
    - It currently requires more energy to initiate the reaction than it produces.
    - Heat produced is so intense that containment vessels melt.

  Why does fusion require energy?
    - To combine, two nuclei must be close enough for the strong nuclear force to join them. But when the positive nuclei approach, the electrostatic force of repulsion is greater than the nuclear force. This means that the nuclei must be HIGHLY energetic to overcome the repulsion force.
    - This means HIGH temperatures (millions of degrees Celsius), which is difficult to achieve while containing the atoms.

- Nuclear fusion is the energy-producing process taking place in the core of the <u>Sun and stars</u>.

    - The core temperature of the Sun is about 15 million °C. At these temperatures, four hydrogen atoms fuse in a series of reactions to form a single helium atom and give off huge amounts of energy.

Here is a typical fusion equation:

$$^{2}_{1}H + ^{3}_{1}H \rightarrow ^{4}_{2}He + ^{1}_{0}n$$