Energy from Nuclear Reactions

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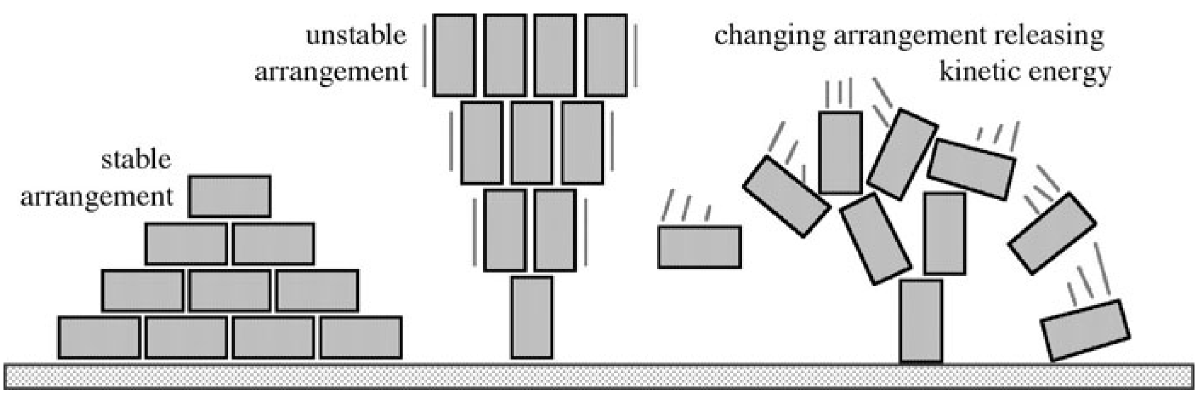
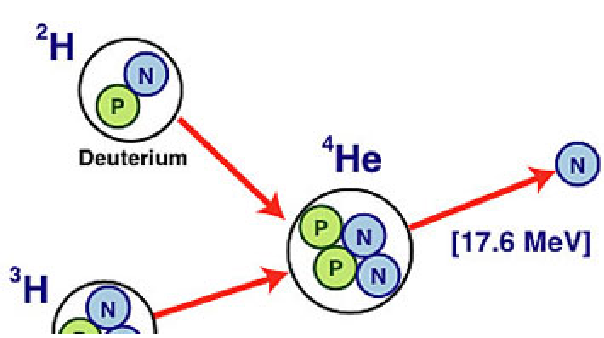
Carbon-based fuels always react chemically with oxygen to produce carbon dioxide and energy. In a **chemical** reaction, all of the atoms present *before* the reaction are present *after* the reaction. In such a reaction, the arrangement of the atoms and electrons in the carbon-based fuel and oxygen is **less stable** than the arrangement of the atoms and electrons in the carbon dioxide (and maybe water). Energy is always produced when there is a change from an **unstable** to a **stable** arrangement.

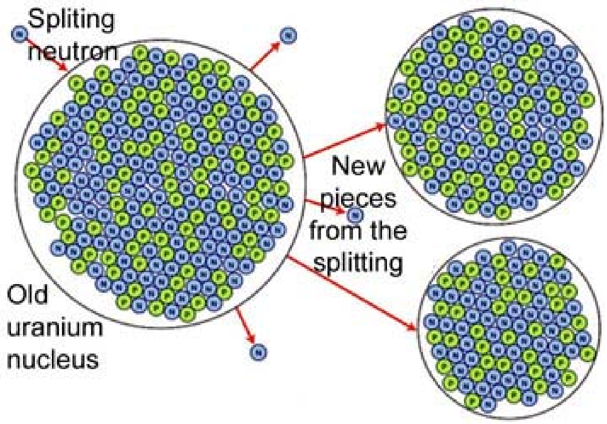
In general, an unstable arrangement of bodies is more likely to release energy than a stable arrangement. When the arrangement changes from unstable to stable, energy is released. (See diagram below.) Thus an unstable arrangement may be said to possess greater potential energy than a stable arrangement.



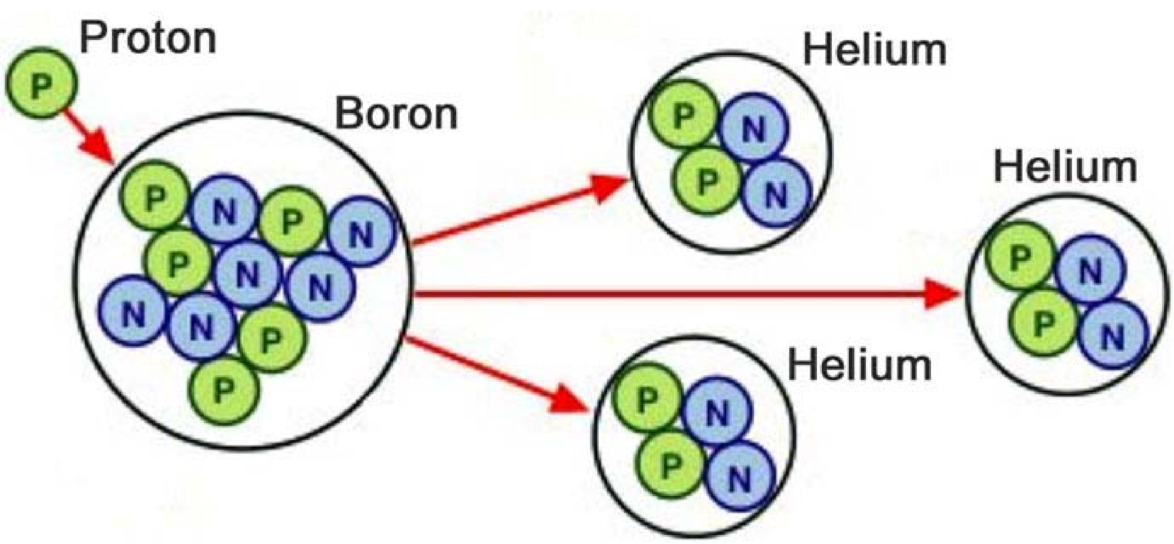
Some nuclear arrangements of **neutrons** and **protons** are more unstable than others, so **unstable nuclei** may be said to have the greater amount of potential energy than stable nuclei. When a nuclear arrangement reacts to become more stable, kinetic energy is released. The nucleus of an iron isotope with mass number 56 is more stable than any other element's nucleus. Generally speaking, the farther from 56 an element's mass number is, the more unstable that element's nucleus tends to be. Nuclear energy is released when an unstable nucleus is rearranged to make a stable nucleus. In a **nuclear reaction** the specific atoms present *before* the reaction are *different* than those present *after* the reaction. Also a nuclear reaction typically produces *far more energy* than a chemical reaction because the change from unstable to stable involves the much more powerful nuclear forces, rather than the relatively modest electric forces.



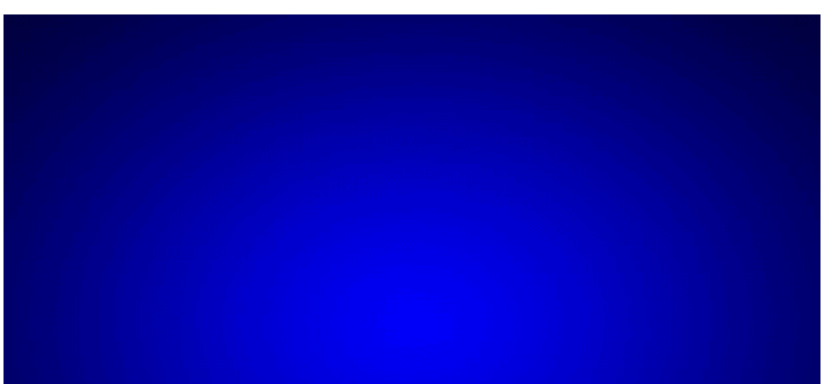
When light unstable nuclei with small mass numbers combine to make heavier more stable nucleii closer to mass number 56, energy is released, and we say that nuclear **fusion** has occurred. The combining of the **isotope Deuterium** with the **isotope Tritium** to make a **Helium** nucleus and a neutron is one common example of a fusion reaction. The Tokamak/ITER device proposes to use a magnetic containment to heat a **plasma** of Deuterium and Tritium and produce nuclear energy from this fusion reaction.



When elements with very large mass numbers such as U-236 split apart to make smaller more stable nuclei closer to 56 in mass number, we say that nuclear **fission** has occurred. In this reaction, a neutron combines with a U-235 nucleus to produce an unstable U-236 nucleus. The U-236 fissions to produce 3 neutrons, plus Barium and Krypton nuclei. The multiple neutrons produced are very important in sustaining the chain reactions, which characterize commercial fission reactors. However, nuclear fission is not necessarily restricted to heavy elements. Energy is released any time a relatively unstable nuclear arrangement changes into a more stable arrangement. In the reaction below, for example, a proton (hydrogen nucleus) causes a B-11 isotope to fission into three Helium nuclei.



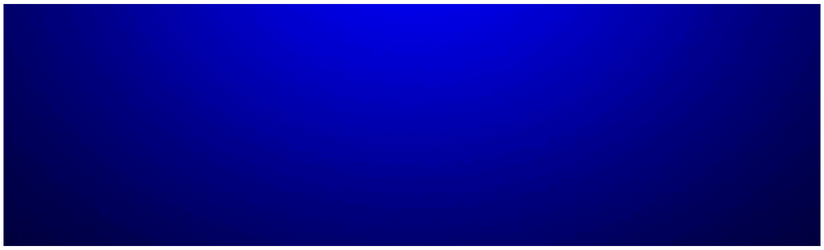
This is the reaction that everyone hopes can be made to happen in the p-B polywell Nuclear Reactor. (The fact that no neutrons are produced turns out to be the greatest advantage for this reaction.) Also, it should probably be pointed out that the simplified reaction above is not what really happens. In fact, it's more like the following animation:



There are some intermediate steps to this more complete description of the reaction:

1) the Proton fuses with the B-11 isotope.

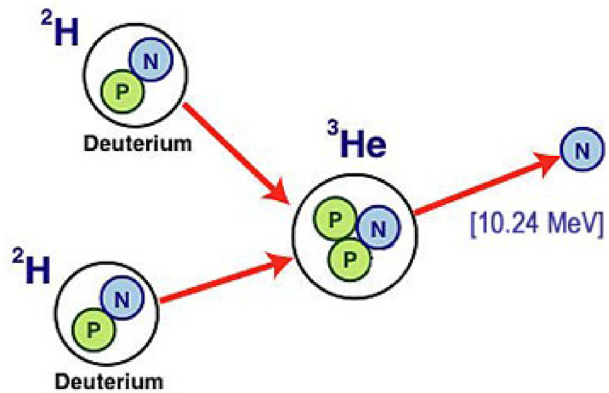
2) the resulting unstable Carbon fissions into a Helium and a Beryllium.



3) The Beryllium fissions into two more Helium nuclei.

However, the details really don't matter, because the net effect in this full version is the same as in the simplified one: it starts with a proton and a B-11 nucleus, and it ends with three highly energetic Helium nuclei. Some people call it a fission reaction because it is the fission that produces the energy.

This fourth reaction is often used in the fusor (a simple fusion device that led to the polywell); and this reaction has also been used in the early Polywells. It is somewhat easier to make this reaction happen because it requires a lot less kinetic energy on the part of the reacting nuclei. Unfortunately the reaction produces neutrons, which can, in turn, weaken the reaction containment, produce radioactive waste, and possibly produce Plutonium for nuclear weapons. Fortunately these same neutrons can also be used to "cook" the nuclear waste from commercial fission reactors that has been such a problem for so many years. Cooking the nuclear waste with neutrons transforms it into isotopes with much shorter half-lives, which will decay to relatively safe levels in periods of maybe 30 years, as opposed to 30,000 years for the present nuclear waste.



When a configuration of nucleons changes from an unstable arrangement to a stable one, the nucleons that take part lose a small amount of mass. This loss of mass determines the energy released by that rearrangement. For example, when a proton and a B-11 nucleus combine and then fission to produce three alpha particles, they lose about 0.01 **atomic mass units** (10^-2 amu) or 1.66 x 10^-29 kilograms.

To demonstrate this mass-energy relationship mathematically, we will first need to know the change in mass of the nucleons taking part in this p-B reaction. Then we will convert the change in mass to Joules. We will use the following masses in amu *per nucleon*:

H = 1.00794; B = 1.00090; He = 1.00065

Subtract the mass of a single He nucleon from the H mass, to obtain a loss of 0.00729 amu for the single H nucleon (the proton). Subtract the single He mass from the single B mass, to obtain a loss of 0.00025 amu *per single nucleon* in the Boron nucleus. Multiply the 0.00025 times the 11 nucleons in B, to obtain a *total* loss of 0.00275 amu for the B

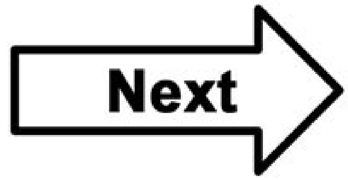
Total of the H loss 0.00729 plus B loss 0.00275 = 0.01004 amu,
which is about 10^-2 amu/fission.

There are 6.02 x10^23 atoms in 0.001 kg of hydrogen atoms,
So we divide to obtain the mass in kilograms of *one* hydrogen atom.
0.001 kg ÷ 6.02 x10^23 atoms = 1.66 x10^-27 kg/atom

Since the loss in mass is about 10^-2 of an amu, we can multiply that times the mass of one atom: 10^-2 x 1.66 x10^-27 kg = 1.66 x 10^-29 kg which is the loss of mass in kg per fission.

Here is Einstein's relativity formula: $\Delta E = \Delta mc^2$.
In the present case, this means that
energy/fission = mass loss/fission x (light speed)^2 or

1.66×10^{-29} kg/fission x $(3 \times 10^{8}$ m/sec$)^2$ = 1.5×10^{-12} J/fission, which is the figure we used **HERE** to show that 2 teaspoons of Boron could send an F-16 to the moon.



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