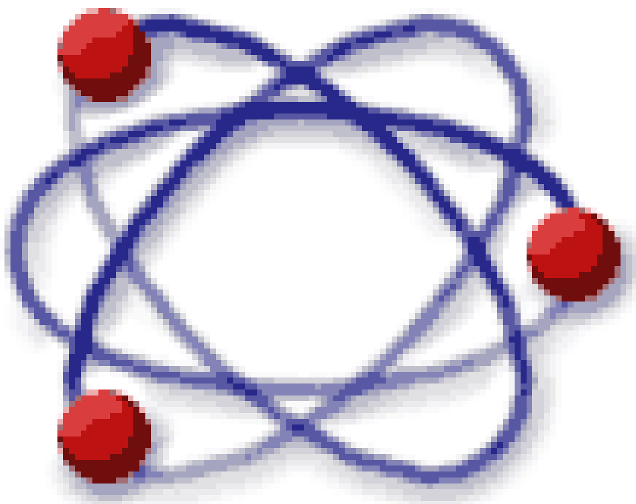
Nuclear Energy



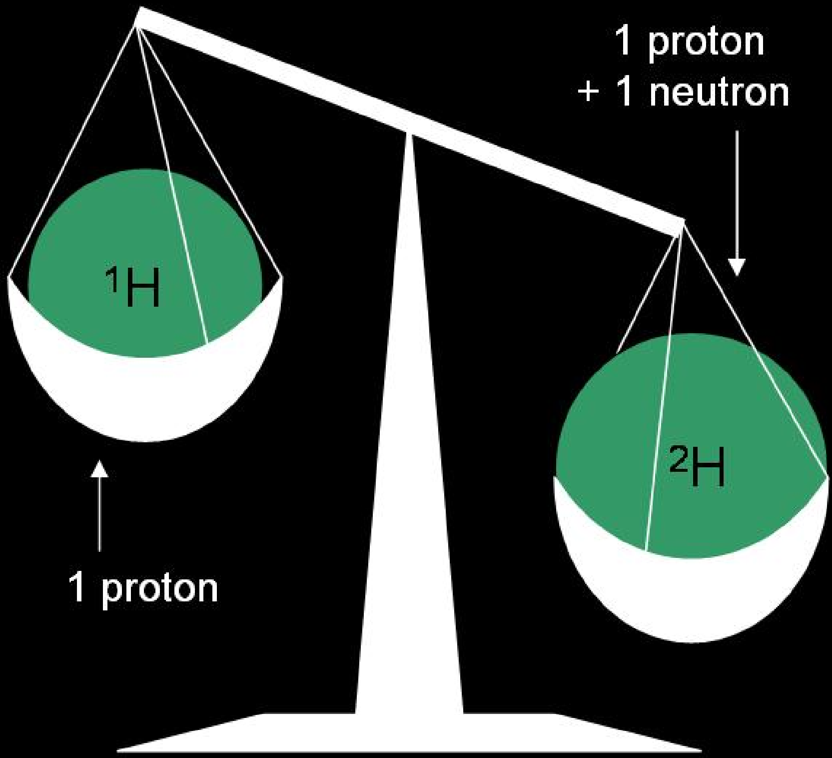
Isotopes

Mass Defect

$E = mc^2$

Isotopes

Thanks to the mass spectrometer Physicists were able to measure the mass of the atoms of elements. In this way they made the remarkable discovery that the atoms of a particular element do not always have the same mass. What they all have in common is their positive charge!



Two isotopes of hydrogen

[Mass spectrometer simulation]

Isotopes

In other words, isotopes are atoms with the same atomic number, but different mass numbers. This lead to the search for an additional subatomic particle that would be responsible for the extra mass, but have no charge. This additional particle is the NEUTRON.

Match the terms with the correct definitions.

Nuclide	The number of protons in the nucleus. Tells what element the nuclide is.
Mass Number	An atom of a particular nuclear structure.
Atomic Number	A nuclear particle
Nucleon	Total number of nucleons in the nucleus

Isotopes

Circle the isotopes of the same element with the same colour.

$^{12}_{6}X$ $^{12}_{5}X$ $^{14}_{6}X$ $^{13}_{6}X$

That's right

Mass number
A = N + Z

Atomic number
Z = no of protons

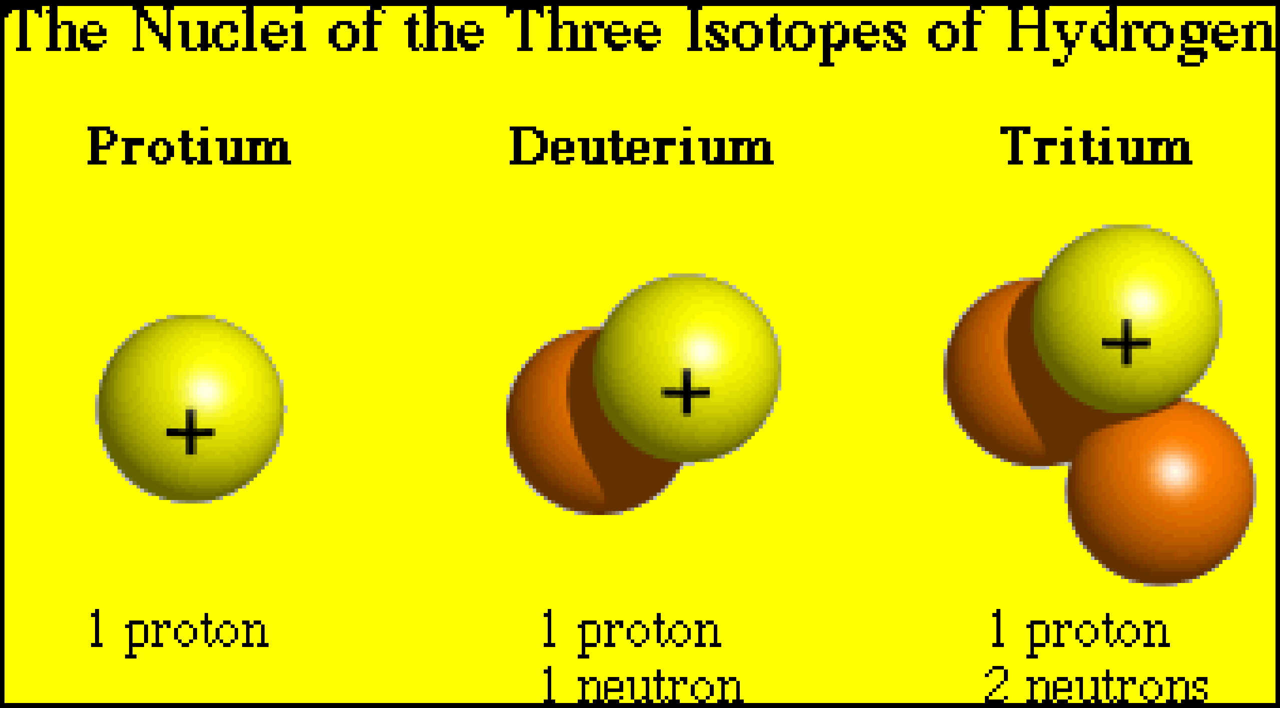
Chemical symbol for the element

$^{12}_{6}X \rightarrow ^{12}_{6}C$

Isotopes

Some elements have a large number of isotopes. Some isotopes are unstable, which means that they will decay spontaneously into more stable nuclei by the emission of particles and energy.

However, the percentage of isotopes of a particular element mined on the Earth is remarkably constant no matter what part of the World it has been extracted from.



Atomic mass unit

Since the mass of atoms and nucleons is too small to be measured with conventional methods, it is also convenient to define an atomic unit of mass (u):

$$1 \text{ u} = 1.660566 \times 10^{-27} \text{ kg}$$

In these units the masses of proton, neutron and electron become:

$$m_p = 1.007276 \text{ u}$$

$$m_n = 1.008665 \text{ u}$$

$$m_e = 0.000549 \text{ u}$$

Mass defect

The atomic mass of $^{40}_{20}Ca$ is 39.96259 u. Work out the total mass of the particles making up the atom of $^{40}_{20}Ca$.

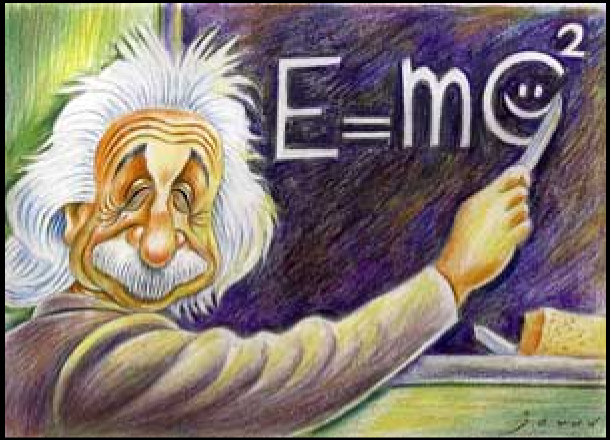
The isotope of Ca considered above is made of 20 protons, 20 neutrons and 20 electrons:

20 x 1.00728 u + 20 x 1.00867 u + 20 x 0.00055 u = 40.3300 u

Why does this happen? The law of conservation of mass seems to be broken. In fact the mass of the individual particles is greater than their mass when they are all fitted together in a single atom.

Mass defect

The result of the previous slide can only be explained with Einstein's theory of Relativity in which he equates energy E with an equivalent amount of mass m by the most famous equation in Physics:



The excess of mass we calculated in the single particles making up the isotope of Ca is <u>the mass equivalence of the energy required to separate the atom into its individual particles Δm</u>.

Mass defect

We can work out the Δm:

$$39.96259 \text{ u} + \Delta m = 40.33000 \text{ u}$$

Mass of whole atom

Mass equivalence of energy to separate atom

Mass of individual particles

$$\Delta m = 40.33000 \text{ u} - 39.96259 \text{ u} = 0.36741 \text{ u}$$

This difference between the mass of an atom and its individual particles is called MASS DEFECT Δm.

Mass defect

This mass defect does not seem big compared with the other two masses calculated, but what this tells us is the energy released when an atom is formed from its constituent particles:

$$\Delta E = \Delta mc^2$$

Calculate ΔE for the example studied.

$\Delta E = \Delta mc^2 = (0.36741 \times 1.66056 \times 10^{-27}\ \text{kg}) \times (2.998 \times 10^{8}\ \text{m/s})^2$

$= 5.484 \times 10^{-11}\ \text{J}$

Is this a big or a small energy?

Mass defect

It is easier to express energies in nuclear reactions in electron-volts than joules.

An electron-volt is:

$$1 \text{ eV} = 1.60 \times 10^{-19} \text{ J}$$

$$1 \text{ MeV} = 1.60 \times 10^{-13} \text{ J}$$

Research and describe a word definition of the electron-volt.

What is the energy equivalence of the mass defect in the problem studied?

$$\Delta E = 5.484 \times 10^{-11} \text{ J} / 1.602 \times 10^{-19} \text{ J} = 342.4 \text{ MeV}$$

Mass defect

Calculate the energy equivalence of 1 atomic mass unit.

$m = 1\ u = 1.66\ 10^{-27}$ kg

$E = mc^2 = 1.66\ 10^{-27}$ kg x $(3 \times 10^8)^2 = 1.494 \times 10^{-10}$ J =

= 931 MeV

In fact, 1 MeV = 1.6×10^{-13} J

1 u = 931 MeV

And for the mass difference Δm in the example is:

0.36741 x 931 MeV = 342.4 MeV

Mass defect

All nuclides have mass defect and in addition the mass defect per nucleon changes from nuclide to nuclide. In fact, the mass defect per nucleon increases rapidly from the lighter atoms to reach a maximum with Fe. After Fe this mass defect slowly decreases again.

The fact that mass defect per nucleon is different for different nuclides has important implications:

- atoms cannot be made by bringing together the right number of protons, neutrons and electrons (repulsion between protons is too strong to win at ordinary temperature)

- it is possible to rearrange the protons, electrons and neutrons in an atom to form different nuclides.