MASS AND ENERGY

1. Nuclear Energy

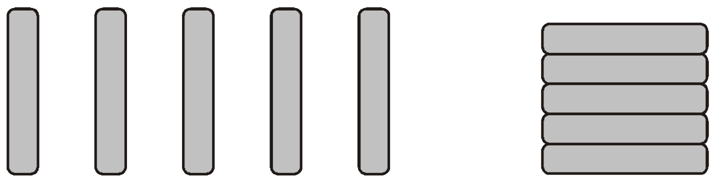
Atomic mass of carbon: ${}^{12}_{6}C$ = 12.00000 u (*units*)
Unit of atomic mass: 1 u = 1/12 of a ${}^{12}_{6}C$ -Atoms = 1.66×10^{-27} kg

mass of an electron: m_e = 0.0005 u = 9.1083×10^{-31} kg
mass of a proton: m_p = 1.0073 u = 1.6724×10^{-27} kg
mass of a neutron: m_n = 1.0087 u = 1.6747×10^{-27} kg

Isotop	${}^{2}_{1}H$	${}^{4}_{2}He$	${}^{12}_{6}C$	${}^{56}_{26}Fe$	${}^{238}_{92}U$
mass of all electrons (in u)	0.0005	0.0010	0.0030	0.0130	0.0460
mass of all protons (in u)	1.0073	2.0146	6.0438	26.1898	92.6716
mass of all neutrons (in u)	1.0087	2.0174	6.0522	30.2610	147.2702
sum of all masses	2.0165	4.0330	12.0990	56.4638	239.9878
relative atomic mass	2.0141	4.0026	12.0000	55.8470	238.0560
mass defect	0.0024	0.0304	0.0990	0.6168	1.9318
mass defect per nucleon	**0.0012**	**0.0076**	**0.0083**	**0.0110**	**0.0081**

That's strange: An atom has less mass than the sum of all particles it consists of. The difference is called **mass defect.**

It is as if you had a number of bricks with certain mass and if you pile them, the mass of the pile is less than the mass of all bricks together.



1 kg + 1 kg + 1 kg + 1 kg + 1 kg = 4.999 kg

mass defect = 5 kg - 4.999 kg = 0.001 kg = 1 g

What about the 1 g mass defect? It would be transformed into energy according to Einstein's famous equation: $\boldsymbol{E = m \times c^2}$

E = Energy
m = mass
c = speed of light = 300,000 km/s = 300,000,000 m/s = 3×10^8 m/s

The speed of light is very big. Its square is much more bigger:

$$c^2 = (300{,}000{,}000 \text{ m/s})^2 = (300{,}000{,}000 \text{ m/s}) \times (300{,}000{,}000 \text{ m/s}) =$$
$$= 90{,}000{,}000{,}000{,}000{,}000 \text{ m}^2/\text{s}^2 = 9 \times 10^{16}. \text{ m}^2/\text{s}^2$$

If a mass of 1 g is transformed into energy, that would be an energy of 9×10^{13} Joule.

$$E = m \times c^2 = 0.001\ \text{kg} \times (3 \times 10^8\ \text{m/s})^2 = 9 \cdot 10^{13}\ \frac{\text{kg} \cdot \text{m}^2}{\text{s}^2} = \underline{\mathbf{9 \times 10^{13}\ Joule}}$$

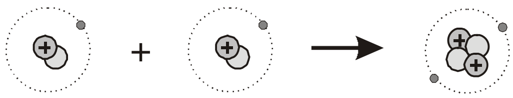
This would be enough energy for 14 years for a city like Bangalore.

How to gain nuclear energy

From the table you can read, that the *mass defect per nucleon*[1] for iron is biggest. So for iron (and the elements near to iron) the nucleus is most stable. Iron has the biggest **binding energy.**

> You would **gain** energy, if you **fuse** elements with **small** atomic number to form an element with an atomic number smaller than 26 (iron).

This is how the Sun (and all other stars) gain energy. In the Sun deuterium (this is an isotope of hydrogen with a proton and a neutron in its nucleus) is fused to Helium.



+ energy

$$^2_1\text{H} + {}^2_1\text{H} \longrightarrow {}^4_2\text{He} + \text{energy}$$

2.0141 g + 2.0141 g = 4.0026 g + 0.0256 g (mass defect)
1 g + 1 g = 1.99 g + 0.01 g (mass defect)
2 g hydrogen = 1.99 g helium + 0.01 g energy

Our Sun transforms each second 4.25 million tons of its hydrogen into 3.83×10^{26} Joule energy.

In the last 4 billions of years the Sun has lost only 0.03 percent of its mass to produce energy.

> You would **gain** energy, if you **split** big elements into smaller elements.

This happens in nuclear power stations. **Uranium** is split up into smaller elements and energy is released.

> You **need** energy to **build up** elements with **big** mass number (up to Uranium) by fusing elements with smaller atomic number.

This happens if a big star at the end of its life explodes as a nova or a super-nova and the immense amount of energy is used to build up elements with atomic number bigger than 26 (iron).

Earth, you and we, we wouldn't exist without those elements, that were build up by exploding stars billions of years ago.

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[1] protons and neutrons are nucleons