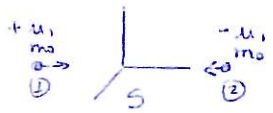
FUSION and FISSION

Mass / Energy Conversion

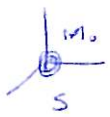
a) Conservation of energy

Inelastic collision

before collision



after collision



M0 at rest in S

Kinetic energy is not conserved, because this is an inelastic collision, but total energy is

before: $\frac{2m_0}{\sqrt{1-u^2/c^2}}c^2$ = after: M_0c^2 $\Rightarrow$ $M_0 \neq 2m_0$, $\boxed{M_0 = \frac{2m_0}{\sqrt{1-u^2/c^2}} > 2m_0}$

↑ simple exercise that does not take into account binding energies

total mass is larger than the rest mass of constituents

$\Rightarrow$ #) Binding Energy

But careful !!

When we bind two particles / nuclei into a new nucleus / atom as it is done in FUSION, there is release of energy

The mass of a bound system is less than that of separated particles / atoms by the binding energy

↳ Equivalently, to break such system, we need to add energy

↳ The system is BOUND, because of attractive forces { Coulomb force for atom / nuclear force for nucleus } which need to be overcome for the system to be broken

Take for example the hydrogen atom. Its ground state energy is $-13.6\,eV$
To separate the (p) and the (e), to ionize this atom, we need to give at least $+13.6\,eV$ to the system

Compare:

ground state energy of (H)
$-13.6\,eV$

rest energy of (p) = 938 MeV
rest energy of (e) = 0.511 MeV

In total, the H atom's total energy (and thus its total mass) is slightly smaller than the sums of the rest energies (rest masses) of its constituents
this effect is called <u>mass defect</u>

→) When the (H) atom is formed by recombination of a (p) and an (e) a minute fraction of the total energies of (p) and (e) is released

→) But when (p)'s and (n)'s combine to form a nucleus the mass defect is more evident

<u>Example</u>

^4_2He nucleus
mass = $6.6467 \times 10^{-27}\,kg$

$2(m_p + m_n) = 6.6950 \times 10^{-27}\,kg$

$2(m_p + m_n)c^2 - M_{^4_2He}c^2 = 4.347 \times 10^{-12}\,J = 2.7 \times 10^7\,eV$
$= \underline{27\,MeV}$

<u>FUSION</u> is the formation of <u>light</u> nuclei from protons, neutrons, and other light nuclei
It is associated with energy release.

↳ This is the reaction found in <u>stars</u>. It is also the principle for the H-bomb, which turns H into He.

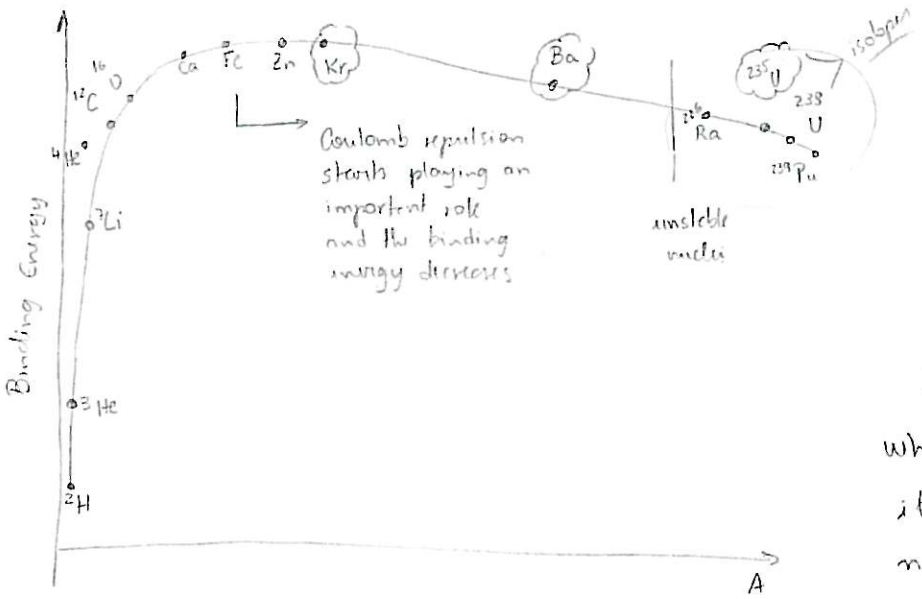
The problem is reaching the enormous kinetic energy for the particles to overcome Coulomb repulsion and recombine into a new nucleus (stable by strong force)

FISSION release of energy can also happen when a heavy nucleus is split into two

↓

How can we understand fission? Doesn't it sound like a contradiction of fusion?

→) As we increase the number of nucleons, the nucleus becomes more tightly bound, the binding energy increases, it gets more difficult to break the nucleus (because of the STRONG FORCE)



BUT, when the number of nucleons gets large the Coulomb repulsion becomes important and the binding energy decreases.

The binding energy of ^{235}U is smaller than the binding energies of Ba and Kr.

When ^{235}U splits into Ba and Kr it releases energy and also neutrons, which can start a chain reaction

From the book: Tipler

$$^{235}U + n \longrightarrow {}^{92}Kr + {}^{142}Ba + 2n + 179.4\ MeV$$

other reaction involving isotopes of Kr, Ba

$$^{235}_{92}U + n \longrightarrow {}^{89}_{36}Kr + {}^{144}_{56}Ba + 3n + 177\ MeV$$

($3n$ → chain reaction)

*) Radium → Madame Curie (Nobel Prize twice)

*) Shell Model → Maria Goeppert-Mayer (Nobel Prize)