PRE-U REVISION . QUANTUM & ATOMIC PHYSICS AF 3/19

NUCLEAR & PARTICLE PHYSICS

CHEMICAL processes involve the exchange and interactions between electrons in atomic and molecular structures. Energies are typically a few eV. [$1 eV = 1.60 \times 10^{-19} J$]. Ionization energy of Hydrogen is 13.6eV, photoelectric effect work functions for metals is 2.4eV (Na) → 5.1eV (Au).

NUCLEAR processes (radioactivity, fission, fusion....) have energies of a few MeV

HIGH ENERGY ("particle physics") processes are when KE of particles ≃ their rest mass energy i.e mc^2, so a few GeV

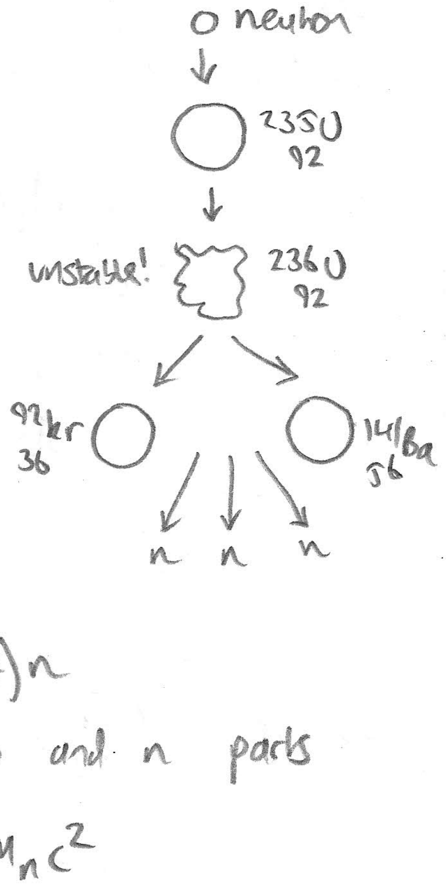
NUCLEAR FISSION

[Otto Hahn 1879-1968]

well.... Requires neutrons in ${}^{235}_{92}U$ example

The spontaneous fragmentation of a heavy atomic nucleus, releasing MeV worth of energy. $10^6 \times$ more energy dense than burning fossil fuels!

Example: $\boxed{{}^{235}_{92}U + n \longrightarrow {}^{141}_{56}Ba + {}^{92}_{36}Kr + 3n}$



Reaction produces 2 more neutrons, so if uncontrolled, can result in a **chain reaction**

↳ **nuclear explosion** (Atomic weapons etc).

If neutron flux controlled using non fissile absorbers (eg graphite moderator rods), can result in a sustained source of heat ie a **nuclear reactor**

BINDING ENERGY

$${}^{A}_{Z}X \xrightarrow{B} Z \times p + (A-Z)n$$

Energy required to break an atom into its p and n parts

Hence:

$$Mc^2 + B = ZM_pc^2 + (A-Z)M_nc^2$$

↑ mass of element X

or $$\boxed{B_X = Zm_p c^2 + (A-Z)m_n c^2 - M_X c^2}$$ for ${}^A_Z X$

m_p	proton mass	$1.6726218 \times 10^{-27}$ kg	$= 1.00728\,u = 938.272\,MeV/c^2$
m_n	neutron mass	$1.6749275 \times 10^{-27}$ kg	$= 1.00866\,u = 939.565\,MeV/c^2$
m_e	electron mass	$9.1093836 \times 10^{-31}$ kg	$= 5.48580 \times 10^{-4}\,u = 0.510999\,MeV/c^2$
u	Atomic mass unit $= \frac{1}{12}$ mass of ${}^{12}_{6}C$	$1.6605390 \times 10^{-27}$ kg	$= 931.494\,MeV/c^2$

$c = 299792458$ m/s $e = 1.60217662 \times 10^{-19}$ C

[In nuclear and particle physics MeV/c^2 or GeV/c^2 are useful mass units. $1\,GeV/c^2 = 1.7826619 \times 10^{-27}$ kg]
$= 1.073544\,u$]

Now for nuclear reaction (not α, β decay) $\sum_i {}^{A_i}_{Z_i}X_i \to \sum_j {}^{A_j}_{Z_j}Y_j$

Energy conservation means (since total # of protons & neutrons is the same on both sides)

$$\sum_i (M_i c^2 + B_i) = \sum_j (M_j' c^2 + B_j')$$

' means 'products'

so energy released, which corresponds to mass loss × c^2 is:

$$\Delta E = \sum_i M_i c^2 - \sum_j M_j' c^2 = \sum_j B_j' - \sum_i B_i$$

= difference in output total binding energy − input binding energy.

So for ${}^{235}_{92}U + n \to {}^{141}_{56}Ba + {}^{92}_{36}Kr + 3n$

$$\Delta E = B_{Ba} + B_{Kr} - B_U$$

{ No binding energy for n }