Nuclear chemistry

- **What are the difference between ordinary chemical reaction and nuclear transformation ?**

- **Nuclear transformation involve the nucleus , change in the matter .**

- **Nuclear reaction accompanied by high energy change than ordinary chemical reaction .**

Review

❖**Most naturally occurring elements are mixtures of isotopes , which are represented by symbols of the form**

$^{A}_{Z}X$

❖**Where X is the symbol of the element , A = mass number , and Z = atomic number**

❖**Nuclide is the nucleus of a specific isotope .**

❖**A nucleon is proton or neutron**

$^{6}_{3}Li$ **and** $^{7}_{3}Li$

The forces between the nucleons

- **The force between the nucleons are very strong compares by electrostatic forces .**

- **The powerful cohesive forces between nucleons are exist**

- **These forces are charge dependent**

  P – P , n – n , n - p

- **To explain these forces , it is postulated a theory , that , protons and neutrons are bound together by a very rapid exchange of nuclear particle .**

- **This particle given a name meson or poin (π)**

- **Three of π are known.**

- **π^+ (poin)**
- **$P^+ \rightarrow n^0 + \pi^+$**
- **$\pi^+ + n^0 \rightarrow P^+$**

- ii) π^- (poin)
- $n^0 \rightarrow P^+ + \pi^-$
- $\pi^- + P^+ \rightarrow n^0$

- iii) π^0 (poin)
- $P^+ \rightarrow P^+ + \pi^0$
- $\pi^0 + n^0 \rightarrow n^0$
- $n^0 \rightarrow n^0 + \pi^0$
- $\pi^0 + P^+ \rightarrow P^+$

Definitions

- **A stable isotope is one that does not spontaneously decompose into another nuclide .**

- **An radioactive nuclide is one that spontaneously decomposes into another nuclide**

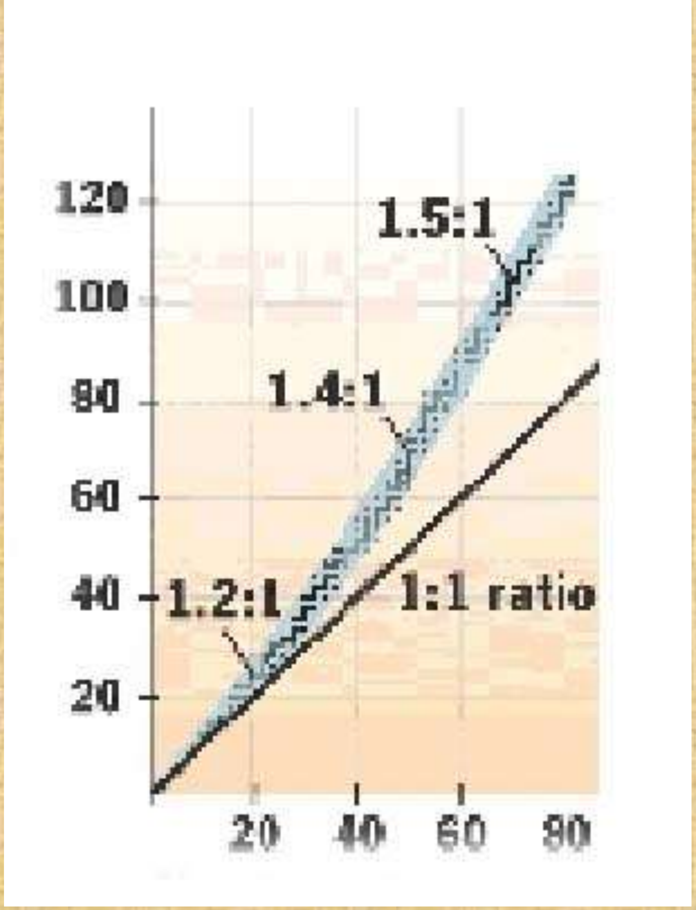
Stable Nuclides

❖The number of neutrons is equal to or greater than number of protons (except for ^{1}H and ^{3}He)

❖Up to Z = 20 , the number of protons and neutrons are nearly equal , above 20 the ratio of n/p increases slowly to about 1.6 : 1 .

❖The zone of stability (next slide) contains all stable nuclides , but some nuclides in this band are unstable .

Zone of nuclear stability



Number of neutrons

Number of protons

Stable Nuclides (cont'd)

- Certain numbers of protons and neutrons (called magic numbers) confer unusual stability : 2,8,20,26,28,50,82,and 126 .

- Tc (Z= 43) , Pm (Z=61) , and all elements beyond Bi (Z=83) have no stable isotopes .

- Nuclear stability is greater for nuclides containing even numbers of protons , neutrons , or both .

Stable Isotopes

Of protons	Of neutrons	Of stable nuclides
Even	Even	157
Even	Odd	53
Odd	Even	50
Odd	Odd	4

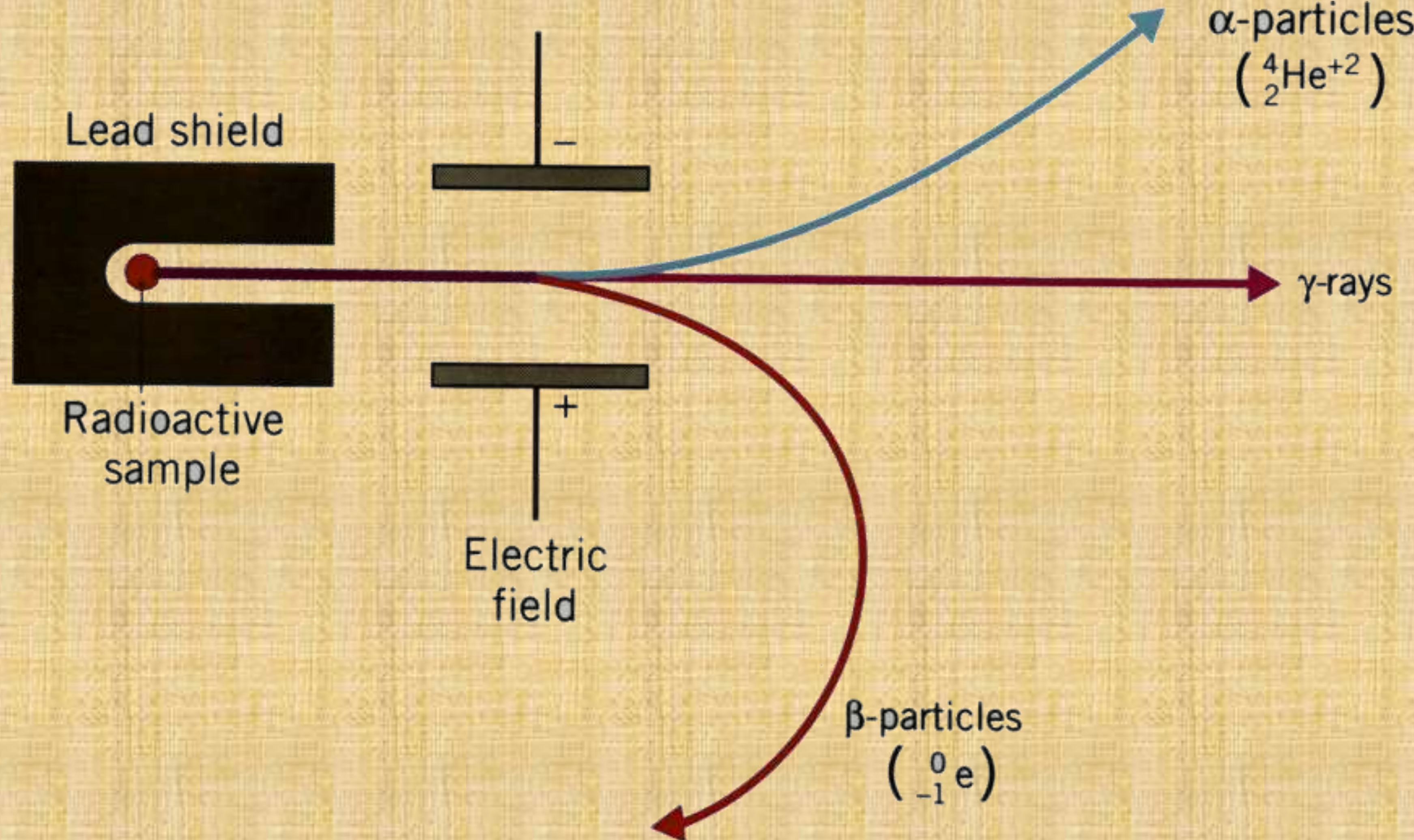
Radioactivity

❖Three kinds of emissions from naturally radioactive materials are known .

α Particles are high – energy ^4He nuclei

β Particles are high – energy electrons that originate from the nucleus .

ϒ Rays are very short wavelength (high – energy) electromagnetic radiation .


α-particles
($^{4}_{2}He^{+2}$)
Lead shield
–
γ-rays
+
Radioactive sample
Electric field
β-particles
($^{0}_{-1}e$)

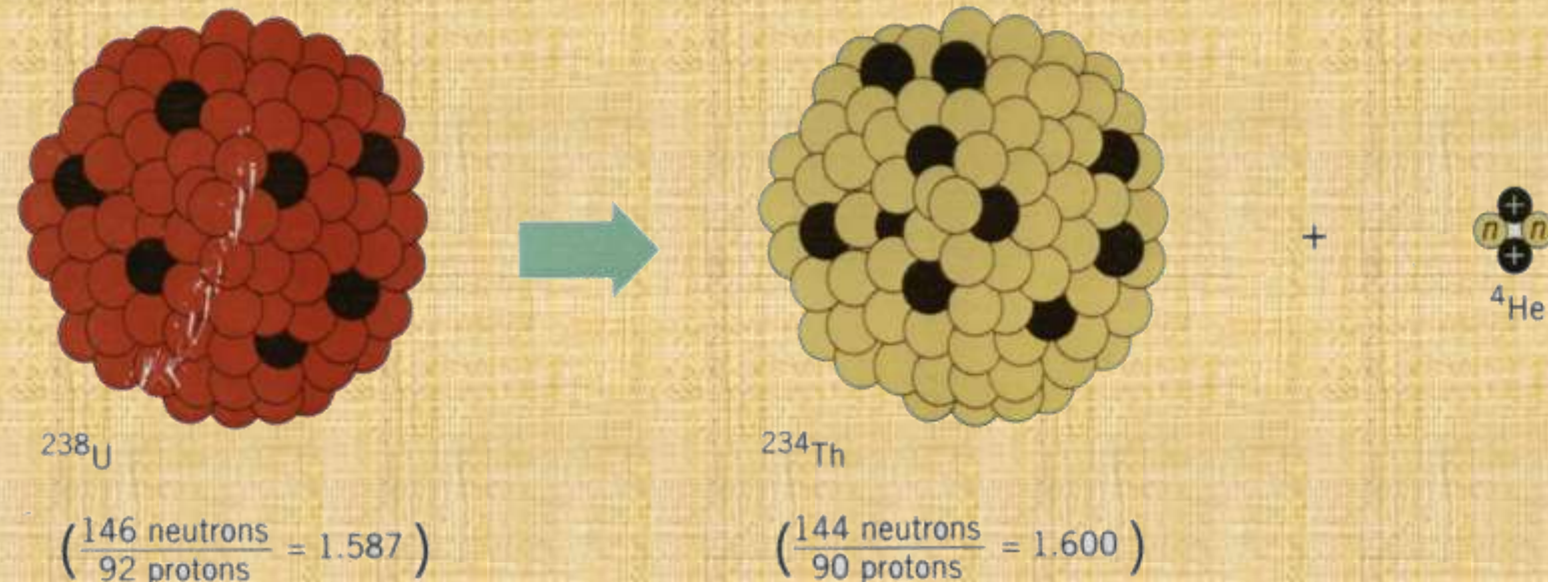
Nuclear Equations

❖ A nuclear equation describes any process in which a nuclide undergoes change

❖ In a balanced nuclear equation the sum of the mass numbers and atomic numbers on the reactant and product side of the equation must be equal .

❖ $^{238}_{92}U \rightarrow {}^{234}_{90}Th + {}^{4}_{2}\alpha$

❖ Z: 92 = 90 + 2 , A: 238 = 234 + 4



^{238}U
$\left(\frac{146 \text{ neutrons}}{92 \text{ protons}} = 1.587\right)$
^{234}Th
$\left(\frac{144 \text{ neutrons}}{90 \text{ protons}} = 1.600\right)$
+
n n
^{4}He

Beta decay

- Beta decay increases the atomic number by one, without changing the mass number.

- $^{14}_{6}C \rightarrow {}^{14}_{7}N + {}^{0}_{-1}\beta$

- The β particle dose not exist in the nucleus , but is created at the instant of its emission .

Positron Emission

❖A positron is identical to an electron , except its charge is positive .

❖Positron emission (called β^+) decreases the atomic number by one , without changing the mass number .

$$^{40}_{19}K \rightarrow {}^{40}_{18}Ar + {}^{0}_{1}\beta$$

❖The symbol for the positron and beta particle is the same , except for the sign .

Electron capture

❖In electron capture an electron in a low energy orbital of the atom is capture by the nucleus and converts a proton to a neutron .

$$^{44}_{22}Ti + {}^{0}_{-1}e \rightarrow {}^{44}_{21}Sc$$

❖X rays (not γ rays) accompany electron capture , because the atom produced is in an excited electronic state .

❖Electron capture and positron emission both decrease the atomic number by 1 .

γ - radiation

- It is electromagnetic radiation of very short wavelength .

- Dose not cause change in the mass number or in the atomic number of the nucleus .

Example :

$$[\,^{240}_{94}Pu\,] \rightarrow [\,^{236}_{92}U]^* + \,^{4}_{2}He$$

$$[\,^{236}_{92}U]^* \rightarrow \,^{236}_{92}U + \gamma$$

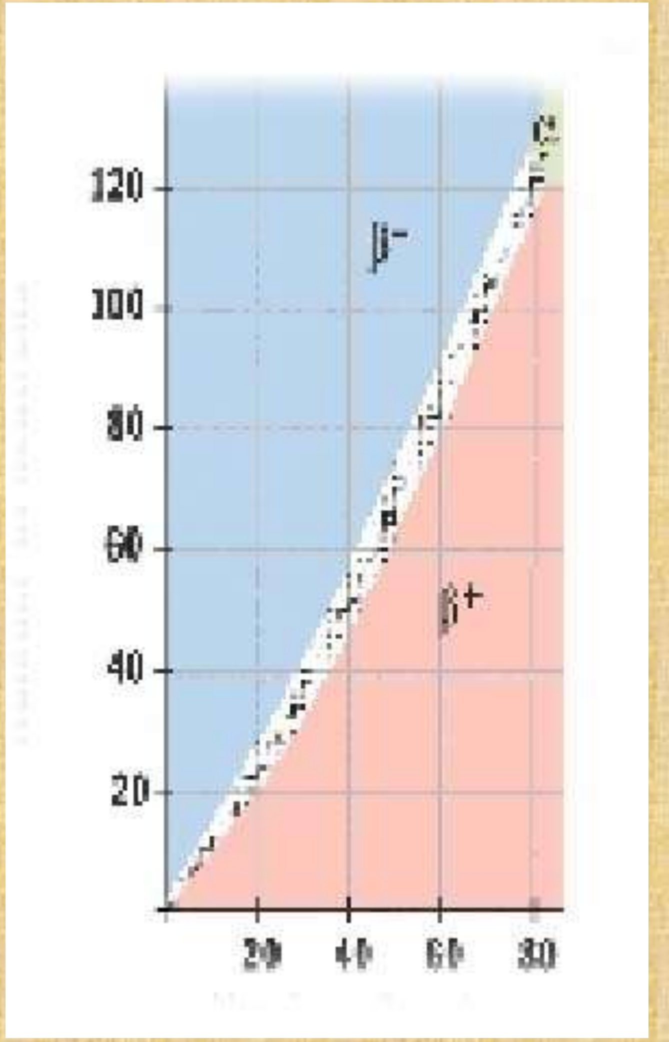
Predicting Modes of Decay

- **For radioactive elements**

- **When Z > 83 , α emission is often observed**

- **If A > atomic mass of element β^- decay occurs**

- **If A < atomic mass of element β^+decay , or electron capture occurs**



Energy and Mass

- **The energy equivalent of mass is calculated from**

  $E = mc^2$

- **Where E is energy , m is mass , and c is the speed of light .**

- **When a nuclear change occurs a measurable difference in the mass of the products and reactant is observed .**

Nuclear energy

$E = mc^2$

m = mass of the parent – [total mass of the products]

Ex:

$^{210}_{84}Po \rightarrow \, ^{206}_{82}Pb + \, ^{4}_{2}He$

m = mass of ^{210}Po - [mass of ^{206}Pb + mass of $^{4}_{2}He$]

= 209.9829u – [205.9745u + 4.0026u]

= 0.00584u

❖ **Usually E is given in Mev**

❖ **For ISU E in Joules . So we Converted Joules to Mev , as:**

For 1u (mass) = 1.6605×10^{-27} kg

$c = 3 \times 10^{8}$ m / s

$E = 1.6605 \times 10^{-27} \times (3 \times 10^{8} \text{ m/s})^2$

$E = 1.4924 \times 10^{-10}$ J

$1ev = 1.6022 \times 10^{-19}$ J

$1 Mev = 1.6022 x 10^{-13}$ J

For 1u

$E = 1.4924 \times 10^{-10}$ J / 1.6022×10^{-13} J/Mev

E = 931.47 Mev / u

For our ex :

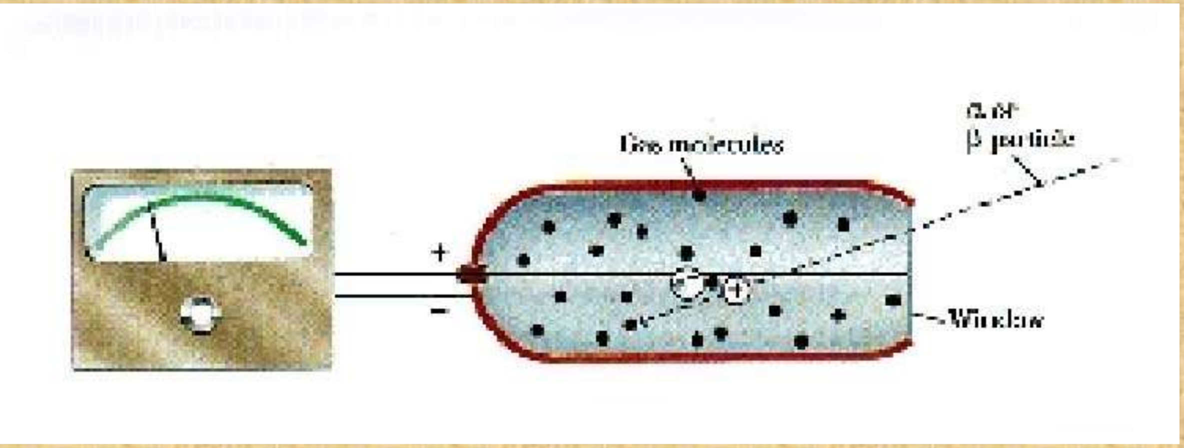
$E = 931.47 \times 0.00584$

E = 5.4 Mev

Detection of radiation

❖Radiation detection is based on the ionization caused by high energy particles and light and includes .

- ❖Exposure of photographic film
- ❖Geiger counters
- ❖Scintillation counters



Decay Rates

- **Radioactive decays obey a first order rate law**

Rate = $-\Delta N / \Delta t = kN$

- **Where N is the number of radioactive nuclei**
- **Usually the half-life , $t_{1/2}$ is given rather than k**

$t_{1/2} = \ln 2 / k = 0.693 / k$

Integrated Rate Law

❖First order radioactive decay is expressed by the equation

$$\ln (N / N_{\circ}) = -kt = 0.693\ t/t_{1/2}$$

❖N = number of radioactive atoms present at time t ,
N_0 = number present at t = 0

❖Since the disintegration rate R is proportional to the number of radioactive atoms

$$R/ R_0 = N/N_{\circ} \text{, so}$$

$$\text{In} (R/ R_0) = -0.693\ t/t_{1/2}$$

Finding $t_{1/2}$ by Experiment

The decay rate of a sample containing ^{131}I is 561 disintegrations per minute . Exactly 7.00 days later the same sample decays at 307 disintegrations / min . Calculate the half-life of ^{131}I .

Substitute the given values in the integrated rate law and solve for $t_{1/2}$ In(307/561) = -0.693 x 7.00 / $t_{1/2}$

$t_{1/2}$ = -4.85/In(0.547) = 8.04 days

Dating by ^{14}C Radioactivity

Dating of artifacts with ^{14}C is based on a constant activity of 15.3 disintegrations per minute per gram of C for Living organisms .

Upon death the ^{14}C activity decreases with a half-life of 5730 years .

Dating with ^{14}C is valid for objects between 500 and 50.000 years old .

Example : ^{14}C Dating

The age of the Dead sea scrolls were measured using ^{14}C dating methods . If the sample of the scrolls measured had a ^{14}C activity of 11.5 disintegration per minute per gram of carbon , what is the age of the scrolls if the fresh scroll recoreded 15.3 disintegration per minute?

Ans.

$$\ln[N_0 / N] = kt$$

$$\ln [\ 15.3 / 11.5] = (\ 0.693 / 5730)\ t$$

$$t = 2361\ y$$

The activity of source

Activity = - dN / dt = KN

Activity units = curi, (ci)

Ci = 3.7 x 10^{10} dismtegration / s

μci = 3.7 x 10^{4} disintegration / s

Example

$t_{1/2}$ of ${}^{100}_{43}Tc$ a β emitter is 16 s. What is the mass remains after 3 half life time?

1 ⟶ 1/2 ⟶ 1/4 ⟶ 1/8

Ln No/N = k t

K = 0.693 / t1/2 = 0.693/16 = 0.0433 s^{-1}

Total time = 3 x 16 = 48 s

Ln 1/N = 0.0433 x 48

1/N = $e^{2.078}$ 1/N = 7.988 ____ N = 1/7.988

Solution

$k = 0.693 / t_{1/2}$

$k = 0.693 / 16\ s$

$= 0.0433\ s^{-1}$

Activity of the sample in terms of disintegration / s is :

Activity = $0.2 \times 3.7 \times 10^4$

= 7.4×10^3 disintegration /s

Activity = KN

$7.4 \times 10^3 = 0.0433\ N$

$N = 1.71 \times 10^5$ atoms

The mass of the sample

= 1.71×10^{5} atoms x 100 g Tc / 6.02×10^{23} (atoms)

= 2.84×10^{-19} g Tc

Test Your Skill

A sample containing ^{32}P disintegrates to ^{32}S at a rate of 782 disintegrations / min . Exactly 10.00 days later the disintegration rate is 481 disintegrations/ min .

(a) Write the nuclear equation for this decay .

(b) Calculate the half-life of ^{32}P .

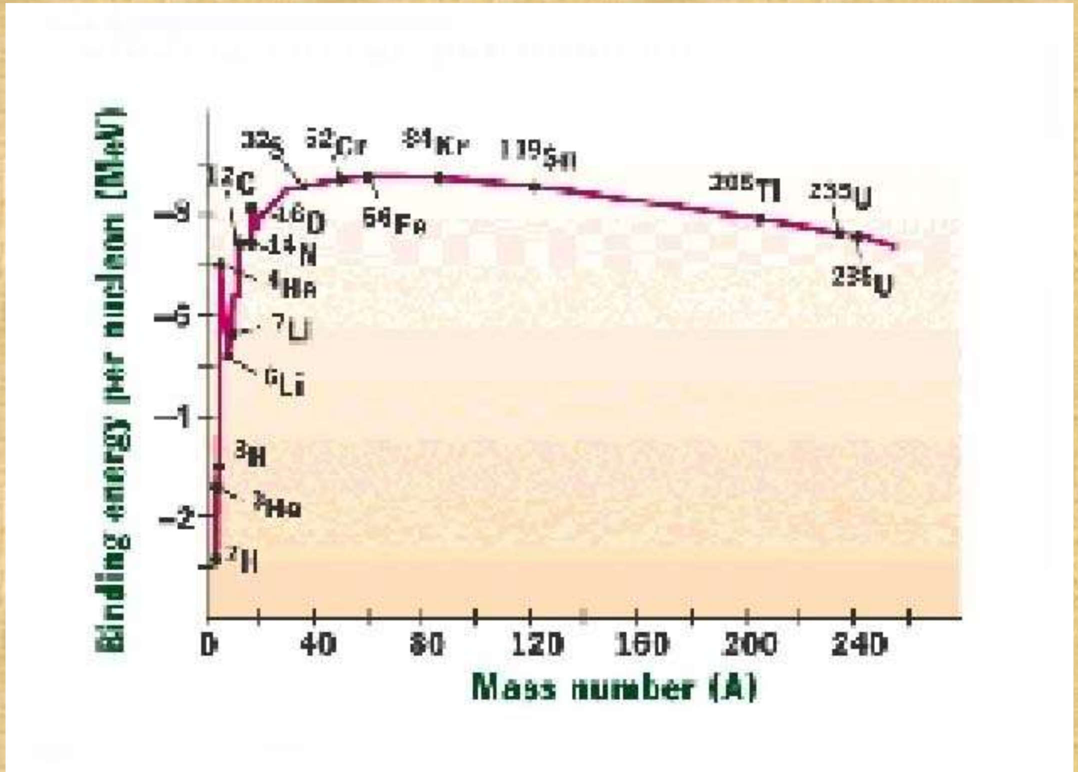
Ans.

(a) $^{32}_{15}P \rightarrow ^{32}_{16}S + ^{0}_{-1}\beta$

(b) $t_{1/2} = 14.3$ **days**

Relative Stability of Nuclides

The relative stability of nuclides is determined by the binding energy per nucleon .



Nuclear Binding Energy

Nuclear Binding energies are often expressed in mega electron – volts

1 u = 931.5 Mev

From the mass defect of 0.042132 u for ^{7}Li , the nuclear binding energy is found

0.042132 u (931.5 Mev / u) = 39.24 Mev

Calculating Mass Defect

The mass of a ^{7}Li atom is 7.016003 u . Calculate the mass defect (in u) given the masses of

1H 1.007825 u

$^{1}_{0}n$ 1.008665 u

Ans.

Mass defect of ^{7}Li =(masses of n + masses of p) –(mass of Li atom)

Mass defect = (3x1.007825u + 4x1.008665u) – (7.016003u)

Mass defect = (3.023475u + 4.03466u) – 7.016003u

Mass defect of ^{7} Li = 0.042132u

Nuclear Binding Energy from Mass Defect

The ^{7}Li nuclide has a mass defect of 0.042132 u . Calculate the binding energy of this nuclide , in KJ /mol , using the equation

$\Delta E = mc^2$

Ans.

$\Delta E = .042132 u \times 1.6605 \times 10^{-27}\ Kg/u \times (3.0 \times 10^{8}\ m/s)^2$

$\Delta E = 6.3 \times 10^{-12}\ J$

Binding Energy per Nucleon

Binding energy per nucleon is found by diving the binding energy by the sum of the mass number of the atom .

The mass defect of 0.042132 u for ^{7}Li is used to find .

Binding energy / nucleon = 0.042132 u / 7 nucleons (931.5 Mev / u)

= 5.606 Mev / nucleon

Nuclear Fission

Nuclear fission forms two nuclei of comparable size from a single heavy nucleus .

Fission reactions are very exoergic, and produce several neutrons in addition to two nuclides .

$$^{236}_{92}U \rightarrow \ ^{141}_{56}Ba + \ ^{92}_{36}Kr + 3\ ^{1}_{0}n$$

Nuclear fusion

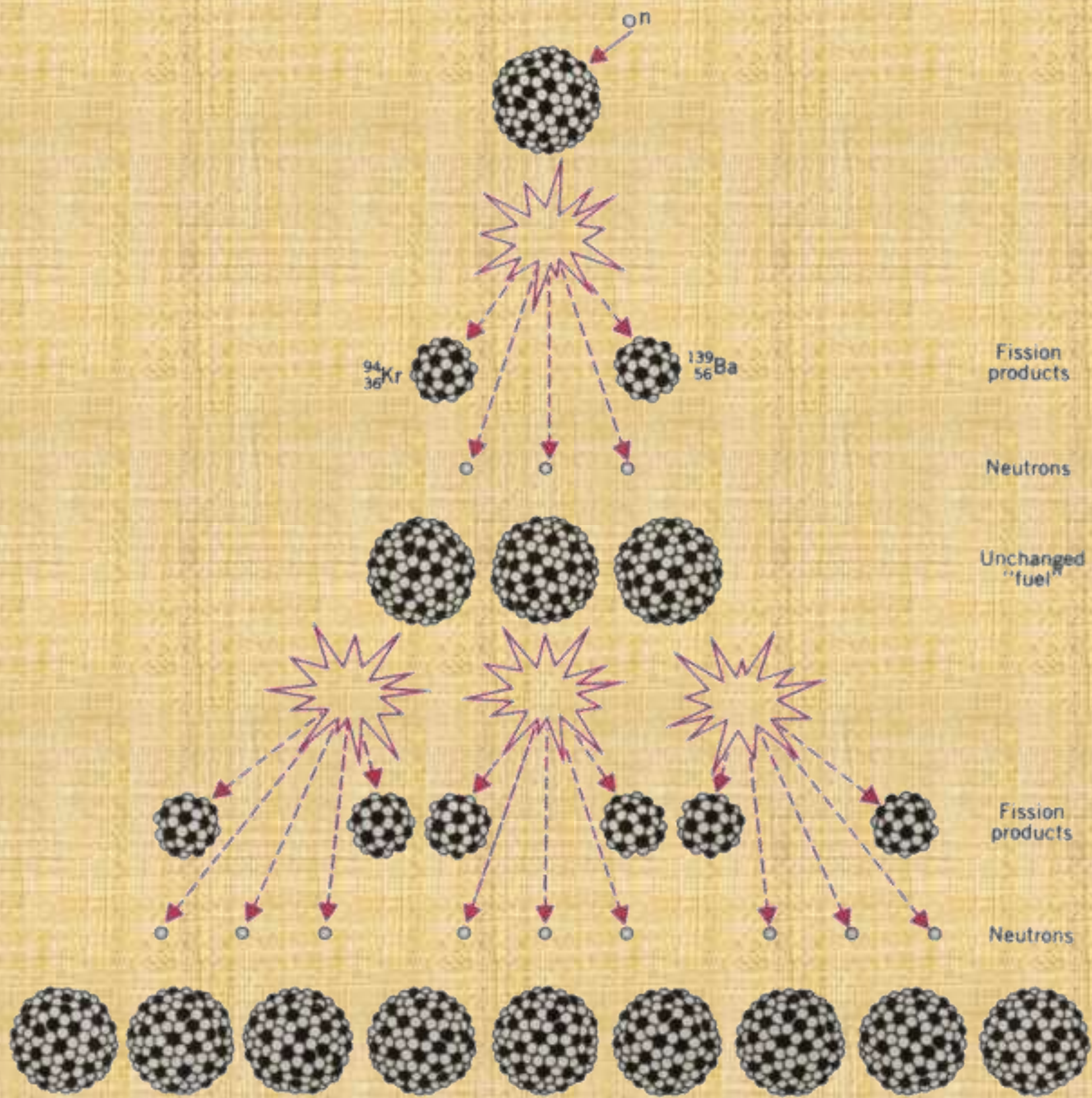
Nuclear fusion is the combination of two light nuclides to form a larger one .

The energy produced by the sun comes from fusion reactions , such as .

$^{1}_{1}H + ^{1}_{1}H \rightarrow ^{2}_{1}H + ^{0}_{1}n$, $\Delta E = - 9.9x10^{7} KJ/mol$

$^{1}_{1}H + ^{2}_{1}H \rightarrow ^{3}_{2}He$, $\Delta E = - -5.2 \times 10^{8}$ kJ / mol

$^{3}_{2}He + ^{1}_{1}H \rightarrow ^{4}_{2}He + ^{0}_{1}\beta$, $\Delta E = - -5.2 \times 10^{8}$ kJ / mol


n
$^{94}_{36}Kr$
$^{139}_{56}Ba$
Fission products
Neutrons
Unchanged "fuel"
Fission products
Neutrons

Fusion Reactors

- **The possibility of fusion reaction is at least several decades away from reality**

- **An international consortium of the U.S . , Japan , Russia ,and European community are jointly designing an exponential thermonuclear power reactor .**