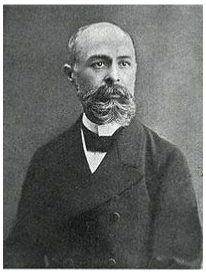
RADIOCHEMISTRY

- ✓ to understand the nuclear forces acting in the nucleus of the atoms
- ✓ the kinds and source of nuclear radiations
- ✓ interactions of nuclear radiation with the matter
- ✓ applications

3

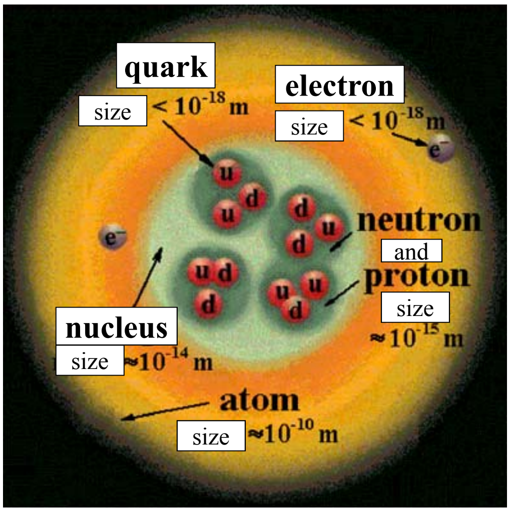


Antoine Henri *Becquerel*
(1852 - 1908)

Maria *Skłodowska-Curie*
(1867 – 1934)

4

The nucleus



after http://astronomyonline.org/Science/Images/Mathematics/AtomicStructureSmall.jpg

$$\Delta E = mc^2$$

A=Z+N

A: mass number
Z: atomic number

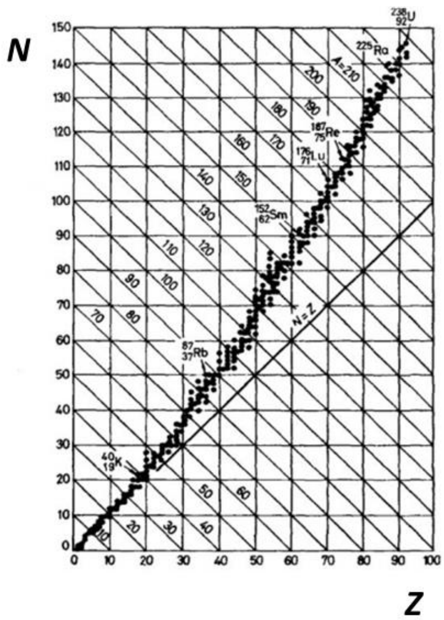
	m	E, MeV
p	1.6726×10^{-24} g	938.27
n	1.6749×10^{-24} g	939.55
e^-	9.109×10^{-28} g	0.51

5

Stable nuclides

$${}^{A}_{Z}X$$

$$A = Z + N$$



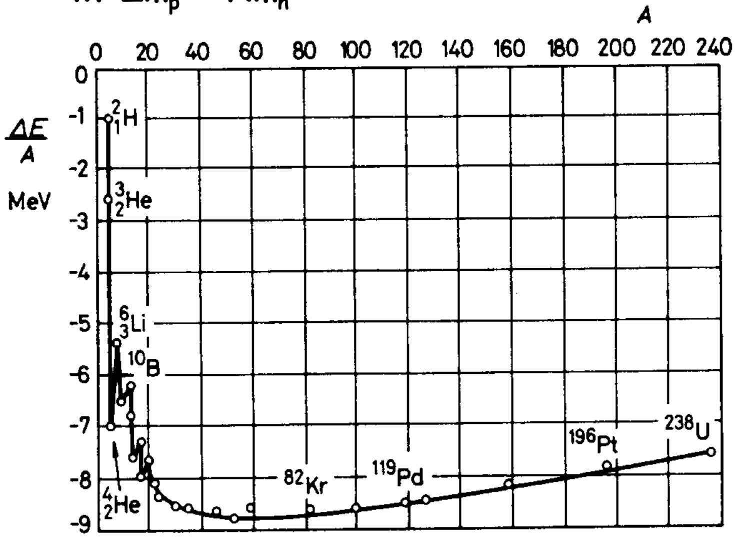
6

The role of the neutrons

Binding energy of the nucleus

$M < Zm_p + Nm_n$

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



7

Classification of the nuclides

Isotope: identical Z
Isobar: identical A
Isotone: identical N

Isotope effect ¡ Radioactive isotope !

applications
- spectroscopies (resonance, MS)
- solvent (NMR, neutron scattering)
- enrichment of isotopes
- CSIA: compound specific isotope analysis

Negligible?
- labelling
- unorthodox organic synthesis routes

8

Radioactivity

Spontaneous transformation of the unstable nucleus.
The properties of the nucleus change in time and energy is released.

All the conservation laws are met.

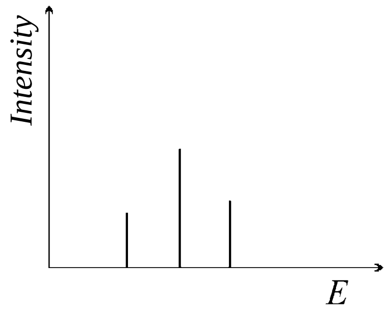
9

Types of radioactive decay

10

Isomeric transition

$${}^{A*}_{Z}X \rightarrow {}^{A}_{Z}X + \gamma \qquad \Delta E = h \cdot \nu$$



line spectrum

Examples

nuclide	$T_{1/2}$	E_{γ}, MeV
^{60m}Co	10.5 min	0.059
^{99m}Tc	6.0 h	0.143

Z	Nuclide	$T_{1/2}$	Way of decay	Particle energy, MeV		Gamma energy, MeV		η	Production	σ'	Daughter
27						2,02 2,60 2,99 3,25 3,47	11 % 16 % 1 % 12 % 1 %				
	^{57}Co	270 d	*E.X.*		100 %	0,014 0,122 0,136	6 % 88 % 10 %	83 % 1 % 1 %	$^{56}Fe(d,n)$ $^{60}Ni(p,\alpha)$	0,9	
	^{58}Co	71,3 d	*E.X.* β^+	 0,47	85 % 15 %	0,81 1,62 0,51 (β^+)	100 % 0,5 %		$^{58}Ni(n,p)$		
	^{60m}Co ^{60}Co	10,5 min 5,27 a	*I* β^-	 0,31 1,48	100 % ≈ 100 % 0,01 %	0,059 1,17 1,33	0 % 100 % 100 %	≈100%	$^{59}Co(n,\gamma)$ $^{59}Co(n,\gamma)$	19 37	^{60}Co
28	^{63}Ni	92 a	β^-	0,067	100 %				$^{62}Ni(n,\gamma)$	0,77	
	^{65}Ni	2,521 h	β^-	0,60 1,01 2,10	≈ 23 % ≈ 8 % ≈ 69 %	0,37 1,11 1,49	5 % 13 % 18 %		$^{64}Ni(n,\gamma)$	0,016	
29	^{64}Cu	12,9 h	β^- β^+ *E.X.*	0,57 0,66	38 % 19 % 43 %	0,51 (β^+) 1,34	 0,6 %		$^{63}Cu(n,\gamma)$	3,0	
	^{66}Cu	5,10 min	β^-	0,76 1,59 2,63	< 0,2 % ≈ 9 % ≈ 91 %	0,83 1,04	0,2 % 9 %		$^{65}Cu(n,\gamma)$	0,56	

β - decays

β⁻-decay $\;{}^{A}_{Z}X \rightarrow {}_{Z+1}^{A}Y + \beta^{-} + \tilde{\nu} + [\gamma]$

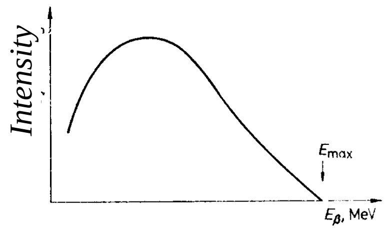
$n \rightarrow p + \beta^{-} + \tilde{\nu}$ exothermic

β⁺-decay $\;{}^{A}_{Z}X \rightarrow {}_{Z-1}^{A}Y + \beta^{+} + \nu + [\gamma]$

$p \rightarrow n + \beta^{+} + \nu$ endothermic

Electron capture $\;e^{-} + {}^{A}_{Z}X \rightarrow {}_{Z-1}^{A}Y^{(*+)} + \nu + [\gamma]$

$e^{-} + p \rightarrow n + \nu$ endothermic



common:

A= constant

ΔZ=±1

ν or $\tilde{\nu}$

Examples: pure β⁻ emitters

nuclide	Energia, MeV	$T_{1/2}$
^{3}H	0.018	12.26 y
^{14}C	0.159	5730 y
^{32}P	1.71	14.3 d
^{35}S	0.167	88 d
^{90}Sr	0.54	28.1 y
^{90}Y	2.25	64 h

Examples: mixed (β+γ) emitters

nuclide	$T_{1/2}$	β-energy, MeV	γ-energy, MeV
^{60}Co	5,27 a	0,31	1,17/1,33
^{131}I	8,07 d	0,61	0,36
^{137}Cs	30,23 a	0,51	0,662

Examples: positron emitters

nuklid	$T_{1/2}$	E_{β^+} MeV
^{11}C	20.3 min	0.97
^{13}N	9.97 min	1.2
^{15}O	124 s	1.7
^{18}F	109.7 min	0.064

15

Examples: EX (electron capture)

Nuclide	$T_{1/2}$	E_{γ} MeV
^{54}Mn	303 d	0.84
^{125}I	60 d	0.035

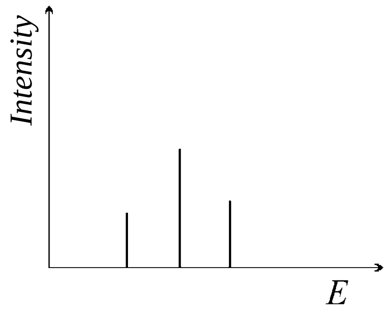
16

α-decay

α particle

$${}^{A}_{Z}X \rightarrow {}^{A-4}_{Z-2}Y + {}^{4}_{2}He^{2+} + [\gamma]$$

4-9 MeV



line spectrum

Example: Alpha emitters

nuclide	$T_{1/2}$
^{235}U	7.1E8 a
^{226}Ra	1600 a
^{222}Rn	3.8 d

17

Radioactive nucleus and its daughter

Isomeric decay:
equal mass, chemically identical

Beta-decays:
equal mass, chemically different

Alpha-decay:
both mass and chemistry are different

18

Radioactivity

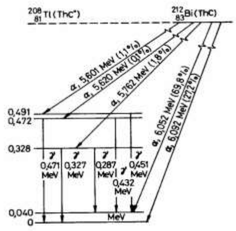
-Spontaneous decay

-Properties change in time
chemical identity
mass

-Energy is released		mass, MeV	typical energy, MeV
hν	from nucleus: gamma-ray	-	
e^-, e^+	from nucleus: beta-particle	0.51	
$^{4}_{2}He^{2+}$	from nucleus: alpha-particle	~3700	4-9 MeV

Charge!
spontaneous fission

Occurs in nature!!!



Kinetics of the decay

Simple decay

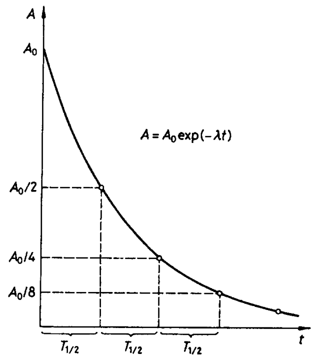
$$A \equiv -\frac{dN}{dt} = \lambda N$$

$$N = N_0 e^{-\lambda t} \quad A = A_0 e^{-\lambda t}$$

$$T_{1/2} = \frac{\ln 2}{\lambda} \qquad [A] = \frac{1}{\text{time}}$$

$$\frac{1 \text{ decay}}{\text{second}} = 1 \text{ becquerel} = 1 \text{ Bq}$$

$$1 \text{ Ci} = 3.7\times10^{10} \text{ Bq}$$



I=kηA

Radiocarbon dating (or simply **carbon dating**)

radiometric dating technique based on the decay of ^{14}C to estimate the age of organic materials (wood, leather, etc.) up to 58,000 - 62,000 years.

Willard Libby, Nobel Prize in Chemistry (1949)

plant or animal alive : exchanging carbon with its surroundings → same proportion of $^{14}C/^{12}C$ as the biosphere.

Once it dies ^{14}C it contains decays, $^{14}C/^{12}C$ gradually reduce.

A mammoth was found in the Siberian permafrost. The ^{14}C content in the body was only 21 % of that found in living animals. Their $^{14}C/^{12}C$ ratio is 10^{-12}. How old is the mammoth ? The half-life of the radiocarbon is 5730 y.

21

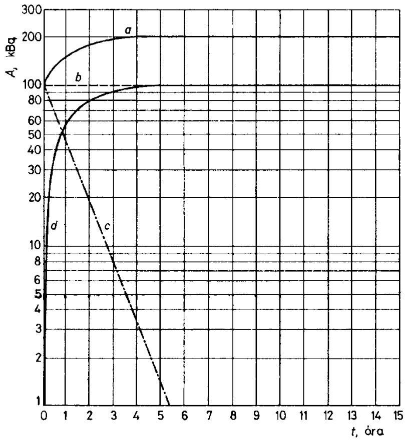
Decay chains

$$X \xrightarrow[T_{1/2,X}]{\lambda_X} Y \xrightarrow[T_{1/2,Y}]{\lambda_Y} Z_{stable}$$

$$A_Y = \lambda_Y N_Y = A_{X,0} \frac{\lambda_Y}{\lambda_Y - \lambda_X}\left(e^{-\lambda_X t} - e^{-\lambda_Y t}\right)$$

relation *of* λ_A and λ_B ?

22



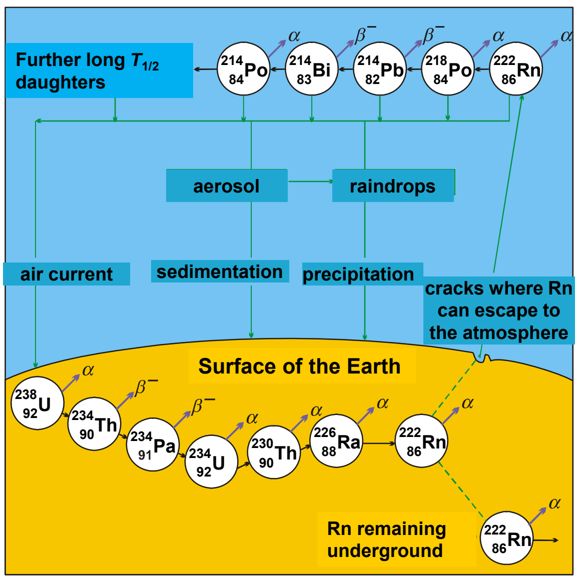
$T_{1/2,X} >> T_{1/2,Y}$

$T_{1/2,X} = 8 \cdot 10^7 h$

$T_{1/2,Y} = 0{,}8 h$

$$^{90}Sr \xrightarrow[28\,a]{\beta^-} {}^{90}Y \xrightarrow[64\,h]{\beta^-} {}^{90}Zr$$

$$^{226}_{88}Ra \xrightarrow[1620\,a]{\alpha} {}^{222}_{86}Rn \xrightarrow[3{,}83\,d]{\alpha} \ldots {}_{82}Pb$$



When former Russian spy Alexander Litvinenko died from polonium-210 poisoning several years ago in London, it triggered a murder investigation that developed like a thriller.

Po-210 generate much heat as the atoms decay - it was used in Russian lunar landers to keep the craft's instruments warm at night.

.

^{210}Po is an α-emitter, that has a half-life of 138.4 days, E_{α} = 5.3 MeV

25

Interaction of the radiation with the matter

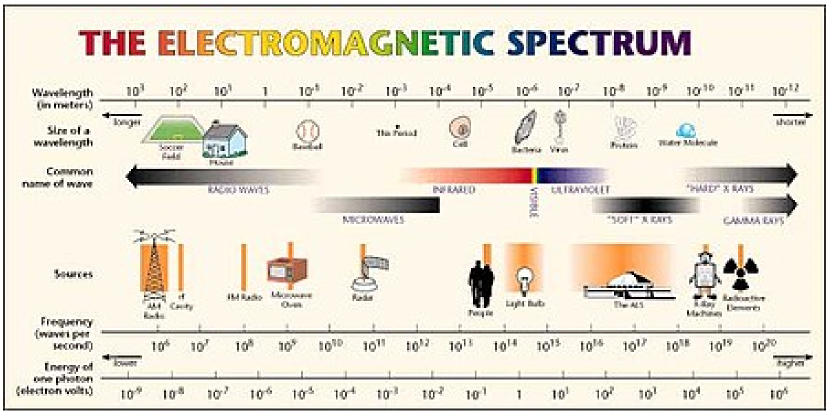
26

Gamma ray/radiation

Electromagnetic radiation, emmitted by the nucleus

Line spectrum

Isomeric transition ("escort" also)



27

Beta-radiations

e^- or e^+ radiation coming from the nucleus

Continuous spectrum

May be exclusive (but ν!)

May be escorted by gamma or characteristic X-rays

Alpha-radiation

${}^{4}_{2}He^{2+}$ particles, emmitted by the nucleus

Linear spectrum

May be escorted by gamma radiation

28