Physical chemistry and radiochemistry

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http://oktatas.ch.bme.hu/oktatas/konyvek/fizkem/PHCR

Requirements

Weekly contact: 2+0+1

Evaluation is based on continuous performance

Lectures: Participation at 67 % (2/3) on the lectures is obligatory

occasional short tests and 2 comprehensive tests

16 October
4 December

Lab practice: All the measurements should be performed and the lab requirements fully completed (active and knowledgable participation + accepted report)

Comprehensive test on the lab practices will be held on 4 December

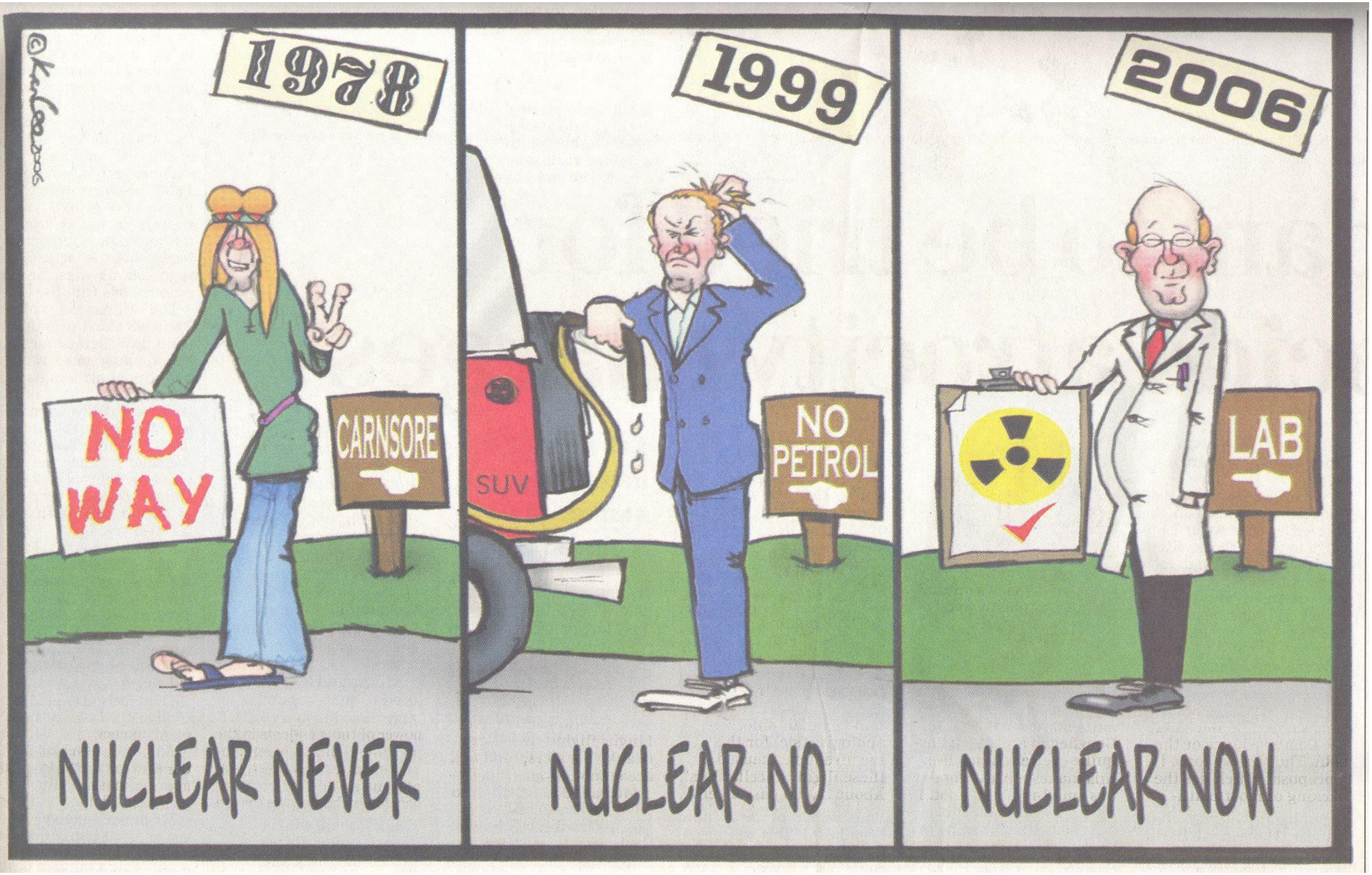
Make up testS: 11 December

Final grade: 80 % lecture related performance (short + comprehensive)

20 % lab practice

RADIOCHEMISTRY

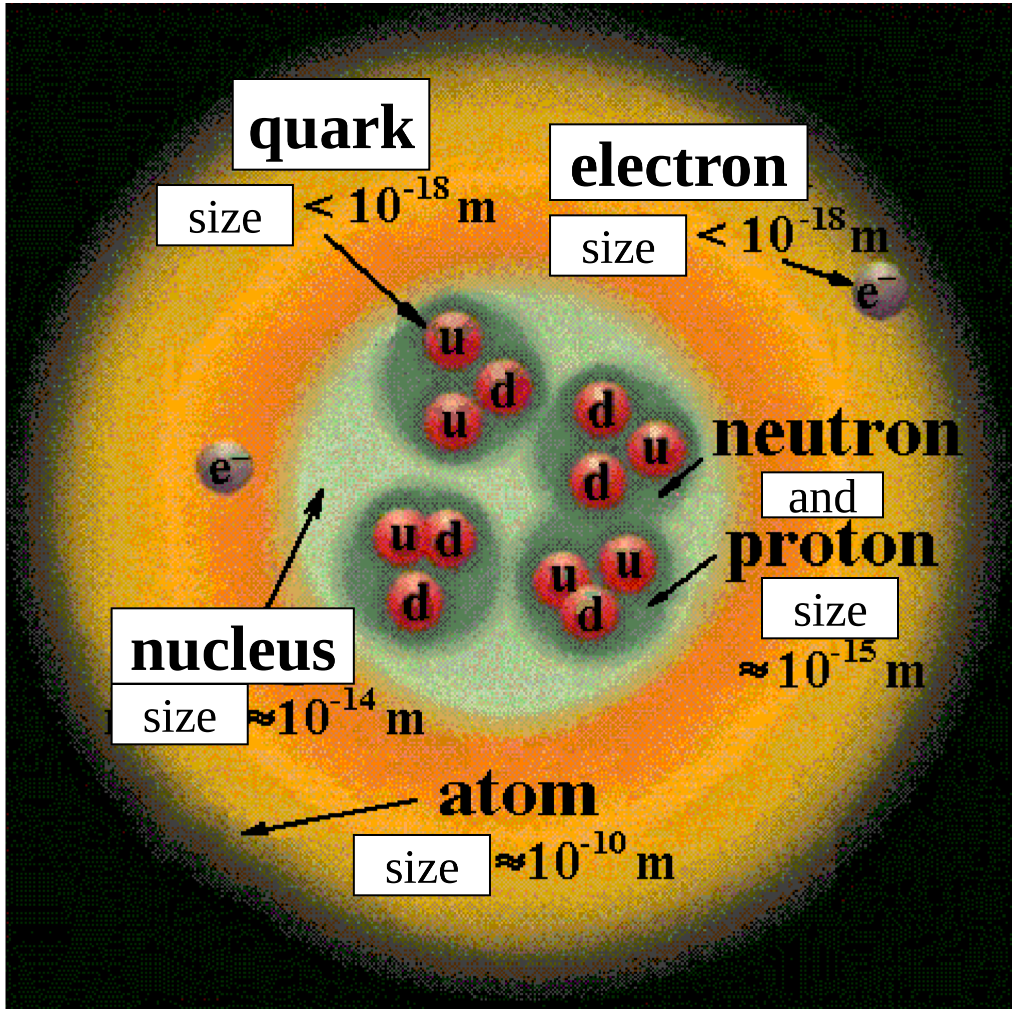
- ✓ to understand the nuclear forces acting in the nucleus of the atoms
- ✓ the kinds and source of nuclear radiations
- ✓ interactions of nuclear radiation with the matter
- ✓ applications


1978
NO WAY
CARNSORE
NUCLEAR NEVER
1999
SUV
NO PETROL
NUCLEAR NO
2006
LAB
NUCLEAR NOW

Antoine Henri *Becquerel*
(1852 - 1908)

Maria *Skłodowska-Curie*
(1867 – 1934)

The nucleus



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

$$\Delta E = mc^2$$

A=Z+N

A: mass number

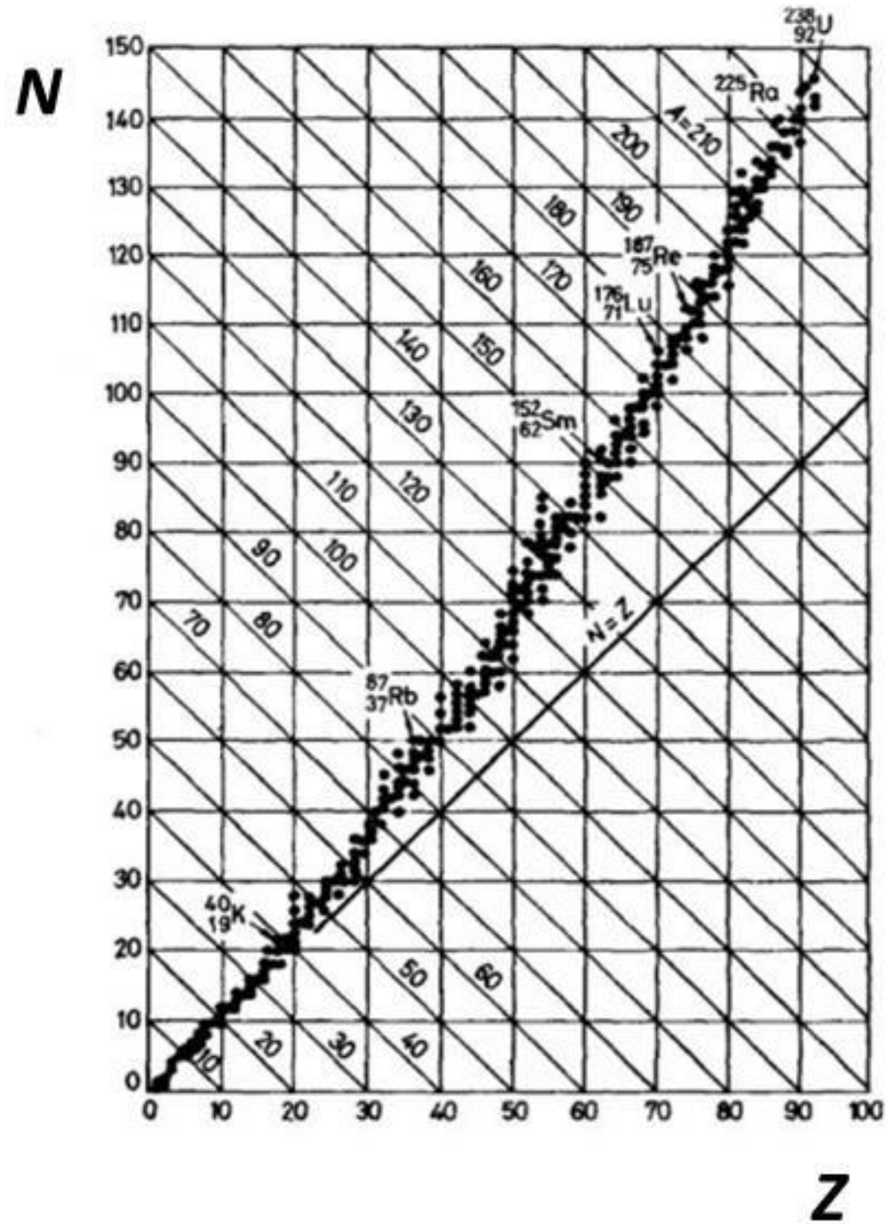
Z: atomic number

	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

Stable nuclides

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

$$A = Z + N$$

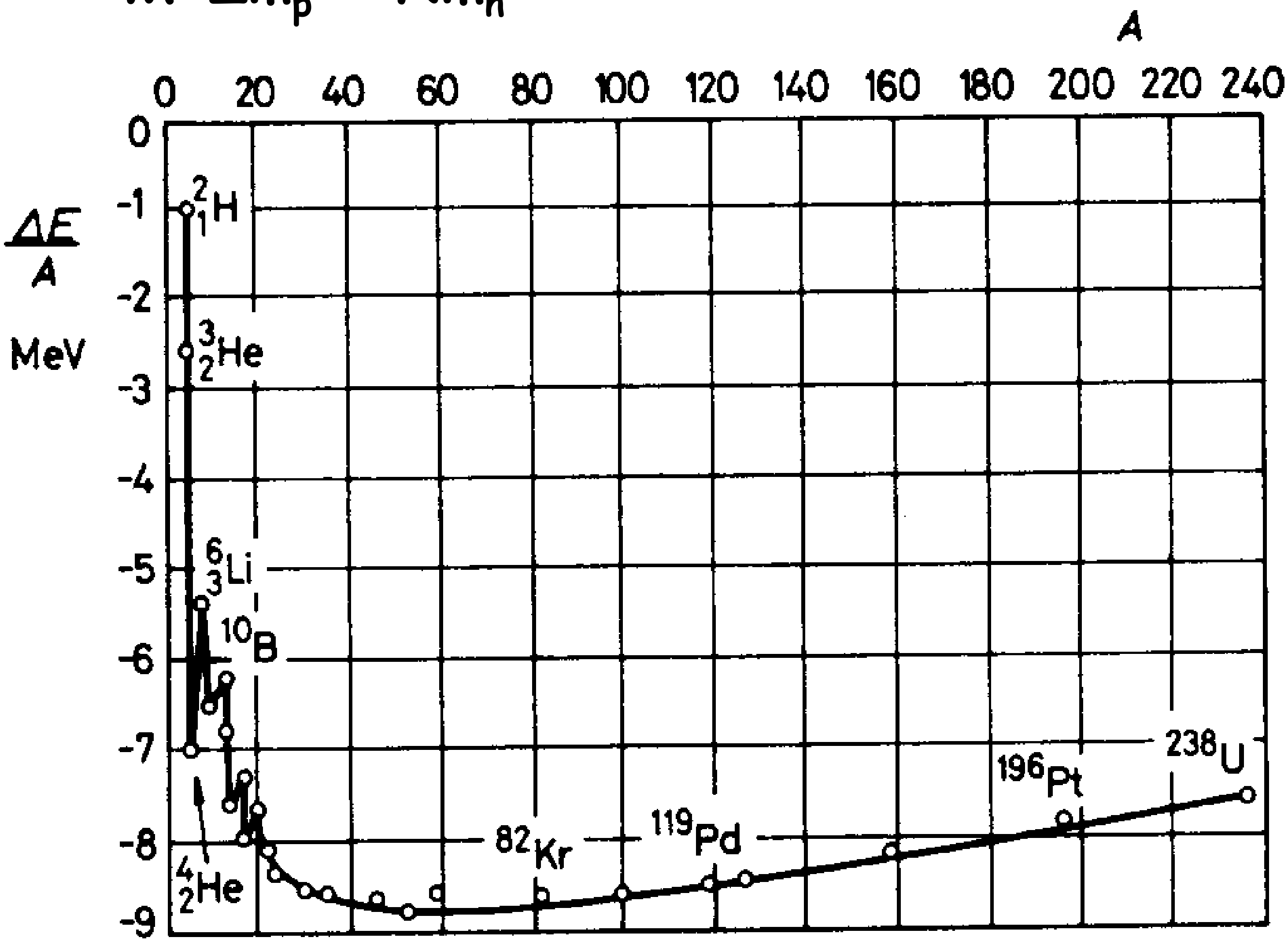


The role of the neutrons

Binding energy of the nucleus

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

$$M < Zm_p + Nm_n$$



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
- unortodox organic synthesis routes

Radioactivity

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

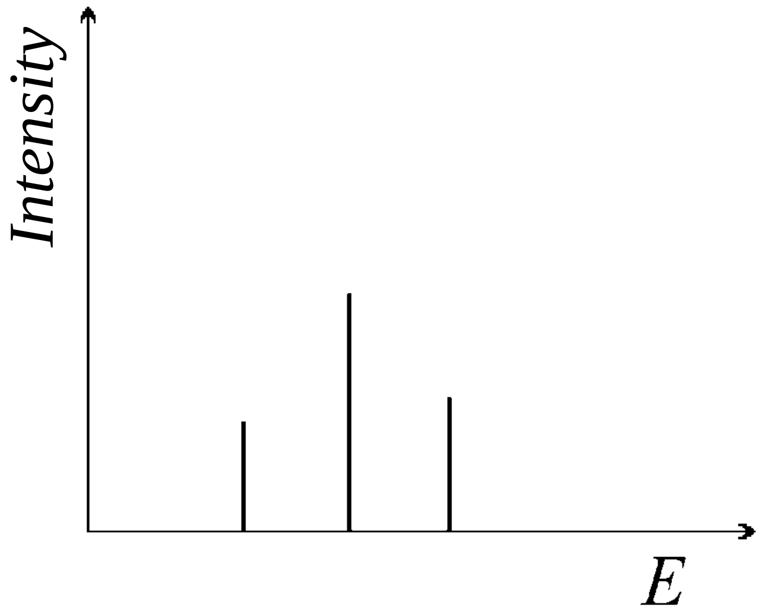
All the conservation laws are met.

Types of radioactive decay

Isomeric transition

$$^{A*}_{Z}X \rightarrow {}^{A}_{Z}X + \gamma$$

$$\Delta E = h \cdot \nu$$



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

β - decays

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

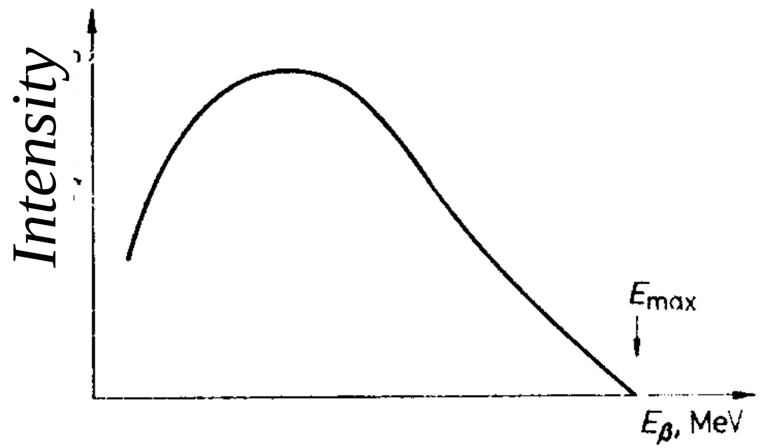
$$n \rightarrow p + \beta^{-} + \tilde{\nu}$$ exothermic

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

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

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

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



common:
- A= constant
- $\Delta Z = \pm 1$
- 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 ($\beta+\gamma$) 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

Examples: EX (electron capture)

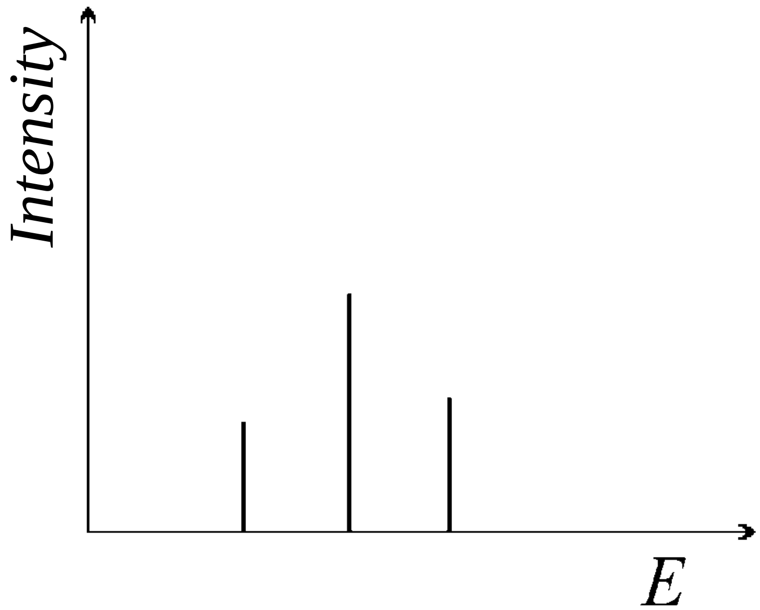
Nuclide	$T_{1/2}$	E_γ MeV
^{54}Mn	303 d	0.84
^{125}I	60 d	0.035

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

Gamma ray/radiation

Electromagnetic radiation, emmitted by the nucleus

Line spectrum

Isomeric transition ("escort" also)

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

Radioactivity

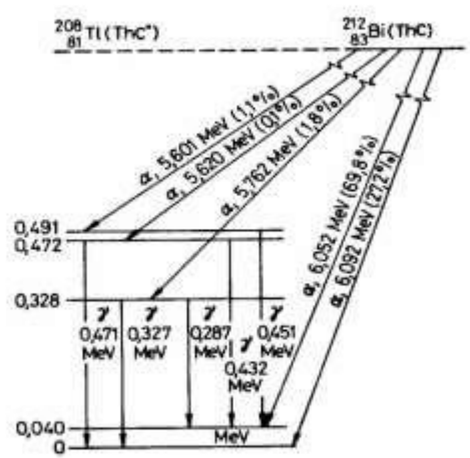
-Spontaneous decay

-Properties change in time
chemical identity
mass

-Energy is released		mass, MeV	typical energy, MeV
$h\nu$	from nucleus: gamma-ray	-	
e^-, e^+	from nucleus: beta-particle	0.51	
${}^4_2He^{2+}$	from nucleus: alpha-particle	~3700	4-9 MeV

Charge!
spontaneous fission

Occurs in nature!!!



Kinetics of the decay

Simple decay

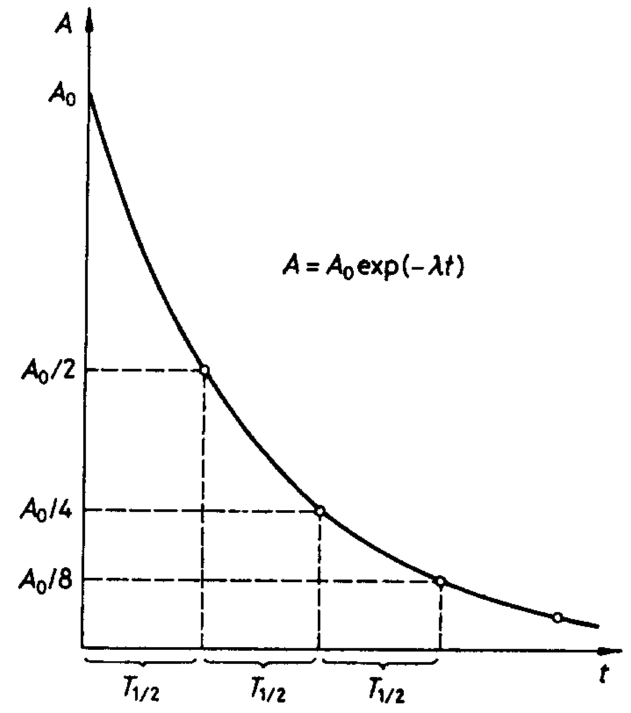
$$A \equiv -\frac{dN}{dt} = \lambda N$$

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

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

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

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



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.