

The microscopic world

atomic nucleus, radioactive decays



Irén Bárdos-Nagy

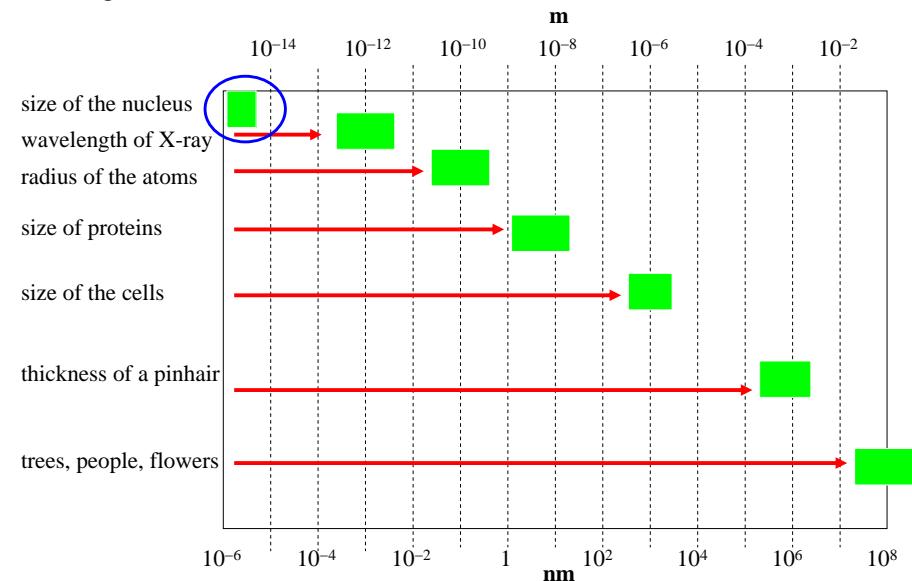


Building elements of atomic structure:

name/where	charge (elementari)	mass (kg)	atomic mass unit
electron/outside the nucleus	-1	$9,1 \cdot 10^{-31}$	0,0005486
proton/inside the nucleus	+1	$1,66 \cdot 10^{-27}$	1,007277
neutron/inside the nucleus	0	$1,67 \cdot 10^{-27}$	1.008665

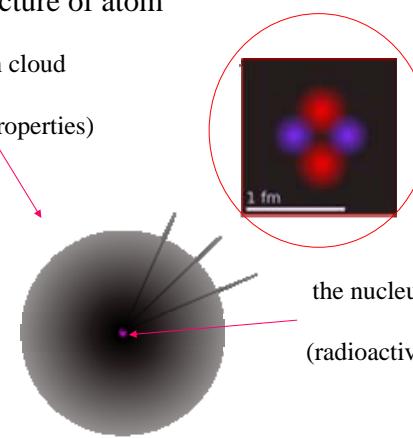
the charge of the electron: $1,6 \cdot 10^{-19}$ C

Length scale of the nature

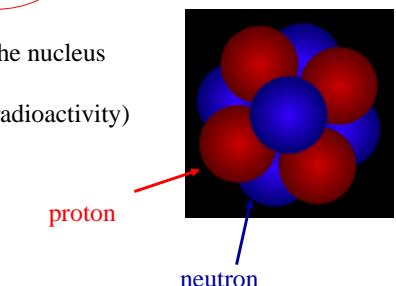


Structure of atom

the electron cloud
(chemical properties)



Structure of nucleus

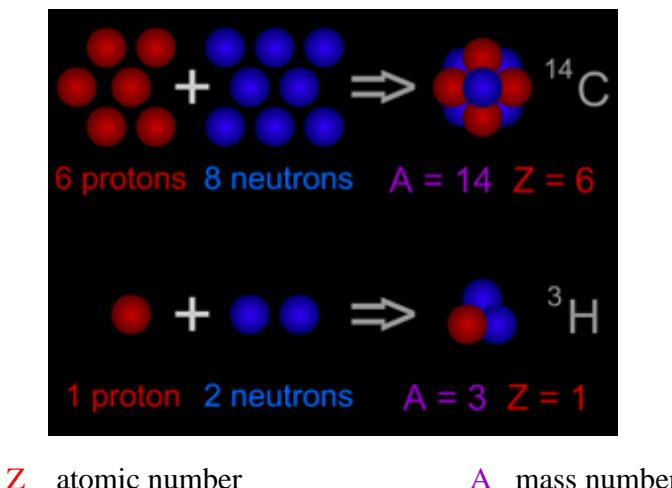


1 Ångström ($1 \cdot 10^{-10}$ m)

The figurative depiction of the He-4 atom

Proton and/or neutron = nucleon

The atomic and the mass number

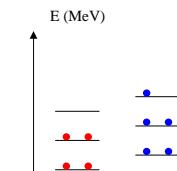


Stability of the nucleus

Coulomb force: electrostatic repulsion between the positively charged protons

Nuclear force: very strong attractive force
act only on short - range (10^{-14} m)
do not depend on the charge

The nucleons have definite energy levels (MeV scale)

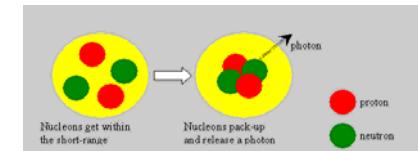


Quantized energy for the nucleus

Binding energy:

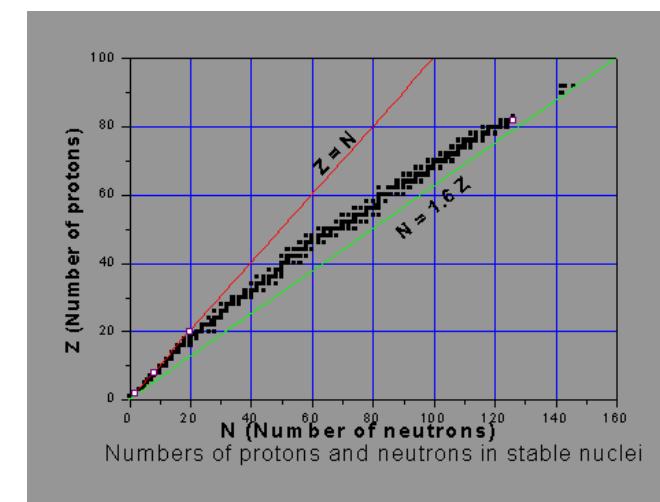
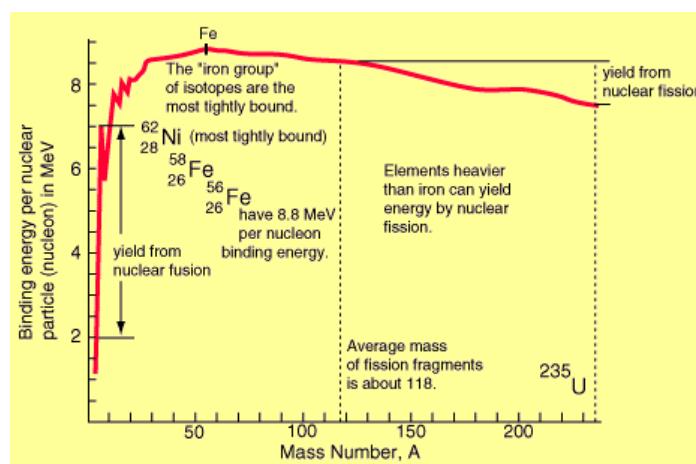
Total mass of 2 protons:	2.01456 amu
Total mass of 2 neutrons:	2.01732 amu
Total mass of nucleons:	4.03188 amu
Mass of the He atom:	4.00153 amu
Mass defect (Δm):	0.03035 amu
Binding energy of ${}^4_2\text{He}$:	28.3 MeV

$$(\Delta E = \Delta m * c^2)$$



${}^4_2\text{He}$ nucleus

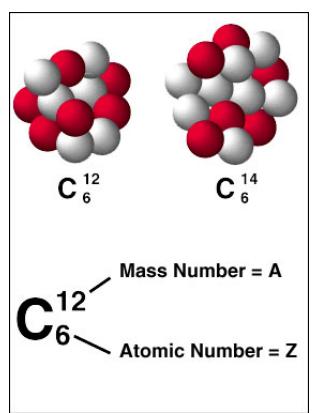
Nuclear binding energies of the different elements



Isotopes:

number of protons is the same

number of neutrons is different



Atomic Number → 36
Kr
Krypton
Atomic Weight → 83.80

mass number → atomic weight

The chemical properties are the same!!

Table of isotopes

		Half life	Stable	Very short	> 100,000 yr	> 10 yr	> 100 days	> 10 days	> 1 day	> 1 hr	> 1 min.
		25S	29S	24S	25S	25S	25S	25S	25S	25S	25S
proton number	neutron number	24Al	29Al	23Al	24Al	25Al	26Al	27Al	28Al	29Al	30Al
1	12	19Mg	20Mg	21Mg	22Mg	23Mg	24Mg	25Mg	26Mg	27Mg	28Mg
2	13	17Na	19Na	19Na	20Na	21Na	22Na	23Na	24Na	25Na	26Na
3	14	17Ne	17Ne	18Ne	19Ne	20Ne	21Ne	22Ne	23Ne	24Ne	25Ne
4	15	14P	15P	16P	17P	18P	19P	20P	21P	22P	23P
5	16	12O	13O	14O	15O	16O	17O	18O	19O	20O	21O
6	17	13N	14N	15N	16N	17N	18N	19N	20N	21N	22N
7	18	14C	15C	16C	17C	18C	19C	20C	21C	22C	23C
8	19	7B	8B	9B	10B	11B	12B	13B	14B	15B	16B
9	20	8Be	9Be	10Be	11Be	12Be	13Be	14Be	15Be	16Be	17Be
10	21	7Li	8Li	9Li	10Li	11Li	12Li	13Li	14Li	15Li	16Li
11	22	6He	7He	8He	9He	10He	11He	12He	13He	14He	15He
12	23	5He	6He	7He	8He	9He	10He	11He	12He	13He	14He
13	24	4He	5He	6He	7He	8He	9He	10He	11He	12He	13He
14	25	3He	4He	5He	6He	7He	8He	9He	10He	11He	12He
15	26	2He	3He	4He	5He	6He	7He	8He	9He	10He	11He
16	27	1H	2H	3H	4H	5H	6H	7H	8H	9H	10H

Hydrogen 1 proton ${}^1\text{H}$ ${}^2\text{H}$ ${}^3\text{H}$

Helium 2 protons ${}^3\text{He}$ ${}^4\text{He}$

Lithium 3 protons ${}^6\text{Li}$ ${}^7\text{Li}$

neutron number

Table of isotopes

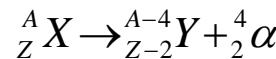
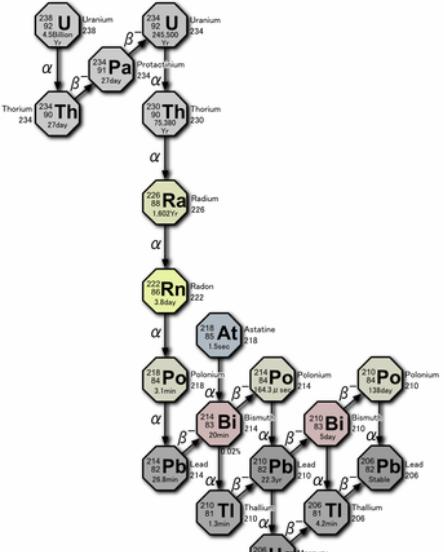
		Half life	Stable	Very short	> 100,000 yr	> 10 yr	> 100 days	> 10 days	> 1 day	> 1 hr	> 1 min.
		54Zn	55Zn	56Zn	57Zn	58Zn	59Zn	60Zn	61Zn	62Zn	63Zn
proton number	neutron number	52Cu	53Cu	54Cu	55Cu	56Cu	57Cu	58Cu	59Cu	60Cu	61Cu
28	30	49Ni	50Ni	51Ni	52Ni	53Ni	54Ni	55Ni	56Ni	57Ni	58Ni
29	31	48Co	49Co	50Co	51Co	52Co	53Co	54Co	55Co	56Co	57Co
30	32	45Fe	46Fe	47Fe	48Fe	49Fe	50Fe	51Fe	52Fe	53Fe	54Fe
31	33	44Mn	45Mn	46Mn	47Mn	48Mn	49Mn	50Mn	51Mn	52Mn	53Mn
32	34	43Cr	44Cr	45Cr	46Cr	47Cr	48Cr	49Cr	50Cr	51Cr	52Cr
33	35	41V	42V	43V	44V	45V	46V	47V	48V	49V	50V
34	36	39Ti	40Ti	41Ti	42Ti	43Ti	44Ti	45Ti	46Ti	47Ti	48Ti
35	37	38Sc	39Sc	40Sc	41Sc	42Sc	43Sc	44Sc	45Sc	46Sc	47Sc
36	38	34Ca	35Ca	36Ca	37Ca	38Ca	39Ca	40Ca	41Ca	42Ca	43Ca
37	39	33Ca	34Ca	35Ca	36Ca	37Ca	38Ca	39Ca	40Ca	41Ca	42Ca
38	40	32K	33K	34K	35K	36K	37K	38K	39K	40K	41K
39	41	30Ar	31Ar	32Ar	33Ar	34Ar	35Ar	36Ar	37Ar	38Ar	39Ar
40	42	29Cl	30Cl	31Cl	32Cl	33Cl	34Cl	35Cl	36Cl	37Cl	38Cl
41	43	28S	29S	30S	31S	32S	33S	34S	35S	36S	37S

neutron number

Radioactive decays and particles

decay	particles
α	α particle = ${}^4_2\text{He}$ nucleus
β^-	β^- particle = electron
β^+	β^+ particle = positron
K – electron capture	characteristic X – ray photon
Isomeric transition	γ – radiation (photon)

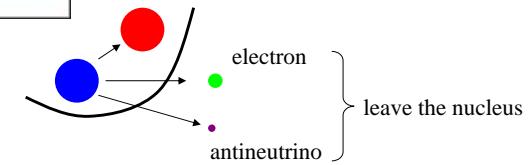
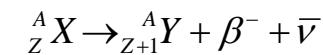
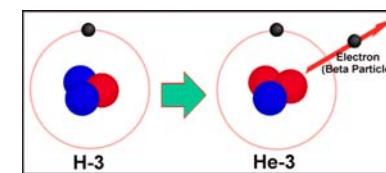
The α decay



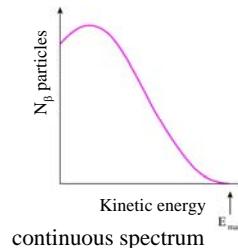
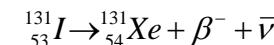
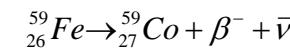
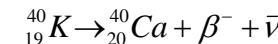
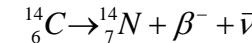
The energy of the emitted α particle is constant in the case of a given nuclid:

line spectrum (MeV)

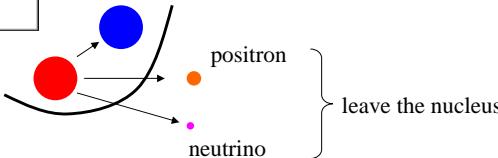
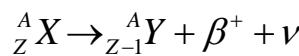
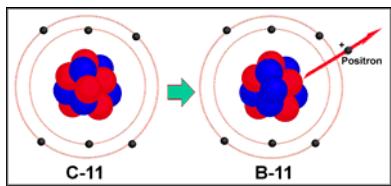
The β^- decay



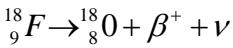
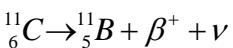
Examples:



The β^+ decay

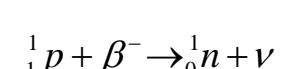
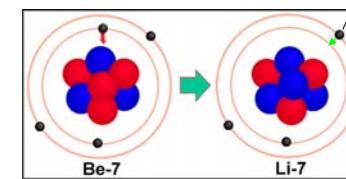


Examples:

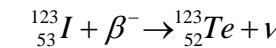
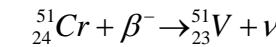
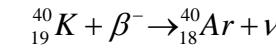


continuous spectrum

K – electron capture (inverse β^- decay)

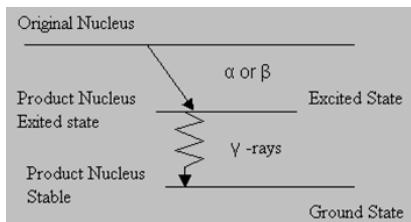
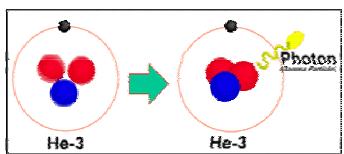


Examples:



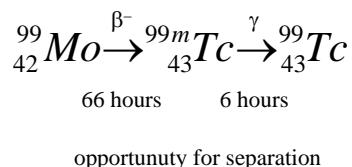
The γ decay

Prompt γ decay

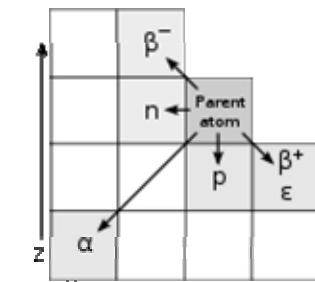
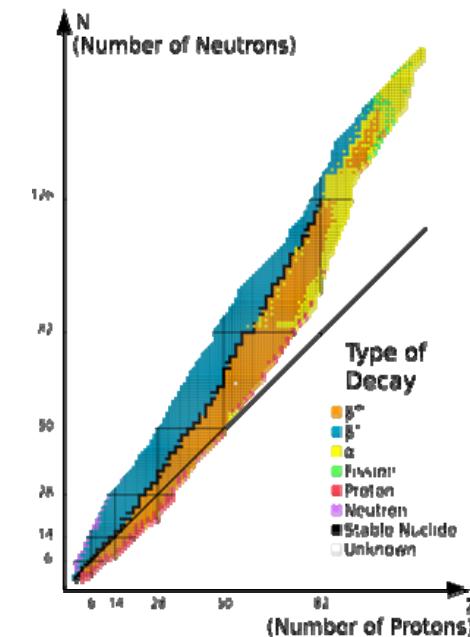


There is no change of the number of protons and neutrons

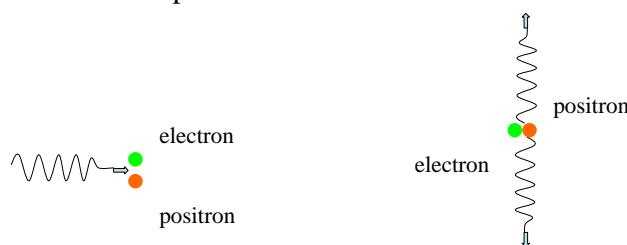
Isomeric transition



Summary



Pair production \longleftrightarrow annihilation



$$E_{ph} \Rightarrow m_{e^-}c^2 + m_{e^+}c^2$$

\downarrow

$\sim 1\text{ MeV}$

$$m_{e^-}c^2 + m_{e^+}c^2 \Rightarrow 2 \cdot E_{ph}$$

\downarrow

$\sim 0.5\text{ MeV}$