Introduction to Radiation Physics

Dr. Sudi Ariyanto

Center for Education and Training
Email: asudi@batan.go.id

Fellowship on Radwaste Management
October 1, 2018

INTRODUCTION TO RADIATION PHYSICS

Dr. Sudi Ariyanto
asudi@batan.go.id

Director
Center for Education and Training
National Nuclear Energy Agency

What do you think of when you hear the word

Radiation ?

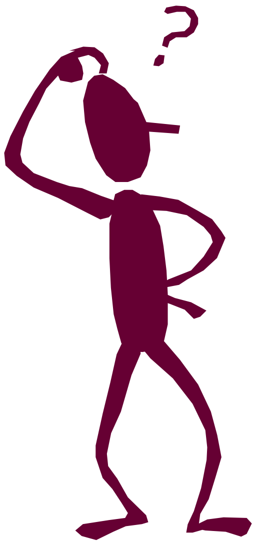
What is Radiation?

RADIATION is an emission or propagation of energy through a medium or space in form of electromagnetic waves or particles.

Type of radiation based on physical properties

1. Particle
    a. Charged particle (alpha, beta)
    b. Uncharged particle (neutron)

2. Electromagnetic waves
    - All spectra of electromagnetic waves (Gamma ray, X-ray, Radio waves, visible light etc.)



Type of Radiation based on Ionization capability

Non-Ionizing

Ionizing

- Directly Ionizing (charged particles)
  - Electron, proton, alpha, etc.
- Indirectly Ionizing (neutral particle)
  - Photon, neutron

Ionizing photon radiation is classified into four categories:

- Characteristic x ray

  Results from electronic transitions between atomic shells.

- Bremsstrahlung

  Results mainly from electron-nucleus Coulomb interactions.

- Gamma ray

  Results from nuclear transitions.

- Annihilation quantum (annihilation radiation)

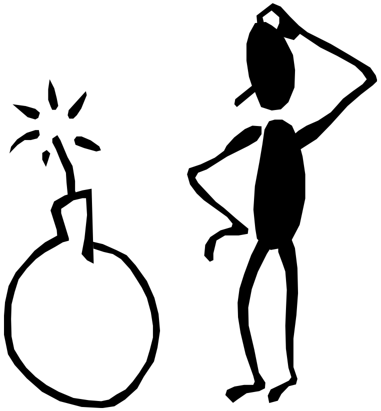
  Results from positron-electron annihilation.

Non-Ionizing Radiations

- MR Imaging (FM Region)
- Ultrasound.
- Microwave.
- Lasers used for various treatments.
- Visible Light to read images.

Is radiation Hazard?

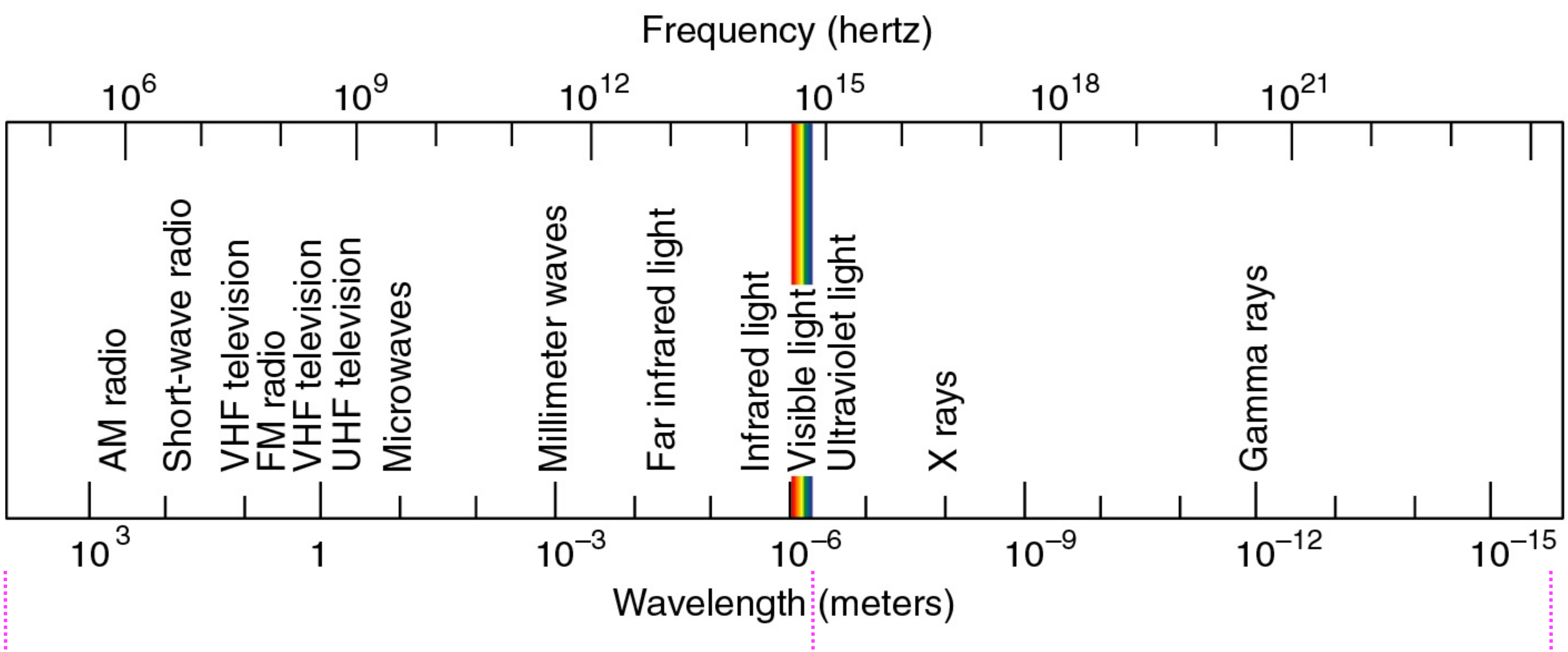
Not All Radiation is hazardous



- **IONIZING RADIATION**
  → HAZARDOUS
- **NON-IONIZING RADIATION**
  → UN-HAZARDOUS

RADIATION

ELECTROMAGNETIC WAVES SPECTRA



LOW ENERGIES (Non-Ionizing Radiation)

HIGH ENERGIES (Ionizing Radiation)

Learn the Order

R	M	I	V	U	X	G
A	I	N	I	L	R	A
D	C	F	S	T	A	M
I	R	R	I	R	Y	M
O	O	A	B	A		A
	W	R	L	V		
	A	E	E	I		
	V	D		O		
	E			L		
				E		
				T		

Electromagnetic Spectrum

batan

RADIO

MICROWAVE

INFRARED

VISIBLE

ULTRAVIOLET

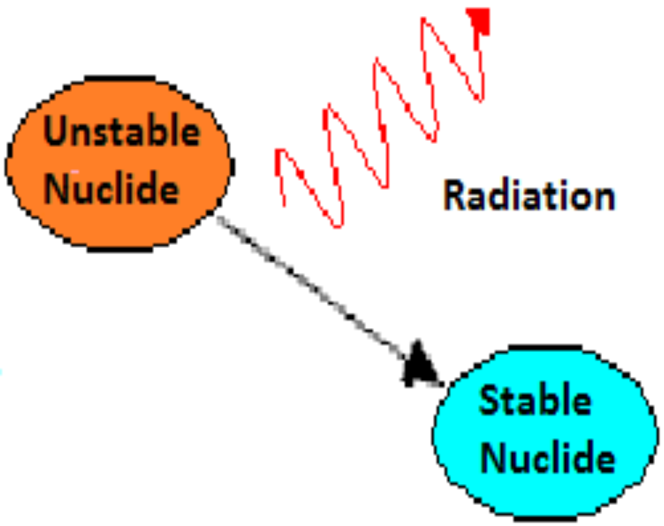
XRAY

GAMMA

LOW ENERGIES (Non-Ionizing Radiation)

HIGH ENERGIES (Ionizing Radiation)

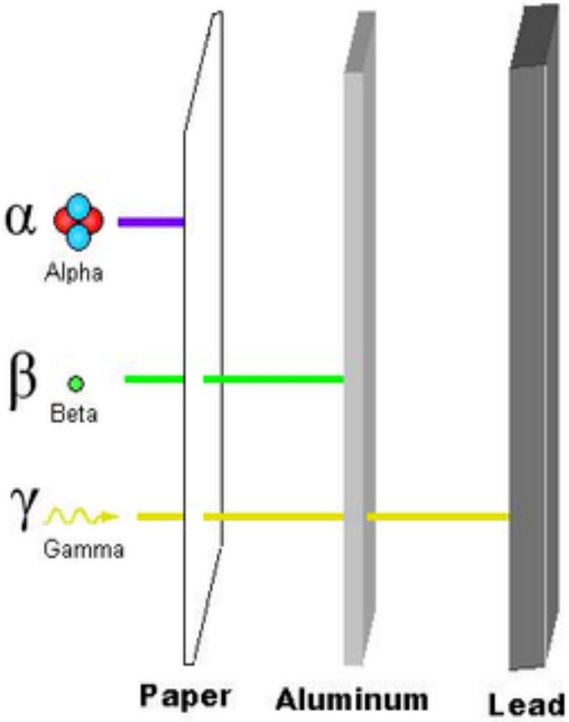
Why Radiation happen ?



Unstable nuclide will spontaneously change into stable nuclide. The change process is called radioactive decay where in each of the decay process the radiation will be emitted (alpha, beta and gamma).

Characteristics of Radiation

Type of Radiation	Ionization	Penetration
Alpha	large	low
Beta	medium	medium
X- ray	Small	large
Gamma ray	Small	More large

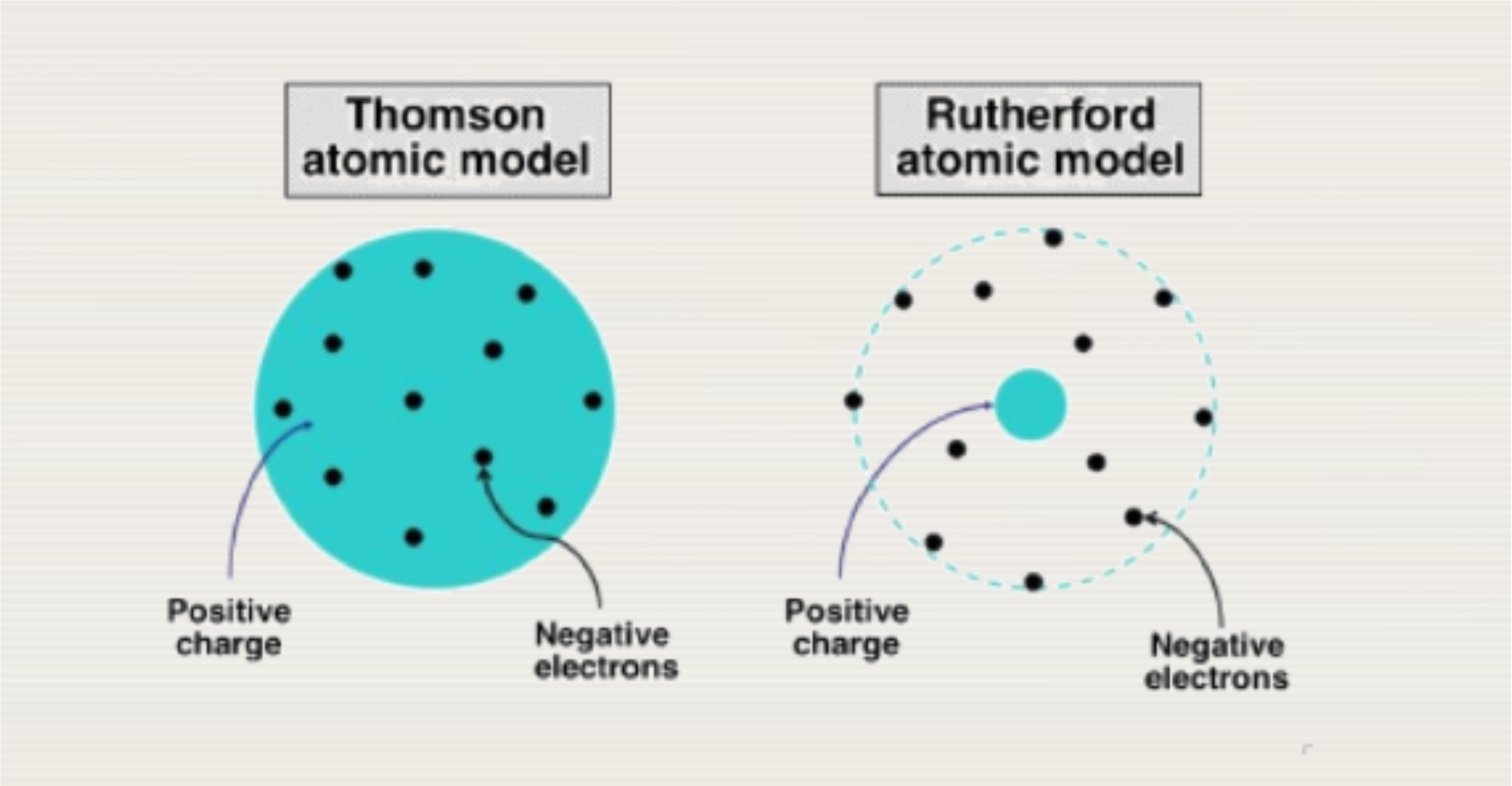


Characteristic of Nuclear Radiation

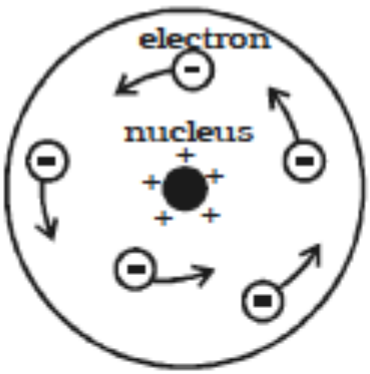
NUCLEAR RADIATION

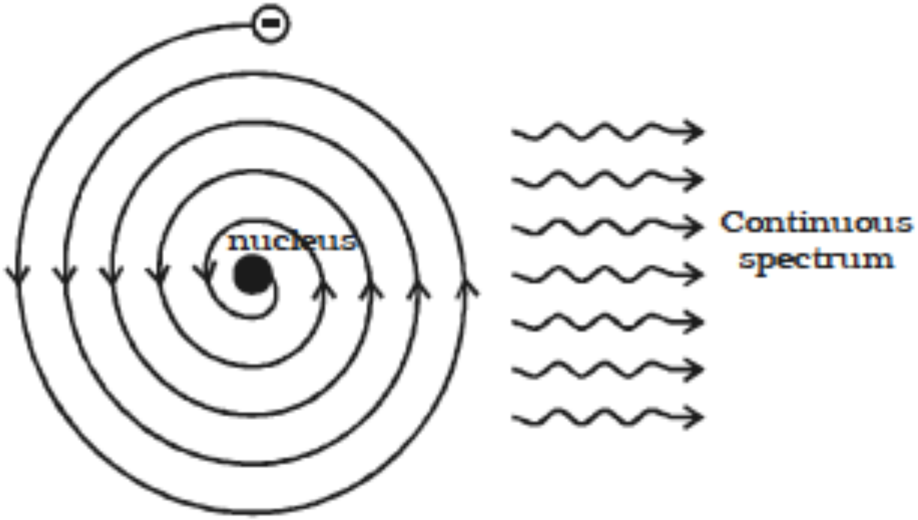
- Invisible
- Senseless
- Colourless
- not influenced by temperature and pressure
- Ionize

Atomic Models



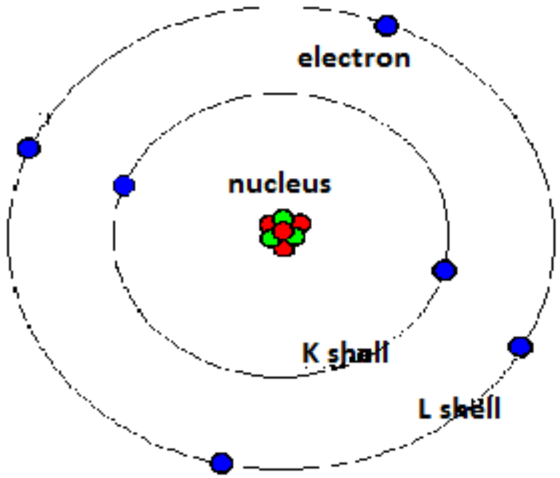
Drawback of Rutherford's Model





Atomic Structure

BOHR'S ATOMIC MODEL



Atomic structure :

- **Nucleus :** proton and neutron
- **Electron** : that revolve around the nucleus in orbit or a certain distance

Shortcoming of Bohr's theory

(i) The theory could not account for the spectra of atoms more complex than hydrogen.

(ii) The theory does not give any information regarding the distribution and arrangement of electrons in an atom.

(iii) It does not explain, the experimentally observed variations in intensity of the spectral lines of the element.

(iv) When the spectral line of hydrogen atom is examined by spectrometers having high resolving power, it is found that a single line is composed of two or more close components. This is known as the fine structure of spectral lines. Bohr's theory could not account for the fine structure of spectral lines.

(v) It is found that when electric or magnetic field is applied to the atom, each of the spectral line split into several lines. The former effect is called as Stark effect, while the latter is known as Zeeman effect. Bohr's theory could not explain the Stark effect and Zeeman effect.

NUCLEUS

$_{Z}X^{A}$

Consisting of protons and neutrons

X : Atomic Symbol

Z : Atomic Number (number of proton)

A : Atomic Mass (number of proton +neutron)

Examples

$_{2}He^{4}$

Element: Helium

Proton (Z) = 2

Neutron (N) = 2

$_{27}Co^{59}$

Element: Cobalt

Proton (Z) = 27

Neutron (N) = 32

- There is no basic relation between the atomic mass number *A* and atomic number *Z* of a nucleus but the empirical relationship:

$$Z = \frac{A}{1.98 + 0.0155A^{2/3}}$$

furnishes a good approximation for stable nuclei.

Nucleus Stability

Depends on the composition of proton and neutron in the nucleus

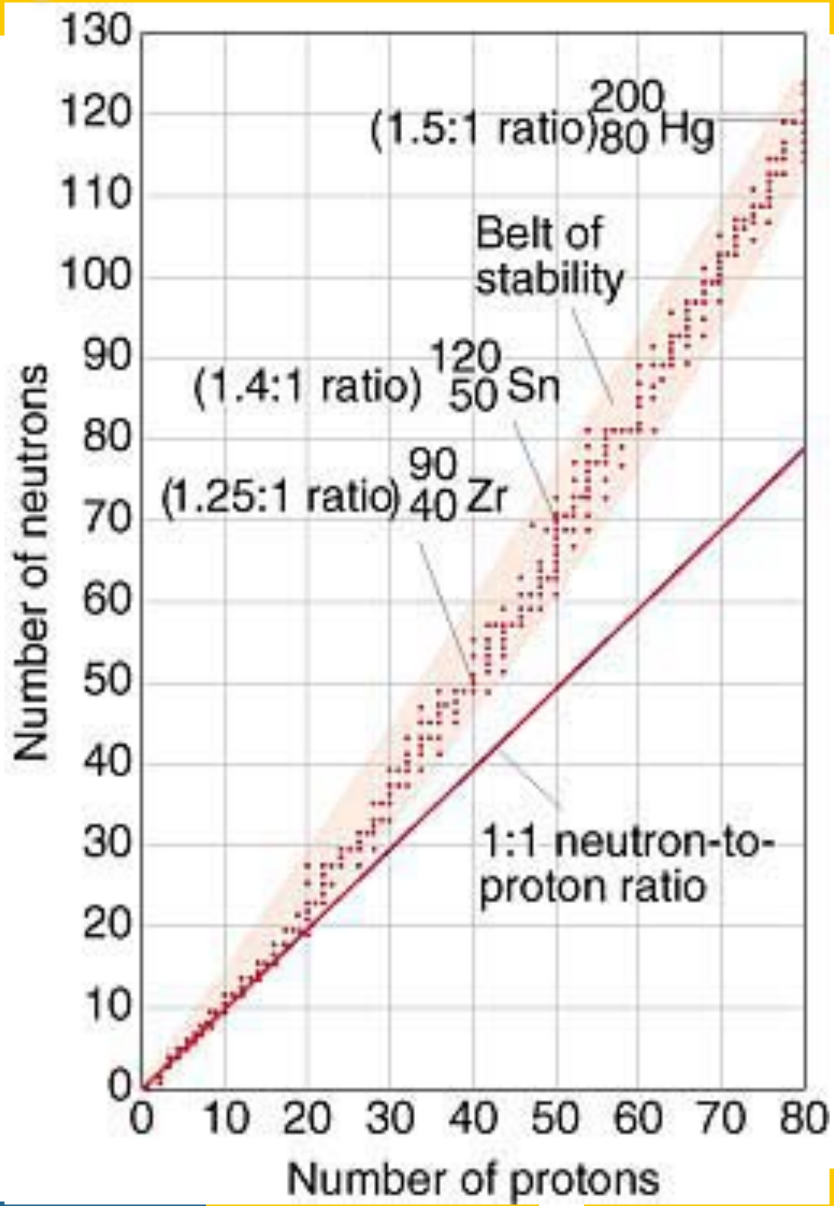
In general:

- **Light nucleus ➔ N = Z**
- **Heavy nucleus ➔ N = 1½ . Z**

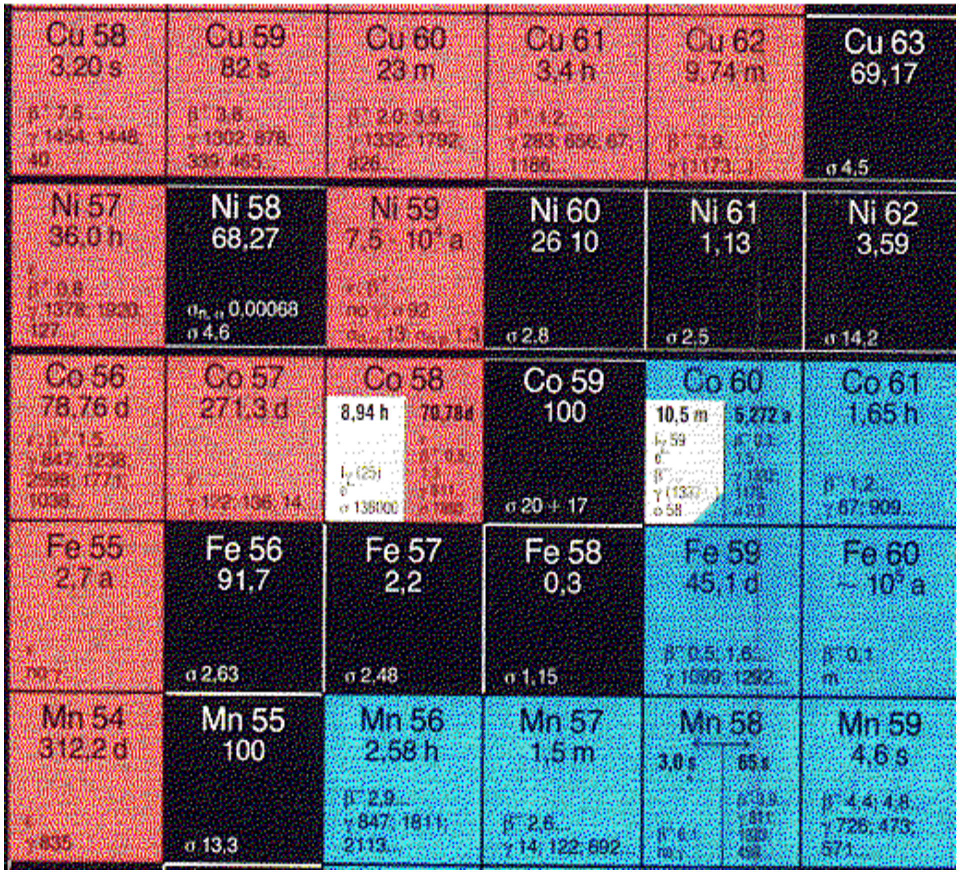
Nucleus Stability

Proton	Neutron	No. of stable Nucl.	Stability
Odd	Odd	4	least stable
Odd	Even	50	more stable
Even	Odd	57	even more stable
Even	Even	168	most stable

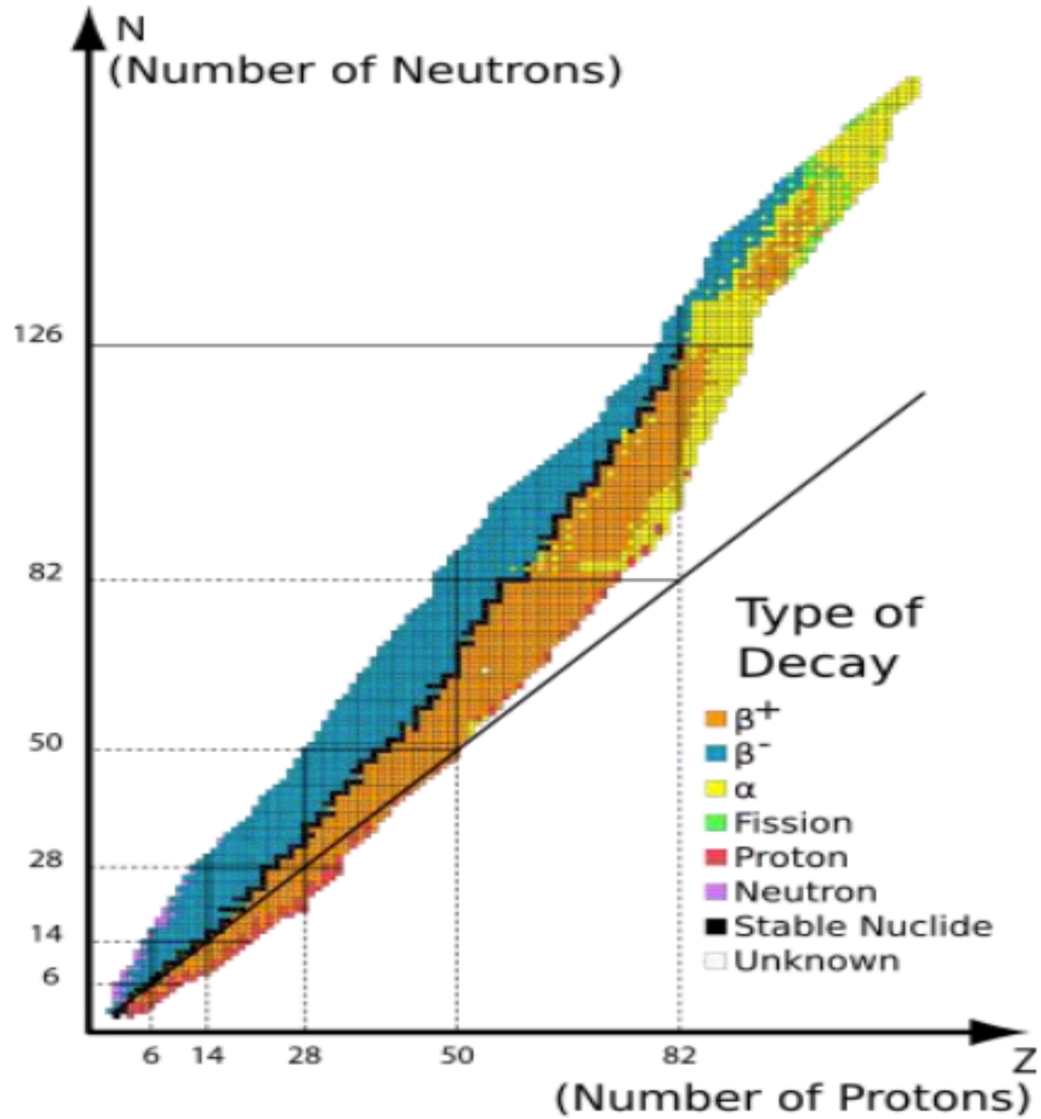
Stability curve

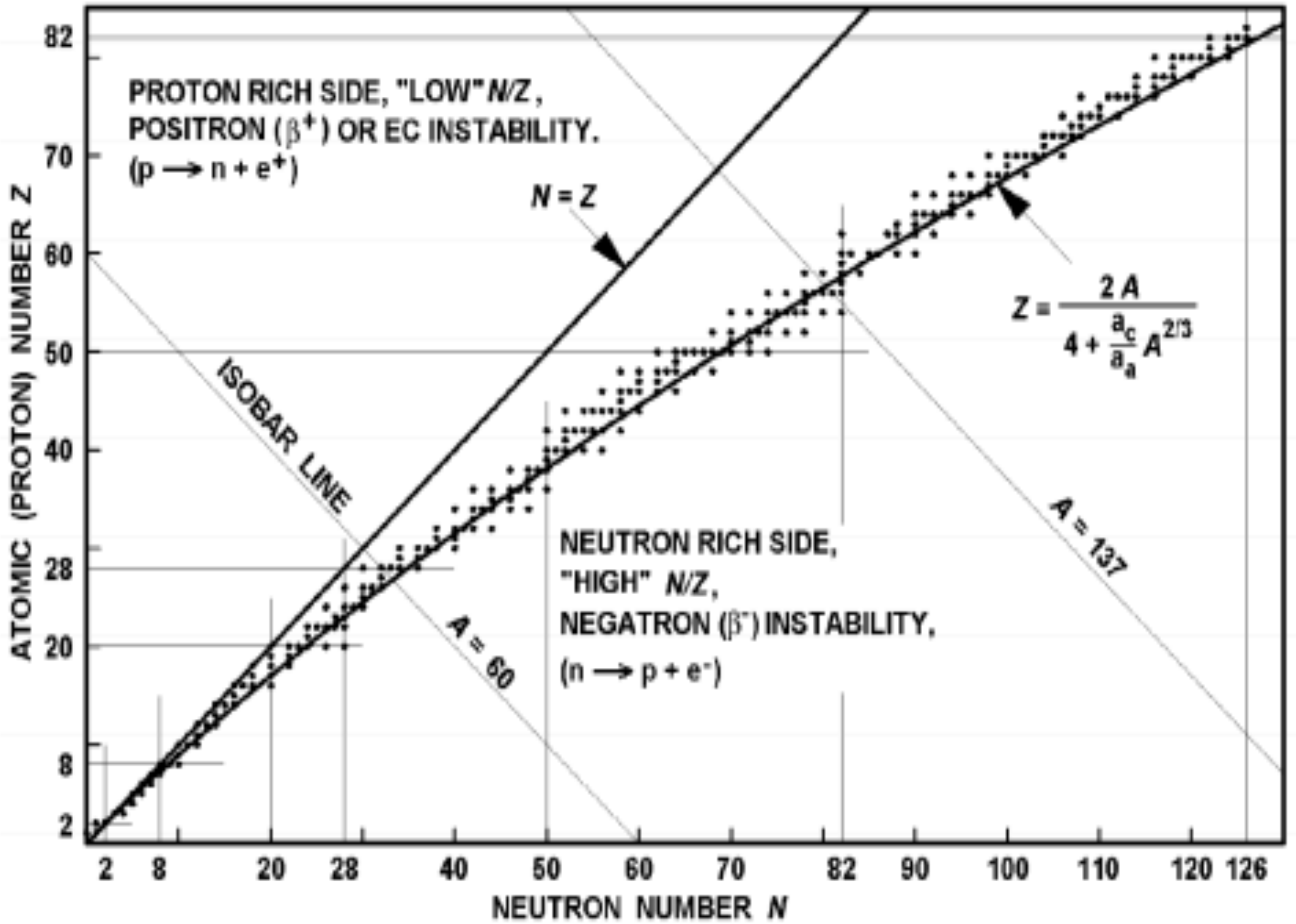


Examples of stable nuclides



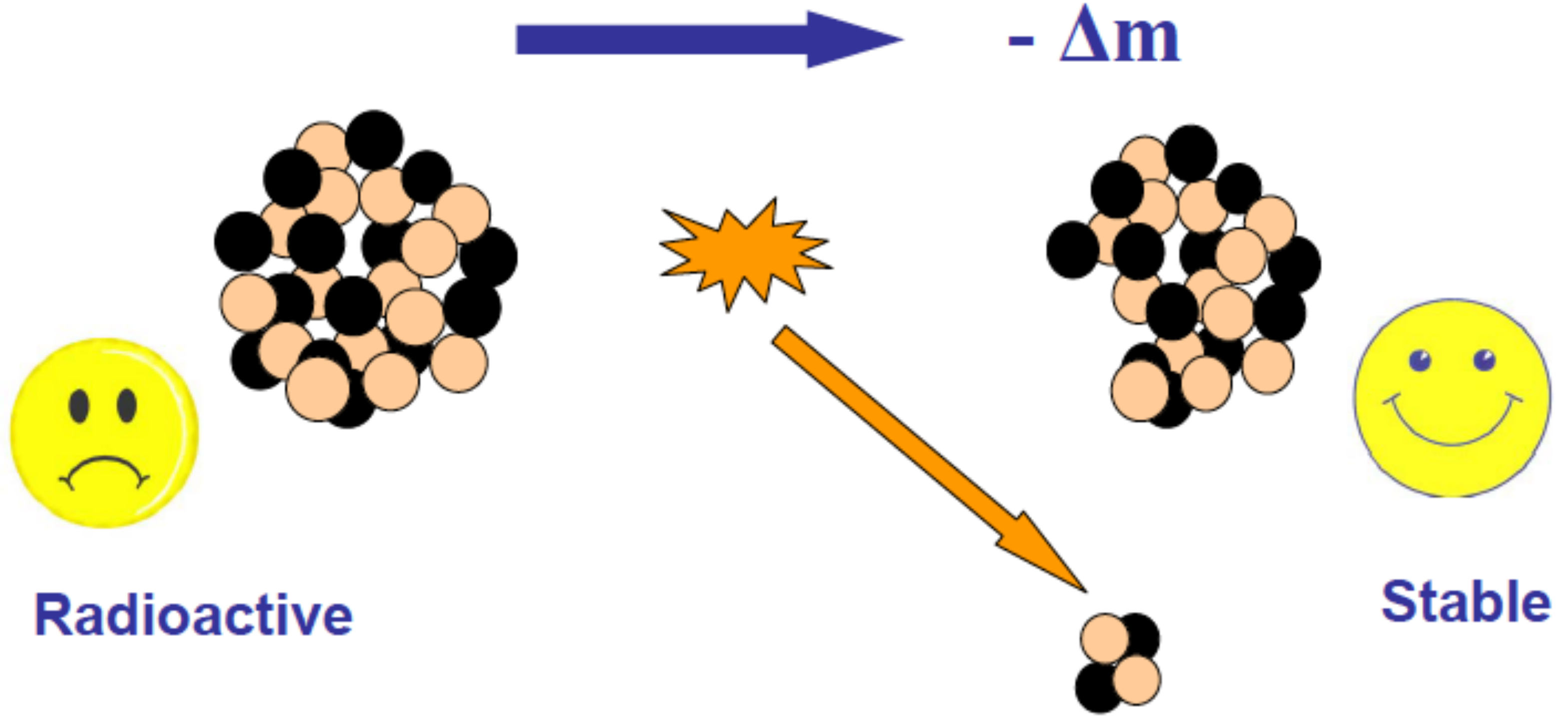
Stable nuclides are shown in black boxes


N
(Number of Neutrons)
126
82
50
28
14
6
6
14
28
50
82
Z
(Number of Protons)
Type of Decay
β+
β-
α
Fission
Proton
Neutron
Stable Nuclide
Unknown


PROTON RICH SIDE, "LOW" N/Z,
POSITRON (β+) OR EC INSTABILITY.
(p ⟶ n + e+)
N = Z
ISOBAR LINE
A = 60
A = 137
NEUTRON RICH SIDE,
"HIGH" N/Z,
NEGATRON (β-) INSTABILITY,
(n ⟶ p + e-)
Z = 2A / (4 + (a_c/a_a) A^{2/3})
ATOMIC (PROTON) NUMBER Z
NEUTRON NUMBER N
82
70
60
50
40
28
20
8
2
2
8
20
28
40
50
60
70
82
90
100
110
120
126

Radioactive decay

Nuclear Transformation



Ionizing Radiation: α, β, or γ

Alpha decay

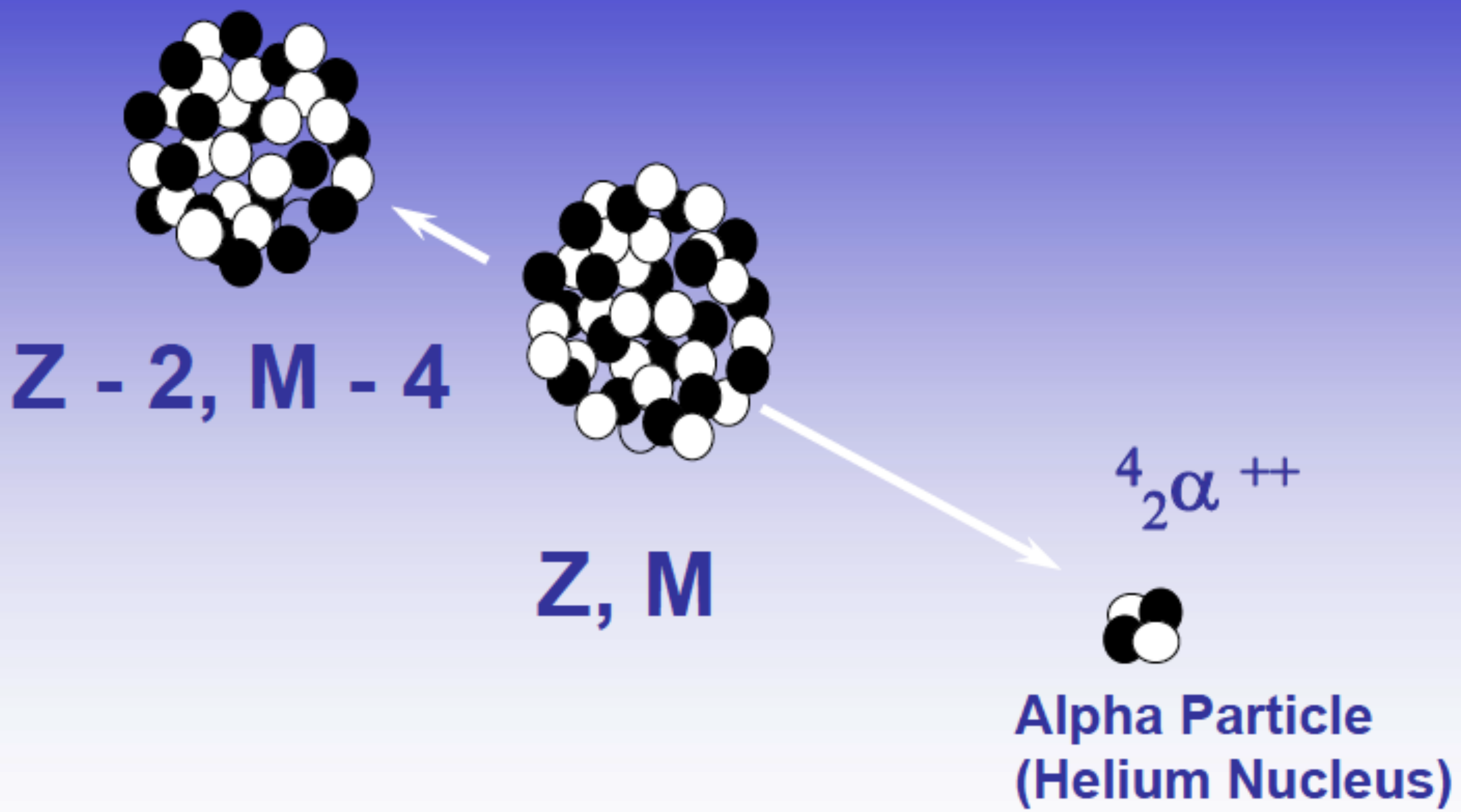
Emission of alpha particle alpha that is identical to the nucleus of Helium atom

$$\alpha \approx {}_{2}He^{4}$$

Charge	:	+ 2 elementer charge
Mass	:	4 amu

Contoh: ${}_{90}Th^{230} \rightarrow {}_{88}Ra^{226} + \alpha$

Alpha Particles



Beta decay

Emission of beta particle

$$\beta^{+} \approx {}_{+1}e^{0}$$

$$\beta^{-} \approx {}_{-1}e^{0}$$

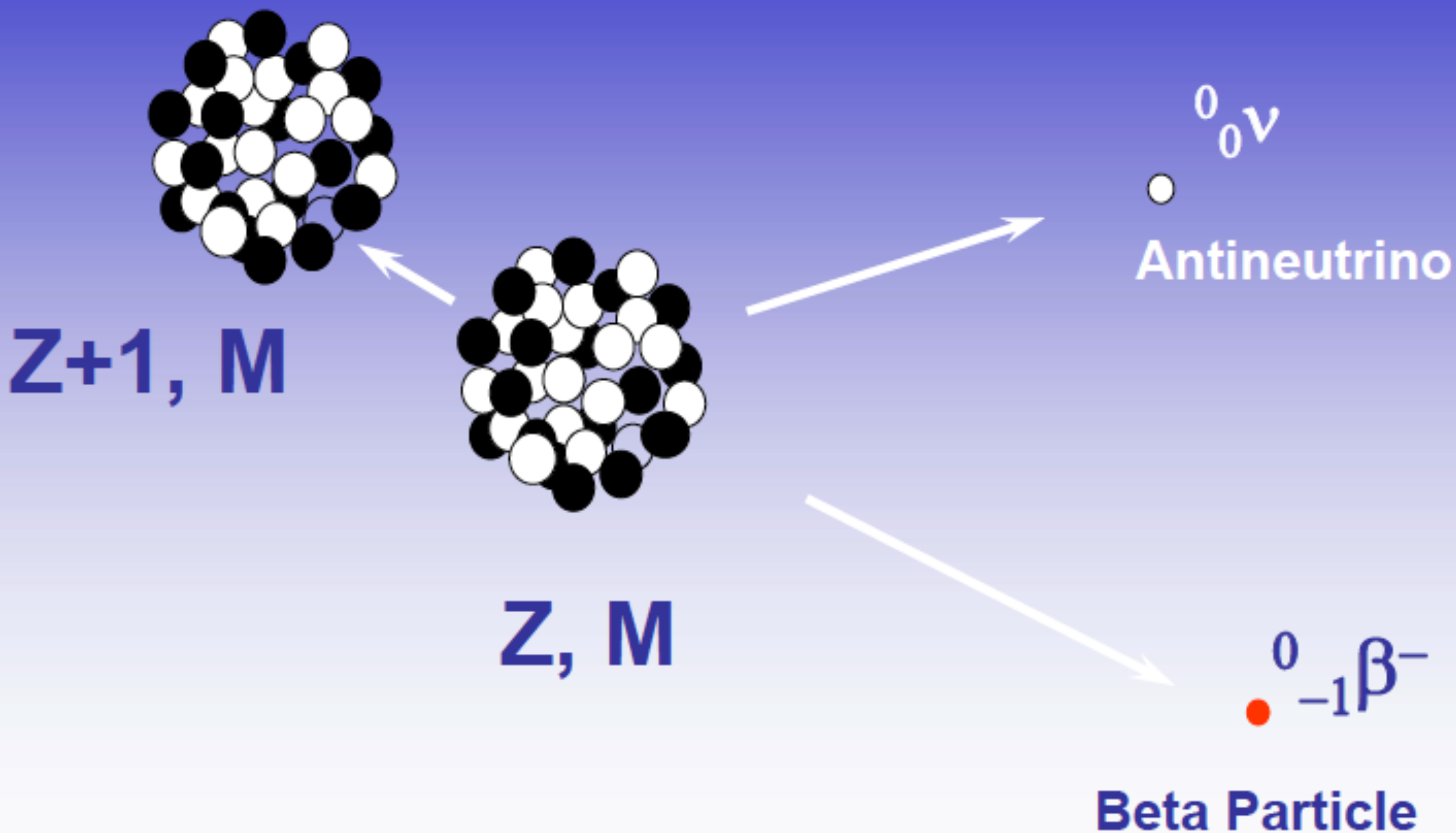
Charge : + or – 1 elementer charge

Mass : 0 amu

Contoh: ${}_{4}Be^{11} \rightarrow {}_{5}B^{11} + \beta^{-}$

${}_{6}C^{10} \rightarrow {}_{5}B^{10} + \beta^{+}$

Beta Particles



Gamma decay

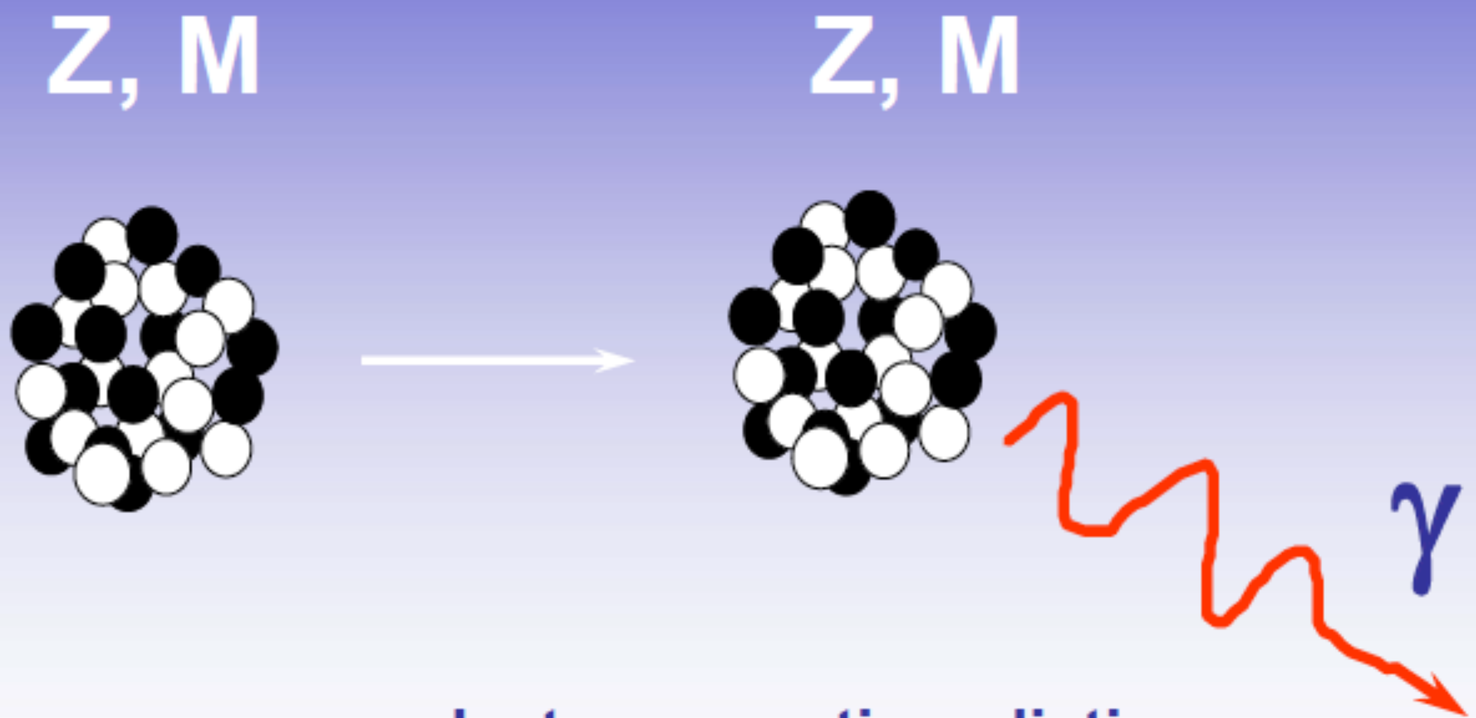
Emission of electromagnetic wave

Charge γ : 0

Mass γ : 0

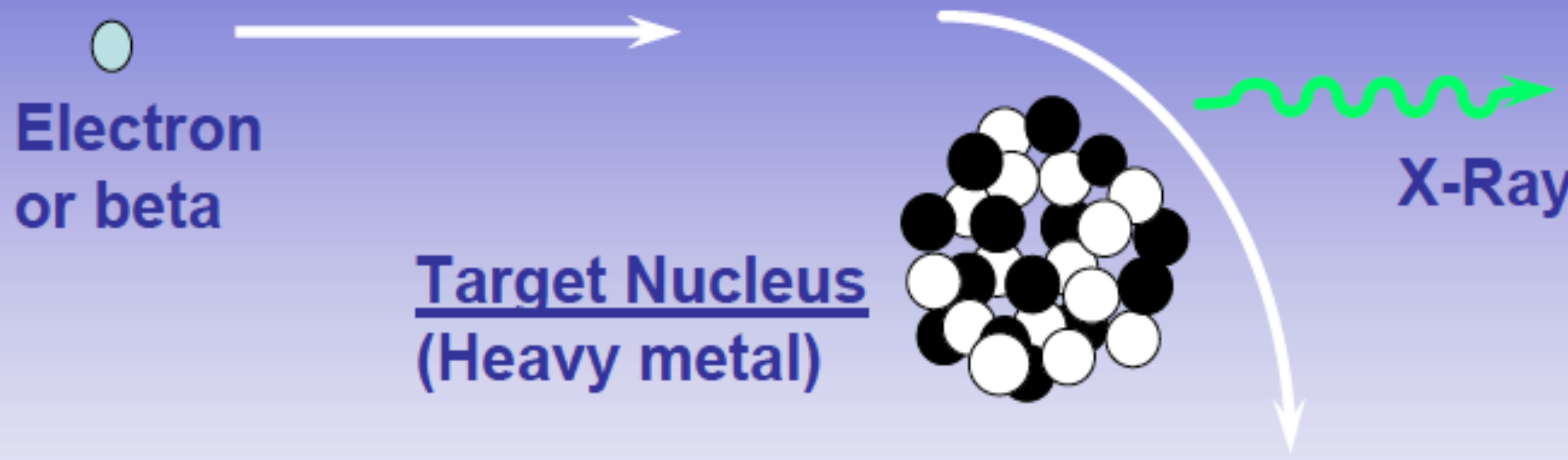
Example: $_{56}Ba^{137*} \rightarrow {}_{56}Ba^{137} + \gamma$

Gamma Rays



Gamma rays are electromagnetic radiation resulting from nuclear transformation.

Production of X-Rays



Example: Radioactive Decay

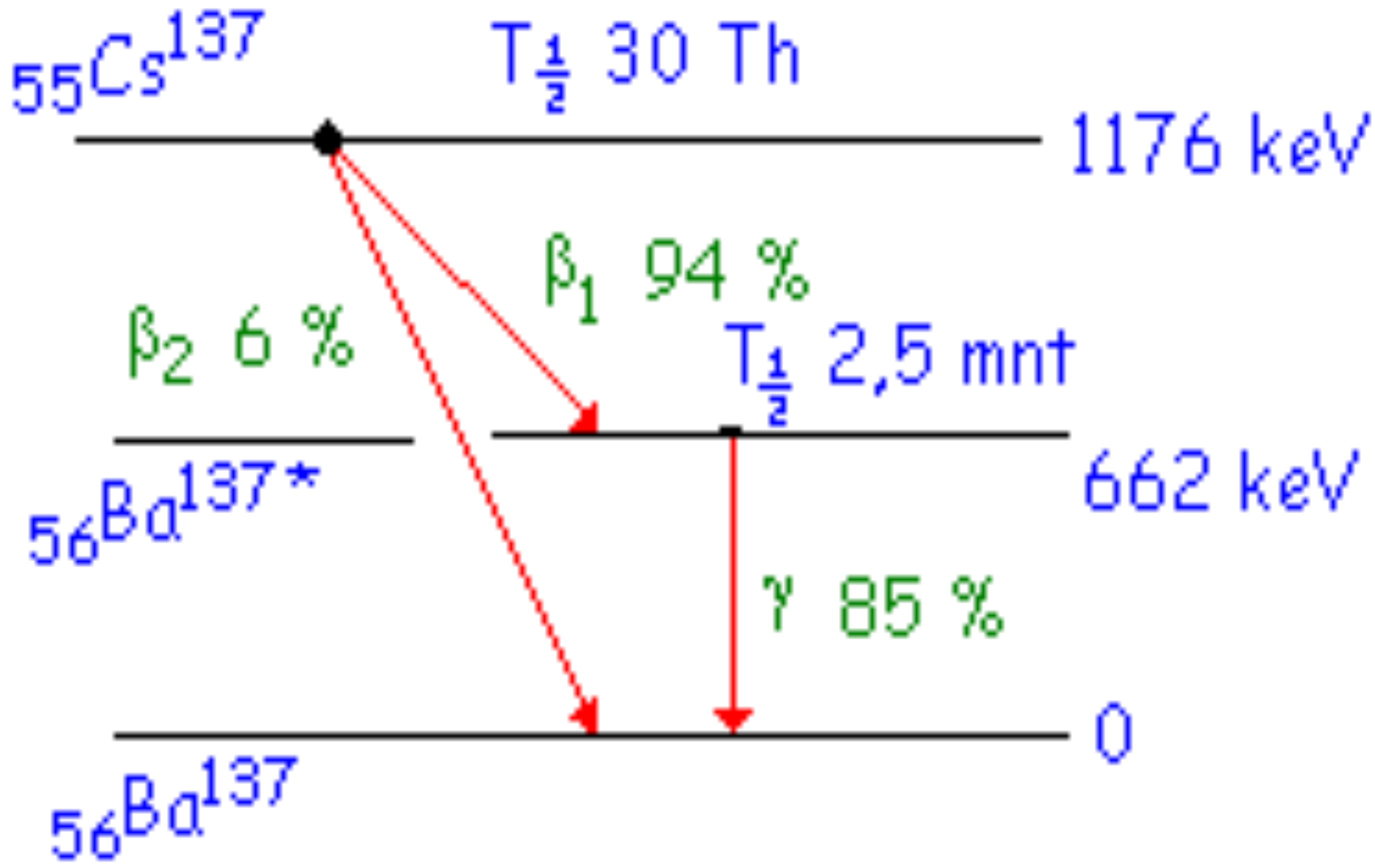
$${}_{90}Th^{230} \rightarrow {}_{88}Ra^{226} + \alpha$$

$${}_{4}Be^{11} \rightarrow {}_{5}B^{11} + \beta^{-}$$

$${}_{6}C^{10} \rightarrow {}_{5}B^{10} + \beta^{+}$$

$${}_{56}Ba^{137*} \rightarrow {}_{56}Ba^{137} + \gamma$$

Decay scheme



What Activity of Radiation ?

Number of disintegration per time unit

Determine the number of radionuclide which is not stable change to become stable nuclide in one second

$$A = A_0 \, e^{-\lambda \cdot t}$$

Unit:

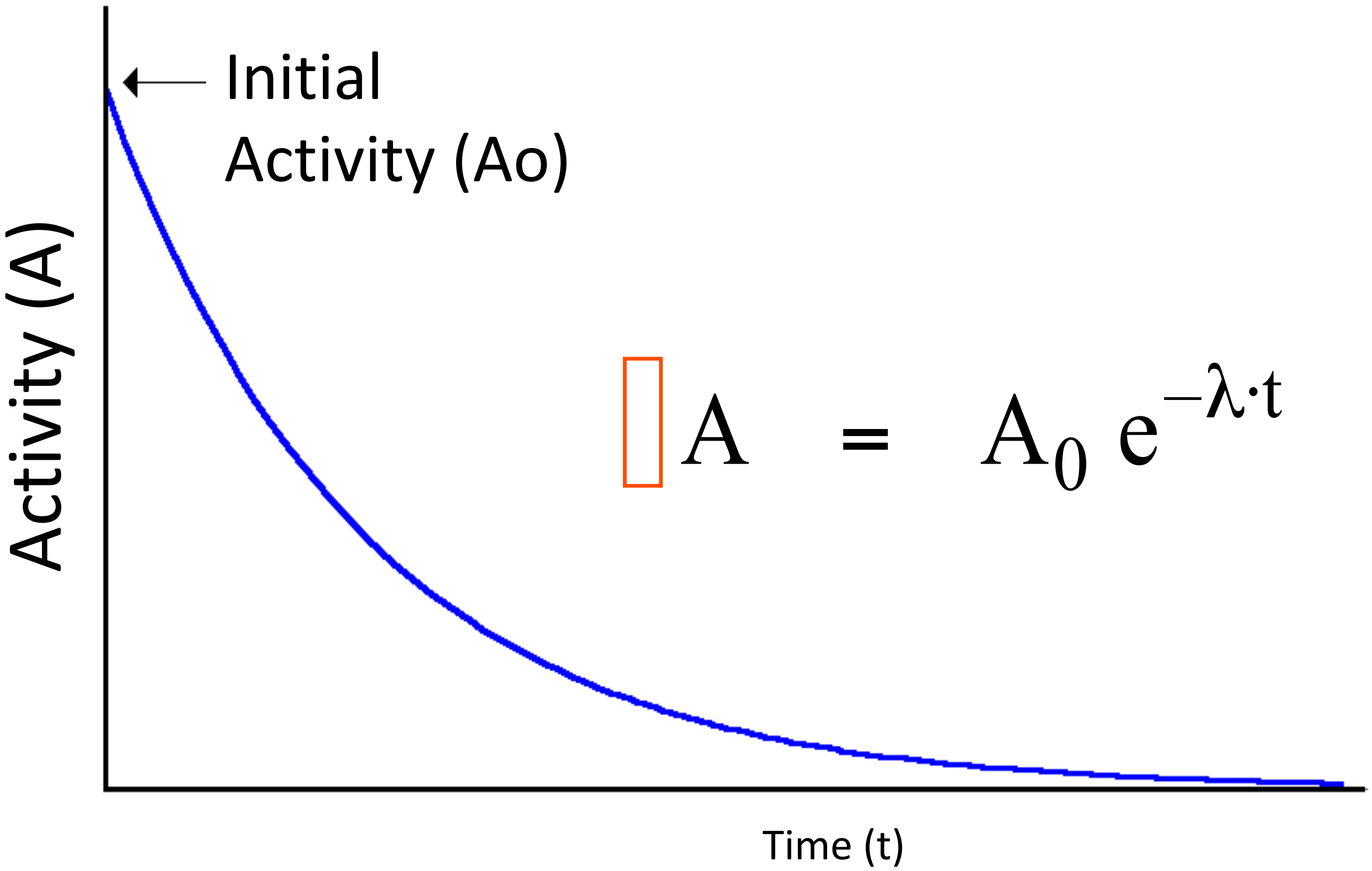
- **Currie (Ci)** **old unit**
- **Bequerel (Bq)** **new unit (SI)**

1 Ci = 3,7 10^{10} Bq or

1 μCi = 3,7 10^4 Bq = 37.000 Bq

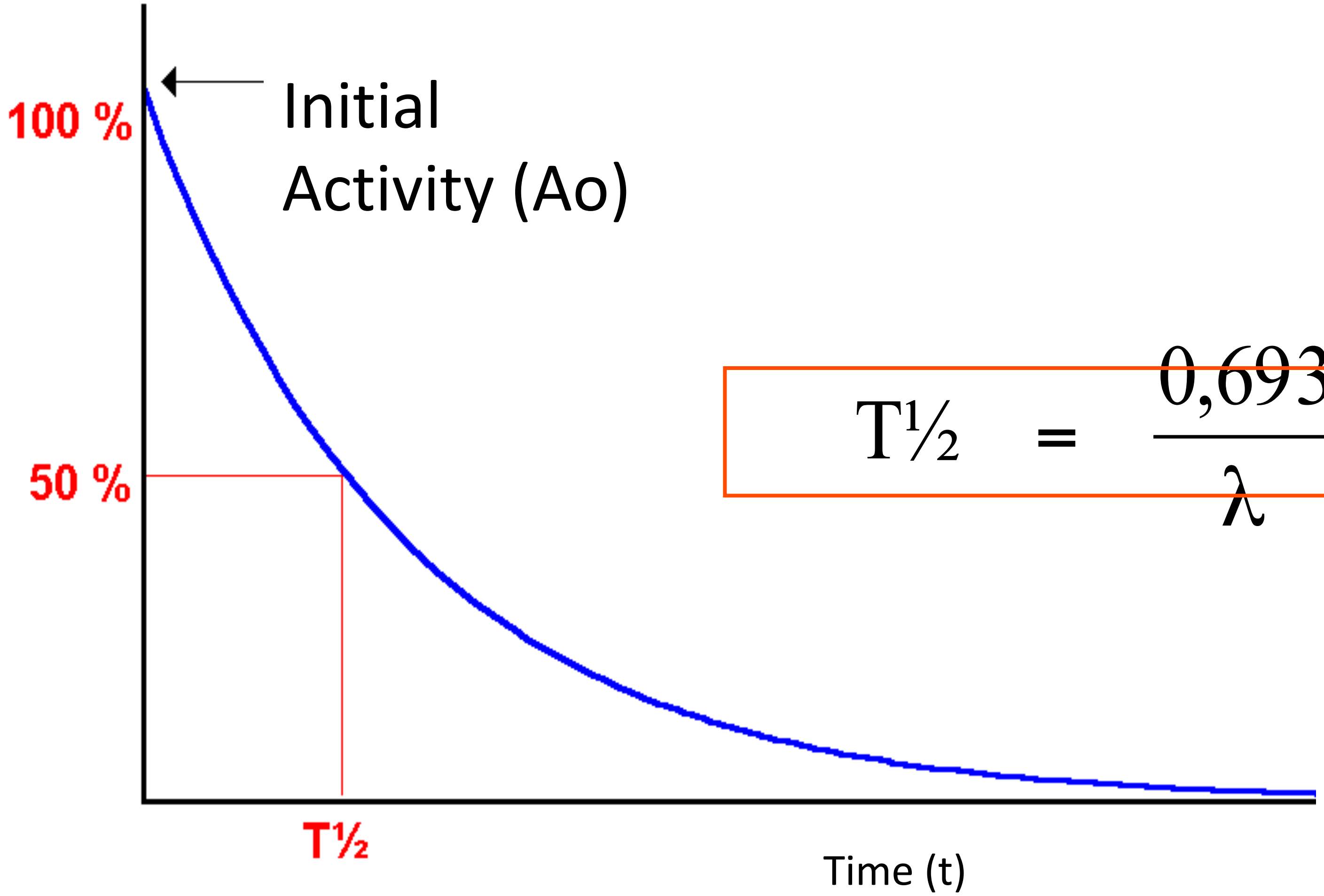
1 Bq = 1 disintegration per second

Activity of Radiation



$$A = A_0 e^{-\lambda \cdot t}$$

Half-life



$$T_{1/2} = \frac{0{,}693}{\lambda}$$

Utilization of $T_{½}$

Time	Activity
0	Ao
1 x T½	0,5 x Ao
2 x T½	0,25 x Ao
3 x T½	0,125 x Ao
4 x T½	0,0625 x Ao
5 x T½	0,03125 x Ao
6 x T½	0,0156 x Ao

$$A = \left(\tfrac{1}{2}\right)^n \cdot A_0$$

$n = \text{time} : T_{1/2}$

Charged Particles Interactions

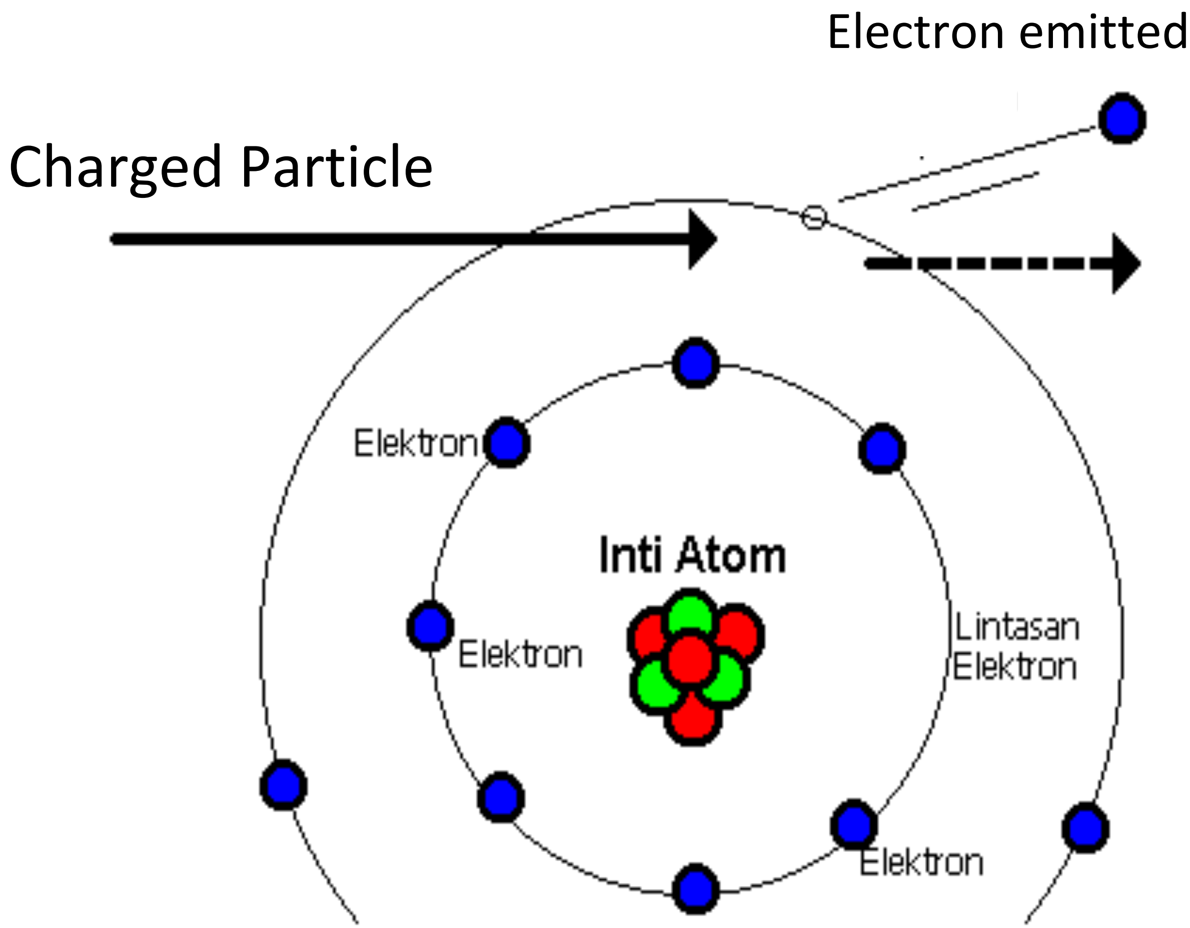
Alpha

1. Ionization
2. Excitation
3. Nuclear reaction

Beta

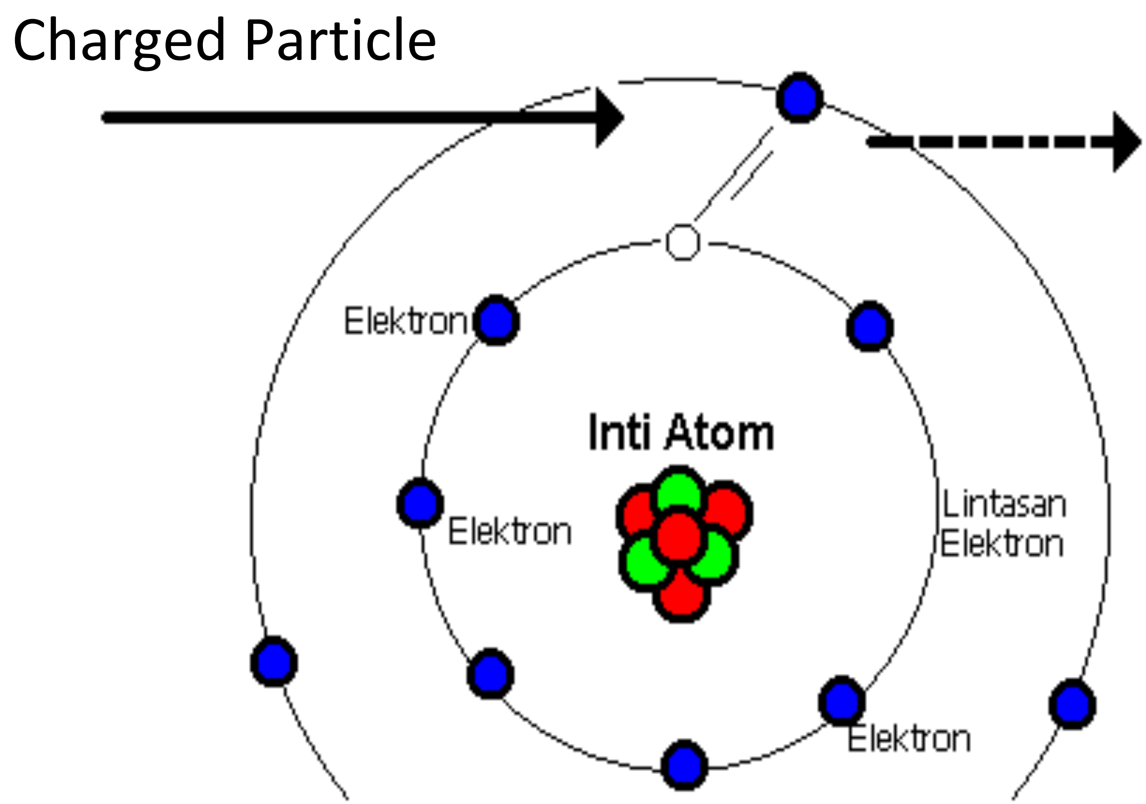
1. Ionization
2. Excitation
3. Brehmsstrahlung

Ionization



Electron emitted
Charged Particle
Elektron
Inti Atom
Elektron
Lintasan
Elektron
Elektron

Excitation



Charged Particle
Elektron
Inti Atom
Elektron
Lintasan Elektron
Elektron

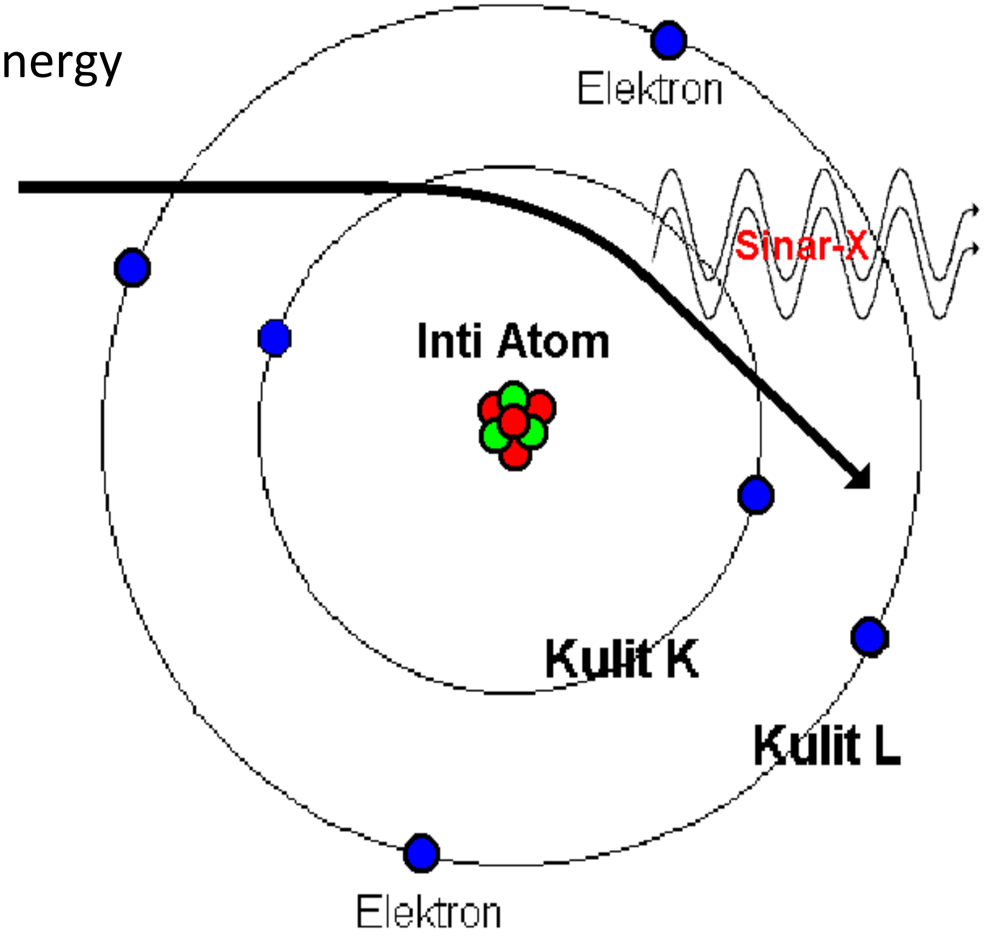
Nuclear reaction

$${}_{4}Be^{9} + \alpha \rightarrow {}_{6}C^{12} + n$$

Brehmsstrahlung

$$F = 3{,}5 \times 10^{-4} \,.\, Z \,.\, E_{max}$$

High energy Beta

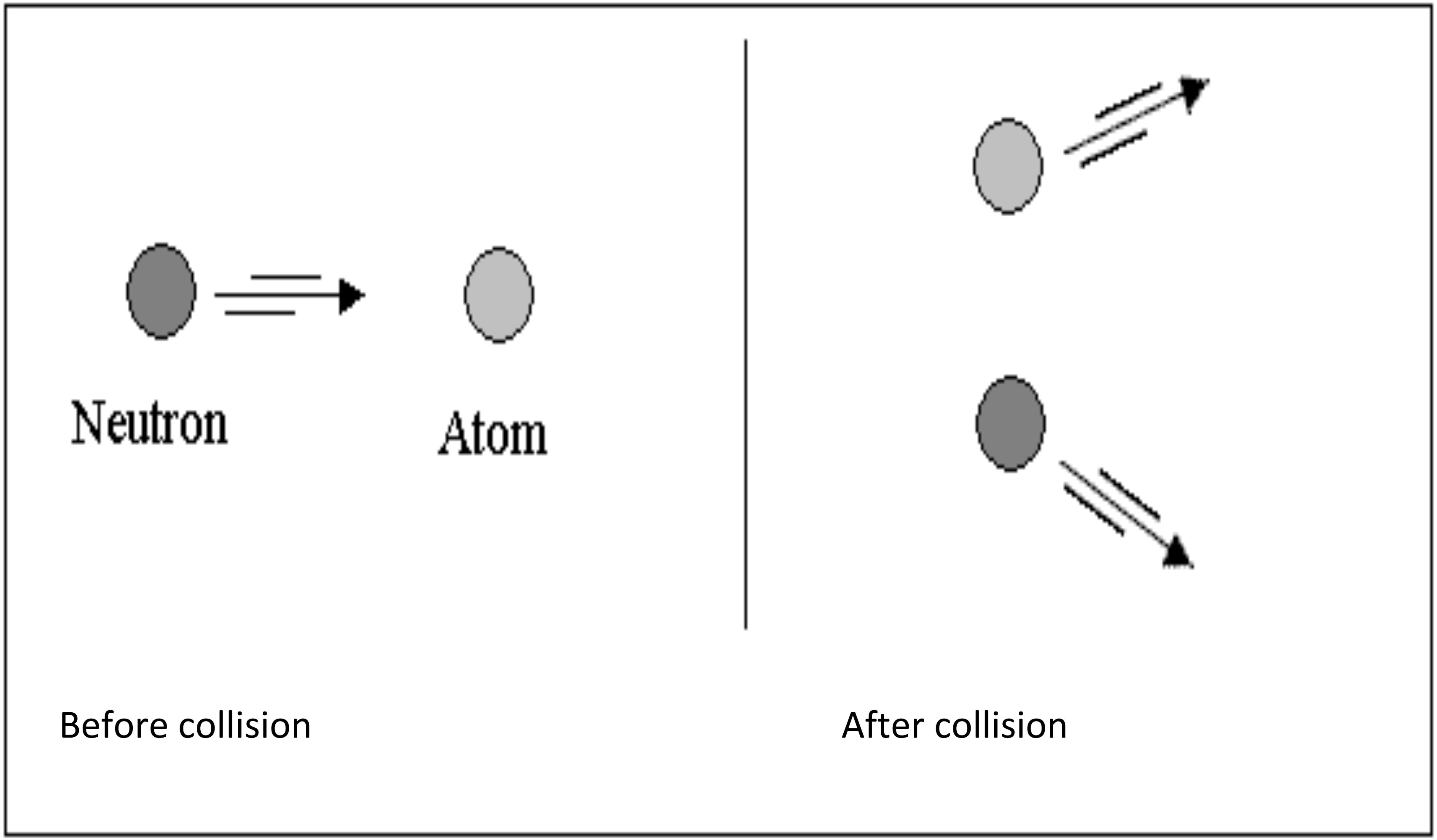


X-ray

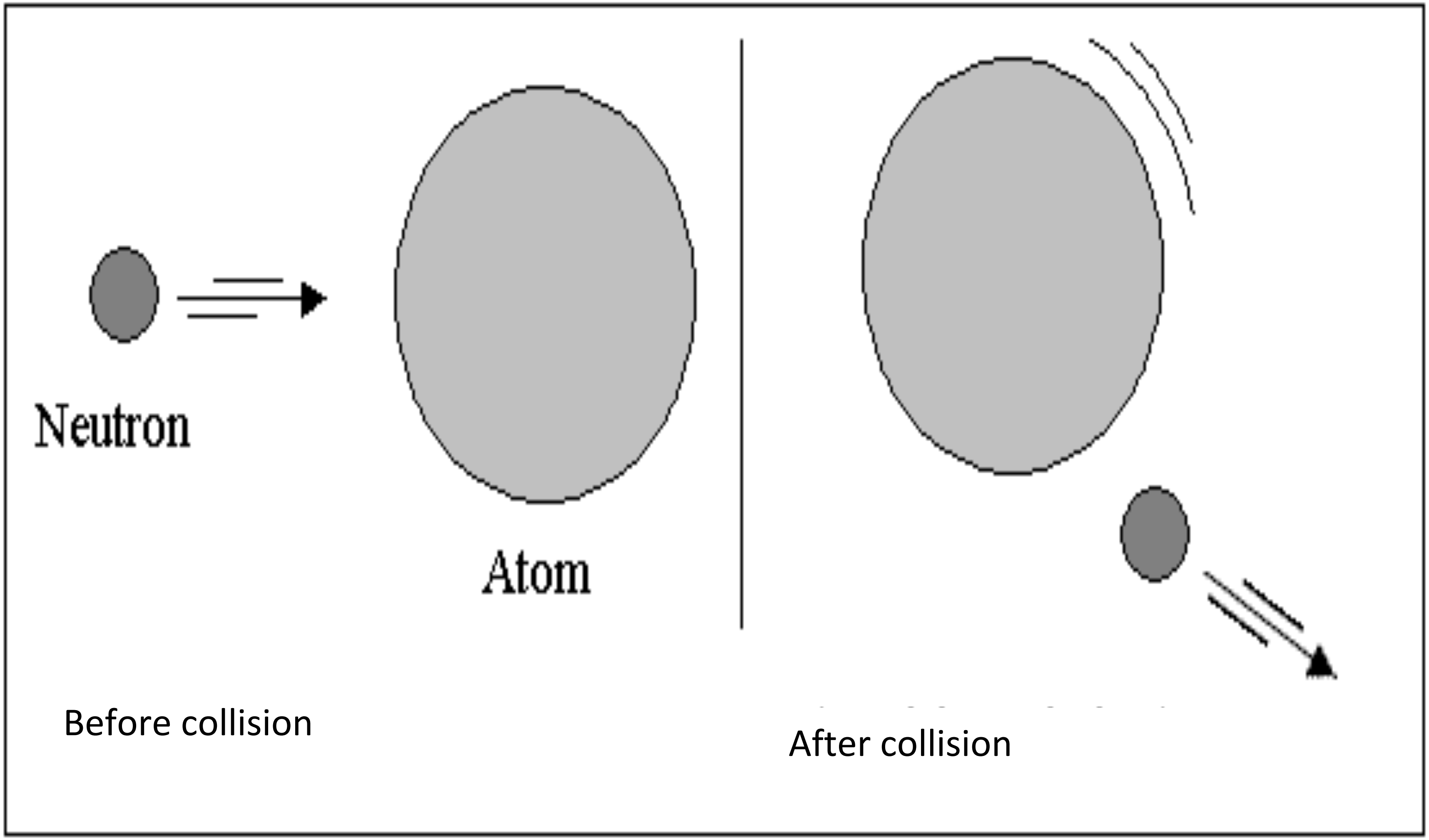
Neutral particle

- Elastic collision
- Inelastic collision
- Nuclear reaction
- Fission

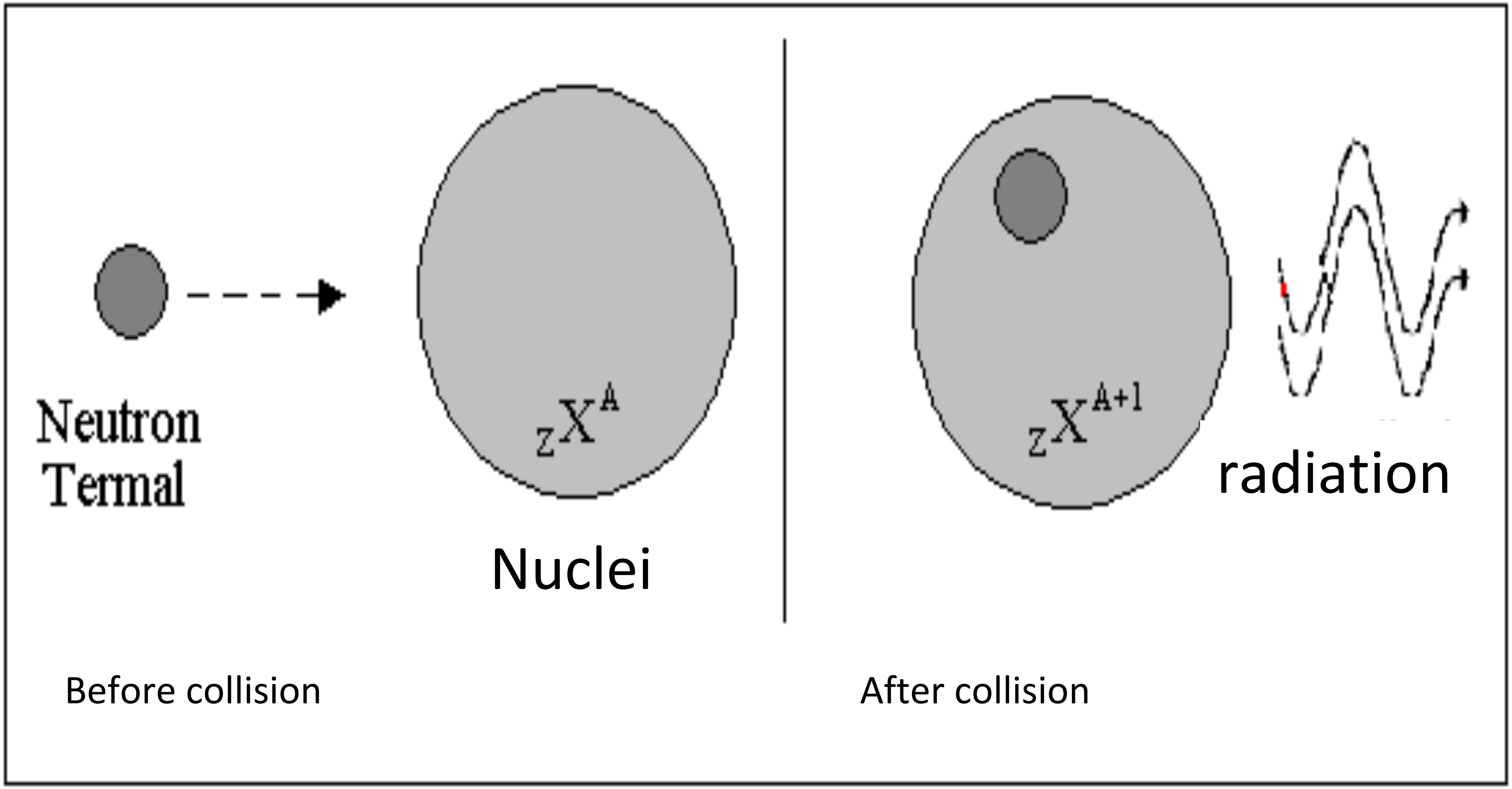
Elastic collision



Inelastic Collision



Nuclear Reaction



Fission

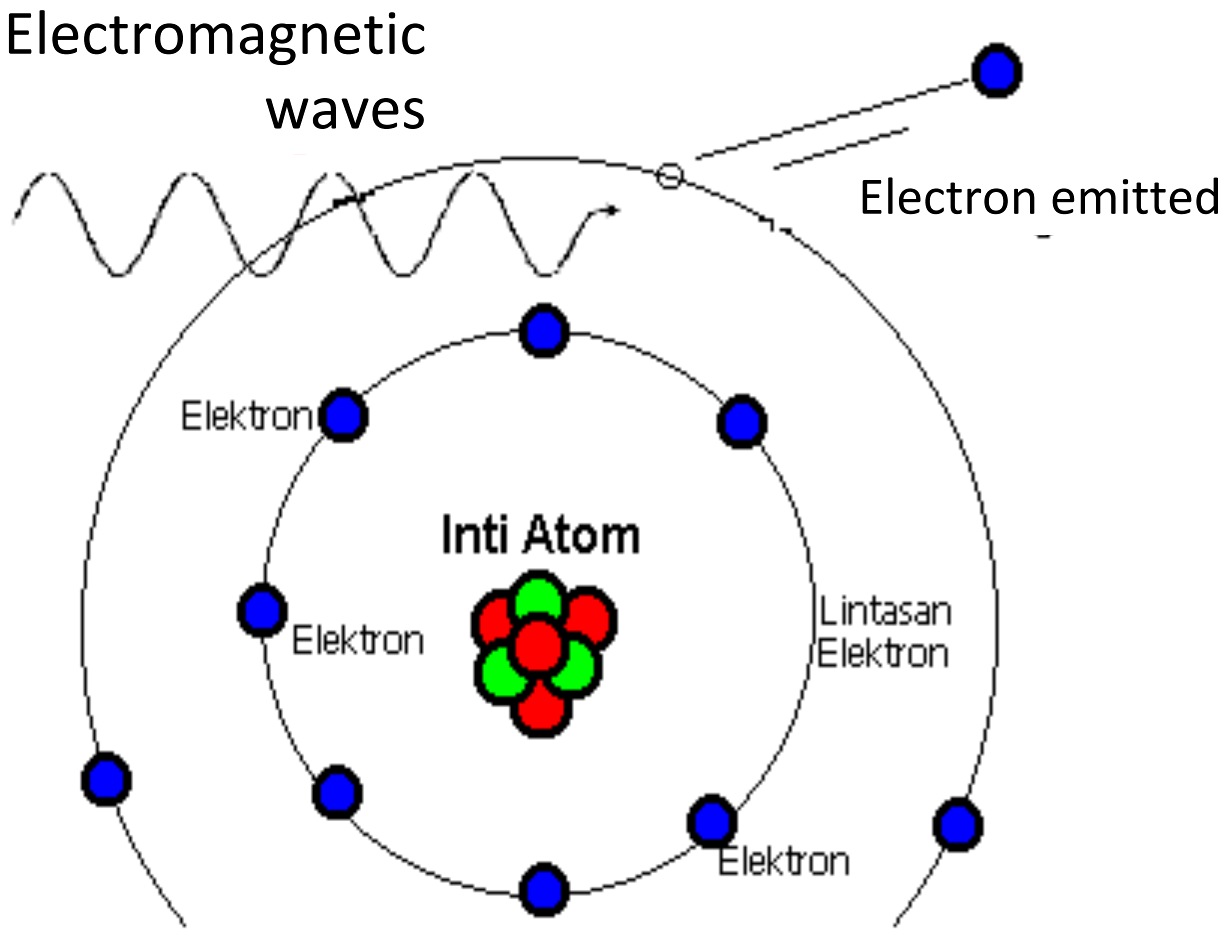
$$U^{235} + n_t \rightarrow Y_1 + Y_2 + (2\text{-}3)n + Q$$

$$_{92}U^{235} + n_t \rightarrow {}_{54}Xe^{140} + {}_{38}Sr^{94} + 2{}_0n^1 + Q$$

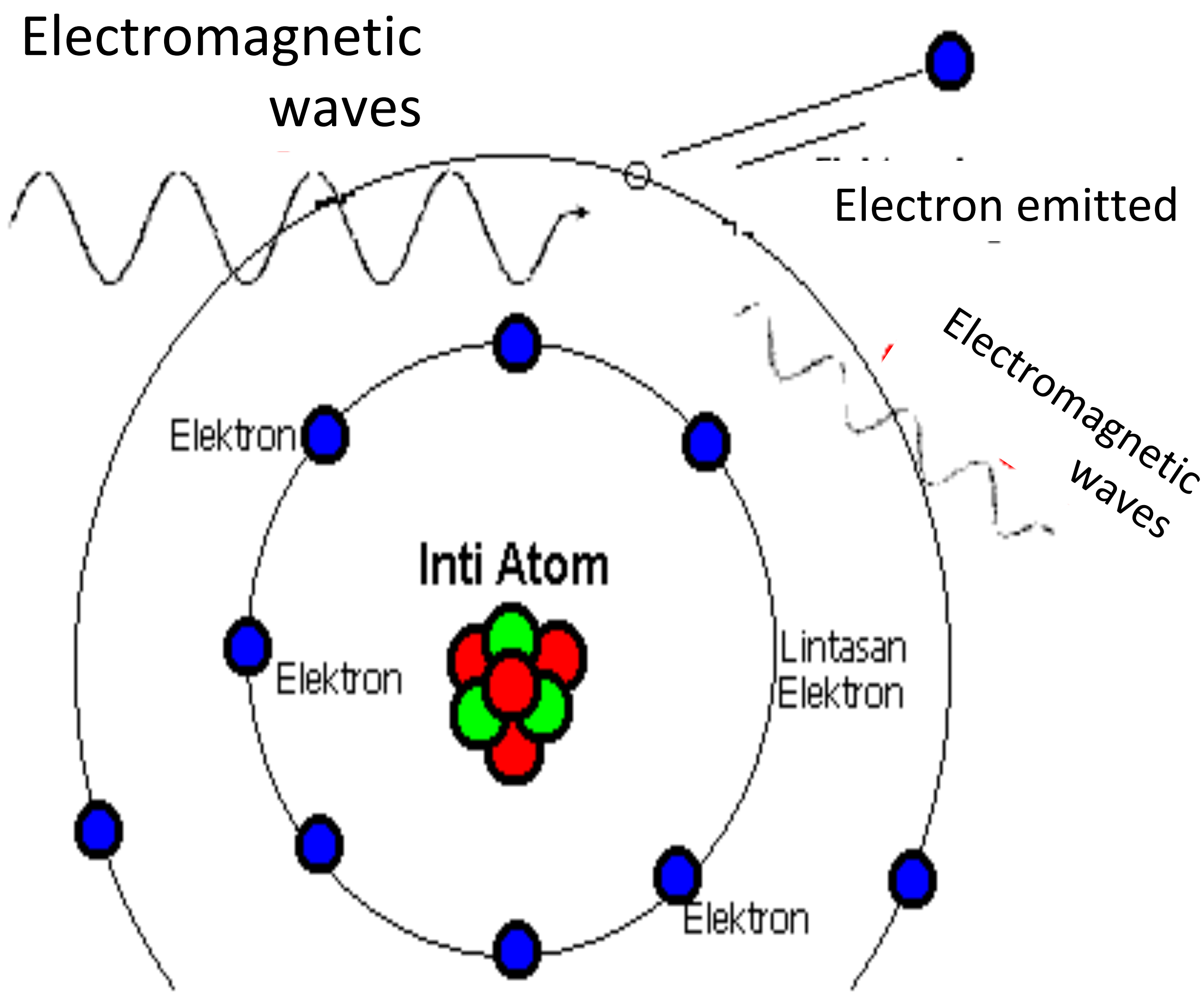
Electromagnetic waves

- Photoelectric
- Compton
- Pair Production

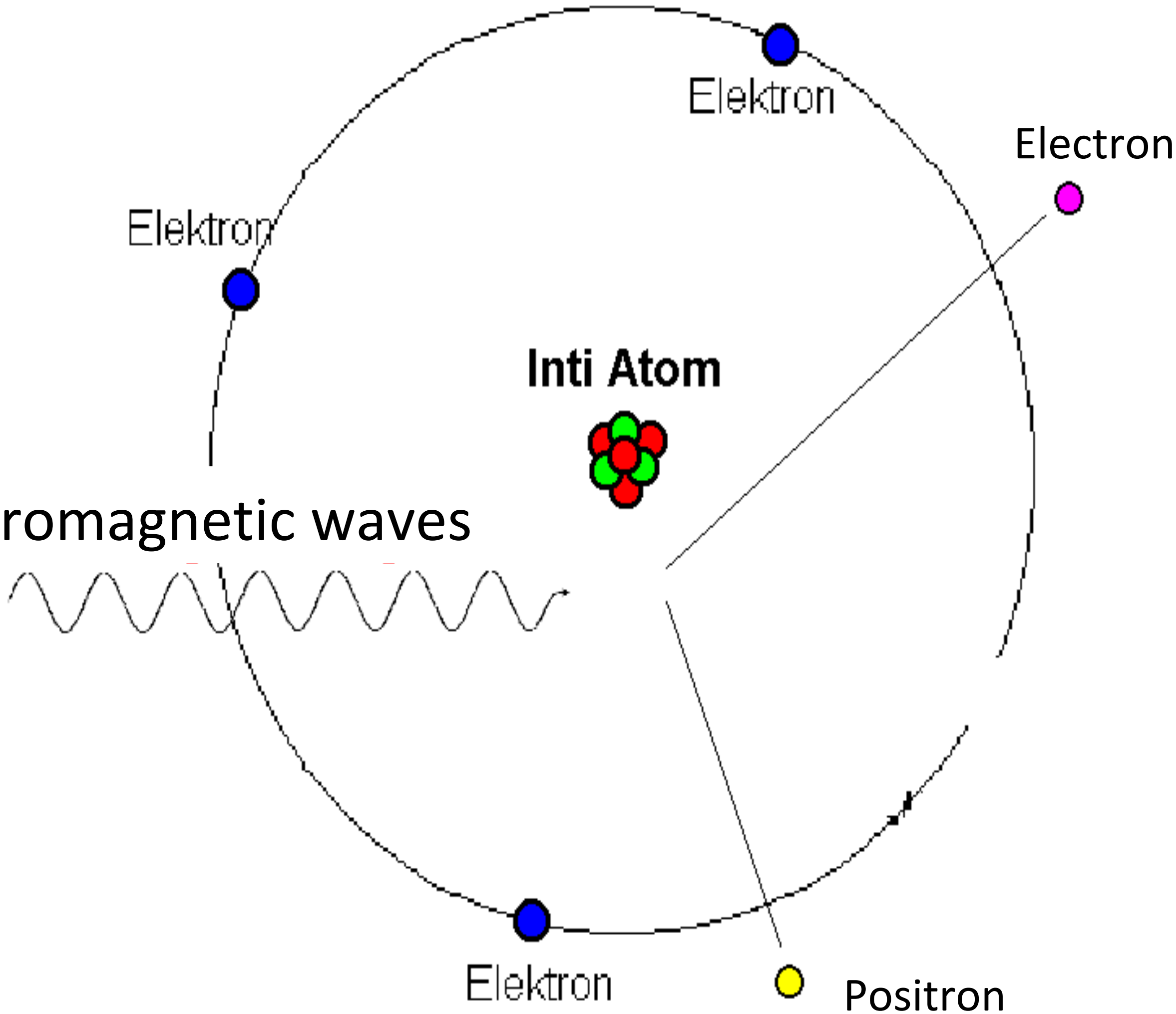
Photoelectric



Compton effect



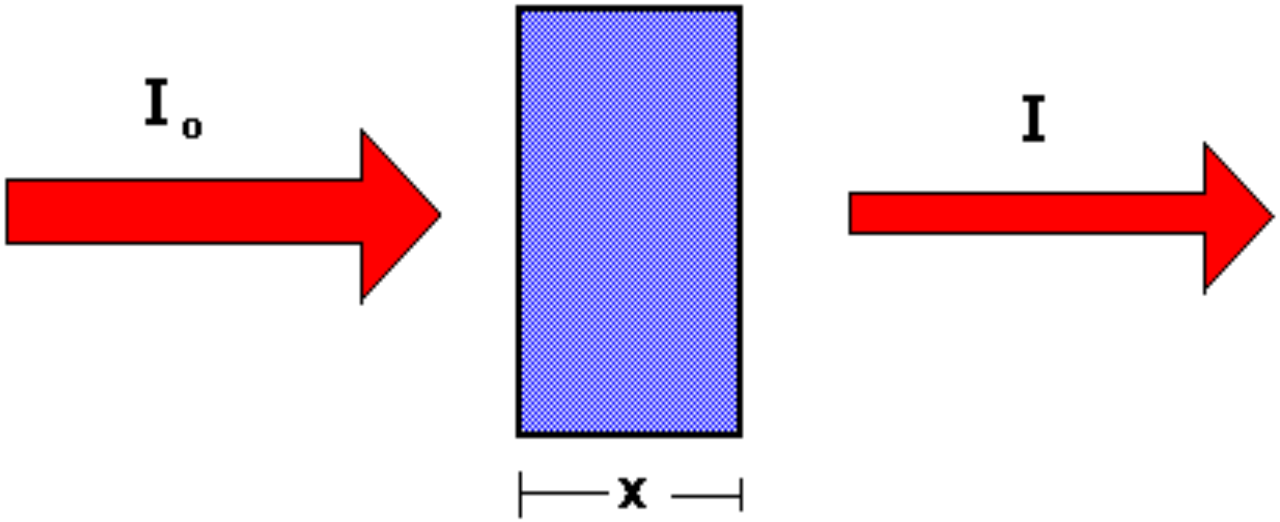
Pair production



Characteristics of radiation

Types	Ionization	Penetration
Alpha	High	Low
Beta	Medium	Medium
Gamma	Low	Very High
X-ray	Low	High

Absorption of Gamma / X-ray



$$I = I_0 e^{-\mu \cdot x}$$

Narrow beam

$$I = B.I_0 e^{-\mu \cdot x}$$

Broad beam

Radiation Sources

Radiation Sources

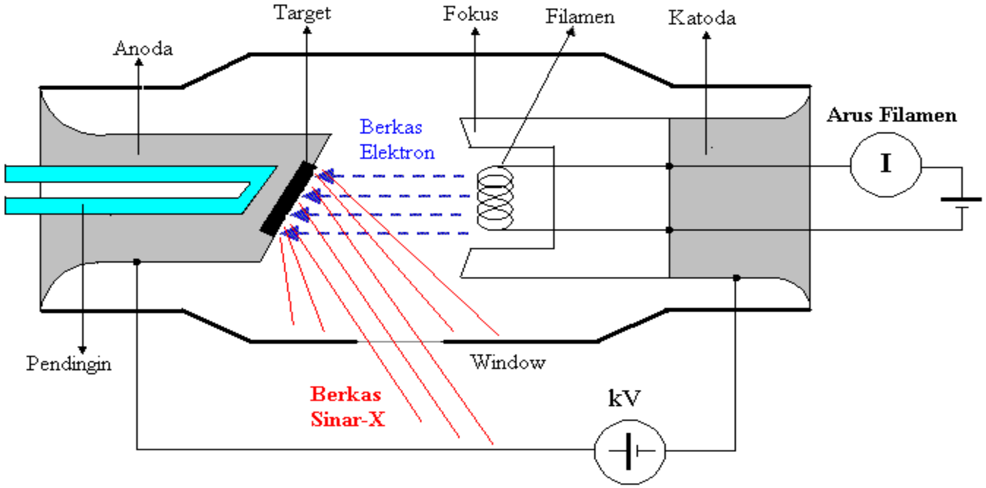
Nature:

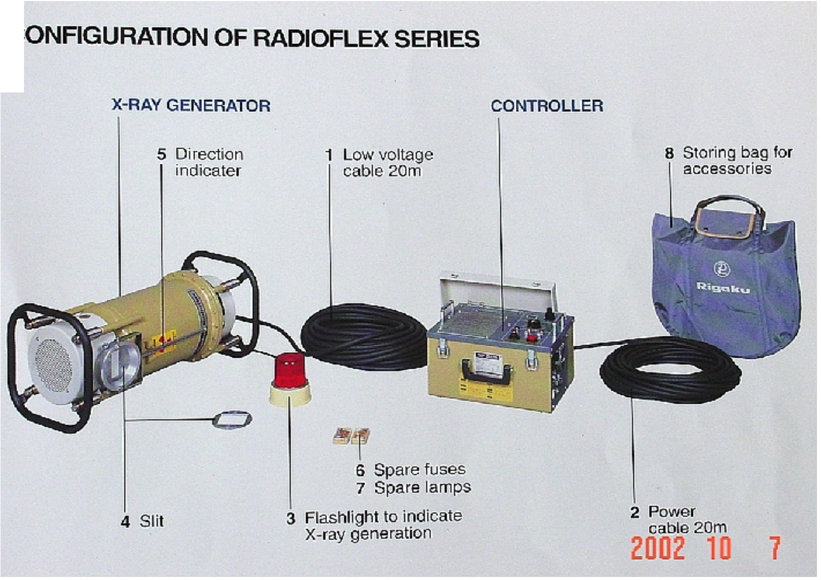
- Cosmic (high energy radiation from cosmic (10^{17}eV), produced: C-14, Be-7, Na-22 and H-3.)
- Terrestrial (primordial radiation (T1/2 = 10^{9} years; Ra-222 (Radon), Ra-220 (Thoron), K-40.)
- Internal (inside the body: K-40,C-14, H-3.)

Artificial:

- Radioactive material (for industry, medical etc: Co-60, Cs-137, I-131, Mo-99.)
- X-ray Machine (for industry and medical)
- Accelerator (to accelerate charge particles: LINAC, Cyclotron.)
- Reactor (for research and power plan)

X-ray Machine





Radioactive sources

Source

Connector

Radioisotope Sources

Type	Energy (MeV)	Half live
Co-60	1,17	5,3 years
Tm-170	0,07	127 days
Se-75	0,4	118 days
Ir-192	0,31	74 days
Cs-137	0,66	30 years
Yb-169	0,17	30 days

Thank you.
Question?

Terima Kasih

BADAN TENAGA NUKLIR NASIONAL

Jl. Kuningan Barat, Mampang Prapatan Jakarta, 12710

(021) 525 1109 | Fax. (021) 525 1110

humas@batan.go.id

Humas Batan @humasbatan badan_tenaga_nuklir_nasional Humas Batan