Kingdom of Morocco
Ministry of Higher Education, Scientific Research and Innovation

THE EIGHTH BIENNIAL AFRICAN SCHOOL OF FUNDAMENTAL PHYSICS AND APPLICATIONS (ASP2024)

Co-organized by Cadi Ayyad University and Mohammed V University at Faculty of Science Semlalia, Marrakesh, Morocco

April 15th–19th and July 7th–21st, 2024

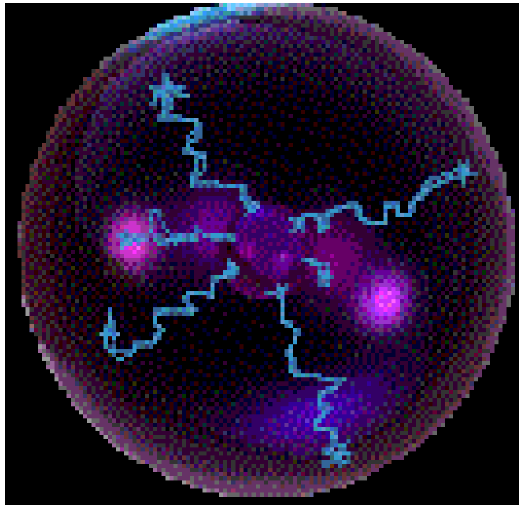
Physics of Ionizing radiation

Pr. R. SEBIHI

University of Mohamed V faculty of Sciences , Rabat

1. Objectives

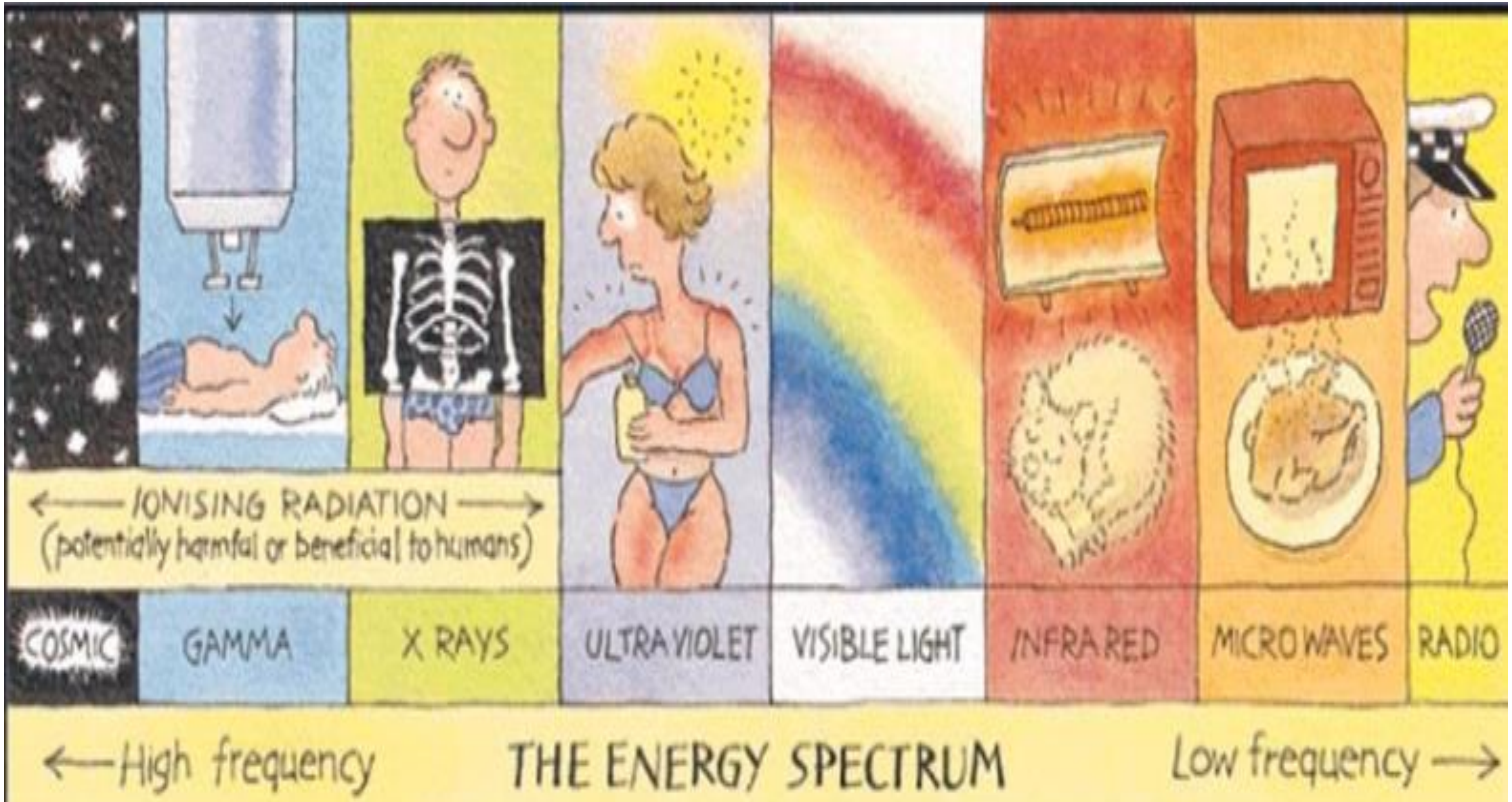
- **To define the types of radiation, their characteristics**
- **To Describe the differences between ionizing and non ionizing radiation**
- **To introduce the world of radioactivity.**
- **The interaction of ionizing radiation with matter**



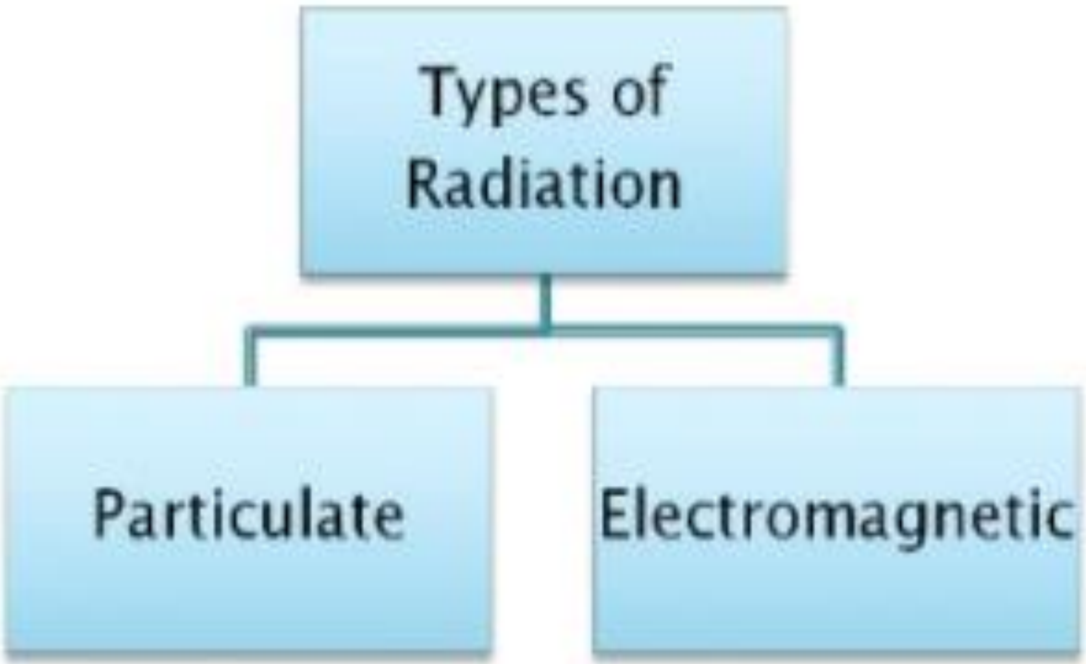
Introduction to physics of Radiation

What is Radiation?

- **The term radiation applies the emission and propagation of energy through space or material.**



What is the classification of radiations?



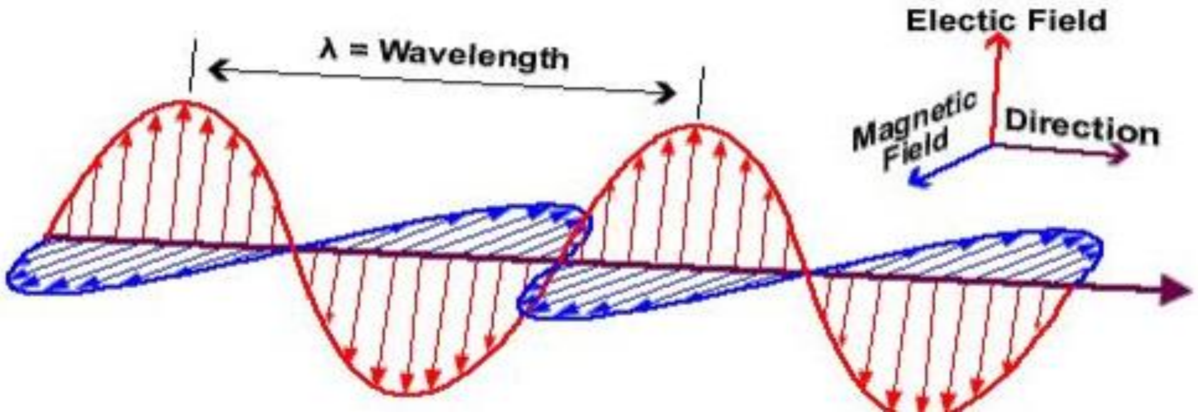
Electromagnetic radiation

- **Photons radiation**

- **Invisible**

- **No mass**, **electricaly neutral**, no physical form

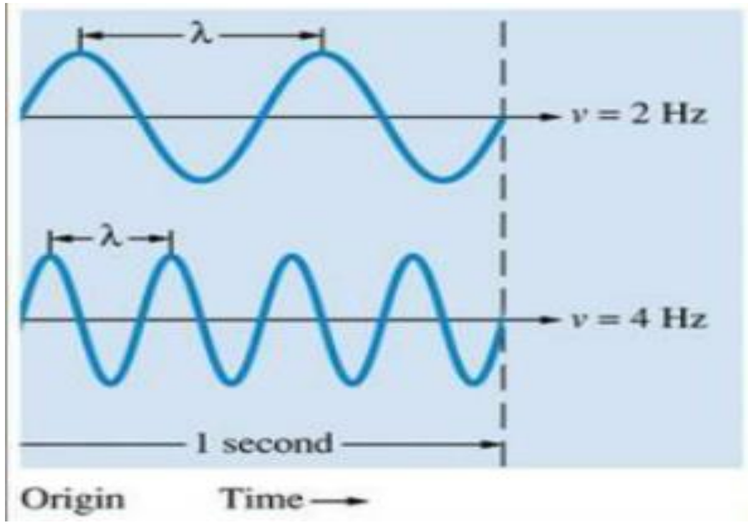
- An electromagnetic wave consists of an electric and magnetic field which vibrates thus making waves and propagating in space



Characteristics of Electromagnetic radiation

- All waves can be described by several characteristics:

- **The wavelength λ** is the shortest distance between equivalent point on a continuous wave
- **The frequency v** is the number of waves that pass a given point per second
- **The amplitude** Amplitude is a measure of the distance between a line through the middle of a wave and a crest



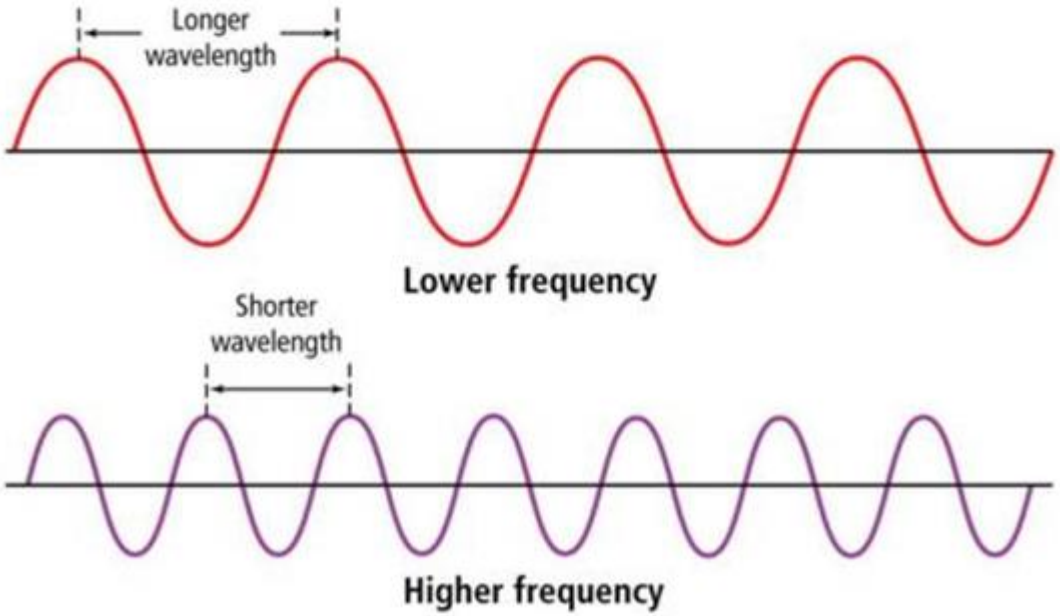
Characteristics of Electromagnetic radiation

- All electromagnetic waves travel at the speed of light :

$C = 3 .10^8$ m/s in a vacuum

- The speed of light is the product of its wavelength and frequency

$$c = \lambda \nu$$



Energy of electromagnetic radiation (photon)

- Electromagnetic radiation energy is given as:

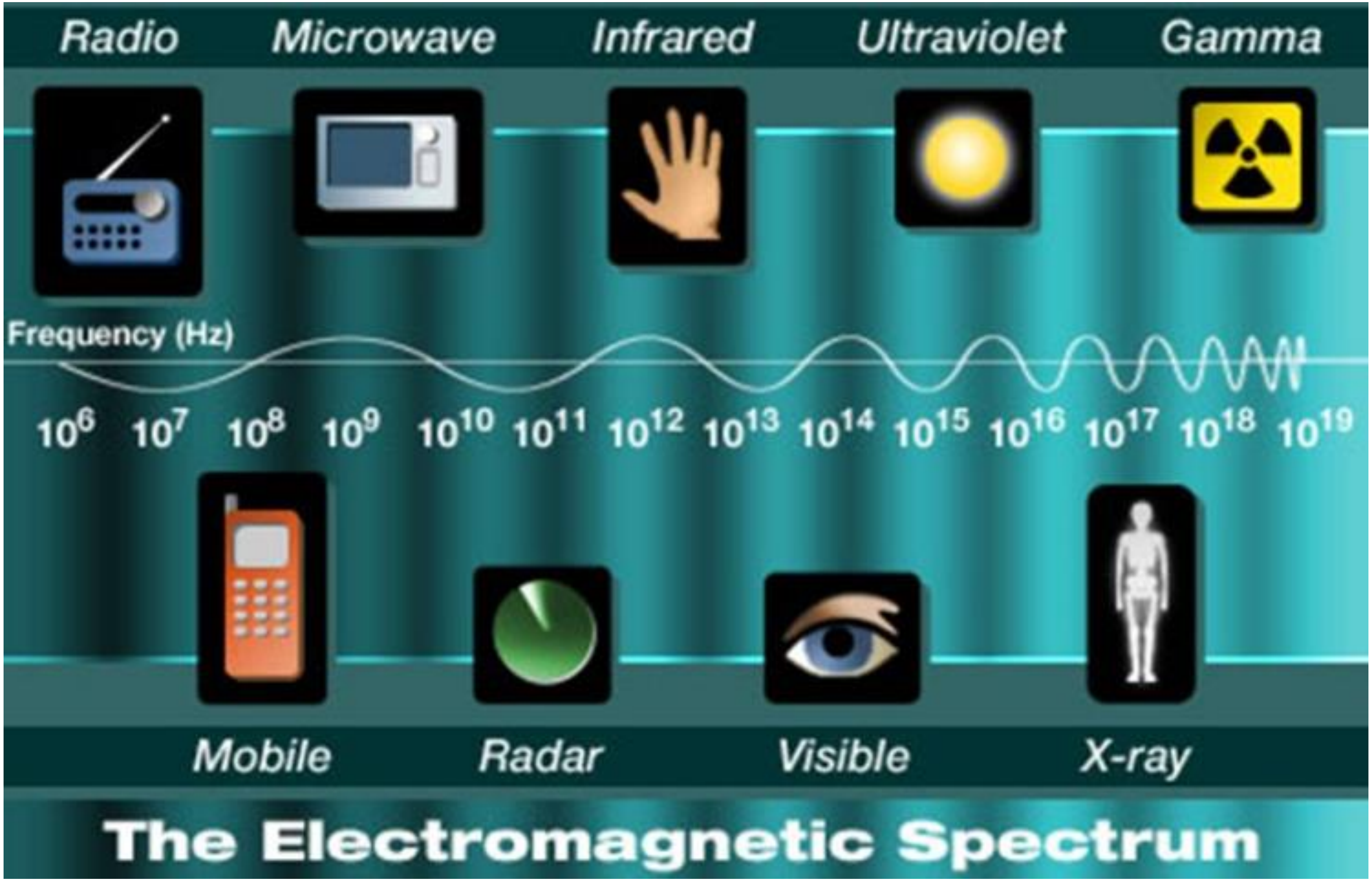
$$\underline{E = hv}$$

$v = C/\lambda$ → $\underline{E = h\,C/\lambda}$

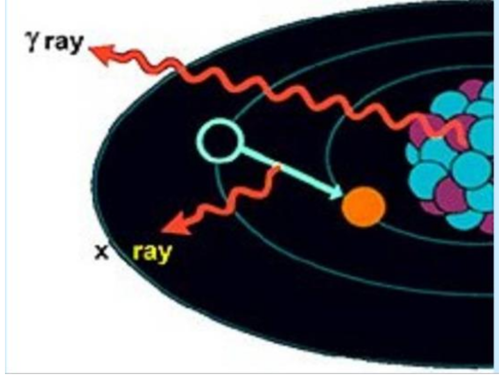
h is the Plank's constant , $h = 6{,}62607004 \times 10^{-34}\ m^2\ kg\ /\ s$

Highest frequency and energy/ shortest wavelength

- High energy photons = short waves
- Lower energy photons = longer waves

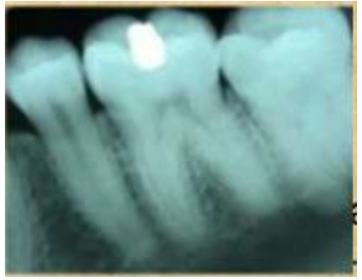

Radio
Microwave
Infrared
Ultraviolet
Gamma
Frequency (Hz)
10^6 10^7 10^8 10^9 10^10 10^11 10^12 10^13 10^14 10^15 10^16 10^17 10^18 10^19
Mobile
Radar
Visible
X-ray
The Electromagnetic Spectrum

Gamma rays



- Gamma rays have **the highest energy,** shortest wavelengths and highest frequencies in the EM spectrum
- It is generated by: changes in energy levels in the nucleus
- Because of their great penetrating ability , gamma rays can cause serious illness.
- However when used in controlled conditions, gamma rays are useful in cancer treatment and diagnosis

X rays

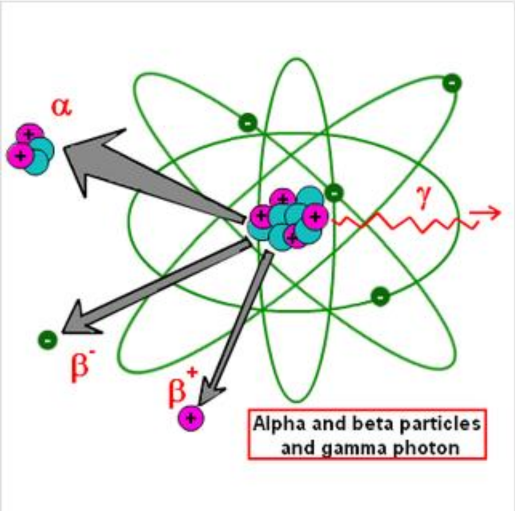


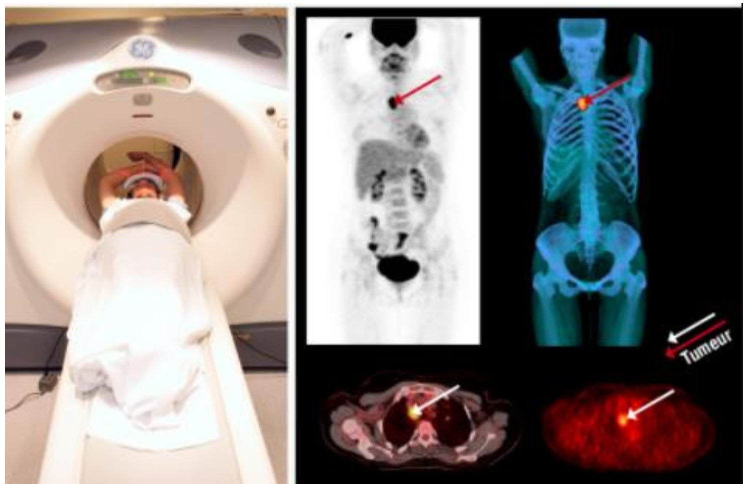
- Xrays have high energy and can penetrate some material
- X rays can pass right through bodies
- X rays are used for diagnostic tool in dentistry and medicine

Particulate radiations

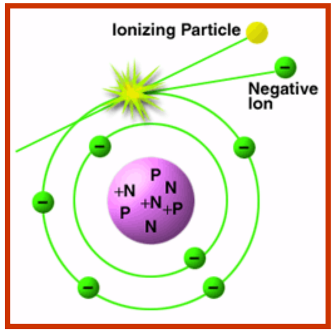
- Have a **mass** and a **charge**
- Consisting of atomic or subatomic particules (electrons, protons,..) which carry energy in the form of **kinetic energy** of mass in motion
- Produced by spontaneous radioactive decay
- The kinetic energy is expressed as:

  - **Ec = ½ x mV^2**





Ionizing and non ionizing radiation:

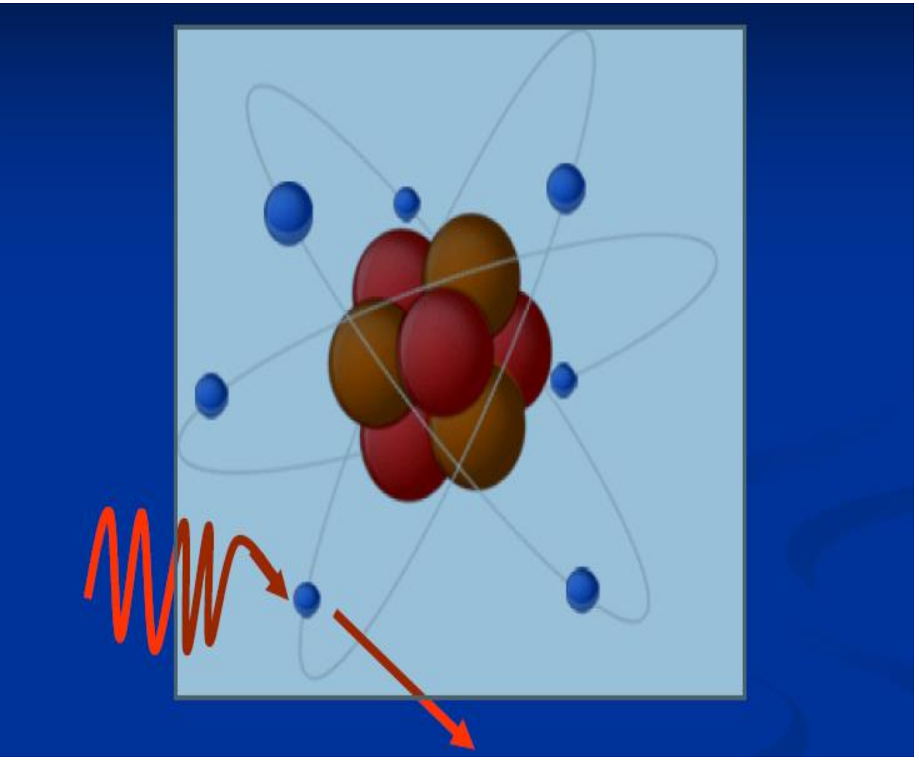


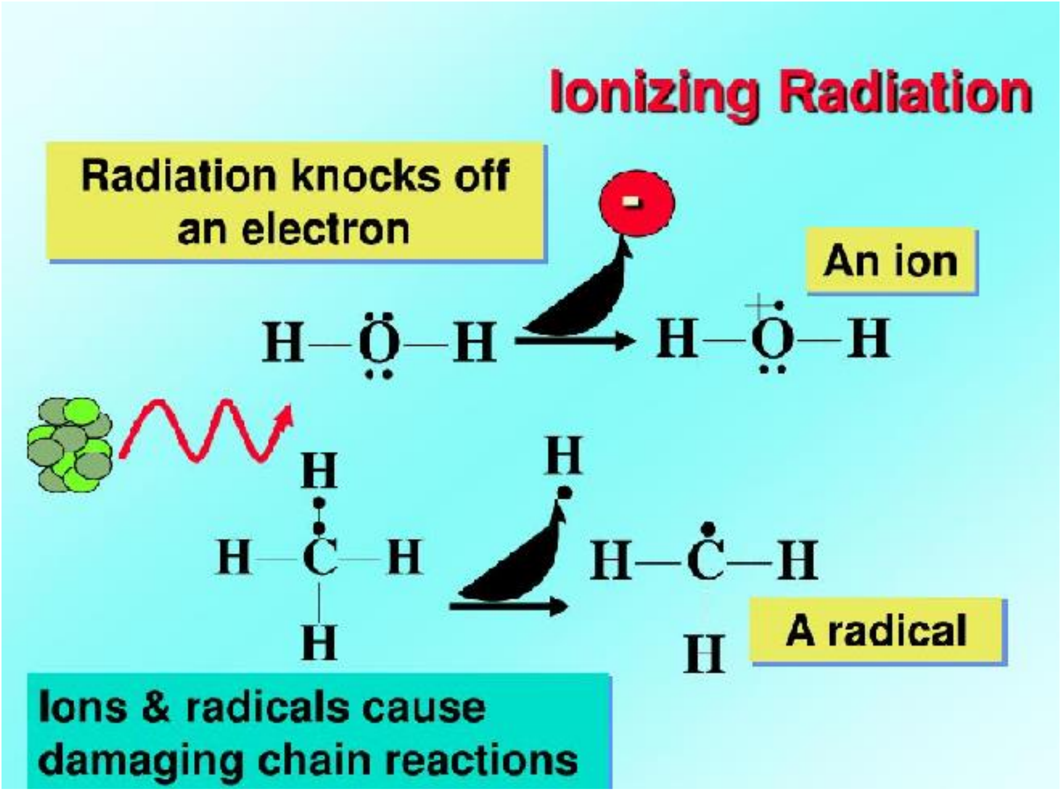
- **Ionizing radiation :** radiation which have sufficient energy to remove orbital electron (creates DNA damage)
- **Non ionizing radiation :** which does not have enough energy to dislodge orbital electrons

What is the ionization

- **Converting atoms into ions**
- **The process of removing an electron from an electrically neutral atom to produce an ion pair.**
- The essential characteristic of high energy radiations when interacting with matter.

Ionizing radiation

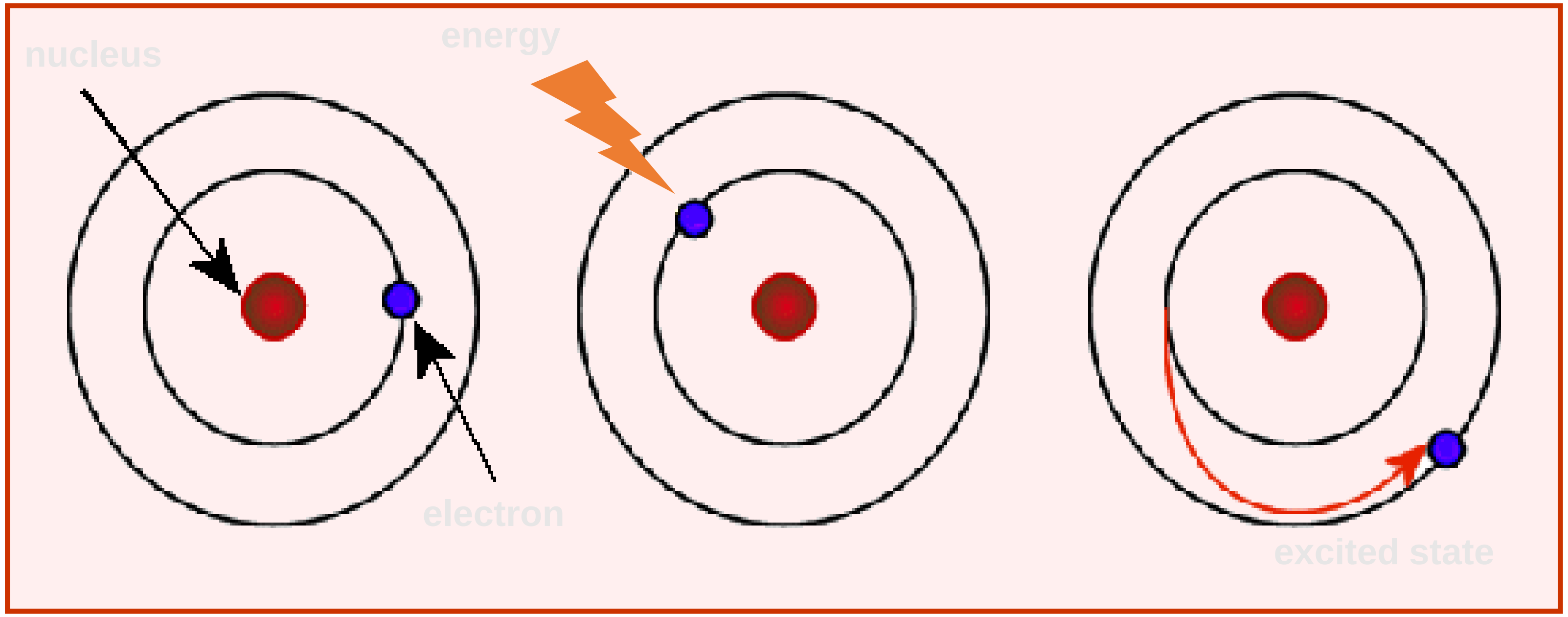




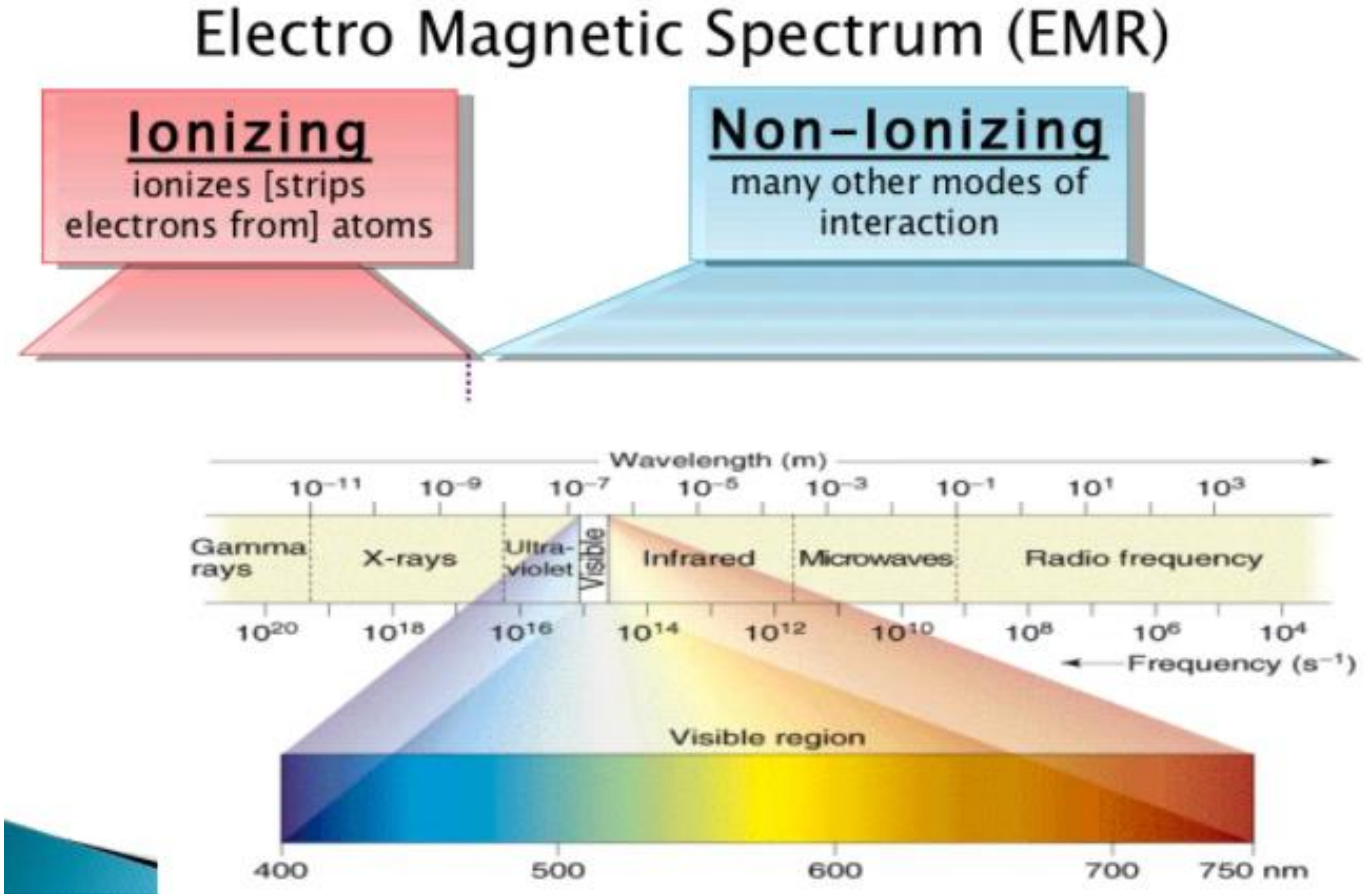
Process where the radiation interact with matter to form ions

Excitation

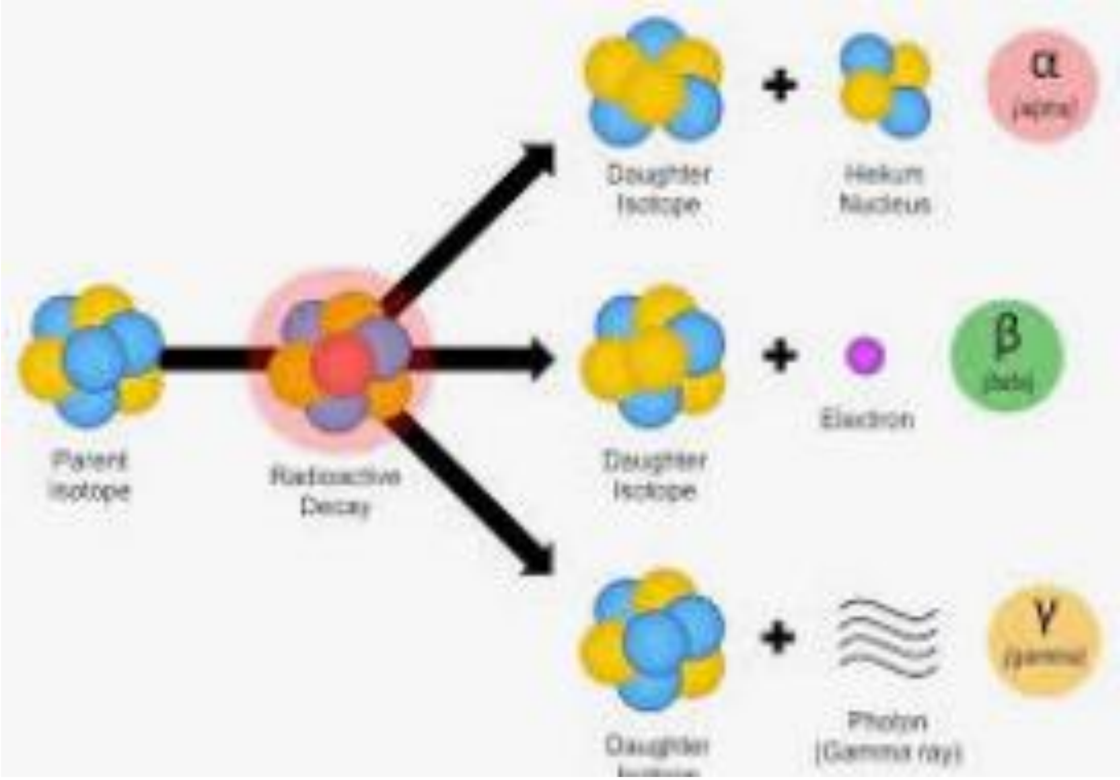
- When the energy of radiation is not sufficent the electron only drop to an upper orbital



EM Ionizing radiations



All Particules are Ionizing radiations



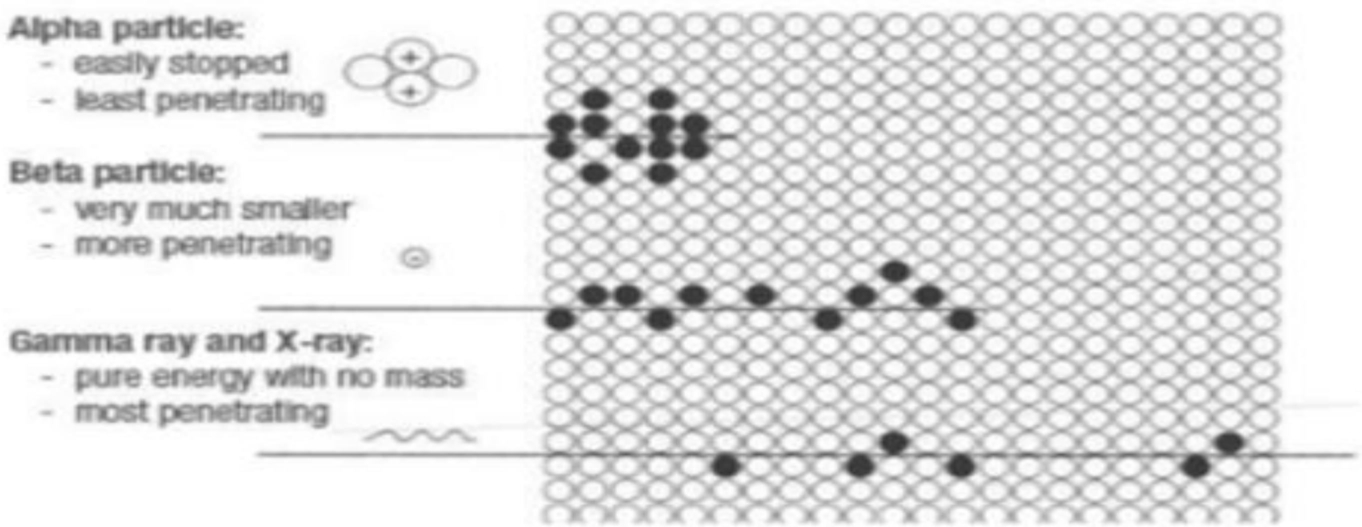
Why study ionizing radiation?

- Because ionizing radiation is useful in:

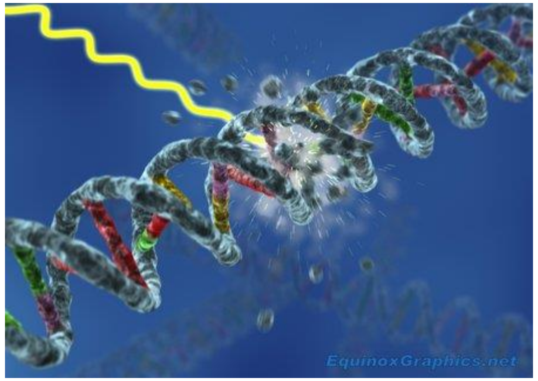
  - ✓**Radiodiagnostic**
  - ✓**Radiotherapy**
  - ✓**Radiation protection**

How do the types of ionizing radiation deposit energy?

- Types of ionizing radiation differ widely in their abilities to penetrate tissues and deposit energy through ionization.



Can exposure to ionizing radiation harm you?



- Yes it can.
- The damage depends on how much and for how long
- A low energy per ionizing event is well enough to break a chemical bond
- Very high exposure received in a short time can cause death.
- Low levels over a long time may cause little damage and your body's cells can usually repair themselfs
- Sometimes the cell makes an incorrect repair
- The effect of incorrect repair could show up years later as cancer

How to protect against ionizing radiation on the job

- Ionizing radiation is widely used in industry and medicine.
- Workers need to take precautions against particle radiation and electromagnetic radiation

✓ **Distance**

✓ **Time**

✓ **Sheilding**

Lead

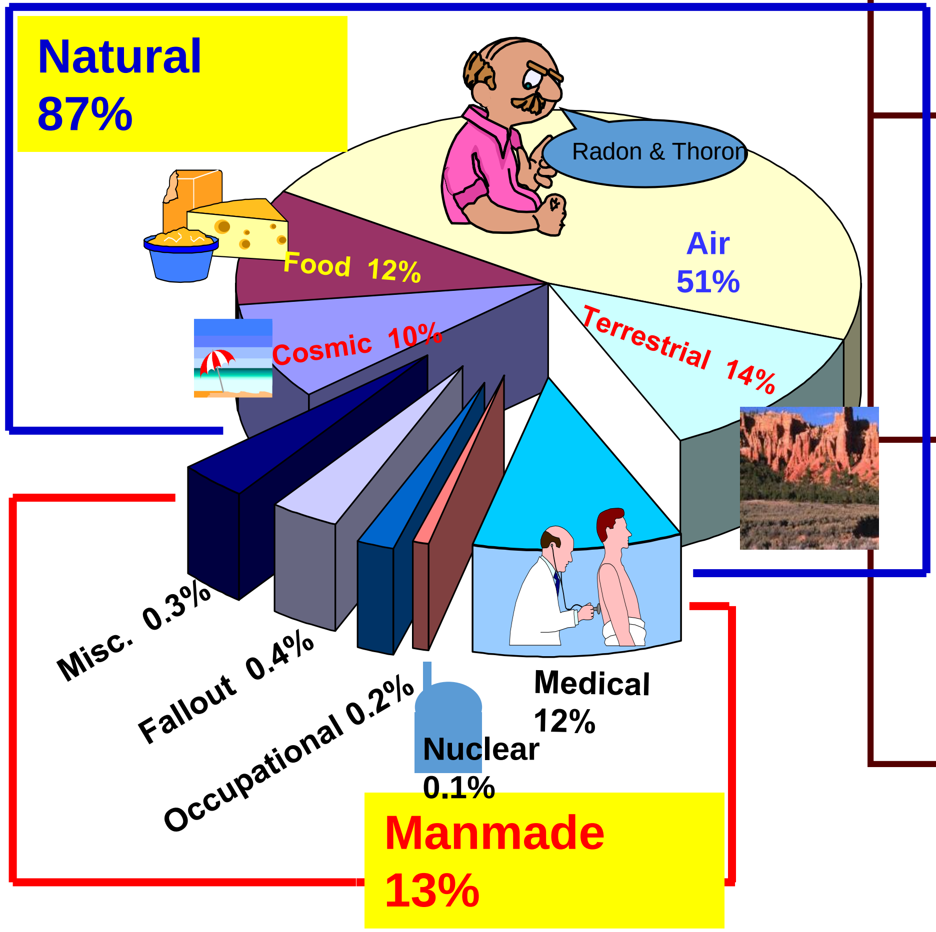
Radiation protection on the job

- This symbol is used on packages of radioactive materials, such as isotopes, and on doors to rooms or areas where radioactive materials are used or stored

Where does your radiation exposure come from?

Exposure to
Ionizing Radiation

- ,



Medical (diagnosis and treatment Diseases)

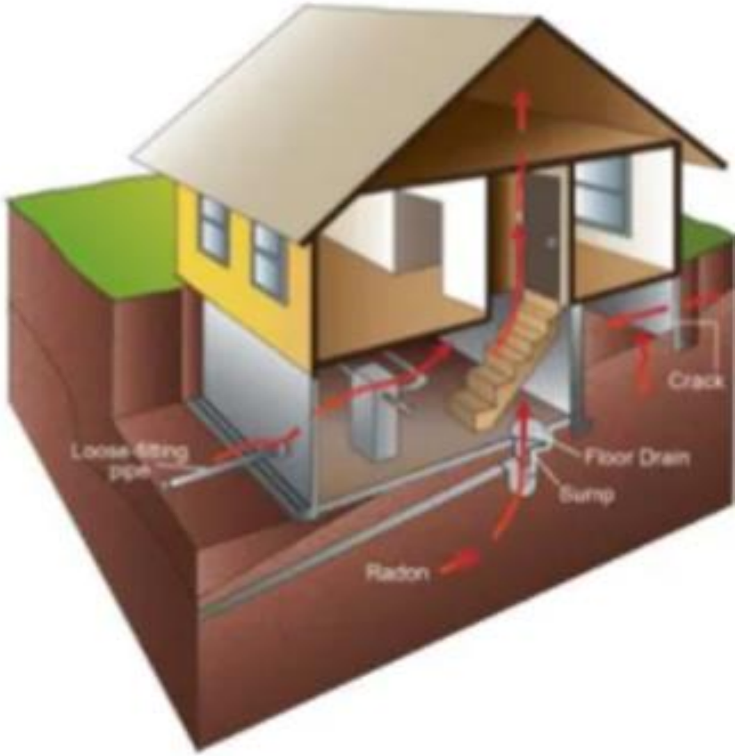
Cosmic Radiation

Radioactive substances present in the ground and commercial sources

Who is exposed most to the natural radiation

, What is Radon (Radon 51% exposure)

Radon is a radioactive gas that comes from the normal decay of uranium found in nearly all soils and water.



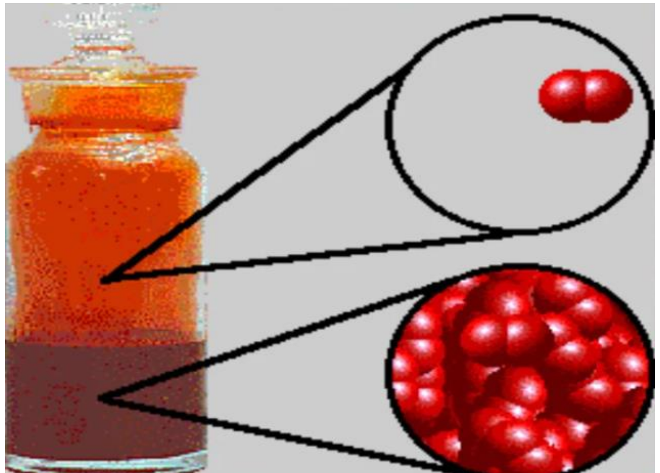
Particulate radiation: Radioativity

What is Matter?

- Matter means:

✓ Any thing that occupies space and has mass

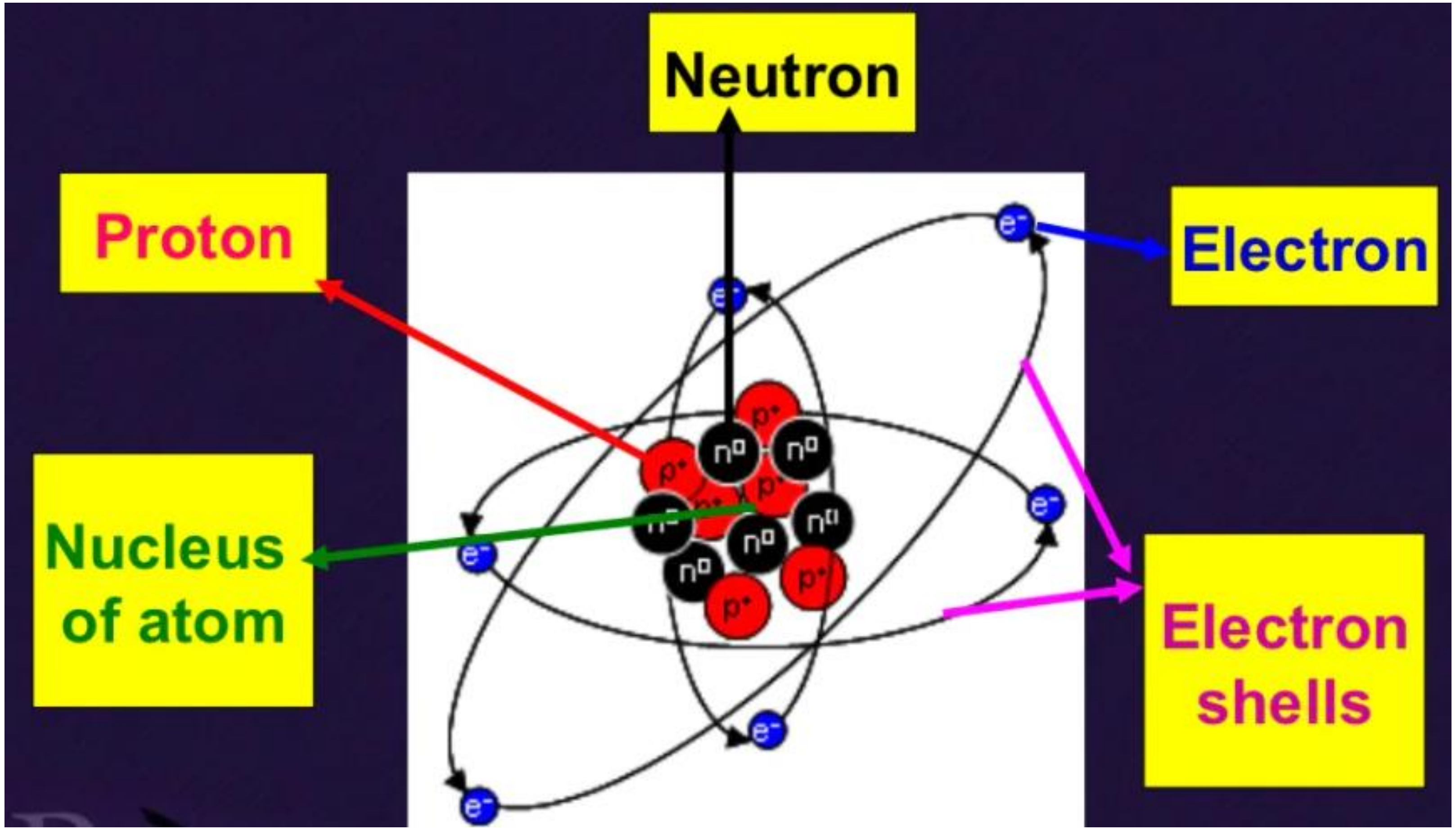
✓ Made up of tiny and discrete particules



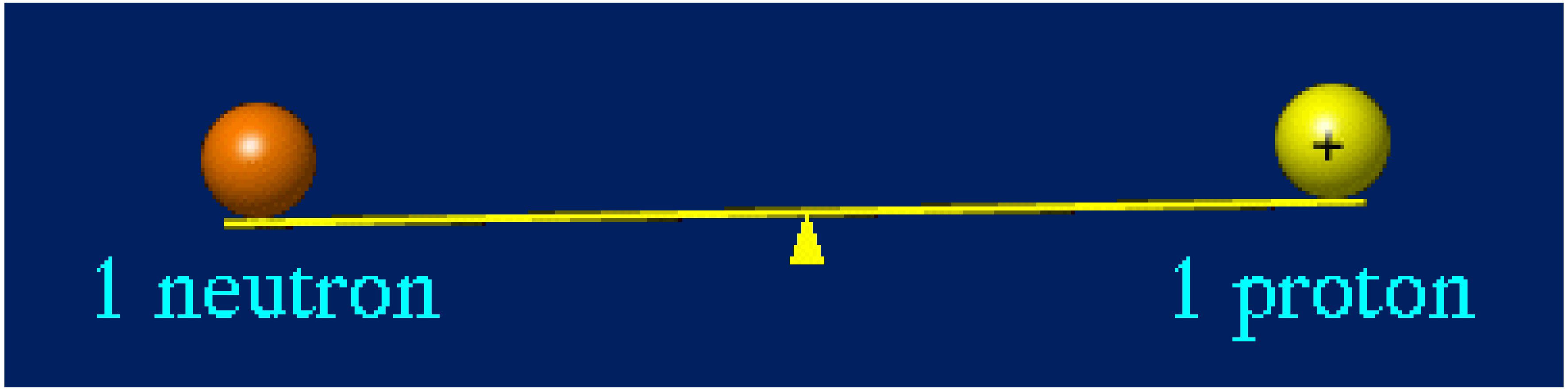
What’s inside the atom?

Atoms

- An atom is the smallest unit of element

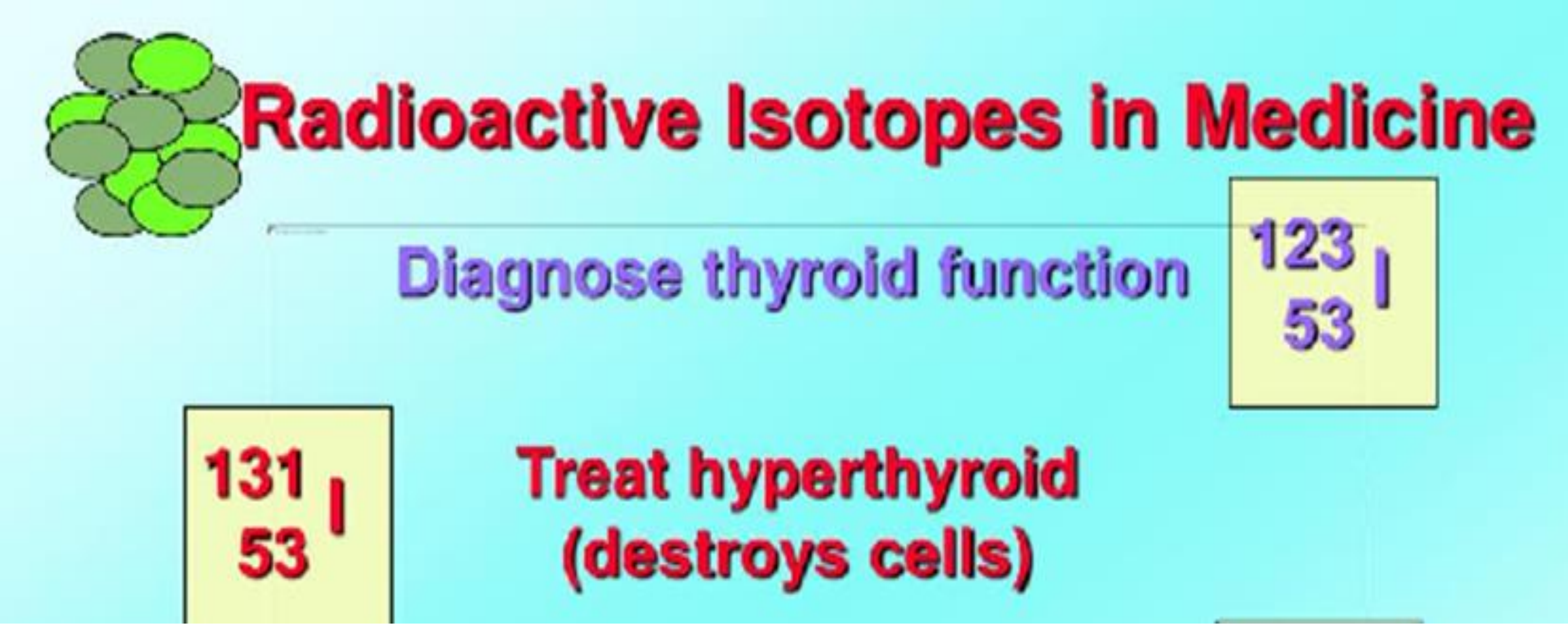


Nucleus



What is an isotope?

- Isotopes are just like **twins**, same genetic but different DNA
- Atoms of the **same element** with **same number of protons** but **different** number of **neutrons**


Radioactive Isotopes in Medicine
Diagnose thyroid function
123
53
I
131
53
I
Treat hyperthyroid
(destroys cells)

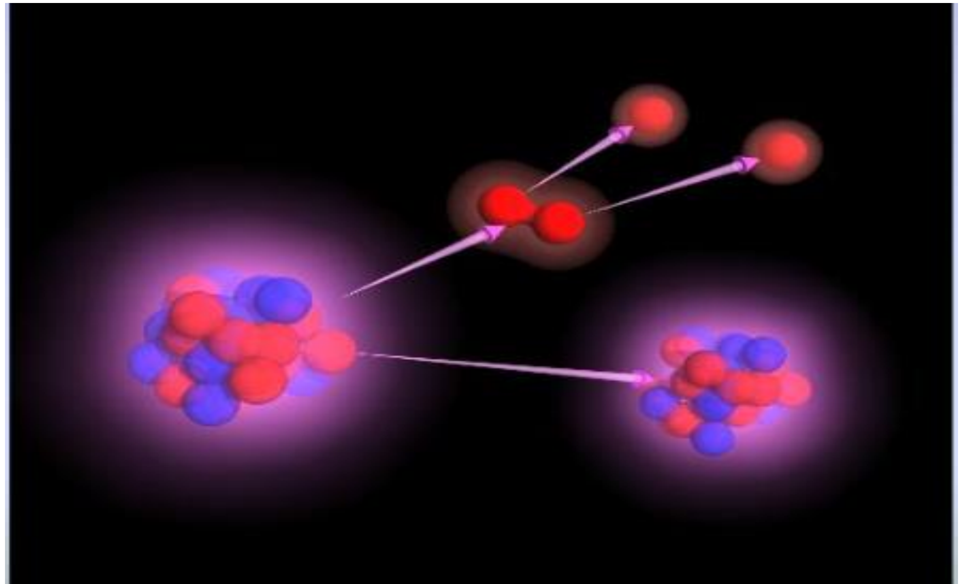
Theory of nuclear radiations

Radioactivity

- Radioactivity can be defined as the phenomenon in which the nucleus of the atom of an element undergoes spontaneous and uncontrollable disintegration (or decay)
- The parent nuclide is the nucleus that undergo radioactive decay, while the daughter nuclide is the new nucleus
- Decomposing involves the nuclide emetting a particle and/or energy
- It may be noted that electrons revolving around the nucleus are not responsible for radioactivity
- **The rays emitted by radioactive elements are called radioactive rays**

- 2 types of Radioactivity

Natural radioactivity **Artificial radioactivity**



Natural Radioactivity

- These are unstable nuclei found in nature.
- Natural radioactivity happens by itself (naturally existing radioactive elements
- **All heavy elements** above **Z = 82** show the phenomenon of radioactivity

Artificial radioactivity

- Artificial radioacticity is induced in the laboratory (with the help of reactor or cyclotron)
- Process in which a stable (non radioactive) nucleus is changed into an unstable (radioactive) nucleus by bombarding it with appropriate atomic projectiles like alpha, neutron, proton.
- All radioisopes used in nuclear medicine are artificial elements.

Artificial radioactivity

Reactor

Artificial radioactivity

cyclotron

What happens to the radioactive nucleus?

- There are three types of radioactive rays:

✓ **Alpha rays (α):**

- Nuclear charge (atomic number) is +2 and the mass number is 4: What we now know to be **helium nucleus**

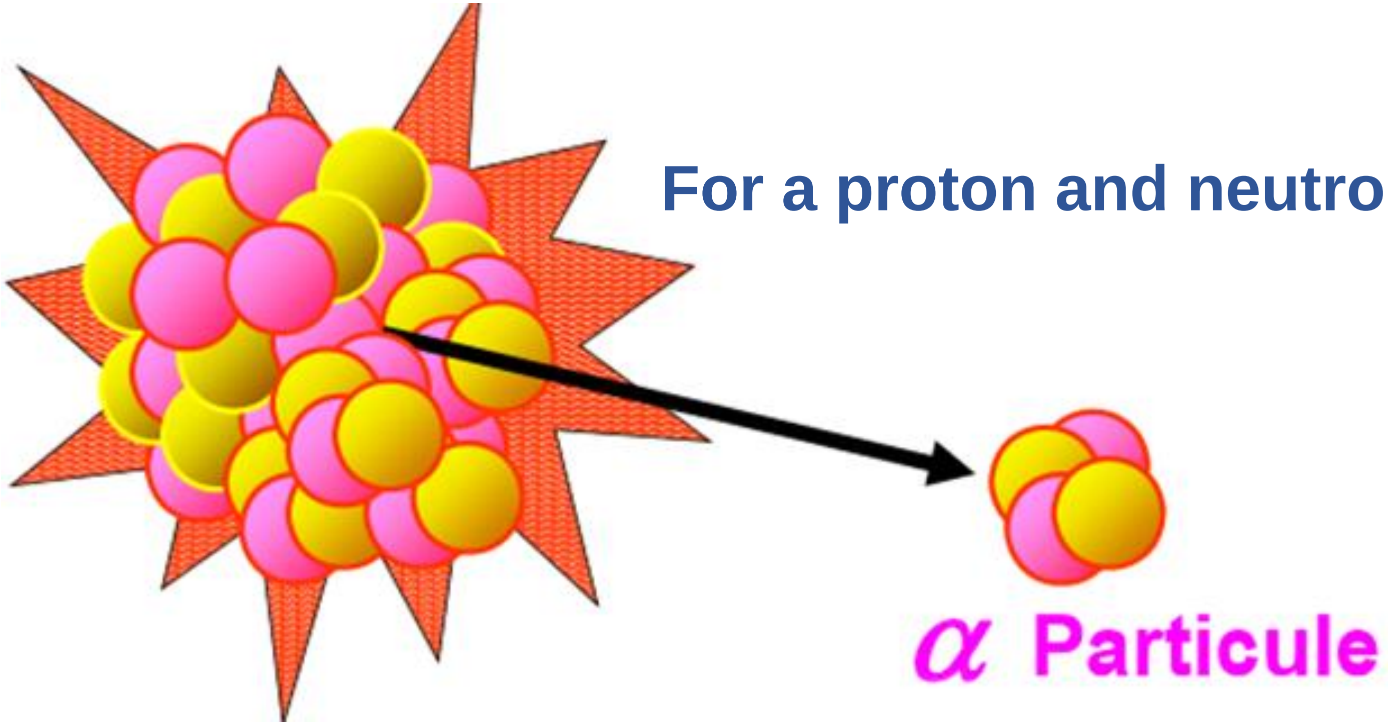
✓ **Beta rays (β)**

- Electron
- Have a charge : beta minus and a positron

✓ **Gamma rays (γ)**

- Form of light energy (not a particule like α and β)

Alpha decay



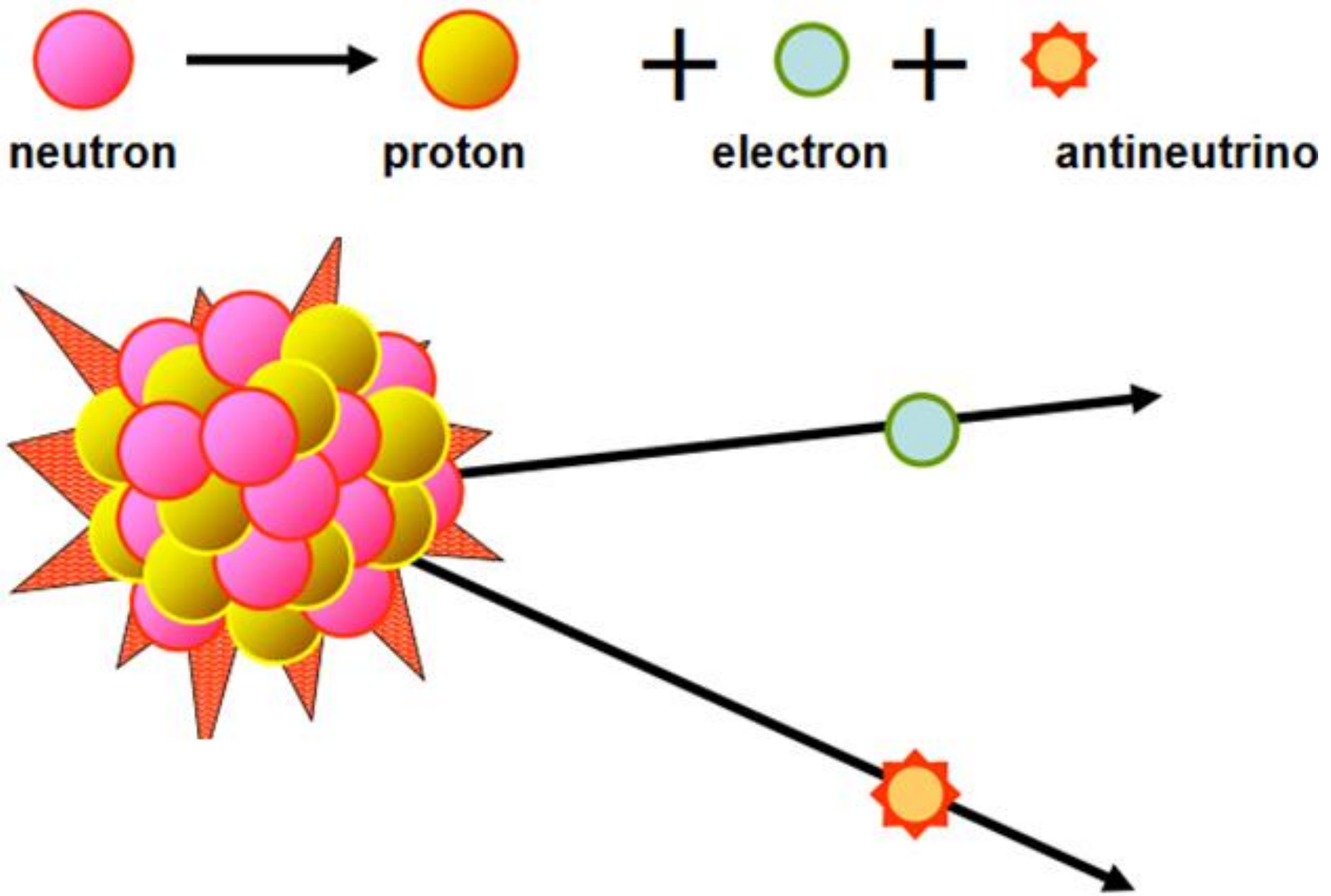
For a proton and neutron rich and heavy nuc

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

Note:

- Alpha decay has the largest ionizing power: ability to ionize molecules and atoms due to largeness of α particule
- Has the lowest penetrating power: ability to penetrate matter
- An example of alpha decay is a smoke detector (amercium241)

Beta decay



To conserve the charge, one of the neutrons changes to a proton

$$\text{nuclei } (A, Z) \rightarrow \text{nuclei } (A, Z+1) + e^{-} + \bar{\nu}$$

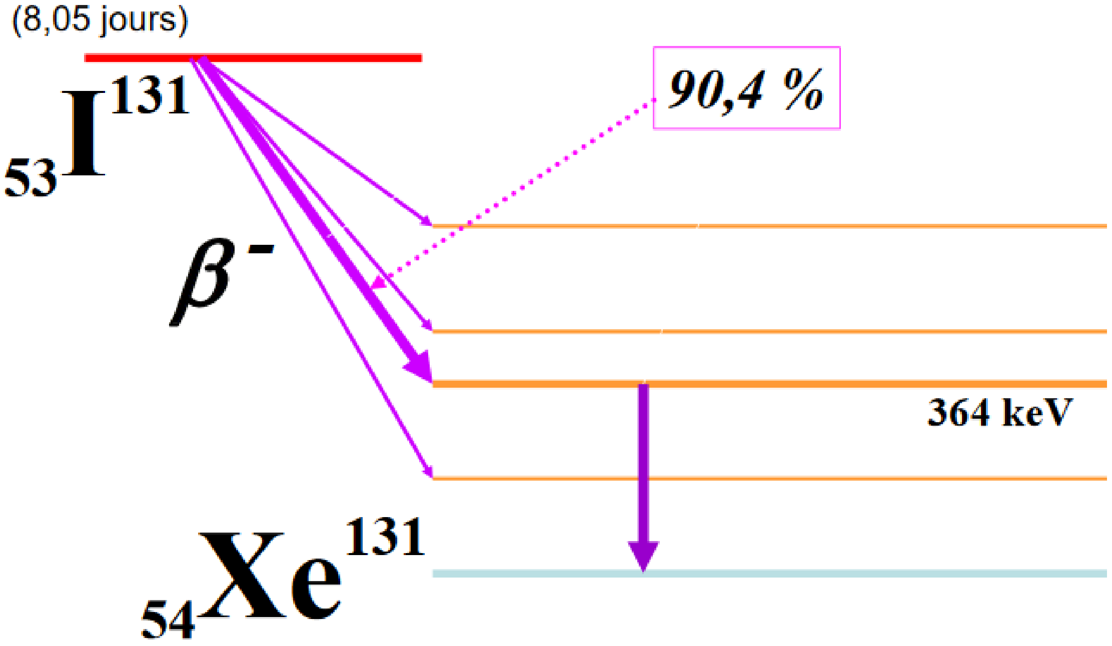
Note:

- The electron emitted in beta decay is not an orbital electron; this electron is created in the nucleus itself
- A beta particle is a fast moving electron which is emitted from the nucleus of an atom undergoing radioactive decay

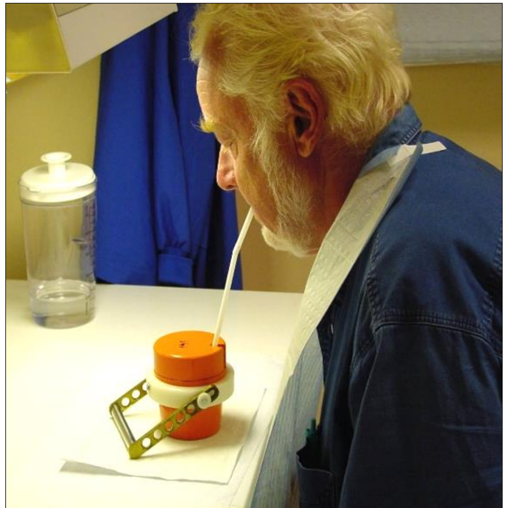
An Important example : Iodine 131

Metabolic therapy (nuclear medicine)

$$^{131}_{53}I \xrightarrow[8{,}02070 \text{ jours}]{\beta^- \; 606 \text{ keV}} {}^{131}_{54}Xe^* \xrightarrow{\gamma \; 364 \text{ keV}} {}^{131}_{54}Xe.$$

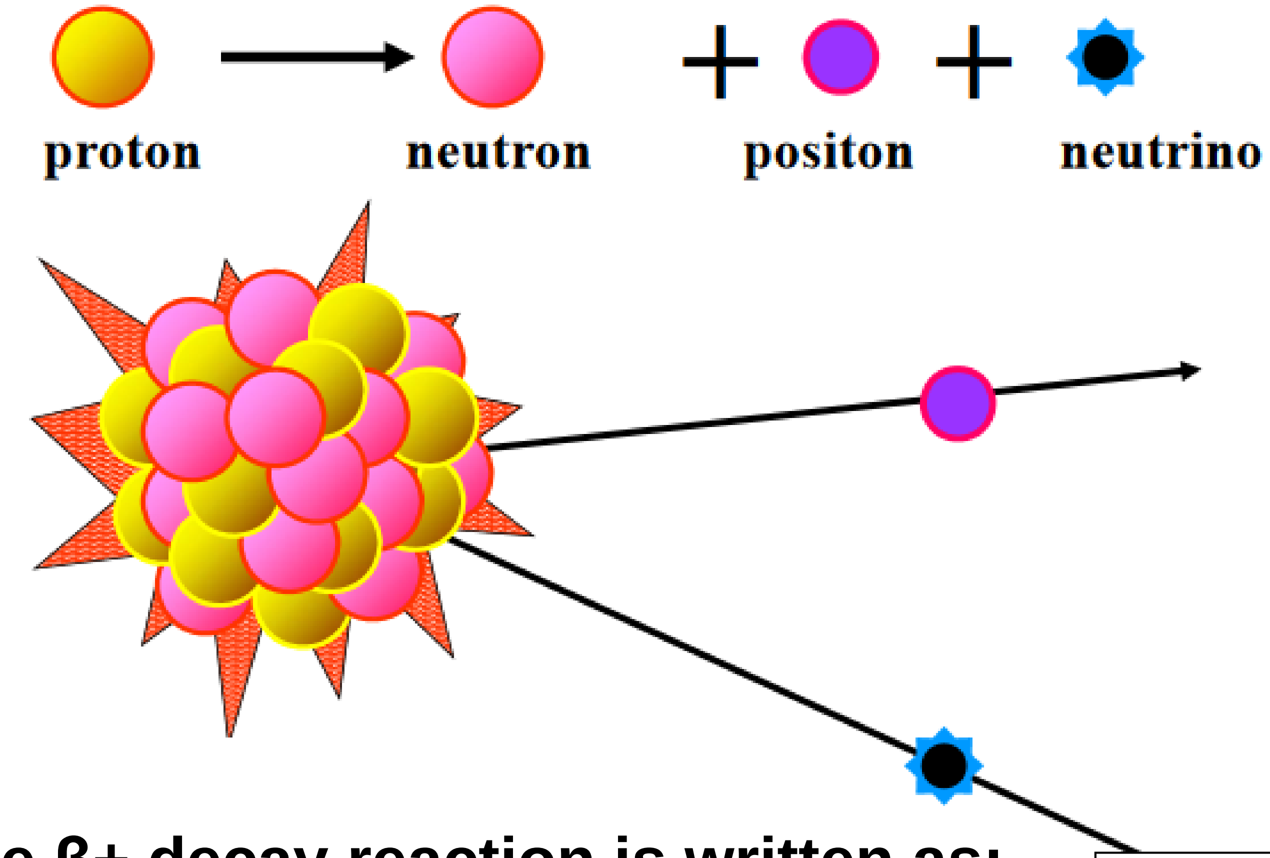


- **131Iodine:** High toxicity
  - Reactor product



Positron decay

- The positron is called **the antiparticle**

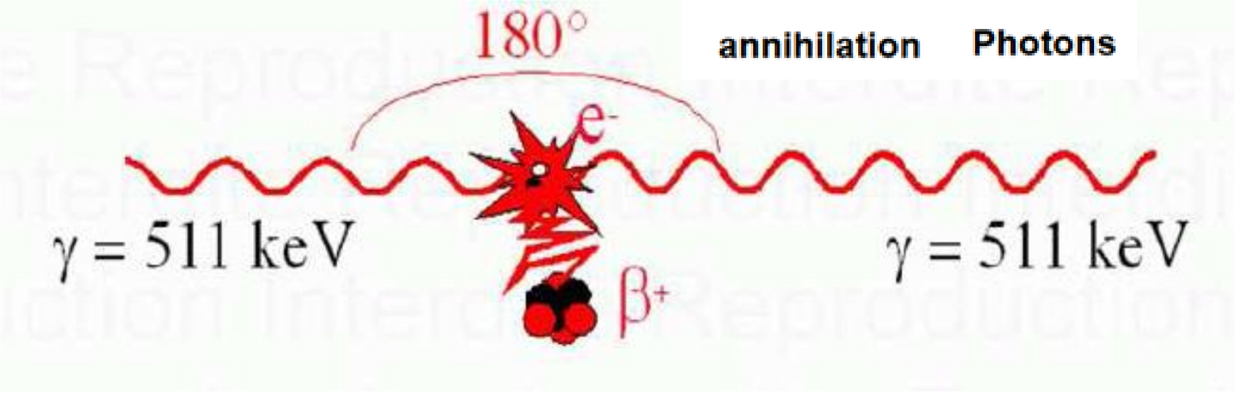


- **The β+ decay reaction is written as:**

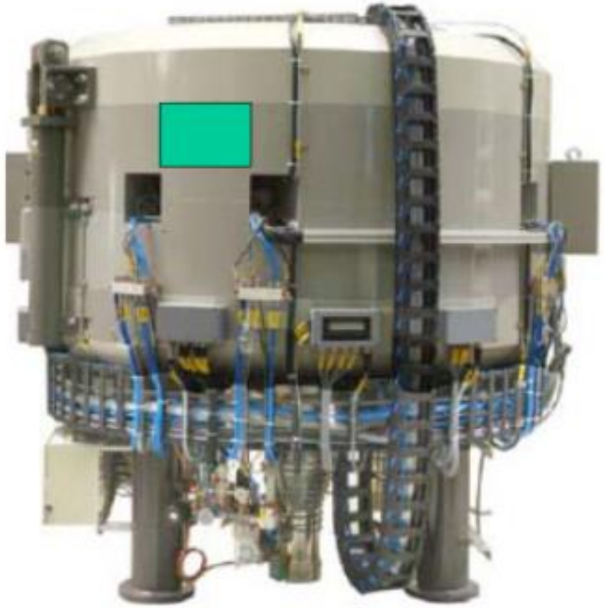
$$ {}^{A}_{Z}X \rightarrow {}^{A}_{Z-1}Y + {}^{0}_{+1}e + \nu $$

Positron annihilation

- When beta particle is emitted , it spreads in matter by losing its energy. At rest the particle combine with one of the free electrons to give rise to 2 photons each having 511KeV energy.The 2 photons are ejected in opposite directions. This phenomenon is called **Positron annihilation**



An Important example: Floride18
Nuclear medicine diagnosis

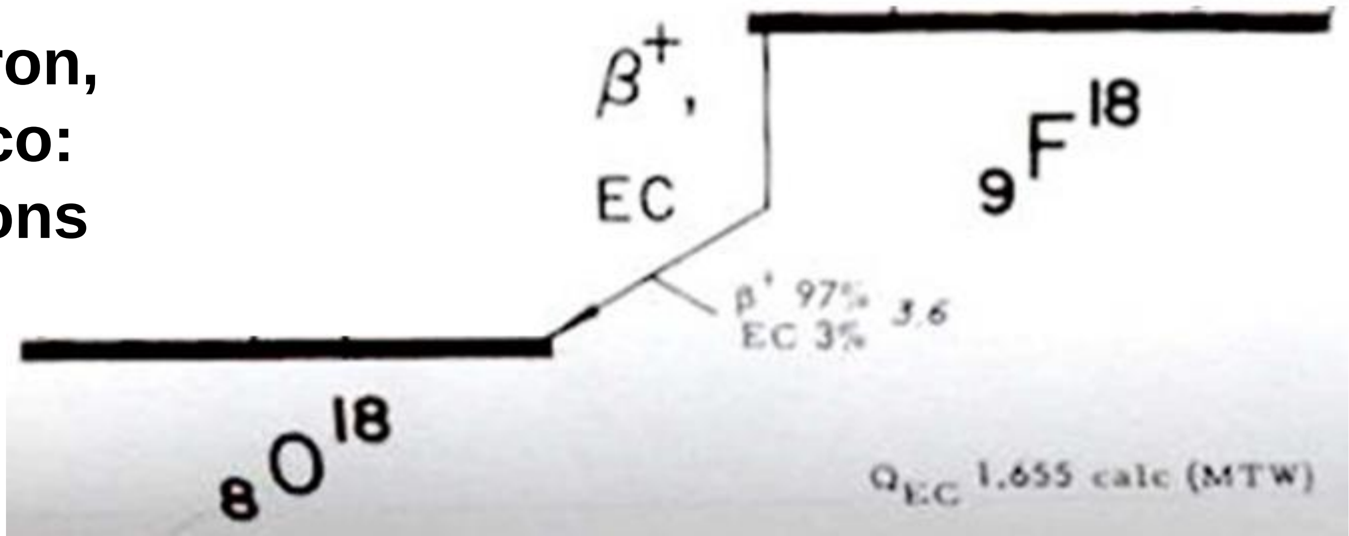


$p + {}^{18}O \Rightarrow {}^{18}F + n$

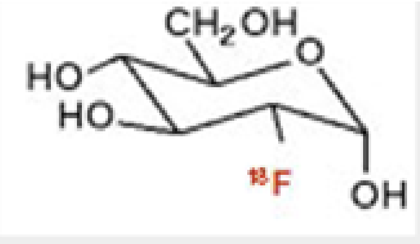
Floride production

Floride disintegration

Cyclotron,
In Morocco:
2 cyclotrons

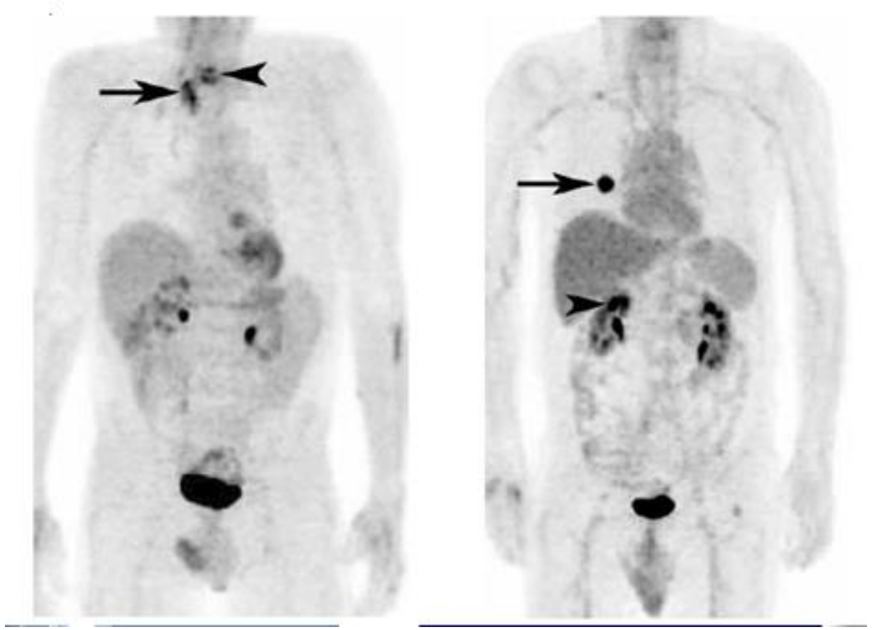


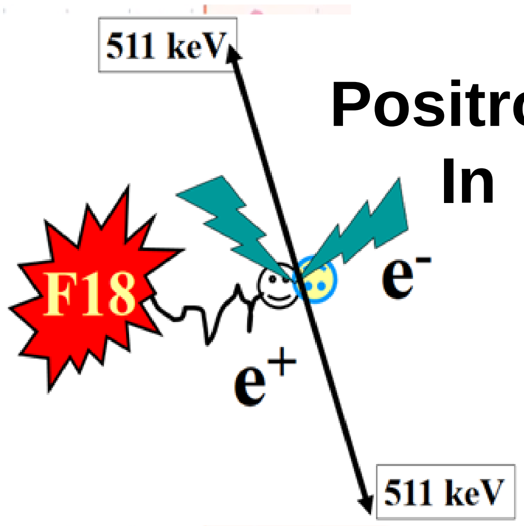
An Important example: Floride18



18F-FDG
Radiotracer

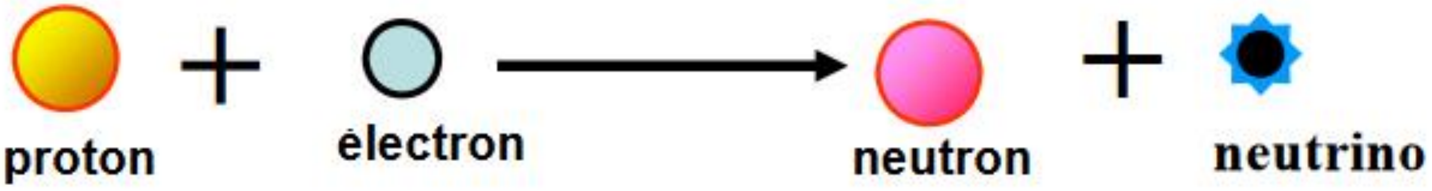
PET scan

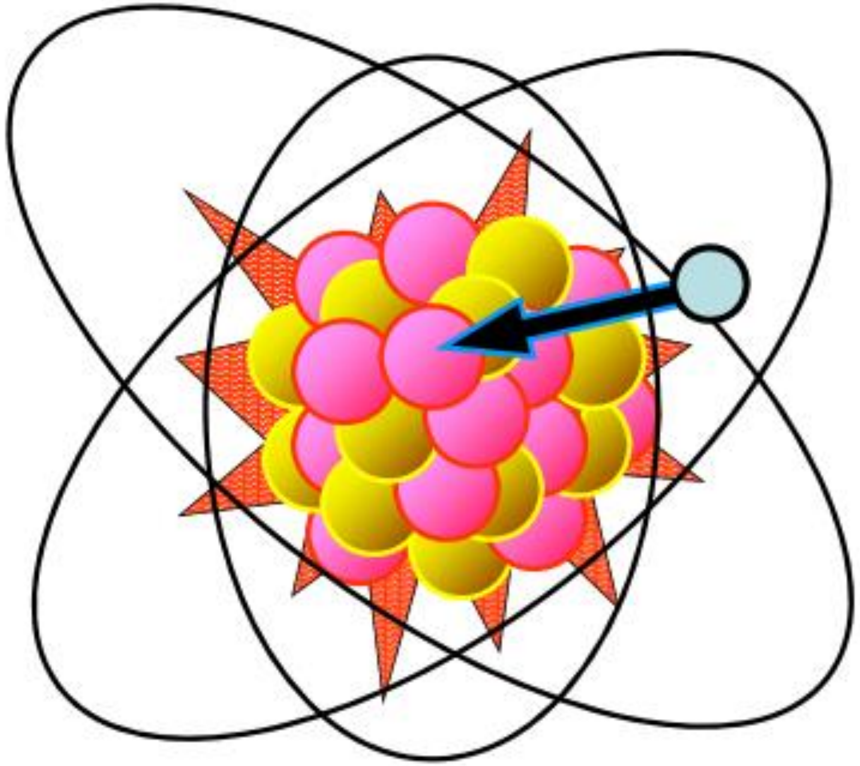




Positron annihilation
In the patient

Electron capture

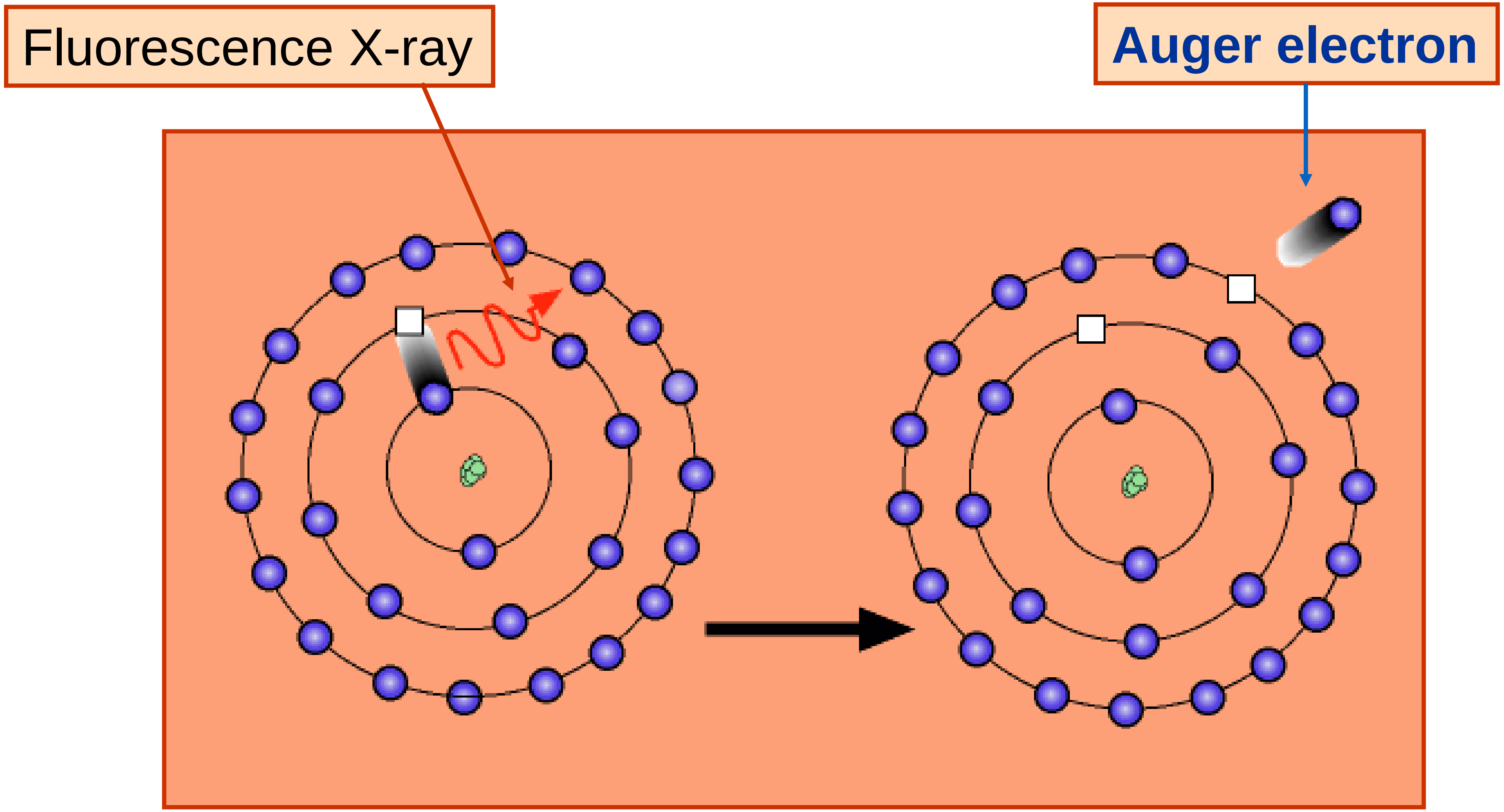




$$p + {}_{-1}^{0}e \rightarrow n + \nu$$

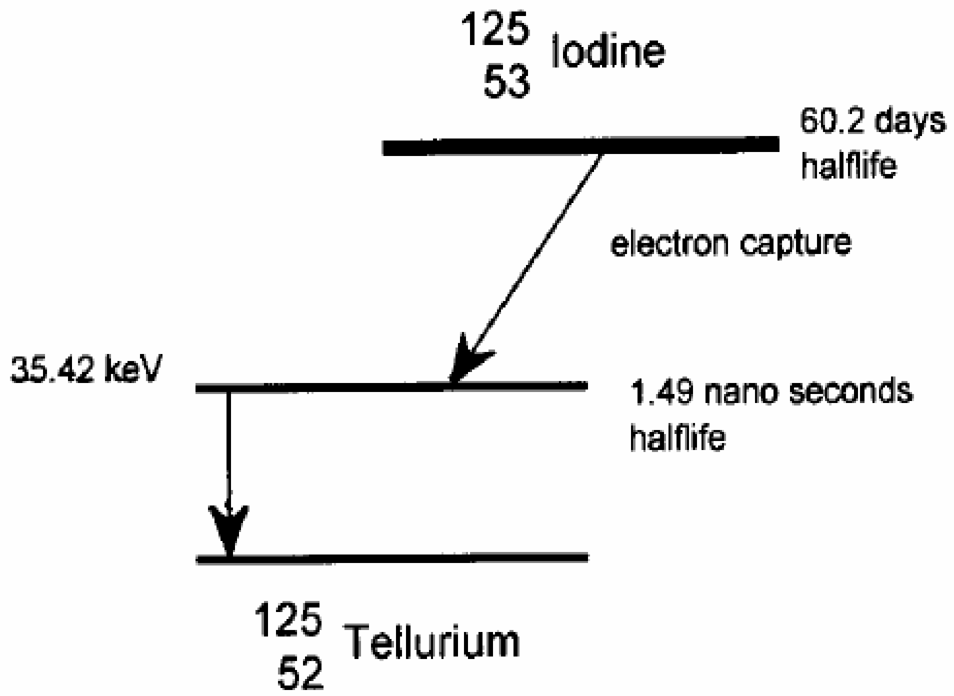
$$_{Z}^{A}X + {}_{-1}^{0}e^{-} \longrightarrow {}_{Z-1}^{A}Y + \nu$$

What happens after an electron capture



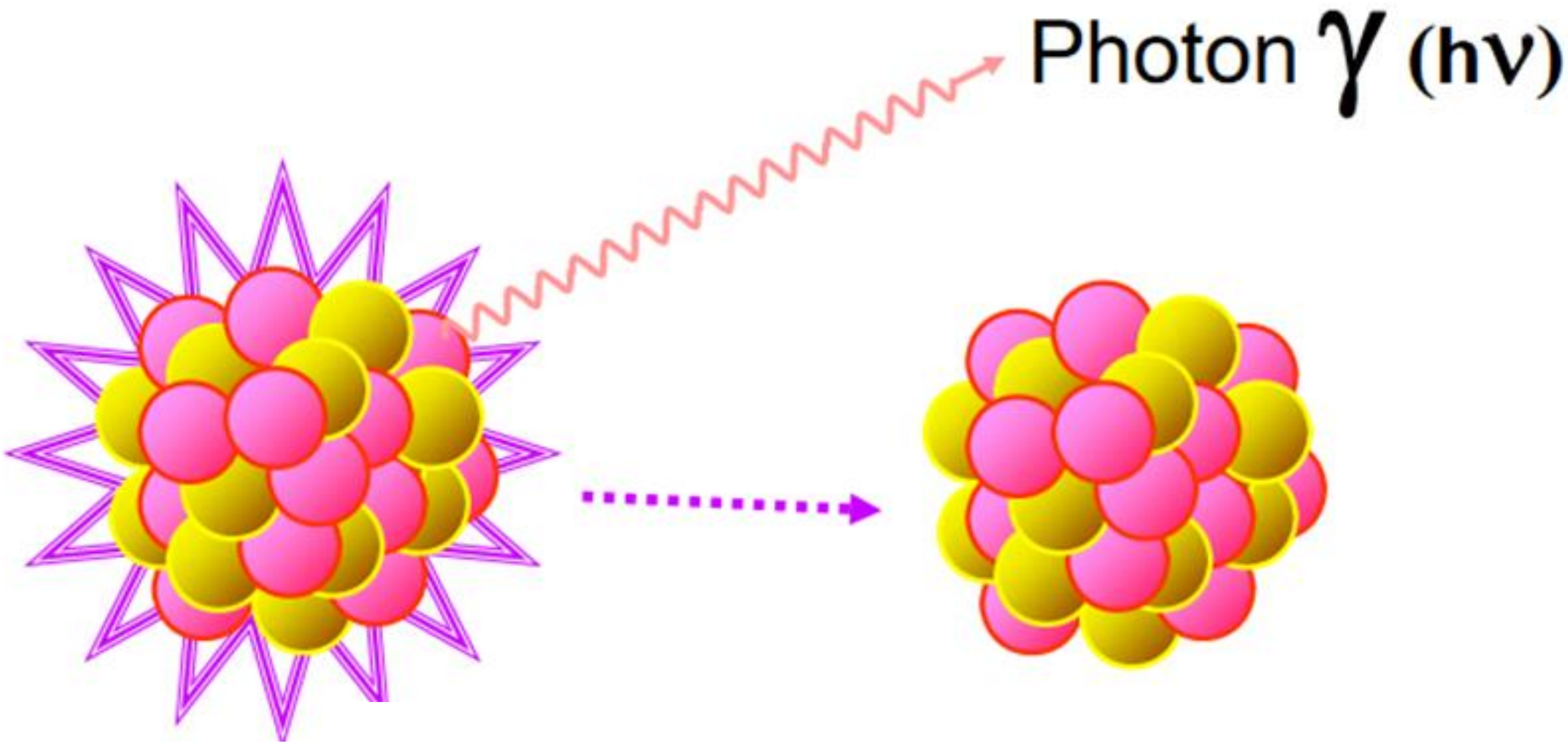
An Important example: Iodine 125

- Laboratory RIA technique



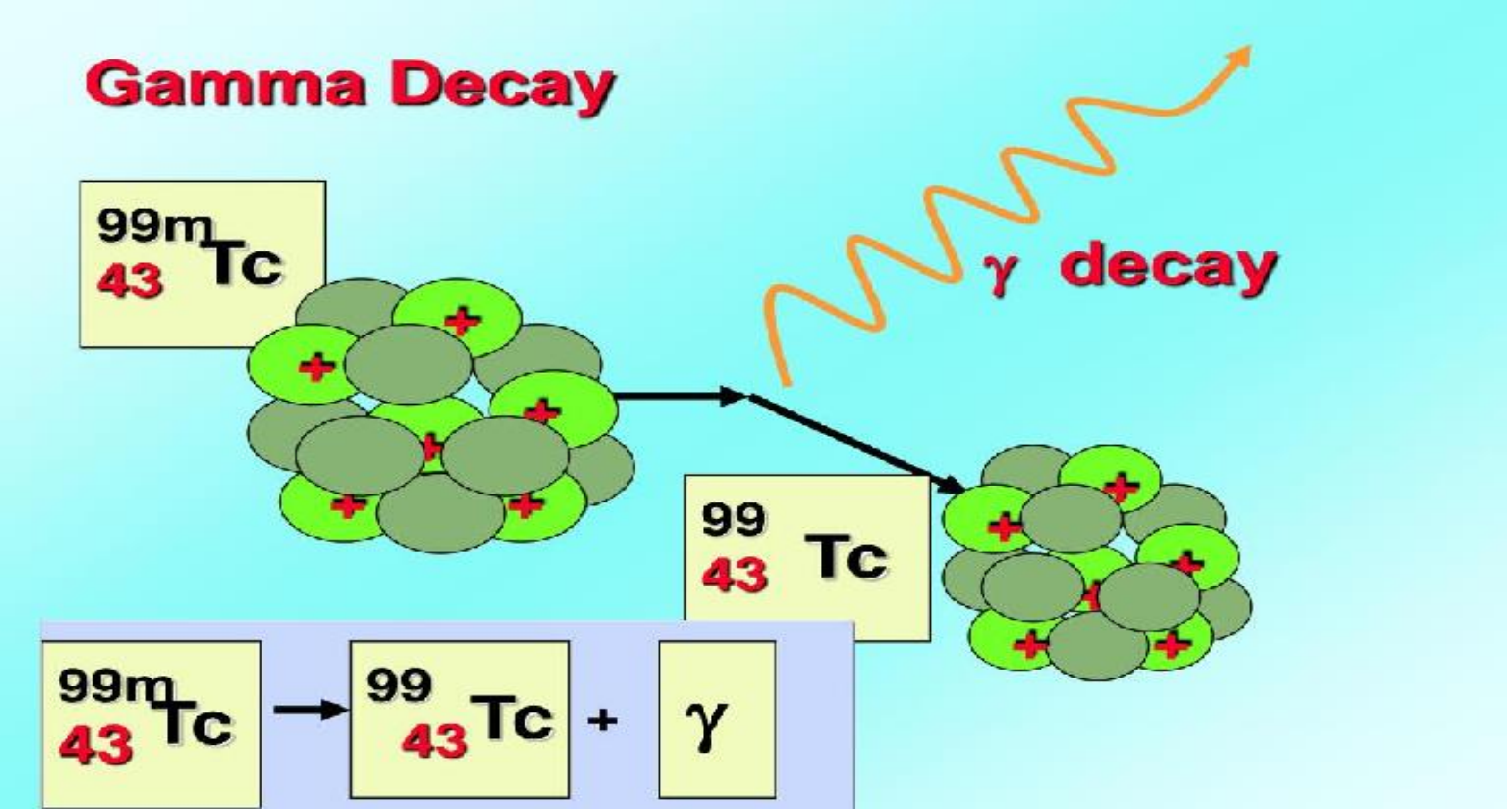
Detector

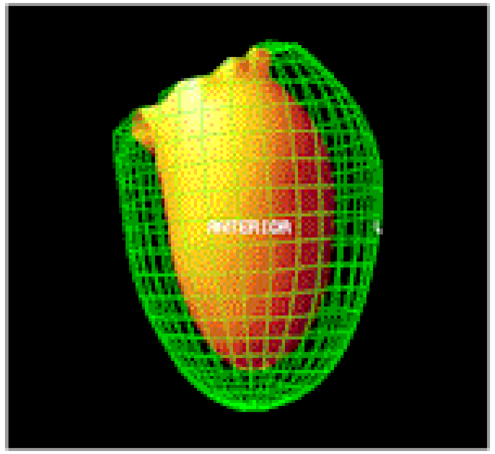
Gamma emission



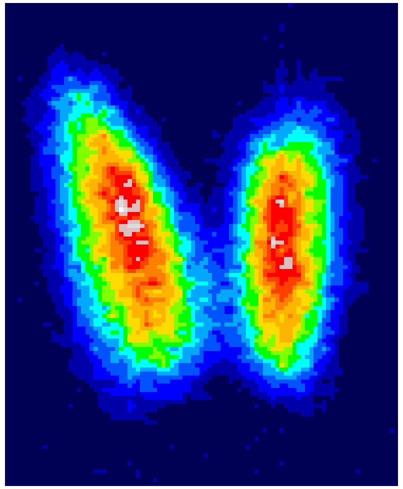
$$ {}^{A}_{Z}X \longrightarrow {}^{A}_{Z}Y + \gamma $$

$$ {}^{99m}_{43}\mathrm{Tc} \xrightarrow[\text{6 heures}]{\gamma\ 141\ \mathrm{keV}} {}^{99}_{43}\mathrm{Tc} $$

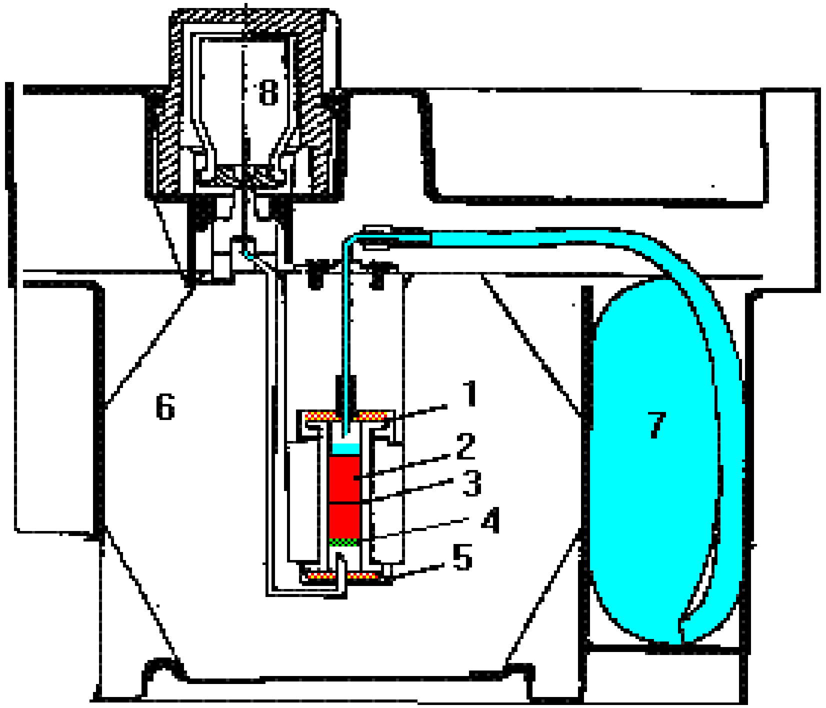




lead syringe shield



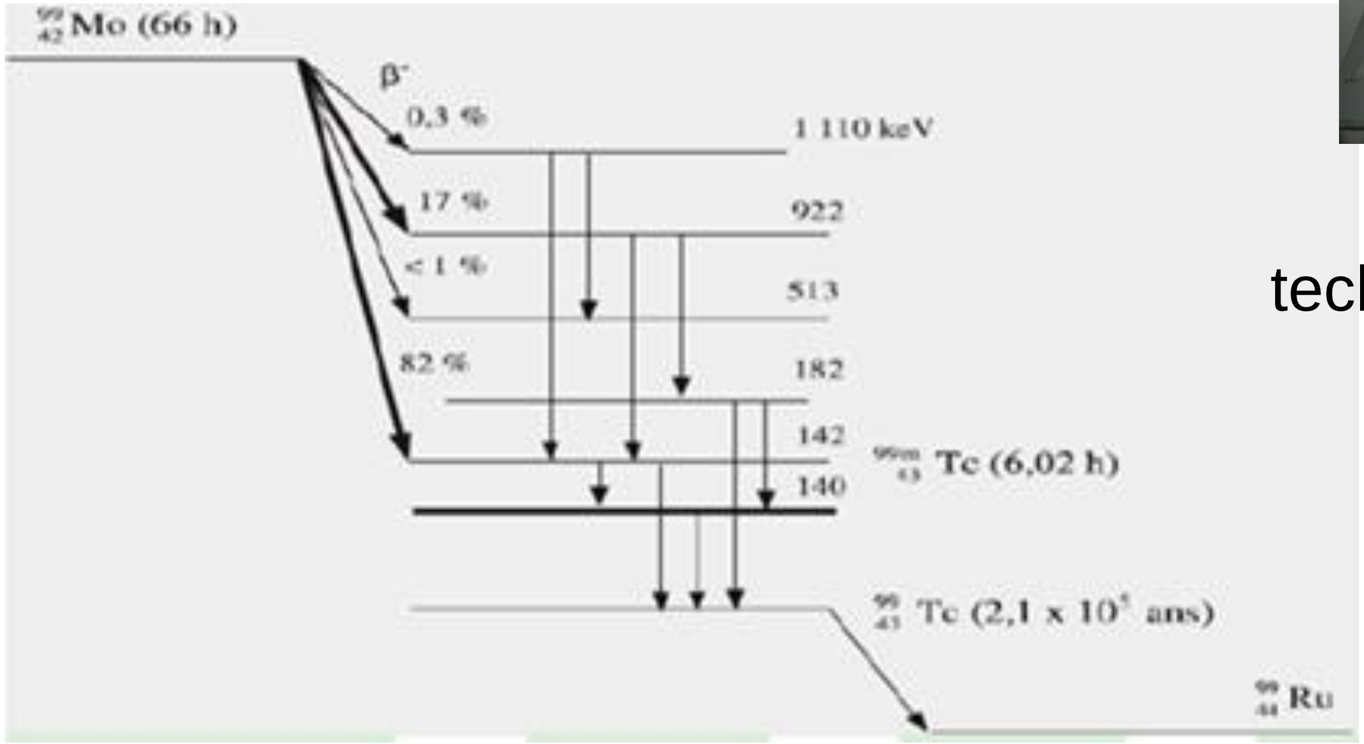
$^{99}Mo/^{99m}Tc$ Generator



$$^{99}_{42}\mathrm{Mo} \xrightarrow[\text{65,94 heures}]{\beta^-\ \ 1{,}216\ \mathrm{MeV}} {}^{99m}_{43}\mathrm{Tc}$$

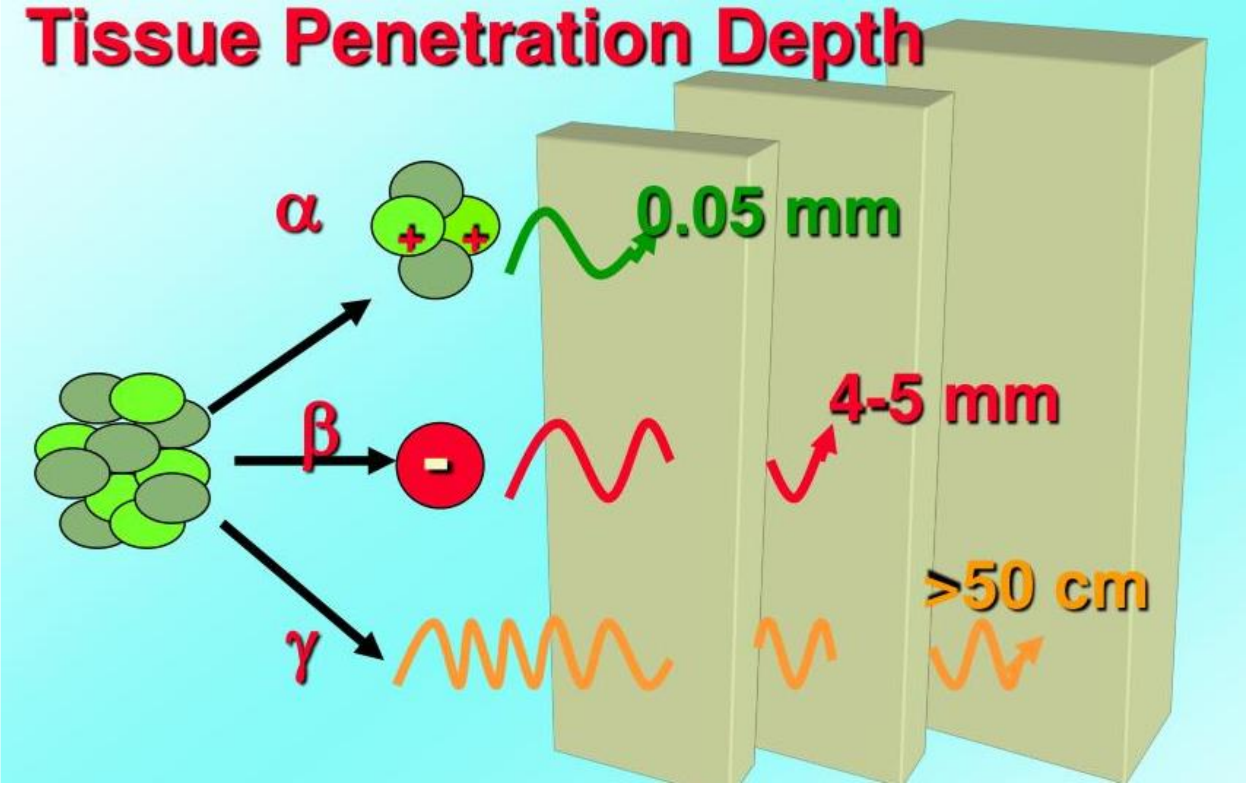
Important example: scintigraphy

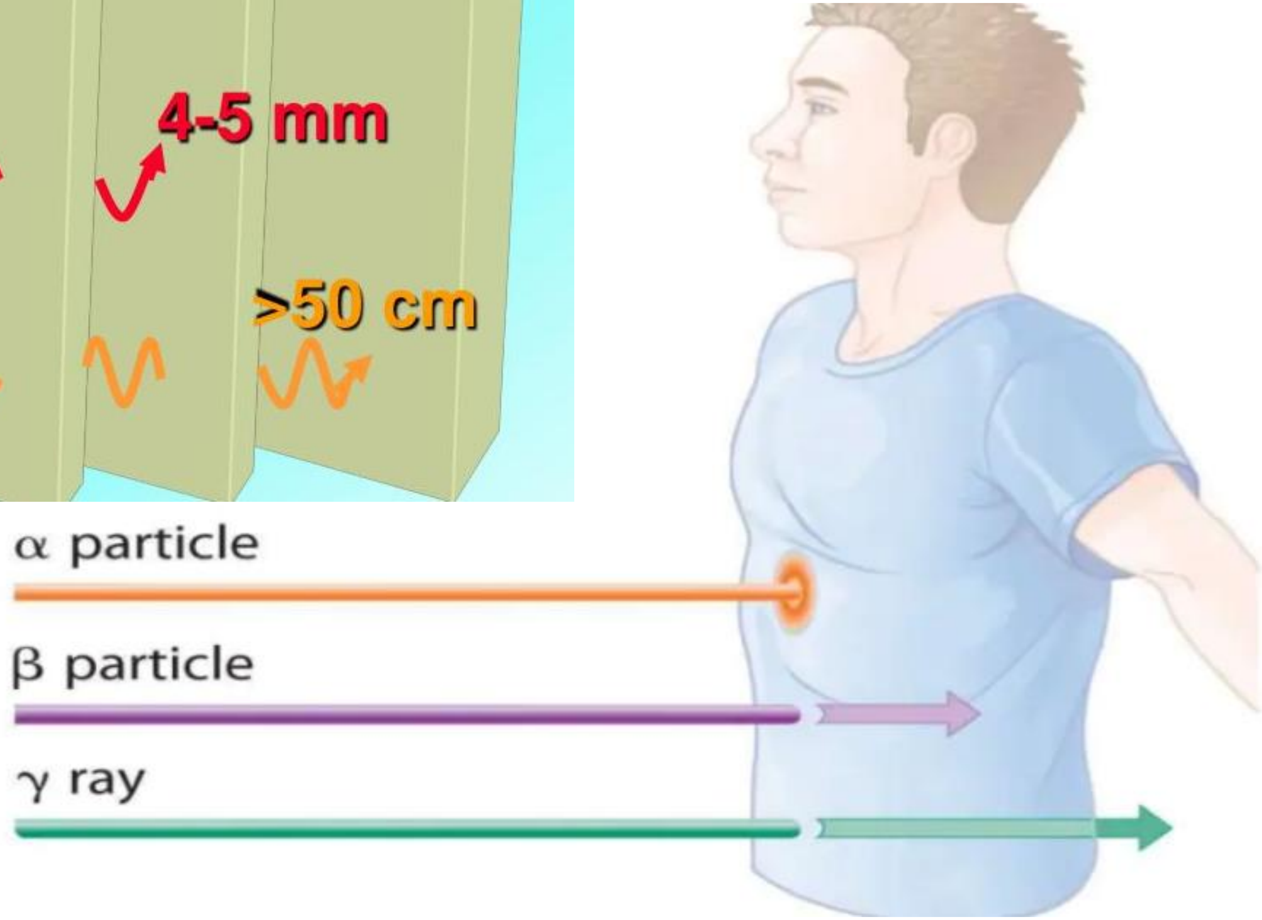
$$ {}^{99}_{42}\mathrm{Mo} \xrightarrow[65{,}94 \text{ heures}]{\beta^- \ 1{,}216 \text{ MeV}} {}^{99m}_{43}\mathrm{Tc} $$



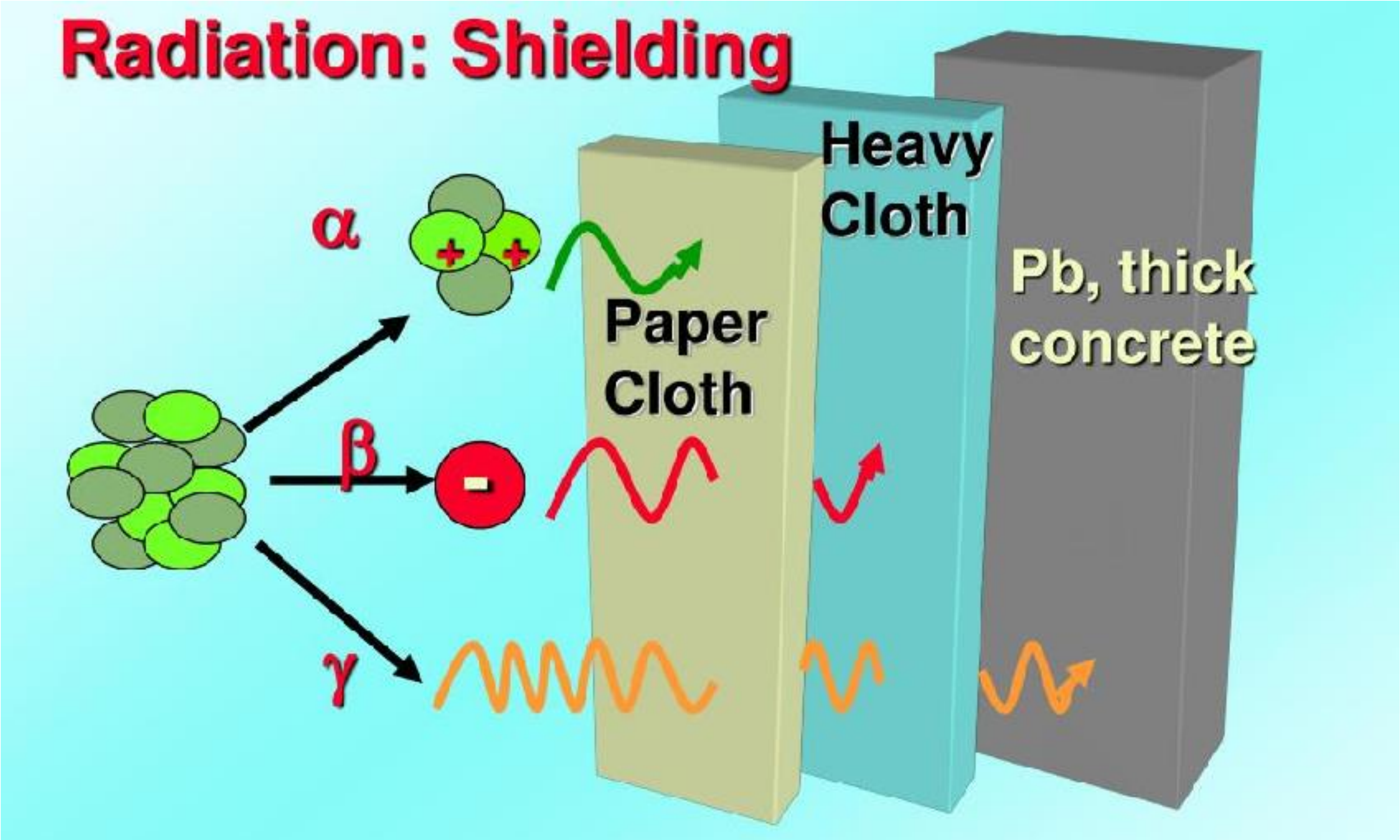
$$ {}^{99m}_{43}\mathrm{Tc} \xrightarrow[6 \text{ heures}]{\gamma \ 141 \text{ keV}} {}^{99}_{43}\mathrm{Tc} $$

Molybdenum
technitium generator
^{99}Mo/^{99m}Tc





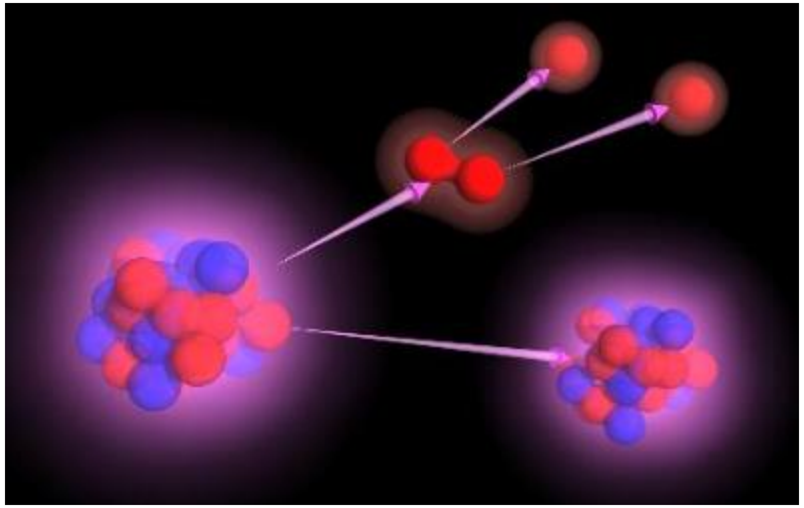
Radiation penetration ability


Radiation: Shielding
α
β
γ
Paper
Cloth
Heavy
Cloth
Pb, thick
concrete

Radioactive isotopes and half life

Radioactive decay law

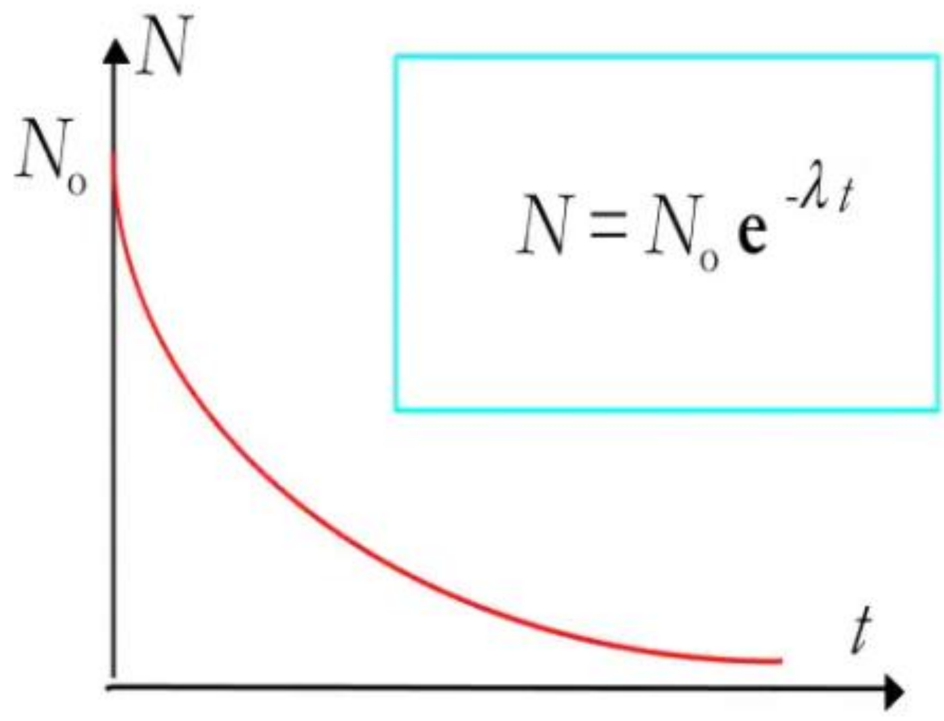
- **Radioactivity is a random event, we do not know which atom will decay at what time, but we can use probability and statictics to tell us how an atom will decay in a certain period of time.**
- The probability of disintegration, is called disintegration or decay constant and it’s noted λ



Radioactive decay law

- The number of radioactive nucleide decreases exponentially with time as indicated by the graph.

Variation of N as a function of time *t*



Activity

- Activity noted **A** is a random process. The number of radioisotopes that will decay deppends on the number of radioisotopes present at that point in time

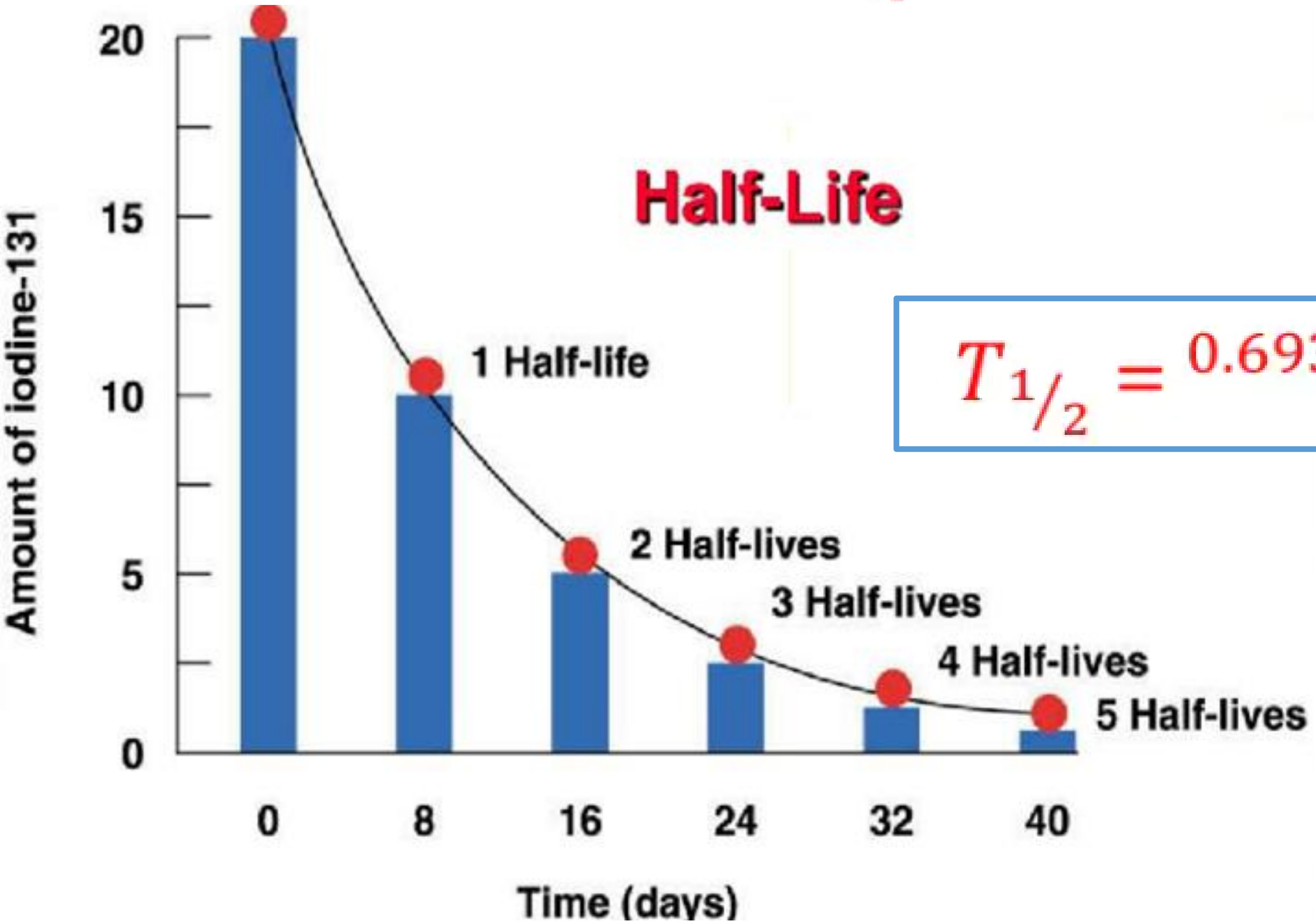
- According to decay law, the rate of disintegration is directly propotional to the number of atoms present

- **A = λN, λ is the decay constant; it is constant for a particular radioisotope**

Ao = λNo

$$A = A_o e^{-\lambda t}$$

Half- life $(T_{1/2})$



$$T_{1/2} = {}^{0.693}/\,\lambda$$

Radionuclides used in nuclear medicine

^{99m}Tc : $(T_{1/2})$ = 6 heures

^{131}I : $(T_{1/2})$ = 8 days

^{18}F : $(T_{1/2})$ = 110 mn

^{125}I : $(T_{1/2})$ = 60 days

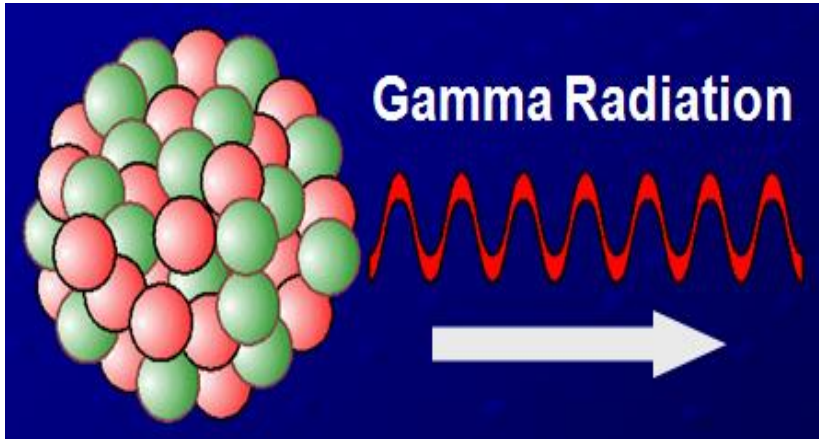
The Use of radioactivity

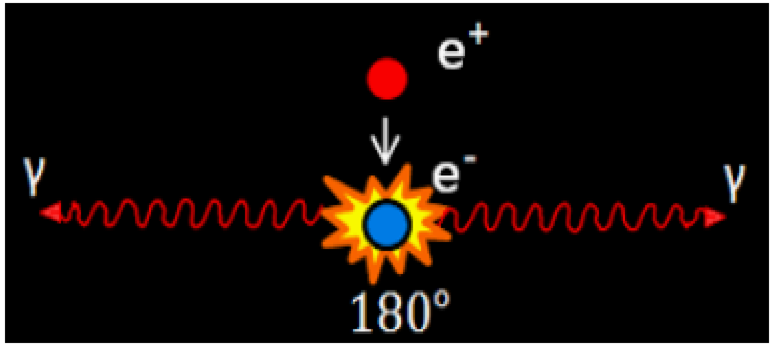
- **Nuclear medicine**
- **Brachytherapy**

Nuclear medicine

❖**For diagnosis:**

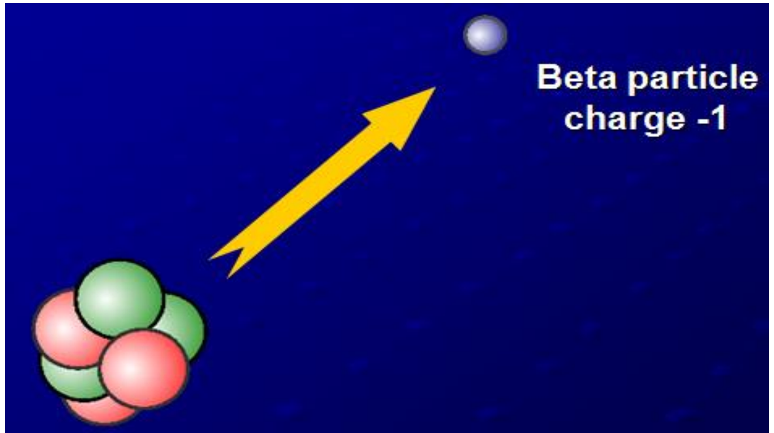
use radionuclides gamma emitter. This radiation can pass through tissues and be detected outside the body.





❖**For therapeutic:**

- **use beta emitter**
- **(a low tissue path, is used to deliver a high local dose).**



Radionuclides used in nuclear medicine

Molybdenium/Technetium Generator

Iodine 131

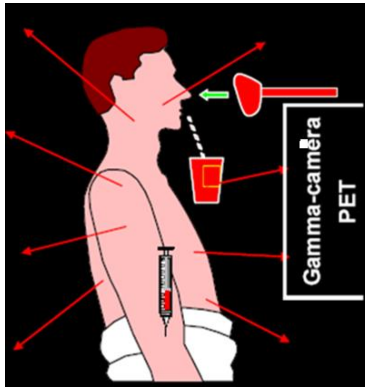
Iodine 125, RIA kit

Samarium

Hot Lab (CHU, FES)

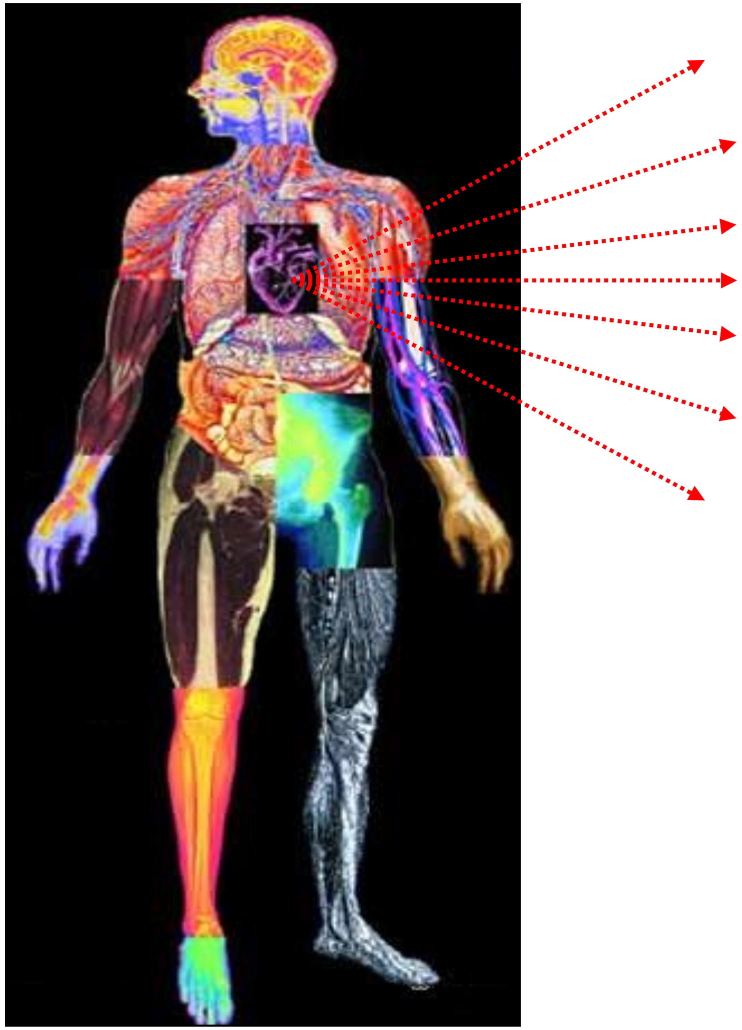
Preparation of the radiotracer

- $^{99}Mo/^{99m}Tc$ generator

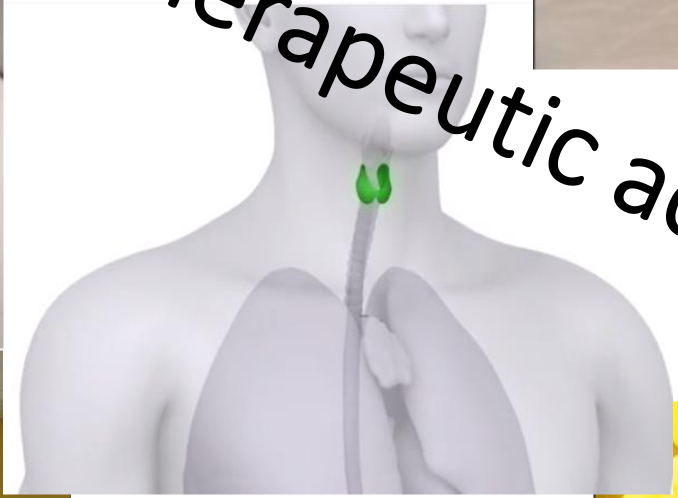


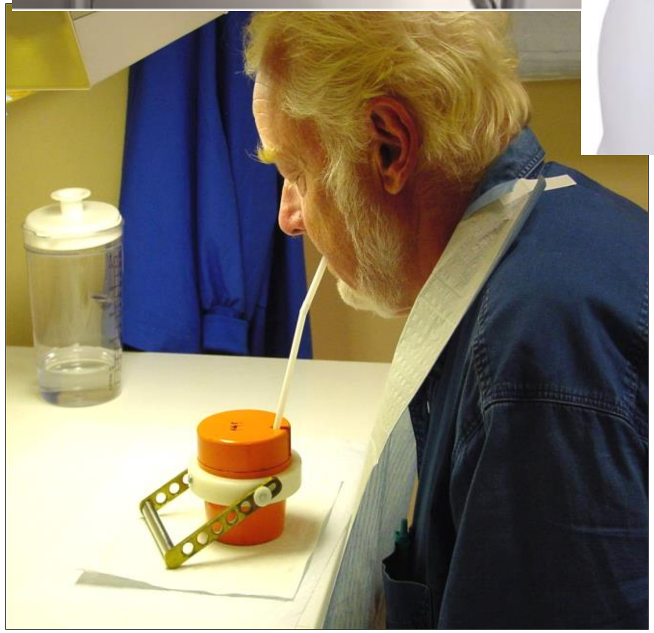
Diagnosis activities

Detection



Therapeutic activity

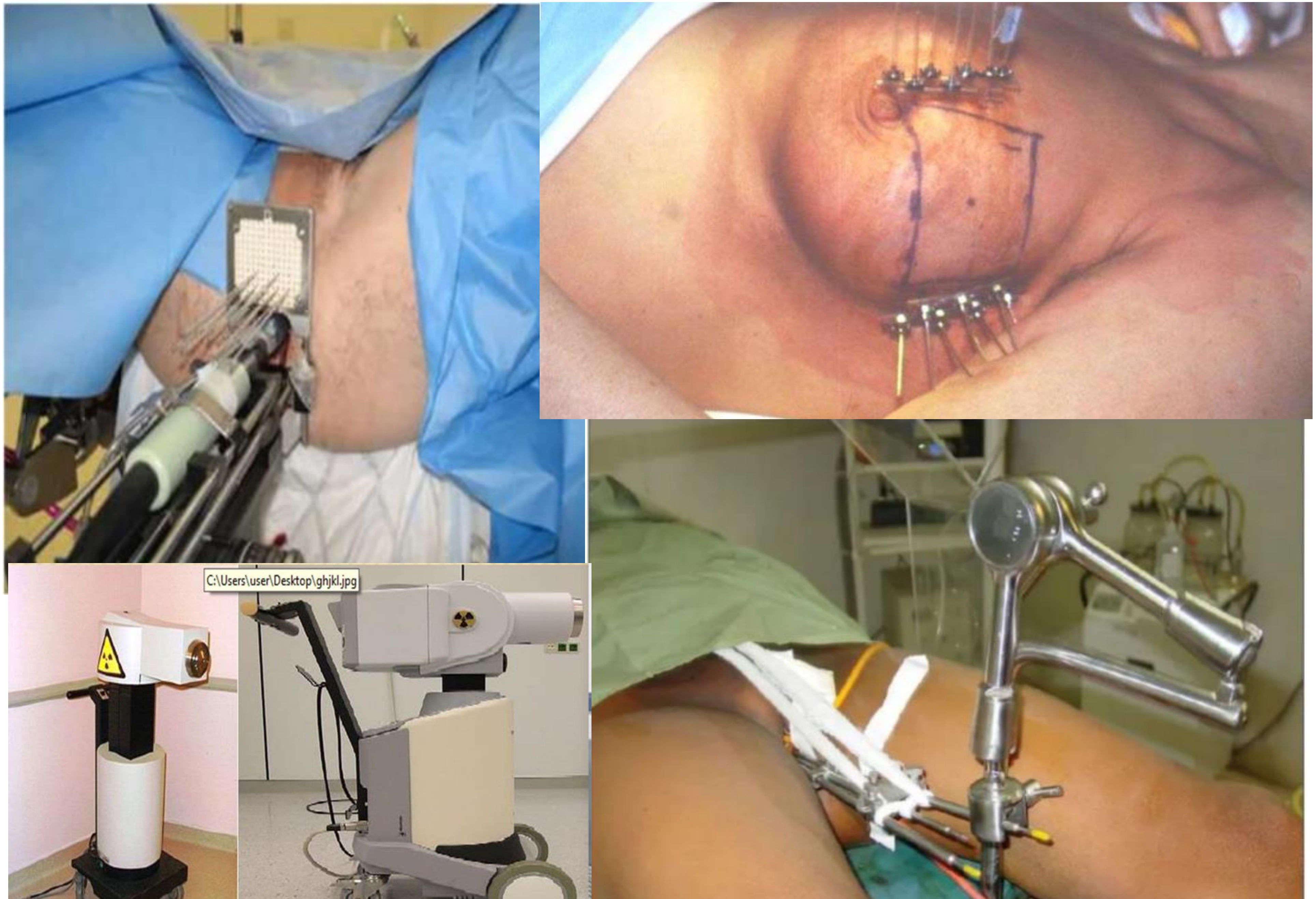




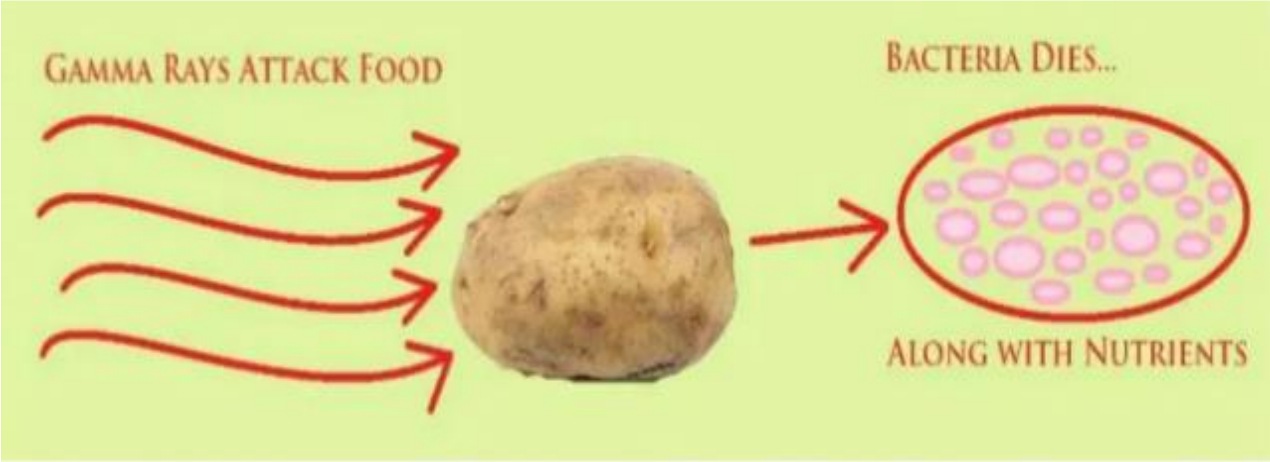


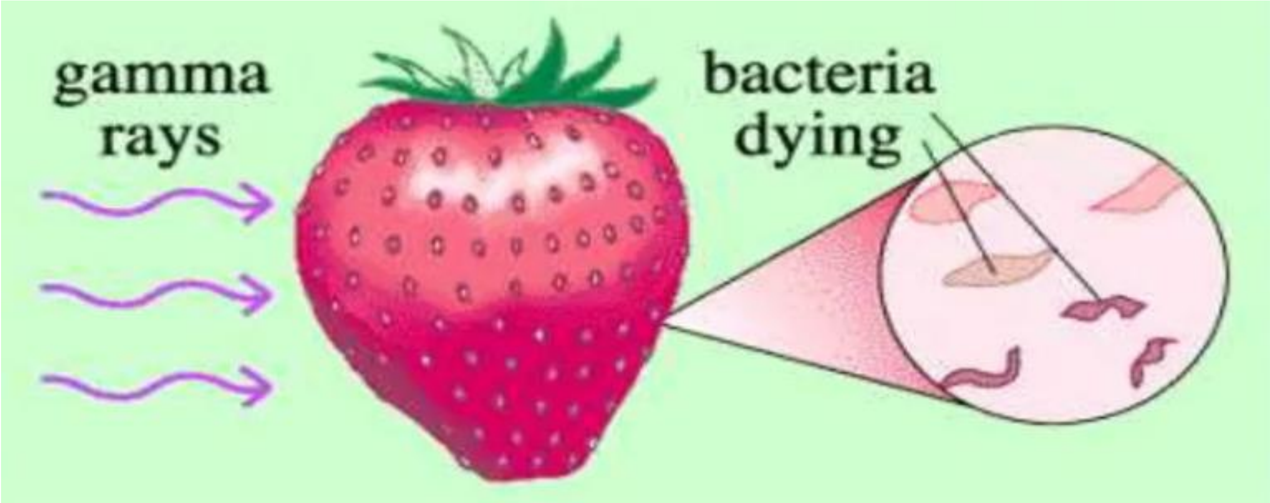
Radio immino assay (RIA) technics

Brachytherapy



Protection of Agricultural material





One irradiator with cobalt source, in Morocco

References

- Thomas Jue Editor Handbook of modern biophysics, biomedical applications of iophsics, Human press

- Knoll, G. F. - Radiation detection and measurement - 3rd ed – Wiley (2000), Available http://www.nist.gov/index.html

- BERGER, M.J., ESTAR, PSTAR AND ASTAR: Computer programs for Calculating Stopping-Power and Ranges for Electrons, Protons and Helium Ions. NIST Report NISTIR-4999

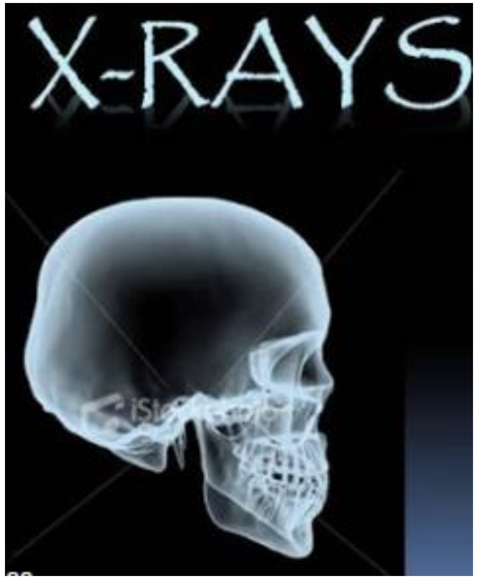
- Simon R. Cherry, Michael E. Phlps, Physics in Nuclear Medicine, Elsevier Health Sciences.

- Nuclear Medicine Physics , a Handbook for Teachers and Students, IAEA publications

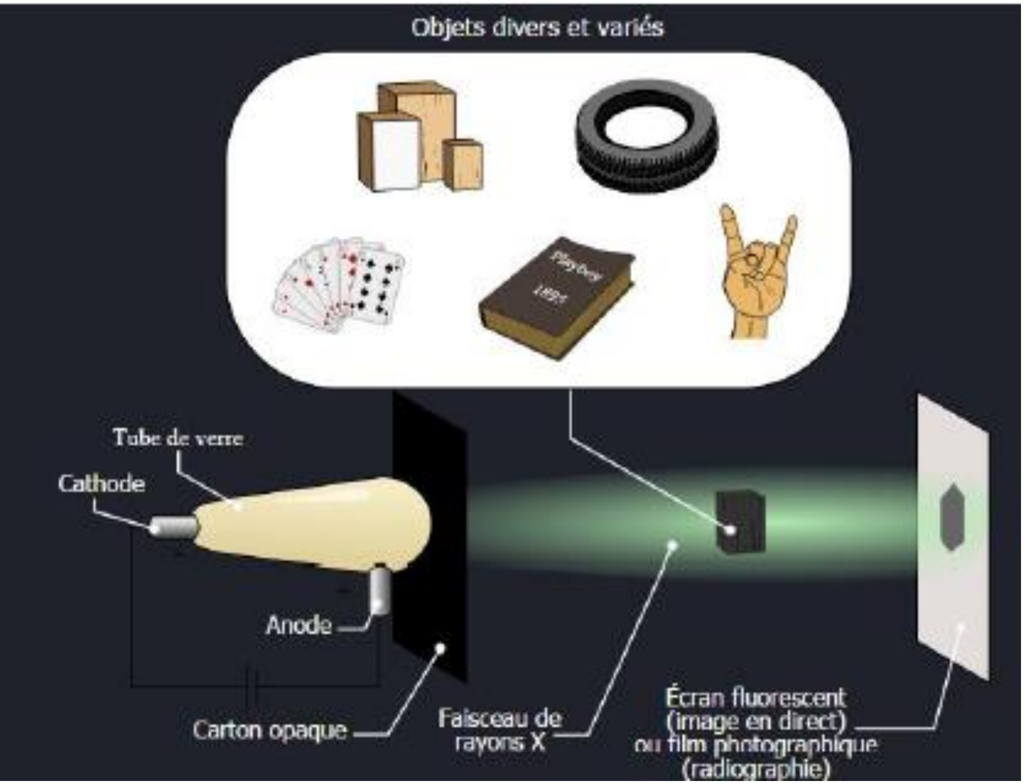
Physics of X rays

Objectives

- To introduce the Nature and Properties of X-rays
- Define the origine of X rays
- Explain the Braking radiation: Bremsstrahlung radiation
- Fluorescence (characteristic) radiation
- X rays production's technology
- Uses of X rays



The discovery of X rays



anatomist and physiologist Kölliker

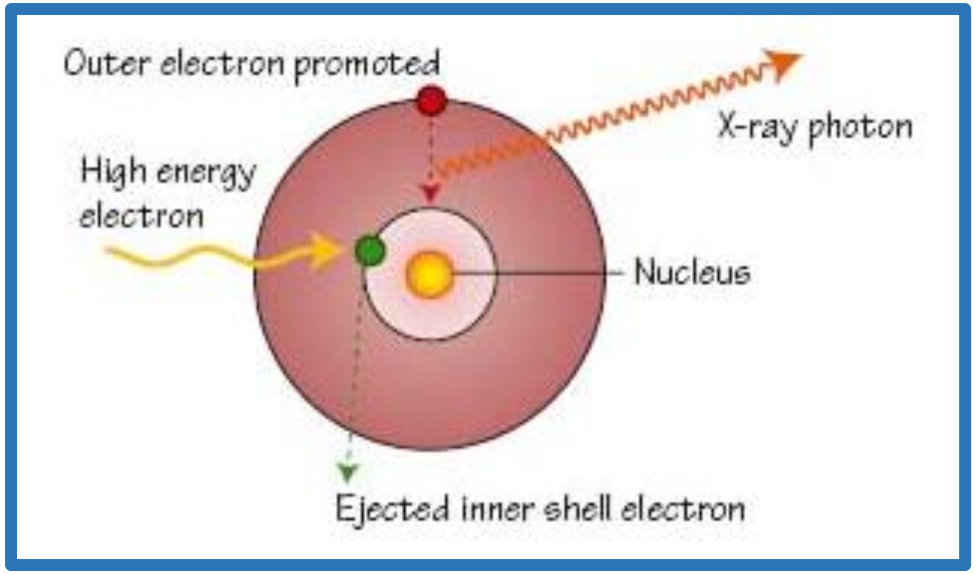
Properties of X rays

- EM radiation can be described by two models:
  - Wave model
  - Photon model
- The energy (E) is related to the wavelength (λ) in the model through Planck constant and the speed of light (c)

$$E = h\,c\,/\,\lambda$$
$$E = h\,\nu$$

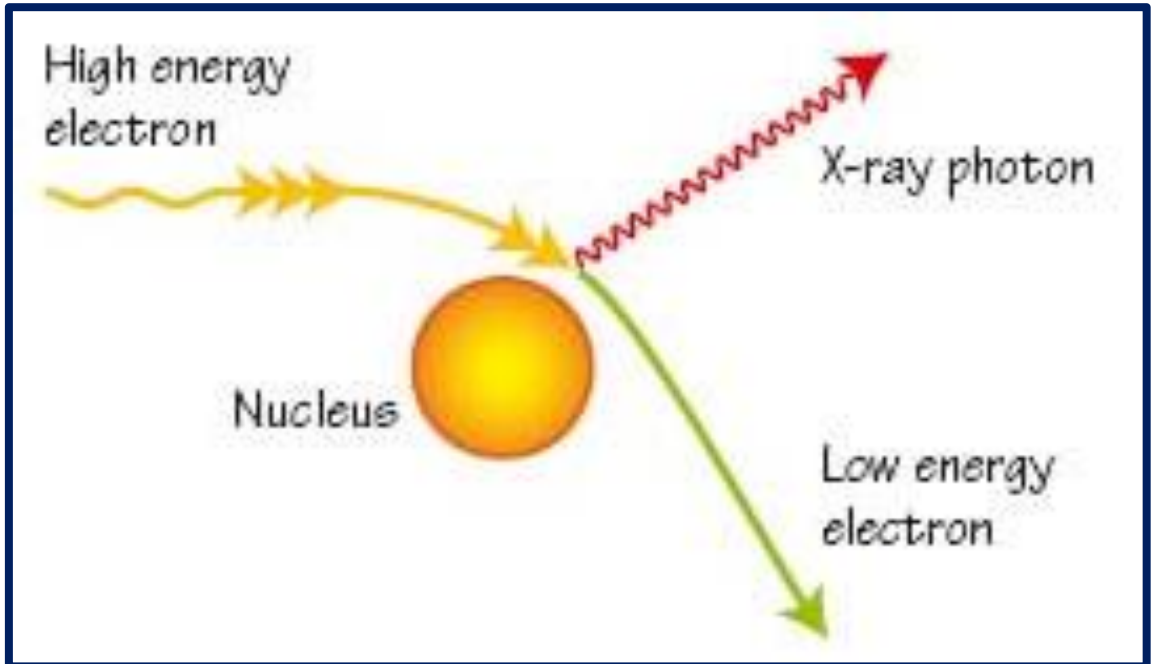
- **10 kev : « soft» X rays**
- **40 -140 kev: Radiodiagnosis**
- **4 - 25 Mev : radiotherapy**

The origine of X rays



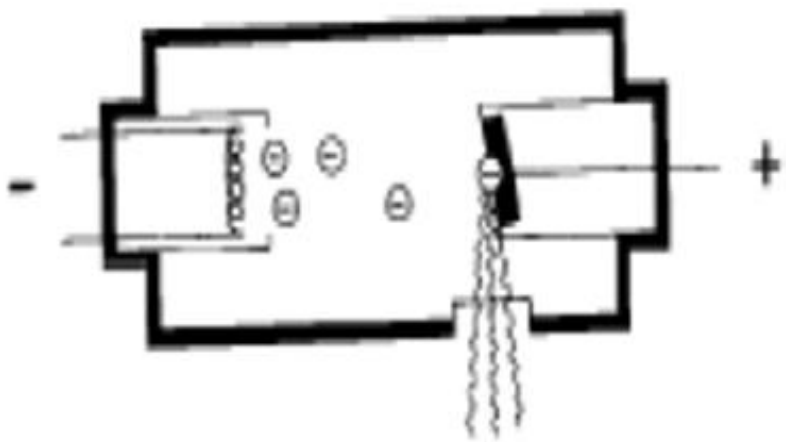
Interaction of incident electrons with atom electron

Interaction of electrons with the nucleus

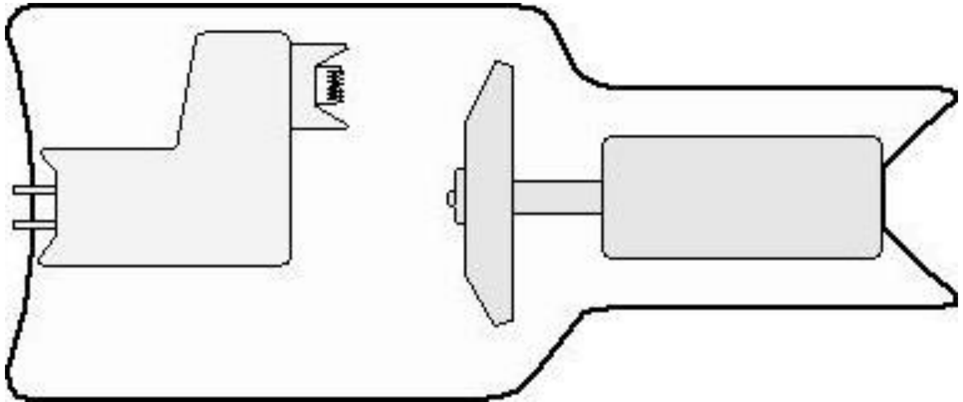


X-Rays production's Technology

X rays production’s technology



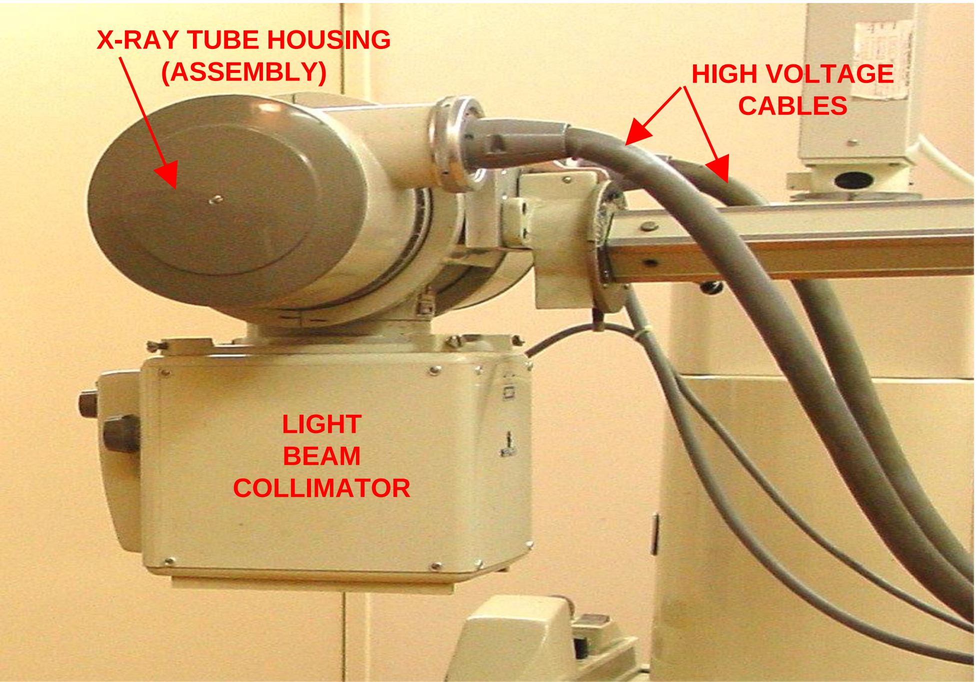
- An RX generator must:
  - ➥produce electrons,
  - ➥ accelerate them,
  - ➥send them to a target.
- The usual X-ray source is represented by the Coolidge tube named after its inventor.

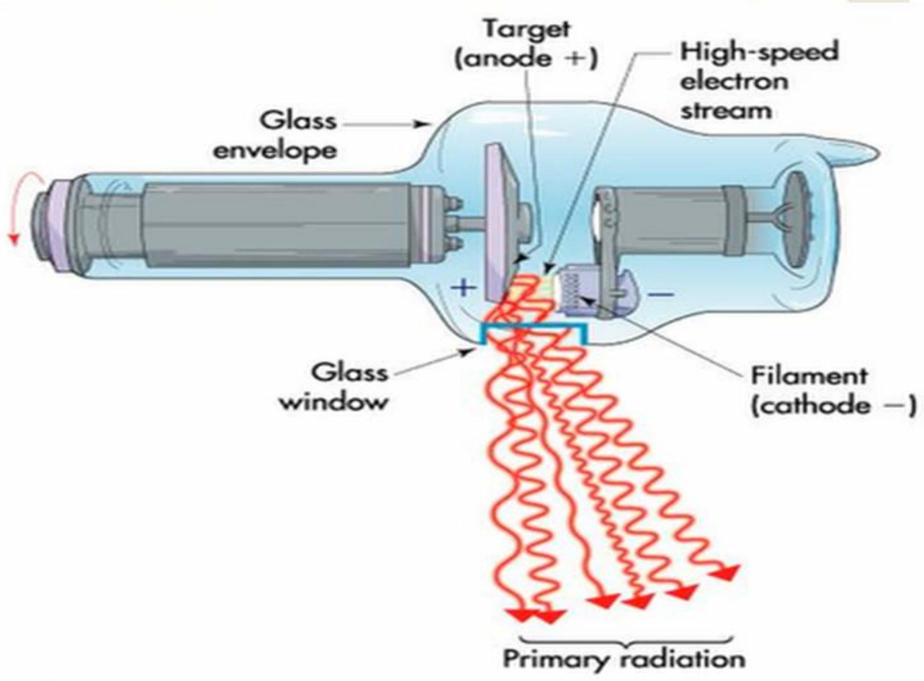


- The kinetic energy of the electrons is converted into X rays (no more 1%) and into heat (99 %) (X-ray emission percentage is low).

X-ray machine's components

- ✓ **The tube head** where the X rays are generated
- ✓ **The control panel** which regulates the amount of the X rays produced and trigger the patient exposure
- ✓ **The power supply** which provide the energy to create the X rays





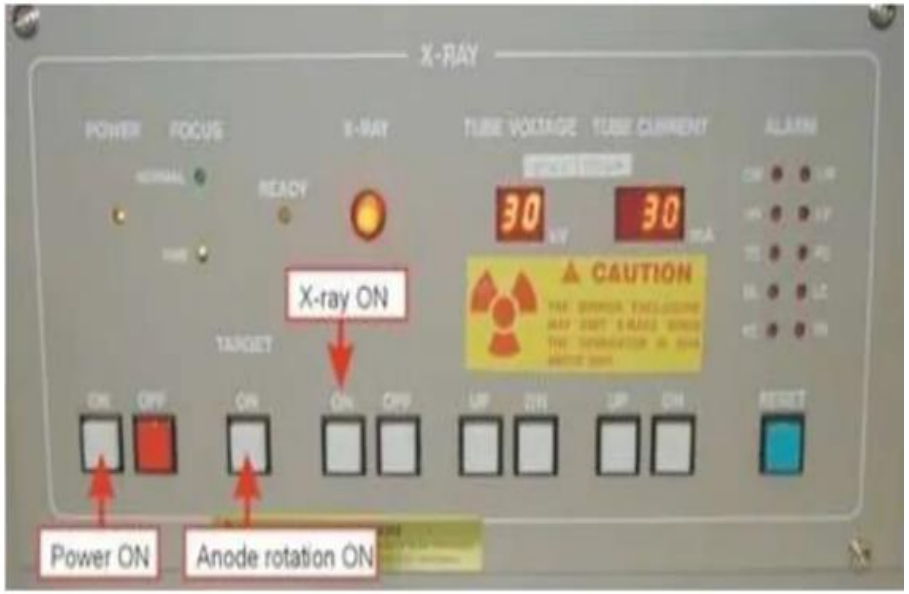
Factors of radiography

- The three factors that can be varied during producing radiograph are:

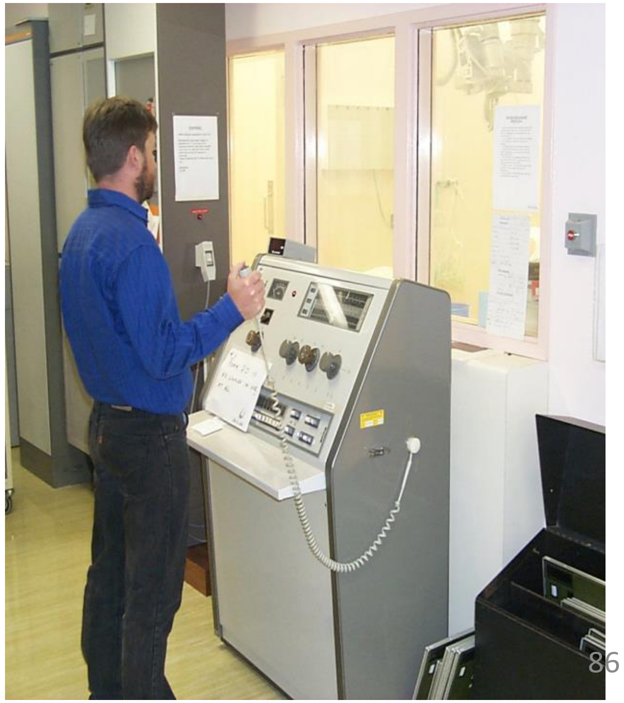
▪ **The kilovoltage (KV)** difference applied between the anode and cathode during exposure

▪ **The millamperage (mA)** applied to the filament

▪ **The duration of exposure**



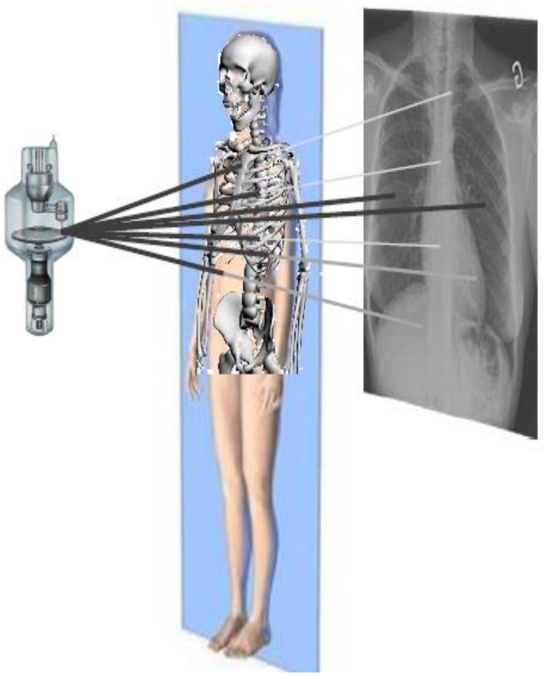
Control panel



Factors of radiography

- **Higher KV** produce X-rays with **higher energy** and greater tissue penetrating power.
- **Increasing mA increases the number of electron's** cloud around the filament.

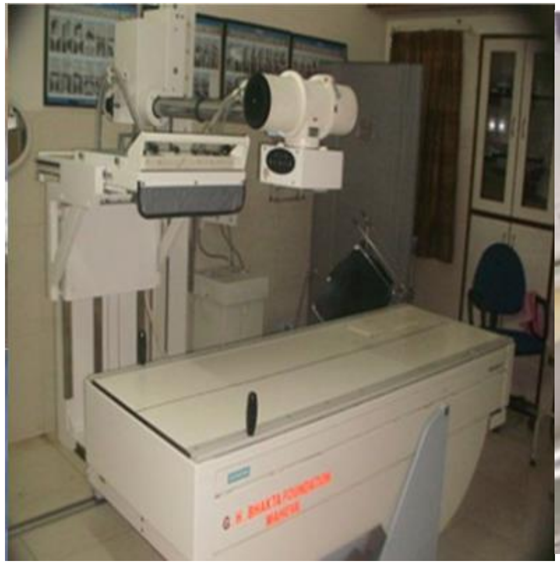
  Which result in **higher number of X-rays** produced per second.



Medical applications

Radiodiagnosis

- X rays are used for the diagnosis of many diseases that cannot be identified by pathological tests (fractures in the bones, diseased organs and the presence of foreign matter in the body.



Radiodiagnosis

- Surgical and set of methods that use computer technology for presurgical planning, and for guiding or performing surgical interventions.

Computer assisted surgery

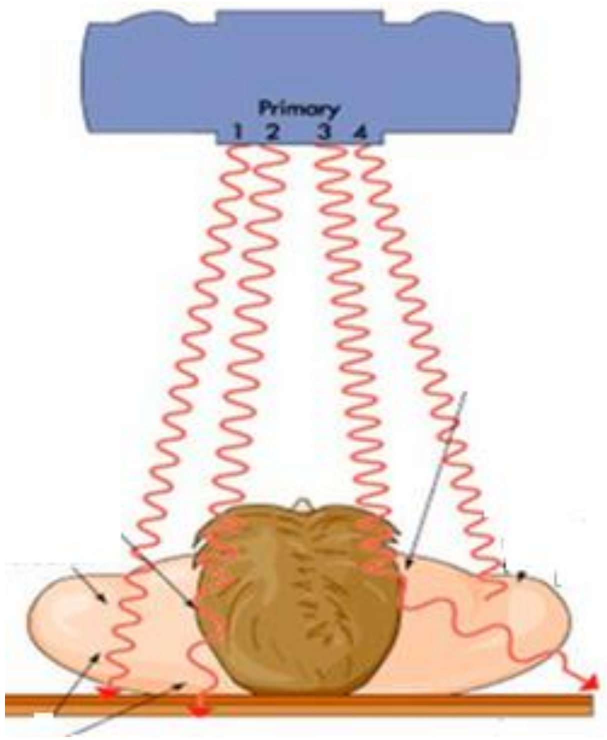
Future developments

- Telesurgery
- Full robotics operation

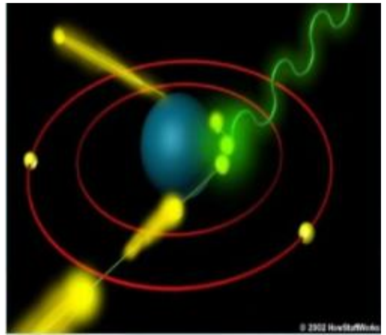
References

- Handbook of X-ray Imaging: Physics and Technology (Series in Medical Physics and Biomedical Engineering) 1st Edition
  by Paolo Russo (Editor)

- The X Rays. Their Production and Application Paperback – Import, 28 January 2013, Kolle Frederick strange



Interactions of Radiation with Matter



Introduction:

- Radiation is classified into two main categories:
- Non-ionizing radiation (cannot ionize matter).
- Ionizing radiation (can ionize matter).
  - ✓ **Directly ionizing radiation** (charged particles): electrons, protons, alpha particle, heavy ions
  - ✓ **Indirectly ionizing radiation** (neutral particles): photons (X ray, gamma ray), neutrons

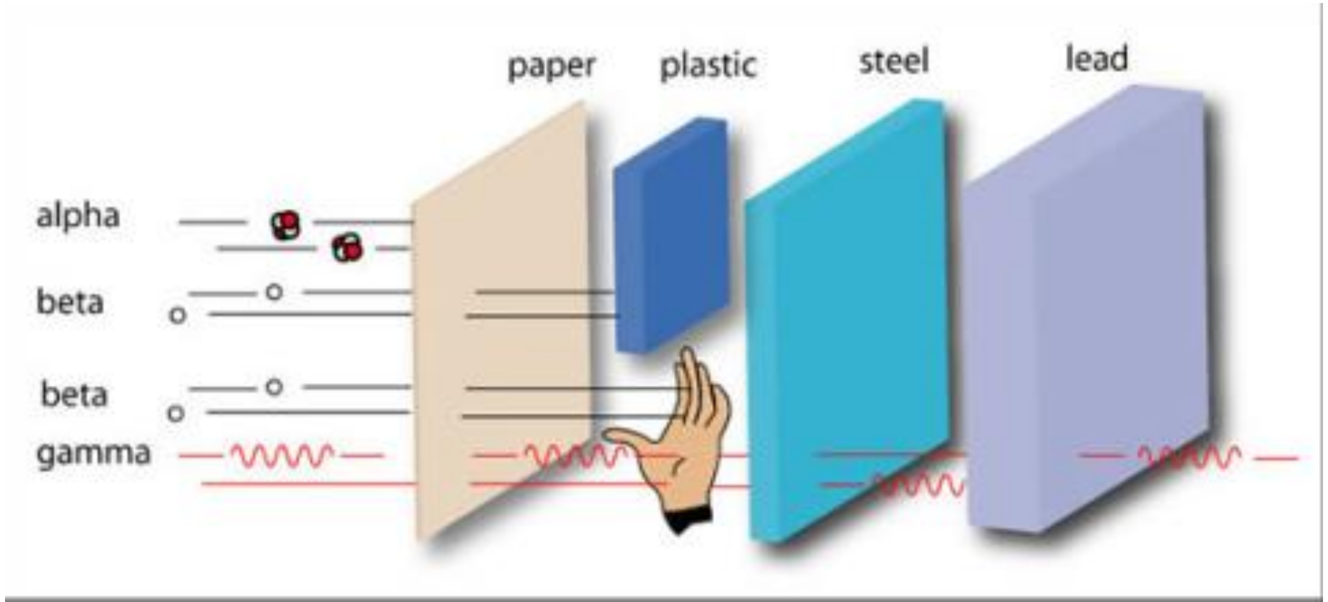
Photon Interactions with matter

What is the difference between Photons and Charged Particles interaction

- **Since photons have no charge, they interact with matter differently than charged particles**

- **For photons, we discuss the probability of interaction per unit distance travelled**

- **As charged particles penetrate matter, they loose energy continuously along their travel path through the creation of ion pairs. Contrast this with photon interactions, where gamma rays (or Xrays) can interact or emerge from a shield with the same energy**



Classification of photon ionizing radiation

- **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.

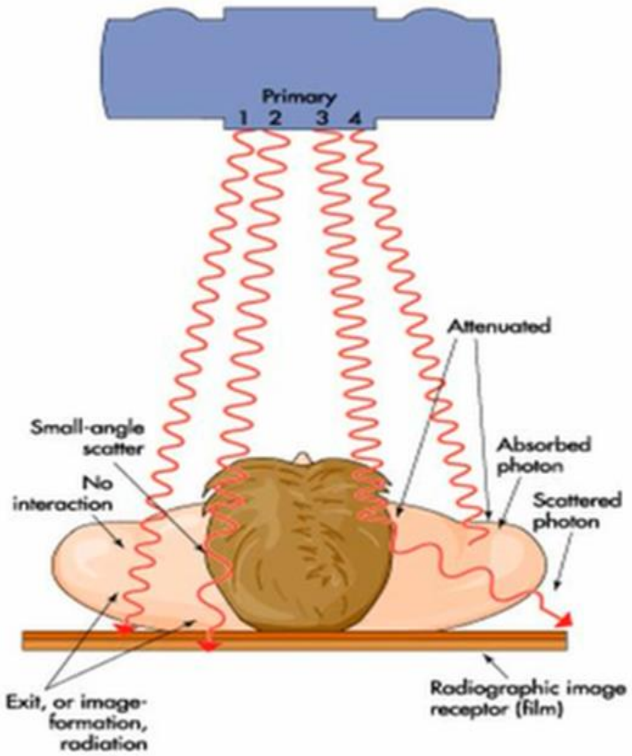
✓ **Annihilation quantum** (annihilation radiation): Results from positron-electron annihilation.

How the photons interact with matter?

- 2 possibilities of photon's interaction with matter:

➢ **Photons interactions with electron**

➢ **Photons interactions with nucleus**



The Five interactions of photons with matter

Photon-electron interaction

- ✓ **Photoelectric effect**
  - Very important in diagnostic radiology
- ✓ **Compton scatter**
  - Very important in diagnostic radiology
- ✓ **Coherent scatter**
  - No importance in diagnostic or therapeutic radiology
- ✓ **Pair production**
  - Very important in therapeutic radiology

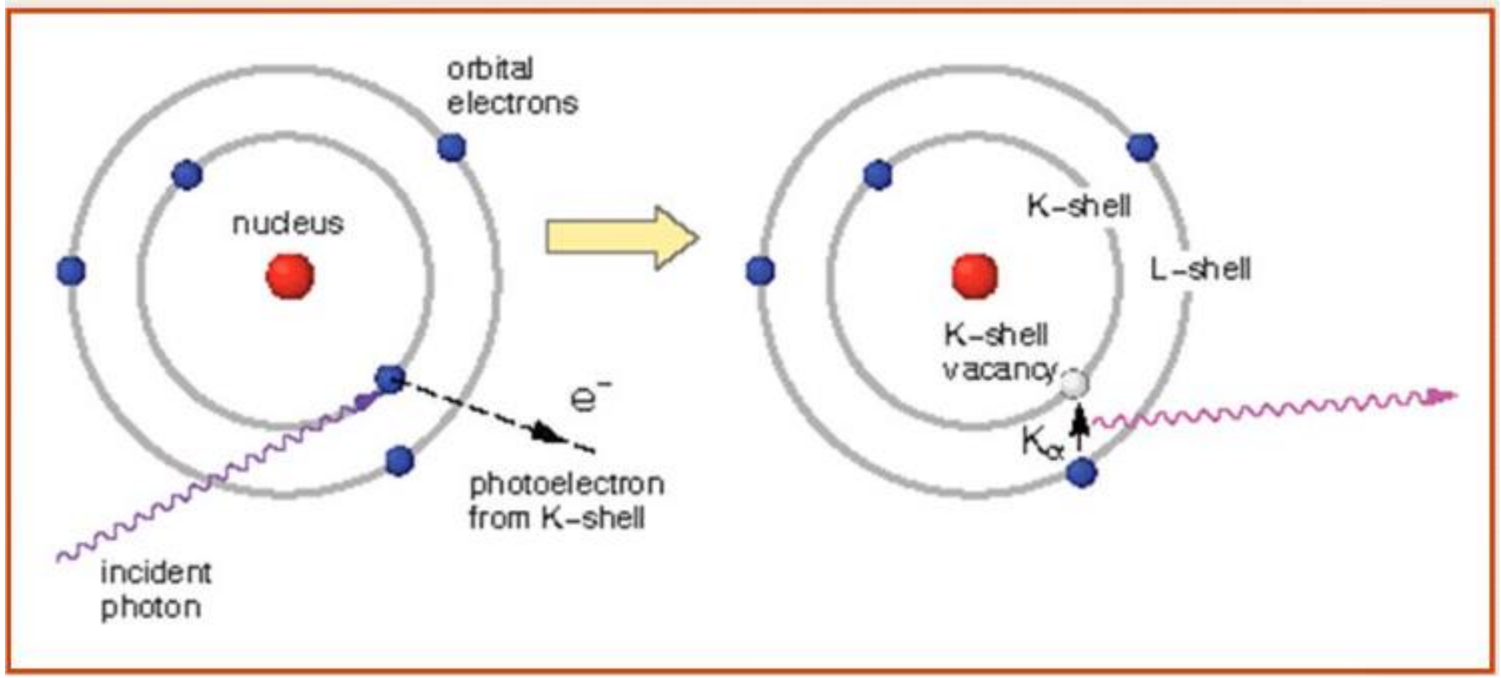
Photon-nucleus interaction

- ✓ **Photodesintegration**
  - Very important in therapeutic radiology

Photon-electron interaction

Photoelectric effect

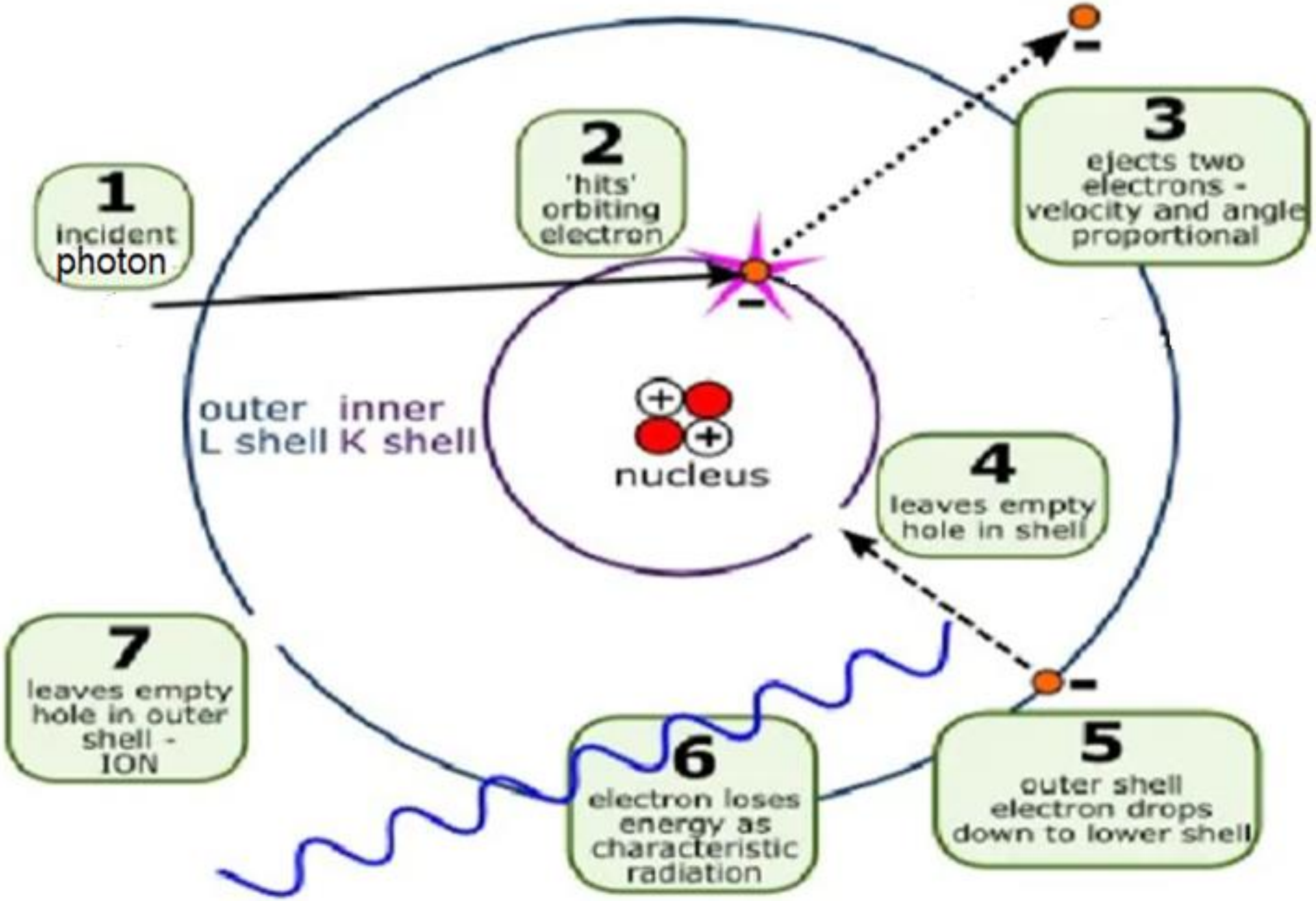
- ✓ The incoming photon interacts with an orbital electron in an inner shell-usually K.
- ✓ **All of the energy** of the incoming photon is **totally transferred to the atom.**
- ✓ Following interaction, the photon ceases to exist
- ✓ The orbital electron is dislodged
- ✓ To dislodge the electron, the energy of the incoming photon must be equal to, or greater than the electron's energy
- ✓ This ejected electron can interact with other atoms until loosing all of its energy.



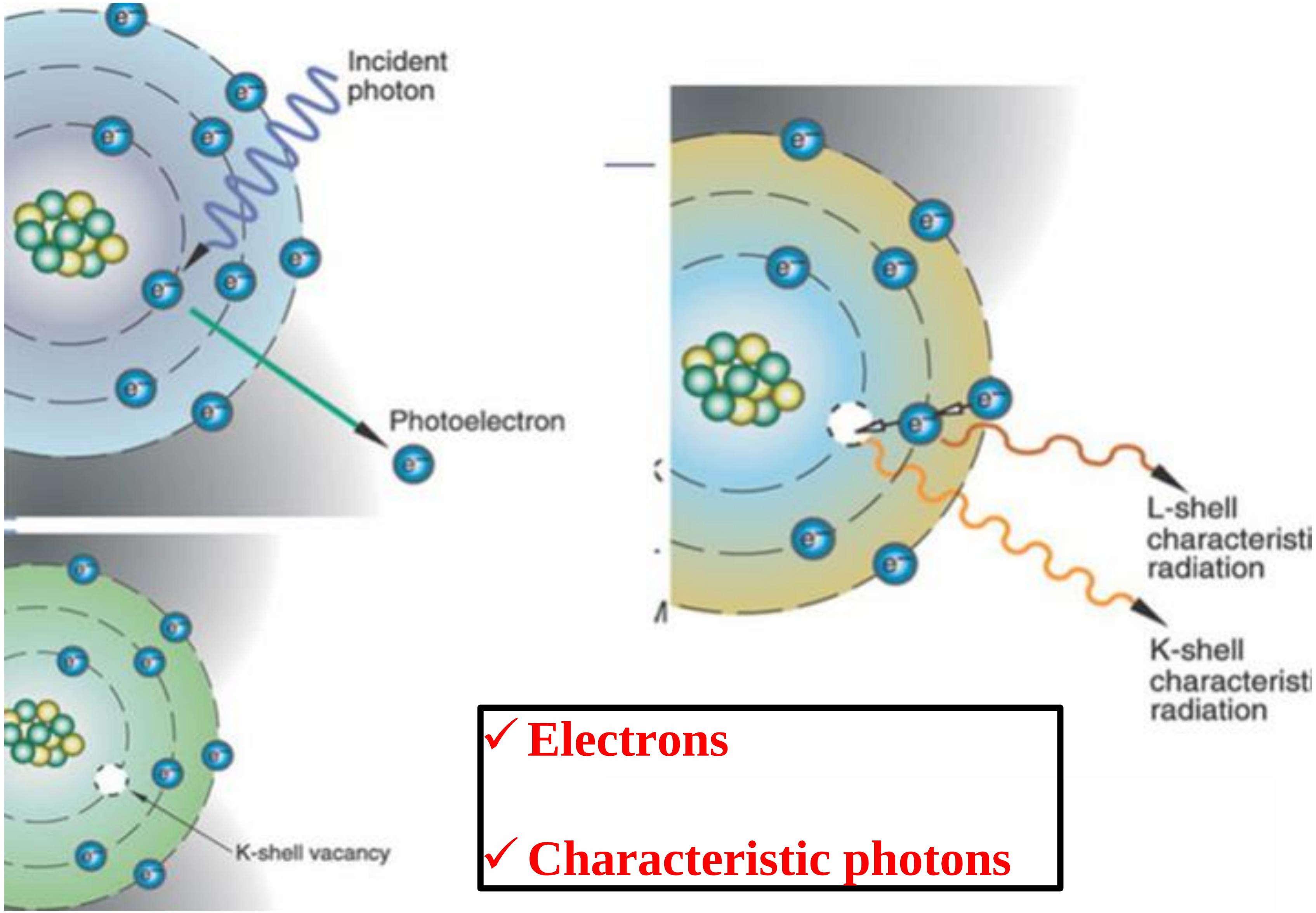
Photoelectric effect

- ✓ These interactions results in an increased patient dose, contributing to biological damage

Photoelectric effect



The byproducts of the photoelectric effect



- ✓ Electrons
- ✓ Characteristic photons

The probability of occurence

- Depends on the following:

✓ The energy of the incident photon

✓ The atomic number of the irradiated object

✓ **It increases as the photon's energy decreases, and the atomic number of the irradiated object increases**

✓ When the incident photon's energy is more or close to the binding energy of orbital electron

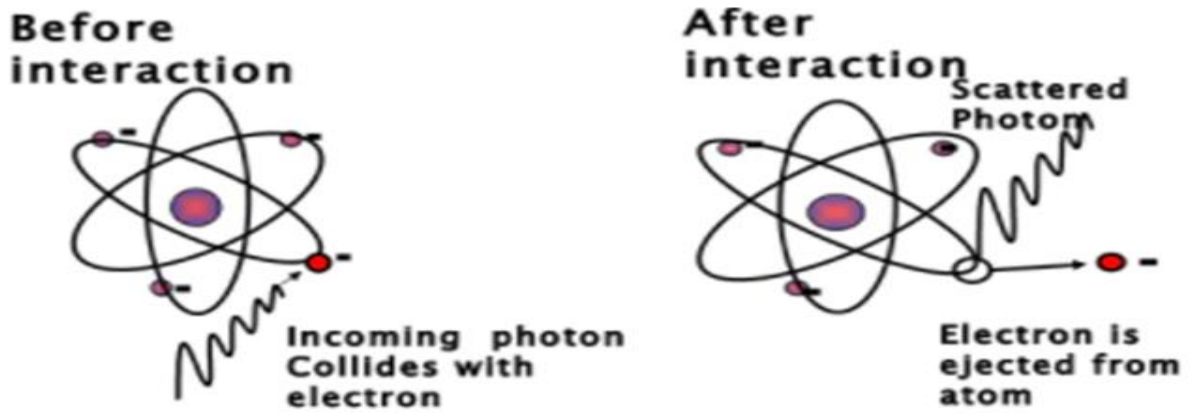
The probability of occurrence = $\frac{Z^3}{E^3}$

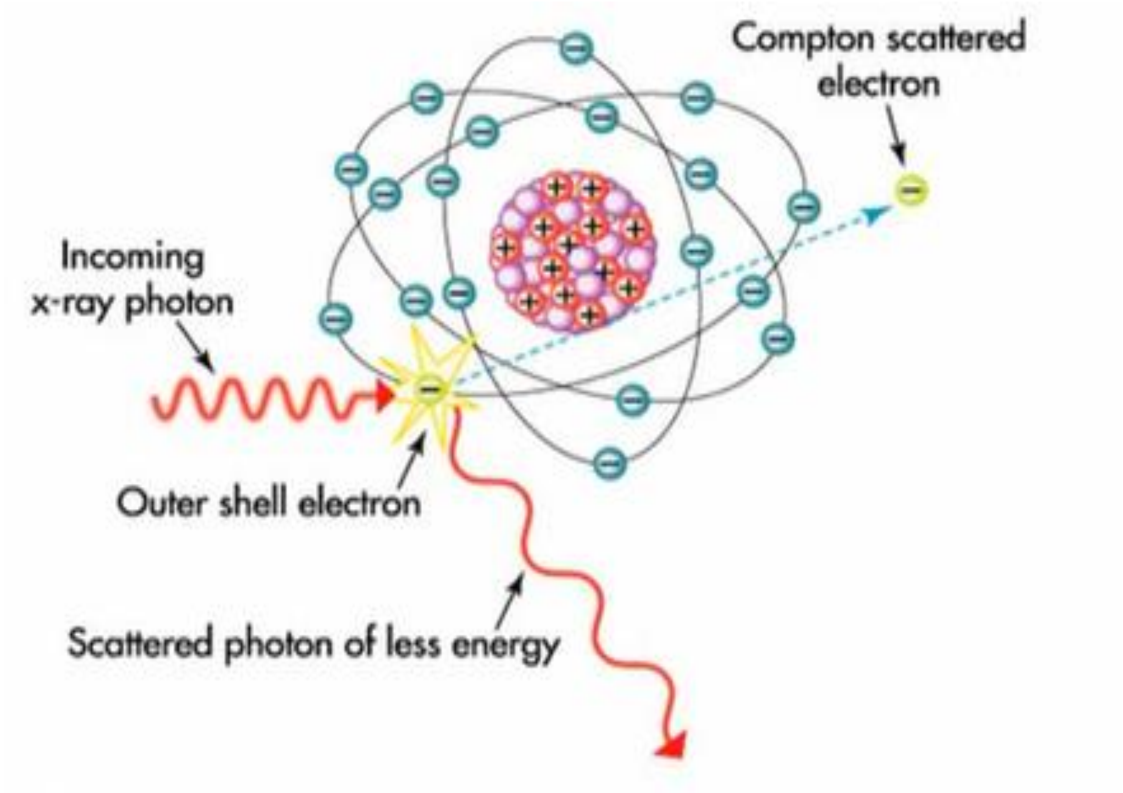
What does this all mean?

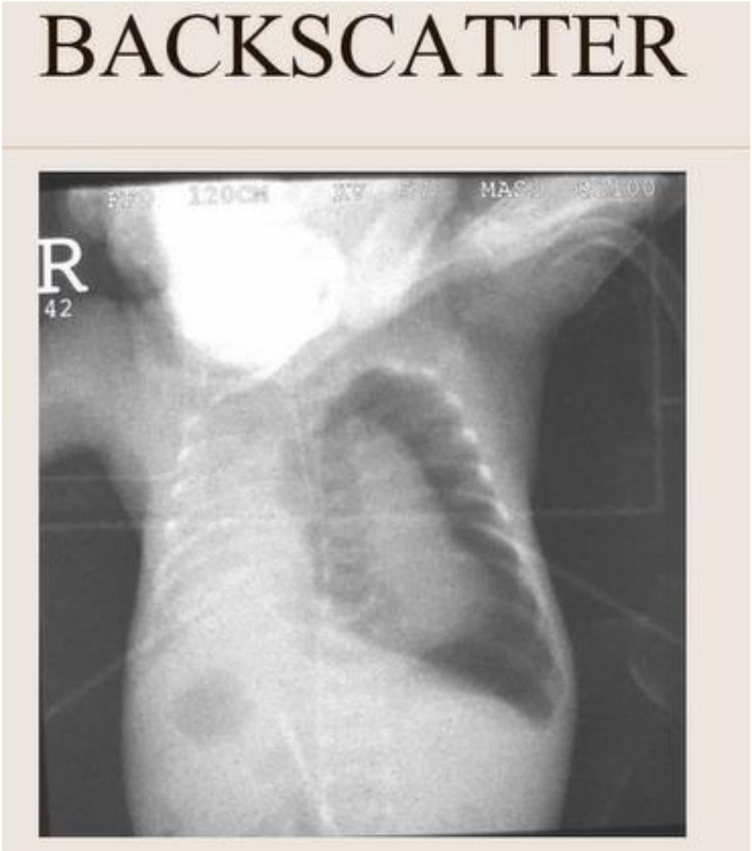
- ✓ **Bones** are more likely to absorb radiation
  - ▪ This is why they apppear **white** on the film
- ✓ **Soft tissues** allow more radiation to pass through than bones
- ▪ These structures will appear **gray** on the film
- ✓ **Air containing structures** allow more radiaton to pass through.These structures will appear **black** on the film

Compton scattering

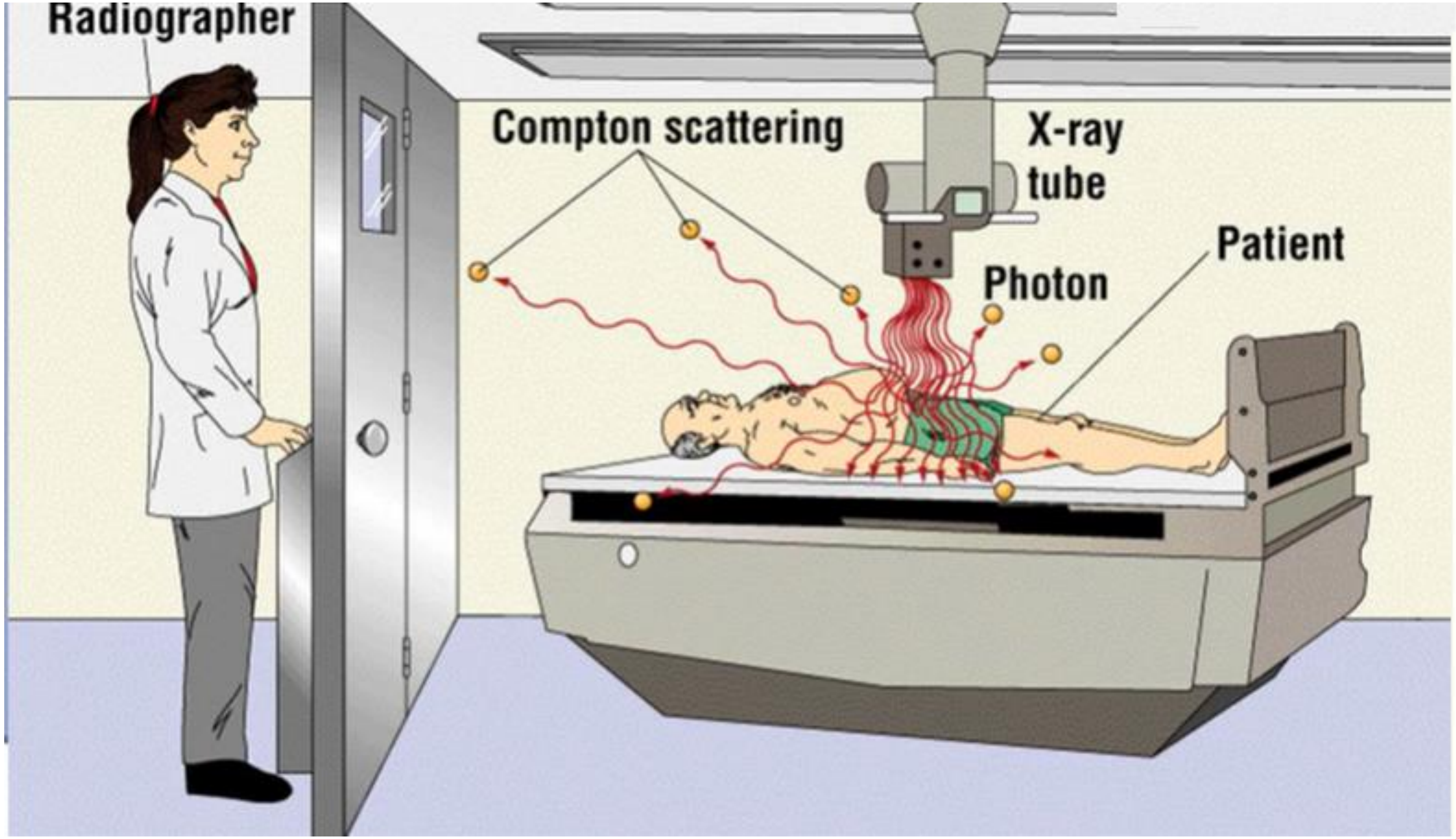
- An incoming photon is partially absorbed in an outer shell electron
- X ray photon transfer **some of its energy** to the electron and the rest of the energy is given to the Compton scattered photon.
- Not much energy is needded to eject an electron from an outer shell
- The electron uses this amount of photon energy to leave the atom.
- The incoming photon, continues on a different path with less energy as scattered radiation







Compton scatter

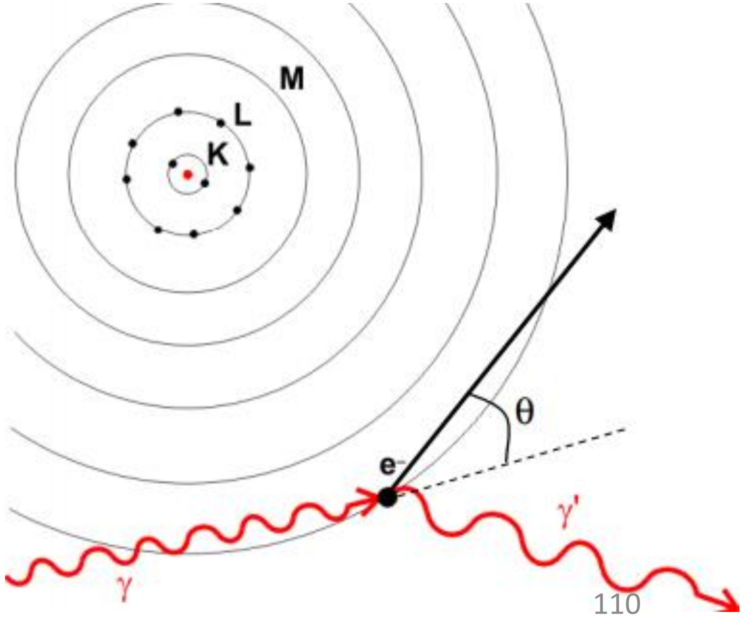


- Scattered X ray’s photon Continues on its way, but in a different direction

Probabily of Compton scatter occurring

- ✓ **Compton scattering is dominant for intermediate photon energies.** Increases as the incoming photon energy increases
- ✓ Results: **Most of the scattered radiation produced during a radiographic procedure**

More probable at KV ranges of 100 or greater



Pair Production

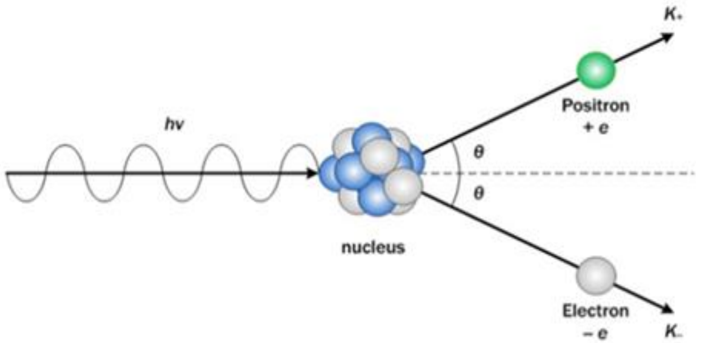
✓ Pair production is of particular importance when high energy photons pass through materials of a high atomic number.

✓ **An incoming photon of 1.02 MeV or greater** interacts with the **electron located very close to the nucleus** of an atom.

✓ The incoming photon disappears

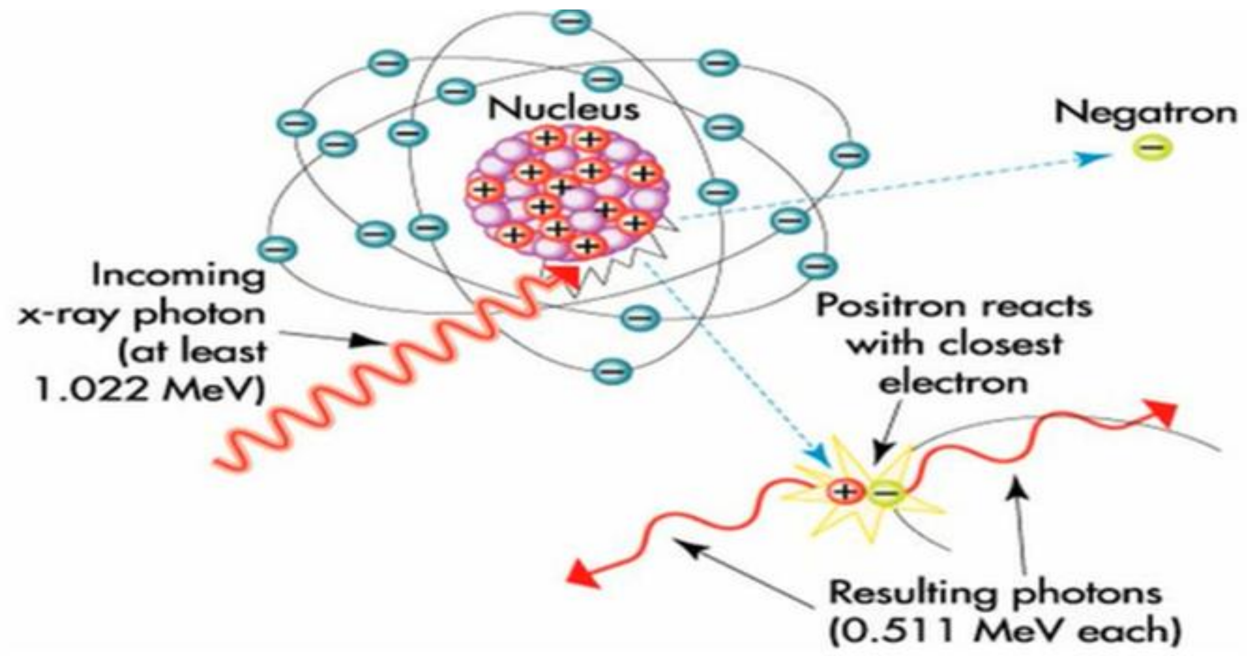
✓ The transformation of energy results in the formation of two particles:

- **Negatron**, Possesses negative charge
- **Positron**, Possesses a positive charge



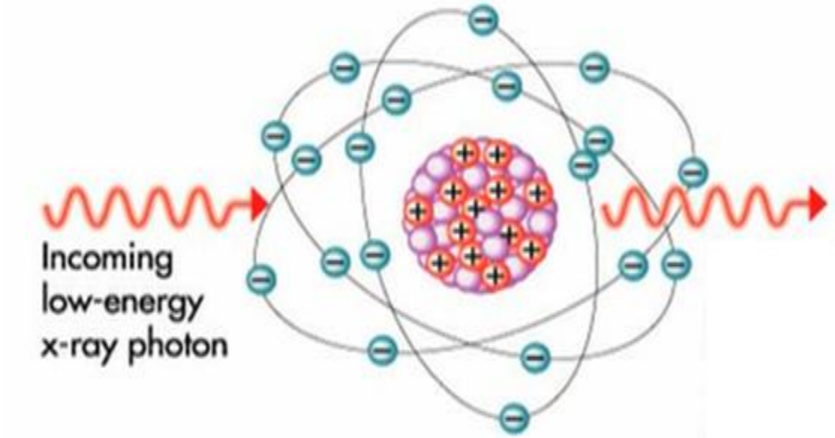
Probability of Pair Production occurring

- Energy ≥ 1,022 Mev

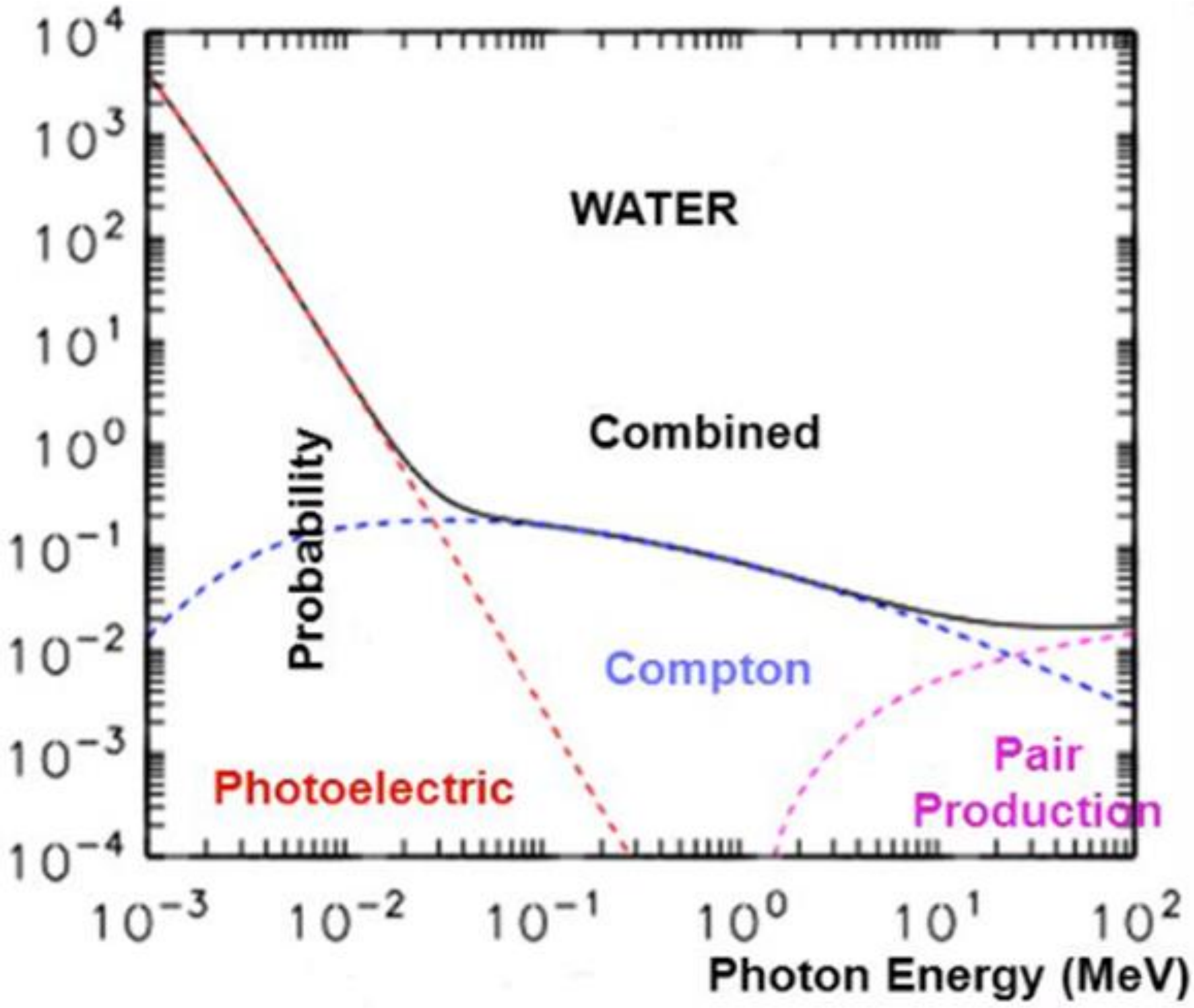


Thomson scattering

- ✓ Also known as Raleigh, coherent, or classical scattering**, occurs below 30 KeV**
- ✓ An incoming photon interacts with an atom.
- ✓ The atom **vibrates** momentarily
- ✓ Energy is released in the form of **an electromagnetic wave**
- ✓ The photon changes its direction, but no energy is transferred



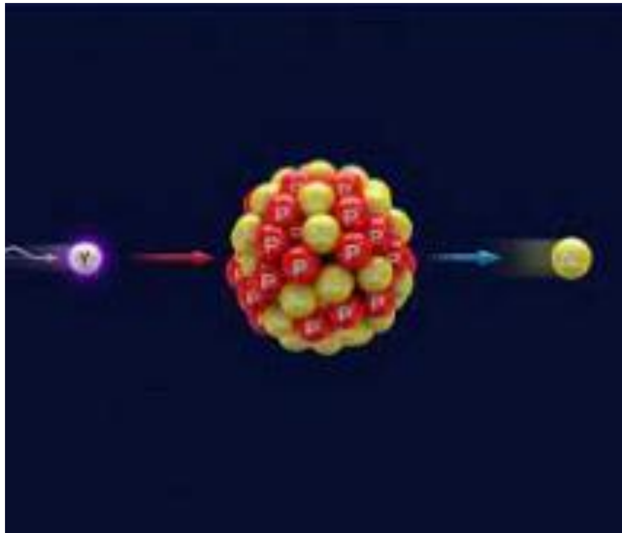
Importance of various interations of X rays with matter



Photon-nucleus interaction

Photodisintegration (PD)

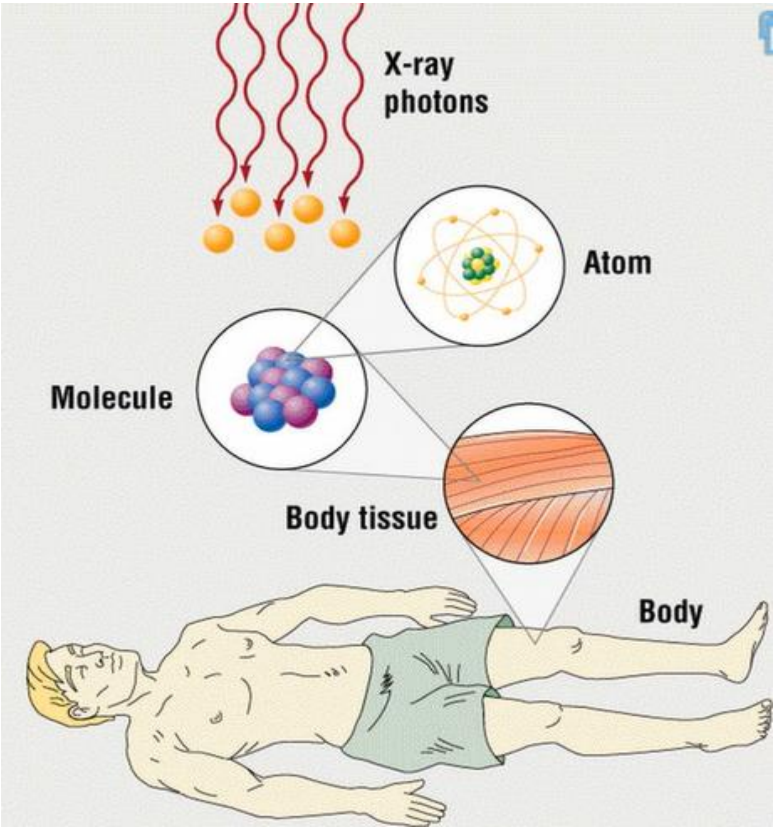
- ✓ Occurs at above 10 Mev of energy
- ✓ **Photodisintegration** is the process by which the X ray photon is captured by the nucleus of the atom.
- ✓ A high energy photon **is absorbed by the nucleus**
- ✓ **The nucleus becomes excited and radioactive**
- ✓ To become stable, the nucleus emits negatrons, protons, alpha particules, clusters of fragments, or gamma rays
- ✓ These high energy photons are found in radiation therapy



Importance of various interations of X rays with matter

Interaction	Where Important
Coherent scattering	Not important in any energy range
Compton scattering	Diagnostic radiology
Photoelectric absorption	Diagnostic radiology
Pair production	Therapeutic radiology
Photodisintegration	Therapeutic radiology

How X rays interact with patients In radiodiagnosis?



- ✓ **Some Xrays absorbed**
- ✓**Some pass straight through the patient**
- ✓**Some scattered**

Depend on three things:

- ✓ **X-ray energy**
- ✓ **Atomic number of the absorber**
- ✓ **Thickness and density of the object**

How images are formed?

- Low density or low atomic number tissues allow more Xrays through causing more blackening of film.
- High density or high number tissues allow less Xray through causing less blackening of the film

Effect of kilovoltage

- Increasing KV, increases the penetrating ability of the X rays photons.
- High KV produces darker images but with poor contrast
- More Xrays photons get through to darken film

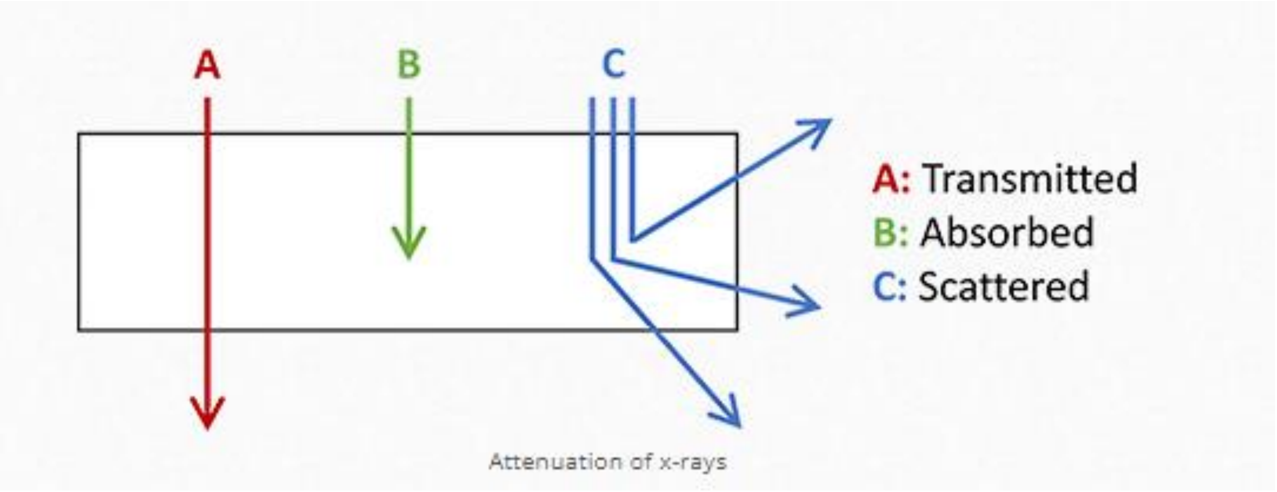
Effect of milliamperage and time

- Increasing the mA, increases the number of Xrays production
- It does not affect the penetrating power of the photons.
- An increased mA will increase overall blackness of the film

Attenuation

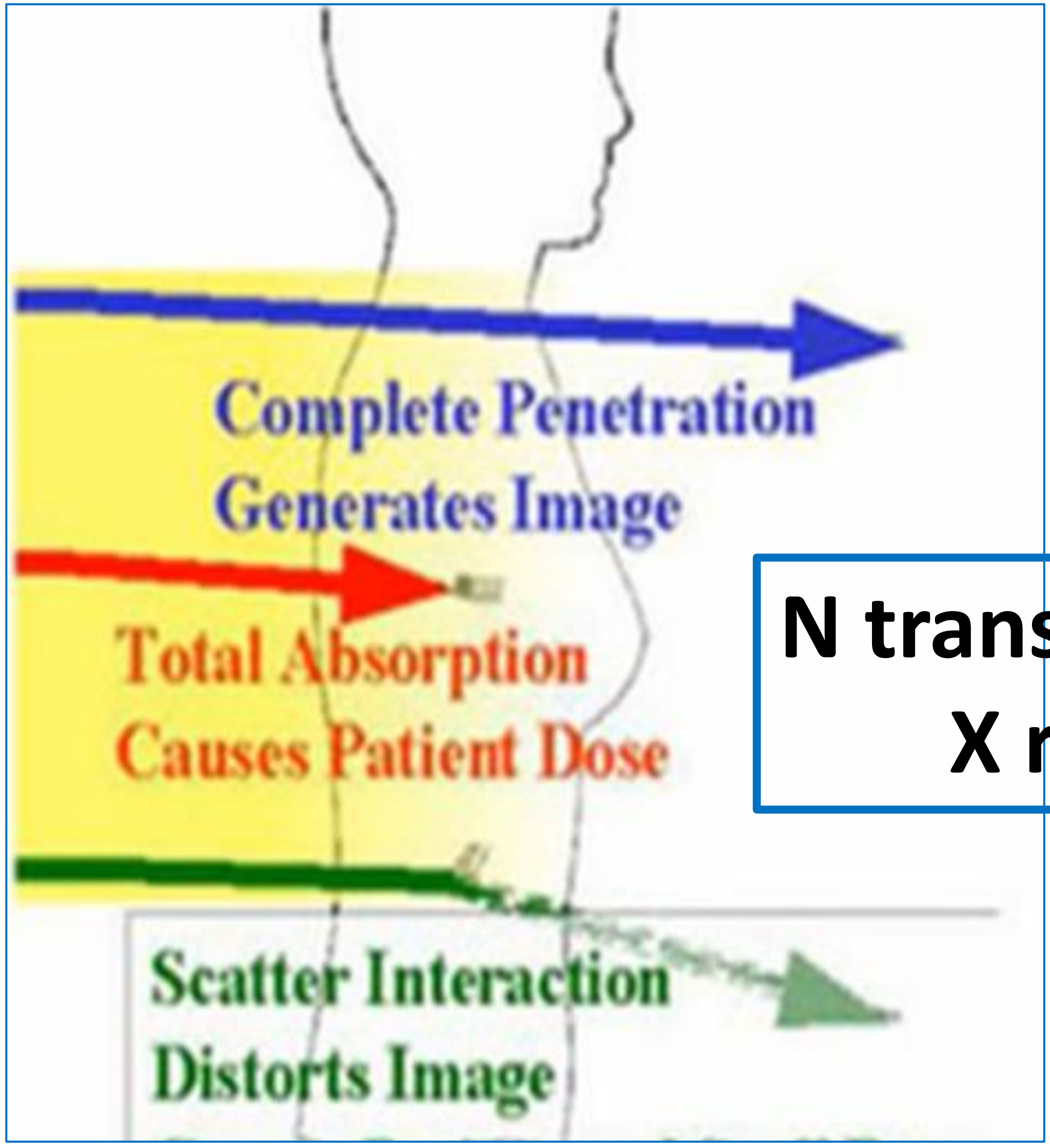
Attenuation photon in matter

- When photons interact with matter three things can occur. The photon may be
  - ✓ Transmitted through the material
  - ✓ Scattered in a different direction from the one traveled by the incident photon
  - ✓ Absorbed by the material such that no photon emerges



Attenuation photon in matter

No incident X rays



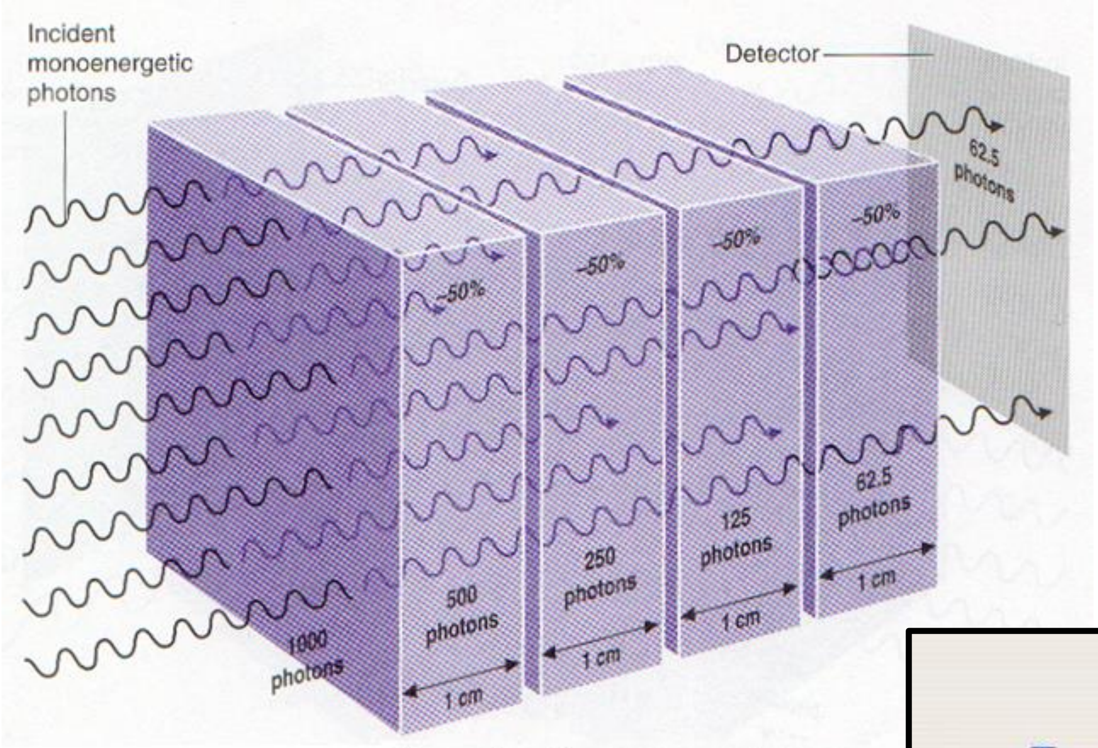
N transmitted X rays

Radiodiagnosis

Attenuation

- The reduction of X ray photons as they pass through matter:
    - Primary radiation - attenuation = remenant or exit radiation

Io



Attenuation of a monoenergetic beam.

I

$$I = I_o e^{-\mu x}$$

Total attenuation coefficient μ

- Total linear attenuation coefficient is the sum of individual linear attenuation coefficients for each type of interaction:

$$\mu = \mu_{\text{Rayleigh}} + \mu_{\text{photo}} + \mu_{\text{Compton}} + \mu_{\text{pair}}$$

Half value layer (HVL)

- **Half value layer (HVL) defined as the thickness of material required to reduce the intensity of an Xray or gamma ray beam to one half of its initial value**
- Relationship between μ and HVL is given by:

• HVL = 0,693/μ

HVL of a typical diagnostic beam is :

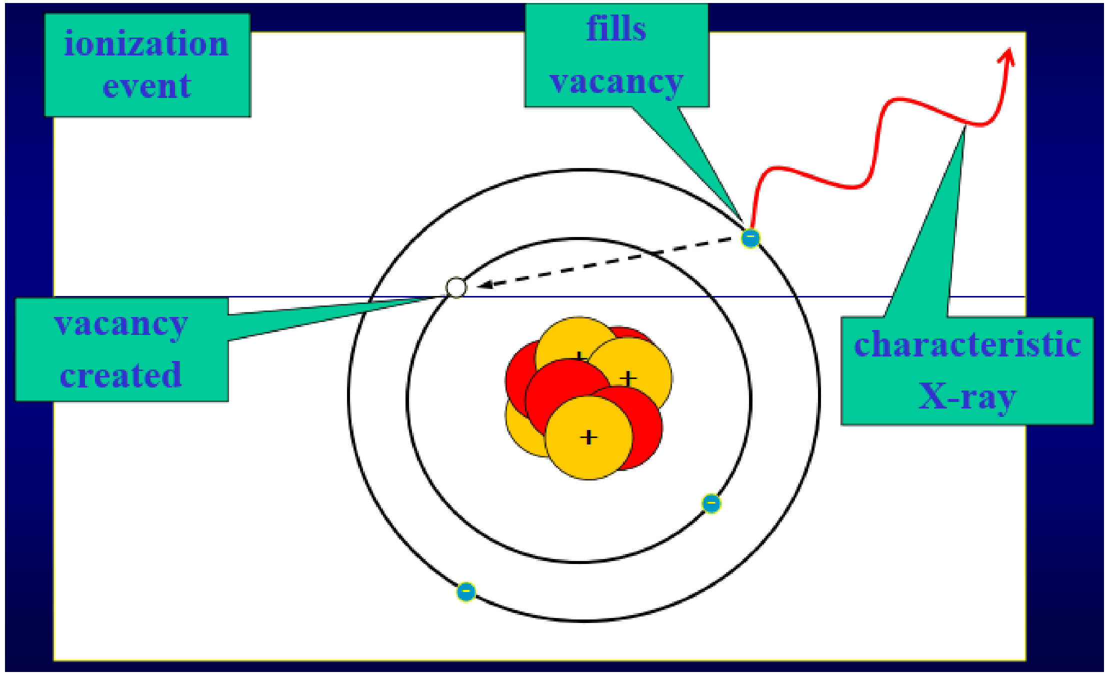
-30 mm : Tissue

-12 mm: Bone

-0.15 mm : Lead

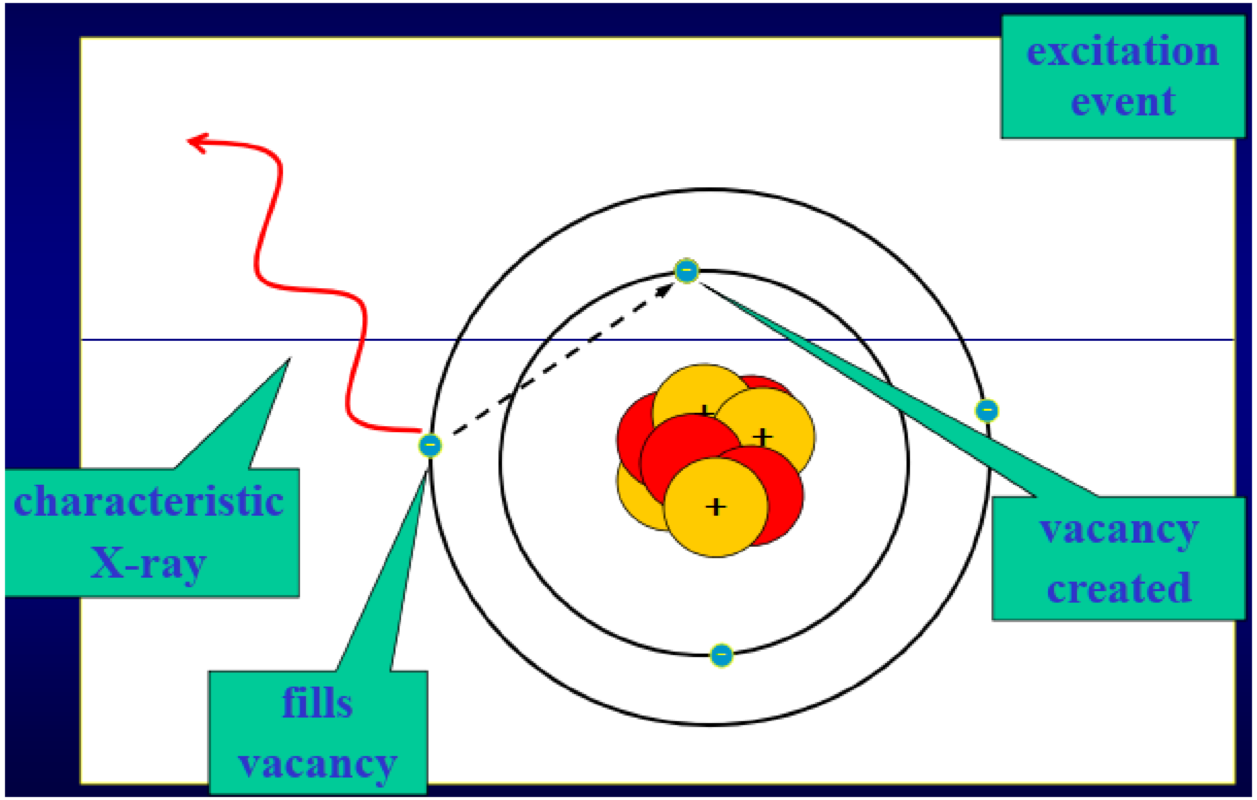
Interaction of particulate radiation with matter

Charged Particle Interactions



Characteristic X-rays (Ionization)

Charged Particle Interactions

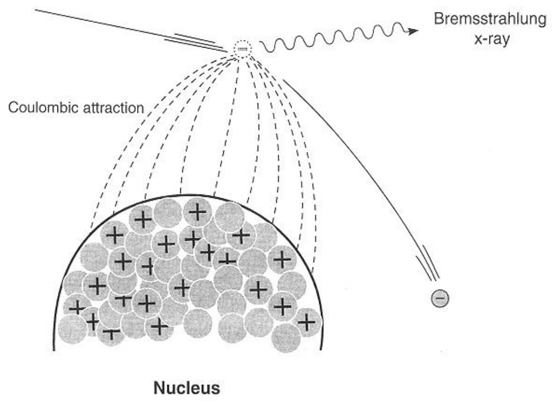


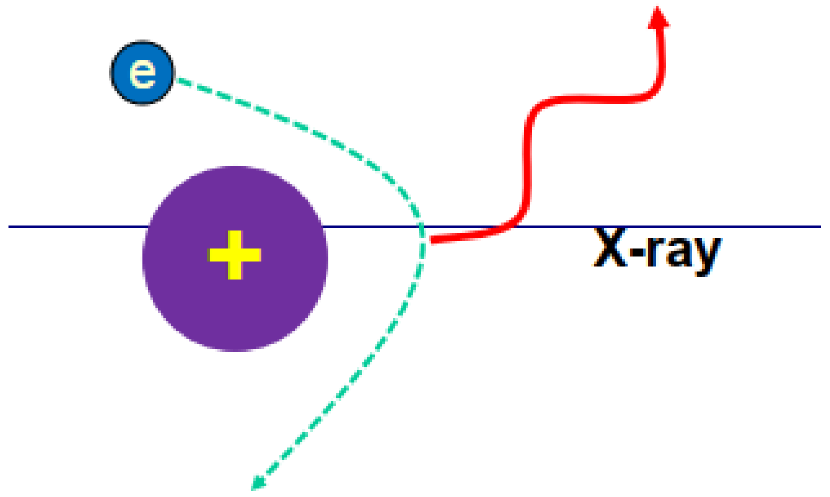
Characteristic X-rays
(Excitation)

Charged Particle Interactions

➢ **Bremsstrahlung “Braking Radiation”**

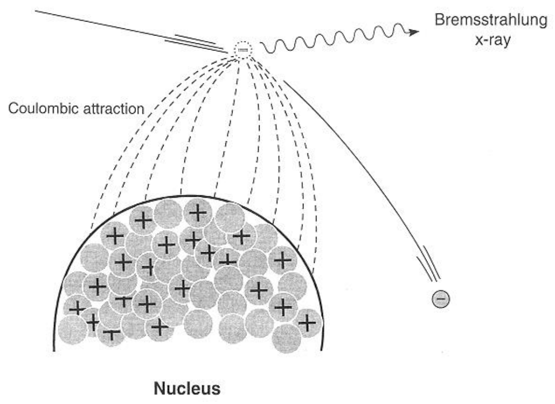
- When a charged particle is deflected from its path by a nucleus, an X-ray is emitted
- The maximum energy of X-ray is equal to the kinetic energy of the electron
- Probability of bremsstrahlung production per atom is proportional to the square of Z of the absorber

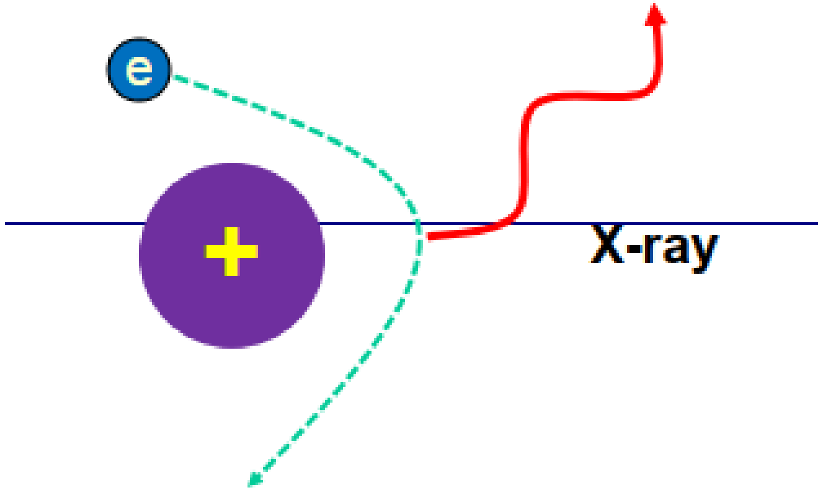




Charged Particle Interactions

- **Charged Particle Interactions**
- When a charged particle is deflected from its path by a nucleus, an X-ray is emitted
- The maximum energy of X-ray is equal to the kinetic energy of the electron
- Probability of bremsstrahlung production per atom is proportional to the square of Z of the absorber





Linear Energy Transfer (LET)

- The linear energy transfer (LET) is defined as: **the amount of energy deposited per unit length (ev/mm)**
- High LET radiations (alpha particles, protons, etc.) are more damaging to tissue than low LET radiations (electrons, gamma and x-rays)

$$LET = dE/dx \ [J.m^{-1}]$$ **Or (eV/mm)**

Ionization Linear Density (ILD)

- **Number of primary and secondary ion pairs produced** per unit length of charged particle's path is called ***specific ionization or*** **ionization linear density (ILD)**
- **Expressed in ion pairs (IP)/mm**
- The average amount of energy expended per ionization is called the "w" value (average of about 34 eV for betas and 35 eV for alphas).

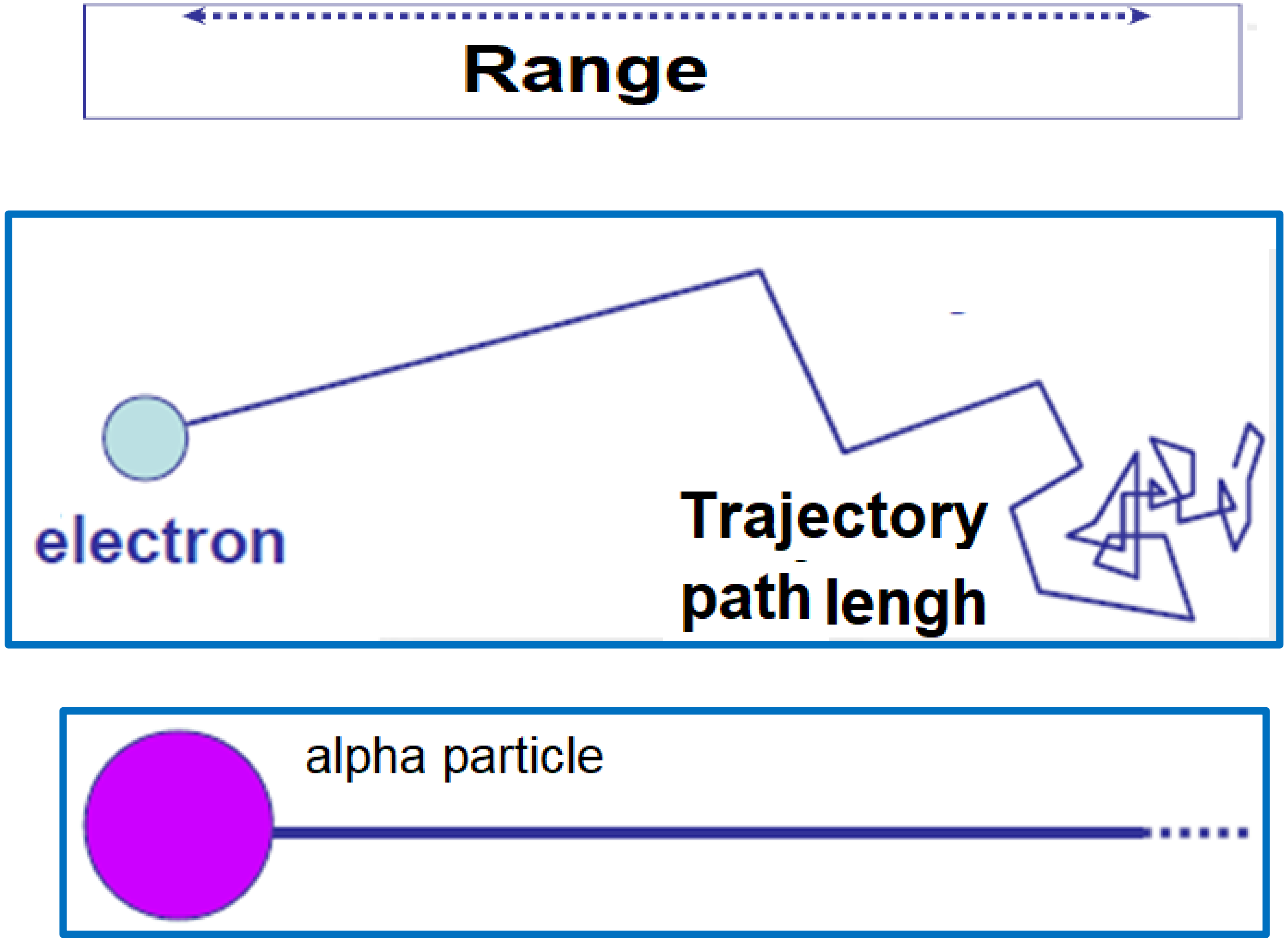
$$ILD = LET / W$$

W: average energy needed to create an ion pair

Path versus range

- ***Path length*** is the actual distance a particle travels
- **Range** is the average distance a charged particle travels in a medium before coming to rest.
- **Range** is the actual depth of penetration in matter
- The path of a heavy charged particle is almost a straight line, but the path of electrons is not straight.

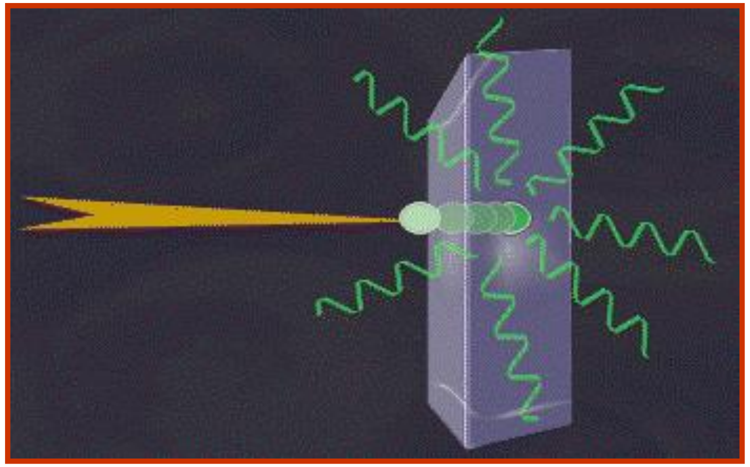
Path versus range



Shielding energetic beta-emitting

- Bremsstrahlung production also depends on the atomic number (Z) of the shielding material. The fraction of beta energy that is converted to photons can be approximated by the following relationship:

$$f = 3.5 \times 10^{-4}\, Z\, E_{max}$$



- **Use low-Z materials**, e.g., plastic, to shield high-energy beta-emitting isotopes to completely **stop the betas and minimize production of bremsstrahlung**

References

- Radiological safety training for radiation – producing (Xray) devices, DOE Handbook, DOE-HDBK-1109-97

- handbook of radioactivity analysis, volume 1: radiation physics and detectors, 3th edition, Michael l’annunziata

Questions/answers

- **Types of radiation**
- ✓ EM radiation and particulate radiation/ ionizing and non ionizing radiation
- **Example of EM ionizing radiation used in medical field**
- ✓ X rays and gamma rays
- **EM radiation characteristics**

Wavelengh, frequency, amplitude, relationship: $C = v \times \lambda$

- **EM radiation characteristics (nature, energy)**
- ✓ Photons, no mass, no charge
- ✓ $E = h\,v = h\,C/\lambda$
- **EM radiation's speed**

$C = 3\ 10^8$ m/s

Questions/answers

- **Particulate radiation characteristics (nature, energy)**

- ✓ Have a mass and charge
- ✓ Particle energy = cinetic energy = ½ mV^2

- **Ionizing radiation/ non ionizing radiation/ examples**
- ✓ Ionizing radiation: Radiation which has enough energy to remove electrons from the orbital
- ✓ Alpha particle – beta particle- X rays – gamma rays
- ✓ Non Ionizing radiation:
- ✓ Not enough energy to remove electrons from the orbital

microwave – infrared- US

- **Human exposure**
- ✓ Cosmic radiation
- ✓ Radioactive substances present in the ground
- ✓ Exposure to Radon, Medical exposure