IASM41

BIOPHYSICAL BASIS OF THE USE OF IONIZING RADIATION IN MEDICINE.

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PRACTICE

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Nuclear medicine department

Main building; -1 floor

MONDAY

Exercise

clinical group

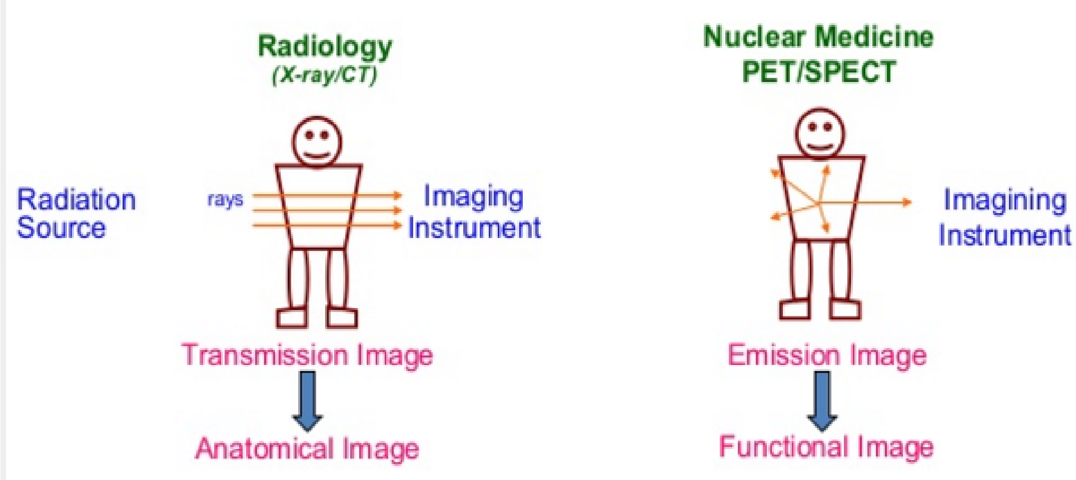
I, II, III,

Introduction

- Radiation has been an effective tool for treating cancer for more than 100 years
- More than 60 percent of patients diagnosed with cancer will receive therapy with radiation source as part of their treatment
- Radiation oncologists and nuclear medicine specialist are cancer specialists who manage the care of cancer patients with radiation for either cure or palliation

Ionising radiation IN MEDICINE

- **Radiology**
  - 100% diagnostic
- **Radiotherapy**
  - 100% **therapy**
- **Nuclear medicine**
  - 60% diagnostic
  - 30% **therapy**



  - 10% *in vitro* assays (laboratory)

Ionising radiation therapy- Types

- External – where the radiation comes from a machine outside the body.
- Internal – where the radiation comes from implants or liquids placed inside the body.

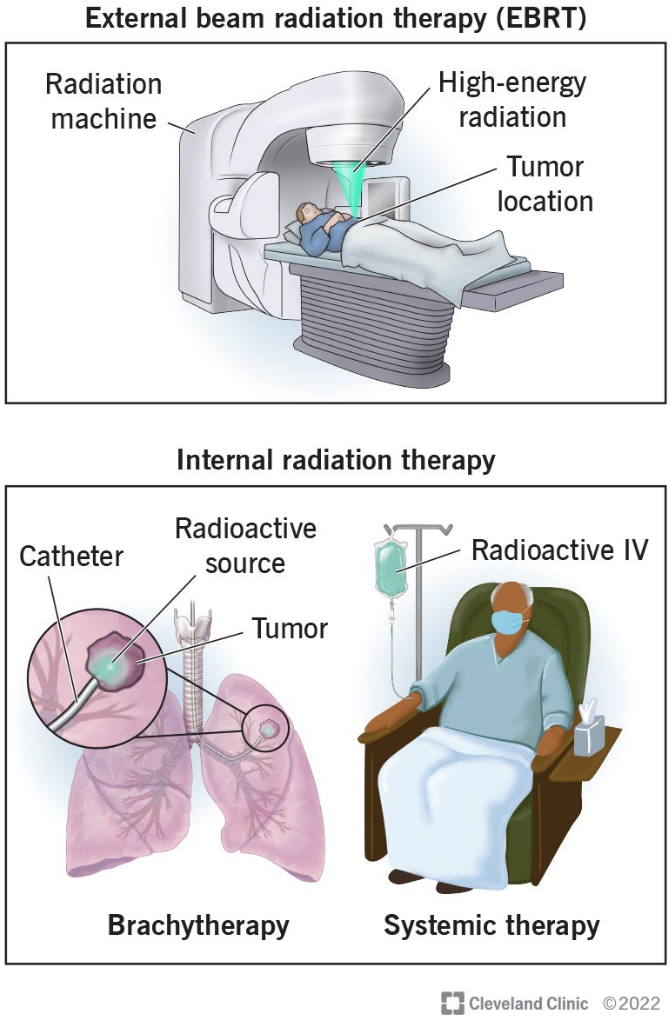
External radiotherapy

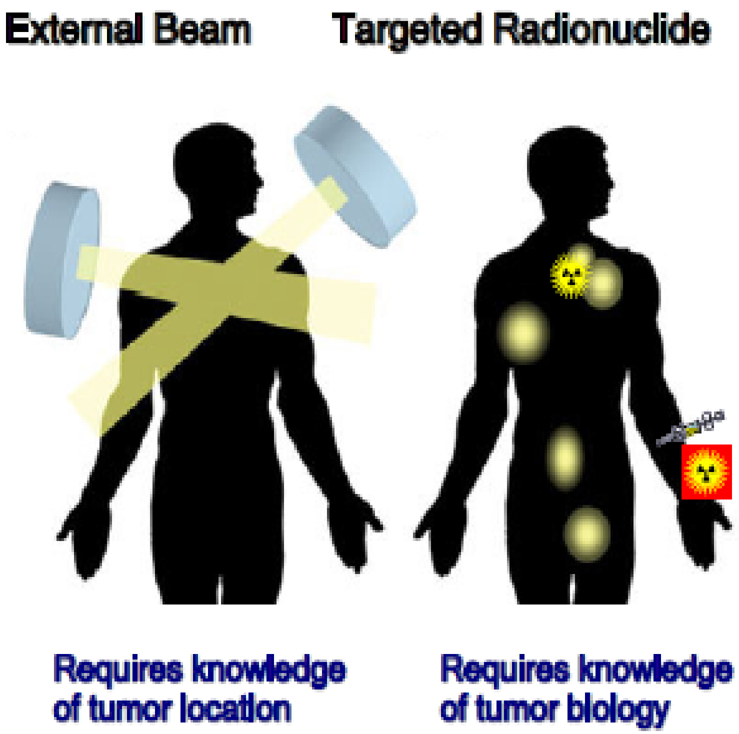
- External radiotherapy is called **RADIOTHERAPY**. A machine directs the high-energy radiation, usually X-rays, at the cancer site.
- **BRACHYTHERAPY** is treatment in which solid radioactive sources are placed inside a body cavity or needles are placed in the tumour.
- External radiotherapy doesn't make you radioactive and you can safely mix with other people, including children.

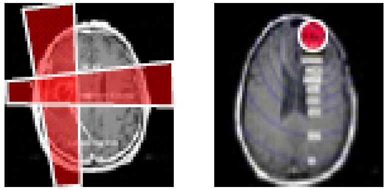
Internal radiotherapy

- Internal radiotherapy is called **RADIONUCLIDE THERAPY**.
- Involves using a liquid source of radiation and is called radionuclide (radioisotope) therapy. It can be taken per os or an injection into a vein.
- The patient will be emitting a radioactivity for a few days.

Ionising radiation therapy- Types







Sources of Ionizing Radiation

- Photons
  - Gamma Rays
    - Emitted from a nucleus of a radioactive atom
      - Cobalt treatment machine
      - Radioisotopes used in brachytherapy
  - X-rays
    - Generated by a linear accelerator when accelerated electrons hit a target
- Particle Beams
  - Beta particles
  - Alpha particles
  - Electrons

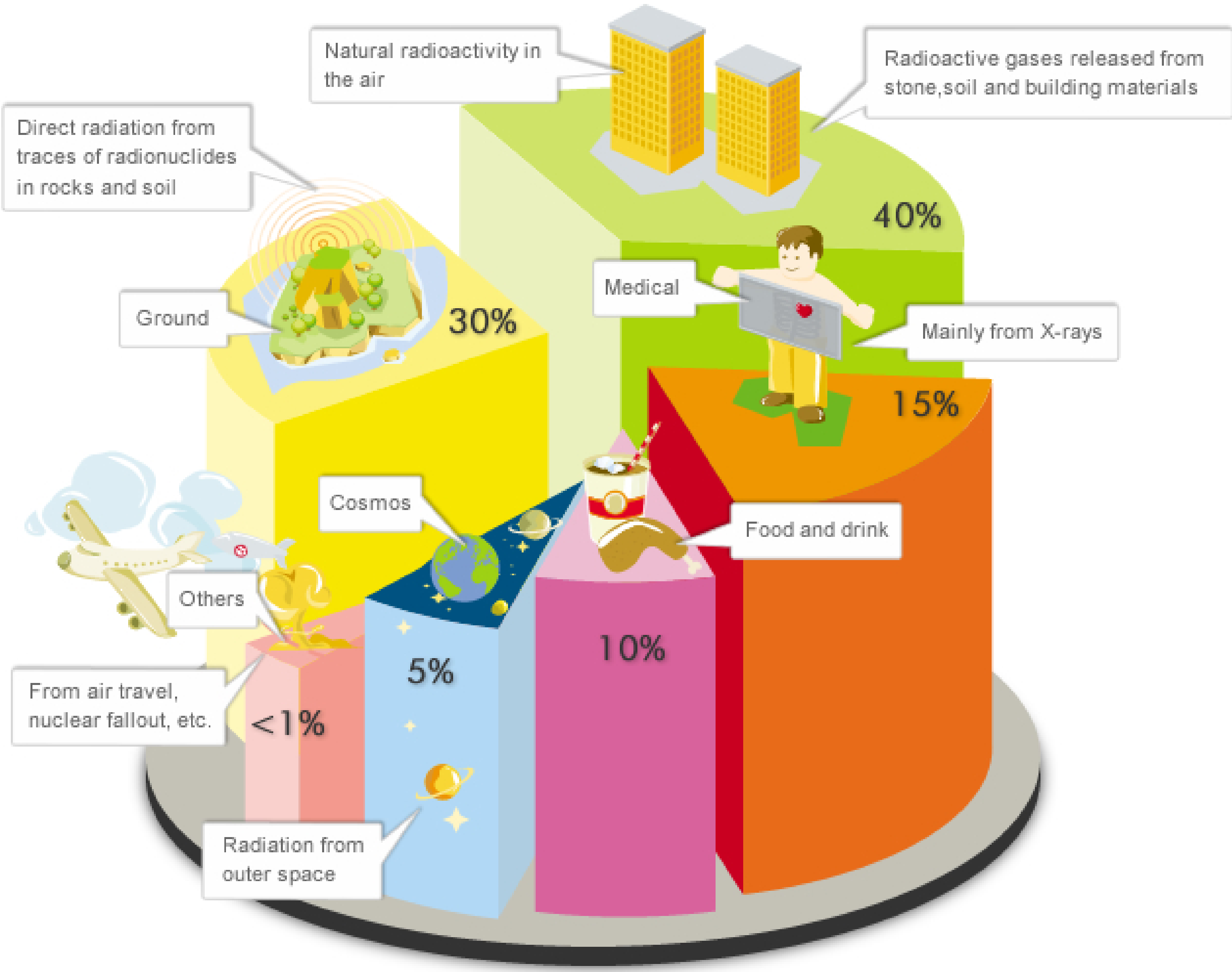
} radioisotopes used in nuclear medicine

Ionising radiation IN MEDICINE

- Radiation sources apy plays a major role in the management of many common cancers either alone or as an adjuvant therapy with surgery and chemotherapy
  - Sites commonly treated include breast, prostate, lung, colorectal, pancreas, esophagus, head and neck, brain, skin, gynecologic, lymphomas, bladder cancers and sarcomas

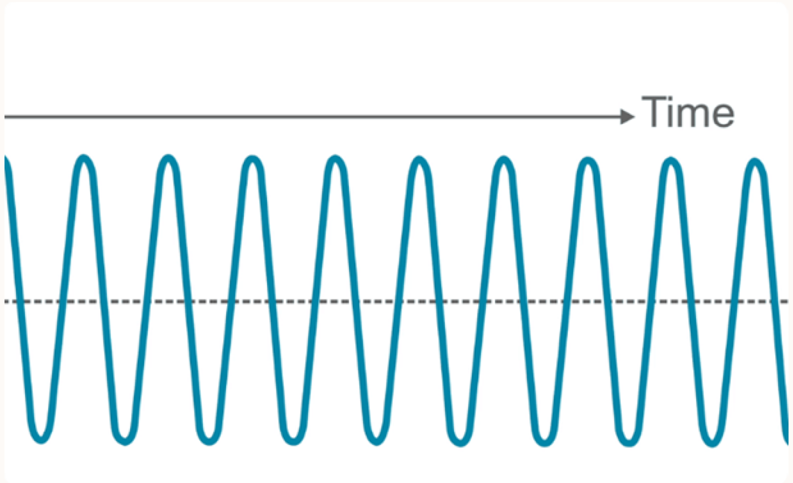
- Radiation is also frequently used in palliation medicine
- e.g. bone metastases, Spinal cord compression
- Vascular compression, e.g., superior vena cava syndrome
- Bronchial obstruction
- Bleeding from gastrointestinal or gynecologic tumors
- Esophageal obstruction

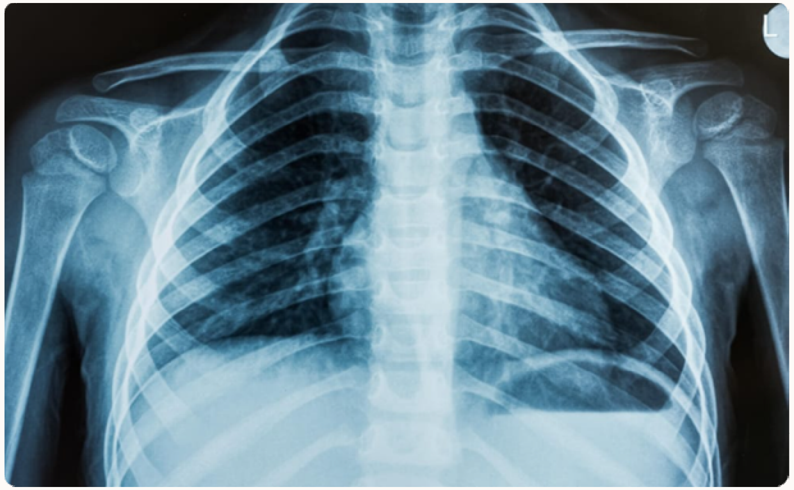
RADIATION



Natural radioactivity in the air
Radioactive gases released from stone,soil and building materials
Direct radiation from traces of radionuclides in rocks and soil
40%
Ground
30%
Medical
Mainly from X-rays
15%
Cosmos
Food and drink
Others
5%
10%
From air travel, nuclear fallout, etc.
<1%
Radiation from outer space

The Two Types of Radiation





Non-ionising radiation

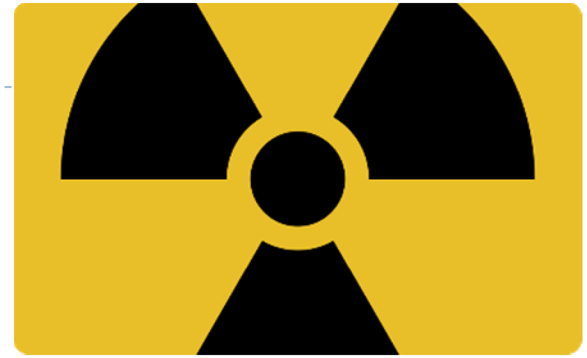
Low energy radiation that does not have enough energy to remove electrons from atoms or molecules, such as radio waves and microwaves.

Ionising radiation

High-energy radiation that has enough energy to remove electrons from atoms or molecules, such as X-rays and gamma rays.

What is Ionizing Radiation?

Understanding the Basics of Ionizing Radiation



Ionizing radiation refers to the type of radiation that carries enough energy to remove tightly bound electrons from atoms, leading to the formation of charged particles called ions, and it can come in two forms: electromagnetic radiation and corpuscular radiation.

1. **ELECTROMAGNETIC**
2. **CORPUSCULAR**

Sources of Ionising Radiation

1

Medical devices

CT scans, x-rays, and nuclear medicine imaging LINAC, Generators.

2

Nuclear power generation

Nuclear power plants rely on controlled nuclear reactions to generate electricity, which produces ionising radiation.

3

Consumer products

Some consumer products, like smoke detectors, contain small amounts of radioactive material that emit ionising radiation.

Applications in Medicine

1. **Diagnostic Imaging**

   Nuclear medicine involves using small amounts of radioactive material to diagnose and treat diseases.

2. **Therapy**

   Radiation therapy uses high-energy radiation from nuclear sources to destroy cancer cells or shrink tumors.

3. **Biomedical Research**

   Nuclear physics techniques help researchers understand biological processes at the molecular scale, informing advances in medicine and health.

Electromagnetic radiation

Attraction and Repulsion

Opposite charges attract each other, while like charges repel. Same for magnetic poles.

Electricity

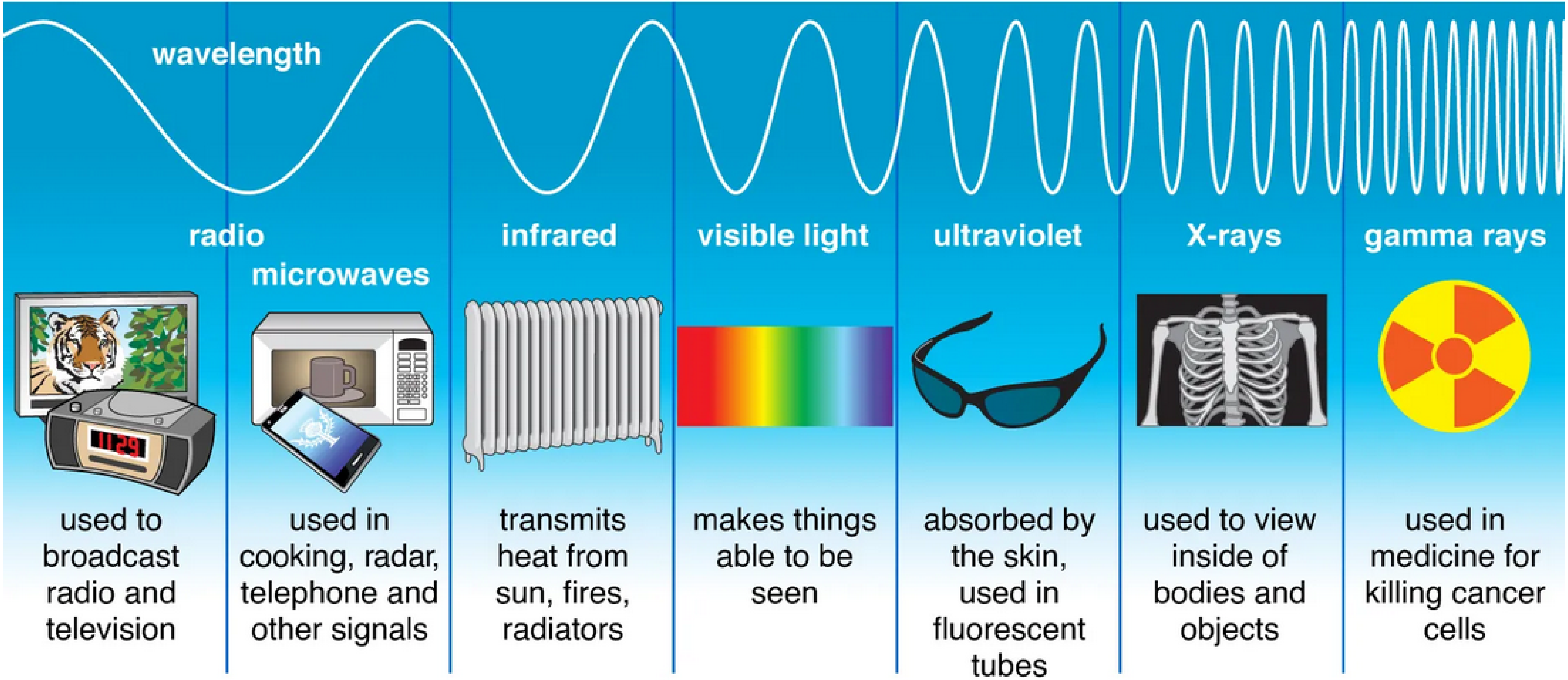
The flow of electrons, allowing you to turn on a light switch, power a computer, or charge your phone.

Magnetism

The force that sticks a magnet to your fridge and guides compass needles to point north.

Electromagnetic force is one of the fundamental forces within the atom and is responsible for the interactions between charged particles, such as electrons and protons, determining the structure and behavior of atoms.

Types of Electromagnetic Radiation



Types of Electromagnetic Radiation

- **Gamma Rays**

  Gamma rays are electromagnetic radiation with the highest energy and the shortest wavelength. They are often produced during nuclear reactions and can penetrate through most materials, making them useful in medical imaging and cancer treatment.

- **X-Rays**

  X-rays have higher energy and shorter wavelengths than visible light. They are commonly used in medical imaging to visualize bones and internal organs.

- **Ultraviolet (UV) Rays**

  UV rays have shorter wavelengths than visible light. They can cause skin damage and increase the risk of skin cancer.

- **Visible Light**

  Visible light is the range of electromagnetic radiation that is visible to the human eye. It consists of different colors, each with a specific wavelength and energy.

- **Infrared (IR) Rays**

  IR rays have longer wavelengths than visible light. They are often used in remote controls, heat lamps, and infrared imaging.

- **Microwaves**

  Microwaves have longer wavelengths than infrared rays. They are commonly used in cooking and communication technologies, such as cell phones and Wi-Fi.

- **Radio Waves**

  Radio waves have the longest wavelengths and the lowest energy among the types of electromagnetic radiation. They are used in various communication systems, including radio and television broadcasting.

CORPUSCULAR RADIATION

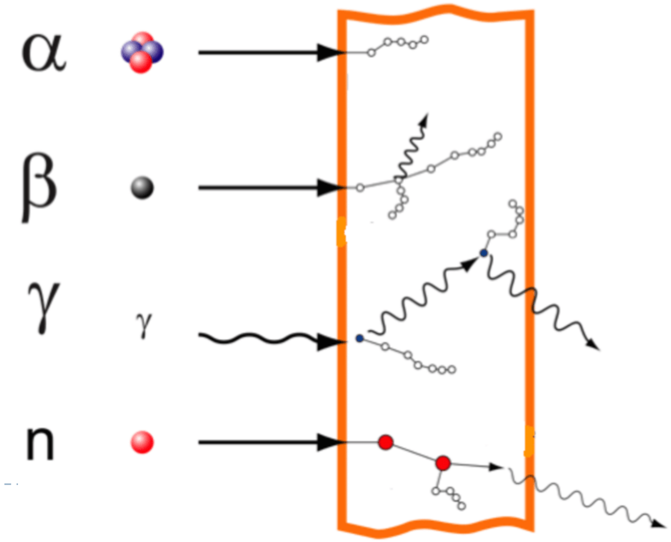
Particle radiation is the radiation of energy by means of fast-moving subatomic particles. Particle radiation is referred to as a particle beam if the particles are all moving in the same direction.

Types of particles may be emitted:

- protons and other hydrogen nuclei stripped of their electrons
- positively charged alpha particles (α), equivalent to a helium-4 nucleus
- positively or negatively charged beta particles (high-energy positrons β+ or electrons β−; the latter being more common)
- neutrons, subatomic particles which have no charge; neutron radiation

Mechanisms that produce particle radiation include:

- alpha decay
- beta decay
- internal conversion
- neutron emission
- nuclear fission and spontaneous fission
- nuclear fusion

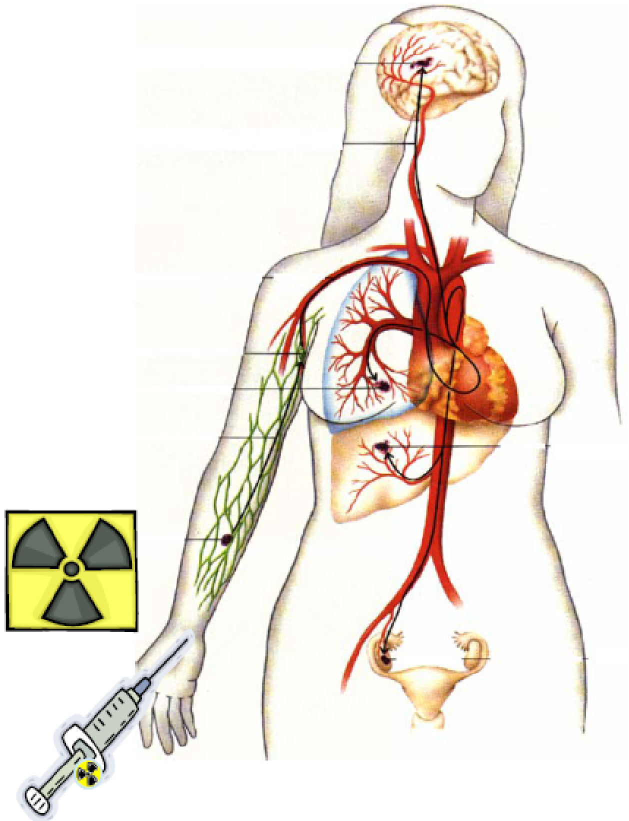


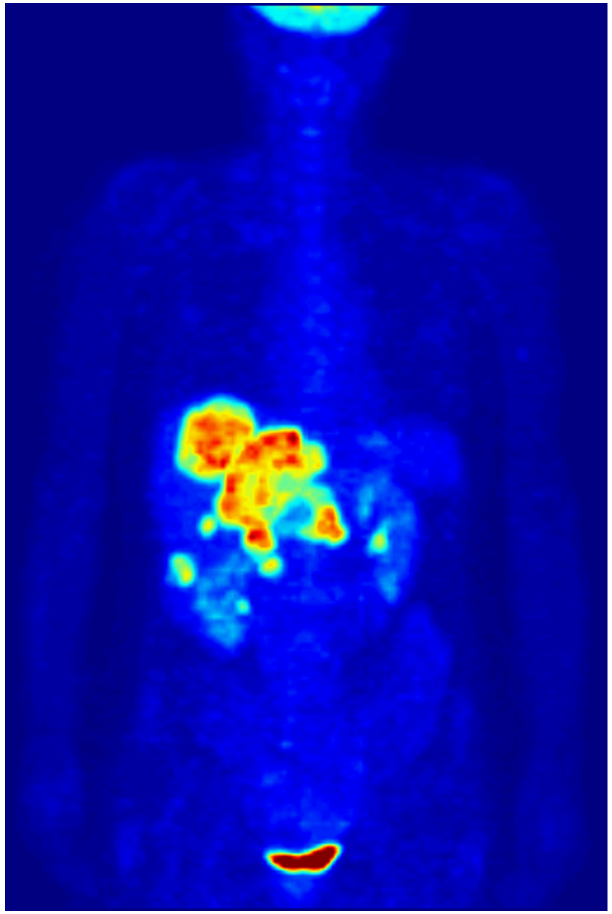
Nuclear Medicine

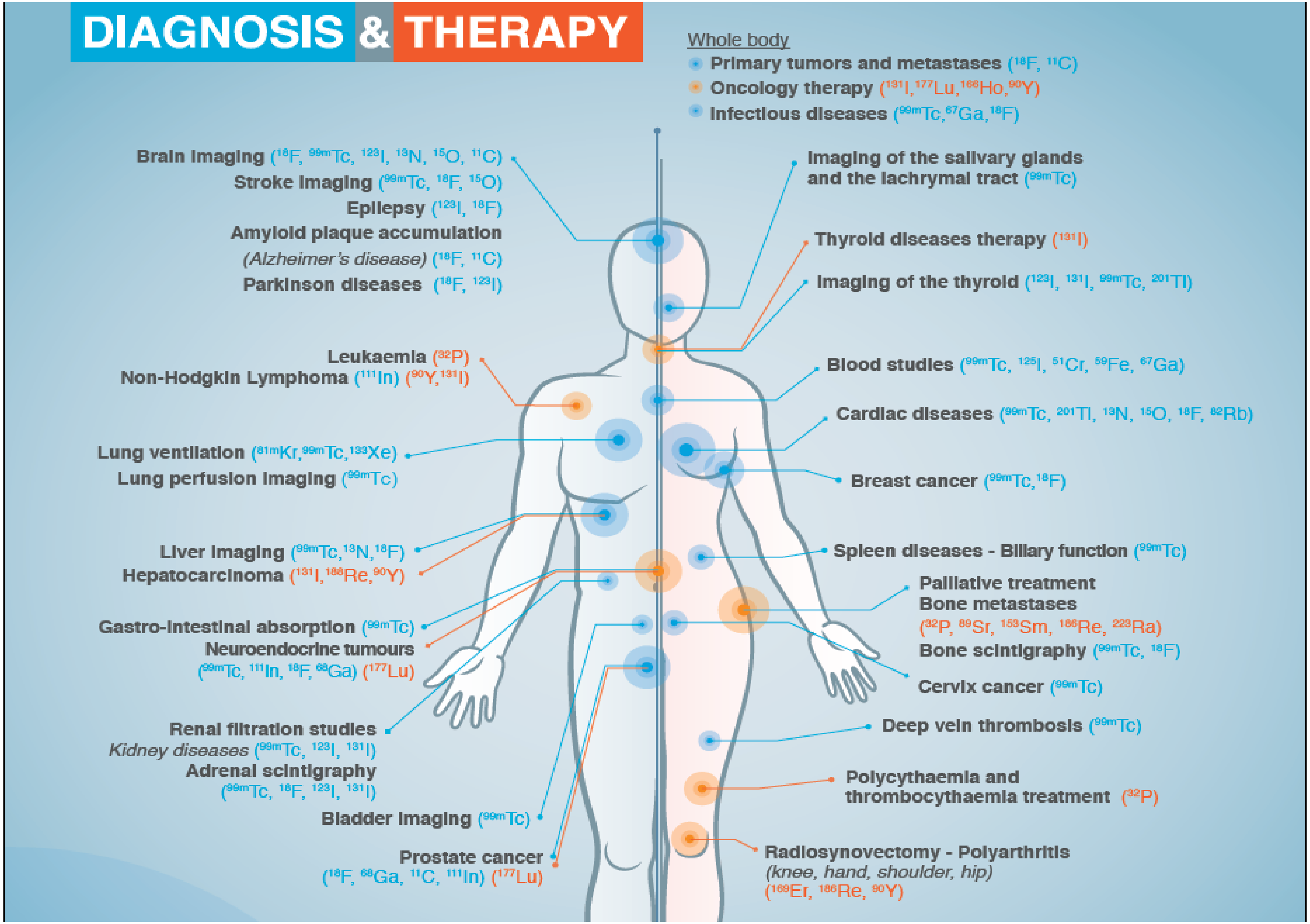
Nuclear medicine pays attention to what happens inside the body's cells. Radiotracers, small amounts of radioactive materials, are injected into the body to detect and quantify a variety of physiological processes through their emissions.

Radiotracers	Imaging systems	Computer Analysis
Help to detect physiological processes through their emissions	Picks up the emissions and creates an image of the body's organs and tissues	Analyses the data to provide the final image

With over 100 radiotracers available, nuclear medicine tracers imaging has a vast range of applications across different specialisms.







http://nuclearmedicineeurope.eu/wp-content/uploads/2019/09/Hygieia_Public_2019_2mm.pdf

RADIATION THERAPY

- *External beam* radiation therapy typically delivers radiation using a linear accelerator
- Internal radiation therapy, called *brachytherapy*, involves placing radioactive sources into or near the tumor

THE RADIATION ONCOLOGY TEAM

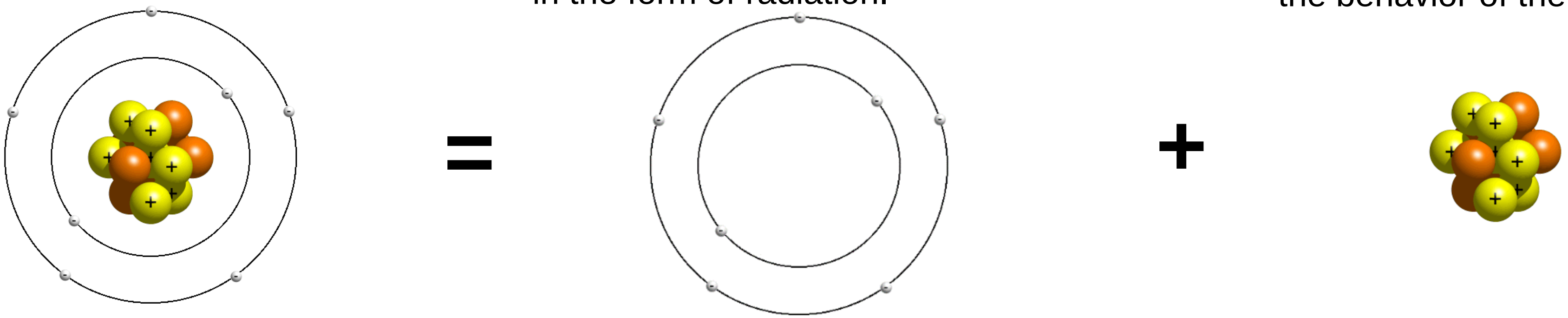
- Oncologist
  - The doctor who prescribes and oversees the radiation therapy treatments
- Medical Physicist
  - Ensures that treatment plans are properly tailored for each patient, and is responsible for the calibration and accuracy of treatment equipment
- Dosimetrist
  - Works with the radiation oncologist and medical physicist to calculate the proper dose of radiation given to the tumor
- Therapist
  - Administers the daily radiation under the doctor’s prescription and supervision
- Oncology Nurse
  - Interacts with the patient and family at the time of consultation, throughout the treatment process and during follow-up care

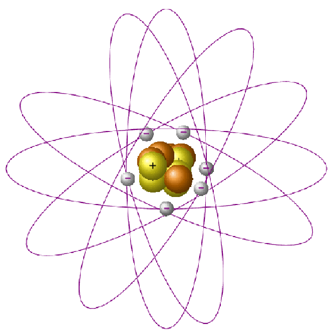
Atomic Structure

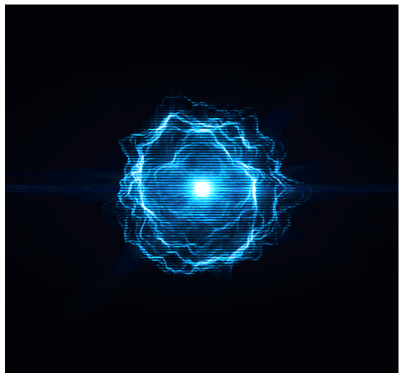
Atoms are composed of protons, neutrons, and electrons.

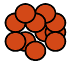
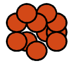
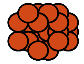
Electrons in an atom occupy specific energy levels. When these levels change, energy is released or absorbed in the form of radiation.

The nucleus is the central part of the atom, where the protons and neutrons are located. Its properties determine the behavior of the atom.

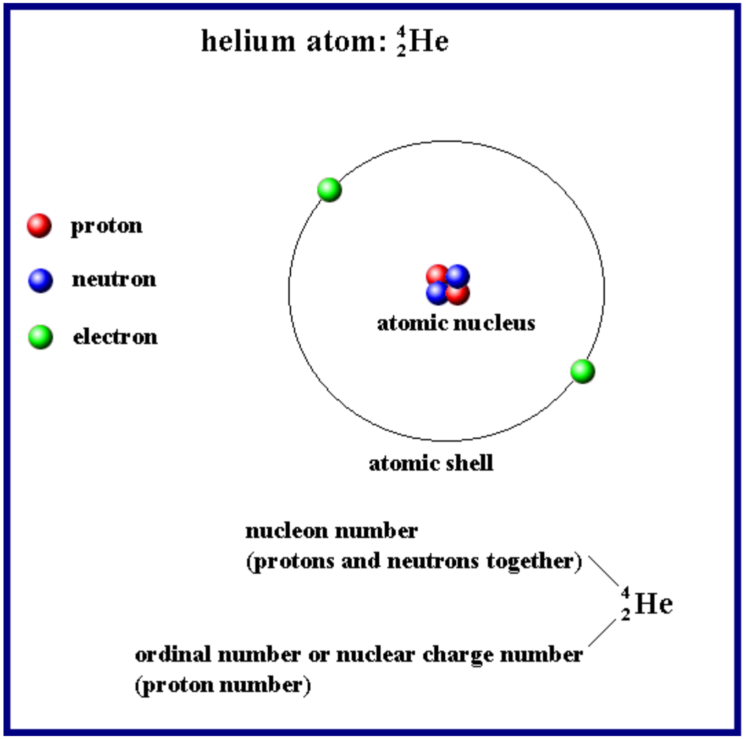






 **+**  **=** 

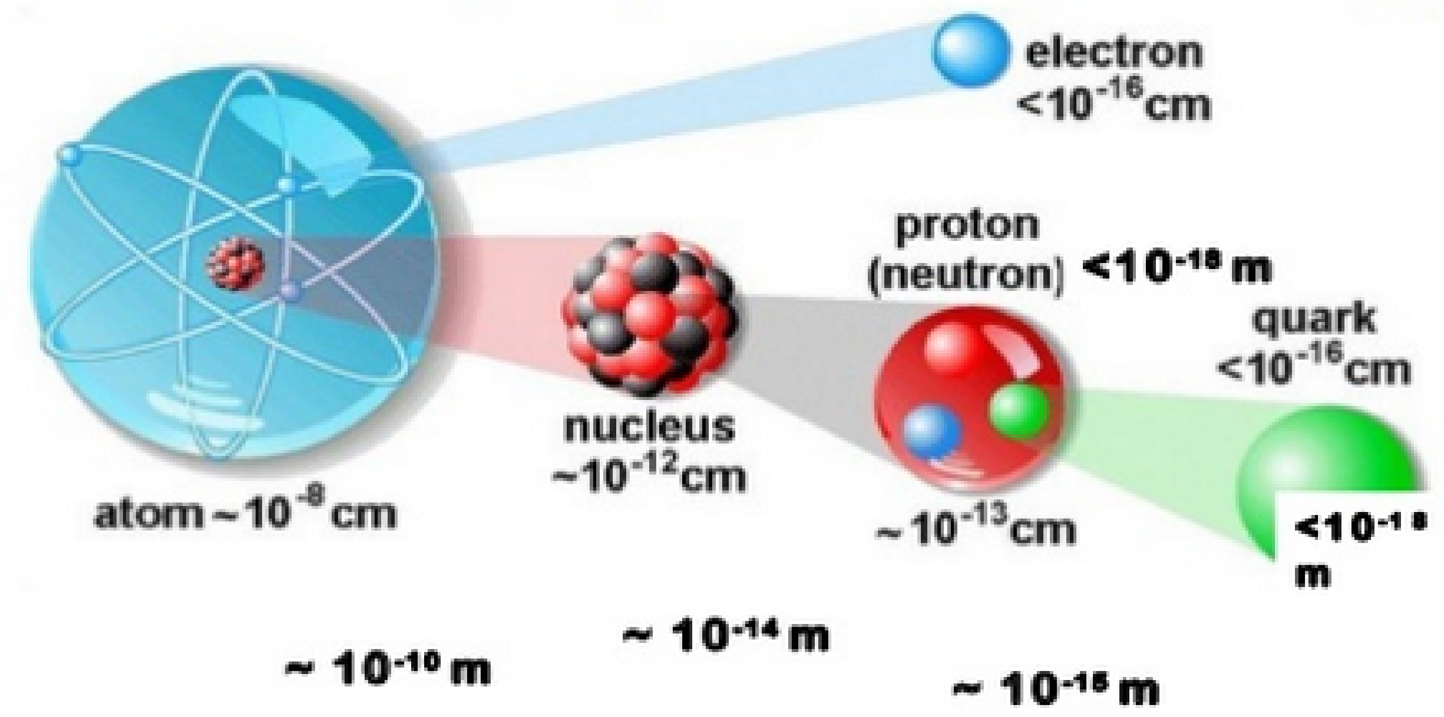
Z **Protons** + **N** **Neutrons** = **A** **Protons + neutrons**



A - The mass number or nucleon number
is the total number of protons and neutrons (together known as nucleons) in an atomic nucleus.

Z - The atomic number
is the charge number of an atomic nucleus. For ordinary nuclei composed of protons and neutrons, this is equal to the proton number

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



99.9% core mass

TERMINOLOGY

The Nucleus

The nucleus is the central part of an atom composed of protons and neutrons, held together by the strong force.

Isotopes

Isotopes are atoms of the same element with different numbers of neutrons, which can affect their stability and decay rate.

Radioactivity

Radioactivity is the spontaneous decay of unstable atomic nuclei, releasing energy in the form of particles and radiation.

ISOTOPES

ATOMS OF THE SAME ELEMENT

- same atomic number Z
- different mass number A

Number of Neutrons = Atomic Mass – Atomic Number

Number of Neutrons = 12 – 6 = 6	Number of Neutrons = 13 – 6 = 7	Number of Neutrons = 14 – 6 = 8
$^{12}_{6}C$	$^{13}_{6}C$	$^{14}_{6}C$
Carbon-12 98.9%	Carbon-13 1.1%	Carbon-14 <0.0001%

ISOBARS

ATOMS OF THE DIFFERENT ELEMENTS

- same mass number A
- different atomic number Z

(i) $_{32}Ce^{76}$, $_{34}Se^{76}$

(ii) $_{26}Fe^{58}$, $_{27}Ni^{58}$

ISOTONES

ATOMS HAVING

- different number of protons
- same number of neutrons

ISOTONE

DEFINITION OF ISOTONE:

The atoms which come from different element, but the amount of neutron is same

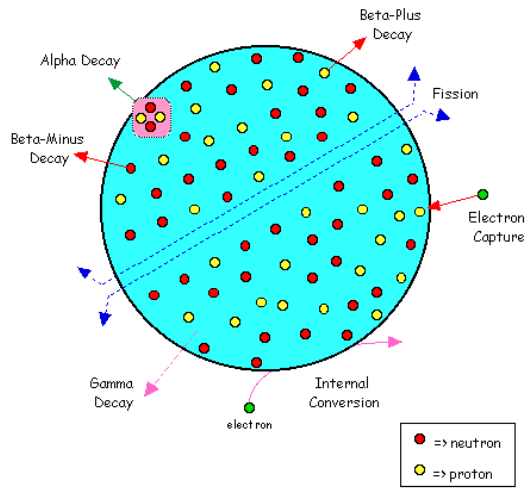
EXAMPLE:

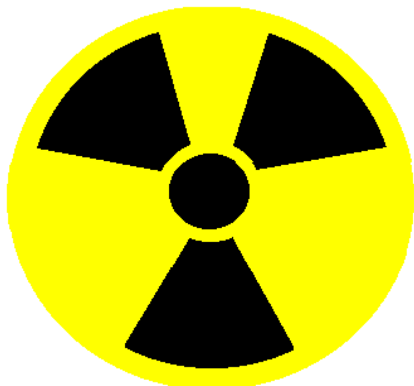
$^{31}_{15}P$ and $^{32}_{16}S$

$^{40}_{20}Ca$ and $^{39}_{19}K$

RADIOACTIVITY

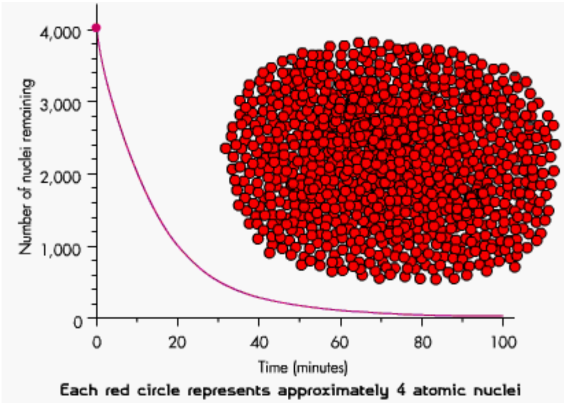
Radioactivity is the release of energy from the decay of the nuclei of certain kinds of atoms and isotopes. Atomic nuclei consist of protons and neutrons bound together in tiny bundles at the center of atoms. Radioactive nuclei are nuclei that are unstable and that decay by emitting energetic particles such as photons, electrons, neutrinos, protons, neutrons, or alphas (two protons and two neutrons bound together). Some of these particles are known as ionizing particles. These are particles with enough energy to knock electrons off atoms or molecules. The degree of radioactivity depends on the fraction of unstable nuclei and how frequently those nuclei decay.

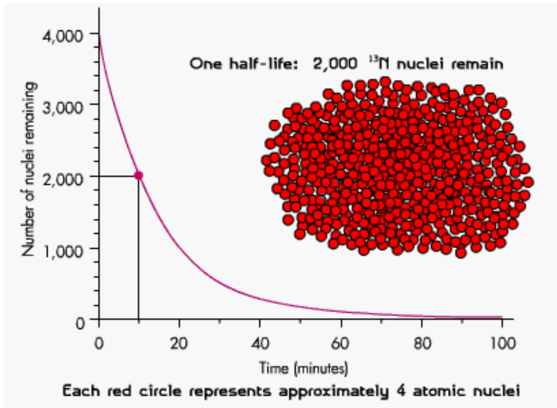


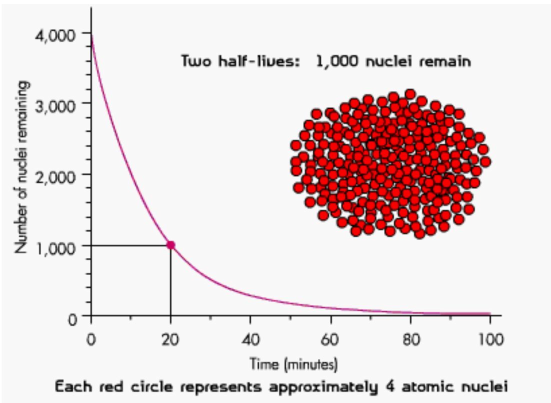


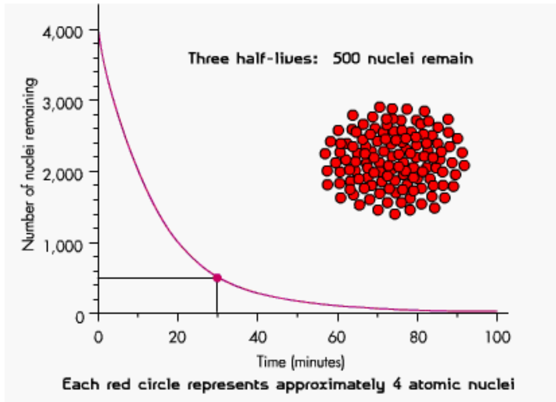
RADIOACTIVE DECAY

Radioactive decay is a random process, but it follows a specific pattern. The decay rate can be described by the half-life of an isotope.









Half-Life

$$T_{\frac{1}{2}} = \frac{\ln 2}{\lambda}$$

1 Definition

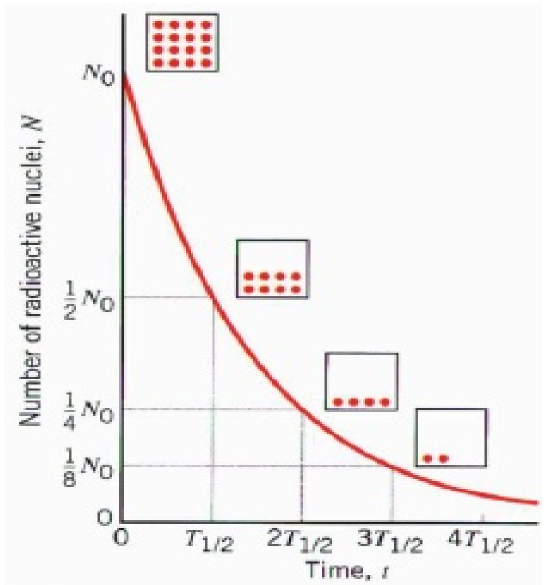
Half-life is the time it takes for half of the atoms in a sample to decay. It depends on the type of isotope and its decay rate.

2 Significance

Half-life is an important parameter in many fields, from radiocarbon dating to nuclear medicine

3 Calculations

Half-life calculations can be used to predict the decay of radioactive material.



Radioisotope	Half Life (approx.)
^{81m}Kr	13 seconds
^{99m}Tc	6 hours
^{131}I	8 days
^{51}Cr	1 month
^{137}Cs	30 years
^{241}Am	462 years
^{226}Ra	1620 years
^{238}U	4.51×10^9 years

$(T_{1/2})_b$ BIOLOGICAL HALF-LIFE

when the kinetics are governed by multiple independent mechanisms.

$(T_{1/2})_e$ EFFECTIVE HALF-LIFE

is the rate of accumulation or elimination of a biochemical or pharmacological substance in an organism; it is the analogue of

$$\frac{1}{(T_{1/2})_e} = \frac{1}{(T_{1/2})_b} + \frac{1}{(T_{1/2})}$$

UNITS OF MEASUREMENT

Becquerel, Curie

There are also units of radioactivity measurement, such as the becquerel and curie. They express the rate of decay of radioactive material.

1Bq=1 decay per second (kilo, mega, giga, tera)

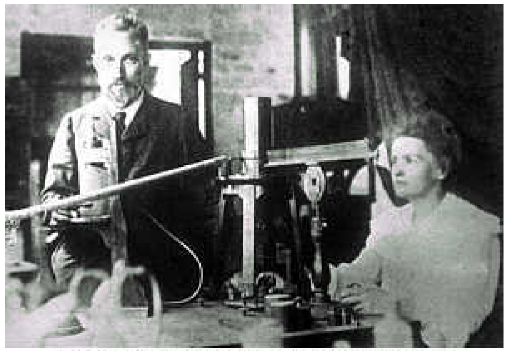
1Ci=3.7x 10^{10} Bq

The unit of radiation therapy is the *Gray (Gy)*, traditionally called the *rad*

1Gy = 100 centigray (cGy)

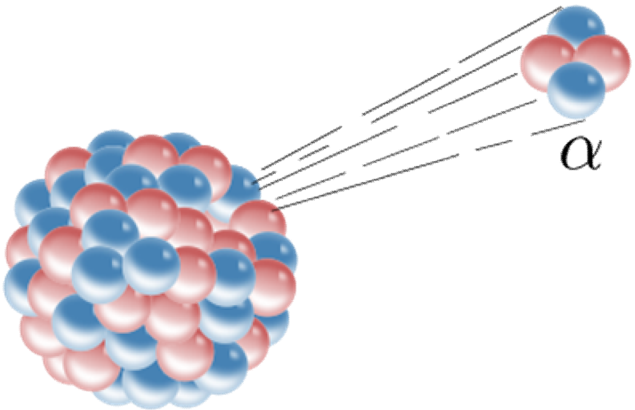
1cGy = 1 rad

Henri Becquerel (CIE 1998)



Pierre & Marie Curie (IBM Worldbook 1999)

Alpha Decay



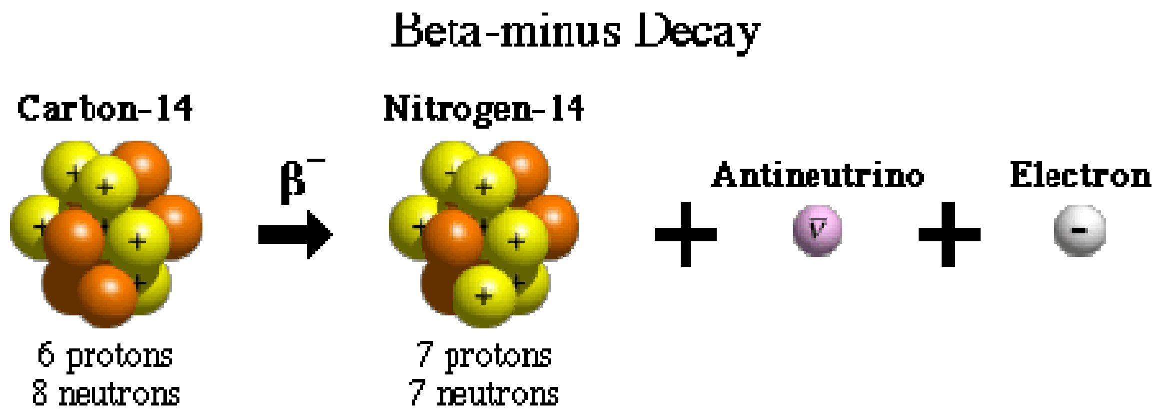
Alpha decay is a type of radioactive decay in which an atomic nucleus emits an alpha particle, consisting of two protons and two neutrons, resulting in a new element with a lower atomic number.

An alpha particle is identical to the nucleus of a helium-4 atom, which consists of two protons and two neutrons. It has a charge of +2 e

$$ {}^{A}_{Z}X \xrightarrow{\alpha} {}^{A-4}_{Z-2}Y $$

BETA DECAY

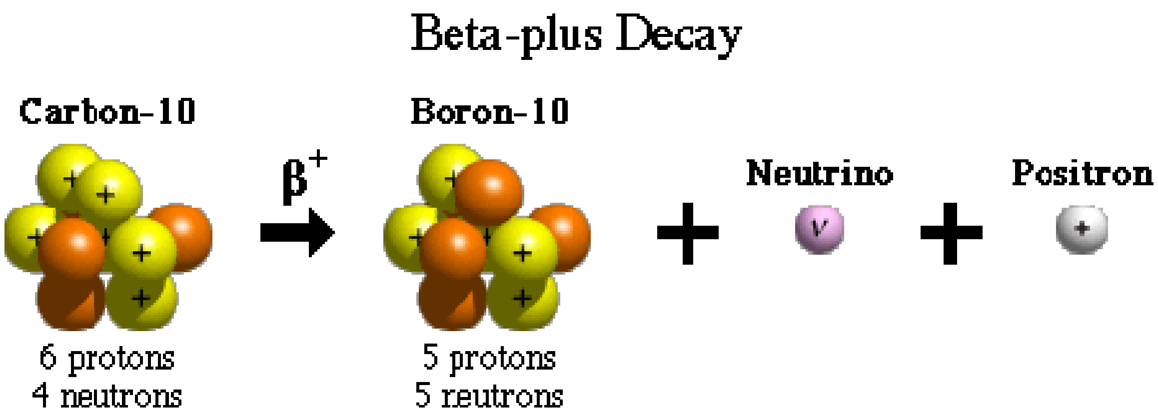
(β-decay) is a type of radioactive decay in which an atomic nucleus emits a beta particle



In beta minus (β−) decay, a neutron is converted to a proton, and the process creates an electron and an electron antineutrino;

$$n \longrightarrow p + e^{-} + \nu^{-}$$

$$^{A}_{Z}X \xrightarrow{\beta^{-}} {}^{A}_{Z+1}Y$$



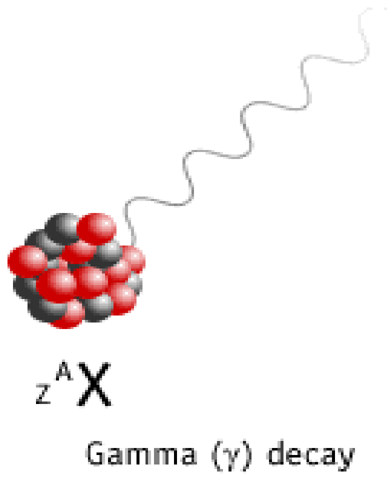
In beta plus (β+) decay, a proton is converted to a neutron and the process creates a positron and an electron neutrino. β+ decay is also known as positron emission

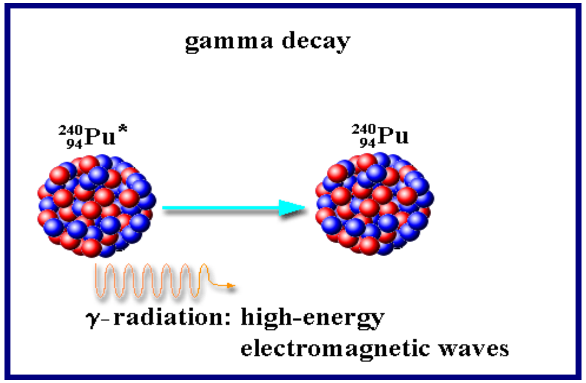
$$p \longrightarrow n + e^{+} + \nu^{+}$$

$$^{A}_{Z}X \xrightarrow{\beta^{+}} {}^{A}_{Z-1}Y$$

GAMMA DECAY

Gamma decay is a type of radioactive decay that occurs when an unstable nucleus releases a high-energy photon known as a gamma ray, resulting in the nucleus transitioning from an excited state to a more stable state.





Types of Atom Decay

- **Alpha Decay**

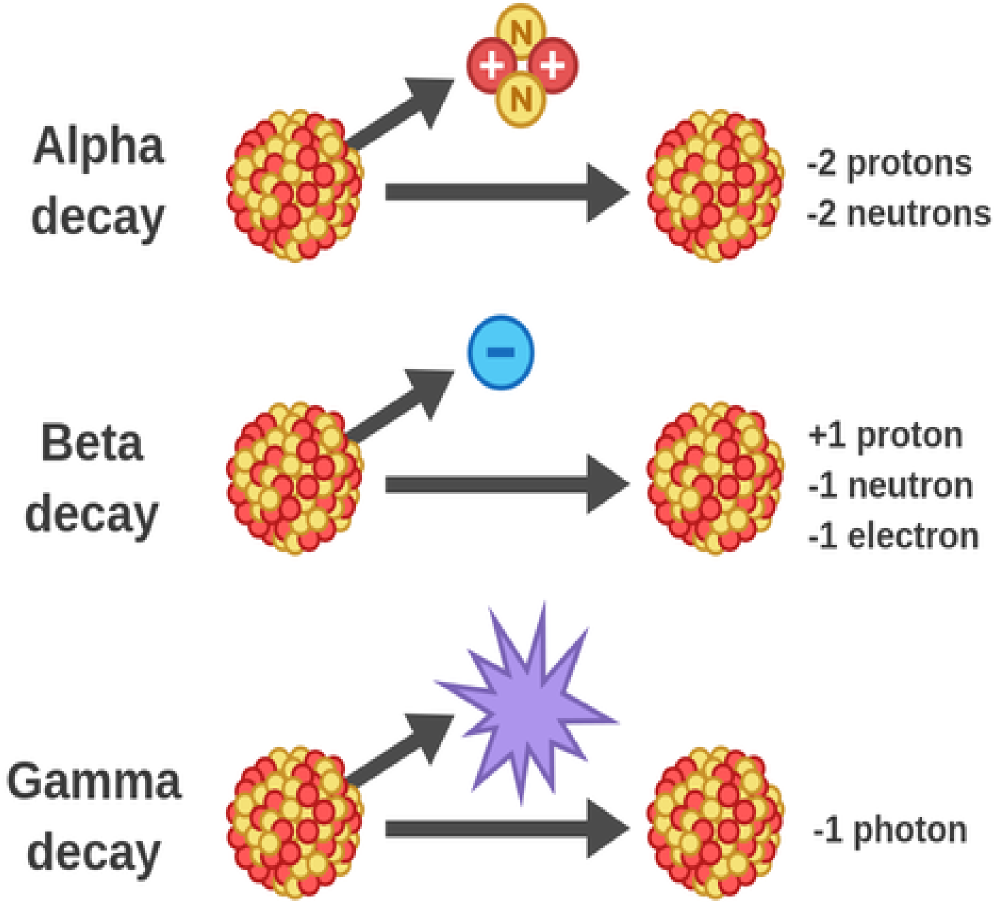
  In alpha decay, an atomic nucleus emits an alpha particle, which consists of two protons and two neutrons. This process reduces the atomic number by 2 and the mass number by 4.

- **Beta Decay**

  In beta decay, a neutron in the atomic nucleus is converted into a proton or a proton is converted into a neutron. This process involves the emission of a beta particle, which can be either an electron or a positron.

- **Gamma Decay**

  In gamma decay, an atomic nucleus releases a gamma ray, which is a high-energy photon. This process does not change the atomic number or mass number of the nucleus, but it reduces the energy of the nucleus.



The Interaction of Radiation with Matter

1

Excitation of Matter

Radiation can displace electrons in atoms, leading to the emission of light and other types of radiation.

2

Ionization of Atoms and Molecules

Radiation can cause the ejection of one or more electrons from atoms and molecules, ionizing them.

3

Scattering

Radiation can scatter off electrons, changing its direction and energy.

Radiation absorption by tissue

Direct ionizing | Indirect Ionizing

INTERACTIONS OF RADIATION AND TISSUES

- When Charged particles have sufficient energy , they are directly ionizing.
  (pass through target matter, and disrupt the atomic structure by producing chemical and biological changes).
- Photons and neutrons (uncharged particle) are indirectly ionizing .(give up their energy to produce fast moving charged particles.)

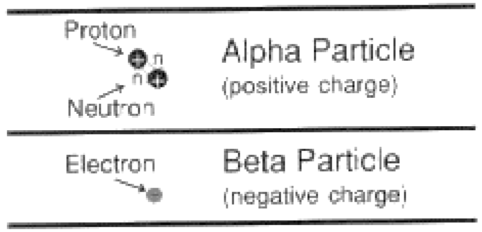
The main effect radiation has on matter is its ability to ionize atoms to become ions, a phenomenon known as IONIZATION.

Alpha, beta, gamma and X radiations are all ionising radiation with the ability to produce ions in living tissue.
The electron ejected off the atom is called the primary electron. When the primary electrons hold energy, a particle ejecting the primary electron may cause it to eject another electron, either on their own atom or on another atom. This is known as secondary ionization.

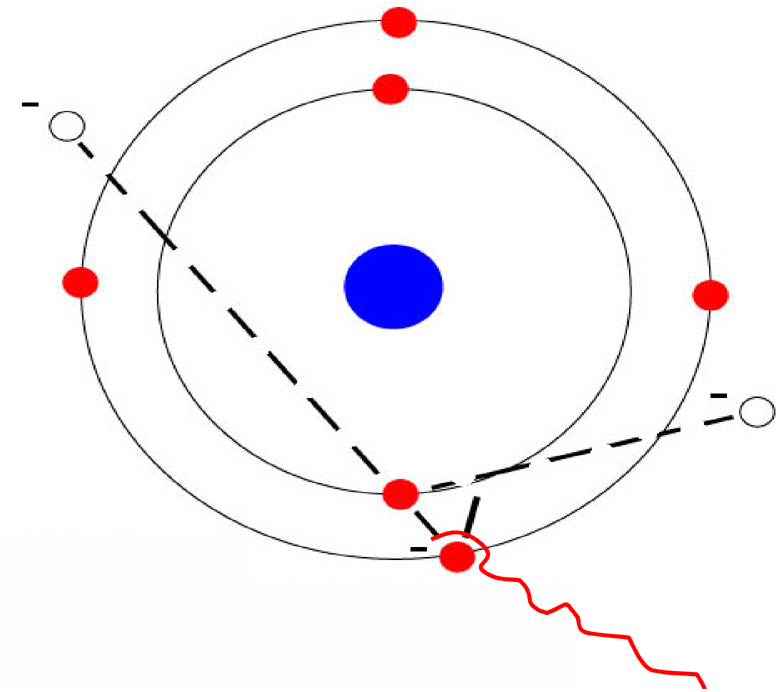
However, ionization does not have to completely eject an electron off the atom. It can raise the energy of the electron instead, raising the electron energy to a higher energy state. When the electron reverts to its normal energy level, it emits energy in the form of radiation, usually in the forms of ultraviolet rays or radio waves.

CHARGED PARTICLES

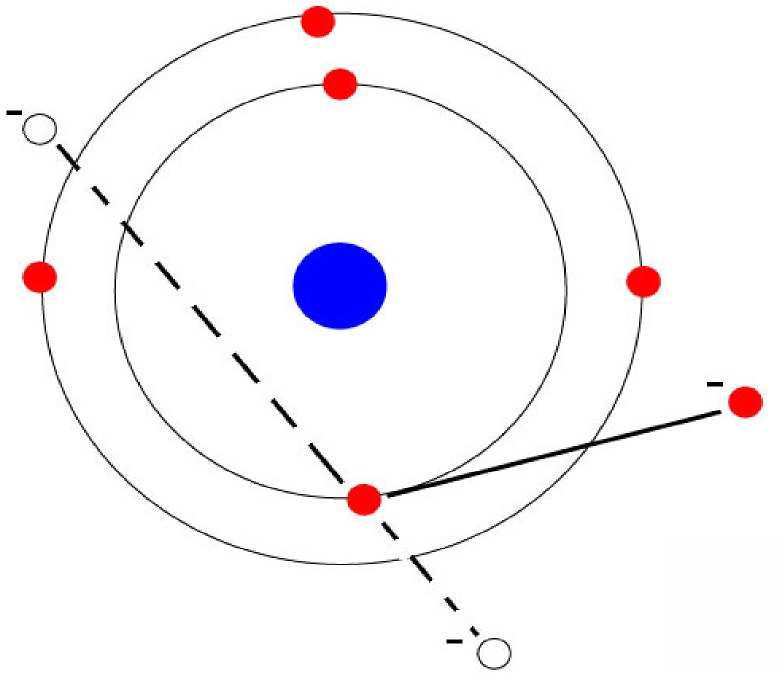
α and β interact with matter via electrostatic forces leaving behind an ionised atom or molecule



excitation



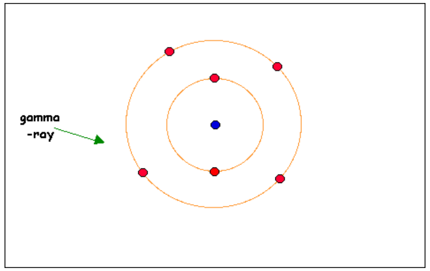
ionization



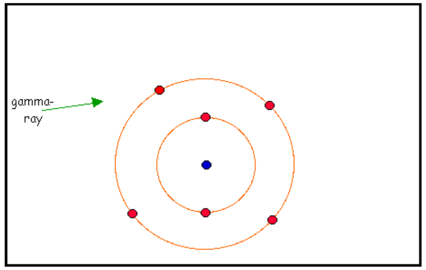
X AND GAMMA RADIATION

Linear energy transfer (LET)

- Photoelectric Effect

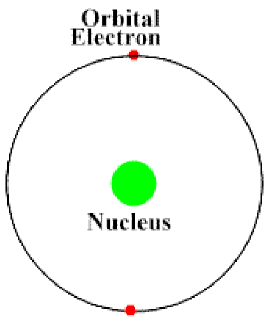


- Compton Effect



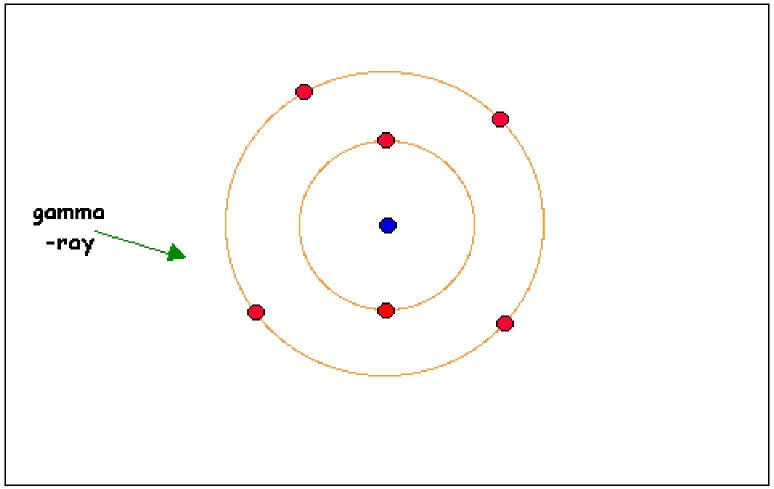
IONIZATION

- Pair Production



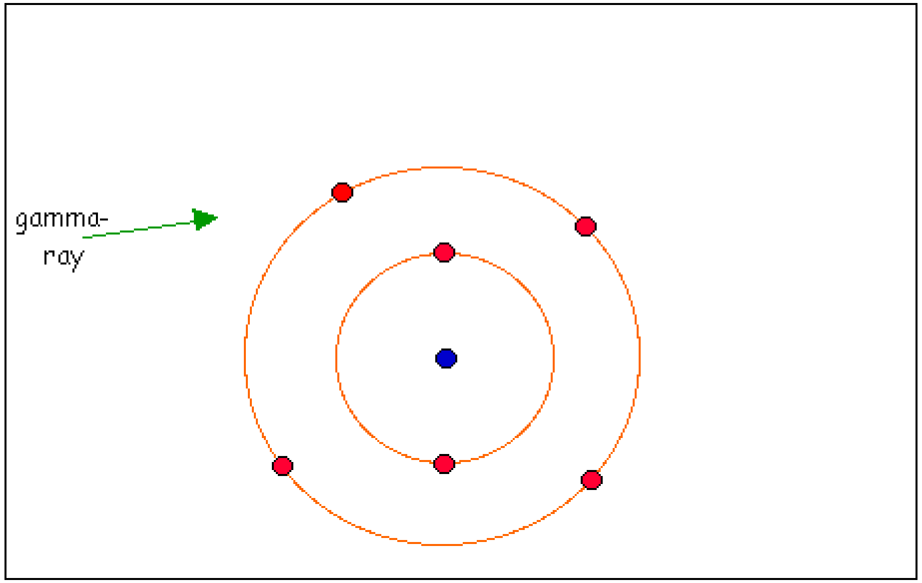
The photoelectric effect

is an absorption process and usually occurs for low energy photons (<0.1 MeV) such as X-rays. The energy EX of the X-ray is transferred (absorbed) to an inner electron, normally a K-shell electron, and this gives the electron sufficient energy to escape from the atom. The atom is left positively charged (ie, an ion) and in an excited state due to the vacancy left in the inner shell. This vacancy is quickly filled by another electron dropping down from a higher shell with the subsequent release of a photon of frequency determined by the two shells involved



The Compton Effect

is essentially an inelastic collision process and generally occurs for high-energy photons (>0.1 MeV) such as gamma rays. An incoming photon of high energy collides with an electron in the valence band, ejecting the electron from the atom. A photon of lower energy (and hence different frequency) than the original is produced that travels at an angle to the direction of the incident photon, determined by conservation of momentum.

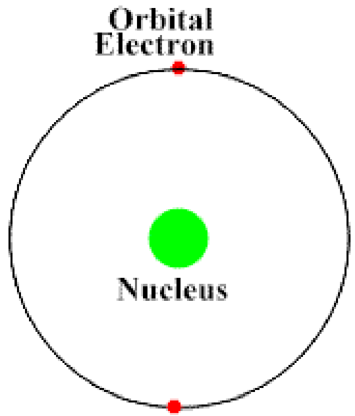


Pair Production

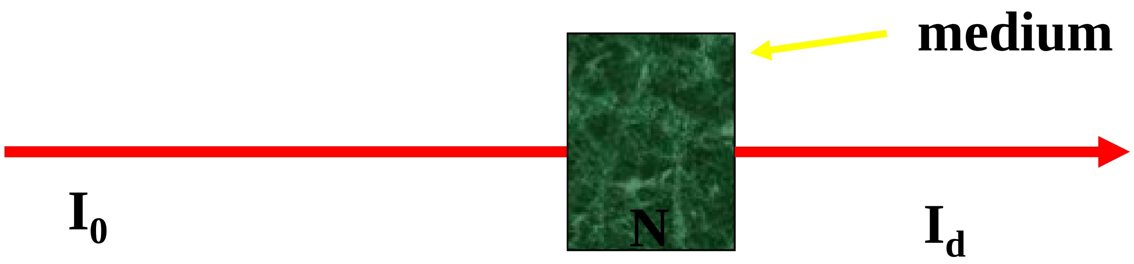
In pair production, a photon transitions to an electron/positron pair. The presence of a massive particle is required. This allows for conservation of energy and momentum as the massive particle is able to absorb some recoil energy.

Pair production typically occurs via interaction of a photon and an atomic nucleus.

Triplet production is a special type of pair production which occurs when the massive particle is an electron. Triplet production is less common and requires more energy than pair production.

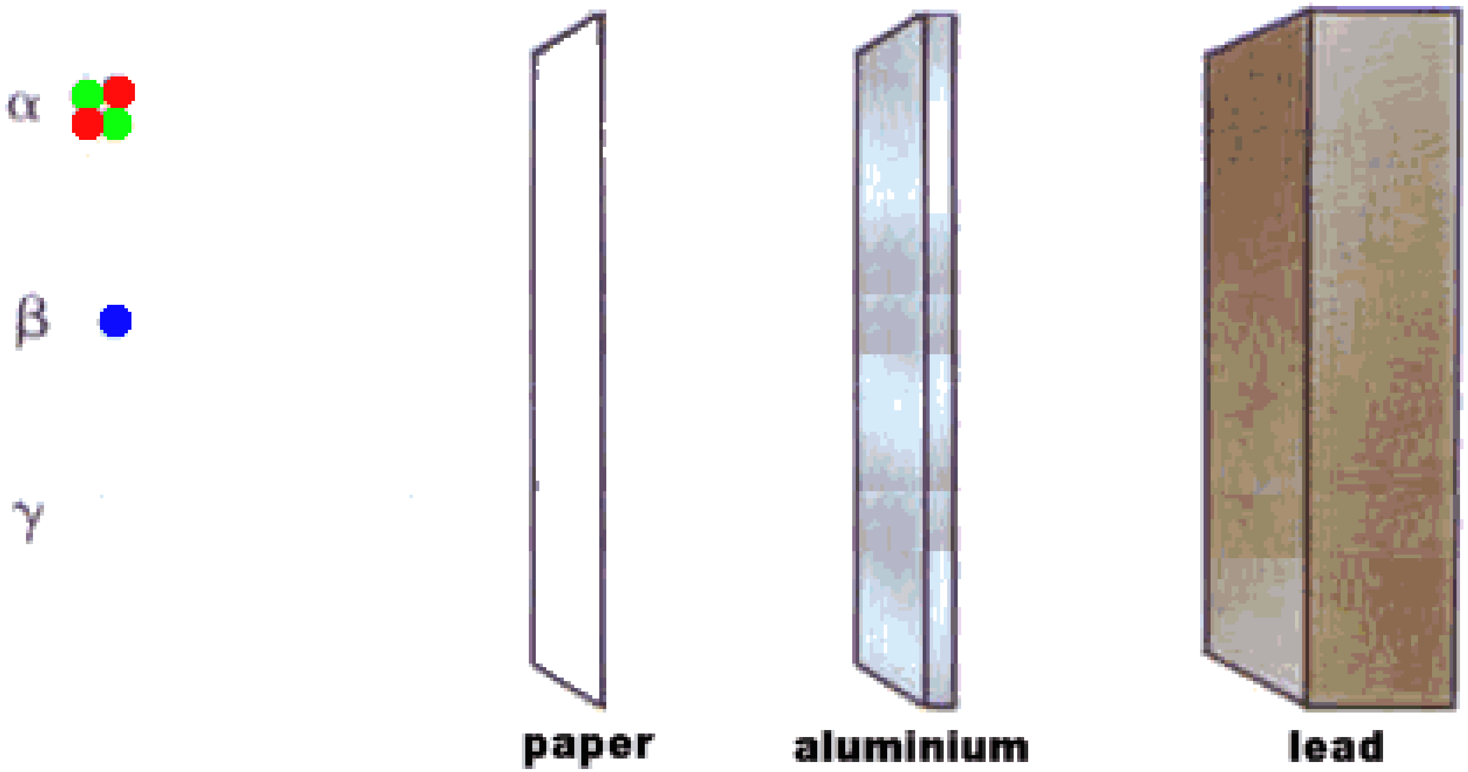


The Effects of Radiation on Matter



The mass stopping power can be approximated for compounds or intimate mixtures by a weighed addition of the mass stopping power of the elemental constituents assuming independent contribution to stopping power

The Effects of Radiation on Matter



Thanks for Your attention