بسم الله الرحمن الرحيم

Radiochemistry

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DANGER
RADIOACTIVE
MATERIAL

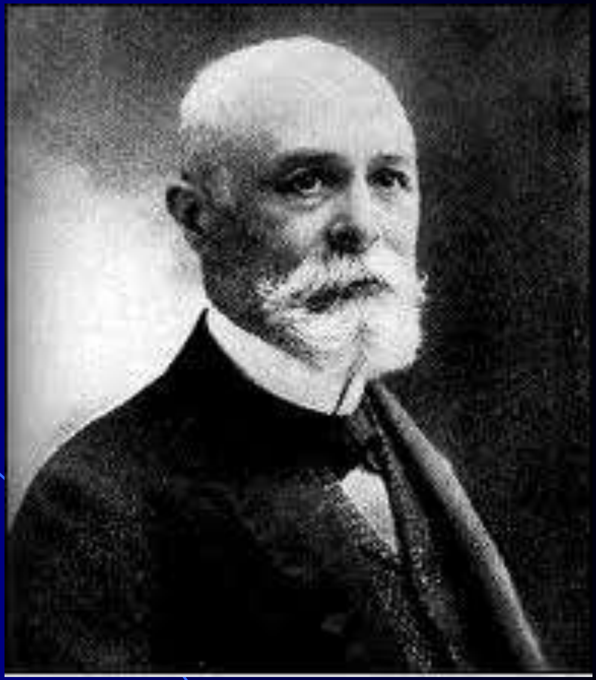
What is Radiation?

Invisible energy waves or particles

What is Radioactivity?

The radioactivity is the property of some atoms to spontaneously give off energy as particles or rays. The atoms that make up the radioactive materials are the source of radiation.

In 1896 Henri Becquerel found that uranium ore gave off penetrating radiation that darkened photographic film without exposing the film to light.



1852-1908 (Nobel 1903)

- Since that time, the scientists discovered more than 50 naturally occurring radioactive isotopes; in addition, scientists are nowadays able to synthesize radioactive isotopes.

- **Since the discovery of radioactive materials, the doors open to use this abundant energy (that liberate from radioactive reaction) in nuclear weapons, radiation therapy energy.**

- **Isotopes** are variants of atoms of a particular chemical element, which have differing numbers of neutrons.

- **Radioactivity** it is the emission of particles and energy by isotope.

- **Radioactive decay** is the process by which an atomic nucleus of an unstable atom loses energy by emitting ionizing particles (ionizing radiation).

- **Nuclear radiation** the nuclei of unstable isotopes undergo spontaneous nuclear reaction that causes liberation of new particles and energy.

- The radiation emitted can be one of three types, called **alpha**, **beta**, or **gamma radiation**

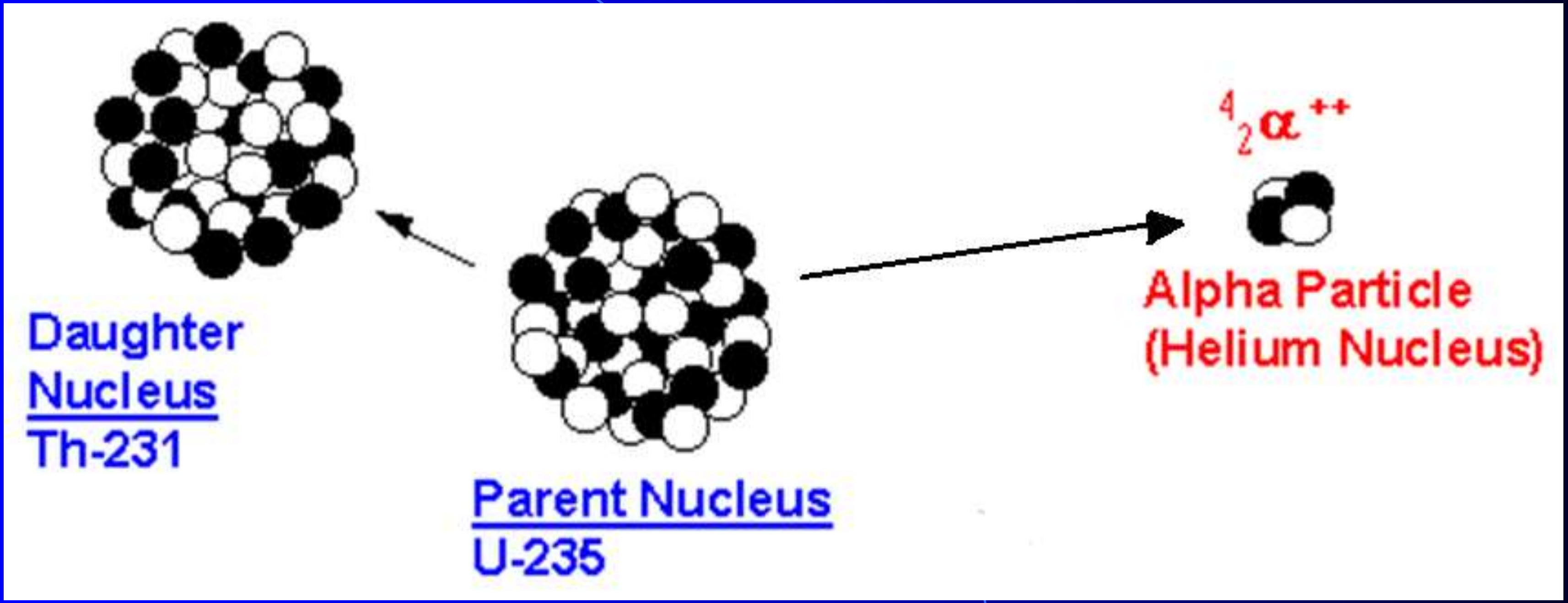
1. **α (alpha) radiation- The emission of an alpha particle (which contains 2 protons and 2 neutrons) from an atomic nucleus. When this occurs, the atom's atomic mass will decrease by 4 units and atomic No. will decrease by 2 particles.**

Alpha Particles

- Two neutrons and two protons
- Charge of +2
- Emitted from nucleus of radioactive atoms
- Transfer energy in very short distances (10 cm in air)
- Shielded by paper or layer of skin
- Primary hazard from internal exposure
- Alpha emitters can accumulate in tissue (bone, kidney, liver, lung, spleen) causing local damage

Alpha Radiation

Alpha particles contain two protons and two neutrons



Alpha Radiation

α has the same constitution as a helium nucleus. Alpha particles may be written as:

$$^{4}_{2}\mathrm{He} \text{ or } ^{4}_{2}\alpha$$

They have a double positive charge and a mass of 4 u

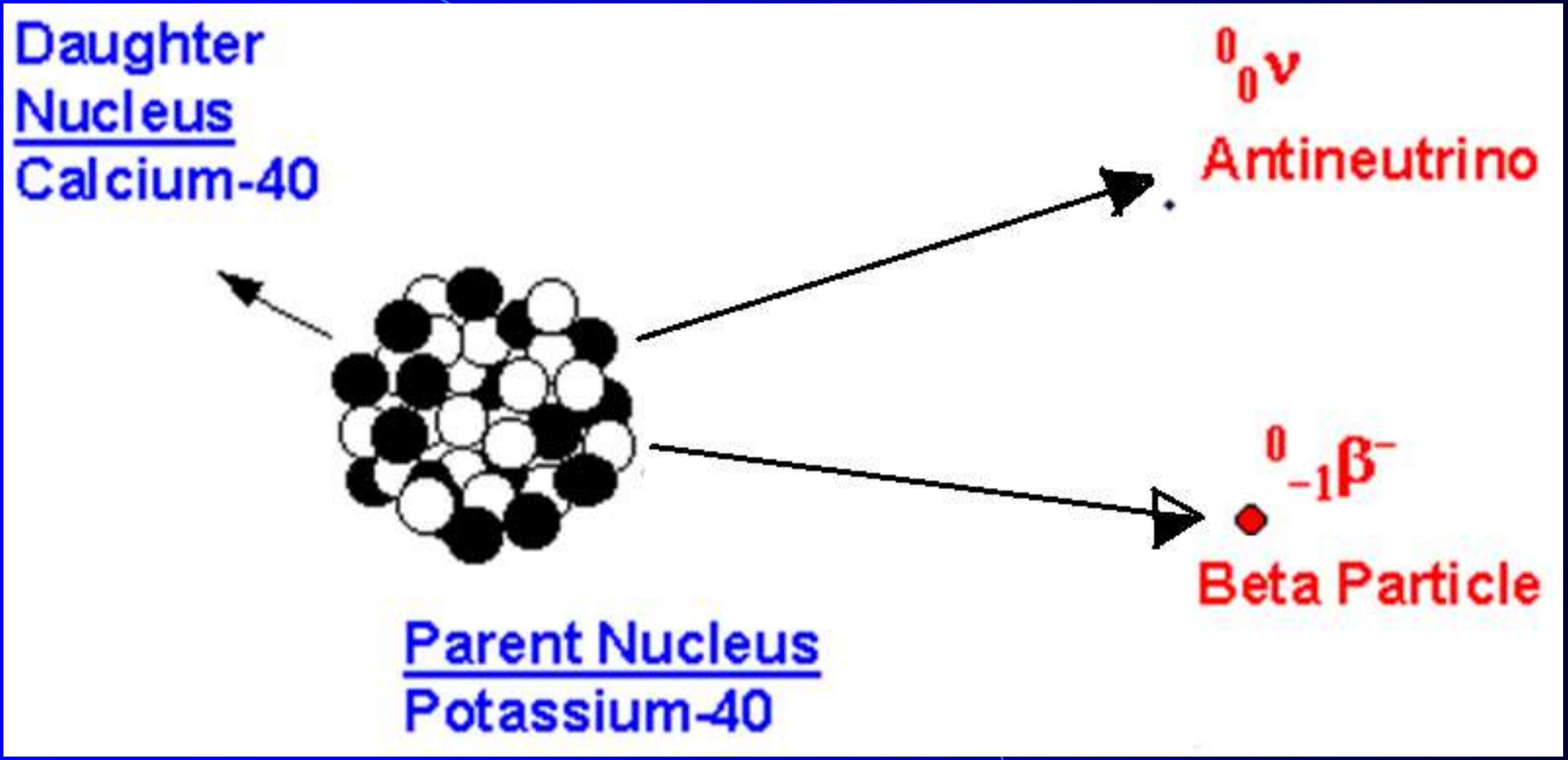
2. β (beta) radiation- the transmutation of a neutron into an electron and a proton. After this happens, the electron is emitted from the nucleus into the electron cloud.

Beta Particles

- Small electrically charged particles
- Similar to electrons
- Charge of -1
- Ejected from nuclei of radioactive atoms
- Emitted with various kinetic energies
- Shielded by wood, body penetration 0.2 to 1.3 cm depending on energy
- Can cause skin burns or be an internal hazard of ingested

Beta-minus Radiation

Beta-minus particles are electrons



Beta-minus Radiation

β^- is produced when a neutron decays

Beta-minus particles may be written as

$$^{0}_{-1}\beta^{-} \text{ or } ^{0}_{-1}e^{-}$$

They have a negative charge and a mass of $^{1}/_{1800}$ u

Beta-minus Radiation

β^- is produced when a neutron decays

$$^{1}_{0}\mathrm{n} \rightarrow {}^{1}_{1}\mathrm{p} + {}^{0}_{-1}\beta^{-}$$

The surplus mass is released as kinetic energy in the b- and as an antineutrino

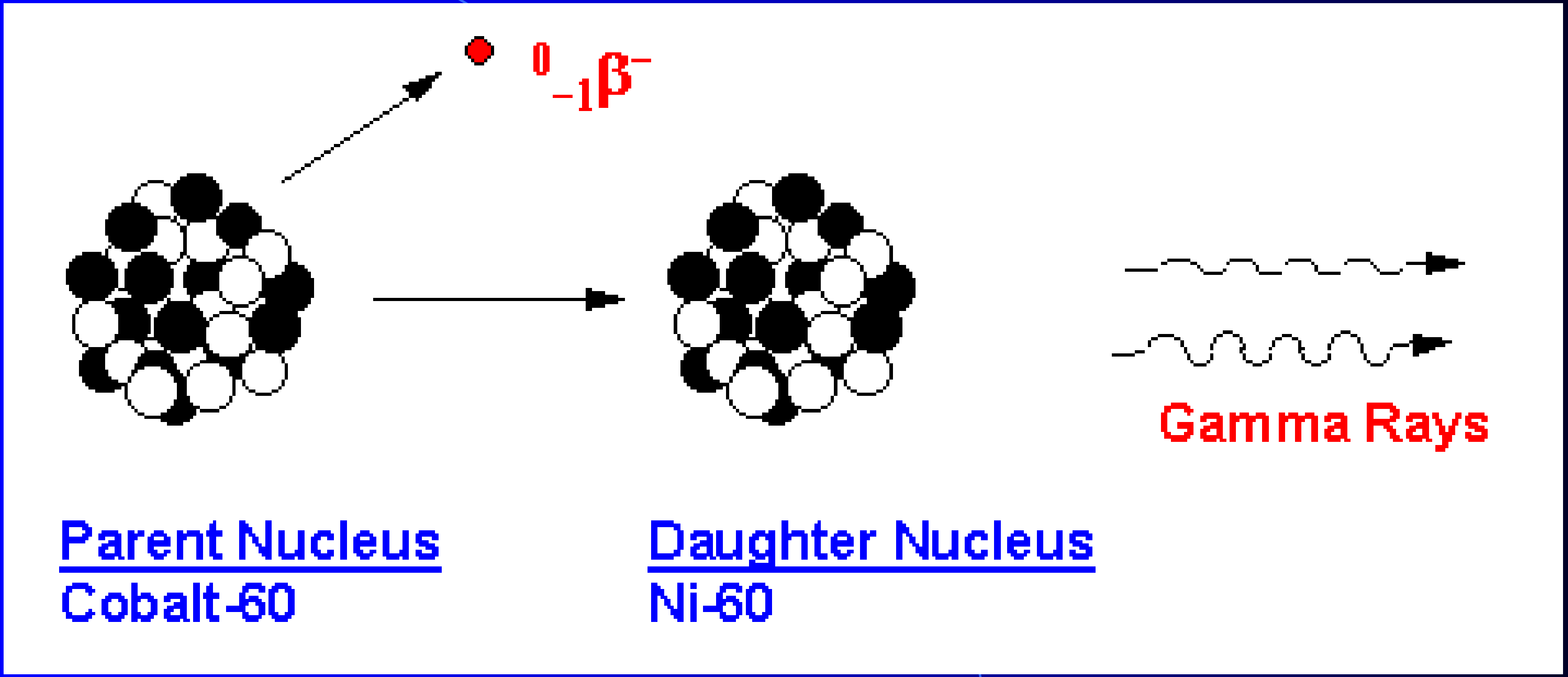
3. **γ (gama)radiation**-it consists of photons with a frequency of greater than 10^{19} Hz. It is much like X-rays, and can pass completely through the human body. Thus gamma rays emitted from outside of the body may cause ionization, and possible health effects, in any organ in the body.

Gamma - Rays

- Electromagnetic photons or radiation (identical to x-rays except for source)
- Emitted from nucleus of radioactive atoms – spontaneous emission
- Emitted with kinetic energy related to radioactive source
- Highly penetrating – extensive shielding required
- Serious external radiation hazard

Gamma Radiation

- Gamma rays are a form of electro-magnetic radiation



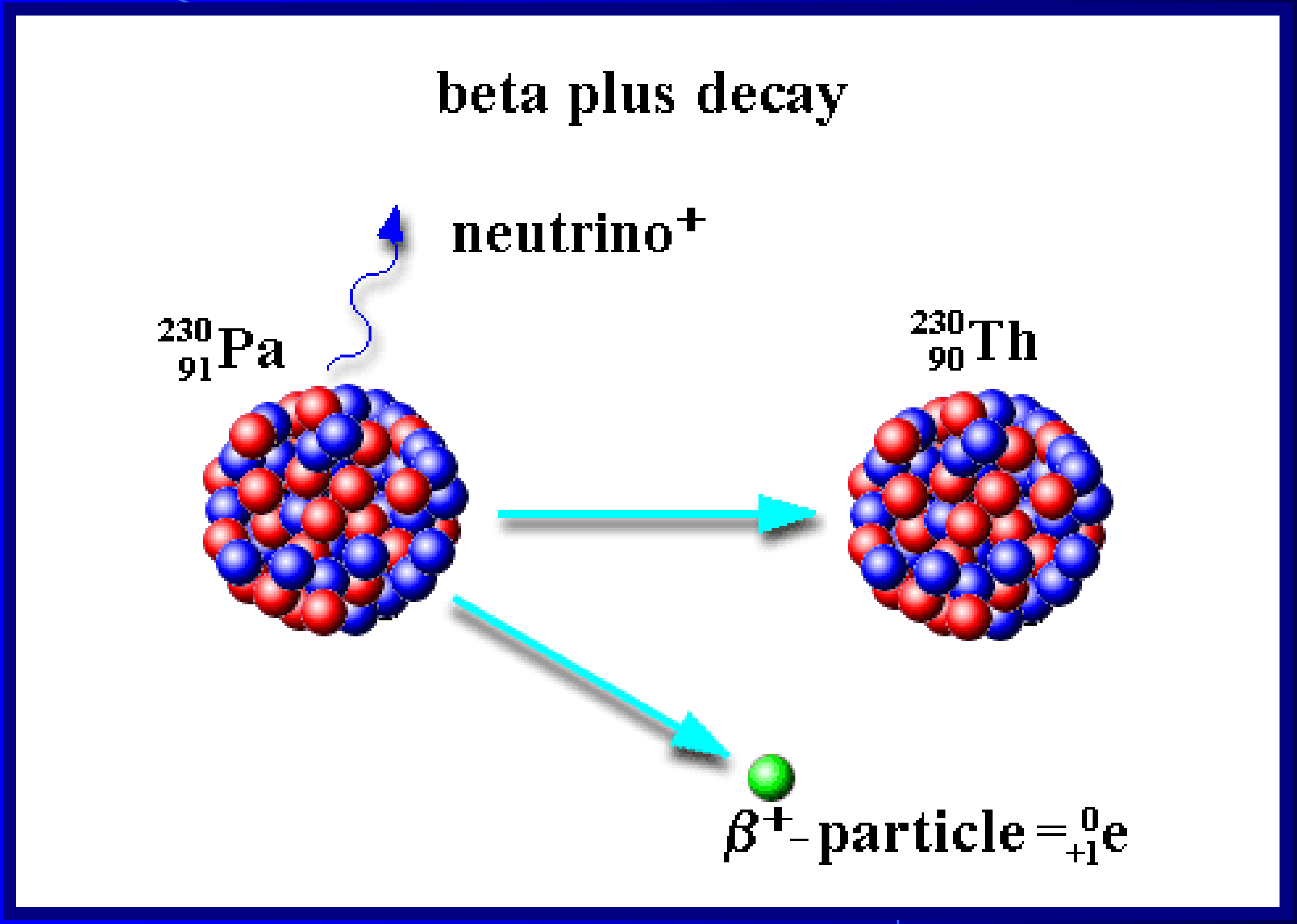
Gamma Radiation

γ release is often associated with α or β decay. Gamma rays remove energy from an unstable nucleus

- **Positron** the same electron mass but opposite charge (+). Because positron is consider to β^+ some references used negatron for β^- and positron for β^+. The only difference between a negative beta particle (negatron) and an electron is the ancestry (proportions).

Beta-plus Radiation

β^+ particles are positrons



Beta-plus Radiation

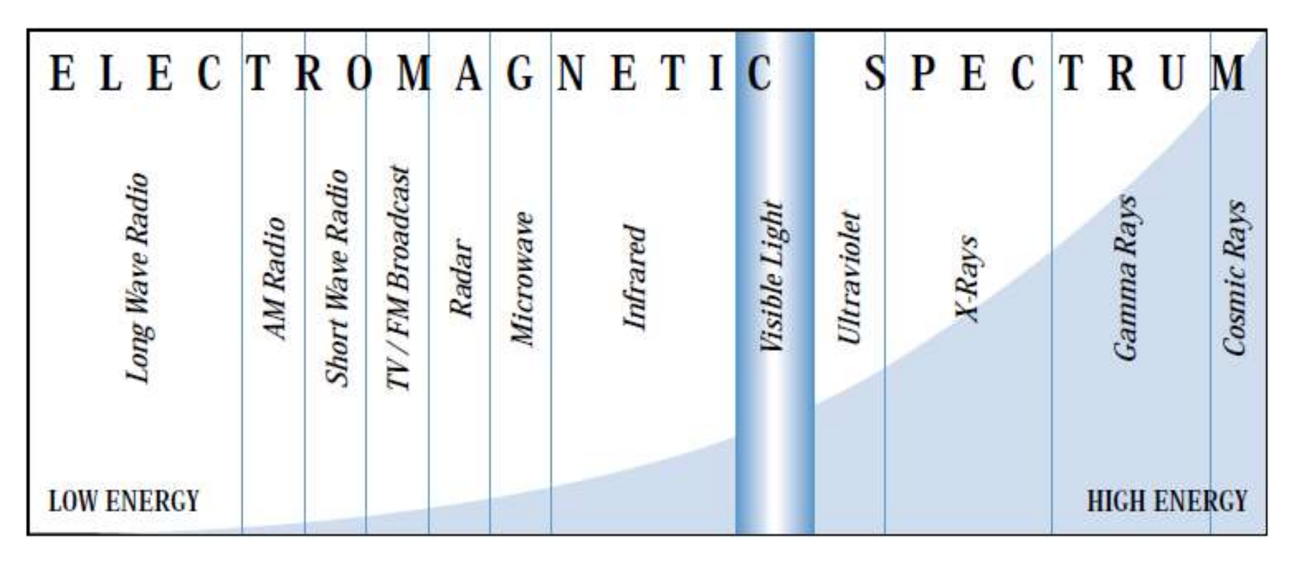
β^+ is produced when a proton decays

$$^{1}_{1}\mathbf{p} \rightarrow {}^{1}_{0}\mathbf{n} + {}^{0}_{+1}\beta^{+}$$

The surplus mass is released as kinetic energy in the β^+ and as a neutrino

- **X-rays** have smaller wavelengths and energy higher than ultraviolet waves. X-ray light tends to act more like a particle than a wave. X-rays have a wavelength in the range of 0.01 to 10 nanometer, and energies in the range 120 eV to 120 keV.

- **X-ray can form ions in matter by knocking electrons off the atoms and molecules in its path creating ions, that's why it is called ionization radiation.**



The Electromagnetic Spectrum

X-rays

- Overlap with gamma-rays
- Electromagnetic photons or radiation
- Produced from orbiting electrons or free electrons – usually machine produced
- Produced when electrons strike a target material inside x-ray tube
- Emitted with various energies & wavelengths
- Highly penetrating – extensive shielding required
- External radiation hazard
- Discovered in 1895 by Roentgen

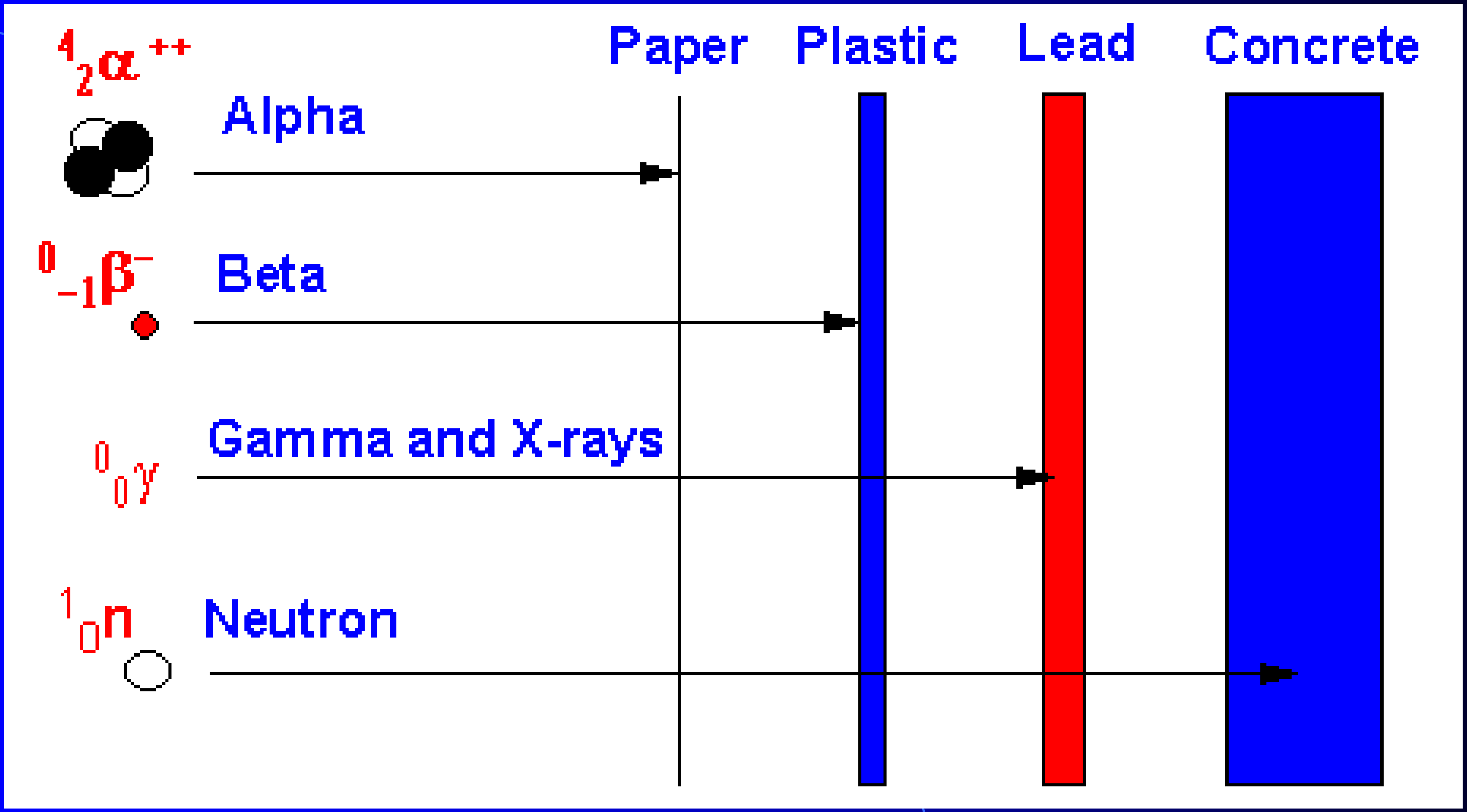
Penetrating power

α has a high mass, It is stopped by a few centimetres of air

β has a small mass, It is stopped by a few millimetres of aluminium

ɣ has zero mass, It is stopped by thick lead or concrete

Penetrating power



Penetrating power

α has a high charge, It is dangerous if swallowed.

β has a small charge, It is dangerous at medium range

γ has high energy, It is dangerous at distance

Decay laws - alpha

- When an isotope emits an α particle
- Its nucleon number decreases by 4
- Its proton number decreases by 2
- For example:

$$^{238}_{92}\mathrm{U} \rightarrow {}^{234}_{90}\mathrm{Th} + {}^{4}_{2}\alpha$$

Decay laws – beta-minus

- When an isotope emits a β^- particle
- Its nucleon number is unchanged
- Its proton number increases by 1
- For example:

$$^{234}_{90}Th \rightarrow {}^{234}_{91}Pa + {}^{0}_{-1}\beta^-$$

Decay laws – beta-plus

When an isotope emits a β^+ particle

Its nucleon number is unchanged

Its proton number decreases by 1

For example:

$$^{230}_{91}\mathrm{Pa} \rightarrow {}^{230}_{90}\mathrm{Th} + {}^{0}_{+1}\beta^{+}$$

Ionization radiation

Ionization

Ionizing radiation is produced by unstable atoms, because they have an excess of energy or mass or both.

Unstable atoms are said to be radioactive. In order to reach stability, these atoms give off, or emit, the excess energy or mass. These emissions are called radiation.

Ionizing and Non-ionizing radiation?

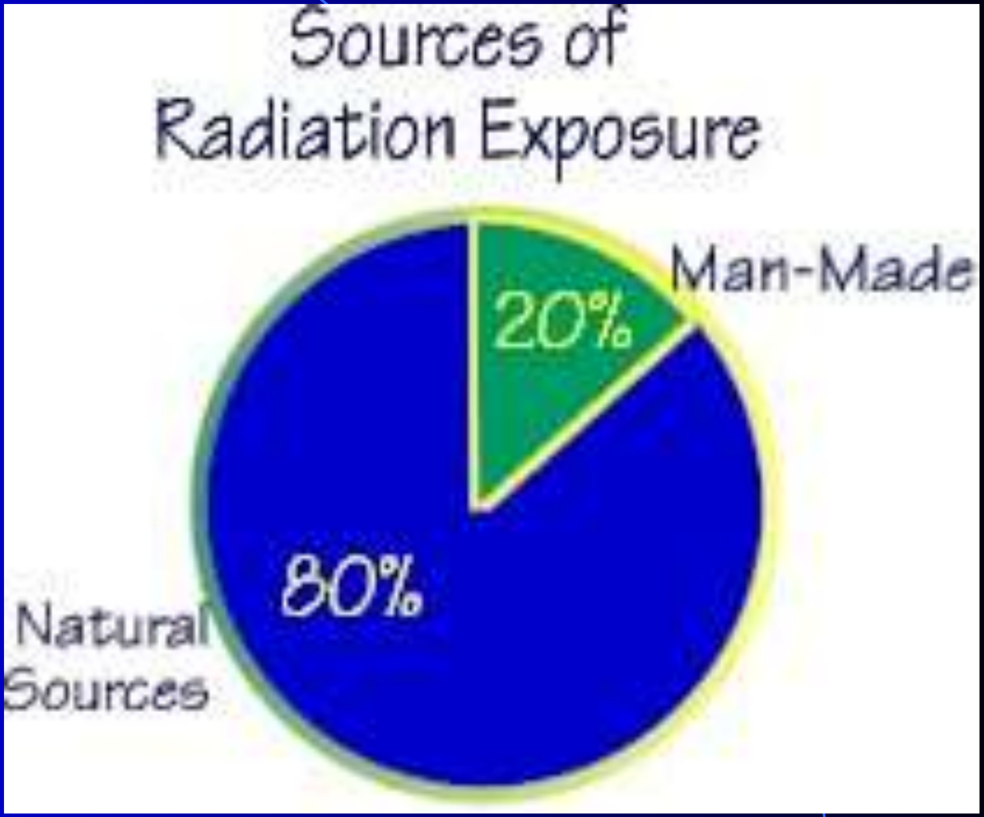
- **Radiation carries a range of energy forming an electromagnetic spectrum.**

- **Radiation that does not have enough energy to break chemical bonds but can vibrate atom is referred to as “Non-ionizing Radiations” e.g. radiowaves, microwaves, infrared, visible light etc.**

- **Radiation that has enough energy to break chemical bonds is referred to as 'ionizing radiation, e.g. alpha particles, beta particles, gamma rays etc.**

Sources of Ionizing Radiation

- Naturally Occurring
- Consumer Products
- Foods and Containers
- Medical Procedures
- Nuclear Plants
- Radiological Sites
- Government & Industry



Cosmic rays

- Very high energy protons from outer space are constantly bombarding the atmosphere, producing showers of ionizing radiation. Most of this cosmic ray radiation is absorbed by the atmosphere. However, the higher you go, the thinner the atmosphere protecting you. A person living at a level of 10,000 feet gets 4 times the cosmic ray exposure of a person living at sea level. A 5-hour flight to Europe gives you the equivalent of about one month's worth of sea-level cosmic ray radiation exposure.

Units of Radiation Exposure

Roentgen (R)

The roentgen is a unit used to measure a quantity called exposure. This can only be used to describe an amount of gamma and X-rays, and only in air. One roentgen is equal to depositing in dry air enough energy to cause 2.58E-4 coulombs per kg.

- **only applies to photons**
- **only applies in air**
- **only applies to energies less than 3 MeV**

Curie (Ci)

1859-1906 (Nobel in 1903)

Named in honor of Pierre Curie

Curie = No. of nuclei that decay per second (picocurie = 10^{-12}Ci, microcurie = 10^{-6}Ci, millicurie = 10^{-3}Ci), One curie = 3.7×10^{10} Becquerel (Bq)

Radiation hazard does not depend on the activity only. It also depends on the type of decay (alpha, beta, photon, etc.).

Rad (radiation absorbed dose): The rad is a unit used to measure a quantity called absorbed dose. This relates to the amount of energy actually absorbed in some material, and is used for any type of radiation and any material. One rad is defined as the absorption of 100 ergs per gram of material. The unit rad does not describe the biological effects of the different radiations.

One rad (D) = 2.4×10^{-3} cal

- (This energy is enough to damage the tissue due to rising in the temperature)

1 Gy = 100 rad

- Gray (Gy) = one joule of energy absorbed by one kilogram of tissue

(An erg is the amount of work done by a force of one dyne exerted for a distance of one centimeter) per gram of material.

- **Rem (roentgen equivalent man):** The rem is a unit used to derive a quantity called equivalent dose. This relates the absorbed dose in human tissue to the effective biological damage of the radiation. Not all radiation has the same biological effect, even for the same amount of absorbed dose. Equivalent dose is often expressed in terms of thousandths of a rem, or mrem. To determine equivalent dose (rem), you multiply absorbed dose (rad) by a quality factor (Q) that is unique to the type of incident radiation.

- 1 rem = 1 rad x RBE (Relative Biological Equivalent)
- RBE of alpha particles = 10 times that of beta particles (10 times more damage)

What is LD_{50}?

It is the dose in rem that is fatal to 50% of the population within 30 days.

Estimated Exposure To The National Population Between 320 – 360 mr/yr

Nuclear reactions

Some radioisotopes contain nuclei which are highly unstable and decay spontaneously by splitting into 2 smaller nuclei. Such spontaneous decays are accompanied by the release of neutrons.

Nuclear reaction can be induced by bombarding atoms with neutrons. The nuclei of the atoms then split into 2 parts. Induced fission decays are also accompanied by the release of neutrons.

$$^{235}_{92}U + ^{1}_{0}n \longrightarrow ^{141}_{56}Ba + ^{92}_{36}Kr + 3\,^{1}_{0}n$$

$$^{235}_{92}U + ^{1}_{0}n \longrightarrow ^{138}_{55}Cs + ^{96}_{37}Rb + 2\,^{1}_{0}n$$

In nuclear reaction, two nuclei with low mass numbers combine to produce a single nucleus with a higher mass number.

$$ {}_{1}^{2}H + {}_{1}^{3}H \longrightarrow {}_{2}^{4}He + {}_{0}^{1}n + Energy $$

- **Another example is carbon – 14 , when this carbon isotope emits beta particle it is changed into isotope of nitrogen this reaction can be represented as the following reaction:**

$$^{14}_{6}C \xrightarrow{\text{Emiting beta paricles}} {}^{14}_{7}N + {}^{0}_{-1}\beta$$

- **All the nuclear equations should be balanced, which means that the sum of protons & neutrons is the same in the products as in the starting materials (there is no loose in either P nor N)**

Sum in the superscript: 14 = 14 + 0 $\therefore$ 14 = 14

Sum in the subscript: 6 = 7 - 1 $\therefore$ 6 = 6

Half life

- It is the time needed for one-half of the original nuclei of an isotope to decay to other substances and represent by the symbol t1/2 which indicate half life.
- The importance of half life, it tell us how long a sample of isotope will exist.

$$^{234}_{90}Th \xrightarrow{t_{1/2}=24.1\ days} {}^{234}_{91}Pa + {}^{0}_{-1}\beta$$

Detecting ionization radiation

There are three main methods of detecting ionization radiation

- **Photographic method.**
- **Scintillation method.**
- **Geiger counter.**

Photographic Method

- A photographic film and paper shielded from light are exposed by ionization radiation. The exposure is detected by developing the film or paper in the usual way. Each person wear badge containing piece of film and the film will changed at certain intervals. Film badges are small portable devices such as x-ray technicians and nurses. The badge is removed monthly and developed. The darker the film badge, the greater the degree of exposure.

scintillation method

There is instruments that contain surface coated with certain substance that gives off flashes of light when hit by ionizing radiation. The scintillation detectors used in were simple phosphor screens which emitted a flash of light when struck by an alpha particle. Modern scintillation counters may use single crystals of NaI doped with thallium.

Geiger-Muller

This device consists of two parts, a detecting tube and a counter. The tube consists of a pair of electrodes between there is a high voltage surrounded by an ionizable gas. The ions cause pulses of current at the electrodes, which are recorded on the counter. The Geiger tube is most sensitive to beta radiation. Gamma radiation can pass without being counted, and some alpha radiation can't make it. The Geiger-Muller counter indicates the counts per minute of radiation, but it doesn't tell you the energy of the radiation.

Dosimeter

Dosimeter works on the property of thermo-luminescence (TLD). The TLD consists of a penlike device and a reading unit. The penlike device, contains a crystal such as lithium fluoride, which absorbs radiation. When the crystal absorbs the radiation, its structure changes slightly. To determine the amount of radiation, the penlike device is placed in its reading unit.

ionization radiation has been known to cause:

- Skin cancer.
- Bone cancer. And damage to bone cells.
- Leukaemia.
- Other types of cancer.
- Damage to brain cells.
- Eye cells.
- Damage to other organ cells and tissues.
- Genetic risk (which is more difficult to determine because it may appear after several generations). This type of risk causes damage to genes of the cell nuclei).

X-ray is also harmful; person must take precaution to avoid exposure. The effect of being exposure to high level of radiation kill the cells (this fact is used to treat cancer), so normally cancer cells is exposed to high energy radiation (X-Ray, ɣ radiation...) to destroy these cells.

The Effects of Radiation on the Cell at the Molecular Level

- When radiation interacts with target atoms, resulting in ionization or excitation.
- The absorption of energy produces damage to molecules by direct and indirect actions.
- For direct action, damage occurs to atoms on key molecules in the biologic system. This causes functional alteration of the molecule.
- Indirect action involves the production of free radicals whose toxic damage on the key molecule results in a biologic effect.

There are three standard ways to limit exposure:

Time: Limiting or minimizing the exposure time will reduce the dose from the radiation source.

- **Distance: Radiation intensity decreases sharply with distance.**

- Shielding: Air or skin can be sufficient to low-energy alpha and beta radiation. Barriers of lead, concrete, or water give effective protection from energetic particles such as γ-rays and neutrons.
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Thank you