Radiation

IN ORDER TO UNDERSTAND RADIATION PHYSICS, ATOMIC MODEL HAS TO BE KNOWN WELL

Motivation

Radiation is used in our daily life, especially in medical imaging.
X-ray Imaging, Computed Tomograpy, Radiotherapy ,Fluoroscopy , ...

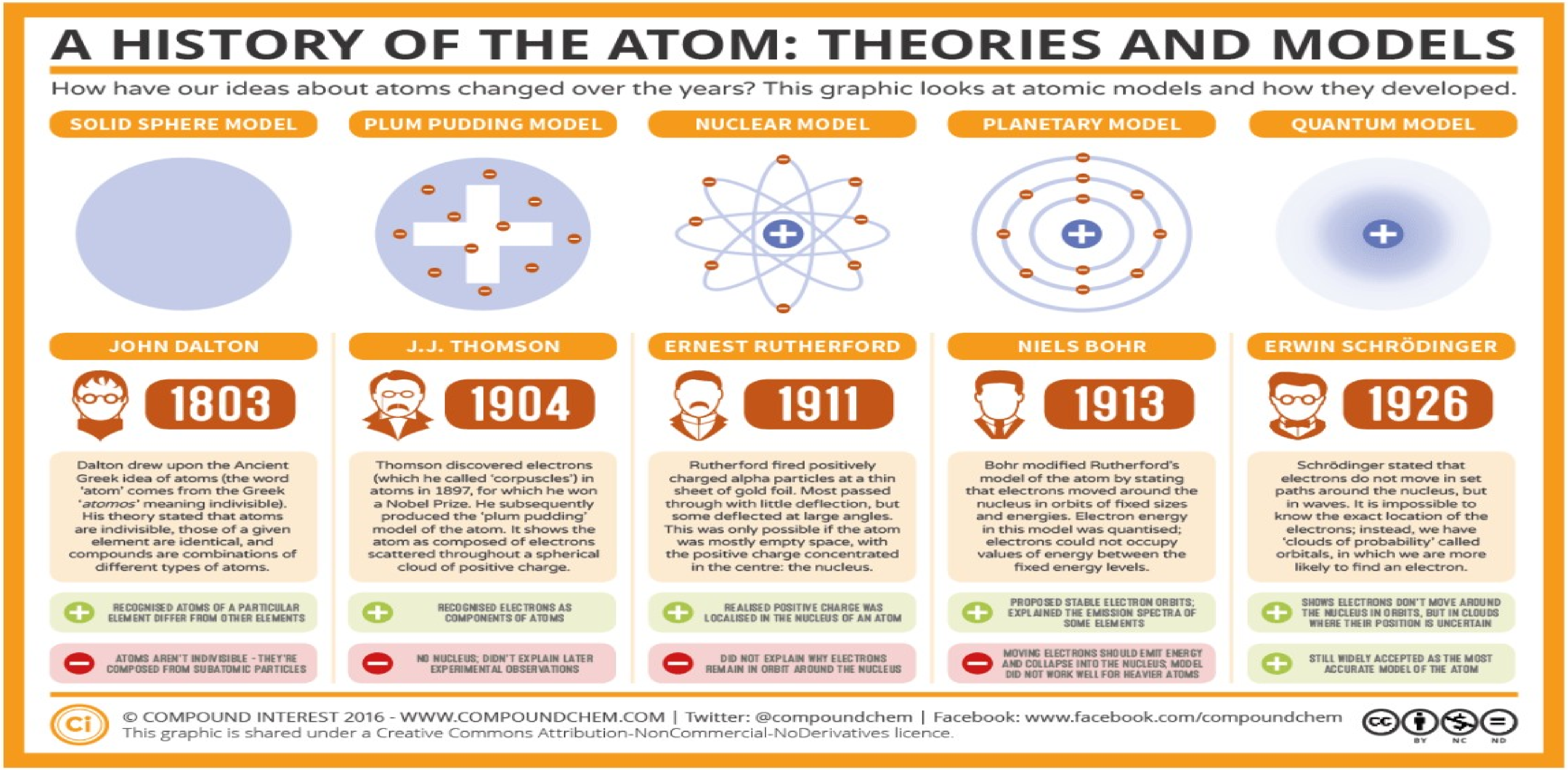
Motivation

Radiation has many beneficial uses.
Radiation is used for many purposes in industry

- Measuring density in materials
- Measuring the thickness of materials
- Detecting smoke
- Sterilising medical equipment
- Eliminating static electricity
- ...
- ...

Learning Objectives

- Models of Atom
- History of Atom, Radiation and Radioactivity
- Nucleus of Atom
- Radiation
- Elektromagnetic Spectrum
- Differences between ionizing and non-ionizing radiation
- Differences between radioactivity and radiation
- Alpha Radiation
- Beta Radiation
- Gamma Radiation
- X-Ray


A HISTORY OF THE ATOM: THEORIES AND MODELS
How have our ideas about atoms changed over the years? This graphic looks at atomic models and how they developed.
SOLID SPHERE MODEL
JOHN DALTON
1803
Dalton drew upon the Ancient Greek idea of atoms (the word 'atom' comes from the Greek '*atomos*' meaning indivisible). His theory stated that atoms are indivisible, those of a given element are identical, and compounds are combinations of different types of atoms.
RECOGNISED ATOMS OF A PARTICULAR ELEMENT DIFFER FROM OTHER ELEMENTS
ATOMS AREN'T INDIVISIBLE - THEY'RE COMPOSED FROM SUBATOMIC PARTICLES
PLUM PUDDING MODEL
J.J. THOMSON
1904
Thomson discovered electrons (which he called 'corpuscles') in atoms in 1897, for which he won a Nobel Prize. He subsequently produced the 'plum pudding' model of the atom. It shows the atom as composed of electrons scattered throughout a spherical cloud of positive charge.
RECOGNISED ELECTRONS AS COMPONENTS OF ATOMS
NO NUCLEUS; DIDN'T EXPLAIN LATER EXPERIMENTAL OBSERVATIONS
NUCLEAR MODEL
ERNEST RUTHERFORD
1911
Rutherford fired positively charged alpha particles at a thin sheet of gold foil. Most passed through with little deflection, but some deflected at large angles. This was only possible if the atom was mostly empty space, with the positive charge concentrated in the centre: the nucleus.
REALISED POSITIVE CHARGE WAS LOCALISED IN THE NUCLEUS OF AN ATOM
DID NOT EXPLAIN WHY ELECTRONS REMAIN IN ORBIT AROUND THE NUCLEUS
PLANETARY MODEL
NIELS BOHR
1913
Bohr modified Rutherford's model of the atom by stating that electrons moved around the nucleus in orbits of fixed sizes and energies. Electron energy in this model was quantised; electrons could not occupy values of energy between the fixed energy levels.
PROPOSED STABLE ELECTRON ORBITS; EXPLAINED THE EMISSION SPECTRA OF SOME ELEMENTS
MOVING ELECTRONS SHOULD EMIT ENERGY AND COLLAPSE INTO THE NUCLEUS; MODEL DID NOT WORK WELL FOR HEAVIER ATOMS
QUANTUM MODEL
ERWIN SCHRÖDINGER
1926
Schrödinger stated that electrons do not move in set paths around the nucleus, but in waves. It is impossible to know the exact location of the electrons; instead, we have 'clouds of probability' called orbitals, in which we are more likely to find an electron.
SHOWS ELECTRONS DON'T MOVE AROUND THE NUCLEUS IN ORBITS, BUT IN CLOUDS WHERE THEIR POSITION IS UNCERTAIN
STILL WIDELY ACCEPTED AS THE MOST ACCURATE MODEL OF THE ATOM
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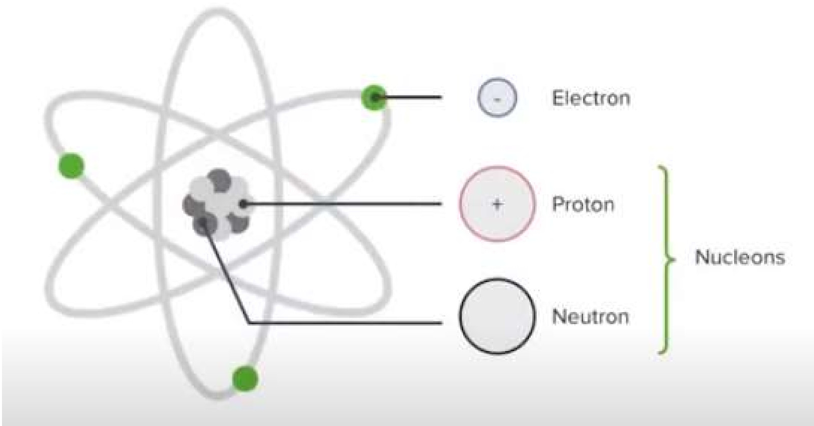
History of atom and radiation (together)

- In 1803 Dalton's model of **atom**
- In 1895 X-rays were discovered by Wilhelm Conrad Rontgen **(Radiation)**
- In 1896 **Radioactivity** discovered by Henri Becquerel
- In 1898 Radium and Polonium discovered by Marie and Pierre Curie (**Radioactivity)**
- In 1904 Thomson's model of **atom**
- In 1911 Rutherford's model of **atom**
- In 1913 Bohr's model of **atom**
- In 1919 Discovery of the **proton** by Rutherford
- In 1932 Discovery of the **neutron** by Chadwick

Atomic Nucleus

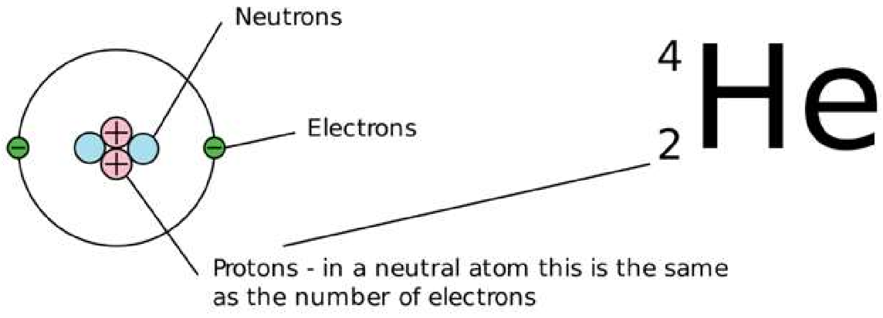
Rutherford's alpha scattering experiment played an imported role to understand the **structure of the atom** and the nucleus.

- There are proton and neutron in the atomic nucleus
- Proton and neutron both are called nucleons
- Not only atoms have proton and neutron, but also they have electrons.
- Electrons revolve around the nucleus in orbit.



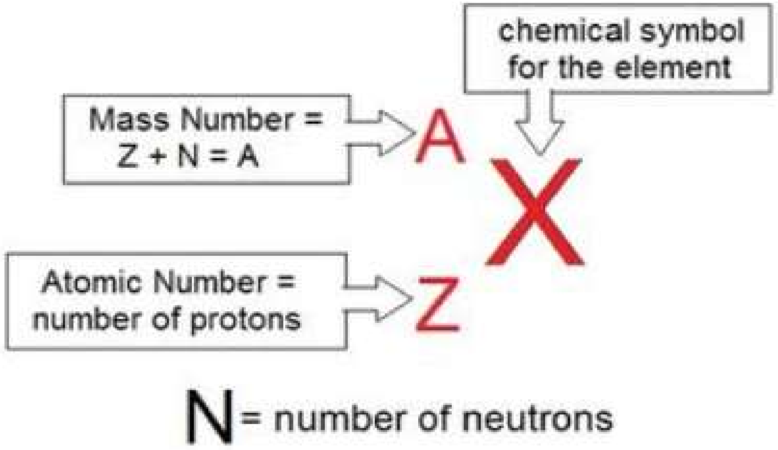
Atomic Number

- The atomic number is the number of proton in the nucleus of an atom
- Number of protons in nucleus **defines** the **identity** of that nucleus.
- Helium is defined as the element which has 2 protons in it's nucleus



Composition of nucleus

- The number of protons in the nucleus is called the **atomic number** (Z).
- The number of neutrons in the nucleus is called **neutron number** (N).
- The total number of neutrons and protons in the nucleus is called the **mass number** (A).
    - **A = Z+N**
- The number of neutrons doesn't change the identity of the element

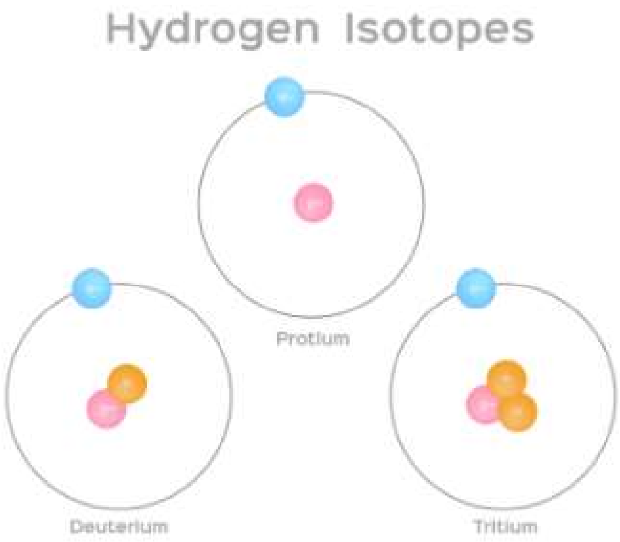


Isotop

In nature, some nucleus have **same number of protons** but different number of neutrons.

These kinds of atoms are called isotopes.

- Hydrogen has three isotopes and they are called (hydrogen), (deuterium),and (tritium).
- All the three nucleus have one proton and
  - hydrogen has no neutron,
  - deuterium has 1 neutron
  - tritium has 2 neutrons



What is Radiation?

What is Radiation?

- **Radiation** is the release of energy in electromagnetic waves or particles

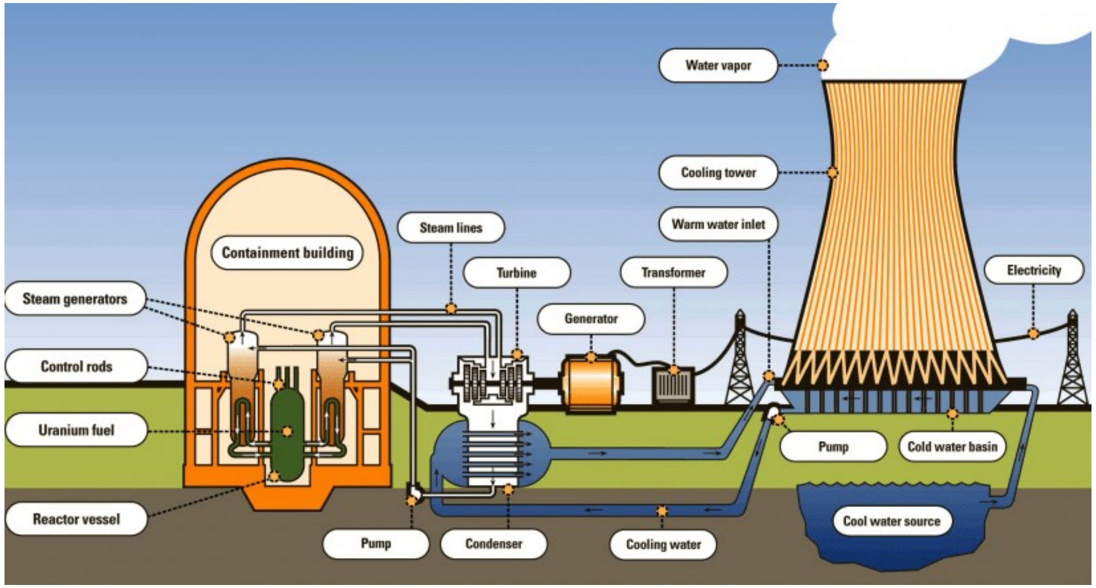
What is Radiation?

- Radiation is energy that moves from one place to another in a form that can be described as waves or particles.
- We are exposed to radiation in our everyday life.
- Some of the most familiar sources of radiation include the sun, microwave ovens in our kitchens and the radios we listen to in our cars.

What is Radiation?

- Most of this radiation carries no risk to our health. But some does.
- In general, radiation has lower risk at lower doses
  - but can be associated with higher risks at higher doses

What is radiation good for? – Some examples



- Energy: radiation allows us to produce electricity via, for example, solar energy and nuclear energy.

What is radiation good for? – Some examples

- Industry and science: with nuclear techniques based on radiation, scientists can examine objects from the past or produce materials.

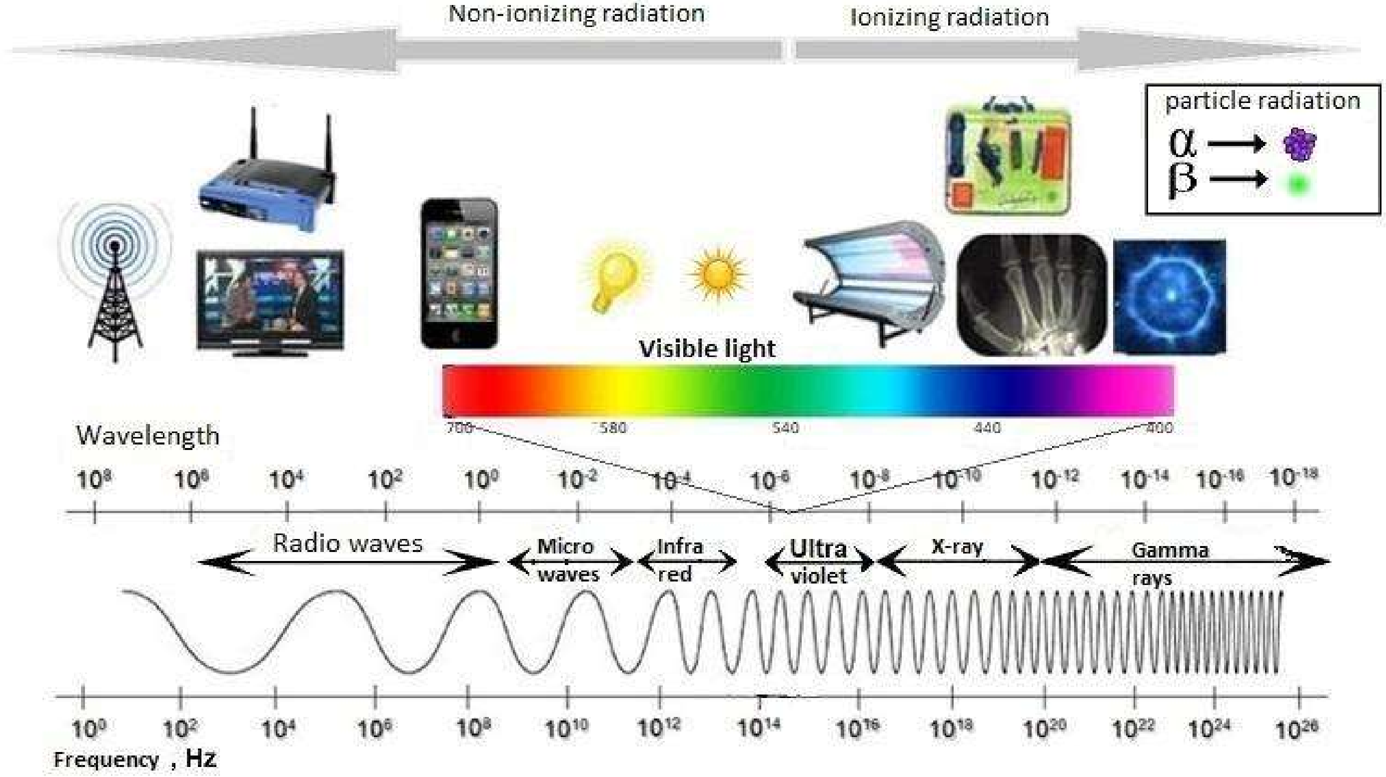
What is radiation good for? – Some examples

- Health: thanks to radiation, we can benefit from medical procedures, such as many cancer treatments, and diagnostic imaging methods.

Which departments use radiation in hospitals?

What types of radiation do you know?

The electromagnetic spectrum



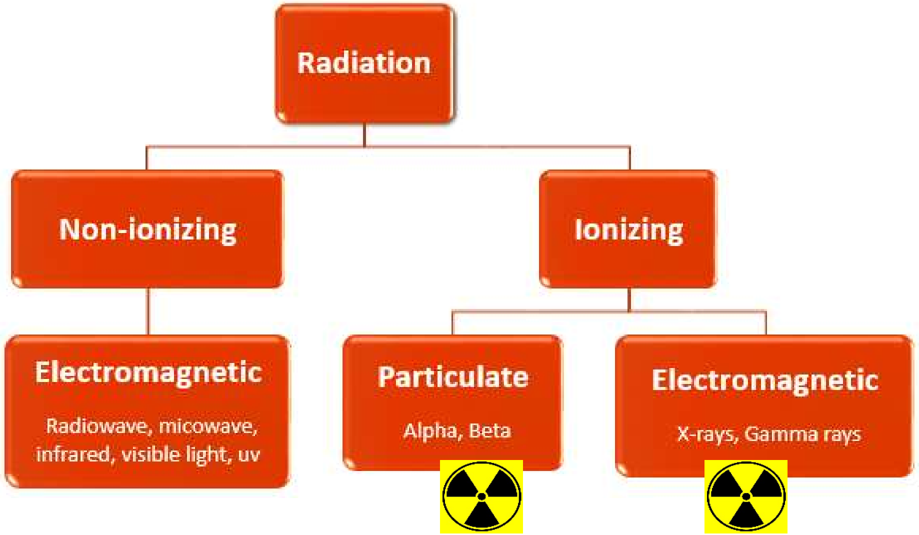
Here we are concerned with only ionizing radiation

Radiation

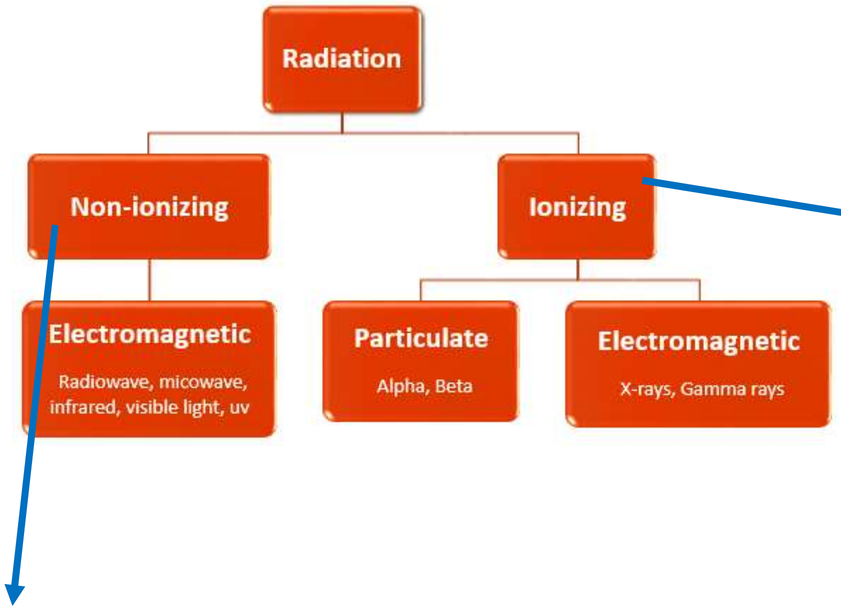
- **Radiation** is the release of energy in electromagnetic waves or particles

- This energy can be low level or high level

- **Low-level energy** is like microwave and radiowave
- **High-level energy** is like X-rays or gamma rays



Radiation



Radiation fall into two main categories.

- ionizing and non-ionizing, depending on its energy and ability to penetrate matter.

Ionizing radiation has enough energy to **remove bound electrons**, cousing atoms to become ionized

Electron removal from an atom is called **ionization.**

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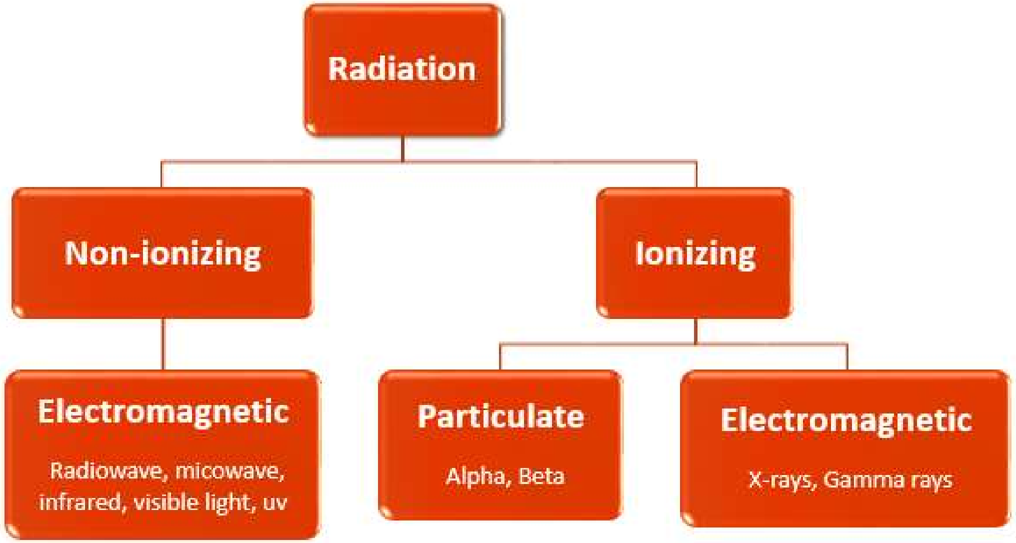
Non-ionizing radiation doesn't have **enough energy** to removed bound electrons.

Radiation

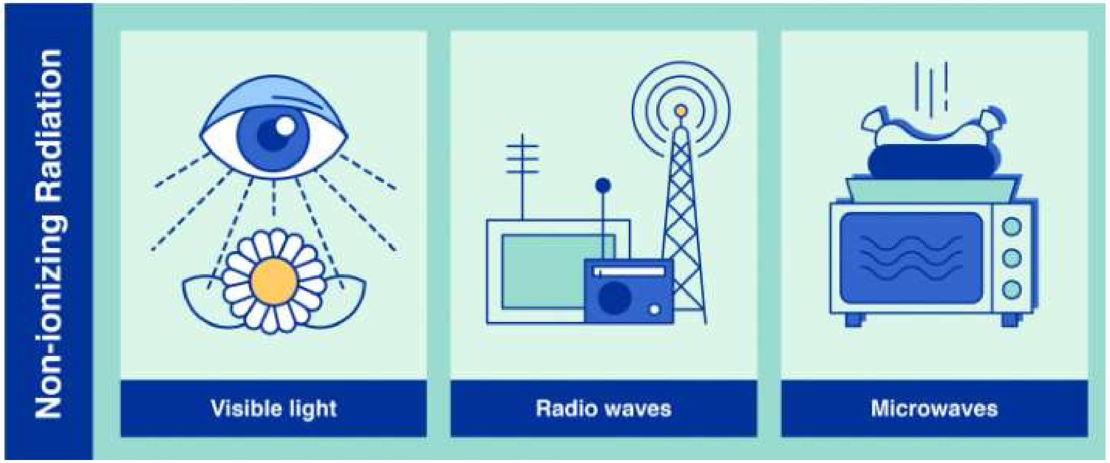


Particulate radiation consists of particles that have mass and energy.

Electromagnetic radiation, consists of photons that have energy, but no mass or charge.

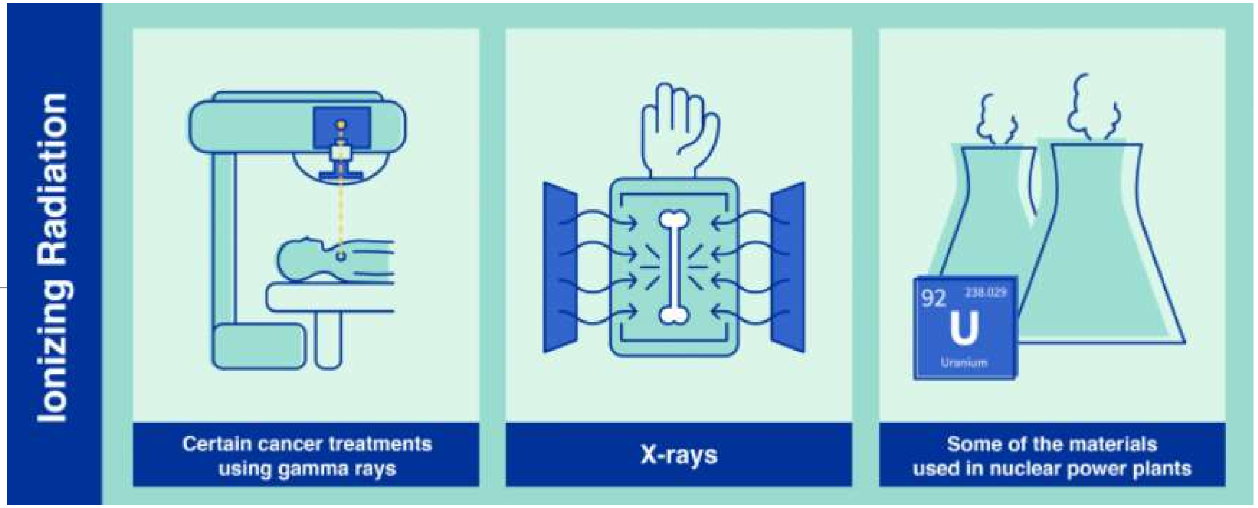
- A photon is sometimes described as a "**packet of light**".

Non-ionizing radiation



- For most people, non-ionizing radiation does not pose a risk to their health.
- But high doses of non-ionizing radiation can be harmful.
- For example, in very hot weather, if people are exposed to the sun's rays for a long time, their skin may be damaged.

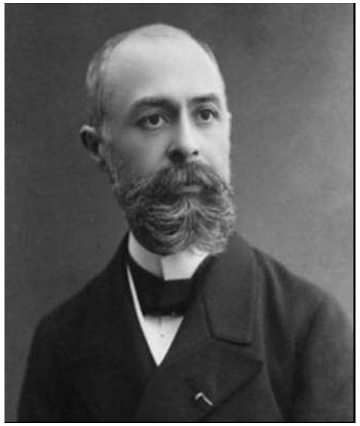
Ionizing radiation



- In high doses, ionizing radiation can damage cells or organs in our bodies or even cause death.
- In the correct uses and doses and with the necessary protective measures,
  - this kind of radiation has many beneficial uses,
  - such as in energy production, in industry, in research and in medical diagnostics and treatment of various diseases, such as cancer.

Radioactivity

- was discovered by Becquerel in 1896
- is the property of some **unstable atoms** (radionuclides) to emit nuclear radiation spontaneously
- **Nuclear decay = radioactivity**
- **Unstable atoms = radionuclides**
- Radioactive decay three main types of radiation are emitted
  - Alpha
  - beta
  - gamma



Antoine Henri Becquerel

There is an electrostatic repulsive force between the protons.

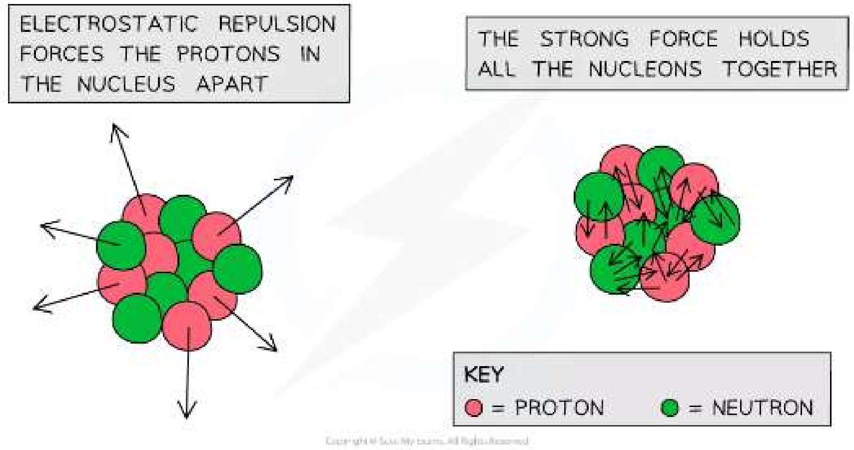
Why don't protons repel each other and move away?

How many fundamental forces are there in nature? Which?

Because the strong nuclear force attracts the protons

Strong Nuclear Force

- It is very different from the electrostatic force that holds negatively charged electrons around a positively charged nucleus.
- Over distances less than 10^{-15} meters and within the nucleus, the strong nuclear force is much stronger than electrostatic repulsions between protons;
  - over larger distances and outside the nucleus, it is essentially nonexistent.



Whilst the electrostatic force is a repulsive force in the nucleus, the strong nuclear force holds the nucleus together

Stable - Unstable

If there is a certain balance between the number of protons and the number of neutrons, that nucleus is stable.

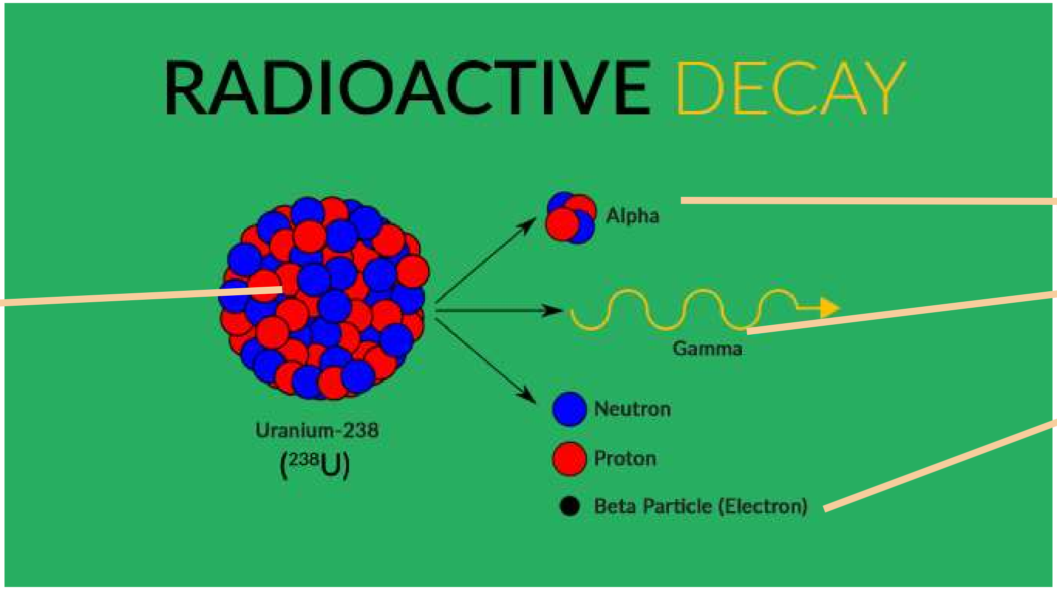
Some nuclei have more protons.

Some nuclei have more neutrons.

If there is an imbalance between the numbers of protons and neutrons, that nucleus is unstable.

What is the difference between radioactivity and radiation?

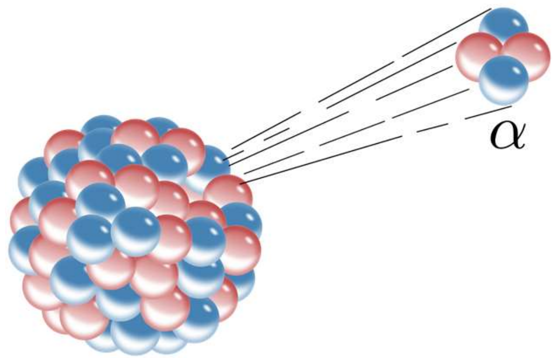
- Radioactive materials are materials that emit radiation.

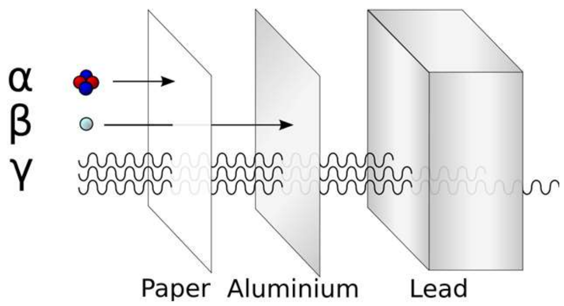


- Radiation is the energy or particles that are released during radioactive decay.

Alpha Radiation

- is particle radiation consisting of two protons and two neutrons.
- is emitted from the nucleus of some radionuclides during radioactive decay.
- is absorbed very quickly by matter
- have only a very short range
- can be shielded by a sheet of paper.





Alpha Decay

- A nucleus emitting an alpha particle loses two protons and two neutrons.
- Therefore, the atomic number Z decreases by 2, the mass number A decreases by 4, and the neutron number decreases by 2.
- The decay can be written

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

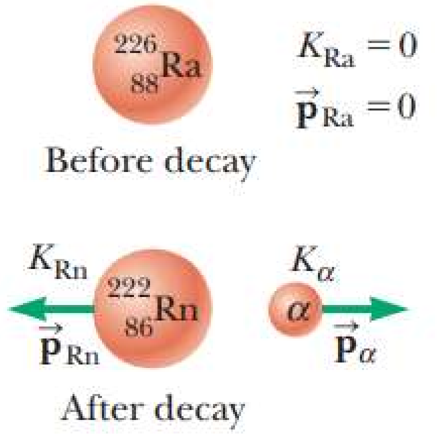
- where X is called the parent nucleus and Y the daughter nucleus.

Alpha Decay

- As a general rule in any decay expression such as this one,
  - The sum of the mass numbers A must be the same on both sides of the decay and
  - The sum of the atomic numbers Z must be the same on both sides of the decay.

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

$$^{226}_{88}\mathrm{Ra} \rightarrow {}^{222}_{86}\mathrm{Rn} + {}^{4}_{2}\mathrm{He}$$



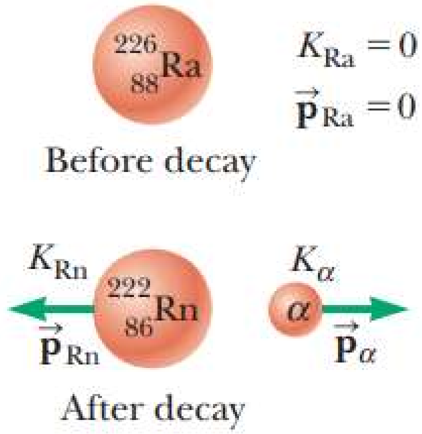
Alpha Decay

- As examples, ^{238}U and ^{226}Ra are both alpha emitters and decay according to the schemes

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

$$^{226}_{88}Ra \rightarrow ^{222}_{86}Rn + ^{4}_{2}He$$

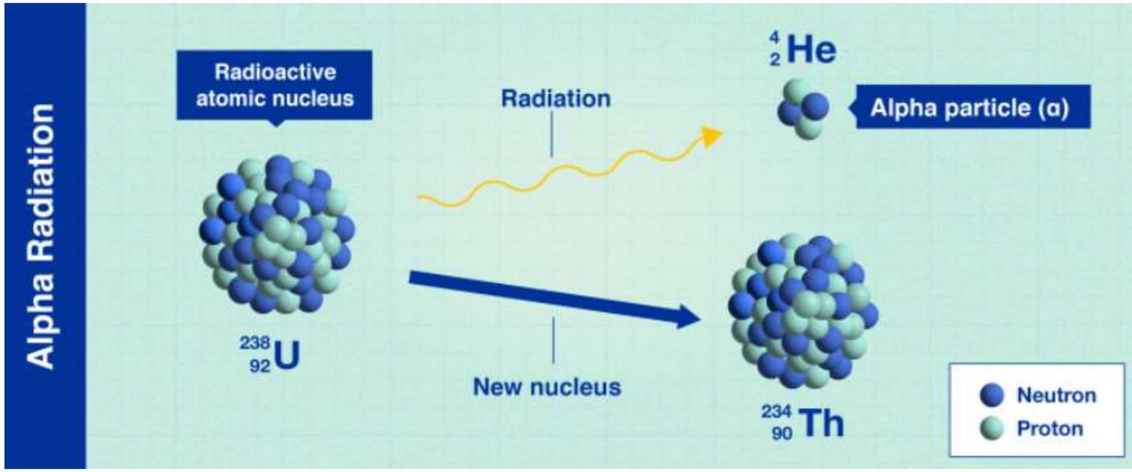
- The decay of ^{226}Ra is shown in Figure.



- When the nucleus of one element changes into the nucleus of another as happens in alpha decay, the process is called spontaneous decay

Alpha radiation

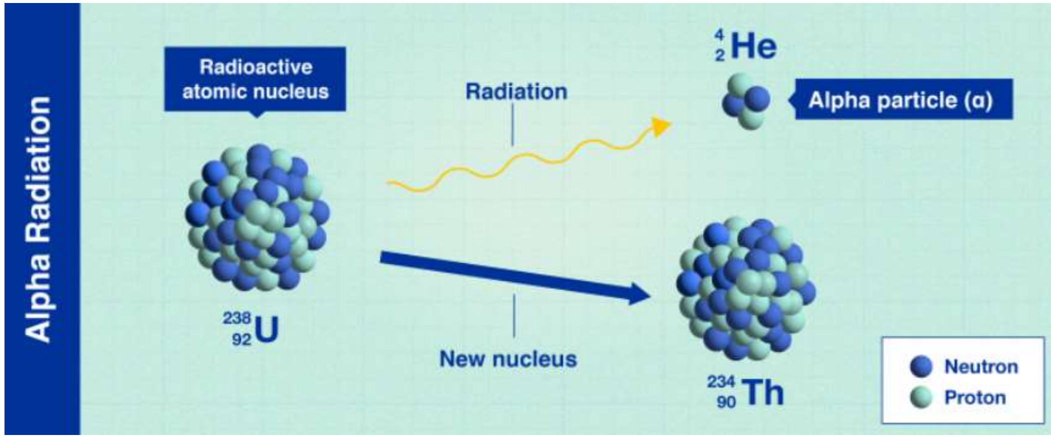
- In alpha radiation, the decaying nuclei release heavy, positively charged particles in order to become more stable.
- These particles cannot penetrate our skin to cause harm and can often be stopped by using even a single sheet of paper.



Alpha radiation

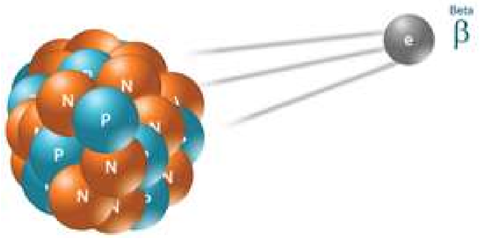
- However, if alpha-emitting materials are taken into the body by breathing, eating, or drinking, they can expose internal tissues directly and may, therefore, damage health.

Americium-241 is an example of an atom that decays via alpha particles, and it is used in smoke detectors across the world

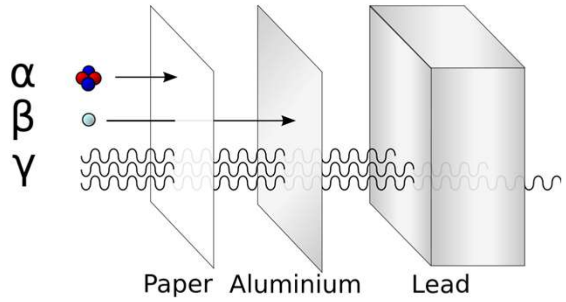


Beta Radiations (β)

- are high energy, high speed electrons (β^-) or positrons (β^+)
- are emited from the nucleus by some radionuclides during radioactive decay

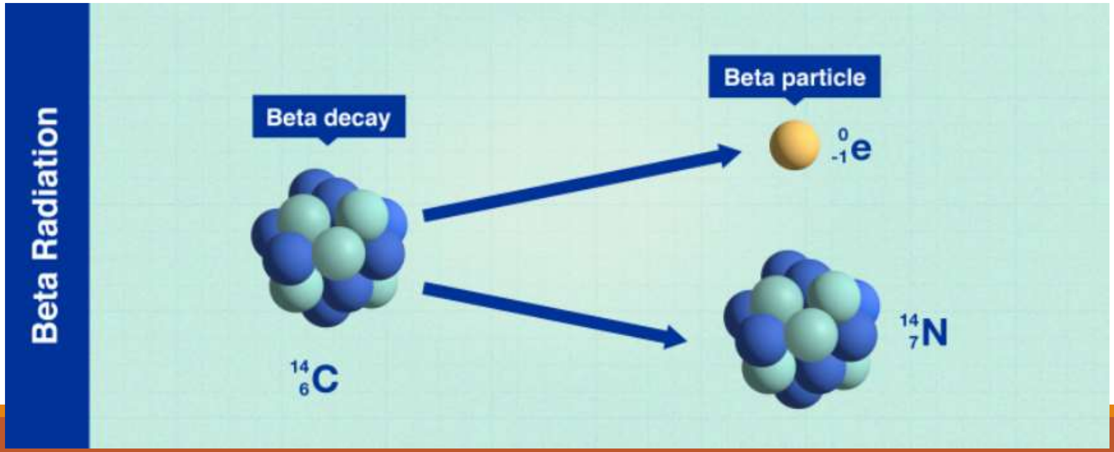


- can be shielded easily, for example, by an aluminium sheet a few millimetres thick.
- has a lower biological effectiveness than alpha radiation.



Beta radiation

- In beta radiation, the nuclei release smaller particles (electrons)
  - that are more penetrating than alpha particles
  - and can pass through e.g., 1-2 centimetres of water, depending on their energy.
- In general, a sheet of aluminium a few millimetres thick can stop beta radiation.



Beta Decay

- When a radioactive nucleus undergoes beta decay,
  - the daughter nucleus contains the same number of nucleons as the parent nucleus
  - but the atomic number is changed by 1, which means that the number of protons changes:

$$^{A}_{Z}X \rightarrow {}^{A}_{Z+1}Y + e^{-} \quad \text{(incomplete expression)}$$
$$^{A}_{Z}X \rightarrow {}^{A}_{Z-1}Y + e^{+} \quad \text{(incomplete expression)}$$

- where,
  - e- designates an electron and
  - e+ designates a positron, with beta particle being the general term referring to either.
- Beta decay is not described completely by these expressions.

Beta Decay

- As with alpha decay, the nucleon number and total charge are both conserved in beta decays.
- Because A does not change but Z does,
  - we conclude that in beta decay, either a neutron changes to a proton or a proton changes to a neutron.
- Note that the electron or positron emitted in these decays is not present beforehand in the nucleus;
  - it is created in the process of the decay from the rest energy of the decaying nucleus.
- Two typical beta-decay processes are

$$^{14}_{6}\text{C} \rightarrow {}^{14}_{7}\text{N} + \text{e}^- \quad \text{(incomplete expression)}$$

$$^{12}_{7}\text{N} \rightarrow {}^{12}_{6}\text{C} + \text{e}^+ \quad \text{(incomplete expression)}$$

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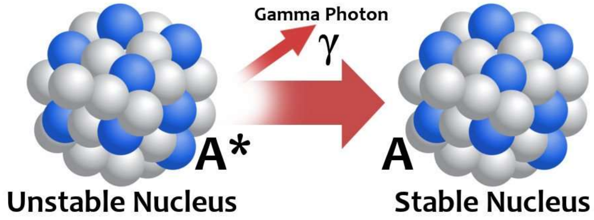
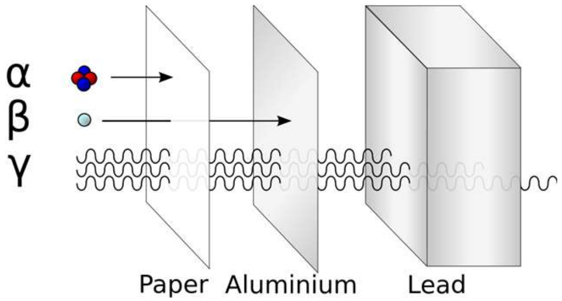
Gamma-Ray

- is a packet of electromagnetic energy
- is the most energetic photons in electromagnetic spectrum.
- is emitted from the nucleus some **unstable** (radioactive) atoms.

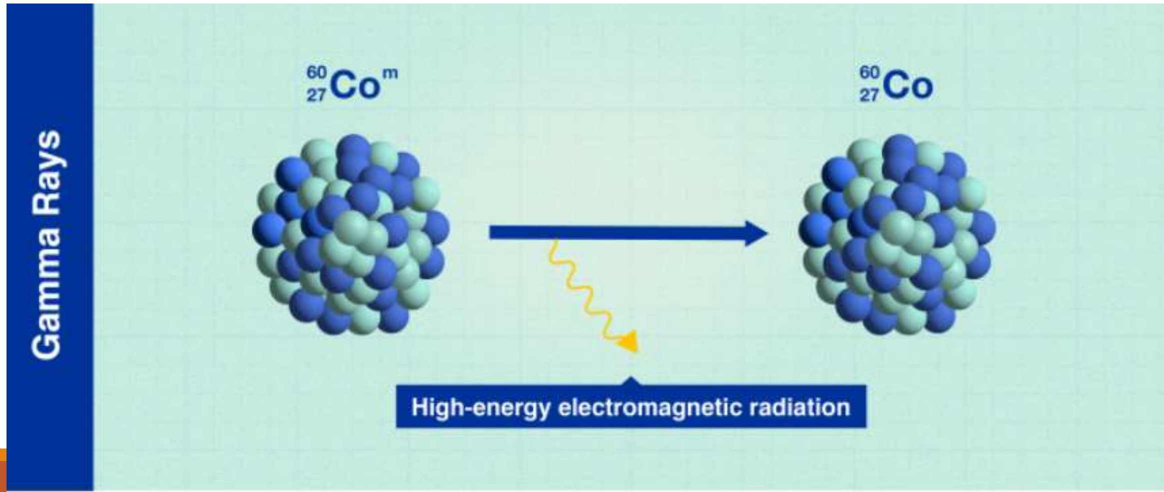


- penetrates matter very easily.
- is harmful to living beings as it penetrates deeply into tissue.
- Heavy materials such as lead and concrete are used as shielding.



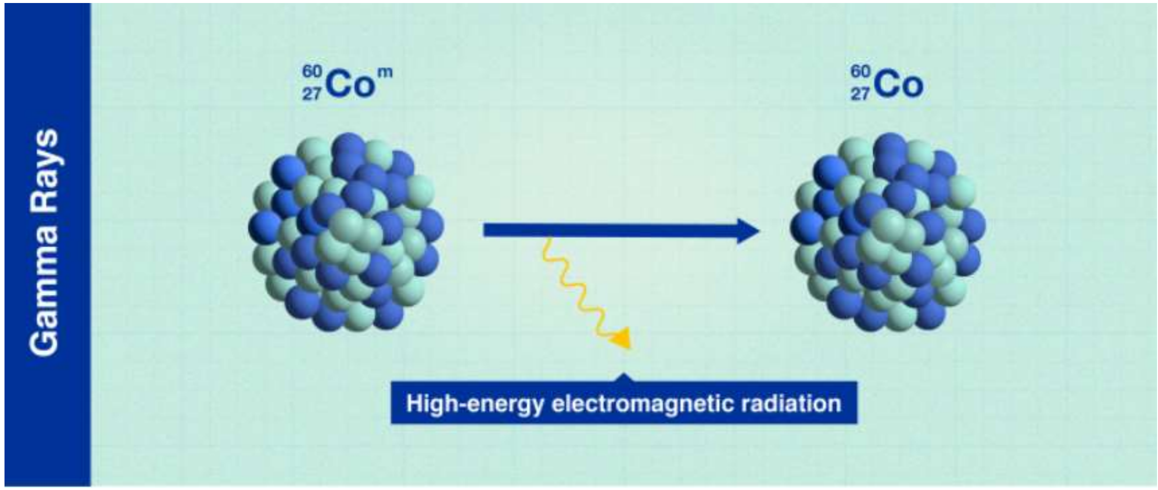
Gamma rays

- Gamma rays, which have various applications, such as cancer treatment, are electromagnetic radiation.
- Some gamma rays pass right through the human body without causing harm,
  - while others are absorbed by the body and may cause damage.



Gamma rays

- The intensity of gamma rays can be reduced to levels that pose less risk by thick walls of concrete or lead.
- This is why the walls of radiotherapy treatment rooms in hospitals for cancer patients are so thick.



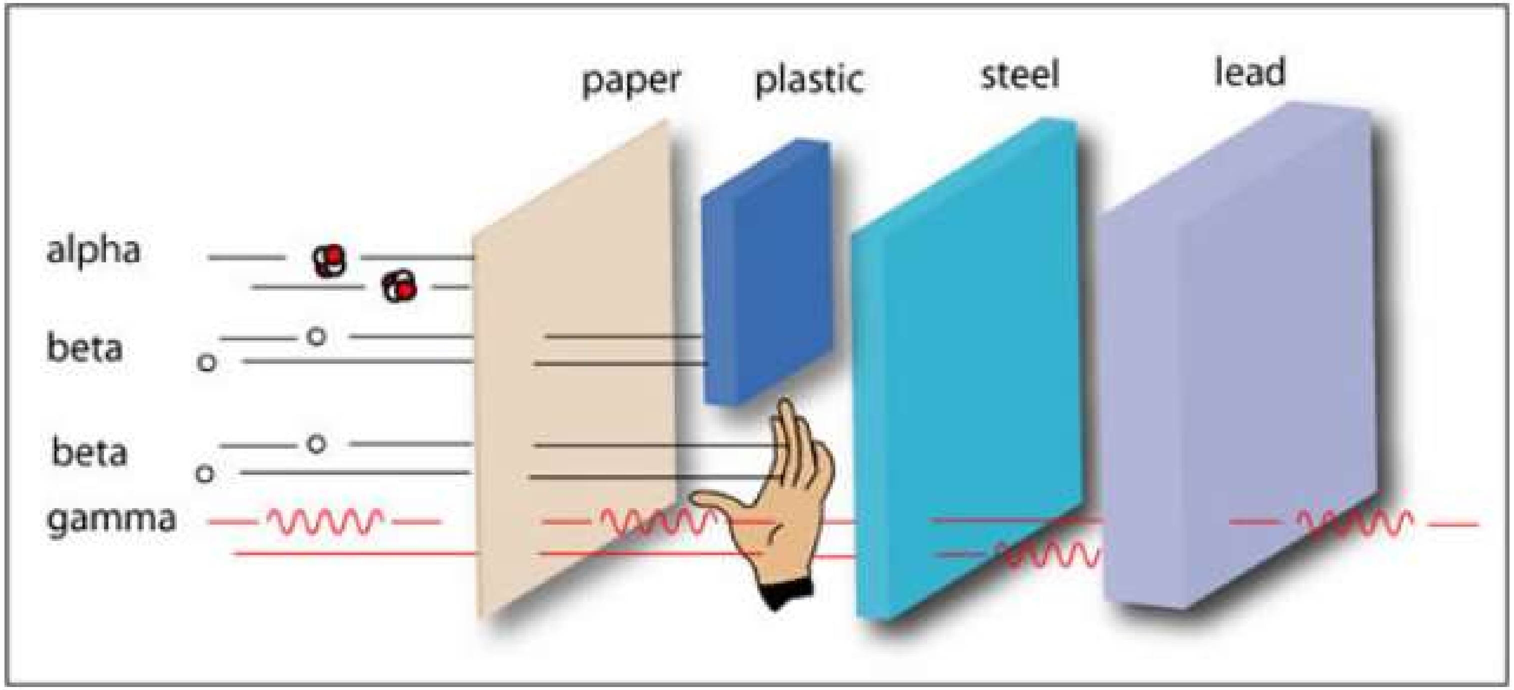
What are the properties of gamma rays?

- Gamma rays are a form of electromagnetic radiation (EMR).
- They are the similar to X-rays, distinguished only by the fact that they are emitted from an excited nucleus.
- Electromagnetic radiation can be described in terms of a stream of photons, which are massless particles each travelling in a wave-like pattern and moving at the speed of light.
- Each photon contains a certain amount (or bundle) of energy, and all electromagnetic radiation consists of these photons.
- Gamma-ray photons have the highest energy in the EMR spectrum and their waves have the shortest wavelength.

.

What are the properties of gamma rays?

- For comparison, ultraviolet radiation has energy that falls in the range from a few electron volts to about 100 eV and does not have enough energy to be classified as ionising radiation.
- The high energy of gamma rays enables them to pass through many kinds of materials, including human tissue.
- Very dense materials, such as lead, are commonly used as shielding to slow or stop gamma rays.



paper
plastic
steel
lead
alpha
beta
beta
gamma