PARTICLES AND RADIATIONS

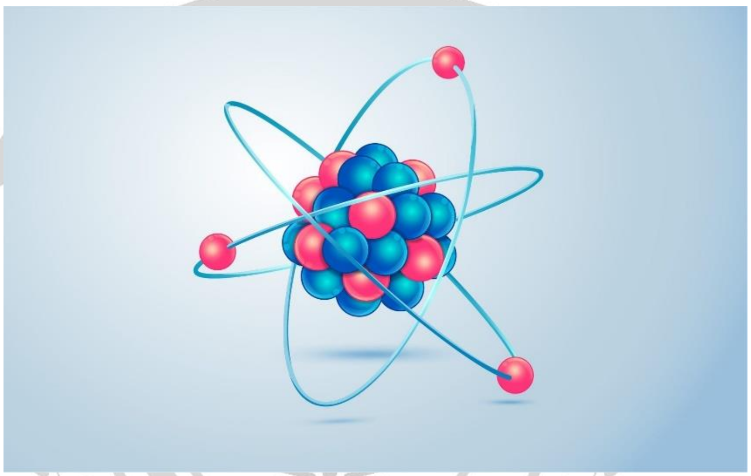
AQA AS Level

Dr Kanzul Iman

WWW.PHYSICSONLINETUITION.COM

1. Constituents of the Atom:

An atom is composed of three main particles: protons, neutrons, and electrons. The protons and neutrons are located in the nucleus at the center of the atom, while electrons orbit the nucleus in electron shells.



2. Properties of Particle:

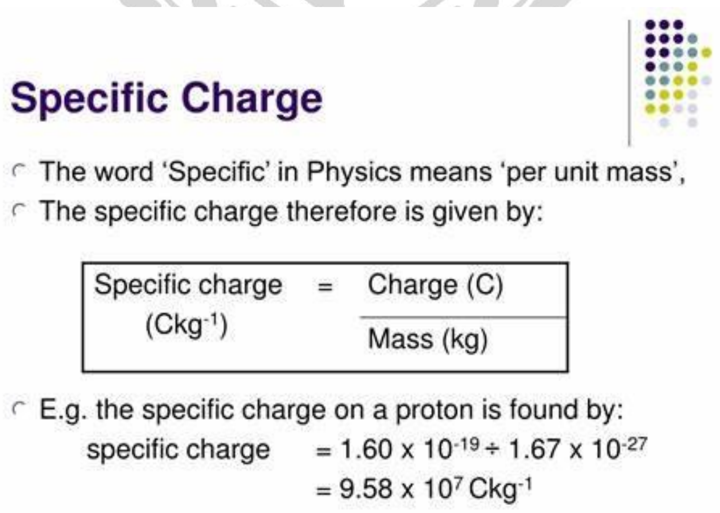
The passage provides information about the charge, mass, and specific charge of each of these particles:

- **Proton:** Protons have a positive charge of +1.6 × 10^(-19) C (Coulombs) and a mass of 1.67 × 10^(-27) kg. Their specific charge is approximately 9.58 × 10^7 C/kg.

- **Neutron:** Neutrons have no net electric charge (charge = 0) and also have a mass of 1.67 × 10^(-27) kg. Therefore, their specific charge is 0 C/kg.

- **Electron:** Electrons have a negative charge of -1.6 × 10^(-19) C and a much smaller mass of 9.11 × 10^(-31) kg. Their specific charge is about 1.76 × 10^11 C/kg.

3. **Specific Charge:** The specific charge of a particle is the charge-mass ratio, calculated by dividing a particle's charge by its mass. It is measured in units of C/kg (Coulombs per kilogram).

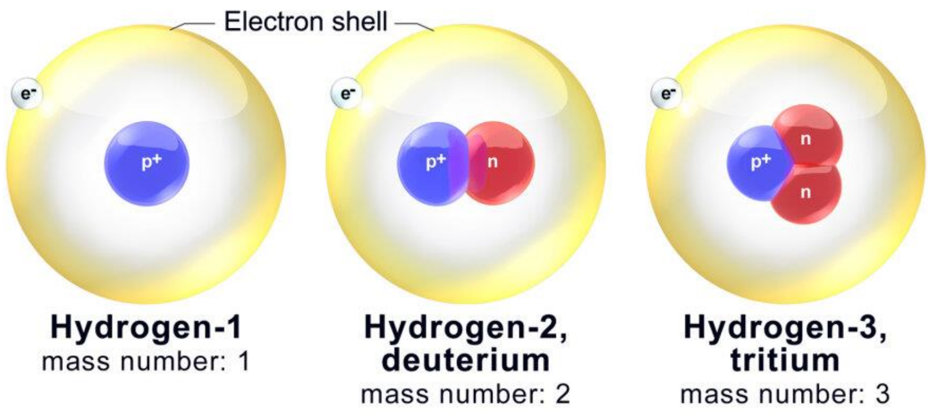


4. **Proton Number and Nucleon Number**:

The passage briefly mentions the concepts of proton number (denoted as Z) and nucleon number (denoted as A) in relation to atoms. The proton number is the number of protons in an atom's nucleus, and the nucleon number is the sum of protons and neutrons in the nucleus. These values are often represented in the form "X," where X is the chemical symbol of the element.

Isotopes:

Isotopes are atoms of the same element that have the same number of protons (which defines the element) but different numbers of neutrons. These different numbers of neutrons result in variations in atomic mass. Carbon-14 (C-14) is indeed an example of an isotope, and it is radioactive. It's used in radiocarbon dating to estimate the age of organic materials.



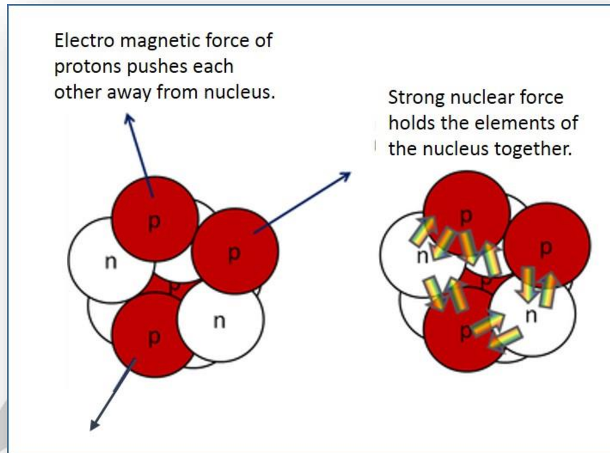
Strong Nuclear Force (SNF):

The strong nuclear force is one of the four fundamental forces of nature and acts within the atomic nucleus. It's responsible for holding protons and neutrons together in the nucleus. This force is attractive and very short-ranged, which means it acts only at very close distances within the nucleus, typically up to about 3 femtometers (fm). It prevents the electrostatic repulsion between positively charged protons from breaking the nucleus apart.

Stable and Unstable Nuclei:

Stable nuclei are those where the binding energy provided by the strong nuclear force is sufficient to overcome the electrostatic repulsion between protons.

Unstable nuclei, on the other hand, have an imbalance in the number of protons and neutrons, causing the strong nuclear force to be insufficient to keep them together.

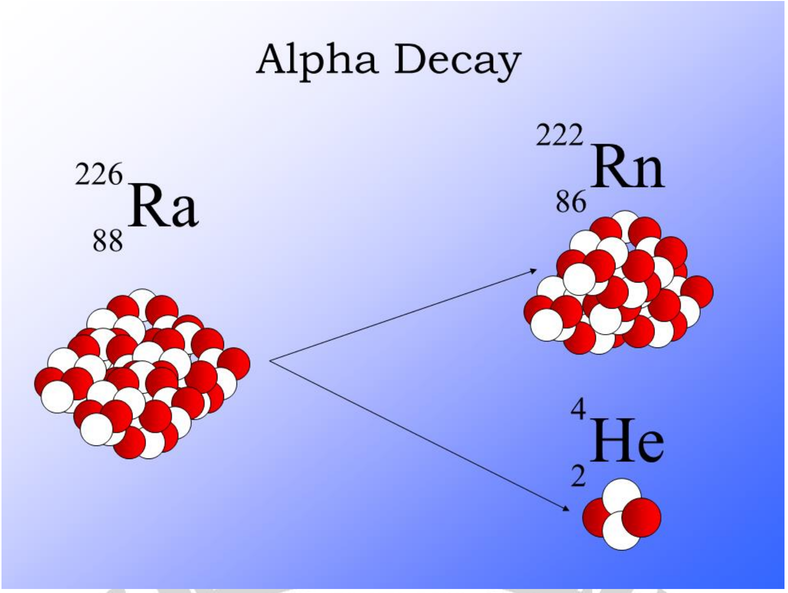


Alpha Decay:

Alpha decay typically occurs in large, heavy nuclei that have an excess of both protons and neutrons. During alpha decay, an alpha particle (which consists of 2 protons and 2 neutrons) is emitted from the nucleus. As a result:

The proton number (atomic number) decreases by 2.

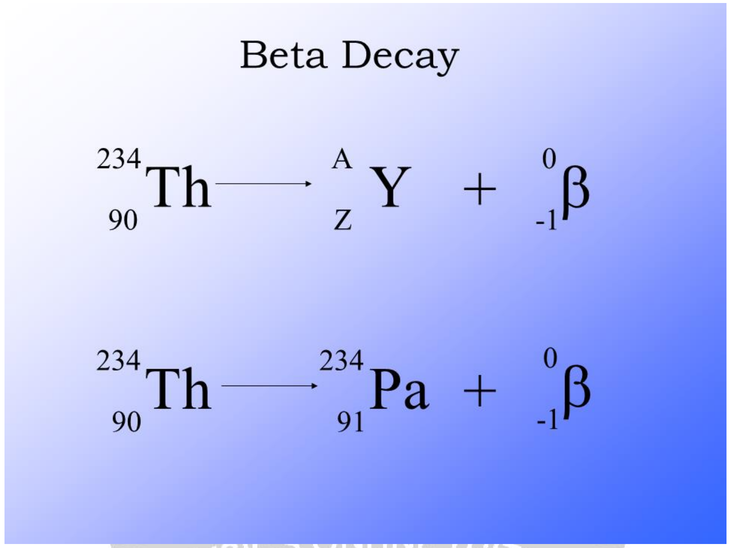
The nucleon number (atomic mass) decreases by 4.



Beta-Minus Decay:

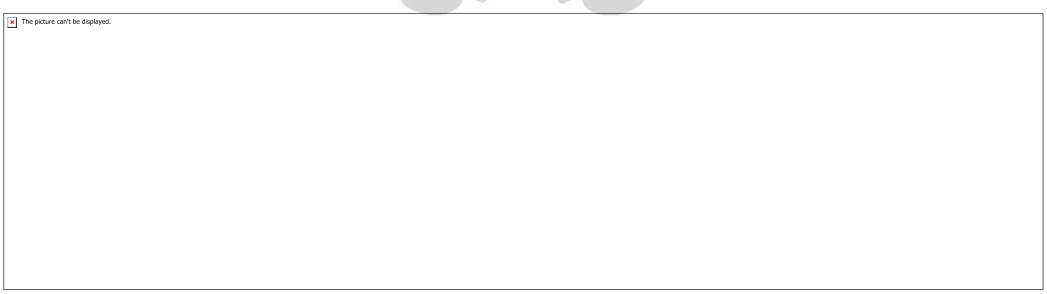
Beta-minus decay occurs in nuclei that are neutron-rich, meaning they have an excess of neutrons. In this type of decay, a neutron is transformed into a proton, an electron (beta-minus particle), and an antineutrino. This process increases the atomic number by 1 while keeping the nucleon number the same.

It's important to note that these nuclear processes are fundamental in understanding the stability and behavior of atomic nuclei, as well as their applications in nuclear physics, medicine, and radiometric dating.



1. Beta-Minus Decay and Neutrinos:

Beta-minus decay involves the emission of electrons (beta-minus particles) from atomic nuclei. Initially, it was believed that only an electron was emitted during this process, but the observed energy levels did not proved the conservation of energy. To account for this discrepancy, scientists hypothesized the existence of neutrinos, which were later observed. Neutrinos play a crucial role in various nuclear processes.



2. Antiparticles:

Every type of particle has a corresponding antiparticle with the same rest energy and mass but opposite properties. For example, the positron is the antiparticle of the electron, and an electron neutrino has an antiparticle called the electron antineutrino.

3. Photons and Electromagnetic Radiation:

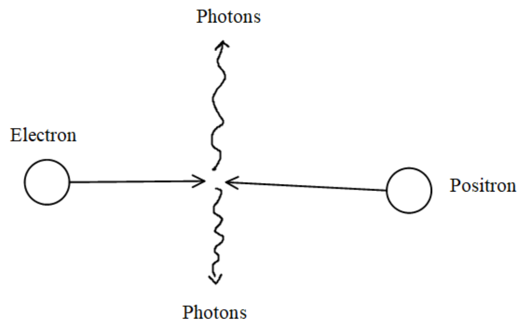
Photons are particles of electromagnetic radiation that have no mass but carry energy. The energy of photons is directly proportional to the frequency of the electromagnetic radiation they represent, as described by the equation

$$E = hf \text{ or } E = hc/\lambda,$$

where h is the Planck constant.

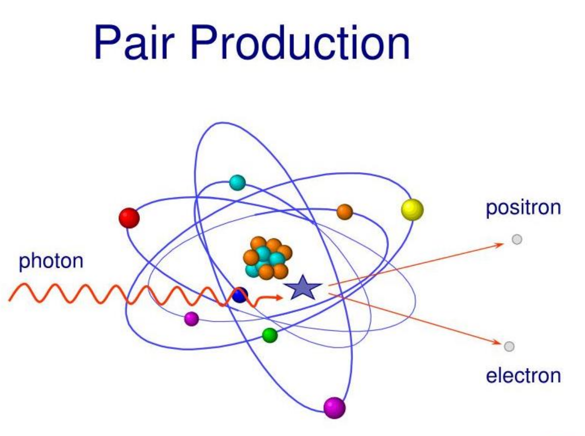
4. Annihilation:

Annihilation occurs when a particle and its corresponding antiparticle collide. Their masses are converted into energy, which is released in the form of two photons moving in opposite directions to conserve momentum. This process has applications in medical imaging, such as in Positron Emission Tomography (PET) scanners, where positron-emitting radioisotopes are used.



5. **Pair Production:**

Pair production is the conversion of a photon into an equal amount of matter and antimatter. This process requires that the photon has energy greater than the combined rest energy of the resulting particles. Any excess energy is converted into kinetic energy for the particles. Pair production is a fundamental process in particle physics.



1. Strong Nuclear Force:

- Exchange Particle: Gluon
- Range: Approximately 3 × 10^-15 meters
- Acts on: Hadrons (particles made of quarks, such as protons and neutrons)

2. **Weak Nuclear Force**:
   - Exchange Particles: W bosons (W+ and W-) and Z boson
   - Range: Very short range, about 10^-18 meters
   - Acts on: All particles and is responsible for processes like beta decay, electron capture, and neutrino interactions.
3. **Electromagnetic Force**:
   - Exchange Particle: Virtual photon (γ)
   - Range: Infinite
   - Acts on: Charged particles, like electrons and protons, and is responsible for electromagnetic interactions.

4. **Gravity**:
   - Exchange Particle: Theoretical graviton (though not yet observed)
   - Range: Infinite
   - Acts on: Particles with mass and is responsible for gravitational interactions.

Classification of Particles:

1. **Leptons**:

Fundamental particles that cannot be further broken down. They do not experience the strong nuclear force. Examples include electrons, muons, and neutrinos.

2. **Hadrons**:

Composite particles made up of quarks, which do experience the strong nuclear force. Hadrons can be further categorized into:

- **Baryons**: Composed of three quarks. Protons are an example of stable baryons.
- **Antibaryons**: Composed of three antiquarks.
- **Mesons**: Composed of a quark and an antiquark.

A **muon** is sometimes known as a "heavy electron", and muons decay into electrons.

Conservation Laws:

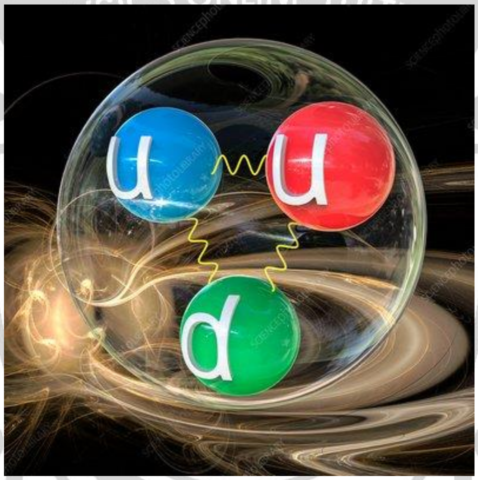
In particle interactions, certain properties must be conserved, including:

- Energy and momentum.
- Electric charge.
- Baryon number.
- Electron lepton number.
- Muon lepton number.

Strangeness is a property that must be conserved in strong interactions but not in weak interactions. **However, in weak interactions strangeness can change by 0, +1 or -1.**

Quarks:

There are three types of quarks and their properties. Quarks have fractional electric charges, baryon numbers, and strangeness values. The properties of antiquarks are the opposite of those of quarks.



Quark

Type of quark	Charge	Baryon number	Strangeness
Up (u)	$+\frac{2}{3}e$	$+\frac{1}{3}$	0
Down (d)	$-\frac{1}{3}e$	$+\frac{1}{3}$	0
Strange (s)	$-\frac{1}{3}e$	$+\frac{1}{3}$	-1

QUARK COMBINATION IN MESONS

Particle	Quark combination(s)	Charge	Strangeness
π^0	uu or $d\bar{d}$	0	0
π^+	$u\bar{d}$	+1	0
π^-	ud	-1	0
k^0	ds	0	+1
k^+	us	+1	+1
k^-	us	-1	-1

Applications of conservation laws

These properties **must always be conserved** in particle interactions:

- Energy and momentum
- Charge
- Baryon number
- Electron lepton number
- Muon lepton number

Strangeness must only be conserved during strong interactions.

To show these conservation laws are obeyed in an interaction, you must find the value of each property before and after the interaction and make sure they are equal.
For example, beta-minus decay:

(as this is a weak interaction, strangeness does not need to be conserved)

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

	Charge	Baryon number	Electron lepton number	Muon lepton number	Strangeness
Before interaction	0	1	0	0	0

After interaction	1-1+0=0	1+0+0	0+1-1	0+0+0	0+0+0
Change	0	0	0	0	0

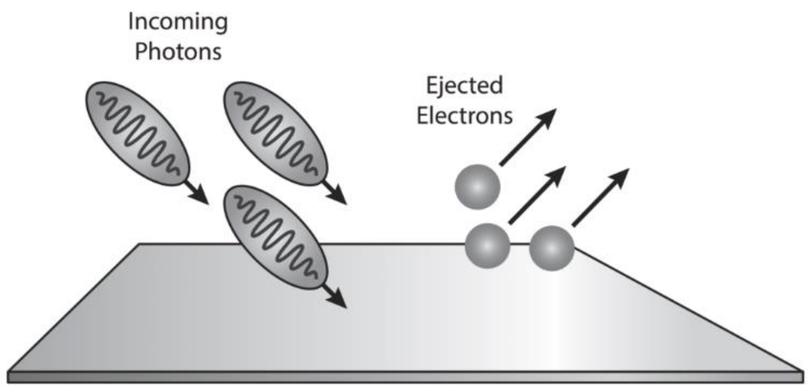
All the conservation laws are obeyed therefore this interaction is possible.

Photoelectric effect

- The photoelectric effect is the emission of photoelectrons from the surface of a metal when exposed to light of a certain frequency, known as the threshold frequency.
- The wave theory couldn't explain the threshold frequency as it predicted that any frequency of light would eventually cause photoelectric emission due to energy gradually increasing with each wave.
- The photon model of light suggests that electromagnetic waves travel in discrete packets called photons, with energy directly proportional to frequency.
- Photoelectrons are emitted only if the light frequency is above the threshold frequency, and each electron absorbs a single photon.
- Increasing the intensity of light, when the frequency is above the threshold, results in more photoelectrons emitted per second.
- The work function (ϕ) is the minimum energy required for electrons to be emitted from a metal's surface.
- The stopping potential (Vs) is the potential difference required to stop photoelectrons with the maximum kinetic energy. The

maximum kinetic energy (Ek(max)) can be calculated using Ek(max) = eVs, where e is the charge of an electron.

- The photoelectric equation, E = hf = Φ + Ek(max), relates the work function, maximum kinetic energy, and the frequency of light.



- Collisions of Electrons with Atoms:

- Electrons in atoms occupy discrete energy levels, and they can gain energy from collisions with free electrons.
- Excitation occurs when an electron gains energy, moving up to a higher energy level temporarily.
- Ionization occurs when an electron gains enough energy to be completely removed from the atom.
- Excited electrons quickly return to their original energy level, emitting the gained energy as photons.
- The practical application of excitation is seen in fluorescent tubes, where a high voltage is applied across mercury vapor to produce light.

Energy Units:

- Energy levels in atoms are described in electron volts (eV), a small unit of energy.
- 1 eV is the energy gained by an electron passing through a 1-volt potential difference.
- To convert between eV and joules (J), you multiply or divide by 1.6 x 10^-19.

Energy Levels and Photon Emission:

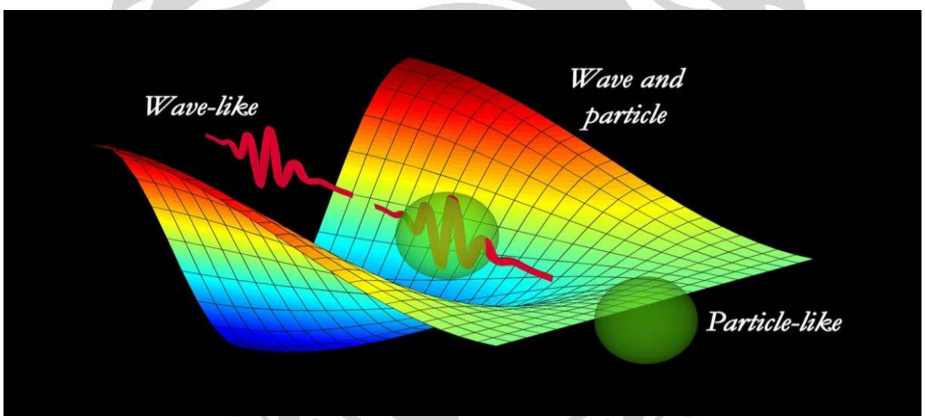
- When light from a fluorescent tube is diffracted, you get a line spectrum with discrete wavelengths.
- This indicates that electrons in atoms can only transition between discrete energy levels.
- Passing white light through a cooled gas produces a line absorption spectrum, with dark lines at specific wavelengths.
- These lines represent energy level differences in the gas atoms.

Equation for Energy Levels:

- The difference between two energy levels (ΔE) is equal to a specific photon energy.
- This is expressed as $\Delta E = E1 - E2$, where E1 and E2 represent energy levels.
- The energy of a photon is given by $E = hf$, where h is the Planck constant.

- Wave-Particle Duality:

- Light and electrons can exhibit both wave and particle properties.
- Light waves demonstrate phenomena like diffraction and interference.
- The photoelectric effect shows light behaving as particles.
- Electrons also display wave-particle duality, observed through electron diffraction.
- Louis de Broglie proposed an equation that relates the wavelength (λ) of a particle to its momentum (mv), with h being the Planck constant.



Light and electrons are having both wave like and particle like properties