TOPIC 1 Structure and Properties of the Nucleus

SQ 12.1.1 Which two types of particles make up the atomic nucleus?

Answer

The atomic nucleus comprises two types of particles, protons and neutrons. Together they are called nucleons.

SQ 12.1.2 Write the charge and mass of a proton.

Answer

The proton has a positive charge of the same magnitude as that of the electron, 1.6×10^{-19} C, and its mass is 1.67×10^{-27} kg.

SQ 12.1.3 Who discovered the neutron and what are its properties?

Answer

The existence of the neutron was pointed out in 1932 by James Chadwick. It is electrically neutral, and its mass is nearly the same as that of the proton.

SQ 12.1.4 What is a protium?

Definition

A proton is the nucleus of the simplest atom, hydrogen, which is called a protium.

SQ 12.1.5 What are nuclides?

Definition

Besides hydrogen, the nuclei of all other elements consist of both neutrons and protons. These different nuclei are called nuclides.

SQ 12.1.6 Define atomic number and mass number.

Atomic Number

The number of protons in a nucleus is called the atomic number, represented by Z.

Mass Number

The total number of nucleons, that is the sum of neutrons and protons, is represented by A.

Formula

$A = N + Z$

SQ 12.1.7 How is a given nucleus specified symbolically?

Answer

The symbol ${}^{A}_{Z}X$ is used, where X is the chemical symbol for the element, A is the mass number and Z is the atomic number.

SQ 12.1.8 Define the unified mass scale.

Definition

By definition, 1 u is exactly one twelfth the mass of a carbon-12 atom.

Value

$1\,\text{u} = 1.6606 \times 10^{-27}\,\text{kg} = 931\,\text{MeV}$

SQ 12.1.9 Write the masses of the proton, neutron and electron in unified mass units.

Values

The mass of a proton is 1.007276 u, that of a neutron is 1.008665 u, and that of an electron is 0.000549 u.

SQ 12.1.10 Define isotopes.

Definition

Nuclei that contain the same number of protons but different numbers of neutrons are called isotopes.

SQ 12.1.11 Give the isotopes of carbon and state which are stable.

Answer

The isotopes of carbon are ^{12}C
^{13}C and ^{14}C.

Stability

Among them ^{12}C and ^{13}C are stable, but ^{14}C is unstable and decays into nitrogen.

SQ 12.1.12 What do different isotopes of a given element have in common?

Answer

All isotopes of a given element have the same number of protons, that is the same atomic number Z, but different numbers of neutrons.

TOPIC 2 Fundamental Forces of Nature

SQ 12.2.1 Name the four fundamental forces of nature.

Answer

The four fundamental forces are gravity, electromagnetism, the weak nuclear force and the strong nuclear force.

SQ 12.2.2 What do the fundamental forces control?

Answer

Despite the apparent complexity within the universe, all interactions are governed by these four forces. They control how objects move, interact and behave at different scales, from nucleons in the atom to massive galaxies.

SQ 12.2.3 Describe the gravitational force.

Description

Gravity is the weakest of the four fundamental forces, but it is a long-range attractive force.

Law

The force between two bodies is proportional to the product of their masses and inversely proportional to the square of the distance between them.

SQ 12.2.4 When is gravitational force significant and when is it negligible?

Answer

Gravitational force is considered significant for massive objects such as the Sun or giant planets, because their masses are large. However, on an atomic level this force is negligibly weak.

SQ 12.2.5 Describe the electromagnetic force.

Description

The electromagnetic force is responsible for electric field and magnetic field interactions. Like gravity it follows an inverse square law, but it is much stronger than gravity.

SQ 12.2.6 Which phenomena does the electromagnetic force govern?

Answer

It governs a vast range of phenomena, from atomic structure, chemical bonding, electricity, magnetism and light propagation.

SQ 12.2.7 What did Maxwell's equations show?

Answer

James Clerk Maxwell formulated four fundamental equations that unified electricity and magnetism into electromagnetism. They showed that electric and magnetic fields are not separate forces but are two aspects of a single electromagnetic force.

SQ 12.2.8 Why must a strong nuclear force exist?

Reason

If we consider only electromagnetism and gravity, the nucleus should fly off in different directions. The stability of the nucleus implies that another force exists which is stronger than the gravitational and electromagnetic forces.

SQ 12.2.9 Describe the strong nuclear force.

Description

Strong nuclear forces are responsible for holding the nuclei of atoms together. They exist only inside the nucleus, so they are short-range forces.

Action

The strong nuclear force acts as an attractive force between all nucleons.

SQ 12.2.10 How does the strong force hold the nucleus?

Explanation

Protons attract each other via the strong nuclear force while at the same time repelling each other via the electric force. A neutron, being electrically neutral, can attract other neutrons or protons via the strong nuclear force.

SQ 12.2.11 Describe the weak nuclear force.

Description

Weak nuclear forces are responsible for radioactive decay, particularly beta decay, and for interactions involving neutrinos.

Property

Unlike the other fundamental forces, the weak force can change the identity of particles.

SQ 12.2.12 Why is the weak nuclear force essential?

Answer

It is essential for processes like nuclear fusion in stars and the decay of unstable atomic nuclei.

TOPIC 3 Matter and Anti-Matter

SQ 12.3.1 Who predicted the existence of anti-particles and when?

Answer

It was predicted by Paul Dirac in 1928 that the fundamental particles have their anti-particles.

SQ 12.3.2 What are the properties of anti-particles?

Answer

The rest masses of the anti-particles are the same as those of their corresponding particles, but with opposite charges and magnetic moments.

SQ 12.3.3 Describe the positron.

Description

The positron is the anti-particle of an electron, represented by e^+. Its rest mass is the same as that of an electron, but it carries a positive charge of the same magnitude.

SQ 12.3.4 Which was the first discovered anti-particle?

Answer

The positron was the first discovered anti-particle, found by Anderson in 1932 in a cloud chamber experiment.

SQ 12.3.5 How are anti-particles represented?

Answer

Usually the anti-particles are represented by a letter with a bar over it. For example, the anti-proton is represented by $\bar{p}$ and the anti-neutrino by $\bar{
u}$.

SQ 12.3.6 Which particles are recognized as elementary particles?

Answer

The quarks and leptons have been recognized as the fundamental or elementary particles among the many discovered particles. These elementary particles also have anti-particles.

SQ 12.3.7 What are cosmic rays?

Definition

Cosmic rays are high-energy particles coming from outer space with unknown sources. They consist mostly of protons, neutrons and heavier nuclei, which continually bombard the Earth.

SQ 12.3.8 What happens when cosmic rays interact with the atmosphere?

Answer

When these particles interact with the atoms of the gases of the Earth's atmosphere, they produce showers of secondary particles which rain down on us all the time.

SQ 12.3.9 **Which particles are emitted during fission in a nuclear reactor?**

Answer
When nuclei of an unstable radioactive element undergo fission reactions, they emit a variety of particles such as neutrons, neutrinos, alpha particles, photons, electrons and positrons.

SQ 12.3.10 **Which particles appear in accelerator collisions?**

Answer
When accelerated charged particles are bombarded on a target or collide head-on with each other, the debris from these reactions contains particles like pions, kaons, muons and even anti-protons.

SQ 12.3.11 **Define pair production.**

Definition
Pair production occurs when a gamma ray, that is a high energy photon, passes near an atomic nucleus and an electron-positron pair is emitted.

SQ 12.3.12 **Why is a third particle necessary in pair production?**

Reason
The presence of a third particle, such as a nucleus, is necessary to conserve linear momentum. The nucleus experiences some recoil during the process.

SQ 12.3.13 **What is the minimum photon energy required for pair production?**

Answer
According to mass-energy equivalence, the minimum energy must equal the sum of the rest mass energies of the created particles.

Value
$2m_0c^2 = 1.02\,\text{MeV}$

SQ 12.3.14 **What happens if a photon has energy greater than 1.02 MeV?**

Answer
A photon with energy greater than $1.02\,\text{MeV}$ creates an electron-positron pair, and the excess energy goes into the kinetic energies of the particles.

SQ 12.3.15 **Which conservation laws does pair production satisfy?**

Answer
The process of pair production satisfies the laws of conservation of charge, momentum and energy. It can occur for any particle and anti-particle.

SQ 12.3.16 **Can pair production take place in vacuum?**

Answer
No. Pair production cannot take place in vacuum; it can happen only in the vicinity of an external object such as a nucleus, which experiences some recoil to conserve energy and momentum at the same time.

SQ 12.3.17 **Define annihilation of matter.**

Definition
Annihilation is the opposite process of pair production. When an electron and a positron interact with each other, they annihilate into two gamma ray photons.

Reaction
$e^- + e^+ \rightarrow \gamma + \gamma$

SQ 12.3.18 **What is the energy of each photon in electron-positron annihilation?**

Answer
The energy of each gamma ray photon is $0.51\,\text{MeV}$, which is equal to the rest mass energy of an electron or a positron.

SQ 12.3.19 **Why can an electron-positron pair not decay into a single photon?**

Reason
In an annihilation reaction both energy and momentum must be conserved. A single photon could not conserve momentum, so two photons are produced moving in opposite directions.

SQ 12.3.20 **Which other annihilation reactions can be carried out?**

Answer
Besides electron and positron annihilation, the annihilation reactions of other particles and their anti-particles can also be carried out, such as proton and anti-proton, lepton and anti-lepton, and quark and anti-quark.

TOPIC 4 Radioactivity

SQ 12.4.1 **Define natural radioactivity.**

Definition
Nuclei whose atomic numbers are greater than 82 are found naturally unstable and spontaneously emit radiations. Such nuclei are called radioactive, and the emission of radiation is known as natural radioactivity.

SQ 12.4.2 **Name the three types of radioactive radiations.**

Answer
These radiations are of three types, namely α β and γ radiations.

SQ 12.4.3 **Define artificial radioactivity.**

Definition
Unstable isotopes can be produced artificially by bombarding a stable element with high-energy particles such as neutrons, protons, alpha particles or gamma rays, causing it to become unstable and emit radiation.

Name
Such radioactive isotopes are named radioisotopes or radionuclides.

SQ 12.4.4 **How do alpha particles behave in an electric field?**

Answer
Alpha particles deflect towards the negative terminal of the electric field, showing that they have a positive charge.

SQ 12.4.5 **Describe the speed and range of alpha particles.**

Answer
Alpha particles are emitted at high speeds, typically a few percent of the speed of light. However, they can travel only several centimetres in air due to their large mass.

SQ 12.4.6 **How do beta particles behave in an electric field?**

Answer
Beta particles deflect towards the positive terminal of the electric field, showing that they have a negative charge. Their deflection is more than that of alpha particles, proving that they are lighter particles.

SQ 12.4.7 **Describe the speed of beta particles.**

Answer
Beta particles are fast-moving electrons and move with speeds up to 0.9995 of the speed of light.

SQ 12.4.8 **Describe the nature of gamma radiations.**

Answer
Gamma radiations pass through an electric field without deflection, showing that they have no charge. They are electromagnetic radiations consisting of photons, moving with the speed of light with the highest penetrating power but the lowest ionization power.

SQ 12.4.9 **When does a nucleus emit an alpha particle?**

Reason
If the nucleus has more protons than neutrons, the electrostatic force of repulsion becomes greater than the strong nuclear force of attraction. In this case the nucleus becomes unstable and emits alpha particles.

SQ 12.4.10 **What is an alpha particle and what happens in alpha decay?**

Answer
An alpha particle is equivalent to a helium nucleus consisting of two protons and two neutrons.

Result
The atomic number Z decreases by 2 while the mass number A decreases by 4.

SQ 12.4.11 **Write the general equation of alpha decay.**

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

SQ 12.4.12 **Write the alpha decay of radium-226.**

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

SQ 12.4.13 **What is transmutation of elements?**

Definition
In a nuclear reaction the daughter nucleus is different from the parent nucleus. This transition of one element into another is called the transmutation of elements.

SQ 12.4.14 **Define the disintegration energy or Q-value.**

Definition
The mass of the parent nucleus is greater than the total mass of the daughter nucleus and the alpha particle. This difference in mass-energy is called the disintegration energy Q, or the Q -value of the decay.

SQ 12.4.15 **When does beta-minus decay occur?**

Reason
Some nuclides have a neutron-to-proton ratio that is too large, and these are the source of β^- decay.

SQ 12.4.16 **Are beta particles orbital electrons?**

Answer
No. The beta particles are not the orbital electrons; they are created within the nucleus at the moment of emission, although they are indistinguishable from orbital electrons.

SQ 12.4.17 **Write the fundamental process of beta-minus decay.**

Reaction
$^{1}_{0}n \rightarrow {}^{1}_{1}p + {}^{0}_{-1}e + \bar{u}$
A neutron changes to a proton, and to conserve charge it emits an electron.

SQ 12.4.18 **Write the general equation of beta-minus decay.**

Formula
$^{A}_{Z}X \rightarrow {}^{A}_{Z+1}Y + {}^{0}_{-1}e + \bar{u}$
The total number of nucleons A remains the same, but the atomic number Z increases by one.

SQ 12.4.19 **Give an example of beta-minus decay.**

Example
The isotope of thorium is unstable and decays into protactinium by beta emission.

Reaction
$^{234}_{90}\mathrm{Th} \rightarrow {}^{234}_{91}\mathrm{Pa} + {}^{0}_{-1}e + \bar{u}$

SQ 12.4.20 **When does beta-plus decay occur?**

Reason
There are nuclides that have a neutron-to-proton ratio too small for stability, and they decay by emitting a positron instead of an electron.

SQ 12.4.21 **Write the general equation of beta-plus decay.**

Formula
$^{A}_{Z}X \rightarrow {}^{A}_{Z-1}Y + {}^{0}_{+1}e + u$
In this process a proton in the nucleus decays into a neutron and a positron, plus a neutrino.

SQ 12.4.22 **Give an example of beta-plus decay.**

Example
Neon decays into fluorine by emitting a positron and a neutrino.

Reaction
$^{19}_{10}\mathrm{Ne} \rightarrow {}^{19}_{9}\mathrm{F} + {}^{0}_{+1}e + u$

SQ 12.4.23 Why must a neutrino be released in positron emission?

Reason

The neutrino is required to conserve energy and momentum in the decay, since without it the emitted positron would not have a continuous energy spectrum.

SQ 12.4.24 Why are neutrinos difficult to observe?

Reason

Both the neutrino and the anti-neutrino have zero charge and very small mass, which is why they are very difficult to observe when passing through matter.

SQ 12.4.25 Describe the energy spectrum of alpha particles.

Answer

In alpha decay of a particular radionuclide, every emitted alpha particle has the same sharply defined kinetic energy. The graph shows distinct spikes, meaning alpha particles have discrete energies.

SQ 12.4.26 Why does beta decay have a continuous energy spectrum?

Reason

In beta emission the energy is shared between the beta particle and the anti-neutrino in varying proportions.

Result

The energy of an electron or positron may range from zero to a maximum value, giving a continuous spectrum.

SQ 12.4.27 Write the general equation of gamma decay.

Formula

$^{A}_{Z}X^* \to {}^{A}_{Z}X + \gamma$

Here $^{A}_{Z}X^*$ represents an excited nucleus and $^{A}_{Z}X$ the ground state of the nucleus.

SQ 12.4.28 Compare the ionization power of alpha, beta and gamma radiations.

Alpha Particles	Beta Particles	Gamma Rays
About 10^4 ion pairs per mm in air.	About 10^2 ion pairs per mm in air.	About 1 ion pair per mm in air.

SQ 12.4.29 Compare the penetrating power of alpha, beta and gamma radiations.

Alpha Particles	Beta Particles	Gamma Rays
Absorbed by a paper.	Absorbed by 1-5 mm of aluminium sheet.	Absorbed by 1-10 cm of lead sheet.

SQ 12.4.30 What is the difference between a beta particle and an electron?

Answer

A beta particle is created within the nucleus at the moment of emission, whereas an electron is an orbital particle of the atom. However, they are indistinguishable from one another once emitted.

TOPIC 5 Fundamental Particles

SQ 12.5.1 Define a fundamental particle.

Definition

By the term fundamental particle we mean a particle that has no internal structure, which means that it is indivisible.

SQ 12.5.2 Which particles are presently considered fundamental?

Answer

Presently the fundamental constituents of matter are considered to be quarks and leptons. They are considered the basic building blocks of matter.

SQ 12.5.3 What happens when a nucleus is smashed in a high energy accelerator?

Answer

Entirely new types of particles are created which apparently do not exist within the atoms of ordinary matter. They are the outcome of the violent collisions needed to probe the basic structure of matter.

SQ 12.5.4 What are strange particles?

Definition

Among the more than a hundred new particles identified, those not accounted for by the theoretical scheme were named strange particles. They are always created in pairs.

Example

$\pi^- + p \to k^0 + \Lambda^0$

SQ 12.5.5 What is the spin of electrons, protons, neutrons, photons and pions?

Answer

The characteristic spin of electrons, protons and neutrons is $\frac{1}{2}$, the spin of the photon is 1, and the spin of pions is taken as zero.

SQ 12.5.6 Define fermions.

Definition

Half spin particles obey Pauli's exclusion principle, which says that only one particle of a kind occupies a given quantum state. These particles are called fermions.

SQ 12.5.7 Define bosons.

Definition

The particles with zero or whole number spin do not obey Pauli's exclusion principle. They are called bosons, as they obey Bose-Einstein statistics.

SQ 12.5.8 Distinguish between fermions and bosons.

Fermions	Bosons
They have half integral spin.	They have zero or whole number spin.
They obey Pauli's exclusion principle.	They do not obey Pauli's exclusion principle.
Electrons, protons and neutrons are examples.	Photons and pions are examples.

SQ 12.5.9 Define baryons.

Definition

The nucleons and the heavier particles such as Λ^0 and k^+ which decay to nucleons are called baryons, meaning heavy.

SQ 12.5.10 Define leptons.

Definition

The particles that do not interact strongly with nucleons are called leptons, meaning small. They include the electrons, tau and neutrino.

SQ 12.5.11 What are mesons?

Definition

Mesons are midsized particles whose masses were mostly less than nucleon masses but more than the electron mass. Other mesons found later have masses greater than nucleons.

Examples

The strongly interacting particles are called pi mesons or pions, while the weakly interacting ones were named mu mesons or muons.

SQ 12.5.12 What evidence shows that protons and neutrons are not fundamental?

Answer

Both of the beta decay processes, that is beta-minus and beta-plus, provide evidence that protons and neutrons are not fundamental particles and must be made up of even smaller constituents, named quarks.

SQ 12.5.13 Differentiate between hadrons and leptons with examples.

Hadrons	Leptons
They experience the strong force.	They do not experience the strong force.
Protons, neutrons and pions are examples.	Electrons and neutrinos are examples.

SQ 12.5.14 How are hadrons further divided?

Answer

Hadrons are composite subatomic particles divided into two broad categories. Some are bosons, referred to as mesons such as the pion, while others are fermions, known as baryons, with protons and neutrons being the key examples.

SQ 12.5.15 How many quarks make up baryons and mesons?

Answer

Baryons are made of an odd number of quarks, usually three quarks. Mesons are made up of an even number of quarks, usually one quark and one anti-quark.

SQ 12.5.16 Through which interactions do leptons interact?

Answer

The leptons interact only through weak or electromagnetic interactions. No experiments have yet revealed any internal structure for the leptons.

SQ 12.5.17 How are the six leptons grouped?

Answer

All known leptons have spin $\frac{1}{2}$, so they are all fermions. The six known leptons are grouped as three pairs, each pair including a charged particle, its associated neutrino, and the corresponding anti-particles.

SQ 12.5.18 Why are neutrinos rarely observed?

Reason

Charged leptons can combine with other particles to form composite particles such as atoms and positronium, while neutrinos rarely interact with anything and are consequently rarely observed.

TOPIC 6 Quarks

SQ 12.6.1 Who proposed the quark model and when?

Answer

In 1964, M. Gell-Mann and George Zweig proposed that none of the hadrons, not even the proton and neutron, are truly fundamental, but instead are made up of combinations of more fundamental entities called quarks.

SQ 12.6.2 Name the six quark flavours.

Answer

The three quarks originally proposed were named up, down and strange (u, d, s). The other three quarks are called charm, bottom and top (c, b, t).

SQ 12.6.3 What are the charges of quarks?

Answer

All quarks have a spin and an electric charge which is a fraction of the previously thought smallest charge e on an electron.

SQ 12.6.4 Do quarks appear on their own?

Answer

No. Quarks are invisible and they never appear on their own. All hadrons are considered to be made up of combinations of quarks, plus the gluons that hold them together.

SQ 12.6.5 Write the quark composition of a proton and verify its charge.

Composition

The proton has a quark composition of uud.

Charge

$$q = \frac{2}{3} + \frac{2}{3} - \frac{1}{3} = +1$$

SQ 12.6.6 Write the quark composition of a neutron and verify its charge.

Composition

The neutron has a quark composition of udd.

Charge

$$q = \frac{2}{3} - \frac{1}{3} - \frac{1}{3} = 0$$

SQ 12.6.7 Write the quark composition of the π^+ meson.

Composition

The π^+ meson consists of an up quark and an antidown quark, that is $u\bar{d}$.

Charge

$q = \frac{2}{3} + \frac{1}{3} = +1$

SQ 12.6.8 What is colour charge?

Definition

Each flavour of quark can have one of three colours, usually designated red, green and blue. The anti-quarks are coloured antired, antigreen and antiblue.

SQ 12.6.9 Why are baryons and mesons colourless?

Answer

Baryons are made up of three quarks, one of each colour. Mesons consist of a quark and anti-quark pair of a particular colour and its anti-colour. Both are thus colourless or white.

SQ 12.6.10 What is quantum chromodynamics?

Definition

Each quark carries a colour charge, and the strong force between quarks is referred to as the colour force. This theory of the strong force is called quantum chromodynamics, indicating that the force acts between colour charges.

SQ 12.6.11 Explain beta decay in terms of quarks.

Explanation

A neutron with composition udd converts into a proton with composition uud by changing a down quark into an up quark.

Process

$d \rightarrow u + e^- + \bar{u}$

SQ 12.6.12 How does a proton and a neutron convert into each other?

Answer

A neutron changes into a proton when a down quark changes into an up quark, emitting an electron and an anti-neutrino. A proton changes into a neutron when an up quark changes into a down quark, emitting a positron and a neutrino.

SQ 12.6.13 Why is a free neutron unstable?

Answer

A neutron is stable only inside the nucleus. Free neutrons decay with a half life of about 10 minutes.

TOPIC 7 Higgs Boson

SQ 12.7.1 Which particles are considered fundamental in the modern picture?

Answer

Fundamental particles are considered to be the six quarks, the six leptons and the gauge bosons, which are the carriers of the fundamental forces.

SQ 12.7.2 How do leptons and quarks interact with each other?

Answer

Leptons and quarks interact with each other by sending and receiving bosons. For example, electromagnetic interactions occur when two charged particles exchange photons.

SQ 12.7.3 Name the carriers of the four fundamental forces.

Carriers

The photon carries the electromagnetic force.
Gluons carry the strong force between quarks.
The W^+
W^- and Z bosons carry the weak nuclear force.
Gravitons are the carriers of the gravitational force.

SQ 12.7.4 When and where was the Higgs boson discovered?

Answer

The Higgs boson is a special particle discovered in 2012 at the Large Hadron Collider at CERN.

SQ 12.7.5 State the role of the Higgs boson in the generation of mass.

Role

The Higgs boson is associated with the Higgs field that permeates all of space. Its crucial role is that it provides an explanation for how the other particles get mass by interacting with it.

SQ 12.7.6 Why is the rest mass of a photon zero?

Reason

Particles that interact strongly with the Higgs field get more mass, such as the W^+
W^- and Z bosons. Particles like photons do not interact with the Higgs field, so their rest mass is considered zero.

SQ 12.7.7 Write the mass of the Higgs boson.

Value

The Higgs boson has a mass of around $125\,\mathrm{GeV/c^2}$ and decays rapidly into other particles.

SQ 12.7.8 Give two key facts about the Higgs boson.

Facts

The Higgs boson gets its mass from its interactions with its associated Higgs field.
It can be a unique portal to find the conditions of the universe shortly after the Big Bang, and signs of dark matter.

TOPIC 8 Conservation Laws

SQ 12.8.1 Which conservation laws do all nuclear processes obey?

Laws

Conservation of energy, momentum and charge, including the nucleon number and charge number.
Conservation of baryon number.
Conservation of lepton number.

SQ 12.8.2 **Give examples of hadrons and non-hadrons.**

Hadrons
Mesons such as pions and kaons, and baryons such as protons, neutrons, omega, sigma and lambda particles.

Non-Hadrons
Leptons such as electrons and muons, and photons and gravitons.

TOPIC 9 The Asymmetry of Matter and Anti-Matter

SQ 12.9.1 **What is the asymmetry of matter and anti-matter?**

Answer
Many observations show that there is an asymmetry between matter and anti-matter. This is one of the most remarkable features of our universe, which consists almost entirely of matter rather than anti-matter.

SQ 12.9.2 **Give the assumed composition of the universe as evidence of asymmetry.**

Composition
The universe is assumed to be composed of 5% ordinary matter, which is 71% hydrogen atoms and 24% helium atoms.

Evidence
There is no contribution of anti-hydrogen or anti-helium atoms in the composition of the universe.

SQ 12.9.3 **To what is the matter and anti-matter asymmetry due?**

Answer
Experimental results explain that the asymmetry is due to the violation of conservation of baryon number, that is there is an imbalance in the number of baryons and anti-baryons.

SQ 12.9.4 **What happens if particle-antiparticle symmetry is violated?**

Answer
If the particle-antiparticle symmetry is also violated, then there will be a mechanism for making more quarks than anti-quarks, more leptons than anti-leptons, and eventually more matter than anti-matter.

TOPIC 10 Most of the Matter in the Observable Universe is Plasma

SQ 12.10.1 **How much of the universe do we actually know about?**

Answer
We know about only the 5% part of our universe; we still do not know about its remaining 95%.

SQ 12.10.2 **What is the universe made of according to the book?**

Composition
The universe consists of about 27% of unknown matter called dark matter, and about 68% of a mysterious antigravity material known as dark energy.

Result
Adding these gives 95% which is out of our knowledge.

SQ 12.10.3 **Why is most of the matter in the observable universe plasma?**

Reason
In the 5% of the universe we know about, hydrogen and helium are almost in the plasma state.

Result
These figures indicate that 95% of the 5% of the observable universe is in the plasma state, while the remaining is in the form of ordinary matter.

TOPIC 11 Theories About the Forces Between Particles

SQ 12.11.1 **Name the two theories explaining the forces between particles.**

Answer
To explain the interactions between the masses of particles through different mediators, we have the quantum field theory and the string theory.

SQ 12.11.2 **State the quantum field theory.**

Statement
According to this theory, each particle is represented by a field called a quantum field, which is responsible for transmitting a force from one particle to another by a mediator.

SQ 12.11.3 **Give an example illustrating the quantum field theory.**

Example
A positively charged particle produces an electric field in the space around it. This charged particle exerts an attractive force on a nearby negatively charged particle through its field.

SQ 12.11.4 **What are field particles?**

Definition
The energy and momentum of all fields are quantized. The quanta that exchange momentum and energy from one type of particle to another in their field are called field particles, and they are all bosons.

SQ 12.11.5 **Name the field particles which mediate each force.**

Mediators
The electromagnetic force is mediated by photons.
The strong nuclear force is mediated by gluons.
The electro-weak force is mediated by the W and Z bosons.
The gravitational force is mediated by gravitons.

SQ 12.11.6 **State the string theory.**

Statement
String theory is an advanced concept in theoretical physics proposing that the fundamental particles of the universe, instead of being point-like, are actually tiny vibrating strings.

SQ 12.11.7 **What determines the properties of particles in string theory?**

Answer

These strings can be open or closed loops, and their vibrations determine the properties of particles, including mass and force.

SQ 12.11.8 **What is the status of string theory?**

Answer

The string theory framework offers a potential theory of everything, but it still remains unproved experimentally.

TOPIC 12 The Standard Model

SQ 12.12.1 **What is the standard model?**

Definition

The standard model is the collection of theories that describe the smallest experimentally observed particles of matter, and the interaction between energy and matter.

SQ 12.12.2 **Which three categories of particles form the standard model?**

Categories

Matter, which makes up only 5% of the universe, is composed of quarks and leptons.
The fundamental bosons provide the three forces.
The Higgs boson provides an explanation of how other particles get mass.

SQ 12.12.3 **Which three forces do the fundamental bosons provide?**

Answer

The fundamental bosons provide electromagnetism, the strong nuclear force and the weak nuclear force.

SQ 12.12.4 **Why is the standard model considered incomplete?**

Reason

It is currently unable to explain many important features of the known universe, such as gravity, dark matter which is 27% of the universe, and dark energy which is 68% of the universe.