Chapter 9

Nature of Science

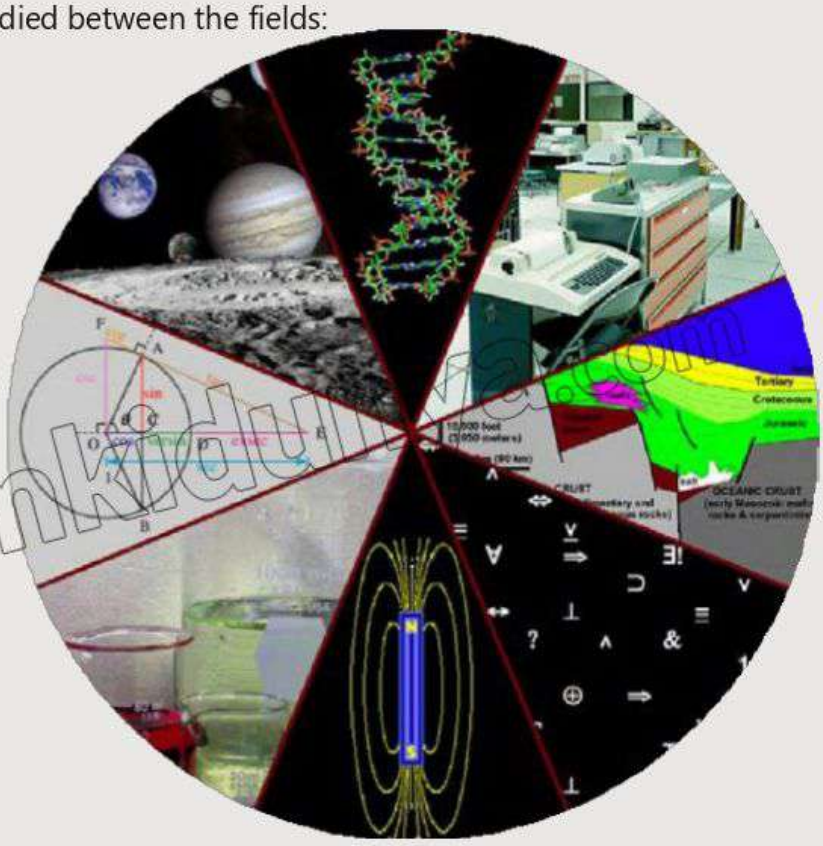
Student Learning Outcomes

After completing this chapter, students will be able to:

[SLO: P-09-G-01] Describe physics as the study of matter, energy, space, time and their mutual connections and interactions

[SLO: P-09-G-02] Explain with examples that physics has many sub-fields, and in today's world involves interdisciplinary fields. (Students should be able to distinguish in terms of the broad subject matter that is studied between the fields:

- Biophysics
- Astronomy
- Astrophysics
- Cosmology
- Thermal Physics
- Optics
- Classical Mechanics
- Quantum Mechanics
- Relativistic Mechanics
- Nuclear Physics
- Particle Physics
- Electromagnetism
- Acoustics
- Computational Physics
- Geophysics
- Climate Physics)



[SLO: P-09-G-03] Explain with examples how Physics is a subset of the Physical Sciences and of the natural sciences

[SLO: P-09-G-04] Brief with examples that science is a collaborative field that requires interdisciplinary researchers working together to share knowledge and critique ideas

[SLO: P-09-G-05] Understand the terms 'hypothesis', 'theory' and 'law' in the context of research in the physics

[SLO: P-09-G-06] Explain, with examples in Physics, falsifiability as the idea that a theory is scientific only if it makes assertions that can be disproven

[SLO: P-09-G-07] Differentiate the terms 'science', 'technology' and 'engineering' with suitable examples

Science is a collective knowledge about the natural phenomena, processes and events occurring around us. The process starts with asking a question, how and why the things in the world behave as such. We try to look orderliness and regularities among various phenomena apparently of diverse nature. Such study of nature gave birth to a single discipline, known as Natural Philosophy now known as science. There was a tremendous increase in the volume of scientific knowledge at the beginning of nineteenth century. That made it necessary to classify the study of nature basically into two main disciplines.

(i.) The biological sciences which deal with the living things.

(ii.) The physical sciences which are about the study of non-living things.

Physics is important and basic part of physical sciences beside other disciplines such as chemistry and geology.

9.1 Scope of Physics

Physics is the fundamental science that deals with the constituents of the universe, that is, matter, energy, space, time and their mutual relationships and interactions. It strives to understand how the universe works, from the smallest subatomic particles to the largest star and galaxies. We have studied some of the basic properties of matter, energy and their mutual inter-relationship in the earlier chapters of this book. We will discuss in detail the concept of space and time in the higher classes. Briefly, the space is the three-dimensional extent in which all objects and events occur. It provides framework to define positions and motions of various objects under some force.

Do You Know?

This toy which worked by steam invented by Hero, from Alexandria in the 3rd century. However, the people did not think of using such things for luxury and comfort in those days.

The time measures the sequence and durations of events. It is considered fourth dimension. For example, oscillating motion such as that of a swinging pendulum relies on the time interval that determine frequency of oscillations. Another example is the time dilation which is a phenomenon discussed by special theory of relativity where time passes slowly for an observer moving at ultra-high speed compared to one relatively at rest. Physics explores how these fundamental concepts are inter connected. For example, the theory of relativity explains how space and time are not absolute quantities but are related to each other. It describes the relationship between space and time and how they are influenced by gravity and speed, for example, the bending of light around

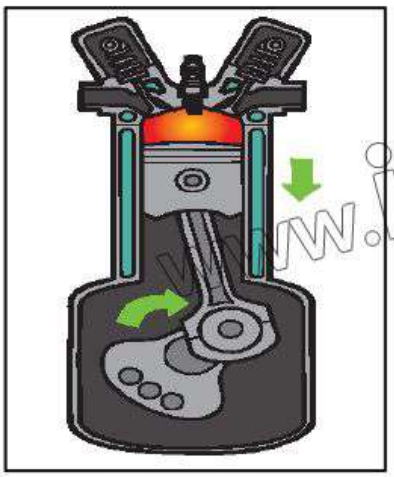
massive objects like stars. Another branch of physics, the quantum mechanic, explains the behavior of particles at the atomic and subatomic levels. It is how the physics has applied its principles to wide variety of phenomena, from everyday occurrences such as related to motion and heat to the extreme conditions found in the universe.

9.2 Branches of Physics

Due to expanding scope of research in Physics, it is usually divided into following branches?

1. Mechanics: It is a study of motion and the physical effects which influence motion. It is based on Newton's laws of motion and gravitation and is often called classical mechanics.

Gears in a mechanical system



Heat engine

2. Heat and thermodynamics: It deal with the thermal energy possessed by the materials and it is used when it flows from one body to another.

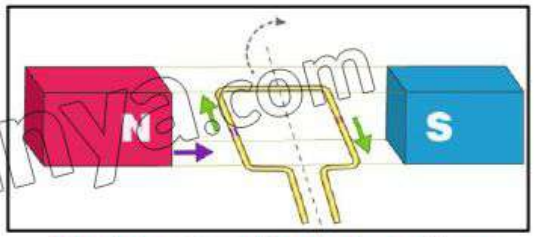
3. Acoustics: It deals with the nature and physical aspects of audible sound energy.

Pressure horn

Dispertion of light

4. Optics: It deal with the physical aspects of visible light.

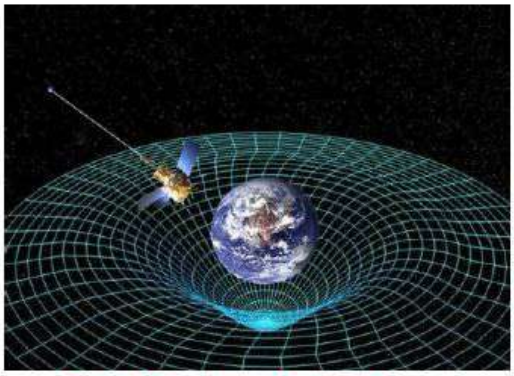
5. Electromagnetism: It is the study of electromagnetic phenomenon and mutual relationship between electric current and magnetic field.



Electric current is produced in a coil rotated in a magnetic field

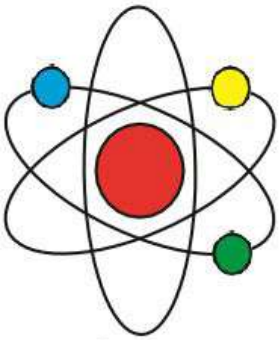
6. Quantum Mechanics: It explains the behavior of particles at the atomic and subatomic level.

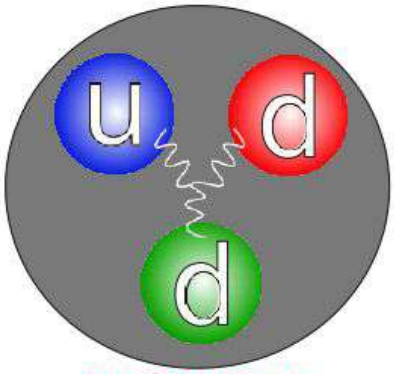

Excited states of atom


Einstein view of gravity as space time curvature

7. Relativistic Mechanics: It explains how space and time are not absolute quantities but related to observer. It describes the relationship between them and how they are influenced by gravity and speed.

8. Nuclear Physics: It is the study of the properties of nuclei of the atoms.


Nuclear atom

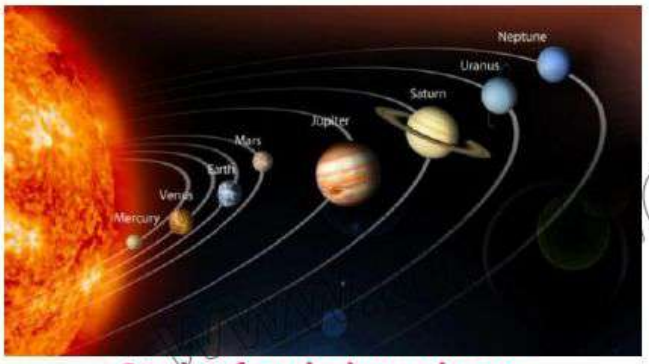


Quark Structure of a Neutron

9. Particle Physics: It is the study of subatomic particles and elementary particles which are basic building blocks of matter.

10. Astronomy: It is study of distribution of celestial bodies like planets, stars and galaxies.

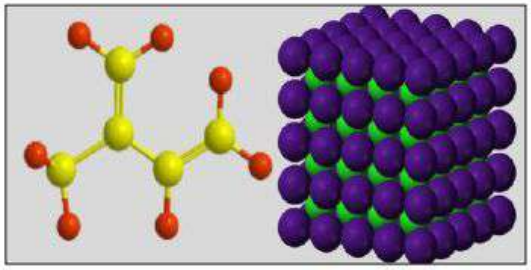

Extended Universe



Study of exploring universe

11. Cosmology: It explores the large structure and evolution of the universe.

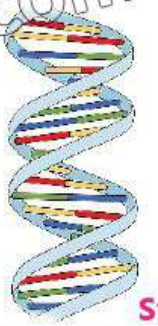
12. Solid State Physics: It is the study of some specific properties of matter in solid form.


Electrical bonding of solids

9.43 Interdisciplinary Nature of Physics

It refers to integration and interaction of Physics with various other fields of study. Physics, being fundamental science, provides essential principles, techniques and methods that are applicable across a wide range of disciplines. Some of these are:

1. Biophysics: Some biological systems and processes are described using the principles and technique of physics under this field of Study. Examples include the mechanics of biological structures, physical properties of cells, tissues and organs.

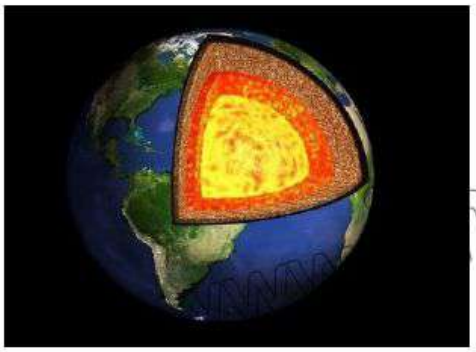

DNA Structure

2. Medical Physics: It applies physical principles to develop techniques and technologies for health diagnosis and treatment. The examples include imaging techniques, such as X-rays; ultra sound, MRI and CT scan and also radiation therapy for cancer treatment.


Magnetic Resonance Imaging (MRI)


Study of celestial bodies

3. Astrophysics: It deals with the physical properties and processes of celestial bodies and phenomena. For example, the interaction between the matter and energy in space to understand the universe as a whole.



Internal structure of the Earth

4. **Geophysics:** It applies physical principle to the study of internal structure of the Earth, its magnetic and gravitational fields, seismic activity (earthquake), volcanoes, etc.

5. **Climate Physics:** It includes the study of physical process in the environment, including atmospheric dynamics, climate change and weather conditions.

A tornado

Computer graphics

6. **Computation Physics:** It is about the use of computational techniques and methods to solve complex physical problems.

9.4 Interdisciplinary Research

Collaboration and interdisciplinary nature of science is essential for addressing the complex issues and challenges of today. By working together and sharing knowledge, scientist can achieve more significant breakthrough and contribute to a deeper understanding of the natural and physical world around us. It allows us to contribute to advance in technology, healthcare, environmental issues and many other areas. We need collaborated efforts because:

(I). Solution of complex issues requires multifacet expertise

Many challenging issues, such as climate change, disease prevention and treatment, sustainable energy solution are of diverse nature. It is difficult for one discipline to address them adequately. Such as understanding and mitigating climate change require knowledge for meteorology, oceanography, physics, chemistry, biological and environmental sciences. Similarly, the health care issues such as recent Covid epidemic involved combined efforts of expertise

from biology, chemistry, physics, medical technologies and data science to combat this challenge.

(ii). Interdisciplinary approaches foster innovation

Combined different perspectives and methodologies evolve innovation or out of box solutions. This approach can lead to novel insight and breakthroughs that might not emerge working in isolation. For example, nano-technology is a blend of physics, chemistry, material science and engineering to create materials and devices at the nano-scale with unique applications in medical, energy and electronics. In an other field of "artificial intelligence" the development involves computer science, mathematical logic, neuroscience etc. The collaboration across these fields enhanced the development of intelligence systems and their applications.

(iii). Rapid sharing of knowledge and information across the globe

Sharing and collaboration of knowledge across the globe brings rapid advances in science. The online internet information exchanges, conferences and workshops provide platforms bringing together researchers from different fields to share their fresh findings, discussion and brainstorming new approaches. Collaborated research projects and research journals are also means of collaborate research.

Interdisciplinary research and collaboration leads to a more holistic understanding of challenging issues by interacting with different perspectives such as that of environment and space exploration.

9.5 Scientific Method

Scientific method is a systematic approach used to search for truth of an issue and problem solving regarding natural and physical world. It is based on the following steps.

1. Identify or recognize an issue or a problem.
2. Gather information through observations of its various aspects.
3. Propose an explanation or a guess work known as hypothesis.
4. Perform experiment or collect evidences to test the hypothesis.
5. Record, organize and analyze gathered data, plotting and interpreting graphs to reach at a conclusion which is called a theory.
6. Repeated tests of the theory to wide range of similar issues then lead towards the formulation of a law.

Some key steps are elaborated here.

1. Observation

The first step in scientific method is to make observations of natural processes and to collect the data about them. This may be done either by ordinary observations or by obtaining the results from different experiments. For example, it is our common observation that shadow of an opaque object is formed when it is placed in the path of light coming from the Sun or a lamp (Fig.9.1).

Fig. 9.1

2. Hypothesis

On the basis of the data collected through observations or experimentation, we can develop a hypothesis. This is done in order to test its logical results, i.e., it is assumed that nature will act in a particular way under certain specific circumstances. From the above example, we assume that shadows of opaque objects are formed when they come in the path of light because light travels in a straight line.

3. Experiment

Experiment is an organized repeatable process which is used to test the truth of a hypothesis.

To verify the assumption made in the above example, four card boards, each with a hole, are placed in a straight line, such that the hole in 1st card is in front of a torch. When we see through the hole in cards, we can see the light of the torch (Fig. 9.2-a). If any of these cards is displaced, we cannot see light passing through (Fig. 9.2-b). Thus, this experiment proves that light travels in a straight line.

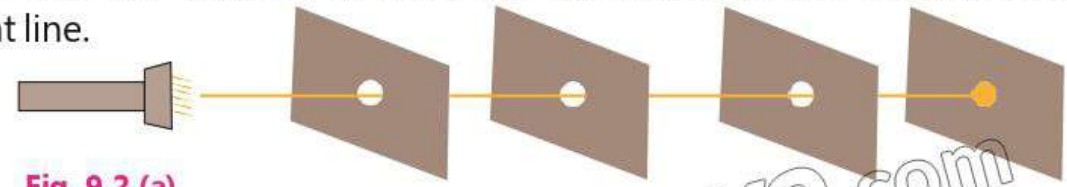


Fig. 9.2 (a)

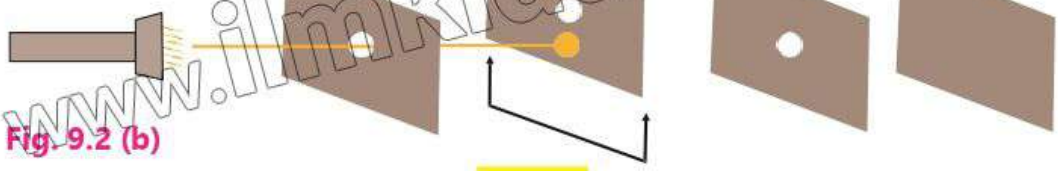
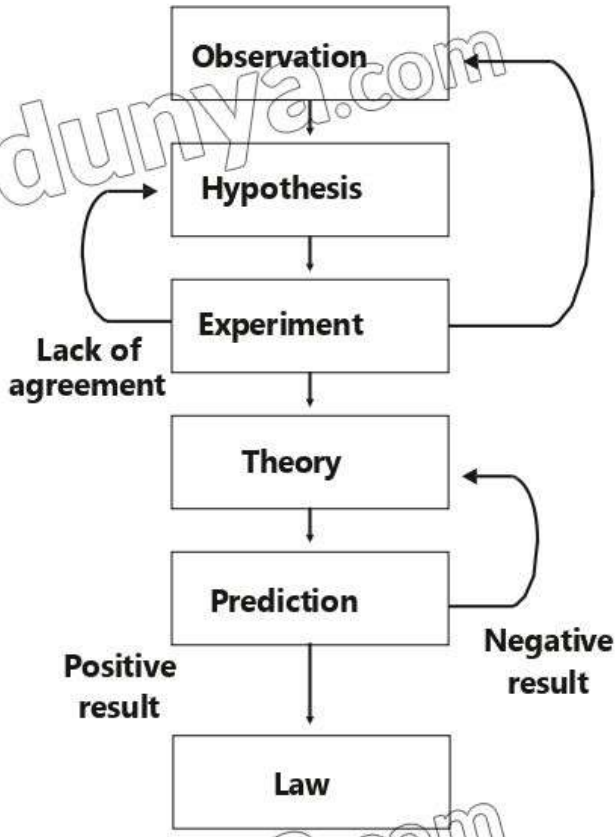


Fig. 9.2 (b)

4.Theory

After the successful verification of an assumption and with the help of careful experimentation, it becomes a theory and is applicable to similar phenomena. With the help of the above experiment, the assumption has been proved that light travels in a straight line. So it then becomes a theory.

It is a logical explanation of the causes and effects of an issue or an event that occurs in nature.



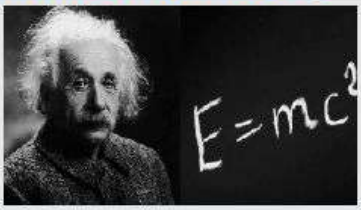
5. Prediction

After the careful analysis of a theory we can make predictions about certain unknown aspects of nature. To verify the prediction, experiments are designed to test the theory over and over again. If test result do not agree, hypothesis is changed or rejected.

6. Falsifiability

It is a concept introduced that suggests a theory to be considered scientific if it also make predictions that can be tested and potentially proven false. The requirement of falsifiability ensures that theories are not based on vague, non-specific or untestable claims. It distinguishes scientific theories from false or pretended beliefs that cannot be experimentally tested.

For Your Information!



In the 20th century, Albert Einstein declared that mass and energy, the two concerns of Physics, are forms of each other. His theory of relativity altered man's views of the universe.

7. Law

When a theory has been tested many times and generally accepted as true, it is called a law. The law is such a statement regarding the behaviour of nature which explains the observations and experiments of the past and can predict about other aspects of nature. From the fact that light travels in a straight line, we can predict that shadow of an opaque object, similar in shape, is formed whenever it is placed in the path of light. For example, the shadow of a ball will be round whereas the shadow of a rectangular block will be a rectangle After testing the theory under different situations, this becomes a law of science that light travels in a straight line.

The theories or laws of physics are man made ideas about the way the things work. They are liable to be disproved or modified with the future advances in science which brings fresh facts and new insights about the natural and physical world.

9.6 Scientific Base of Technologies and Engineering

Science or to be more specific, physics plays a vital role being the core of each invention based on physical laws and principles. Technology refers to the methods and techniques developed by using scientific knowledge. It may be a machine technology or a software programme of information technology. For example,

(i) Automobile technology is based on the principles of the thermodynamics.

(ii) Radar technology is based on the detection and reflection principles of electromagnetic waves.

(iii) Laser technology is based on the principles of atomic physics. It is widely used in medical diagnosis and treatment, metallurgy, industry, telecommunication and space exploration.

Engineering is the process of applying various technologies and scientific principles to design various instruments, tools and build things that help to meet specific needs in every walk of life. Engineers also consider factors like cost effectiveness and safety measures when designing various products. Examples include:

(I) A civil engineer designs a bridge that can withstand strong winds, earthquakes, intense weather conditions and heavy traffic.

(ii) A software engineer designs a user friendly application of a smartphone.

(iii) An aviation engineer looks for lighter material which can withstand sudden and severe disturbances and extreme weather conditions during the flight of an aeroplane.

Though the science, technology and engineering fields seem distinct but they often work together. Scientific discoveries lead to new technologies and engineers rely on scientific knowledge for our benefits and comforts. They are the potent for change in the outlook of mankind in shaping life style and influencing our way of thinking.

KEY POINTS

- Science is a collective knowledge about the natural phenomena and events.
- Physics is the fundamental branch of science which deals with matter, energy, space, time and their mutual relationships.
- There are many sub fields of physics called its branches such as mechanics, heat, optics, electromagnetism, etc.
- Interdisciplinary nature of physics refers to integration and interaction of physics with other disciplines of science. Some of them are biophysics astrophysics, geophysics, climate physics and computational physics.
- Scientific method is a specific and systematic approach for the search of the truth about a natural phenomenon or event. Its steps include observation, hypothesis, experiment, theory, prediction and law.
- The advancement in the science knowledge and its applications through various technologies and engineering has changed the outlook of mankind and have made our lives easier and comfortable.

EXERCISE

A Multiple Choice Questions

Tick (✓) the correct answer.

9.1 Physics is a branch of:

(a) Social science (b) Life science

(c) Physical science (d) Biological science

9.2 Which branch of science plays vital role in technology and engineering?

(a) Biology (b) Chemistry (c) Geology (d) Physics

9.3 Automobile technology is based on:

(a) acoustics (b) electromagnetism

(c) optics (d) thermodynamics

9.4 A user friendly software application of smart phone use:

(a) laser technology (b) information technology

(c) medical technology (d) electronic technology

9.5 The working of refrigeration and air conditioning involves:

(a) electromagnetism (b) mechanics

(c) climate science (d) thermodynamics

9.6 What is the ultimate truth of a scientific method?

(a) Hypothesis (b) Experimentation

(c) Theory (d) Law

9.7 The statement "If I do not study for this test, then I will not get good grade" is an example of:

(a) theory (b) observation

(c) prediction (d) law

9.8 Which of the following are methods of investigation?

(a) Observation (b) Experimentation

(c) Research (d) All of these

9.9 A hypothesis:

(a) may or may not be testable (b) is supported by evidence

(c) is a possible answer to a question (d) all of these

9.10. A graph of an organized data is an example of:

(a) collecting data (b) forming a hypothesis

(c) asking question (d) analyzing data

9.11. The colour of a door is brown. It is an example of:

(a) observation (b) hypothesis

(c) prediction (d) law

B Short Answer Questions

9.1 State in your own words, what is science? Write its two main groups.
9.2 What is physics all about? Name some of its branches.
9.3 What is meant by interdisciplinary fields? Give a few examples.
9.4 List the main steps of scientific method.
9.5 What is a hypothesis? Give an example.
9.6 Distinguish between a theory and a law of physics.
9.7 What is the basis of laser technology?
9.8 What is falsifiabilty concept? How is it important?

C Constructed Response Questions

9.1 Is the theory of science an ultimate truth? Describe briefly.
9.2 Do you think that the existing laws of nature may need a change in future? Describe briefly.
9.3 Describe three jobs that need the use of scientific knowledge.
9.4 Describe when a theory is rejected or need its modification.
9.5 Comment on the statement. " A theory is capable of being proved right but not being proved wrong is not a scientific theory".
9.6 What has been the general reaction to new ideas about established truths?
9.7 If a hypothesis is not testable, is the hypothesis wrong? Explain.
9.8 Explain how a small amount of data cannot prove that a prediction is always correct but can prove it is not always correct.
9.9 What is the relationship between an experiment and a hypothesis?
9.10 Describe why the solution of complex problems need interdisciplinary research and collaboration.

D Comprehensive Questions

9.1 Describe the scope of physics. What are the main branches of physics? State briefly.
9.2 What is meant by interdisciplinary fields of physics? Give three examples.
9.3 What is scientific method? Describe its main steps with examples.
9.4 Differentiate the terms, science, technology and engineering with examples.
9.5 What is the scope of physics in everyday life? Give some examples.

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Glossary

Acceleration: Rate of change of velocity with time.

Accuracy: Relative measurement reflected by the number of significant figures.

Artificial Satellites: Objects moving in fixed circular orbits around the Earth.

Base Quantity: Such quantity, which can be expressed independently without the reference of any other quantity.

Base Units: The units in System International, which are seven in number.

Biofuel Energy: Energy obtained from waste organic materials.

Centre of Gravity: The point of body where its weight acts.

Centripetal Acceleration: Acceleration produced by the centripetal force.

Centripetal Force: The force which keeps an object to move in a circular path.

Circular Motion: Motion of a body along a circular path.

Components of a Vector: Such vectors when added give the resultant vector.

Couple: When two equal and unlike parallel forces act at different points of a body, then they constitute a couple.

Density: Mass of unit volume of a substance.

Derived Quantity: A quantity which is expressed with reference to base quantities.

Derived Units: Units which can be derived from base units.

Displacement: The shortest distance between two points.

Dynamics: Study of motion of bodies under action of forces.

Efficiency: Ratio of output and input.

Elastic Potential Energy: Energy of a compressed or stretched spring.

Elasticity: The property of the solids because of which they restore their original shape when external force ceases to act.

Electromagnet: A temporary magnet when electric current flows through a coil wrapped around an iron rod.

Energy: Ability of a body to do work.

Equilibrium: A state of a body which has no acceleration.

Force: The agent that changes or tends to change the state of a body.

Fossil Fuels: Oil, gas and coal which can be burnt.

Friction: The force that tends to prevent the bodies from sliding over each other.

Geothermal Energy: Energy of the hot rocks deep under the surface of the Earth.

Gravitational Field: The region around an object where its force of gravity acts.

Gravitational Force: Mutual force of attraction between the objects.

Gravitational Potential Energy: Energy of body due to its position in the gravitational field.

Heat: The form of energy, which is transferred from one place to another because of difference of temperature.

Horizontal Component: The component of a vector which is along horizontal or x-direction.

Hydraulic Brakes: Brakes working according to Pascal's law.

Hydraulic Press: A press that work under Pascal's law.

Hydroelectric Generation: Conversion of kinetic energy of flowing water into electrical energy.

Inertia: The characteristic of a body due to which it resists against any change in its state.

Internal Energy: Total energy of molecules of an object.

Joule: The unit of work in System International.

Kilowatt-hour: Work done in one hour at a rate of one Kilowatt.

Kinematics: Study of motion of bodies without taking into consideration of the mass and forces.

Kinetic Energy: Energy of a body due to its motion.

Kinetic Friction: Friction during motion.

Least Count: The minimum measurement recorded by an instrument.

Light Year: The unit of distance for celestial bodies equal to 9.46×10^{15} m

Like Parallel Forces: Forces acting along parallel lines in the same direction.

Limiting Friction: The maximum value of static friction.

Line of Action of a Force: The straight line along which the force acts.

Linear Motion: The motion of body along a straight line.

Mass: That characteristics of a body, which determines the acceleration produced by the application of a force.

Mechanics: The branch of Physics which deals with the study of motion of bodies.

Magnet: It attracts magnetic materials and stays north-south direction when suspended freely.

Magnetic Compass: A direction indicating device using a magnetic needle.

Magnetic Field: Space around a magnetic in which force is exerted on another magnet.

Momentum: The product of mass and velocity of a moving body.

Neutral Equilibrium: The condition of a body in which its centre of gravity neither rises nor lowers of its original position after disturbance.

Orbital Speed: A critical speed of a satellite in order to keep on moving around the Earth at a specific height.

Parallel Forces: Forces acting along the parallel lines.

Physical Quantities: Measurable characteristics of objects.

Physics: That branch of Science, which explains the properties of matter, energy, space and time.

Plasma: A state of matter in which most of the atoms are ionized into positive ions and electrons.

Power: Rate of doing work.

Precision: Determined by the instrument used equal to its least count.

Prefix: Symbols added to a unit to write it by power of 10.

Pressure: Force exerted normally on unit area of an object.

Random Motion: Motion without any consideration of time and direction.

Perpendicular Components: The components of a vector which are mutually perpendicular to each other.

Resolution of a Vector: Division of a vector into its components.

Resultant Vector: Such a vector which shows the combined effect of two or more vectors.

Rolling Friction: The friction produced during the motion of one body over the other with the help of wheels.

Scalar Quantities: Quantities which can be specified by their magnitudes only.

Scientific Method: Logical applications of argumentsthat explain a certain phenomenon.

Scientific Notation: The number written as power of ten or prefix in which there is only one non zero number before decimal.

Significant Figures: In a measurement, the correctly known digits and the first doubtful digit.

Sliding Friction: The friction between two surfaces sliding against each other.

Solar Energy: Energy of the sunlight.

Speed: Distance covered by a body in one second.

Stable Equilibrium: The condition of a body in which it comes to its original condition after being disturbed.

Static Friction: The force of friction arising due to applied external force before motion of one body over the other.

Temperature: Degree of hotness or coldness of a body.

Tension: The force acting along a string

Thermometry: Art of measurement of temperature.

Torque: Product of force and its moment arm.

Trigonometric Ratios: The ratios of the sides of a right-angled triangle.

Uniform Acceleration: Equal changes in velocity in equal intervals of time.

Uniform Speed: Equal distances covered by a body in equal intervals of time.

Uniform Velocity: Equal changes in displacement in equal intervals of time.

Unlike Parallel Forces: Forces acting along parallel lines but in opposite directions.

Unstable Equilibrium: The condition of a body in which it does not come to its original condition after disturbance.

Vectors Quantities: Quantities which can be specified by magnitude as well as direction.

Velocity: Rate of change of displacement with time.

Vertical Component: The component of a vector which is along vertical or y-direction.

Vibratory Motion: The to and fro motion of body about a fixed point.

Volume Expansion: Increase in volume.

Watt: The unit of power in System International.

Weight: The force with which the Earth pulls a body towards its centre.

Wind Energy: Kinetic energy of fast-moving air/wind.

Work: The product of force and the displacement in the direction of force.

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