LESSON

PHYSICAL WORLD

Introduction

Humans have always been curious about the world around them. The night sky with its bright celestial objects has fascinated humans since time immemorial. The regular repetitions of the day and night, the annual cycle of seasons, the eclipses, the tides, the volcanoes, the rainbow have always been a source of wonder. The world has an astonishing variety of materials and a bewildering diversity of life and behaviour. The inquiring and imaginative human mind has responded to the wonder and awe of nature in different ways. This human endeavour led, in course of time, to modern science and technology.

What is science and what is the so-called scientific method?

The word science originates from the Latin verb scientia meaning “to know”. Science is a systematic attempt to understand natural phenomena in as much detail and depth as possible, and use the knowledge so gained to predict, modify and control phenomena. Science is exploring, experimenting and predicting from what we see around us. The curiosity to learn about the world, unravelling the secrets of nature is the first step towards the discovery of science.

The scientific method involves several interconnected steps : Systematic observations, controlled experiments, qualitative and quantitative reasoning, mathematical modelling, prediction and verification or falsification of theories. Speculation and conjecture also have a place in science; but ultimately, a scientific theory, to be acceptable, must be verified by relevant observations or experiments.

The interplay of theory and observation (or experiment) is basic to the progress of science. Science is ever dynamic. There is no ‘final’ theory in science and no unquestioned authority among scientists. As observations improve in detail and precision or experiments yield new results, theories must account for them, if necessary, by introducing modifications. Sometimes the modifications may not be drastic and may lie within the framework of existing theory. For example, when Johannes Kepler (1571-1630) examined the extensive data on planetary motion collected by Tycho Brahe (1546-1601), the planetary circular orbits in heliocentric theory (sun at the centre of the solar system) imagined by Nicolas Copernicus (1473–1543) had to be replaced by elliptical orbits to fit the data better.

In the beginning of the twentieth century, it was realised that Newtonian mechanics, till then a very successful theory, could not explain some of the most basic features of atomic phenomena. Similarly, the then accepted wave picture of light failed to explain the photoelectric effect properly. This led to the development of a radically new theory (Quantum Mechanics) to deal with atomic and molecular phenomena.

What is Physics ?

Physics is a basic discipline in the category of **Natural Sciences**, which also includes other disciplines like Chemistry and Biology. The word **Physics** comes from a Greek word meaning nature. Its Sanskrit equivalent is Bhautiki that is used to refer to the study of the physical world. We can broadly describe physics as a study of the basic laws of nature and their manifestation in different natural phenomena. Here we remark on two principal thrusts in physics : **unification** and **reduction.**

Unification: In Physics, we attempt to explain diverse physical phenomena **in terms of a few concepts and laws**. The effort is to see the physical world as manifestation of some universal laws in different domains and conditions. For example, the same law of gravitation (given by Newton) describes the fall of an apple to the ground, the motion of the moon around the earth and the motion of planets around the sun. Similarly, the basic laws of electromagnetism (Maxwell's equations) govern all electric and magnetic phenomena. The attempts to unify fundamental forces of nature reflect this same quest for unification.

Reduction : A related effort is to derive the properties of a bigger, more complex, system from the properties and interactions of its constituent simpler parts. This approach is called **reductionism** and is at the heart of physics. For example, the subject of thermodynamics, developed in the nineteenth century, deals with bulk systems in terms of macroscopic quantities such as temperature, internal energy, entropy, etc. Subsequently, the subjects of kinetic theory and statistical mechanics interpreted these quantities in terms of the properties of the molecular constituents of the bulk system.

Scope and Excitement of Physics

The scope of physics can be explained by looking at its various sub-disciplines. There are domains of interest.

Macroscopic Domain

The macroscopic domain includes phenomena at the laboratory, terrestrial and astronomical scales.
Classical Physics deals mainly with macroscopic phenomena and includes subjects like **Mechanics**, **Electrodynamics, Optics** and **Thermodynamics**.

- Mechanics founded on Newton's laws of motion and the law of gravitation is concerned with the motion (or equilibrium) of particles, rigid and deformable bodies, and general systems of particles. The propulsion of a rocket by a jet of ejecting gases, propagation of water waves or sound waves in air, the equilibrium of a bent rod under a load, etc., are problems of mechanics.
- Electrodynamics deals with electric and magnetic phenomena associated with charged and magnetic bodies. Its basic laws were given by Coulomb, Oersted, Ampere and Faraday, and encapsulated by Maxwell in his famous set of equations. The motion of a current-carrying conductor in a magnetic field, the response of a circuit to an ac voltage (signal), the working of an antenna, the propagation of radio waves in the ionosphere, etc., are problems of electrodynamics.
- Optics deals with the phenomena involving light. The working of telescopes and microscopes, colours exhibited by thin films, etc., are topics in optics.
- Thermodynamics, in contrast to mechanics, does not deal with the motion of bodies as a whole. Rather, it deals with systems in macroscopic equilibrium and is concerned with changes in internal energy, temperature, entropy, etc., of the system through external work and transfer of heat. The efficiency of heat engines and refrigerators, the direction of a physical or chemical process, etc., are problems of interest in thermodynamics.

Microscopic Domain

The microscopic domain of physics deals with the constitution and structure of matter at the minute scales of atoms and nuclei (and even lower scales of length) and their interaction with different probes such as electrons, photons and other elementary particles. Quantum Theory is currently accepted as the proper framework for explaining microscopic phenomena.

Now we can see that the scope of physics is truly vast. It covers a tremendous range of magnitude of physical quantities like length, mass, time, energy, etc. At one end, it studies phenomena at the very small scale of length (10^{-14} m or even less) involving electrons, protons, etc.; at the other end, it deals with astronomical phenomena at the scale of galaxies or even the entire universe whose extent is of the order of 10^{26} m. The two length scales differ by a factor of 10^{40} or even more.

Physics is exciting in many ways. To some people the excitement comes from the elegance and universality of its basic theories, from the fact that a few basic concepts and laws can explain phenomena covering a large range of magnitude of physical quantities. To some others, the challenge in carrying out imaginative new experiments to unlock the secrets of nature, to verify or refute theories, is thrilling. Applied physics is equally demanding. Application and exploitation of physical laws to make useful devices is the most interesting and exciting part and requires great ingenuity and persistence of effort.

What lies behind the phenomenal progress of physics in the last few centuries?

(i) It was realised that for scientific progress, only qualitative thinking, though no doubt important, is not enough. Quantitative measurement is central to the growth of science, especially physics, because the laws of nature happen to be expressible in precise mathematical equations.

(ii) The basic laws of physics are universal — the same laws apply in widely different contexts.

(iii) The strategy of approximation turned out to be very successful. Most observed phenomena in daily life are rather complicated manifestations of the basic laws.

Physics, Technology and Society

The connection between physics, technology and society can be seen in many examples. The discipline of thermodynamics arose from the need to understand and improve the working of heat engines. The steam engine, as we know, is inseparable from the Industrial Revolution in England in the eighteenth century, which had great impact on the course of human civilisation.

Sometimes technology gives rise to new physics; at other times physics generates new technology. An example of the latter is the wireless communication technology that followed the discovery of the basic laws of electricity and magnetism in the nineteenth century.

Some of the important examples of physics giving rise to technology are :

- The great physicist Ernest Rutherford had dismissed the possibility of tapping energy from atoms. But only a few years later, in 1938, Hahn and Meitner discovered the phenomenon of neutron-induced fission of uranium, which would serve as the basis of nuclear power reactors and nuclear weapons.
- The silicon ‘chip’ that triggered the computer revolution in the last three decades of the twentieth century.
- The development of alternative energy resources.

Below is the table that lists some of the great physicists, their major contribution and the country of origin.

Table: Some physicists from different countries of the world and their major contributions

Name	Major contribution/discover	Country of Origin
Archimedes	Principle of buoyancy; Principle of the lever	Greece
Galileo Galilei	Law of inertia	Italy
Christiaan Huygens	Wave theory of light	Holland
Isaac Newton	Universal law of gravitation; Laws of motion; Reflecting telescope	U.K.
Michael Faraday	Laws of electromagnetic induction	U.K.
James Clerk Maxwell	Electromagnetic theory; Light-an electromagnetic wave	U.K.
Heinrich Rudolf Hertz	Generation of electromagnetic waves	Germany
J.C. Bose	Ultra short radio waves	India
W.K. Roentgen	X-rays	Germany
J.J. Thomson	Electron	U.K.
Marie Sklodowska Curie	Discovery of radium and polonium; Studies on natural radioactivity	Poland
Albert Einstein	Explanation of photoelectric effect; Theory of relativity	Germany
Victor Francis Hess	Comsmic radiation	Austria
R.A. Millikan	Measurement of electronic charge	U.S.A.
Ernest Rutherford	Nuclear model of atom	New Zealand
Niels Bohr	Quantum model of hydrogen atom	Denmark
C.V. Raman	Inelastic scattering of light by molecules	India
Louis Victor ode Borglie	Wave nature of matter	France
M.N. Saha	Thermal ionization	India
S.N. Bose	Quantum statistics	India
Wolfgang Pauli	Exclusion principle	Austria
Enrico Fermi	Controlled nuclear fission	Italy
Werner Heisenberg	Quantum mechanics; Uncertainty principle	Germany
Paul Dirac	Relativistic theory of electron; Quantum statistics	U.K.
Edwin Hubble	Expanding universe	U.S.A.
Ernest Orlando Lawrence	Cyclotron	U.S.A
James Chadwick	Neutron	U.K.
Hideki Yukawa	Theory of nuclear forces	Japan
Homi Jehangir Bhabha	Cascade process of cosmic radiation	India
Lev Davidovich Landau	Theory of condensed mater; Liquid helium	Russia
S. Chandrasekhar	Chandrasekhar limit, structure and evolution of stars	India
John Bardeen	Transistors; Theory of super conductivity	U.S.A.
C.H. Townes	Maser; Laser	U.S.A.
Abdus Salam	Unification of weak and electromagnetic interactions	Pakistan

Below is the table that lists some important technologies and the principles of physics they are based on.

Table: Link between technology and physics

Technology	Scientific principle(s)
Steam engine	Laws of thermodynamics
Nuclear reactor	Controlled nuclear fission
Radio and Television	Generation, propagation and detection of electromagnetic waves
Computers	Digital logic
Lasers	Light amplification by stimulated emission of radiation
Production of ultra high magnetic fields	Superconductivity
Rocket propulsion	Newton's laws of motion
Electric generator	Faraday's law of electromagnetic induction
Hydroelectric power	Conversion of gravitational potential energy into electrical energy
Aeroplane	Bernoulli's principle in fluid dynamics
Particle accelerators	Motion of charged particles in electromagnetic fields
Sonar	Reflection of ultrasonic waves
Optical fibres	Total internal reflection of light
Non-reflecting coatings	Thin film optical interference
Electron microscope	Wave nature of electrons
Photocell	Photoelectric effect
Fusion test reactor (Tokamak)	Magnetic confinement of plasma
Giant Metrewaves Radio Telescope (GMRT)	Detection of cosmic radio waves
Bose-Einstein condensate	Trapping and cooling of atoms by laser beams and magnetic fields.

Fundamental Forces in Nature

We all have an intuitive notion of force. In our experience, force is needed to push, carry or throw objects, deform or break them. We also experience the impact of forces on us, like when a moving object hits us or we are in a merry-go-round. The correct notion of force was arrived at by Isaac Newton in his famous laws of motion. He also gave an explicit form for the force for gravitational attraction between two bodies.

In the macroscopic world, besides the gravitational force, we encounter several kinds of forces: muscular force, contact forces between bodies, friction (which is also a contact force parallel to the surfaces in contact), the forces exerted by compressed or elongated springs and taut strings and ropes (tension), the force of buoyancy and viscous force when solids are in contact with fluids and so on In the microscopic domain again, we have electric and magnetic forces, nuclear forces involving protons and neutrons, interatomic and intermolecular forces, etc.

At the present stage of our understanding, we know of four fundamental forces in nature, which are described as under:

Gravitational Force

- This force is the force of mutual attraction between any two objects by virtue of their masses.
- It is a universal force.
- Every object experiences this force due to every other object in the universe.
- For example, all objects on the earth experience the force of gravity due to the earth. In particular, gravity governs the motion of the moon and artificial satellites around the earth, motion of the earth and planets around the sun, and, of course, the motion of bodies falling to the earth.
- It plays a key role in the large-scale phenomena of the universe, such as formation and evolution of stars, galaxies and galactic clusters.

Electromagnetic Force

- Electromagnetic force is the force between charged particles.
- When charges are at rest, the force is given by Coulomb's law : attractive for unlike charges and repulsive for like charges. Charges in motion produce magnetic effects and a magnetic field gives rise to a force on a moving charge. Electric and magnetic effects are, in general, inseparable – hence the name electromagnetic force.
- Electromagnetic force acts over large distances and does not need any intervening medium.
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- It is enormously strong compared to gravity. The electric force between two protons, for example, is 1036 times the gravitational force between them, for any fixed distance.
- It is mainly the electromagnetic force that governs the structure of atoms and molecules, the dynamics of chemical reactions and the mechanical, thermal and other properties of materials.
- For example, When we hold a book in our hand, we are balancing the gravitational force on the book due to the huge mass of the earth by the 'normal force' provided by our hand. The latter is nothing but the net electromagnetic force between the charged constituents of our hand and the book, at the surface in contact. If electromagnetic force were not intrinsically so much stronger than gravity, the hand of the strongest man would crumble under the weight of a feather !

Strong Nuclear Force

- The strong nuclear force binds protons and neutrons in a nucleus.
- It is the strongest of all fundamental forces, about 100 times the electromagnetic force in strength.
- It is charge-independent and acts equally between a proton and a proton, a neutron and a neutron, and a proton and a neutron.
- Its range is, however, extremely small, of about nuclear dimensions (10^{-15}m).
- It is responsible for the stability of nuclei.
- The electron, does not experience this force.

Weak Nuclear Force

- The weak nuclear force appears only in certain nuclear processes such as the β-decay of a nucleus.
- The weak nuclear force is not as weak as the gravitational force, but much weaker than the strong nuclear and electromagnetic forces.
- The range of weak nuclear force is exceedingly small, of the order of 10^{-16} m.

Towards Unification of Forces

Great advances in physics often amount to unification of different theories and domains like :

- Newton unified terrestrial and celestial domains under a common law of gravitation.
- Maxwell unified electromagnetism and optics with the discovery that light is an electromagnetic wave.
- Einstein attempted to unify gravity and electromagnetism but could not succeed in this venture.
- The electromagnetic and the weak nuclear force have now been unified and are seen as aspects of a single 'electro-weak' force.
  Many of these ideas are still speculative and inconclusive.

Nature of Physical Laws

In any physical phenomenon governed by different forces, several quantities may change with time. A remarkable fact is that some special physical quantities, however, remain constant in time. They are the conserved quantities of nature. Understanding these conservation principles is very important to describe the observed phenomena quantitatively.

For motion under an external conservative force, the total mechanical energy i.e. the sum of kinetic and potential energy of a body is a constant. The familiar example is the free fall of an object under gravity. Both the kinetic energy of the object and its potential energy change continuously with time, but the sum remains fixed. This law restricted for a conservative force should not be confused with the general law of conservation of energy of an isolated system.

The general law of conservation of energy is true for all forces and for any kind of transformation between different forms of energy. In the falling object example, if you include the effect of air resistance during the fall and see the situation after the object hits the ground and stays there, the total mechanical energy is obviously not conserved. The general law of energy conservation, however, is still applicable. The initial potential energy of the stone gets transformed into other forms of energy : heat and sound. The total energy of the system remains unchanged.

Until the advent of Einstein's theory of relativity, the law of conservation of mass was regarded as another basic conservation law of nature, since matter was thought to be indestructible. It was (and still is) an important principle used, for example, in the analysis of chemical reactions. According to Einstein's theory, mass m is equivalent to energy E given by the relation $E = mc^2$, where c is speed of light in vacuum.

In a nuclear process mass gets converted to energy (or vice-versa). This is the energy which is released in a nuclear power generation and nuclear explosions.

Energy is a scalar quantity. But all conserved quantities are not necessarily scalars. The total linear momentum and the total angular momentum (both vectors) of an isolated system are also conserved quantities. These laws can be derived from Newton's laws of motion in mechanics. But their validity goes beyond mechanics. They are the basic conservation laws of nature in all domains, even in those where Newton's laws may not be valid.

The conservation laws of nature are very useful in practice too. For example, we may not know the complicated forces that act during a collision of two automobiles; yet momentum conservation law enables us to bypass the complications and predict or rule out possible outcomes of the collision. In nuclear and elementary particle phenomena also, the conservation laws are important tools of analysis.

Conservation laws have a deep connection with symmetries of nature that you will explore in more advanced courses in physics. For example, an important observation is that the laws of nature do not change with time! If you perform an experiment in your laboratory today and repeat the same experiment (on the same objects under identical conditions) after a year, the results are bound to be the same. It turns out that this symmetry of nature with respect to translation (i.e. displacement) in time is equivalent to the law of conservation of energy.

Space is homogeneous and there is no (intrinsically) preferred location in the universe. To put it more clearly, the laws of nature are the same everywhere in the universe. (Caution : the phenomena may differ from place to place because of differing conditions at different locations. For example, the acceleration due to gravity at the moon is one-sixth that at the earth, but the **law of gravitation** is the same both on the moon and the earth.) This symmetry of the laws of nature with respect to translation in space gives rise to conservation of linear momentum.

Symmetries of space and time and other abstract symmetries play a central role in modern theories of fundamental forces in nature.

PROBLEMS

Exercise-I

Note for the student

The exercises given here are meant to enhance your awareness about the issues surrounding science, technology and society and to encourage you to think and formulate your views about them. The questions may not have clear-cut 'objective' answers.

Note for the teacher

The exercises given here are not for the purpose of a formal examination.

Q.1 Some of the most profound statements on the nature of science have come from Albert Einstein, one of the greatest scientists of all time. What do you think did Einstein mean when he said : "The most incomprehensible thing about the world is that it is comprehensible"?

Q.2 "Every great physical theory starts as a heresy and ends as a dogma". Give some examples from the history of science of the validity of this incisive remark.

Q.3 "Politics is the art of the possible". Similarly, "Science is the art of the soluble". Explain this beautiful aphorism on the nature and practice of science.

Q.4 Though India now has a large base in science and technology, which is fast expanding, it is still a long way from realising its potential of becoming a world leader in science. Name some important factors, which in your view have hindered the advancement of science in India.

Q.6 No physicist has ever "seen" an electron. Yet, all physicists believe in the existence of electrons. An intelligent but superstitious man advances this analogy to argue that 'ghosts' exist even though no one has 'seen' one. How will you refute his argument ?

Q.7 The shells of crabs found around a particular coastal location in Japan seem mostly to resemble the legendary face of a Samurai. Given below are two explanations of this observed fact. Which of these strikes you as a scientific explanation ?

a) A tragic sea accident several centuries ago drowned a young Samurai. As a tribute to his bravery, nature through its inscrutable ways immortalised his face by imprinting it on the crab shells in that area.

b) After the sea tragedy, fishermen in that area, in a gesture of honour to their dead hero, let free any crab shell caught by them which accidentally had a shape resembling the face of a Samurai. Consequently, the particular shape of the crab shell survived longer and therefore in course of time the shape was genetically propagated. This is an example of evolution by artificial selection.

[Note: This interesting illustration taken from Carl Sagan's 'The Cosmos' highlights the fact that often strange and inexplicable facts which on the first sight appear 'supernatural' actually turn out to have simple scientific explanations. Try to think out other examples of this kind].

Q.8 The industrial revolution in England and Western Europe more than two centuries ago was triggered by some key scientific and technological advances. What were these advances ?

Q.9 It is often said that the world is witnessing now a second industrial revolution, which will transform the society as radically as did the first. List some key contemporary areas of science and technology, which are responsible for this revolution.

Q.10 Write in about 1000 words a fiction piece based on your speculation on the science and technology of the twenty-second century.

Q.11 Attempt to formulate your 'moral' views on the practice of science. Imagine yourself stumbling upon a discovery, which has great academic interest but is certain to have nothing but dangerous consequences for the human society. How, if at all, will you resolve your dilemma?

Q.12 Science, like any knowledge, can be put to good or bad use, depending on the user. Given below are some of the applications of science. Formulate your views on whether the particular application is good, bad or something that cannot be so clearly categorised :
(a) Mass vaccination against small pox to curb and finally eradicate this disease from the population. (This has already been successfully done in India).
(b) Television for eradication of illiteracy and for mass communication of news and ideas.
(c) Prenatal sex determination
(d) Computers for increase in work efficiency
(e) Putting artificial satellites into orbits around the Earth
(f) Development of nuclear weapons
(g) Development of new and powerful techniques of chemical and biological warfare.
(h) Purification of water for drinking
(i) Plastic surgery
(j) Cloning

Q.13 India has had a long and unbroken tradition of great scholarship — in mathematics, astronomy, linguistics, logic and ethics. Yet, in parallel with this, several superstitious and obscurantistic attitudes and practices flourished in our society and unfortunately continue even today — among many educated people too. How will you use your knowledge of science to develop strategies to counter these attitudes ?

Q.14 Though the law gives women equal status in India, many people hold unscientific views on a woman's innate nature, capacity and intelligence, and in practice give them a secondary status and role. Demolish this view using scientific arguments, and by quoting examples of great women in science and other spheres; and persuade yourself and others that, given equal opportunity, women are on par with men.

Q.15 "It is more important to have beauty in the equations of physics than to have them agree with experiments". The great British physicist P. A. M. Dirac held this view. Criticize this statement. Look out for some equations and results in this book which strike you as beautiful.

Q.16 Though the statement quoted above may be disputed, most physicists do have a feeling that the great laws of physics are at once simple and beautiful. Some of the notable physicists, besides Dirac, who have articulated this feeling, are : Einstein, Bohr, Heisenberg,

Chandrasekhar and Feynman. You are urged to make special efforts to get access to the general books and writings by these and other great masters of physics.
(See the Bibliography at the end of this book.) Their writings are truly inspiring !

Q.17 Textbooks on science may give you a wrong impression that studying science is dry and all too serious and that scientists are absent-minded introverts who never laugh or grin. This image of science and scientists is patently false. Scientists, like any other group of humans, have their share of humorists, and many have led their lives with a great sense of fun and adventure, even as they seriously pursued their scientific work. Two great physicists of this genre are Gamow and Feynman. You will enjoy reading their books listed in the Bibliography.

Exercise-II

Q.1 The word 'Physics' comes from a Greek word, Name the word.

Q.2 What do you understand by scientific attitude?

Q.3 Name the contribution made by the following physicists:
(i) Maxwell (ii) Max Planck (iii) C. V. Raman (iv) de Broglie

Q.4 What are Biological Sciences? Give three examples.

Q.5 What is unified field theory?

Q.6 What is the basic mechanism behind all forces?

Q.7 Every great physical theory starts as a heresy and ends as a dogma? Give examples for the validity of this remark.

Q.8 Mention some areas in which Physics has contributed to development.

Q.9 Why do we need Quantum theory?

Q.10 What do you mean by mass energy equivalence? Give Example

Q.11 Name the three basic perceptions that made science – Physics to progress?

Q.12 Briefly explain the ideas discussed by the following topics in Physics.
(i) Mechanics (ii) Optics

Q.13 Match the scientist in column A against the country of origin in column B.

	A		B
(i)	Newton	(i)	USA
(ii)	Michelson	(ii)	Denmark
(iii)	Bhadha	(iii)	Italy
(iv)	Landau	(iv)	France
(v)	Bohr	(v)	India
(vi)	Archimedes	(vi)	U.S.S.R.

(vii)	Galileo	(vii)	Germany
(viii)	Curie	(viii)	Britain
(ix)	Heisenberg	(ix)	Japan
(x)	Yukawa	(x)	Greece
(xi)	Boyle	(xi)	England
(xii)	Bernoulli	(xii)	Switzerland
(xiii)	Ohm	(xiii)	Germany
(xiv)	Faraday	(xiv)	England
(xv)	Rutherford	(xv)	England