PHYSICS

PART I

TEXTBOOK FOR CLASS XI

विद्यया ऽमृतमश्नुते

एन सी ई आर टी
NCERT

राष्ट्रीय शैक्षिक अनुसंधान और प्रशिक्षण परिषद
NATIONAL COUNCIL OF EDUCATIONAL RESEARCH AND TRAINING

Foreword

The National Curriculum Framework (NCF), 2005 recommends that children's life at school must be linked to their life outside the school. This principle marks a departure from the legacy of bookish learning which continues to shape our system and causes a gap between the school, home and community. The syllabi and textbooks developed on the basis of NCF signify an attempt to implement this basic idea. They also attempt to discourage rote learning and the maintenance of sharp boundaries between different subject areas. We hope these measures will take us significantly further in the direction of a child-centred system of education outlined in the National Policy on Education (1986).

The success of this effort depends on the steps that school principals and teachers will take to encourage children to reflect on their own learning and to pursue imaginative activities and questions. We must recognise that, given space, time and freedom, children generate new knowledge by engaging with the information passed on to them by adults. Treating the prescribed textbook as the sole basis of examination is one of the key reasons why other resources and sites of learning are ignored. Inculcating creativity and initiative is possible if we perceive and treat children as participants in learning, not as receivers of a fixed body of knowledge.

These aims imply considerable change is school routines and mode of functioning. Flexibility in the daily time-table is as necessary as rigour in implementing the annual calendar so that the required number of teaching days are actually devoted to teaching. The methods used for teaching and evaluation will also determine how effective this textbook proves for making children's life at school a happy experience, rather than a source of stress or boredom. Syllabus designers have tried to address the problem of curricular burden by restructuring and reorienting knowledge at different stages with greater consideration for child psychology and the time available for teaching. The textbook attempts to enhance this endeavour by giving higher priority and space to opportunities for contemplation and wondering, discussion in small groups, and activities requiring hands-on experience.

The National Council of Educational Research and Training (NCERT) appreciates the hard work done by the textbook development committee responsible for this book. We wish to thank the Chairperson of the advisory group in science and mathematics, Professor J.V. Narlikar and the Chief Advisor for this book, Professor A.W. Joshi for guiding the work of this committee. Several teachers contributed to the development of this textbook; we are grateful to their principals for making this possible. We are indebted to the institutions and organisations which have generously permitted us to draw upon their resources, material and personnel. We are especially grateful to the members of the National Monitoring Committee, appointed by the Department of Secondary and Higher Education, Ministry of Human Resource Development under the Chairpersonship of Professor Mrinal Miri and Professor G.P. Deshpande, for their valuable time and contribution. As an organisation committed to systemic reform and continuous improvement in the quality of its products, NCERT welcomes comments and suggestions which will enable us to undertake further revision and refinement.

Director

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THE CONSTITUTION OF INDIA

PREAMBLE

WE, THE PEOPLE OF INDIA, having solemnly resolved to constitute India into a [1][**SOVEREIGN SOCIALIST SECULAR DEMOCRATIC REPUBLIC**] and to secure to all its citizens :

JUSTICE, social, economic and political;

LIBERTY of thought, expression, belief, faith and worship;

EQUALITY of status and of opportunity; and to promote among them all

FRATERNITY assuring the dignity of the individual and the [2][unity and integrity of the Nation];

IN OUR CONSTITUENT ASSEMBLY this twenty-sixth day of November, 1949 do **HEREBY ADOPT, ENACT AND GIVE TO OURSELVES THIS CONSTITUTION.**

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1. Subs. by the Constitution (Forty-second Amendment) Act, 1976, Sec.2, for "Sovereign Democratic Republic" (w.e.f. 3.1.1977)
2. Subs. by the Constitution (Forty-second Amendment) Act, 1976, Sec.2, for "Unity of the Nation" (w.e.f. 3.1.1977)

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A NOT FOR THE TEACHERS

To make the curriculum learner-centred, students should be made to participate and interact in the learning process directly. Once a week or one out of every six classes would be a good periodicity for such seminars and mutual interaction. Some suggestions for making the discussion participatory are given below, with reference to some specific topics in this book.

Students may be divided into groups of five to six. The membership of these groups may be rotated during the year, if felt necessary.

The topic for discussion can be presented on the board or on slips of paper. Students should be asked to write their reactions or answers to questions, whichever is asked, on the given sheets. They should then discuss in their groups and add modifications or comments in those sheets. These should be discussed either in the same or in a different class. The sheets may also be evaluated.

We suggest here three possible topics from the book. The first two topics suggested are, in fact, very general and refer to the development of science over the past four centuries or more. Students and teachers may think of more such topics for each seminar.

1 . Idea that changed the civilization

Suppose human beings are becoming extinct. A message has to be left for future generations or alien visitors. Eminent physicist R P Feynman wanted the following message left for future beings, if any.

“ Matters is made up of atoms “

A lady student and teacher of literature, wanted the following message left:

“Water existed, so human beings could happen”.

Another person thought it should be: **“Idea of wheel for motion”**

Write down what message each one of you would like to leave for future generations. Then discuss it in your group and add or modify, if you want to change your mind. Give it to your teacher and join in any discussion that follows.

2. Reductionism

Kinetic Theory of Gases relates the Big to the Small, the Macro to the Micro. A gas as a system is related to its components, the molecules. This way of describing a system as a result of the properties of its components is usually called Reductionism. It explains the behaviour of the group by the simpler and predictable behaviour of individuals. Macroscopic observations and microscopic properties have a mutual interdependence in this approach. Is this method useful . This way of understanding has its limitations outside physics and chemistry, may be even in these subjects. A painting cannot be discussed as a collection of the properties of chemicals used in making the canvas and the painting. What emerges is more than the sum of its components.

Question: Can you think of other areas where such an approach is used?

Describe briefly a system which is fully describable in terms of its components. Describe one which is not. Discuss with other members of the group and write your views. Give it to your teacher and join in any discussion that may follow.

3. Molecular approach to heat

Describe what you think will happen in the following case. An enclosure is separated by a porous wall into two parts. One is filled with nitrogen gas (N_2) and the other with CO_2. Gases will diffuse from one side to the other.

CONTENTS

CHAPTER ONE

PHYSICAL WORLD

1.1 WHAT IS PHYSICS?

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. One kind of response from the earliest times has been to observe the physical environment carefully, look for any meaningful patterns and relations in natural phenomena, and build and use new tools to interact with nature. This human endeavour led, in course of time, to modern science and technology.

The word Science originates from the Latin verb Scientia meaning 'to know'. The Sanskrit word Vijnan and the Arabic word Ilm convey similar meaning, namely 'knowledge'. Science, in a broad sense, is as old as human species. The early civilisations of Egypt, India, China, Greece, Mesopotamia and many others made vital contributions to its progress. From the sixteenth century onwards, great strides were made in science in Europe. By the middle of the twentieth century, science had become a truly international enterprise, with many cultures and countries contributing to its rapid growth.

What is Science and what is the so-called Scientific Method? 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 an 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. There is much philosophical debate about the nature and method of science that we need not discuss here. The interplay of theory and observation (or experiment) is basic to the progress of 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. Occasionally, however, the existing theory is simply unable to explain new observations. This causes a major upheaval in science. 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. Just as a new experiment may suggest an alternative theoretical model, a theoretical advance may suggest what to look for in some experiments. The result of experiment of scattering of alpha particles by gold foil, in 1911 by Ernest Rutherford (1871–1937) established the nuclear model of the atom, which then became the basis of the quantum theory of hydrogen atom given in 1913 by Niels Bohr (1885–1962). On the other hand, the concept of antiparticle was first introduced theoretically by Paul Dirac (1902–1984) in 1930 and confirmed two years later by the experimental discovery of positron (antielectron) by Carl Anderson.

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. A precise definition of this discipline is neither possible nor necessary. We can broadly describe physics as a study of the basic laws of nature and their manifestation in different natural phenomena. The scope of physics is described briefly in the next section. Here we remark on two principal thrusts in physics : unification and reduction. 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 (section 1.4) reflect this same quest for unification. 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. In particular, the temperature was seen to be related to the average kinetic energy of molecules of the system.

1.2 SCOPE AND EXCITEMENT OF PHYSIC

We can get some idea of the scope of physics by looking at its various sub-disciplines. Basically, there are two domains of interest: macroscopic and microscopic. The macroscopic domain includes phenomena at the laboratory, terrestrial and astronomical scales. The microscopic domain includes atomic, molecular and nuclear phenomena*. 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

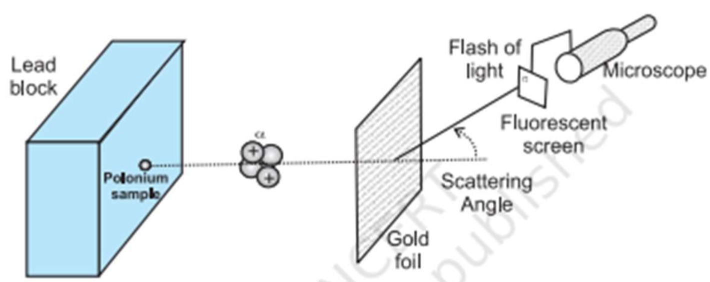


Fig. 1.1 *Theory and experiment go hand in hand in physics and help each other's progress. The alpha scattering experiments of Rutherford gave the nuclear model of the atom.*

chemical process, etc., are problems of interest in thermodynamics. 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. Classical physics is inadequate to handle this domain and Quantum Theory is currently accepted as the proper framework for explaining microscopic phenomena. Overall, the edifice of physics is beautiful and imposing and you will appreciate it more as you pursue the subject. You can now 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 1026 m. The two length scales differ by a factor of 1040 or even more. The range of time scales can be obtained by dividing the length scales by the speed of light : 10–22 s to 1018 s. The range of masses goes from, say, 10–30 kg (mass of an electron) to 1055 kg (mass of known observable universe).

Hypothesis, axioms and models

One should not think that everything can be proved with physics and mathematics. All physics, and also mathematics, is based on assumptions, each of which is variously called a hypothesis or axiom or postulate, etc.

For example, the universal law of gravitation proposed by Newton is an assumption or hypothesis, which he proposed out of his ingenuity. Before him, there were several observations, experiments and data, on the motion of planets around the sun, motion of the moon around the earth, pendulums, bodies falling towards the earth etc. Each of these required a separate explanation, which was more or less qualitative. What the universal law of gravitation says is that, *if we assume* that any two bodies in the universe attract each other with a force proportional to the product of their masses and inversely proportional to the square of the distance between them, then we can explain all these observations in one stroke. It not only explains these phenomena, it also allows us to predict the results of future experiments.

A hypothesis is a supposition without assuming that it is true. It would not be fair to ask anybody to prove the universal law of gravitation, because it cannot be proved. It can be verified and substantiated by experiments and observations.

An axiom is a self-evident truth while a model is a theory proposed to explain observed phenomena. But you need not worry at this stage about the nuances in using these words. For example, next year you will learn about Bohr's model of hydrogen atom, in which Bohr assumed that an electron in the hydrogen atom follows certain rules (postutates). Why did he do that? There was a large amount of spectroscopic data before him which no other theory could explain. So Bohr said that if we assume that an atom behaves in such a manner, we can explain all these things at once.

Einstein's special theory of relativity is also based on two postulates, the constancy of the speed of electromagnetic radiation and the validity of physical laws in all inertial frame of reference. It would not be wise to ask somebody to prove that the speed of light in vacuum is constant, independent of the source or observer.

In mathematics too, we need axioms and hypotheses at every stage. Euclid's statement that parallel lines never meet, is a hypothesis. This means that if we assume this statement, we can explain several properties of straight lines and two or three dimensional figures made out of them. But if you don't assume it, you are free to use a different axiom and get a new geometry, as has indeed happened in the past few centuries and decades.

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? Great progress usually accompanies changes in our basic perceptions. First, 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. The second most important insight was that the basic laws of physics are universal — the same laws apply in widely different contexts. Lastly, the strategy of approximation turned out to be very successful. Most observed phenomena in daily life are rather complicated manifestations of the basic laws. Scientists recognised the importance of extracting the essential features of a phenomenon from its less significant aspects. It is not practical to take into account all the complexities of a phenomenon in one go. A good strategy is to focus first on the essential features, discover the basic principles and then introduce corrections to build a more refined theory of the phenomenon. For example, a stone and a feather dropped from the same height do not reach the ground at the same time. The reason is that the essential aspect of the phenomenon, namely free fall under gravity, is complicated by the presence of air resistance. To get the law of free fall under gravity, it is better to create a situation where in the air resistance is negligible. We can, for example, let the stone and the feather fall through a long evacuated tube. In that case, the two objects will fall almost at the same rate, giving the basic law that acceleration due to gravity is independent of the mass of the object. With the basic law thus found, we can go back to the feather, introduce corrections due to air resistance, modify the existing theory and try to build a more realistic theory of objects falling to the earth under gravity.

1.3 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. The applications of physics are not always easy to foresee. As late as 1933, 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. Yet another important example of physics giving rise to technology is the silicon 'chip' that triggered the computer revolution in the last three decades of the twentieth century. A most significant area to which physics has and will contribute is the development of alternative energy resources. The fossil fuels of the planet are dwindling fast and there is an urgent need to discover new and affordable sources of energy. Considerable progress has already been made in this direction (for example, in conversion of solar energy, geothermal energy, etc., into electricity), but much more is still to be accomplished. Table1.1 lists some of the great physicists, their major contribution and the country of origin. You will appreciate from this table the multi-cultural, international character of the scientific endeavour. Table 1.2 lists some important technologies and the principles of physics they are based on. Obviously, these tables are not exhaustive. We urge you to try to add many names and items to these tables with the help of your teachers, good books and websites on science. You will find that this exercise is very educative and also great fun. And, assuredly, it will never end. The progress of science is unstoppable! Physics is the study of nature and natural phenomena. Physicists try to discover the rules that are operating in nature, on the basis of observations, experimentation and analysis. Physics deals with certain basic rules/laws governing the natural world. What is the nature

Table 1.1 Some physicists from different countries of the world and their major contributions

Name	Major contribution/discovery	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

Name	Major contribution/discovery	Country of Origin
Victor Francis Hess	Cosmic 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 de Borglie	Wave nature of matter	France
M.N. Saha	Thermal ionisation	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 matter; 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

of physical laws? We shall now discuss the nature of fundamental forces and the laws that govern the diverse phenomena of the physical world.

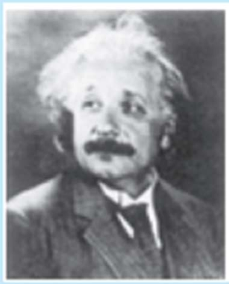
1.4 FUNDAMENTAL FORCES IN NATURE*

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. Going from this intuitive notion to the proper scientific concept of force is not a trivial matter. Early thinkers like Aristotle had wrong ideas about it. 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. We shall learn these matters in subsequent chapters. 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

Table 1.2 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 laws 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 Metrewave Radio Telescope (GMRT)	Detection of cosmic radio waves
Bose-Einstein condensate	Trapping and cooling of atoms by laser beams and magnetic fields.

contact with fluids, the force due to pressure of a fluid, the force due to surface tension of a liquid, and so on. There are also forces involving charged and magnetic bodies. In the microscopic domain again, we have electric and magnetic forces, nuclear forces involving protons and neutrons, interatomic and intermolecular forces, etc. We shall get familiar with some of these forces in later parts of this course. A great insight of the twentieth century physics is that these different forces occurring in different contexts actually arise from only a small number of fundamental forces in nature. For example, the elastic spring force arises due to the net attraction/repulsion between the neighbouring atoms of the spring when the spring is elongated/compressed. This net attraction/repulsion can be traced to the (unbalanced) sum of electric forces between the charged constituents of the atoms. In principle, this means that the laws for 'derived' forces (such as spring force, friction) are not independent of the laws of fundamental forces in nature. The origin of these derived forces is, however, very complex. At the present stage of our understanding, we know of four fundamental forces in nature, which are described in brief here :



Albert Einstein (1879-1955)

Albert Einstein, born in Ulm, Germany in 1879, is universally regarded as one of the greatest physicists of all time. His astonishing scientific career began with the publication of three path-breaking papers in 1905. In the first paper, he introduced the notion of light quanta (now called photons) and used it to explain the features of photoelectric effect that the classical wave theory of radiation could not account for. In the second paper, he developed a theory of Brownian motion that was confirmed experimentally a few years later and provided a convincing evidence of the atomic picture of matter. The third paper gave birth to the special theory of relativity that made Einstein a legend in his own life time. In the next decade, he explored the consequences of his new theory which included, among other things, the mass-energy equivalence enshrined in his famous equation $E = mc^2$. He also created the general version of relativity (The General Theory of Relativity), which is the modern theory of gravitation. Some of Einstein's most significant later contributions are: the notion of stimulated emission introduced in an alternative derivation of Planck's blackbody radiation law, static model of the universe which started modern cosmology, quantum statistics of a gas of massive bosons, and a critical analysis of the foundations of quantum mechanics. The year 2005 was declared as International Year of Physics, in recognition of Einstein's monumental contribution to physics, in year 1905, describing revolutionary scientific ideas that have since influenced all of modern physics.

1.4.1 Gravitational Force

The gravitational 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. All objects on the earth, for example, 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.

1.4.2 Electromagnetic Force

Electromagnetic force is the force between charged particles. In the simpler case 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. Like the gravitational force, electromagnetic force acts over large distances and does not need any intervening medium. It is enormously strong compared to gravity. Theelectric force between two protons, for example, is 1036 times the gravitational force between them, for any fixed distance. Matter, as we know, consists of elementary charged constituents like electrons and protons. Since the electromagnetic force is so much stronger than the gravitational force, it dominates all phenomena at atomic and molecular scales. (The other two forces, as we shall see, operate only at nuclear scales.) Thus 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. It underlies the macroscopic forces like 'tension', 'friction', 'normal force', 'spring force', etc. Gravity is always attractive, while electromagnetic force can be attractive or repulsive. Another way of putting it is that mass comes only in one variety (there is no negative mass), but charge comes in two varieties : positive and negative charge. This is what makes all the difference. Matter is mostly electrically neutral (net charge is zero). Thus, electric force is largely zero and gravitational force dominates terrestrial phenomena. Electric force manifests itself in atmosphere where the atoms are ionised and that leads to lightning.

Satyendranath Bose (1894-1974)

Satyendranath Bose, born in Calcutta in 1894, is among the great Indian physicists who made a fundamental contribution to the advance of science in the twentieth century. An outstanding student throughout, Bose started his career in 1916 as a lecturer in physics in Calcutta University; five years later he joined Dacca University. Here in 1924, in a brilliant flash of insight, Bose gave a new derivation of Planck's law, treating radiation as a gas of photons and employing new statistical methods of counting of photon states. He wrote a short paper on the subject and sent it to Einstein who immediately recognised its great significance, translated it in German and forwarded it for publication. Einstein then applied the same method to a gas of molecules.

The key new conceptual ingredient in Bose's work was that the particles were regarded as indistinguishable, a radical departure from the assumption that underlies the classical Maxwell-Boltzmann statistics. It was soon realised that the new Bose-Einstein statistics was applicable to particles with integers spins, and a new quantum statistics (Fermi-Dirac statistics) was needed for particles with half integers spins satisfying Pauli's exclusion principle. Particles with integers spins are now known as bosons in honour of Bose.

An important consequence of Bose-Einstein statistics is that a gas of molecules below a certain temperature will undergo a phase transition to a state where a large fraction of atoms populate the same lowest energy state. Some seventy years were to pass before the pioneering ideas of Bose, developed further by Einstein, were dramatically confirmed in the observation of a new state of matter in a dilute gas of ultra cold alkali atoms - the Bose-Eintein condensate.

If we reflect a little, the enormous strength of the electromagnetic force compared to gravity is evident in our daily life. 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 ! Indeed, to be consistent, in that circumstance, we ourselves would crumble under our own weight !

1.4.3 Strong Nuclear Force

The strong nuclear force binds protons and neutrons in a nucleus. It is evident that without some attractive force, a nucleus will be unstable due to the electric repulsion between its protons. This attractive force cannot be gravitational since force of gravity is negligible compared to the electric force. A new basic force must, therefore, be invoked. The strong nuclear force 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 (10–15m). It is responsible for the stability of nuclei. The electron, it must be noted, does not experience this force.

Recent developments have, however, indicated that protons and neutrons are built out of still more elementary constituents called quarks.