Chapter 1 Physical World

Science is a systematic attempt to understand natural phenomena in as much detail and depth as possible, and then to use the knowledge so gained to predict, modify and control the phenomena.

The scientific method involves the following steps:

(i) Taking a large number of systematic observations through controlled experiments.

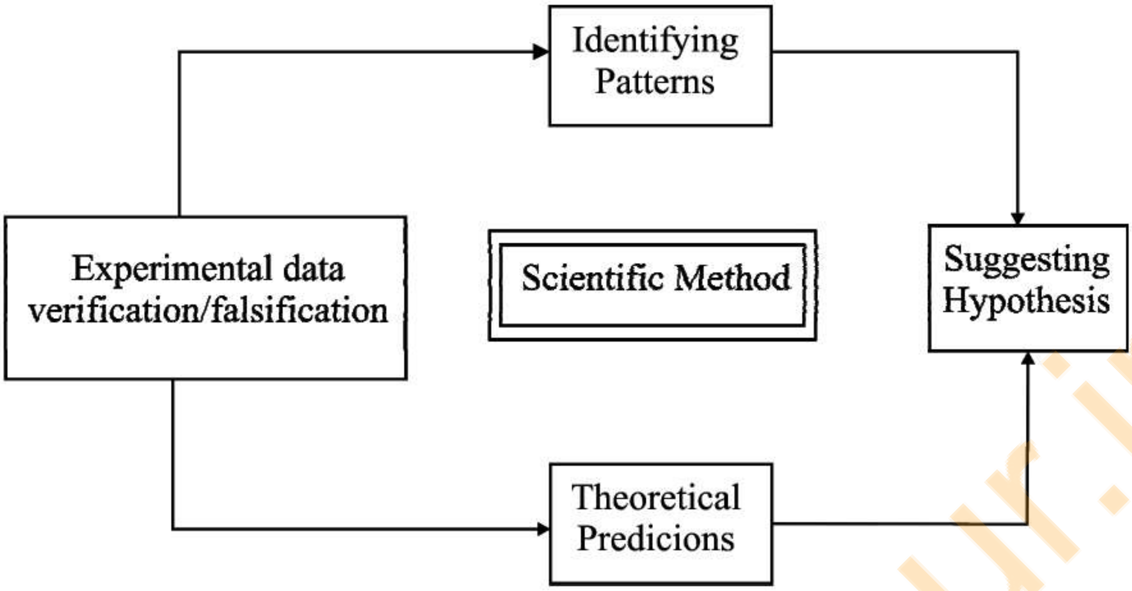
(ii) Studying these observations and looking for their logical behavior based on qualitative and quantitative reasoning.

(iii) Mathematical modeling, i.e., suggesting some model to account for the observed behavior.

(iv) Theoretical prediction of what is not actually observed on the basis of the suggested model.

(v) Verification or falsification of the model.

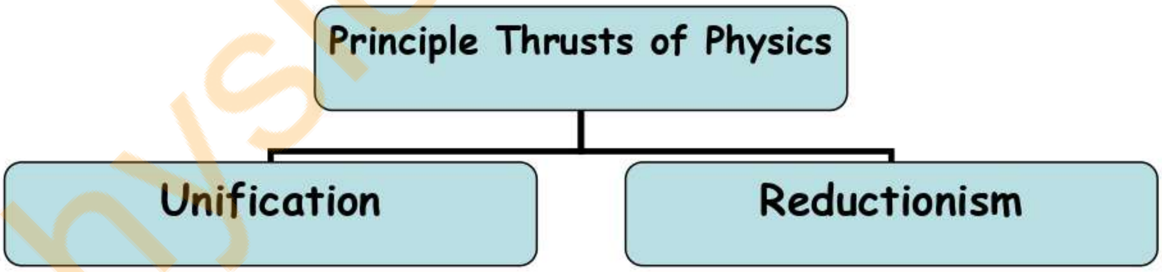
- Speculation and conjecturing also have a place in the scientific method but it must be verified by experiments.



What is Physics?

Physics is the study of basic laws of nature and their manifestation in different natural phenomena. In physics, we attempt to explain diverse physical phenomena in terms of few concepts and laws.

In the study of Physics, there are two principal thrusts.



UNIFICATION

Unification means attempting to explain diverse physical phenomena in terms of a few concepts and laws.

- **For example**, the same law of gravitation given by Newton accounts for (i) fall of an apple to the ground (ii) motion of satellites around the planets (iii) motion of planets around the sun. Similarly, the basic laws of electromagnetism in the form of Maxwell's equations explain all the electric and magnetic phenomena.

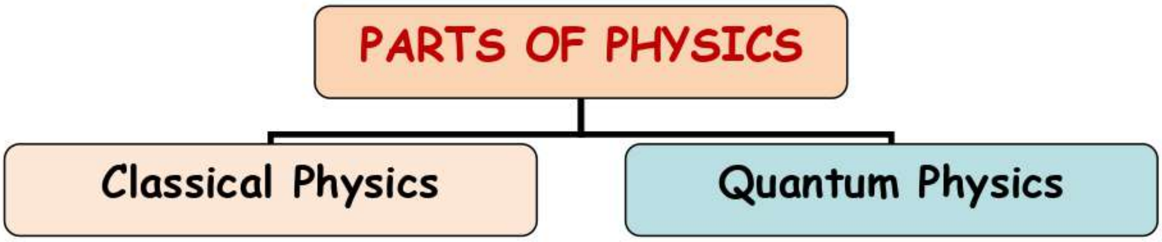
REDUCTIONISM

Reductionism means attempting to derive the properties of a bigger, more complex system from the properties of its constituent simpler parts.

- **For example,** the subject of thermodynamics deals with bulk systems in terms of macroscopic quantities like temperature, pressure, internal energy, entropy etc. The later development of kinetic theory and statistical mechanics interpreted these quantities in terms of the properties of the molecular constituents of the bulk system. For example, temperature of the bulk system was related to the average kinetic energy of the molecules of the system.

PARTS OF PHYSICS

Basically there are two parts of physics.



Classical Physics:

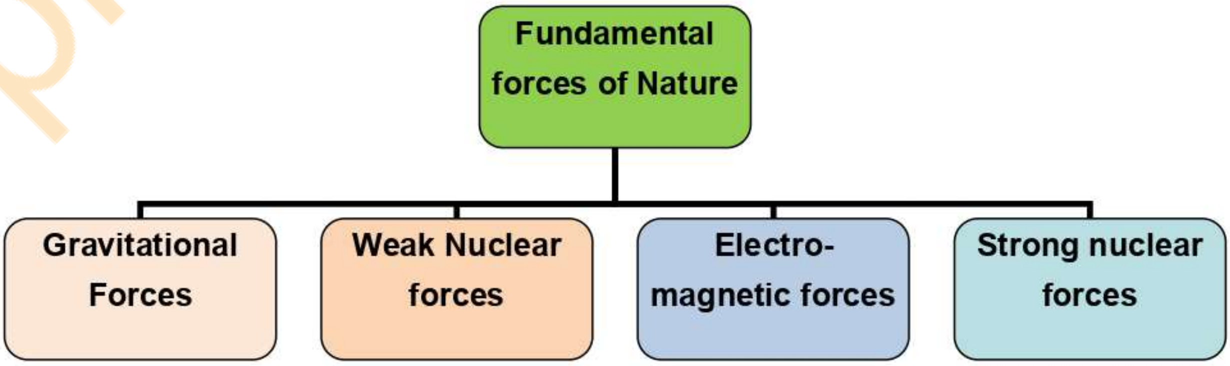
Classical Physics deals with mainly with macroscopic phenomena and includes subjects like Mechanics, Electrodynamics, Optics and Thermodynamics.

Quantum Physics:

Quantum Physics is the part of physics which is used to explain the microscopic phenomena, like constitution and structure of matter at the minute scales of atoms and nuclei, and their interaction with different probes such as electrons, photons and other elementary particles.

Fundamental Forces of Nature

There are four fundamental forces, which govern the macroscopic as well as microscopic world.



(a) Gravitational forces:

The gravitational force is the force of mutual attraction between any two objects by virtue of their masses.

Some of the important feature/properties of gravitational forces are:

1. Gravitational forces are universal attractive forces, i.e., they exist between microscopic as well as macroscopic objects irrespective of their size, shape, separation and intervening medium.
2. These are the weakest forces in nature.
3. They operate over very long distance especially when the bodies are massive. For example, rotation of earth around the sun is due to gravitational pull of sun on earth.
4. Gravitational forces obey inverse square law, i.e., they vary inversely as the square of the distance between the two bodies.
5. Gravitational forces are central forces, i.e., they act along the line joining the centers of two bodies.
6. Gravitational forces are conservative forces.
7. The field particle of gravitational force is called 'graviton'. The concept of exchange of field particle (gravitons) between two bodies, explain how the two bodies interact from a distance.

(b) Weak Nuclear Forces:

The weak nuclear forces are the forces of interaction between elementary particles of short life times.

- The weak nuclear force appears only in certain nuclear processes such as the β-decay of a nucleus.

Some of the important properties of weak nuclear forces are:

1. The weak nuclear forces are 10^{25} times stronger than the gravitational forces.
2. The weak nuclear forces exist between leptons and leptons; leptons and mesons etc.

Other properties of weak nuclear forces are yet under investigation.

(c) Electromagnetic forces:

The electromagnetic forces are the forces between charged particles. When the charges are at rest, the forces are called electrostatic forces.

The forces between unlike charges are attractive and the forces between like charges are repulsive. These forces are governed by Coulomb's Law.

NOTE: Some of the macroscopic forces are also explained in terms of electromagnetic forces. For example;

(i) Forces between two surfaces in contact.

(ii) Force of Friction.

(iii) Tension in a string/rope.

(iv) Forces due to a spring.

Some of the salient features of electromagnetic forces are:

1. These forces may be attractive or repulsive. Like charges repel each other and unlike charges attract each other.
2. These forces are governed by Coulomb's law, which are similar to Newton's law of gravitation.
3. They obey inverse square law.
4. Electrostatic forces (between two protons) are 10^{36} times stronger than gravitational forces between them, for any fixed distance.
5. They operate over distances which are not very large.
6. They are also conservative forces.
7. They are also conservative forces.
8. The field particle of electromagnetic force is photon, which carries no charge and has zero rest mass.

(d) Strong Nuclear Forces:

The forces that bind the neutrons and protons together in a nucleus are called the strong nuclear forces.

Some of the salient features of nuclear forces are:

1. Nuclear forces are the strongest forces in nature. They are 10^{38} times stronger than gravitational forces, 10^{2} times stronger than electrostatic forces and 10^{13} times stronger than the weak forces.

2. Nuclear forces have the shortest range. They operate within the nucleus only, i.e., upto distance of the order of 10^{-14} meter.
3. Nuclear forces do not depend on charge on the nucleon.
4. Nuclear forces do not obey inverse square law. They vary inversely as some higher power of distance between nucleons.
5. They are basically attractive forces. Only when distance between nucleons is less than 0.8 fermi, nuclear forces become repulsive.
6. Nuclear forces are non central forces.
7. They are also non-conservative forces.
8. The field particle for nuclear forces is the 'π-meson'.

The relative strength of four types of basic forces in nature can be represented as

$$F_G : F_W : F_E : F_N = 1 : 10^{25} : 10^{36} : 10^{38}$$

Unification of Forces

"By unification of forces, we mean that there exists a relationship between the various forces of nature". A lot of efforts have been made towards unification of different forces and domains of Physics.

Some of the main achievements in the direction of unification are as follows:

S.No.	Name of Physicist	Year	Achievement in unification
1.	Isaac Newton	1687	Unified terrestrial and celestial mechanics
2.	Haris Christian Oersted	1820	Electric and magnetic phenomena are inseparable aspects
3.	Michael Faraday	1830	of a unified domain: electromagnetism
4.	James Clerk Maxwell	1873	Unified electricity, magnetism and optics; showed that light is an electromagnetic wave.
5.	Sheldon Glashow, Abdus Salam, Steven Weinberg	1979	Weak nuclear forces and the electromagnetic force could by viewed as different aspects of a single electro-weak force.
6.	Carlo Rubia, Simon Vander Meer	1984	Verified exptally the prediction of the theory of electroweak forces.

Nature of Physical Laws

Any physical phenomenon is governed by a number of factors (quantities), several of these quantities may change with time. But a remarkable fact is that there are some special physical quantities which remain constant in time. These are called the conserved quantities of nature. Understanding the conservation principles is very important in describing the natural phenomena quantitatively. Conservation laws are in fact important tools of analysis.

In Classical Physics, we often deal with the following conservation laws:

1. Law of conservation of energy
2. Law of conservation of linear momentum
3. Law of conservation of angular momentum
4. Law of conservation of charge

A brief discussion of these laws is given here:

(a)Law of conservation of energy

"The sum total of energy of all kinds in this universe remains constant". Energy can neither be created nor it can be destroyed, it can only be transformed form one form to the other or transported from one place to the other, but the total amount of energy of never changes".

(b) Law of conservation of linear momentum:

"In the absence of an external force, the linear momentum of a system remains unchanged."

(c) Law of conservation of angular momentum

We know that a rotating body has inertia. Therefore, such an object also possesses momentum associated with its rotation.

This momentum of a body associated with its rotational motion is called 'angular momentum'. We shall later read that

Angular momentum (L) = moment of inertia (I) ×angular speed (ω)

According to the law of conservation of angular momentum:

"If the total external torque acting on a system is zero, angular momentum of the system remains constant".

- Torque plays the same role in rotational motion as force plays in translational motion.

(d) Law of conservation of charge:

"If means that charges (in the form of electron) are neither created nor destroyed, but are simply transferred from one body of another".

Einstein's Mass- Energy Equivalence

According to Einstein's theory mass is equivalent to energy.

"When a material body of mass 'm' (kg) is converted completely into energy the amount of energy liberated (in J) is $E = mc^2$"

Where, c is the speed of light in free space.

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