Chapter

1

Basic Concepts

1.1 WHAT IS PHYSICS?

Physics is defined as the study of properties of matters and interactions between fundamental constituents of the universe. The concept of physics is well explained by the interface of matters with fundamental and general laws. For that, we need to know about how the matters are measured and compared. At the same time, the experiments are also designed to establish the units for those measurements and comparisons. One purpose of physics (in allied health) is to study and conduct those principles in biological subjects.

Why physics concepts are so important, for example, if scientist wants to develop clocks to compare the time interval or sequence of two successive events with extreme accuracy. You may wonder whether such accuracy is needed or worth the effort of scientist. Here is one example of the worth is: Without clocks of extreme accuracy, the global positioning system (GPS), that is, now vital to worldwide navigation would be useless.

Physics concept is accepted and understand better by experimental observations and quantitative measurements, like all other sciences. To find the limited number of fundamental laws that overrule the natural phenomena to the biological subjects and to use it to develop more theories that predict the results which are the main objectives of physics. The fundamental laws used in developing theories are expressed in the language of mathematics, the tool that provides a bridge between theory and experiment in health science.

Summary

Physics is the branch of science that studies matter, energy and how they interact. Simply, ***Physics is about the study of properties of matter in the universe***.

1.2 MEASURING THINGS

Learning measurable quantities are measured in physics by using different kinds of tools and instruments, among these notable quantities are length, time, mass, temperature, pressure and electric current.

Physical quantities are compared with a **standard** and its own unit. The unique name for the unit is also assigned to measure the quantity. For example, the quantity of length is measured in **meter (*m*)**. The standard corresponds to exactly 1.0 unit of the quantity. As we can measure, the standard for length, which corresponds to exactly 1.0 m, is the distance traveled by light in a vacuum in a **unit** time, i.e. a certain fraction of second. We can define a unit and its standard in any way we care to. However, the important thing is to do so in such a way that scientist around the world will agree that our definitions are both sensible and practical.

Once we have set up a standard—say, for length—we must work out procedures by which ***any length*** whatever it may be, for example, sensible things from the radius of an atom, the wheelbase of a car, distance between two places or even the distance to the sun, can be expressed in terms of the standard. Rulers are commonly used to measure the length which give us one such procedure for measuring length. However, many of our comparisons must be indirect. You cannot use a ruler for certain measures, for example, to measure the radius of an atom or the distance from the earth to the sun.

Likewise, there are so many physical quantities which are having a problem to organize them. Fortunately, they are not all independent; for example, speed is the ratio of an object that travel in a unit time, simply length to a time. That is what we should have an international agreement—a small number of physical quantities, such as length and time and assign standards to them alone. We then define all other physical quantities in terms of these base quantities and their standards (called base standards). Speed, for example, is defined in terms of the base quantities length and time and their base standards.

Base standards must be both invariable and accessible. If we define the length standard as the distance between one's forehead and their index finger on a stretched arm, we certainly have an accessible standard length—but it will, of course, vary from person to person. The demand for precision in science and engineering pushes us to aim first for invariability and its accessibility. Then we can apply a great effort to make duplicates of the base standards that are accessible to those who need them in a standard manner.

1.3 STANDARDS OF LENGTH, MASS AND TIME

In physics, the laws are stated in terms of basic quantities which are length (L), mass (M), and time (T). All other quantities are also expressed in terms of these three.

In 1960, International System of Units abbreviated as SI, for the practical system of units and placed a rule for prefixes, derived units and the former supplementary units, and other matters. The SI system also proposed a set of standards for measure length, mass, and other basic quantities. In this system, the units of length, mass, and time are the meter, kilogram, and second, respectively. Other SI standards established by the committee are those for temperature (the kelvin), electric current (the ampere), luminous intensity (the candela), and the amount of substance (the mole).

Length: Length is the measurable quantities which are used for identifying the size of an object or distance from one place to other. Typical measures of length are like "how long an object is" or simply the distance between two points. It is used for identifying the size of an object or distance from one place to another. The length of an object is its extended dimension, that is, its longest side.

As per decision taken by 17th CGPM, 1983, Resolution that ***Length (meter (m) was redefined as the distance travelled by light in vacuum during a time of 1/299 792 458 second***. The definition of the meter in force since 1960, based upon the transition between the levels $_{2}p^{10}$ and $_{5}d^{5}$ of the atom of krypton 86, is abrogated. In effect, this latest definition establishes that the speed of light in vacuum is precisely 299 792 458 m per second.

Mass: In physics, mass is a quantitative measure of inertia, fundamental properties of all matters and is the measure of ***the amount of matter in an object***. Mass is usually measured in grams (g) or kilograms (kg).

In other way, mass measures the quantity of matter regardless of both its location in the universe and if the gravitational force applied on it which is described as weight. An object's mass is constant in all circumstances unless an external gravitational force act on it; force acts on mass is depends on gravity. It may vary from place to place. For example, moon's gravity and earth's gravity

Your mass on the earth and the moon is equal but your weight on the moon varies about one-sixth of your weight on the earth. That is because of the gravitational force on the earth.

Rest mass: To be more specific about mass, we need to mention the concept of rest mass, also known as **intrinsic mass**. It is an object's rest mass, that is, constant in all circumstances. Albert Einstein showed that mass actually increases with speed, although the effect is only significant at speeds that are considerable fractions of the speed of light.

Mass conservation: Mass conservation is one of the fundamental laws in science. The product mass developed from the reactions is always to the mass of products that entered the reaction.

Time: Time is an ongoing sequence of events taking place, for example, the past, present, and future. The basic unit of time is the second. There are also minutes, hours, days, weeks, months, and years. We can measure time using clocks.

Time is defined as the duration between two events and it is also called time interval. In the international system of measurement (SI) the second (s) is the basic unit of time.

1.4 SI BASE UNITS AND THE RADIAN AND STERADIAN

The definitions of the SI supplementary units, the radian and steradian, which are now interpreted as SI derived units and generally accepted.

SI derived units are uniquely defined only in terms of SI base units.

Meter (m): The meter is the length of the path travelled by light in vacuum during a time interval of 1/299 792 458 of a second.

Kilogram (kg): The kilogram is the unit of mass; it is equal to the mass of the international prototype of the kilogram.

Second (sec): The second is the duration of 9 192 631 770 periods of the radiation corresponding to the transition between the two hyperfine levels of the ground state of the cesium-133 atom.

Ampere (amp): Often shortened to "amp", is the base unit of electric current in the International system of units (SI).

The ampere is that constant current that produce attractive force of 20×10^{-6} newton per meter of length between two straight, parallel conductors of infinite length and negligible circular cross section, and placed 1 meter apart in vacuum. A force would produce between these conductors are equal to 231027 newton per meter of length. This is also called **ampere** force law.

Kelvin (K): The kelvin, unit of thermodynamic temperature, is the fraction 1/273.16 of the thermodynamic temperature of the triple point of water which is a hundredth of a degree Celsius above the freezing point.

Mole (mol)

1. The mole is the amount of substance of a system which contains as many elementary entities as there are atoms in 0.012 kilogram of carbon 12. It is also defined as exactly 6.02214076 1023 particles, which may be atoms, molecules, ions, or electrons.
2. When the mole is used, the elementary entities must be specified and may be atoms, molecules, ions, electrons, other particles, or specified groups of such particles.

In the definition of mole, it is understood that unbound atoms of carbon 12, at rest and in their ground state, are referred to note that this definition specifies at the same time the nature of the quantity whose unit is the mole.

Candela (cd): The candela is the luminous intensity, in a given direction, of a source that emits monochromatic radiation of frequency 54031012 Hertz and that has a radiant intensity in that direction of (1/683) watt per steradian.

Radian (rad): The radian is the plane angle between two radii of a circle that cut off on the circumference an arc equal in length to the radius.

Steradian (sr): The steradian is the solid angle that, having its vertex in the centre of a sphere, cuts off an area of the surface of the sphere equal to that of a square with sides of length equal to the radius of the sphere.

1.5 TEMPERATURE AND HEAT

In physics, there is a big difference between temperature and heat. Although it is not at all obvious, temperature is related to the energy of the atoms and molecules of an object. Heat is the type of energy that flows from one body to another where there is a difference between their temperatures between the bodies.

People used to think heat was a fluid that flowed from hot objects to cold ones. But this is not true, as discovered by physicist **Benjamin Thompson** ***(1752–1814)***. It is important to realize the minute difference between heat and temperature scales of measuring hotness or coldness of any object. They are interconnected but do not mean the same thing ***(Heat ≠ Temperature)***, The core difference is that heat deals with thermal energy, whereas temperature is more concerned with molecular kinetic energy.

Heat describes the transfer of thermal energy between molecules within a system and is measured in Joules. Heat measures how energy moves or flows from one object. An object can gain heat or lose heat, but it cannot have in its own heat. Heat is a measure of change, never a property possessed by an object or system. Therefore, it is classified as a process variable.

Temperature describes the average kinetic energy of molecules within a material or system and is measured in *Celsius* ***(°C)***, *Kelvin* ***(K)***, *Fahrenheit* ***(°F)***, *or Rankine* ***(R)***. It is a measurable physical property of an object—also known as a state variable. Other measurable physical properties include velocity, mass, and density.

NOTE

In reality, coldness does not exist, simply coldness is the absence of heat, that is what we experienced cold, in the absence of heat. It is clashing atom of energy.)

1.6 THERMODYNAMICS

It is the branch of physics that deals with the study of transfer of heat from one object into other object in the forms of energy and vice-versa.

A thermodynamical system is said to be in thermally equilibrium when macroscopic variables (like pressure, volume, temperature, mass, composition, etc.) that characterize the system do not change with time.

1.6.1 Thermodynamical System

Thermodynamical system state is an assembly of an extremely large number of particles whose macroscopic variables can be expressed in terms of pressure, volume and temperature.

Thermodynamic system is classified into the following three systems (Fig. 1.1):

i. **Open system:** It exchanges both energy and matter with its surroundings.
ii. **Closed system:** It exchanges only energy (not matter) with its surroundings.
iii. **Isolated system:** It exchanges neither energy nor matter with its surroundings.

A thermodynamic system is not always in equilibrium. For example, a gas allowed to expand freely against vacuum. Similarly, a mixture of petrol vapor and air, when ignited by a spark is not an equilibrium state. Equilibrium is acquired eventually with time.

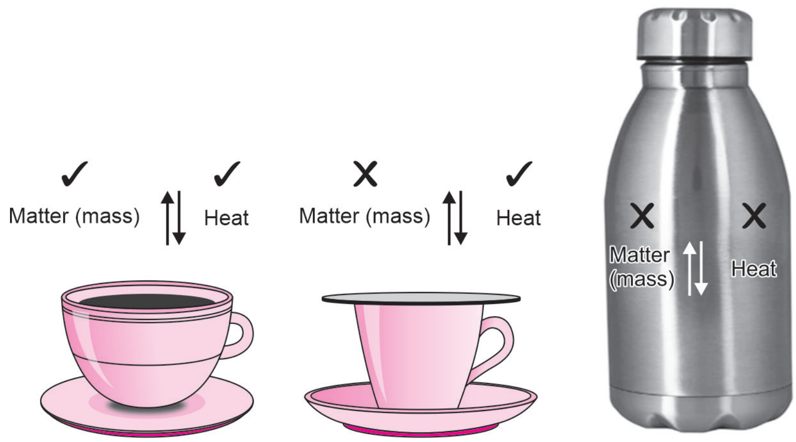

Fig. 1.1: Thermodynamical system: (a) Open system, (b) closed system and (c) isolate system

1.7 LAWS OF THERMODYNAMICS

The basic four laws of thermodynamics define fundamental characterize physical quantities such as temperature, energy, and entropy. These characteristics are in thermal equilibrium. The laws describe how these quantities behave under various circumstances, and forbid certain phenomena.

Four laws of thermodynamics are as follows.

1.7.1 Zeroth Law of Thermodynamics

It is also known as law of thermal equilibrium. It has given the name of zero because it was established after first law and second law. So, it was put forward to both the first and second as it provides logical basis for the concept of temperature of system. If two systems

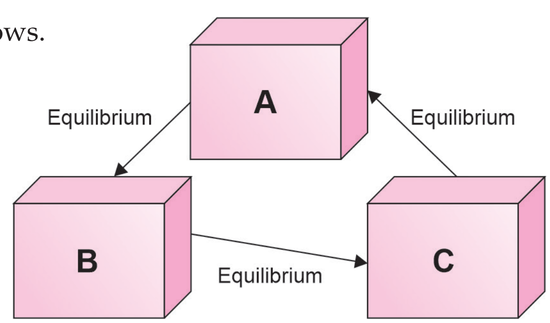

Fig. 1.2: Zeroth law of thermodynamics

are in thermal equilibrium with a third system, they are in thermal equilibrium with each other (Fig. 1.2). This law helps define the notion of temperature.

According to this law, if systems B and C separately are in thermal equilibrium with another system A, then systems B and C will also be in thermal equilibrium with each other. This is also the principle by which thermometers are used.

1.7.2 The First Law of Thermodynamics

The first law of thermodynamics, also known as law of conservation of energy, states that ***energy can neither be created nor to be destroyed; energy can only be transferred or changed from one form to another***. For example, turning on a light would seem to produce energy; however, it is electrical energy that is converted in that way energy is conserved.

A way of expressing the first law of thermodynamics is that any change in the internal energy (ΔE) of a system is given by the sum of the heat (q) that flows across its boundaries and the amount of work (w) is done on the system by the surroundings:

$$(\Delta E = q + w)$$

This law says that there are two kinds of processes that are heat and work, which can lead to a change in the internal energy of a system. Since both heat and work can be measured and quantified, this is the same as saying that any change in the energy of a system must result in a corresponding change in the energy of the surroundings that is outside of the system. In other words, energy can neither be created nor destroyed. If heat flows into a system or the surroundings to do work on it, the internal energy increases and the sign of q and w are positive. Conversely, heat flow out of the system or work done by the system (on the surroundings) will be at the expense of the internal energy, and q and w will therefore be negative.

Similarly, the internal energy E of system gas is increased by transferring heat q into the gas causing the gas molecules to move faster. If heat enters the gas, q will be a positive number. Conversely, we can decrease the internal energy of the gas by transferring heat out of the gas. We can achieve this by placing the container in an ice bath. If heat exits the gas, q will be negative number. This sign convention for heat q is represented in Fig. 1.3.

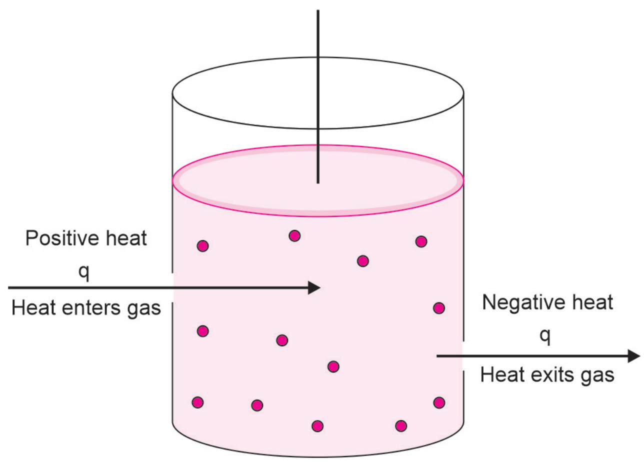

Fig. 1.3: The second law of thermodynamics

1.7.3 The Second Law of Thermodynamics

The second law of thermodynamics states that the entropy of any isolated system always increases. Entropy (degree of randomness, Fig. 1.4.) is a measure of the disorder and exists a useful variable in a system. All systems gain entropy at the end time. Isolated systems spontaneously evolve towards thermal equilibrium which is the state of maximum entropy of the system. More simply put: The entropy of the universe (the ultimate isolated system) only increases and never decreases.

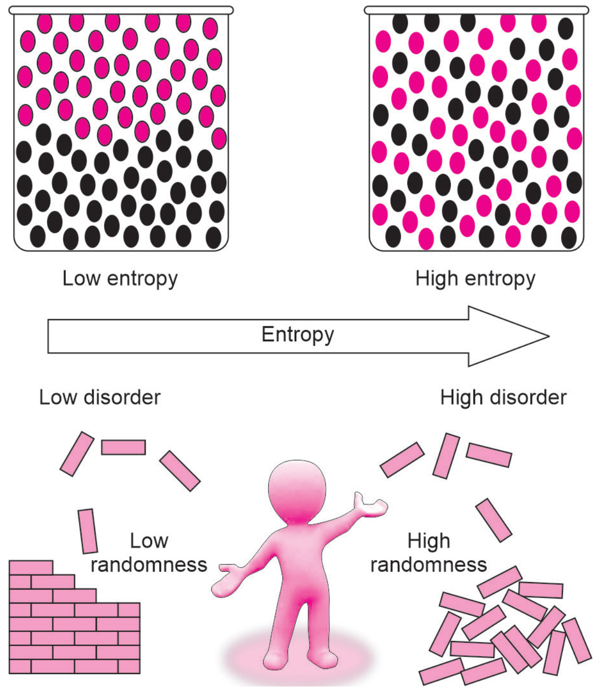

Fig. 1.4: The second law of thermodynamics

A simple way to think of the second law of thermodynamics is that a room, if not cleaned and tidied, will invariably become messier and more disorderly with time regardless of how careful one is to keep it clean. When the room is cleaned, its entropy decreases, but the effort to clean it has resulted in an increase in entropy outside the room that exceeds the entropy lost.

1.7.4 The Third Law of Thermodynamics

The third law of thermodynamics states that in a closed system the entropy (disorder) of a system approaches a constant value as the temperature approaches absolute zero (Fig.1.5). The entropy of a system at absolute zero is typically zero, and in all cases is determined only by the number of different ground states it has. Specifically, the entropy of a pure crystalline substance (perfect order) at absolute zero temperature is zero. This statement holds true if the perfect crystal has only one state with minimum energy.

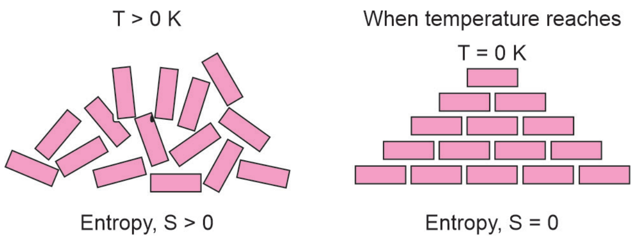

Fig. 1.5: The third law of thermodynamics

1.8 ACOUSTICS

The branch of physics that is concerned with the study of sound is known as acoustics. It also defined as the study of mechanical wave in solid, liquid and gas.

In general, ***Acoustics is the science that deals with the study of sound and its production, transmission, and effects.***

Acoustician is a person who studies about acoustics and ***acoustical engineering*** is the field where the person is working in the acoustics technology. The main application of acoustics is to make the music or speech sound as good as possible. It is achieved by reducing the sound barriers and increasing the factors that help in proper transmission of sound waves. Initially, acoustics was used only in industries which are based on sound like an auditorium, theatre but today, the application of acoustics has spread to many fields like medicine, warfare, architectural industries, etc.

1.8.1 Acoustic Energy

The commotion energy that passes through a matter in the form of wave is called acoustic energy. It is also concerning the mechanical vibration from its own components. Any acoustic event has the following stages.

- Cause or generating mechanism
- Acoustic wave propagation
- Reception effect

Propagation of sound: When a sound is produced, it travels like a wave in the form of vibration through air and when it reaches a person through ear, it is interpreted as sound. ***The process in which some form of sound is converted into sonic energy where producing a sound wave is called transduction process***. Sound waves carry its energy throughout the propagating medium. The acoustic wave equation is the fundamental equation that describes sound wave propagation. Wave propagation is the key process in any of the acoustic event. Sound propagates in liquids as a ***pressure wave*** and in solids as ***longitudinal*** or ***transverse waves***.

1.8.2 Types of Acoustics

1.8.2.1 Environmental Noise

In everyday life, noise that created in a roadways and vibrations are created in a big industries which are all concerned in environmental noise. In addition, railways, aircraft and general activities that also creates an unwanted or harmful noise. This noise which affects human based on their exposure, it may vary from emotional to physiological and psychological.

Environmental noise can also carry a sense of energy (lively) in a particular areas, which can be desirable. However, the adverse effects of noise exposure could include: interference with speech or other 'desired' sounds, annoyance, sleep disturbance, anxiety, hearing damage and stress-related emotional and cardiovascular health problems.

1.8.2.2 Musical Acoustics

Musical acoustics is concerned with the study of physics of music, i.e. how sounds are used to make music that helped in representing the pitch and duration of a sound in musical notation. There are so many areas of musical acoustics which include human voice, musical instruments, and music therapy.

The following three concepts can be considered the standard measuring units of music acoustics Hertz, cent and decibel.

Hertz is the standard measure of the frequency of oscillations in a wave motion. The frequency is 1 Hz when one oscillation occurs in one second. Similarly, when 1000 oscillations occurs in one second, then the frequency is 1000 Hz, or 1 kHz (kilohertz).

Frequency is nothing but number of cycles per second.

The unit most commonly used to measure micro-intervals is called **cent** (German Cent, Latin centum, meaning "one hundred"). It stands for one hundredth of an equal-tempered semitone. In other words, one octave consists of 1200 cents.

The **decibel (dB)** is used to measure the intensity level of a sound, but it is also widely used in electronics, signals, and communication industries. The dB is a logarithmic way of describing a ratio. The ratio may be power, sound pressure, voltage or intensity or several other things.

1.8.2.3 Ultrasounds

Ultrasounds are the sounds with a frequency greater than the human audible limit (20 Hz to 20 kHz, beyond the limit is called ***noise***). However, there is no difference in physical properties when compared to normal sound. Ultrasound is used in many fields. Ultrasonic devices are used in measuring distances and in detecting objects. Vast area of ultrasound physics are in medicine and imaging technology.

1.8.2.4 Infrasounds

Infrasounds are the sounds with a frequency of less than 20 Hz. The study of such sounds is called infrasonics. Applications include detection of petrol formation under the earth and the possibility of earthquakes.

Vibration and dynamics: It is the study of how mechanical systems vibrate and interact with their environment. Applications include vibration control which helps to protect a building from earthquakes and ground vibrations used in railways. Vibrational property may also define as the heaviness of an object.

1.9 POWER

Power is the rate at which the work is done or it is the amount of energy consumed per unit time. Having no direction, it is a scalar quantity. Power is increased if work is done faster or energy is transferred in less time. In the SI system, the unit of power is the joule per second (J/s), known as the watt ($P = W/t$).

1.10 ENERGY

Energy is defined as the capacity of a physical system to perform a work. Energy is a conserved quantity and the law of conservation of energy states that energy can neither be created nor to be destroyed but can only be converted from one form to another. The SI unit of energy is Joule.

Units of energy: The international system of units of measurement of energy is **Joule**. The unit of energy is named after James Prescott Joule. Joule is a derived unit and it is equal to the energy expended in applying a force of **one newton through a distance of one meter**.

1.10.1 Forms of Energy

Energy exists in several forms such as heat, kinetic or mechanical energy, light, potential energy, and electrical energy.

- **Heat:** Heat or thermal energy is energy from the movement of atoms or molecules. It may be considered as energy relating to temperature.
- **Kinetic energy:** Kinetic energy is energy of motion. A swinging pendulum has kinetic energy.
- **Potential energy:** This is energy due to an objects in position. For example, a ball kept on a table has potential energy with respect to the floor because gravity acts upon it.
- **Mechanical energy:** Mechanical energy is the sum of the kinetic and potential energy of a body. It is also defined as the energy of a substance or system by its motion.
- **Light:** Consists of photons, which are a form of energy produced when atom is heated.
- **Electrical energy:** This is energy from the movement of charged particles in an electric conductor such as protons, electrons, or ions.
- **Magnetic energy:** This form of energy results from a magnetic field.
- **Chemical energy:** Chemical energy is released or absorbed by chemical reactions. It is produced by breaking or making chemical bonds between atoms and molecules.
- **Nuclear energy:** This is energy from interactions with the protons and neutrons of an atom. Typically, this relates to the strong force. Examples are energy released by fission and fusion reactions.

1.10.2 Kinetic Energy and Work

Kinetic energy: Kinetic K is energy associated with the *state of motion* of an object. If the object moves faster, it has high kinetic energy. When the object is stationary, its kinetic energy is zero. For an object of mass m whose speed v is well below the speed of light,

$$K = \frac{1}{2}mv^2 \text{ (kinetic energy).}$$

Work: Work W is energy transferred to or from an object by means of a force acting on the object. Energy transferred to the object is positive work, and energy transferred from the object is negative work. The work done by force is the product of the force and the distance moved in the same direction (displacement).

$$\text{Work} = \text{force} \times \text{displacement}$$

1.11 FORCE AND DERIVATIVES

Force: Force is a quantitative description of an interaction of object that causes a change in an object's motion. An object may increase its speed, slow down, or change direction in response to a force acting on it. Objects are pushed or pulled by forces acting on them.

Contact force: Contact force is defined as the force exerted when two objects are in physical and direct contact with each other. Other forces, such as gravitation and electromagnetic forces, can exert themselves even across the empty vacuum of space.

Units of force: Force is a vector quantity; it has both direction and magnitude. It is a study of motion, acceleration which are changes in velocities. It can cause an object to change in velocity as well its accelerate. The SI unit for force is the ***newton* (N)**. One newton of force is equal to 1 $kg \cdot m/s^2$. Force is also represented by the symbol **F**.

Force is proportional to acceleration. In calculus terms, force is the derivative of momentum with respect to time.

Newtonian mechanics: It is the study of the relationship between a force and the acceleration, it was first denoted by Sir Isaac Newton (1643–1727) and it is called **Newtonian mechanics**.

Physicists now view newtonian mechanics as a special concept of comprehensive theories. Still, it is a very important special case because it applies to the motion of objects ranging in size from the very small (almost on the scale of atomic structure) to astronomical levels (galaxies and clusters of galaxies) of variations.

1.12 NEWTON'S LAWS OF MOTION

The concept of force was originally defined by Sir Isaac Newton, in his three laws of motion. He explained gravity as an attractive force between bodies that possessed mass.

1.12.1 First Law

In an inertial reference frame, an object either remains at the state of rest or continues to move at a constant velocity, unless an external force acted upon it.

In other words, the first law states two things:

1. A stationary object will only move if there is an unbalanced force acting on it.
2. A moving object will only change its speed or direction of motion, if there is an unbalanced force acting on it.
   - The first part states that a book on a table is resting on it, unless an unbalanced force act on it.
   - A ball rolling along a flat surface will slow down and eventually come to halt. But this is because of friction, which is also a type of force that slows down the ball. A ball rolling down a slope is also affected by friction, but the force of gravity that causes it to move is stronger. In a place without the forces of friction, air resistance and gravity (e.g. in outer space) a moving object would keep on moving in a straight line if there were no force to slow it down or change its direction.

1.12.2 Second Law

The second law states that the rate of change of momentum of a body, is directly proportional to the force applied on it and this change in momentum takes place in the direction of the applied force.

$$F = ma \quad ...(1.1)$$

For example, weight is a force that we feel on earth caused by the gravity. Weight is calculated as

$$W = mg \quad ...(1.2)$$

Where, m is the mass of the object and g is the local gravitational acceleration (not to be confused with G, the universal gravitational constant), roughly equal to 9.8 meters per second^2 (32 feet per second^2) on earth.

We can express Newton's second law in terms of momentum. The momentum p of a particle is defined as the product of its mass m and velocity v:

$$P = mv \quad ...(1.3)$$

Newton's second law states that the resultant force acting on a particle equals the time rate of change of momentum of the particle

$$F = \frac{dp}{dt} \quad ...(1.4)$$

For a particle of fixed mass (constant m), from eq (1.4)

$$F = \frac{dp}{dt} = \frac{d(mv)}{dt} = \frac{mdv}{dt} = ma$$

$$\vec{F} = m\,\vec{a} \qquad ...(1.5)$$

Equ (1.5), is the equation of Newton's second law in vector form.

1.12.3 Third Law

Newton's third law states that for every action, there is an equal and opposite reaction. As you sit on your table, your body acts on the table with one force, and the table reacts on your body with another force. This is an **example** of **Newton's third law** of motion.

When one body exerts a force on a second body, the second body simultaneously exerts a force equal in magnitude and opposite in direction on the first body.

According to Newton's third law, interacting objects experience two forces—**action** and **reaction**. The size of the forces acting on one object equals the size of the forces acting on the second object. Additionally, the direction of the force on one object is opposite to the direction of the force on the second object. Let us consider a man attempting to lift a heavy weight. If the man can pull up with a force, then the weights in turn will pull down with a force of same value.

1.13 FUNDAMENTAL FORCES

There are four fundamental forces that govern the interactions of physical systems. Scientists continue to pursue an unified theory of these forces.

- Gravitation is the force that acts between masses. All particles experience the force of gravity. While the graviton has been proposed as the particle mediating gravity, it has not yet been observed.
- The electromagnetic force acts between electrical charges and the mediating particle is the photon.
- The strong nuclear force holds the nucleus of the atom together, mediated by gluons acting on quarks, antiquarks, and the gluons themselves.
- The weak nuclear force is mediated by exchanging W and Z bosons, and is seen in beta decay of neutrons in the nucleus. At very high temperatures, the weak force and the electromagnetic force are indistinguishable.

1.14 MASS-ENERGY EQUIVALENCE

Derivation: Force is defined as rate of change of momentum, *i.e.*

$$F = \frac{d(mv)}{dt} \qquad ...(1.6)$$

According to the theory of relativity, both mass and velocity are variable. Therefore,

$$F = \frac{d(mv)}{dt} = m\frac{dv}{dt} + v\frac{dm}{dt} \qquad ...(1.7)$$

Let the force F *act on the body which* displace the body through a small distance dx. Then, the increase in the kinetic energy (dEk) of the body is equal to the work done (Fdx).

Hence, $$dE_k = F\,dx = m\frac{dv}{dt}dx + v\frac{dm}{dt}dx$$

or $$dE_k = mv\,dv + v^2\,dm \qquad ...(1.8)$$

According to the law of variation of mass with velocity

$$m = \frac{m_0}{\sqrt{1 - v^2 / c^2}} \qquad \text{...(1.9)}$$

Squaring both sides, $$m^2 = \frac{m_0^2}{1 - (v^2 / c^2)}$$

or $$m^2c^2 = m_0^2c^2 + m^2v^2$$

Differentiating, $$c^2 2m\,dm = m^2 2v\,dv + v^2\,2m\,dm$$

or $$c^2\,dm = mv\,dv + v^2\,dm \qquad \text{...(1.10)}$$

From equations (1.8) and (1.10), $dE_k = c^2\,dm$ ...(1.11)

Thus, a change in KE (dEk) is directly proportional to a change in mass *dm of an object*.

When a body is at resting state, its velocity is zero, (KE = 0) and $m = m^0$. When its velocity is v, its mass becomes m. Therefore, integrating equation (6),

$$E_x = \int_0^{-k} dE_k = c^2 \int_{m_0}^{m} dm = c^2(m - m_0)$$

∴ $$E_x = mc^2 - m_0c^2$$

This is the relativistic formula for KE

When the body is at rest, the internal energy stored in the body is m_0c^2. m_0c^2 is called the rest mass energy. The total energy (E) of the body is the sum of K.E. (Ek) and rest mass energy (m_0c^2).

∴ $$E = E_k + m_0c^2 = (mc^2 - m_0c^2) + m_0c^2 = mc^2.$$

∴ $$E = mc^2$$

This is Einstein's mass-energy relation.