JAMIA URDU HIND

State's Madrasa Tul Oloom For Research In Urdu Language Of National Importance

AWESOME REVIEW SERIES OF JAMIA URDU HIND

PHYSICS (10+2)

Preface

Dear Students of Jamia Urdu Hind of past and present,
We understand you don't need the help of anyone …………..,
But we just want to take care of the way you design everything.
Something we want to share with you owing to your association with JUH!!!
We can't find a reason why Allah gave this idea of writing **Awesome Review Series of JUH with mnemonics** to us to present subjects in this review form having complete points touching all competitive exams of respective standard in the shortest form as per your need and desire based on NCERT and Madrasa Board? But that is not the question to be asked; May be…….. The question is how did Allah know that we needed a student like you.
Wonderful students are carefully created by Allah,
Wonderful moments are carefully planned by Allah,
Wonderful innovative truth seeker like you are carefully gifted by Allah!!
Always read between the line……
To educate the children of non-educated persons are tougher than that of educated persons hence **Muslims** are least educated minority community in the country as per Decoded Minority Report since British Imperialism. There is **declining Muslim IAS Officers from 1950 (13 %) to 2000 (2.92 %)** among its 14% population in India. IAS officer is the pillar of governance. Hence, more than 50000 Madarsa and 14% literacy to India are contributed by Muslims **without grants from government**. Madarsa has produced architecture of Taj Mahal, Lal Qila, Qutub Minar along with Abusena in medicine and Khaiyam in mathematics. Madrasa for **Urdu Courses in India is like Dinosaurs with Lal Qila, Qutub Minar, Jama Masjid, Taj Mahal as remnant for scientific research.** In the past, Urdu has gathered a good deal of political dust, which it must shed in the interest of its health & growth. The basic problems of a language are educational, literary or administrative and if we confine ourselves to these spheres, we will discover that solutions become easier to find. India will never be a developed nation until power practice of biased mind will be ceased and surrendered completely and voluntarily.
BP Singhal, MP(RS), Ex-DG, IPS said : Could a community that ruled India for **over 950 years** and belonged to a privileged class even during British Raj, becomes socially handicapped. This now encounters the worst conditions (**worse than SC/ST**) in their own land (as per minority report) and urgently needs emergency educational support to achieve 100% literacy so as to make India a developed nation **(Ref: Problems & Policy of Minority in India)**.

We provide education through literacy campaign in the country and our positive move has empowered the most deprived class to be in the nation's mainstream. Education and Nation are incomplete without Urdu and like Hindi, Urdu is the thread of Bharat's beaded necklace where all super power of the world is quit on the united front. One can use all the superlatives about the literary work of the institution but this won't mean anything to anybody. We state the facts that are verifiable.
You are served by the country as you serve the country because your leaders are exactly like you.
No human society can develop in all its dimensions if it does not produce meaningful literature for its children and young readers. Therefore, the framework of a society should be established around the pillars of knowledge by converting it into a democratic force and take it into every corner of our country. There is a great hunger for knowledge in the country and our motto, therefore, should be all for knowledge and knowledge for all (President of India).

People do not remember what one says but they always remember what one tries to make them feel and nothing is better than honesty and goodness in the world!!! Never expect, do not criticize, do the best you can, surely you will rise very high in your life if you have confidence, trust and hope like Einstein, Newton, Mendal, Aryabhat, Edison, Khaiyam, Abusena and Archemedes.

Confidence:
Once, all villagers decided to pray for rain. On prayer day, all people gathered and only one boy came with an umbrella………
that"s confidence……..
Trust:
Trust should be like the feeling of a one year old baby, when you throw him in air, he laughs....because he knows you will catch him……..
That"s trust....
Hope:
A human being can live for 40 days without water, 8 minutes without air, but not a single second without one thing………
That"s hope..........

-Writer's Union of JUH

A NOTE 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. Ideas that changed civilisation

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

"Matter 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.

CONTENTS

PHYSICAL WORLD

1. Physics deals with the study of the basic laws of nature and their manifestation in different phenomena. The basic laws of physics are universal and apply in widely different contexts and conditions.
2. The scope of physics is wide, covering a tremendous range of magnitude of physical quantities.
3. Physics and technology are related to each other. Sometimes technology gives rise to new physics; at other times physics generates new technology. Both have direct impact on society.
4. There are four fundamental forces in nature that govern the diverse phenomena of the macroscopic and the microscopic world. These are the .gravitational force., the electromagnetic force., the .strong nuclear force., and the .weak nuclear force.. Unification of different forces/domains in nature is a basic quest in physics.
5. The physical quantities that remain unchanged in a process are called conserved quantities. Some of the general conservation laws in nature include the laws of conservation of mass, energy, linear momentum, angular momentum, charge, parity, etc. Some conservation laws are true for one fundamental force but not for the other.
6. Conservation laws have a deep connection with symmetries of nature. Symmetries of space and time, and other types of symmetries play a central role in modern theories of fundamental forces in nature.

UNITS AND MEASUREMENTS

1. Physics is a quantitative science, based on measurement of physical quantities. Certain physical quantities have been chosen as fundamental or base quantities (such as length, mass, time, electric current, thermodynamic temperature, amount of substance, and luminous intensity).
2. Each base quantity is defined in terms of a certain basic, arbitrarily chosen but properly standardised reference standard called unit (such as metre, kilogram, second, ampere, kelvin, mole and candela). The units for the fundamental or base quantities are called fundamental or base units.
3. Other physical quantities, derived from the base quantities, can be expressed as a combination of the base units and are called derived units. A complete set of units, both fundamental and derived, is called a system of units.
4. The International System of Units (SI) based on seven base units is at present internationally accepted unit system and is widely used throughout the world.
5. The SI units are used in all physical measurements, for both the base quantities and the derived quantities obtained from them. Certain derived units are expressed by means of SI units with special names (such as joule, newton, watt, etc).
6. The SI units have well defined and internationally accepted unit symbols (such as m for metre, kg for kilogram, s for second, A for ampere, N for newton etc.).
7. Physical measurements are usually expressed for small and large quantities in scientific notation, with powers of 10. Scientific notation and the prefixes are used to simplify measurement notation and numerical computation, giving indication to the precision of the numbers.
8. Certain general rules and guidelines must be followed for using notations for physical quantities and standard symbols for SI units, some other units and SI prefixes for expressing properly the physical quantities and measurements.
9. In computing any physical quantity, the units for derived quantities involved in the relationship(s) are treated as though they were algebraic quantities till the desired units are obtained.
10. Direct and indirect methods can be used for the measurement of physical quantities. In measured quantities, while expressing the result, the accuracy and precision of measuring instruments along with errors in measurements should be taken into account.
11. In measured and computed quantities proper significant figures only should be retained. Rules for determining the number of significant figures, carrying out arithmetic operations with them, and rounding off the uncertain digits must be followed.

12. The dimensions of base quantities and combination of these dimensions describe the nature of physical quantities. Dimensional analysis can be used to check the dimensional consistency of equations, deducing relations among the physical quantities, etc. A dimensionally consistent equation need not be actually an exact (correct) equation, but a dimensionally wrong or inconsistent equation must be wrong.

MOTION IN A STRAIGHT LINE

1. An object is said to be in *motion* if its position changes with time. The position of the object can be specified with reference to a conveniently chosen origin. For motion in a straight line, position to the right of the origin is taken as positive and to the left as negative.
2. *Path length* is defined as the total length of the path traversed by an object.
3. *Displacement* is the change in position : ¤x = $x2$. $x1$. Path length is greater or equal to the magnitude of the displacement between the same points.
4. An object is said to be in *uniform motion* in a straight line if its displacement is equal in equal intervals of time. Otherwise, the motion is said to be *non-uniform*.
5. *Average velocity* is the displacement divided by the time interval in which the displacement occurs . On an *x-t* graph, the average velocity over a time interval is the slope of the line connecting the initial and final positions corresponding to that interval.
6. *Average Speed* is the ratio of total path length traversed and the corresponding time interval.
The average speed of an object is greater or equal to the magnitude of the average velocity over a given time interval.
7. *Instantaneous velocity* or simply velocity is defined as the limit of the average velocity as the time interval ¤t becomes infinitesimally small.
The velocity at a particular instant is equal to the slope of the tangent drawn on position-time graph at that instant.
8. *Average acceleration* is the change in velocity divided by the time interval during which the change occurs.
9. *Instantaneous acceleration* is defined as the limit of the average acceleration as the time interval ¤t goes to zero.
The acceleration of an object at a particular time is the slope of the velocity-time graph at that instant of time. For uniform motion, acceleration is zero and the *x-t* graph is a straight line inclined to the time axis and the *v-t* graph is a straight line parallel to the time axis. For motion with uniform acceleration, *x-t* graph is a parabola while the *v-t* graph is a straight line inclined to the time axis.
10. The area under the velocity-time curve between times $t1$ and $t2$ is equal to the displacement of the object during that interval of time.
11. For objects in uniformly accelerated rectilinear motion, the five quantities, displacement x, time taken t, initial velocity $v0$, final velocity v and acceleration a are related by a set of simple equations called *kinematic equations of motion*. If the position of the object at time t = 0 is 0. If the particle starts at $x = x0$, x in above equations is replaced by (x . x *0*).

POINTS TO PONDER

1. The path length traversed by an object between two points is, in general, not the same as the magnitude of displacement. The displacement depends only on the end points; the path length (as the name implies) depends on the actual path. In one dimension, the two quantities are equal only if the object does not change its direction during the course of motion. In all other cases, the path length is greater than the magnitude of displacement.
2. In view of point 1 above, the average speed of an object is greater than or equal to the magnitude of the average velocity over a given time interval. The two are equal only if the path length is equal to the magnitude of displacement.
3. The origin and the positive direction of an axis are a matter of choice. You should first specify this choice before you assign signs to quantities like displacement, velocity and acceleration.
4. If a particle is speeding up, acceleration is in the direction of velocity; if its speed is decreasing, acceleration is in the direction opposite to that of the velocity. This statement is independent of the choice of the origin and the axis.
5. The sign of acceleration does not tell us whether the particle.s speed is increasing or decreasing. The sign of acceleration (as mentioned in point 3) depends on the choice of the positive direction of the axis. For example, if the vertically upward direction is chosen to be the positive direction of the axis, the acceleration due to gravity is negative. If a particle is falling under gravity, this acceleration, though negative, results in increase in speed. For a particle thrown upward, the same negative acceleration (of gravity) results in decrease in speed.

6. The zero velocity of a particle at any instant does not necessarily imply zero acceleration at that instant. A particle may be momentarily at rest and yet have non-zero acceleration. For example, a particle thrown up has zero velocity at its uppermost point but the acceleration at that instant continues to be the acceleration due to gravity.
7. In the kinematic equations of motion [Eq. (3.11)], the various quantities are algebraic, i.e. they may be positive or negative. The equations are applicable in all situations (for one dimensional motion with constant acceleration) provided the values of different quantities are substituted in the equations with proper signs.
8. The definitions of instantaneous velocity and acceleration are exact and are always correct while the kinematic equations (Eq. (3.11)) are true only for motion in which the magnitude and the direction of acceleration are constant during the course of motion.

MOTION IN A PLANE

1. *Scalar quantities* are quantities with magnitudes only. Examples are distance, speed, mass and temperature.
2. *Vector quantities* are quantities with magnitude and direction both. Examples are displacement, velocity and acceleration. They obey special rules of vector algebra.
3. A vector **A** multiplied by a real number □ is also a vector, whose magnitude is □ times the magnitude of the vector **A** and whose direction is the same or opposite depending upon whether □ is positive or negative.
4. Two vectors **A** and **B** may be *added graphically* using *head-to-tail method* or *parallelogram method*.
5. Vector addition is *commutative* : **A** + **B** = **B** + **A.** It also obeys the *associative law* : (**A** + **B**) + **C** = **A** + (**B** + **C**).
6. A *null* or *zero vector* is a vector with zero magnitude. Since the magnitude is zero, we dont have to specify its direction.
7. The *subtraction* of vector **B** from **A** is defined as the sum of **A** and .**B** :
A . **B** = **A**+ (.**B**)
8. A vector **A** can be *resolved* into component along two given vectors **a** and **b** lying in the same plane : **A** = □ **a** + □ **b**
where □ and □ are real numbers.
9. A *unit vector* associated with a vector **A** has magnitude one and is along the vector **A**.
The unit vectors "**i, j**", **k**" are vectors of unit magnitude and point in the direction of the *x*-, *y*-, and *z*-axes, respectively in a right-handed coordinate system.
10. A vector **A** can be expressed as **A** □ *Ax* **i** + *Ay***j.**
11. Vectors can be conveniently added using *analytical method*.

MOTION IN A PLANE

When position of an object is plotted on a coordinate system, **v** is always tangent to
the curve representing the path of the object.
If the velocity of an object changes from **v** to **v**′in time □*t*, then its *average acceleration*
is given by: **a.**

Motion in a plane can be treated as superposition of two separate simultaneous one dimensional motions along two perpendicular directions.
An object that is in flight after being projected is called a *projectile*. If an object is projected with initial velocity **vo** making an angle □o with *x*-axis and if we assume its initial position to coincide with the origin of the coordinate system, then the position and velocity of the projectile at time *t* are given by :
x = (*vo* cos □o) *t*.
The path of a projectile is *parabolic* . The *maximum height* that a projectile attains is obtained.
The *time* taken to reach this height is also obtained.
The horizontal distance travelled by a projectile from its initial position to the position it passes *y* = 0 during its fall is called the *range*, *R* of the projectile.
When an object follows a circular path at constant speed, the motion of the object is called *uniform circular motion*. The magnitude of its acceleration is *ac* = *v*2 /*R*. The direction of *ac* is always towards the centre of the circle.
The angular speed □, is the rate of change of angular distance. It is related to velocity *v* by *v* = □ *R*. The acceleration is *ac* = □ 2*R*. If *T* is the time period of revolution of the object in circular motion and □ is its frequency, we have □ = 2□ □ *v* = 2□ *R*, *ac* = 4□2□2*R*

POINTS TO PONDER

1. The path length traversed by an object between two points is, in general, not the same as the magnitude of displacement. The displacement depends only on the end points; the path length (as the name implies) depends on the actual path. The two quantities are equal only if the object does not change its direction during the course of motion. In all other cases, the path length is greater than the magnitude of displacement.
2. In view of point 1 above, the average speed of an object is greater than or equal to the magnitude of the average velocity over a given time interval. The two are equal only if the path length is equal to the magnitude of displacement.
3. The vector equations (4.33a) and (4.34a) do not involve any choice of axes. Of course, you can always resolve them along any two independent axes.
4. The kinematic equations for uniform acceleration do not apply to the case of uniform circular motion since in this case the magnitude of acceleration is constant but its direction is changing.
5. An object subjected to two velocities **v**1 and **v**2 has a resultant velocity **v** = **v**1 + **v**2. Take care to distinguish it from velocity of object 1 relative to velocity of object 2 : **v**12= **v**1 −¤**v**2. Here **v**1 and **v**2 are velocities with reference to some common reference frame.
6. The resultant acceleration of an object in circular motion is towards the centre only if the speed is constant.
7. The shape of the trajectory of the motion of an object is not determined by the acceleration alone but also depends on the initial conditions of motion (initial position and initial velocity). For example, the trajectory of an object moving under the same acceleration due to gravity can be a straight line or a parabola depending on the initial conditions.

LAWS OF MOTION

1. Aristotle.s view that a force is necessary to keep a body in uniform motion is wrong. A force is necessary in practice to counter the opposing force of friction.
2. Galileo extrapolated simple observations on motion of bodies on inclined planes, and arrived at the law of inertia. Newton.s first law of motion is the same law rephrased thus: .*Everybody continues to be in its state of rest or of uniform motion in a straight line, unless compelled by some external force to act otherwise*.. In simple terms, the First Law is **.If external force on a body is zero, its acceleration is zero…**
3. Momentum (**p**) of a body is the product of its mass *(m)* and velocity *(***v***)* : **p** = *m* **v**
4. **Newton’s second law of motion :**
The rate of change of momentum of a body is proportional to the applied force and takes place in the direction in which the force acts. Thus F= ma where **F** is the net external force on the body and **a** its acceleration. We set the constant of proportionality *k* = 1 in SI units.
The SI unit of force is newton : 1 N = 1 kg m s-2 .
(a) The second law is consistent with the First Law (**F** = 0 implies **a** = 0)
(b) It is a vector equation
(c) It is applicable to a particle, and also to a body or a system of particles, provided **F** is the total external force on the system and **a** is the acceleration of the system as a whole.
(d) **F** at a point at a certain instant determines **a** at the same point at that instant.
That is the Second Law is a local law; **a** at an instant does not depend on the history of motion.
5. Impulse is the product of force and time which equals change in momentum.
The notion of impulse is useful when a large force acts for a short time to produce a measurable change in momentum. Since the time of action of the force is very short, one can assume that there is no appreciable change in the position of the body during the action of the impulsive force.
6. **Newton;s third law of motion:**
To every action, there is always an equal and opposite reaction In simple terms, the law can be stated thus : *Forces in nature always occur between pairs of bodies. Force on a body A by body B is equal and opposite to the force on the body B by A*. Action and reaction forces are simultaneous forces. There is no cause-effect relation between action and reaction. Any of the two mutual forces can be called action and the other reaction. Action and reaction act on different bodies and so they cannot be cancelled out. The internal action and reaction forces between different parts of a body do, however, sum to zero.
7. ***Law of Conservation of Momentum:*** The total momentum of an isolated system of particles is conserved. The law follows from the second and third law of motion.
8. ***Friction***

Frictional force opposes (impending or actual) relative motion between two surfaces in contact. It is the component of the contact force along the common tangent to the surface in contact. Static friction f_s opposes impending relative motion; kinetic friction f_k opposes actual relative motion. They are independent of the area of contact.

POINTS TO PONDER

1. Force is not always in the direction of motion. Depending on the situation, **F** may be along **v**, opposite to **v**, normal to **v** or may make some other angle with **v**. In every case, it is parallel to acceleration.
2. If **v** = 0 at an instant, i.e. if a body is momentarily at rest, it does not mean that force or acceleration are necessarily zero at that instant. For example, when a ball thrown upward reaches its maximum height, **v** = 0 but the force continues to be its weight mg and the acceleration is not zero but g.
3. Force on a body at a given time is determined by the situation at the location of the body at that time. Force is not .carried. by the body from its earlier history of motion. The moment after a stone is released out of an accelerated train, there is no horizontal force (or acceleration) on the stone, if the effects of the surrounding air are neglected. The stone then has only the vertical force of gravity.
4. In the second law of motion **F** = m **a**, **F** stands for the net force due to all material agencies external to the body. **a** is the effect of the force. m**a** should not be regarded as yet another force, besides **F**.
5. The centripetal force should not be regarded as yet another kind of force. It is simply a name given to the force that provides inward radial acceleration to a body in circular motion. We should always look for some material force like tension, gravitational force, electrical force, friction, etc as the centripetal force in any circular motion.
6. Static friction is a self-adjusting force up to its limit $\mu_s N$ ($f_s \le \mu_s N$). Do not put $f_s = \mu_s N$ without being sure that the maximum value of static friction is coming into play.
7. The familiar equation $mg = R$ for a body on a table is true only if the body is in equilibrium. The two forces mg and R can be different (e.g. a body in an accelerated lift). The equality of mg and R has no connection with the third law.
8. The terms .action. and .reaction. in the third Law of Motion simply stand for simultaneous mutual forces between a pair of bodies. Unlike their meaning in ordinary language, action does not precede or cause reaction. Action and reaction act on different bodies.
9. The different terms like .friction., .normal reaction. .tension., .air resistance., .viscous drag., .thrust., .buoyancy. .weight. .centripetal force. all stand for .force. in different contexts. For clarity, every force and its equivalent terms encountered in mechanics should be reduced to the phrase .force on A by B..
10. For applying the second law of motion, there is no conceptual distinction between inanimate and animate objects. An animate object such as a human also requires an external force to accelerate. For example, without the external force of friction, we cannot walk on the ground.
11. The objective concept of force in physics should not be confused with the subjective concept of the .feeling of force.. On a merry-go-around, all parts of our body are subject to an inward force, but we have a feeling of being pushed outward . the direction of impending motion.

WORK, ENERGY AND POWER

1. The *work-energy theorem* states that the change in kinetic energy of a body is the work done by the net force on the body. W =FS Cos theta.
2. A force is *conservative* if (i) work done by it on an object is path independent and depends only on the end points {x_i, x_j}, or (ii) the work done by the force is zero for an arbitrary closed path taken by the object such that it returns to its initial position.
3. For a conservative force in one dimension, we may define a *potential energy* function $V(x)$
such that P= mgh.
4. The principle of conservation of mechanical energy states that the total mechanical energy of a body remains constant if the only forces that act on the body are conservative.
5. The *gravitational potential energy* of a particle of mass m at a height x about the earth's surface is $V(x) = m\,g\,h$ where the variation of g with height is ignored.
6. The elastic potential energy of a spring of force constant k and extension x is *obtained*.
7. The scalar or dot product of two vectors **A** and **B** is written as **A.B** and is a scalar quantity given by : **A.B** = $AB \cos\theta$ where θ is the angle between **A** and **B**. It can be positive, negative or zero depending upon the value of θ. The scalar product of two vectors can be interpreted as the product of magnitude of one vector and component of the other vector along the first vector. For unit vectors : $\hat{i}\cdot\hat{i} = \hat{j}\cdot\hat{j} = \hat{k}\cdot\hat{k} = 1$ and $\hat{i}\cdot\hat{j} = \hat{j}\cdot\hat{k} = \hat{k}\cdot\hat{i} = 0$
Scalar products obey the commutative and the distributive laws.

POINTS TO PONDER

1. The phrase .calculate the work done. is incomplete. We should refer (or imply clearly by context) to the work done by a specific force or a group of forces on a given body over a certain displacement.
2. Work done is a scalar quantity. It can be positive or negative unlike mass and kinetic energy which are positive scalar quantities. The work done by the friction or viscous force on a moving body is negative.
3. For two bodies, the sum of the mutual forces exerted between them is zero from Newton.s Third Law, $\mathbf{F}_{12} + \mathbf{F}_{21} = 0$ But the sum of the work done by the two forces need not *always cancel, i.e.*
$W_{12} + W_{21} \neq 0$. However, it *may sometimes be true*.
4. The work done by a force can be calculated sometimes even if the exact nature of the force is not known. This is clear from Example 6.2 where the WE theorem is used in such a situation.
5. The WE theorem is not independent of Newton.s Second Law. The WE theorem may be viewed as a scalar form of the Second Law. The principle of conservation of mechanical energy may be viewed as a consequence of the WE theorem for conservative forces.
6. The WE theorem holds in all inertial frames. It can also be extended to noninertial frames provided we include the pseudoforces in the calculation of the net force acting on the body under consideration.
7. The potential energy of a body subjected to a conservative force is always undetermined upto a constant. For example, the point where the potential energy is zero is a matter of choice. For the gravitational potential energy *mgh*, the zero of the potential energy is chosen to be the ground. For the spring potential energy $kx^2/2$, the zero of the potential energy is the equilibrium position of the oscillating mass.
8. Every force encountered in mechanics does not have an associated potential energy. For example, work done by friction over a closed path is not zero and no potential energy can be associated with friction.
9. During a collision : (a) the total linear momentum is conserved at each instant of the collision ; (b) the kinetic energy conservation (even if the collision is elastic) applies after the collision is over and does not hold at every instant of the collision. In fact the two colliding objects are deformed and may be momentarily at rest with respect to each other.

System of Particles and Rotational Motion

SHM and Periodic Motion

Periodic motion

- If a particle moves such that it repeats its path regularly after equal intervals of time , it's motion is said to be periodic.
- The interval of time required to complete one cycle of motion is called time period of motion.
- If a body in periodic motion moves back and forth over the same path then the motion is said to be viberatory or oscillatory.
- Examples of such motion are to and fro motion of pendulum, viberations of a tuning fork , mass attached to a spring and many more.
- Every oscillatory motion is periodic but every periodic motion is not oscillatory for example motion of earth around the sun is periodic but not oscillatory.
- Simple Harmonic Motion (or SHM) is the simplest form of oscillatory motion.
- SHM arises when force on oscillating body is directly proportional to the displacement from it's equilibrium position and at any point of motion, this force is directed towards the equilibrium position.

Simple Harmonic Motion (or SHM)

- SHM is a particular type of motion very common in nature.
- In SHM force acting on the particle is always directed towards a fixed point known as equilibrium position and the magnitude of force is directly proportional to the displacement of particle from the equilibrium position and is given by

  $F= -kx$

  where k is the force constant and negative sign shows that fforce opposes increase in x.

- This force os known as restoring force which takes the particle back towards the equilibrium position , and opposes increase in displacement.
- S.I. unit of force constant k is N/m and magnitude of k depends on elastic properties of system under consideration.
- For understanding the nature of SHM consider a block of mass m whose one end is attached to a spring and another end is held stationary and this block is placed on a smooth horizontal surface

GRAVITATION

(1) Introduction :

- In our dairy life we have noticed things falling freely downwords towards earth when thrown upwards or dispped from some hight.
- Fact that all bodies irrespective of their masses are accelerated towards the earth mith a constant aceeleation was first recognized by galive (1564-1642)
- The motion of celesh'al bodies such as moon. earth plametes etc. and attrachieve of moon towards earth and arth towards sun is an interasting subject of study since long time.
- Now the question's what is the force that produces such acceleration is which earth attract all bodies towards the centre and what is the law governing this force.
- Is this law is same for both earthly and weshal bodies.
- Answer to this question was given by Newton as he declared that "laws of nature are same for earthly and weshal Bodies".
- The force between any object falling freely towards earth and that between earth and moon are gowerned by the same laws.
- Johnaase kepler (1571-1631) Studied the planetary motion in detail and formulated his three laws of planetary motion, which were available Universal law of grawitation.

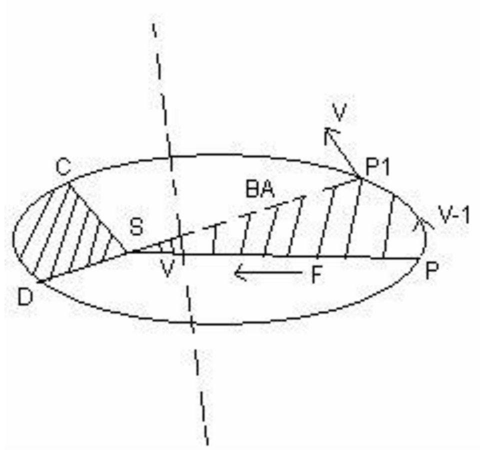
(2) Kepler's Law :-

Kepler's law of planetary motion are :-

(i)Law of orbits :-

Each planet revolues around the sun in an elliptical orbit with sun at one of the foci of the ellipse asd shown in fig (a) below.

Fig (a) An ellipse traced by planet sevolary round the sun.



AO = a - Sewi major axis
BO = b - Sewi minor axis

P - hearest point between planet and sun k/as perihetion
A - farthest point between planet and sun apheiton.

(ii)Law of areas :-
The line joining planet and the sun sweeps equal area in equal intervals of time" [fig b]

This law follows from the observation that when planet is nearer to the sun its velocity increases and It appears to be slower when it is farther from the sun.
(iii)Law of periods :-
The squre of time period of any planet about the sun is propotional to the cube of the semi-major axis."

- If T is the time period of semi major axis a of elliptical orbit then.
  T^2 x a^3 (1)
- If T_1 and T_2 are time periods of any two planets and a_1 and a_2 being their semi major axis resp. then
  T_1^2 x a_1^3 = a_1^3
  T_2^2 x a_2^3 a_2^3 (2)
  This question (2) can be used to find the time period of a planet, when the time period of the other planet and the semi-major axis of orbits of two planets.

(3) Universal law of gravition :-

- Everybody in the universe attracts every other body with a force which is directly proportional to the product of their masses and invessly proportional to the square of distance between them.
- Mathematically Newton's gravitation law is if F is the force acting between two bodies of masses M_1 and M_2 and the distance between them is R then majnitade of force is given as

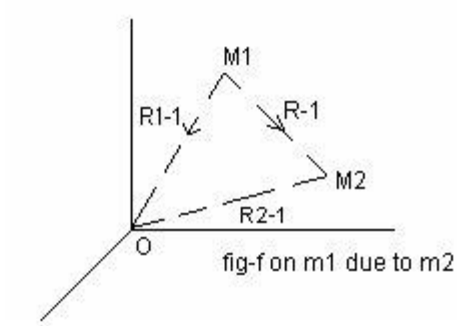


fig-f on m1 due to m2

$$F = \frac{Gm_1m_2}{r^2}$$

- In vector notation

$$F = \frac{Gm_1m_2(-\hat{r})}{r^2}$$

$$F = \frac{-Gm_1m_2\hat{r}}{r^2}$$

- where G- universal gravitational constant
  r^ - unit vector from m_1 to m_2 and r^ = r_1^ - r_2^

3- Gravitational force is attrachive constant is
SI - G= 6.67×10^{-11} nm^2 kg^{-2}
CGS - G= 6.67×10^{-8} dyn cm^2 g^{-2}
Deminsional formula of C1 is $[m^{-1}L^3T^{-2}]$

(4) Acceleration due to gravity of earth :-

- Earth attracts every object lying an its surface towards its centre with a force known as gravitational towards its centre with a force known as gravitational pull or gravity.

- Whenever force acts on any body it produces acceleration and in case of gravitation this acceleration produced under effect of gravity is known as accelesation due to gravity (g)
- Value of accelesation due to gravity is independent of mass of the body and its value near surface of earth is 9.8 ms^{-2}
- Expression for acceleration due to gravity
  Consider mass of earth to be as M_E and its redius be R_E Suppose a body of mass M (much smaller then that fo earth) is kept at the earth surface. Force eseerted by earth on the body of mass m is

$$F = \frac{-GMM_E}{R_E^2}$$

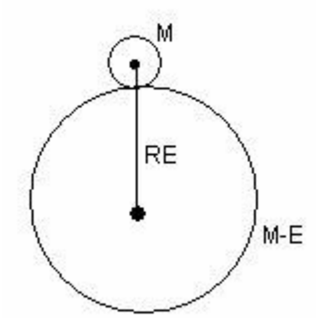
- The force for the body due to earth produces acceleration due to gravity (g) in the motion of the body. From Newton's Second law of motion
  f=mg
  from (4) and (s)

$$g = \frac{-GM_E}{R_E^2}$$

- which is acceleration due to gravity at earth's surface.

(5) Acceleration due to gravity below and above the earth surface :-

(i) Above earth's surface



- An object of mass m is placed at hight h above the earth's active in this object is

$$F = \frac{-GMM_E}{(R_E+h)^2}$$

- From this it can be concluded that value of g decreases as distance above surface of earth increases now,

$$g = \frac{-GM_E}{R_E(1+h/R_E)^2}$$

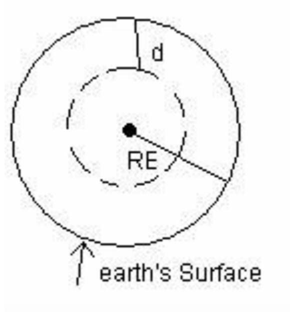
- Where

$$g = \frac{g_o}{(1+h/R_E)^2}$$

- eqn (7) tells us that for small hight h above surface of earth. value of g decreases by factor $(1-2h/R_E)$
  - for h<<R
  $g=g_o(1+h/R_E)^{-2}$
  $g=g_o(1-2h/R_E)$ Expanding by Binomial theriom

(ii) Below the earth's surface

g_o = GM_E / R<sub<e< sub="">2</sub<e<>



- If one goes inside the earth surface the value of g again decreases
- P = density of material of earth them
  $m=(4/3)(R_E)^3P$
  From this acceleration due to gravity at earth's Surface is

$$g = \frac{G(4/3)R_E^3P}{R_E^2}$$

- $g=(4/3)GR_EP$ (8)

g-acceleration due to gravity at depth D below earth's surface
-Body at depth d will experience force only due to portion of reduce (R_E-1d) of earth's
-outer spherical shell of thickness d will not exeperience any force
-M is mas of the portion of earth with radius (R_E-d) then

- $M=(4/3)(R_E-d)^3 P$

$$g = \frac{-GM}{R_E^2}$$

- $g= (4/3)G (R_E-d)P$ (9)

Dividing epn (9) by (8)
$g/g_o= (1-d/R_E)$
or $g=go (1-d/R_E)$
nbsp; (10)
from epn (10) is cleaer that acceeleration due to gravity also decreases with depth.

$$g = \frac{-G4/3(R_E-d)^3 P}{(R_E^2-d)^2}$$

MECHANICAL PROPERTIES OF SOLIDS

1. Stress is the restoring force per unit area and strain is the fractional change in dimension. In general there are three types of stresses (a) tensile stress — longitudinal stress (associated with stretching) or compressive stress (associated with compression), (b) shearing stress, and (c) hydraulic stress.

2. For small deformations, stress is directly proportional to the strain for many materials. This is known as Hooke's law. The constant of proportionality is called modulus of elasticity. Three elastic moduli *viz.*, Young's modulus, shear modulus and bulk modulus are used to describe the elastic behaviour of objects as they respond to deforming forces that act on them.

A class of solids called elastomers does not obey Hooke's law.

3. When an object is under tension or compression, the Hooke's law takes the form *F/A = Y¤L/L*

where *¤L/L* is the tensile or compressive strain of the object, *F* is the magnitude of the applied force causing the strain, *A* is the cross-sectional area over which *F* is applied (perpendicular to *A*) and *Y* is the Young's modulus for the object. The stress is *F/A*.

4. A pair of forces when applied parallel to the upper and lower faces, the solid deforms so that the upper face moves sideways with respect to the lower. The horizontal displacement *¤L* of the upper face is perpendicular to the vertical height *L*. This type of deformation is called shear and the corresponding stress is the shearing stress. This type of stress is possible only in solids. In this kind of deformation the Hooke's law takes the form *F/A = G ¤ ¤L⁄L* where *¤L* is the displacement of one end of object in the direction of the applied force *F*, and *G* is the shear modulus.

5. When an object undergoes hydraulic compression due to a stress exerted by a surrounding fluid, the Hooke's law takes the form *p* = *B* (□*V*/*V*), where *p* is the pressure (hydraulic stress) on the object due to the fluid, □*V*/*V* (the volume strain) is the absolute fractional change in the object's volume due to that pressure and *B* is the bulk modulus of the object.

POINTS TO PONDER

1. In the case of a wire, suspended from celing and stretched under the action of a weight (*F*) suspended from its other end, the force exerted by the ceiling on it is equal and opposite to the weight. However, the tension at any cross-section *A* of the wire is just *F* and not 2*F*. Hence, tensile stress which is equal to the tension per unit area is equal to *F*/*A*.
2. Hooke's law is valid only in the linear part of stress-strain curve.
3. The Young's modulus and shear modulus are relevant only for solids since only solids have lengths and shapes.
4. Bulk modulus is relevant for solids, liquid and gases. It refers to the change in volume when every part of the body is under the uniform stress so that the shape of the body remains unchanged.
5. Metals have larger values of Young's modulus than alloys and elastomers. A material with large value of Young's modulus requires a large force to produce small changes in its length.
6. In daily life, we feel that a material which stretches more is more elastic, but it a is misnomer. In fact material which stretches to a lesser extent for a given load is considered to be more elastic.
7. In general, a deforming force in one direction can produce strains in other directions also. The proportionality between stress and strain in such situations cannot be described by just one elastic constant. For example, for a wire under longitudinal strain, the lateral dimensions (radius of cross section) will undergo a small change, which is described by another elastic constant of the material (called *Poisson ratio*).
8. Stress is not a vector quantity since, unlike a force, the stress cannot be assigned a specific direction. Force acting on the portion of a body on a specified side of a section has a definite direction.

MECHANICAL PROPERTIES OF FLUIDS

1. The basic property of a fluid is that it can flow. The fluid does not have any resistance to change of its shape. Thus, the shape of a fluid is governed by the shape of its container.
2. A liquid is incompressible and has a free surface of its own. A gas is compressible and it expands to occupy all the space available to it.
3. If *F* is the normal force exerted by a fluid on an area *A* then the average pressure *P*av is defined as the ratio of the force to area.

4. The unit of the pressure is the pascal (Pa). It is the same as N m-2. Other common units of pressure are
1 atm = 1.01105 Pa
1 bar = 105 Pa
1 torr = 133 Pa = 0.133 kPa
1 mm of Hg = 1 torr = 133 Pa
5. *Pascal's law* states that: Pressure in a fluid at rest is same at all points which are at the same height. A change in pressure applied to an enclosed fluid is transmitted undiminished to every point of the fluid and the walls of the containing vessel.
6. The pressure in a fluid varies with depth h according to the expression *P* = *P*a + □*gh* where □ is the density of the fluid, assumed uniform.
7. The volume of an incompressible fluid passing any point every second in a pipe of non uniform crossection is the same in the steady flow. *v A* = constant (*v* is the velocity and *A* is the area of crossection) The equation is due to mass conservation in incompressible fluid flow.
8. *Bernoulli's principle* states that as we move along a streamline, the sum of the pressure (*P*), the kinetic energy per unit volume (□*v*2/2) and the potential energy per unit volume (□*gy*) remains a constant. *P* + □*v*2/2 + □*gy* = constant The equation is basically the conservation of energy applied to non viscuss fluid motion in steady state. There is no fluid which have zero viscosity, so the above statement is true only approximately. The viscosity is like friction and converts the kinetic energy to heat energy.
9. Though shear strain in a fluid does not require shear stress, when a shear stress is applied to a fluid, the motion is generated which causes a shear strain growing with time. The ratio of the shear stress to the time rate of shearing strain is known as coefficient of viscosity, □. where symbols have their usual meaning and are defined in the text.

10. *Stokes' law* states that the viscous drag force **F** on a sphere of radius a moving with velocity **v** through a fluid of viscosity is, **F** = – 6□ □a**v**.
11. The onset of turbulence in a fluid is determined by a dimensionless parameter is called the *Reynolds number* given by *Re* = □*vd*/□ Where *d* is a typical geometrical length associated with the fluid flow and the other symbols have their usual meaning.
12. Surface tension is a force per unit length (or surface energy per unit area) acting in the plane of interface between the liquid and the bounding surface. It is the extra energy that the molecules at the interface have as compared to the interior.

POINTS TO PONDER

1. Pressure is a *scalar quantity*. The definition of the pressure as "force per unit area" may give one false impression that pressure is a vector. The "force" in the numerator of the definition is the component of the force normal to the area upon which it is impressed. While describing fluids as a conceptual shift from particle and rigid body mechanics is required. We are concerned with properties that vary from point to point in the fluid.
2. One should not think of pressure of a fluid as being exerted only on a solid like the walls of a container or a piece of solid matter immersed in the fluid. Pressure exists at all points in a fluid. An element of a fluid (such as the one shown in Fig. 10.2) is in equilibrium because the pressures exerted on the various faces are equal.
3. The expression for pressure $P = P_a + □gh$ holds true if fluid is incompressible. Practically speaking it holds for liquids, which are largely incompressible and hence is a constant with height.
4. The gauge pressure is the difference of the actual pressure and the atmospheric pressure.
$P - P_a = P_g$ Many pressure-measuring devices measure the gauge pressure. These include the tyre pressure gauge and the blood pressure gauge (sphygmomanometer).
5. A streamline is a map of fluid flow. In a steady flow two streamlines do not intersect as it means that the fluid particle will have two possible velocities at the point.
6. Bernoulli's principal does not hold in presence of viscous drag on the fluid. The work done by this dissipative viscous force must be taken into account in this case, and P_2 will be lower than the value given by Eq.
7. As the temperature rises the atoms of the liquid become more mobile and the coefficient of viscosity, □, falls. In a gas the temperature rise increases the random motion of atoms and □ increases.
8. The critical Reynolds number for the onset of turbulence is in the range 1000 to 10000, depending on the geometry of the flow. For most cases $Re < 1000$ signifies laminar flow; $1000 < Re < 2000$ is unsteady flow and $Re > 2000$ implies turbulent flow.
9. Surface tension arises due to excess potential energy of the molecules on the surface in comparison to their potential energy in the interior. Such a surface energy is present at the interface separating two substances at least one of which is a fluid. It is not the property of a single fluid alone.

THERMAL PROPERTIES OF MATTER

1. Heat is a form of energy that flows between a body and its surrounding medium by virtue of temperature difference between them. The degree of hotness of the body is quantitatively represented by temperature.
2. A temperature-measuring device (thermometer) makes use of some measurable property (called thermometric property) that changes with temperature. Different thermometers lead to different temperature scales. To construct a temperature scale, two fixed points are chosen and assigned some arbitrary values of temperature. The two numbers fix the origin of the scale and the size of its unit.
3. The Celsius temperature (t_C) and the Farenheit temperare (t_F)are related by $t_F = (9/5)\ t_C + 32$
4. The ideal gas equation connecting pressure (P), volume (V) and absolute temperature (T) is :
$PV = □RT$ where □ is the number of moles and R is the universal gas constant.
5. In the absolute temperature scale, the zero of the scale is the absolute zero of temperature
– the temperature where every substance in nature has the least possible molecular activity. The Kelvin absolute temperature scale (T) has the same unit size as the Celsius scale (T_c), but differs in the origin : $T_C = T - 273.15$
6. The coefficient of linear expansion (□ l) and volume expansion (□v) are defined by the relations
where □l and □V denote the change in length l and volume V for a change of temperature □T. The relation between them is : □v = 3 □ l
7. The specific heat capacity of a substance is defined by where m is the mass of the substance and □Q is the heat required to change its temperature by □T. The molar specific heat capacity of a substance is defined by $Q\ C\ T$ where □ is the number of moles of the substance.

8. The latent heat of fusion (*L*f) is the heat per unit mass required to change a substance from solid into liquid at the same temperature and pressure. The latent heat of vaporisation (*L*v) is the heat per unit mass required to change a substance from liquid to the vapour state without change in the temperature and pressure.
9. The three modes of heat transfer are conduction, convection and radiation.
10. In conduction, heat is transferred between neighbouring parts of a body through molecular collisions, without any flow of matter. For a bar of length *L* and uniform cross section *A* with its ends maintained at temperatures *TC* and *TD*, the rate of flow of heat *H* is obtained where *K* is the thermal conductivity of the material of the bar.
11. Newton's Law of Cooling says that the rate of cooling of a body is proportional to the excess temperature of the body over the surroundings where *T*1 is the temperature of the surrounding medium and *T*2 is the temperature of the body.

POINTS TO PONDER

1. The relation connecting Kelvin temperature (*T*) and the Celsius temperature *t*c *T* = *t*c + 273.15
and the assignment *T* = 273.16 K for the triple point of water are exact relations (by choice). With this choice, the Celsius temperature of the melting point of water and boiling point of water (both at 1 atm pressure) are very close to, but not exactly equal to 0 °C and 100 °C respectively. In the original Celsius scale, these latter fixed points were exactly at 0 °C and 100 °C (by choice), but now the triple point of water is the preferred choice for the fixed point, because it has a unique temperature.
2. A liquid in equilibrium with vapour has the same pressure and temperature throughout the system; the two phases in equilibrium differ in their molar volume (i.e. density). This is true for a system with any number of phases in equilibrium.
3. Heat transfer always involves temperature difference between two systems or two parts of the same system. Any energy transfer that does not involve temperature difference in some way is not heat.
4. Convection involves flow of matter *within a fluid* due to unequal temperatures of its parts. A hot bar placed under a running tap loses heat by conduction between the surface of the bar and water and not by convection within water.

THERMODYNAMICS

1. The zeroth law of thermodynamics states that '*two systems in thermal equilibrium with a third system are in thermal equilibrium with each other*'. The Zeroth Law leads to the concept of temperature.
2. Internal energy of a system is the sum of kinetic energies and potential energies of the molecular constituents of the system. It does not include the over-all kinetic energy of the system. Heat and work are two modes of energy transfer to the system. Heat is the energy transfer arising due to temperature difference between the system and the surroundings. Work is energy transfer brought about by other means, such as moving the piston of a cylinder containing the gas, by raising or lowering some weight connected to it.
3. The first law of thermodynamics is the general law of conservation of energy applied to any system in which energy transfer from or to the surroundings (through heat and work) is taken into account. It states that $\Delta Q = \Delta U + \Delta W$ where ΔQ is the heat supplied to the system, ΔW is the work done by the system and ΔU is the change in internal energy of the system.
4. The specific heat capacity of a substance is defined by *smqt* where *m* is the mass of the substance and ΔQ is the heat required to change its temperature by ΔT. The molar specific heat capacity of a substance is defined by where μ is the number of moles of the substance. For a solid, the law of equipartition of energy gives *C* = 3 *R* which generally agrees with experiment at ordinary temperatures. Calorie is the old unit of heat. 1 calorie is the amount of heat required to raise the
temperature of 1 g of water from 14.5 °C to 15.5 °C. 1 cal = 4.186 J.
5. For an ideal gas, the molar specific heat capacities at constant pressure and volume satisfy the relation *Cp* – *Cv* = *R* where *R* is the universal gas constant.
6. Equilibrium states of a thermodynamic system are described by state variables. The value of a state variable depends only on the particular state, not on the path used to arrive at that state. Examples of state variables are pressure (*P*), volume (*V*), temperature (*T*), and mass (*m*). Heat and work are not state variables. An Equation of State (like the ideal gas equation $PV = \mu RT$) is a relation connecting different state variables.
7. A quasi-static process is an infinitely slow process such that the system remains in thermal and mechanical equilibrium with the surroundings throughout. In a quasi-static process, the pressure and temperature of the environment can differ from those of the system only infinitesimally.

8. In an isothermal expansion of an ideal gas from volume V_1 to V_2 at temperature T the heat absorbed (Q) equals the work done (W) by the gas.
11. In a refrigerator or a heat pump, the system extracts heat Q_2 from the cold reservoir and releases Q_1 amount of heat to the hot reservoir, with work W done on the system. The co-efficient of performance of a refrigerator.
12. The second law of thermodynamics disallows some processes consistent with the First Law of Thermodynamics. It states *Kelvin-Planck statement*. No process is possible whose sole result is the absorption of heat from a reservoir and complete conversion of the heat into work.
Clausius statement: No process is possible whose sole result is the transfer of heat from a colder object to a hotter object. Put simply, the Second Law implies that no heat engine can have efficiency □ equal to 1 or no refrigerator can have co-efficient of performance □ equal to infinity.
13. A process is reversible if it can be reversed such that both the system and the surroundings return to their original states, with no other change anywhere else in the universe. Spontaneous processes of nature are irreversible. The idealised reversible process is a quasi-static process with no dissipative factors such as friction, viscosity, etc.
14. Carnot engine is a reversible engine operating between two temperatures T_1 (source) and T_2 (sink). The Carnot cycle consists of two isothermal processes connected by two adiabatic processes. The efficiency of a Carnot engine is given by T η = 1 – (Carnot engine). No engine operating between two temperatures can have efficiency greater than that of the Carnot engine.
15. If $Q > 0$, heat is added to the system
If $Q < 0$, heat is removed to the system
If $W > 0$, Work is done by the system
If $W < 0$, Work is done on the system

Quantity Symbol Dimensions Unit Remark
Co-efficienty of volume □v [K^{-1}] K^{-1} □v = 3 □1 expansion
Heat supplied to a system □*Q* [$ML^2 T^{-2}$] J *Q* is not a state variable
Specific heat *s* [$L^2 T^{-2} K^{-1}$] J $kg^{-1} K^{-1}$
Thermal Conductivity *K* [$MLT^{-3} K^{-1}$] J $s^{-1} K^{-1}$ $H = - KA$

KINETIC THEORY

1. The ideal gas equation connecting pressure (P), volume (V) and absolute temperature (T) is
PV = □ $RT = k_B NT$ where □ is the number of moles and N is the number of molecules. R and k_B are universal constants.
$R = 8.314$ J $mol^{-1} K^{-1}$, k_B =AR
$N = 1.38 \times 10^{-23}$ J K^{-1}
Real gases satisfy the ideal gas equation only approximately, more so at low pressures and high temperatures.
2. Kinetic theory of an ideal gas gives the relation *P n m v* where *n* is number density of molecules, *m* the mass of the molecule and v^2 is the mean of squared speed. Combined with the ideal gas equation it yields a kinetic interpretation of temperature. This tells us that the temperature of a gas is a measure of the average kinetic energy of a molecule, *independent of the nature of the gas or molecule*. In a mixture of gases at a fixed temperature the heavier molecule has the lower average speed.
3. The translational kinetic energy $E = 2/3\, k_B NT$.
4. The law of equipartition of energy states that if a system is in equilibrium at absolute temperature T, the total energy is distributed equally in different energy modes of absorption, the energy in each mode being equal to _ $k_B T$. Each translational and rotational degree of freedom corresponds to one energy mode of absorption and has energy _ $k_B T$. Each vibrational frequency has two modes of energy (kinetic and potential) with corresponding energy = 2 _ $k_B T$ = $k_B T$.
5. Using the law of equipartition of energy, the molar specific heats of gases can be determined and the values are in agreement with the experimental values of specific heats of several gases. The agreement can be improved by including vibrational modes of motion.
6. The mean free path l is the average distance covered by a molecule between two successive collisions where n is the number density and d the diameter of the molecule.

POINTS TO PONDER

1. Pressure of a fluid is not only exerted on the wall. Pressure exists everywhere in a fluid. Any layer of gas inside the volume of a container is in equilibrium because the pressure is the same on both sides of the layer.

2. We should not have an exaggerated idea of the intermolecular distance in a gas. At ordinary pressures and temperatures, this is only 10 times or so the interatomic distance in solids and liquids. What is different is the mean free path which in a gas is 100 times the interatomic distance and 1000 times the size of the molecule.
3. The law of equipartition of energy is stated thus: the energy for each degree of freedom in thermal equilibrium is _ *k B T*. Each quadratic term in the total energy expression of a molecule is to be counted as a degree of freedom. Thus, each vibrational mode gives 2 (not 1) degrees of freedom (kinetic and potential energy modes), corresponding to the energy 2 _ *k BT* = *k BT*
4. Molecules of air in a room do not all fall and settle on the ground (due to gravity) because of their high speeds and incessant collisions. In equilibrium, there is a very slight increase in density at lower heights (like in the atmosphere). The effect is small since the potential energy (*mgh*) for ordinary heights is much less than the average kinetic energy _ *mv*2 of the molecules.
5. < *v*2 > is not always equal to (< *v* >)2. The average of a squared quantity is not necessarily the square of the average. Can you find examples for this statement.

OSCILLATIONS

1. The motions which repeat themselves are called *periodic motions*.
2. The *period T* is the time required for one complete oscillation, or cycle. It is related to the frequency □ by, v= 1/T assorted lengths suspended from a common rope. The pendulums 1 and 4 have the same lengths and the others have different lengths. Now let us set pendulum 1 into motion. The energy from this pendulum gets transferred to other pendulums through the connecting rope and they start oscillating. The driving force is provided through the connecting rope. The frequency of this force is the frequency with which pendulum 1 oscillates. If we observe the response of pendulums 2, 3 and 5, they first start oscillating with their natural frequencies of oscillations and different amplitudes, but this motion is gradually damped and not sustained. Their frequencies of oscillation gradually change and ultimately they oscillate with *simple pendulums of different lengths suspended from a common support*. The *frequency* □ of periodic or oscillatory motion is the number of oscillations per unit time. In the SI, it is measured in hertz :
1 hertz = 1 Hz = 1 oscillation per second = 1s–1
3. In *simple harmonic motion* (SHM), the displacement *x* (*t*) of a particle from its equilibrium position is given by, *x* (*t*) = *A* cos (□*t* + □) (displacement), in which *A* is the *amplitude* of the displacement, the quantity (□*t* + □) is the phase of the motion, and □ is the *phase constant*. The *angular frequency* □ is related to the period and frequency of the motion by, 2 2 *T* (angular frequency).
4. Simple harmonic motion is the projection of uniform circular motion on the diameter of the circle in which the latter motion occurs.
5. The particle velocity and acceleration during SHM as functions of time are given by, *v* (*t*) = –□*A* sin (□*t* + □) (velocity), *a* (*t*) = –□2*A* cos (□*t* + □) = –□2*x* (*t*) (acceleration), Thus we see that both velocity and acceleration of a body executing simple harmonic motion are periodic functions, having the velocity *amplitude vm*=□ *A* and *acceleration amplitude am* =□ 2*A*, respectively.
6. The force acting simple harmonic motion is proportional to the displacement and is always directed towards the centre of motion.
7. A particle executing simple harmonic motion has, at any time, kinetic energy *K* = _ *mv2* and potential energy *U* = _ *kx2*. If no friction is present the mechanical energy of the system, *E* = *K* + *U* always remains constant even though *K* and *U* change with time.
8. A particle of mass *m* oscillating under the influence of a Hooke's law restoring force given by *F* = – *k x* exhibits simple harmonic motion with ω *k m* = (angular frequency) 2*mTk*(period)Such a system is also called a linear oscillator.
9. The motion of a simple pendulum swinging through small angles is approximately simple harmonic. The period of oscillation is given by, 2*LTg*
10. The mechanical energy in a real oscillating system decreases during oscillations because external forces, such as drag, inhibit the oscillations and transfer mechanical energy to thermal energy. The real oscillator and its motion are then said to be *damped*. If the *damping force* is given by *Fd* = –*bv*, where *v* is the velocity of the oscillator and *b* is a *damping constant*, then the displacement of the oscillator is given by, *x* (*t*) = *A e*–*bt*/2*m* cos (□*t*′ + □) where □,′ the angular frequency of the damped oscillator, If the damping constant is small then □ ′□ ≈□, where □ is the angular frequency of the undamped oscillator. The mechanical energy *E* of the damped oscillator is given by 2 *E(t) kA2e bt m*

11. If an external force with angular frequency □*d* acts on an oscillating system with natural angular frequency □, the system oscillates with angular frequency □*d*. The amplitude of oscillations is the greatest when □*d* = □ a condition called *resonance*.

POINTS TO PONDER

1. The period *T* is the *least time* after which motion repeats itself. Thus, motion repeats itself after *nT* where *n* is an integer.
2. Every periodic motion is not simple harmonic motion. Only that periodic motion governed by the force law *F* = – *k x* is simple harmonic.
3. Circular motion can arise due to an inverse-square law force (as in planetary motion) as well as due to simple harmonic force in two dimensions equal to: –*m*□*2r*. In the latter case, the phases of motion, in two perpendicular directions (*x* and *y*) must differ by □/2. Thus, a particle subject to a force –*m*□*2r* with initial position (o, *A*) and velocity (□*A*, o) will move uniformly in a circle of radius *A*.
4. For linear simple harmonic motion with a given □ two arbitrary initial conditions are necessary and sufficient to determine the motion completely. The initial condition may be (i) initial position and initial velocity or (ii) amplitude and phase or (iii) energy and phase.
5. From point 4 above, given amplitude or energy, phase of motion is determined by the initial position or initial velocity.
6. A combination of two simple harmonic motions with arbitrary amplitudes and phases is not necessarily periodic. It is periodic only if frequency of one motion is an integral multiple of the other's frequency. However, a periodic motion can always be expressed as a sum of infinite number of harmonic motions with appropriate amplitudes.
7. The period of SHM does not depend on amplitude or energy or the phase constant. Contrast this with the periods of planetary orbits under gravitation (Kepler's third law).
8. The motion of a simple pendulum is simple harmonic for small angular displacement.
9. For motion of a particle to be simple harmonic, its displacement *x* must be expressible in either of the following forms : *x* = *A* cos □*t* + *B* sin □*t x* = *A* cos (□*t* + □), *x* = *B* sin (□*t* + □)
The three forms are completely equivalent (any one can be expressed in terms of any other two forms). Thus, damped simple harmonic motion [Eq. (14.31)] is not strictly simple harmonic. It is approximately so only for time intervals much less than *2m*/*b* where *b* is the damping constant.
10. In forced oscillations, the steady state motion of the particle (after the force oscillations die out) is simple harmonic motion whose frequency is the frequency of the driving frequency □*d*, not the natural frequency □ of the particle.
11. In the ideal case of zero damping, the amplitude of simple harmonic motion at resonance is infinite. This is no problem since all real systems have some damping, however, small.
12. Under forced oscillation, the phase of harmonic motion of the particle differs from the phase of the driving force.

WAVES

1. *Mechanical waves* can exist in material media and are governed by Newton's Laws.
2. *Transverse waves* are waves in which the particles of the medium oscillate perpendicular to the direction of wave propagation.
3. *Longitudinal waves* are waves in which the particles of the medium oscillate along the direction of wave propagation.
4. *Progressive wave* is a wave that moves from one point of medium to another.
5. *The displacement* in a sinusoidal wave propagating in the positive x direction is given by *y* (*x*, *t*) = *a sin* (*kx* – □*t* + □) where *a is the* amplitude of the wave, *k* is the angular wave number, □ *is the* angular frequency, (*kx* – □ *t* + □) *is the* phase, *and* □ *is the* phase constant or phase angle.
6. *Wavelength* □ of a progressive wave is the distance between two consecutive points of the same phase at a given time. In a stationary wave, it is twice the distance between two consecutive nodes or antinodes.
7. *Period T* of oscillation of a wave is defined as the time any element of the medium takes to move through one complete oscillation. It is related to the *angular frequency* □ through the relation *T* = 2π ω
8. *Frequency v* of a wave is defined as 1/*T* and is related to angular frequency by 2
9. *Speed* of a progressive wave is given by k T *v*
10. *The speed of a transverse wave* on a stretched string is set by the properties of the string. The speed on a string with tension *T* and linear mass density □ is *v* = *T* μ

11. *Sound waves* are longitudinal mechanical waves that can travel through solids, liquids, or gases. The speed *v* of sound wave in a fluid having *bulk modulus B* and density □ is *vB*=ρ
The speed of longitudinal waves in a metallic bar is *vY*=ρ
For gases, since *B* = □*P*, the speed of sound is *vP*=γρ
12. When two or more waves traverse the same medium, the displacement of any element of the medium is the algebraic sum of the displacements due to each wave. This is known as the *principle of superposition* of waves 1( )*niiy f x vt*== Σ –
13. Two sinusoidal waves on the same string exhibit *interference*, adding or cancelling according to the principle of superposition. If the two are travelling in the same direction and have the same amplitude *a* and frequency but differ in phase by a *phase constant* □, the result is a single wave with the same frequency □ □ *y* (*x, t*) = 1 12 cos sin t2 2*a kx*.
If □ = 0 or an integral multiple of 2□, the waves are exactly in phase and the interference is constructive; if □ = □, they are exactly out of phase and the interference is destructive.
14. A travelling wave, at a rigid boundary or a closed end, is reflected with a phase reversal but the reflection at an open boundary takes place without any phase change.
For an incident wave *yi* (*x, t*) = *a* sin (*kx* – □*t*) the reflected wave at a rigid boundary is *yr* (*x, t*) = – *a* sin (*kx* + □*t*) For reflection at an open boundary *yr* (*x,t*) = *a* sin (*kx* + □*t*)
15. The interference of two identical waves moving in opposite directions produces *standing waves*. For a string with fixed ends, the standing wave is given by *y* (*x, t*) = [2*a* sin *kx*] cos □*t*
Standing waves are characterised by fixed locations of zero displacement called *nodes* and fixed locations of maximum displacements called *antinodes*. The separation between two consecutive nodes or antinodes is □/2. A stretched string of length *L* fixed at both the ends vibrates with frequencies given by *v*1,2 2*vLn* = 1, 2, 3, ...
The set of frequencies given by the above relation are called the *normal modes* of oscillation of the system. The oscillation mode with lowest frequency is called the *fundamental mode* or the *first harmonic*. The *second harmonic* is the oscillation mode with *n* = 2 and so on.
A pipe of length *L* with one end closed and other end open (such as air columns) vibrates with frequencies given by *v* n ½ 2L *v* , *n* = 0, 1, 2, 3, ...
The set of frequencies represented by the above relation are the *normal modes* of oscillation of such a system. The lowest frequency given by *v*/4*L* is the fundamental mode or the first harmonic. 16. A string of length *L* fixed at both ends or an air column closed at one end and open at the other end, vibrates with frequencies called its normal modes. Each of these frequencies is a *resonant frequency* of the system.
17. *Beats* arise when two waves having slightly different frequencies, □*1* and □2 and comparable amplitudes, are superposed. The beat frequency is □*beat* = □1 ~ □2
18. The *Doppler effect* is a change in the observed frequency of a wave when the source and the observer O moves relative to the medium. For sound the observed frequency □ is given in terms of the source frequency □*o* by *v* = *vo* 0s*v vv v* + here *v* is the speed of sound through the medium, *vo* is the velocity of observer relative to the medium, and *vs* is the source velocity relative to the medium. In using this formula, velocities in the direction OS should be treated as positive and those opposite to it should be taken to be negative.

POINTS TO PONDER

1. A wave is not motion of matter as a whole in a medium. A wind is different from the sound wave in air. The former involves motion of air from one place to the other. The latter involves compressions and rarefactions of layers of air.
2. In a wave, energy and *not the matter* is transferred from one point to the other.
3. Energy transfer takes place because of the coupling through elastic forces between neighbouring oscillating parts of the medium.
4. Transverse waves can propagate only in medium with shear modulus of elasticity, Longitudinal waves need bulk modulus of elasticity and are therefore, possible in all media, solids, liquids and gases.
5. In a harmonic progressive wave of a given frequency all particles have the same amplitude but different phases at a given instant of time. In a stationary wave, all particles between two nodes have the same phase at a given instant but have different amplitudes.
6. Relative to an observer at rest in a medium the speed of a mechanical wave in that medium (*v*) depends only on elastic and other properties (such as mass density) of the medium. It does not depend on the velocity of the source.
7. For an observer moving with velocity *v*o relative to the medium, the speed of a wave is obviously different from *v* and is given by *v* ± *v*o.

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RAY OPTICS AND OPTICAL INSTRUMENTS

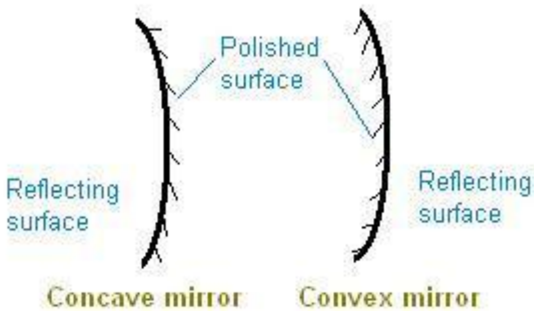
1. Reflection is governed by the equation $\angle i = \angle r'$ and refraction by the Snell's law, $\sin i/\sin r = n$, where the incident ray, reflected ray, refracted ray and normal lie in the same plane. Angles of incidence, reflection and refraction are i, r' and r, respectively.
2. The *critical angle of incidence* i_c for a ray incident from a denser to rarer medium, is that angle for which the angle of refraction is 90°. For $i > i_c$, total internal reflection occurs. Multiple internal reflections in diamond ($i_c \cong 24.4°$), totally reflecting prisms and mirage, are some examples of total internal reflection. Optical fibres consist of glass fibres coated with a thin layer of material of *lower* refractive index. Light incident at an angle at one end comes out at the other, after multiple internal reflections, even if the fibre is bent. 3. *Cartesian sign convention*: Distances measured in the same direction as the incident light are positive; those measured in the opposite direction are negative. All distances are measured from the pole/optic centre of the mirror/lens on the principal axis. The heights measured upwards above *x*-axis and normal to the principal axis of the mirror/
lens are taken as positive. The heights measured downwards are taken as negative.

Mirror equation: $1/V=1/U+1/F$ where u and v are object and image distances, respectively and f is the focal length of the mirror. f is (approximately) half the radius of curvature R. f is negative for concave mirror; f is positive for a convex mirror.
5. For a prism of the angle A, of refractive index n 2 placed in a medium of refractive index n1,
6. *For refraction through a spherical interface* (from medium 1 to 2 of
refractive index n1 and n2, respectively). $R1$ and $R2$ are the radii of curvature of the lens surfaces. f is positive for a converging lens; f is negative for a diverging lens. The power of a lens $P = 1/f$.
The SI unit for power of a lens is dioptre (D): 1 D = 1 m–1. If several thin lenses of focal length f1, f2, f3,.. are in contact, the effective focal length of their combination. The total power of a combination of several lenses is $P = P1 + P2 + P3 + \ldots$
7. *Dispersion* is the splitting of light into its constituent colours.
8. *The Eye*: The eye has a convex lens of focal length about 2.5 cm. This focal length can be varied somewhat so that the image is always formed on the retina. This ability of the eye is called *accommodation*. In a defective eye, if the image is focussed before the retina (myopia), a diverging corrective lens is needed; if the image is focussed beyond the retina (hypermetropia), a converging corrective lens is needed. Astigmatism is corrected by using cylindrical lenses.

Magnifying power m of a simple microscope is given by $m = 1 + (D/f)$, where D = 25 cm is the least distance of distinct vision and f is the focal length of the convex lens. If the image is at infinity, $m = D/f$. For a compound microscope, the magnifying power is given by $m = m_e \times m_0$ where $m_e = 1 + (D/f_e)$, is the magnification due to the eyepiece and m_o is the magnification produced by the objective.
10. *Magnifying power m of a telescope* is the ratio of the angle ¤ subtended at the eye by the image to the angle ¤ subtended at the eye by the object.

Spherical Mirror

Mirrors having curved surfaces are known as Spherical Mirrors. There are two types of spherical mirrors – Concave Mirror and Convex Mirror



Concave Mirror

A concave mirror is a spherical mirror whose reflecting surface is curved inwards.

Convex Mirror

A convex mirror is a spherical mirror whose reflecting surface is curved outwards. In a convex mirror the reflection of light takes place from its outer surface.

Use of Concave Mirror

1. A concave mirror forms image according to the position of the object. If an object is placed very close to a concave mirror i.e. between the focus and the pole, then the image formed is virtual, erect and highly magnified. Because of this property concave mirrors are used as:

(a) As a dentist's mirror (to see a larger image of teeth),

(b) For examining eyes, ears, nose and throat by Doctors

(c) Shaving mirror.

2. When a light emitting object is placed at the focus of a concave mirror, then all the reflected rays become parallel to the principal axis. This property of a concave mirror is used in;

(a) A torch

(b) Behind the headlights of vehicles and light posts etc.

3. Large concave mirrors are used to concentrate sunlight to produce heat in solar furnaces.

Use of Convex Mirror

A convex mirror forms virtual, erect and diminished image of objects which subsequently increases the field of view. Because f this property of convex mirrors they are used in –

(a) Rear-view mirrors of vehicles

(b) Safety mirrors in stores.

Pole of a Spherical Mirror

The geometrical centre of the central point of a mirror is called pole. It lies on the mirror and is denoted by the letter P (as shown in the adjacent figure).

Center of Curvature

It is the geometrical center of the sphere from which the given spherical mirror is obtained. It is denoted by the letter C.

Aperture

The width of the reflecting surface is called aperture (AB in the figure).

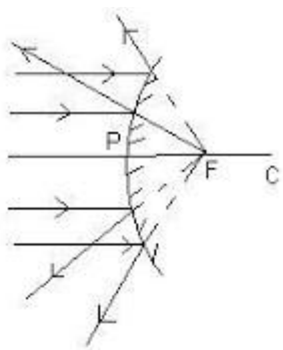
Radius of Curvature

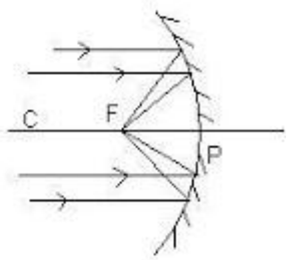
The radius of the curvature is the radius of the sphere from which the spherical mirror is obtained. It is denoted by R which is equal to the distance between the center of curvature (C) and pole (P). .

Principal Axis

The imaginary line passing through the Pole and the Center of Curvature is called the Principal Axis (PC).

Focus





The focus (F) is the point on the principal axis of a spherical mirror where all the incident rays parallel to the principal axis meet or appear to be meeting after reflection. A concave mirror has got a real focus which lies on the same side of reflecting surface whereas a convex mirror has got a virtual focus which is obtained on the opposite side of the reflecting surface by extrapolating the rays reflected from the mirror surface. F is the distance between the focus and the pole of the mirror. Radius of curvature (R) and the focal length (F) of a spherical mirror are related as:

R = 2F

Focal Length

The distance between the focus (F) and the pole (P) is called the focal length. It is generally denoted by f.

(f = R/2).

Light Wave

Light is a form of energy which brings the sensation of sight. Light waves travel with a speed of 3 x 10^8 ms^{-1} in free space. Its speed depends on the medium. Light wave is a transverse wave and does not require any medium to propagate.

Ray and Beam

Light travels in a straight line. An arrow which represents the direction of propagation of light is called the ray of light.

A bundle of rays originating from the same source of light in a particular direction is called a beam of light.

Rectilinear Propagation of Light

The property of light of travelling in a straight line is called the Rectilinear Propagation of Light.

Reflection of Light

The scattering back of the light by any shining and smooth surface is known as reflection of light.

Real and Virtual Image

If light after reflection converges to a point to form an image of its own, it's called a real image. If they are diverging (appear to be meeting at a point), then it forms a virtual image.

Real image can be obtained on a screen but it is not possible in case of virtual image.

Plane Mirror

- Image formed by a plane mirror is - virtual, erect, size equal to that of the object, at the distance behind the mirror as the object is in front of the mirror, and laterally inverted.
- When a plane mirror is turned by an angle 1^O, the reflected ray will turn by an angle of 2^O.
- When the light falls normally on a plane mirror, it will retrace its path.□
- □ o see full size image of a person he needs a mirror of length equal to half of his height.
- The radius of curvature of a plane mirror is infinity, so its R = f = α (infinity).
- The magnification of the image formed by a plane mirror is +1.

POINTS TO PONDER

1. The laws of reflection and refraction are true for all surfaces and pairs of media at the point of the incidence.
2. The real image of an object placed between *f* and 2*f* from a convex lens can be seen on a screen placed at the image location. If the screen is removed, is the image still there? This question puzzles many, because it is difficult to reconcile ourselves with an image suspended in air without a screen. But the image does exist. Rays from a given point on the object are converging to an image point in space and diverging away. The screen simply diffuses these rays, some of which reach our eye and we see the image. This can be seen by the images formed in air during a laser show.
3. Image formation needs regular reflection/refraction. In principle, all rays from a given point should reach the same image point. This is why you do not see your image by an irregular reflecting object, say the page of a book.
4. Thick lenses give coloured images due to dispersion. The variety in colour of objects we see around us is due to the constituent colours of the light incident on them. A monochromatic light may produce an entirely different perception about the colours on an object as seen in
white light.
5. For a simple microscope, the angular size of the object equals the angular size of the image. Yet it offers magnification because we can keep the small object much closer to the eye than 25 cm and hence have it subtend a large angle. The image is at 25 cm which we can see. Without the microscope, you would need to keep the small object at 25 cm which would subtend a very small angle.

WAVE OPTICS

1. Huygens' principle tells us that each point on a wavefront is a source of secondary waves, which add up to give the wavefront at a later time.
2. Huygens' construction tells us that the new wavefront is the forward envelope of the secondary waves. When the speed of light is independent of direction, the secondary waves are spherical. The rays are then perpendicular to both the wavefronts and the time of travel is the same measured along any ray. This principle leads to the well known laws of reflection and refraction.
3. The principle of superposition of waves applies whenever two or more sources of light illuminate the same point. When we consider the intensity of light due to these sources at the given point, there is an interference term in addition to the sum of the individual intensities. But this term is important only if it has a non-zero average, which occurs only if the sources have the same frequency and a stable phase difference.
4. Young's double slit of separation *d* gives equally spaced fringes of angular separation □/*d*. The source, mid-point of the slits, and central bright fringe lie in a straight line. An extended source will destroy the fringes if it subtends angle more than □/*d* at the slits.
5. A single slit of width *a* gives a diffraction pattern with a central maximum. The intensity falls to zero at angles with successively weaker secondary maxima in between. Diffraction limits the angular resolution of a telescope to □/*D* where *D* is the diameter. Two stars closer than this give strongly overlapping images. Similarly, a microscope objective subtending angle 2□ at the focus,
in a medium of refractive ind ex *n*, will just separate two objects spaced at a distance □/(2*n* sin □) which is the resolution limit of a microscope. Diffraction determines the limitations of the concept of light rays. A beam of width *a* travels a distance *a*2/□, called the Fresnel distance, before it starts to spread out due to diffraction.
6. Natural light, e.g., from the sun is unpolarised. This means the electric vector takes all possible directions in the transverse plane, rapidly and randomly, during a measurement. A polaroid transmits only one component (parallel to a special axis). The resulting light is called linearly polarised or plane polarised. When this kind of light is viewed through a second polaroid whose axis turns through 2□, two maxima and minima of intensity are seen. Polarised light can also

be produced by reflection at a special angle (called the Brewster angle) and by scattering through □/2 in the earth's atmosphere.

POINTS TO PONDER

1. Waves from a point source spread out in all directions, while light was seen to travel along narrow rays. It required the insight and experiment of Huygens, Young and Fresnel to understand how a wave theory could explain all aspects of the behaviour of light.
2. The crucial new feature of waves is interference of amplitudes from different sources which can be both constructive and destructive, as shown in Young's experiment.
3. Even a wave falling on single slit should be regarded as a large number of sources which interefere constructively in the forward direction (□ ≅ 0), and destructively in other directions.
4. Diffraction phenomena define the limits of ray optics. The limit of the ability of microscopes and telescopes to distinguish very close objects is set by the wavelength of light.
5. Most interference and diffraction effects exist even for longitudinal waves like sound in air. But polarisation phenomena are special to transverse waves like light waves.

DUAL NATURE OF RADIATION AND MATTER

The history of wave-particle flip-flop

What is light? This question has haunted mankind for a long time. But systematic experiments were done by scientists since the dawn of the scientific and industrial era, about four centuries ago. Around the same time,theoretical models about what light is made of were developed. While building a model in any branch of science, it is essential to see that it is able to explain all the experimental observations existing at that time. It is therefore appropriate to summarize some observations about light that were known in the seventeenth century. The properties of light known at that time included (a) rectilinear propagation of light, (b) reflection from plane and curved surfaces, (c) refraction at the boundary of two media, (d) dispersion into various colours, (e) high speed. Appropriate laws were formulated for the first four phenomena. For example, Snell formulated his laws of refraction in 1621. Several scientists right from the days of Galileo had tried to measure the speed of light. But they had not been able to do so. They had only concluded that it was higher than the limit of their measurement. Two models of light were also proposed in the seventeenth century. Descartes, in early decades of seventeenth century, proposed that light consists of particles, while Huygens, around 1650-60, proposed that light consists of waves. Descartes□ proposal was merely a philosophical model, devoid of any experiments or scientific arguments. Newton soon after, around 1660-70, extended Descartes□ particle model, known as *corpuscular theory*, built it up as a scientific theory, and explained various known properties with it. These models, light as waves and as particles, in a sense, are quite opposite of each other. But both models could explain all the known properties of light. There was nothing to choose between them. The history of the development of these models over the next few centuries is interesting. Bartholinus, in 1669, discovered double refraction of light in some crystals, and Huygens, in 1678, was quick to explain it on the basis of his wave theory of light. In spite of this, for over one hundred years, Newton's particle model was firmly believed and preferred over the wave model. This was partly because of its simplicity and partly because of Newton's influence on contemporary physics. Then in 1801, Young performed his double-slit experiment and observed interference fringes. This phenomenon could be explained only by wave theory. It was realized that diffraction was also another phenomenon which could be explained only by wave theory. In fact, it was a natural consequence of Huygens idea of secondary wavelets emanating from every point in the path of light. These experiments could not be explained by assuming that light consists of particles. Another phenomenon of polarisation was discovered around 1810, and this too could be naturally explained by the wave theory. Thus wave theory of Huygens came to the forefront and Newton's particle theory went into the background. This situation again continued for almost a century. Better experiments were performed in the nineteenth century to determine the speed of light. With more accurate experiments, a value of 3×108 m/s for speed of light in vacuum was arrived at. Around 1860, Maxwell proposed his equations of electromagnetism and it was realized that *all* electromagnetic phenomena known at that time could be explained by Maxwell's four equations. Soon Maxwell showed that electric and magnetic fields could propagate through empty space (vacuum) in the form of electromagnetic waves. He calculated the speed of these waves and arrived at a theoretical value of 2.998×108 m/s. The close agreement of this value with the experimental value suggested that light consists of electromagnetic waves. In 1887 Hertz demonstrated the generation and detection of such waves. This established the wave theory of light on a firm footing. We might say that while eighteenth century belonged to the particle model, the nineteenth century belonged to the wave model of light. Vast amounts of experiments were done during the period 1850-1900 on heat and related phenomena, an altogether different area of physics. Theories and models like kinetic theory and thermodynamics were developed which quite successfully explained the various phenomena, except one. Everybody at any temperature emits radiation of all wavelengths. It also absorbs radiation falling on it. A body which absorbs all the radiation falling on it is called a *black body*. It is an ideal concept in physics, like concepts of a point mass or uniform motion. A graph of the intensity of radiation emitted by a body versus wavelength is called the *black body spectrum*. No theory in those days could explain the complete black body spectrum! In 1900, Planck hit upon a novel idea. If we assume, he said, that radiation is emitted in packets of energy instead of continuously as in a wave, then we can explain the black body spectrum. Planck himself regarded these quanta, or packets, as a property of emission and absorption, rather than that of light. He derived a formula which agreed with the entire spectrum. This was a confusing mixture of wave and particle pictures – radiation is emitted as a particle, it travels as a wave, and is again absorbed as a particle! Moreover, this put physicists in a dilemma. Should we again accept the particle picture of light just to explain one phenomenon? Then what happens to the phenomena of interference and diffraction which cannot be explained by the particle model? But soon in 1905, Einstein explained the photoelectric effect by assuming the particle picture of light. In 1907, Debye explained the low temperature specific heats of solids by using the particle picture for lattice vibrations in a crystalline solid. Both these phenomena belonging to widely diverse areas of physics could be explained only by the particle model and not by the wave model. In 1923, Compton's x-ray scattering experiments from atoms also went in favour of the particle picture. This increased the dilemma further. Thus by 1923, physicists faced with the following situation. (a) There were some phenomena like rectilinear propagation, reflection, refraction, which could be explained by either particle model or by wave model. (b) There were some phenomena such as diffraction and interference which could be explained only by the wave model but *not* by the particle model. (c) There were some phenomena such as black body radiation, photoelectric effect, and Compton cattering which could be explained only by the particle model but *not* by the wave model. Somebody in those days aptly remarked that light behaves as a particle on Mondays, Wednesdays and Fridays, and as a wave on Tuesdays, Thursdays and Saturdays, and we don't talk of light on Sundays! In 1924, de Broglie proposed his theory of wave-particle duality in which he said that not only photons of light but also 'particles' of matter such as electrons and atoms possess a dual character, sometimes behaving like a particle and sometimes as a wave. He gave a formula connecting their mass, velocity, momentum (particle characteristics), with their wavelength and frequency (wave characteristics)! In 1927 Thomson, and Davisson and Germer, in separate experiments, showed that electrons did behave like waves with a wavelength which agreed with that given by de Broglie's formula. Their experiment was on diffraction of electrons through crystalline solids, in which the regular arrangement of atoms acted like a grating. Very soon, diffraction experiments with other 'particles' such as neutrons and protons were performed and these too confirmed with de Broglie's formula. This confirmed wave-particle duality as an established principle of physics. Here was a principle, physicists thought, which explained all the phenomena mentioned above not only for light but also for the so-called particles. But there was no basic theoretical foundation for wave-particle duality. De Broglie's proposal was merely a qualitative argument based on symmetry of nature. Wave-particle duality was at best a principle, not an outcome of a sound fundamental theory. It is true that all experiments whatever agreed with de Broglie formula. But physics does not work that way. On the one hand, it needs experimental confirmation, while on the other hand, it also needs sound theoretical basis for the models proposed. This was developed over the next two decades. Dirac developed his theory of radiation in about 1928, and Heisenberg and Pauli gave it a firm footing by 1930. Tomonaga, Schwinger, and Feynman, in late 1940s, produced further refinements and cleared the theory of inconsistencies which were noticed. All these theories mainly put wave-particle duality on a theoretical footing. Although the story continues, it grows more and more complex and beyond the scope of this note. But we have here the essential structure of what happened, and let us be satisfied with it at the moment. Now it is regarded as a natural consequence of present theories of physics that electromagnetic radiation as well as particles of matter exhibit both wave and particle properties in different experiments, and sometimes even in the different parts of the same experiment.

1. The minimum energy needed by an electron to come out from a metal surface is called the work function of the metal. Energy (greater than the work function □ □)□required for electron emission from the metal surface can be supplied by suitably heating or applying strong electric field or irradiating it by light of suitable frequency.

2. Photoelectric effect is the phenomenon of emission of electrons by metals when illuminated by light of suitable frequency. Certain metals respond to ultraviolet light while others are sensitive even to the visible light. Photoelectric effect involves conversion of light energy into electrical
energy. It follows the law of conservation of energy. The photoelectric emission is an instantaneous process and possesses certain special features.

3. Photoelectric current depends on (i) the intensity of incident light, (ii) the potential difference applied between the two electrodes, and (iii) the nature of the emitter material.
4. The stopping potential (*V*o) depends on (i) the frequency of incident light, and (ii) the nature of the emitter material. For a given frequency of incident light, it is independent of its intensity. The stopping potential is directly related to the maximum kinetic energy of electrons emitted:
*e V*0 = (1/2) *m v*2 *max* = *Kmax*.
5. Below a certain frequency (threshold frequency) □ 0, characteristic of the metal, no photoelectric emission takes place, no matter how large the intensity may be.
6. The classical wave theory could not explain the main features of photoelectric effect. Its picture of continuous absorption of energy from radiation could not explain the independence of *Kmax* on intensity, the existence of □o and the instantaneous nature of the process. Einstein explained these features on the basis of photon picture of light. According to this, light is composed of discrete packets of energy called quanta or photons. Each photon carries an energy *E* (= *h* □) and momentum *p* (= *h*/□), which depend on the frequency (□) of incident light and not on its intensity. Photoelectric emission from the metal
surface occurs due to absorption of a photon by an electron.
7. Einstein's photoelectric equation is in accordance with the energy conservation law as applied to the photon absorption by an electron in the metal. The maximum kinetic energy (1/2)*m v*2
max is equal to the photon energy (*h*□) minus the work function Fi= *hv* of the target metal: 1/2 *m v*2 *max* = *V*0 *e* = *h*□ □ □0 = *h* (□ □ □*0*). This photoelectric equation explains all the features of the photoelectric effect. Millikan's first precise measurements confirmed the Einstein's photoelectric equation and obtained an accurate value of Planck's constant *h*. This led to the acceptance of particle or photon description (nature) of electromagnetic radiation, introduced by Einstein.
8. Radiation has dual nature: wave and particle. The nature of experiment determines whether a wave or particle description is best suited for understanding the experimental result. Reasoning that radiation and matter should be symmetrical in nature, Louis Victor de Broglie attributed a wave-like character to matter (material particles). The waves associated with the moving material particles are called matter waves or de Broglie waves.
9. The de Broglie wavelength (□) associated with a moving particle is related to its momentum *p* as: □ □ *h*/*p*. The dualism of matter is inherent in the de Broglie relation which contains a wave concept (□) and a particle concept (*p*). The de Broglie wavelength is independent of the charge and nature of the material particle. It is significantly measurable (of the order of the atomic-planes spacing in crystals) only in case of sub-atomic particles like electrons, protons, etc. (due to smallness of their masses and hence, momenta). However, it is indeed very small, quite beyond measurement, in case of macroscopic objects, commonly encountered in everyday life.
10. Electron diffraction experiments by Davisson and Germer, and by G. P. Thomson, as well as many later experiments, have verified and confirmed the wave-nature of electrons. The de Broglie hypothesis of matter waves supports the Bohr's concept of stationary orbits.

POINTS TO PONDER
1. Free electrons in a metal are free in the sense that they move inside the metal in a constant potential (This is only an approximation). They are not free to move out of the metal. They need additional energy to get out of the metal.
2. Free electrons in a metal do not all have the same energy. Like molecules in a gas jar, the electrons have a certain energy distribution at a given temperature. This distribution is different from the usual Maxwell's distribution that you have learnt in the study of kinetic theory of gases.
You will learn about it in later courses, but the difference has to do with the fact that electrons obey Pauli's exclusion principle.
3. Because of the energy distribution of free electrons in a metal, the energy required by an electron to come out of the metal is different for different electrons. Electrons with higher energy require less additional energy to come out of the metal than those with lower energies. Work function is the least energy required by an electron to come out of the metal.
4. Observations on photoelectric effect imply that in the event of matterlight interaction, *absorption of energy takes place in discrete units of h*□. This is not quite the same as saying that light consists of particles, each of energy *h*□.
5. Observations on the stopping potential (its independence of intensity and dependence on frequency) are the crucial discriminator between the wave-picture and photon-picture of photoelectric effect.

6. The wavelength of a matter wave given by *hp*□ □ has physical significance; its phase velocity *vp* has no physical significance. However, the group velocity of the matter wave is physically meaningful and equals the velocity of the particle.

ATOMS

1. Atom, as a whole, is electrically neutral and therefore contains equal amount of positive and negative charges.
2. In *Thomson's model,* an atom is a spherical cloud of positive charges with electrons embedded in it.
3. In *Rutherford's model*, most of the mass of the atom and all its positive charge are concentrated in a tiny nucleus (typically one by ten thousand the size of an atom), and the electrons revolve around it.
4. Rutherford nuclear model has two main difficulties in explaining the structure of atom: (a) It predicts that atoms are unstable because the accelerated electrons revolving around the nucleus must spiral into the nucleus. This contradicts the stability of matter. (b) It cannot explain the characteristic line spectra of atoms of different elements.
5. Atoms of each element are stable and emit characteristic spectrum. The spectrum consists of a set of isolated parallel lines termed as line spectrum. It provides useful information about the atomic structure.
6. The atomic hydrogen emits a line spectrum consisting of various series. The frequency of any line in a series can be expressed as a difference of two terms;
Lyman series: 2 2 1 11*Rcn*; *n* = 2, 3, 4,...
Balmer series: 2 2 1 12*Rcn;* *n* = 3, 4, 5,...
Paschen series: 2 2 1 13*Rcn*; *n* = 4, 5, 6,...
Brackett series: 2 21 14*Rcn;* *n* = 5, 6, 7,...
Pfund series: 2 2 1 15*Rcn*; *n* = 6, 7, 8,...

7. To explain the line spectra emitted by atoms, as well as the stability of atoms, Niel's Bohr proposed a model for hydrogenic (single elctron) atoms. He introduced three postulates and laid the foundations of quantum mechanics:
(a) In a hydrogen atom, an electron revolves in certain stable orbits (called stationary orbits) without the emission of radiant energy.
(b) The stationary orbits are those for which the angular momentum is some integral multiple of *h*/2□. (Bohr's quantisation condition.) That is *L* = *nh*/2□, where *n* is an integer called a quantum number.
(c) The third postulate states that an electron might make a transition from one of its specified non-radiating orbits to another of lower energy. When it does so, a photon is emitted having energy equal to the energy difference between the initial and final states. The frequency (□ □of the emitted photon is then given by *h*□ □ *Ei* – *Ef*. An atom absorbs radiation of the same frequency the atom emits, in which case the electron is transferred to an orbit with a higher value of *n*.
Ei + *h*□ □ *Ef*
8. As a result of the quantisation condition of angular momentum, the electron orbits the nucleus at only specific radii. The total energy is also quantised:
E = –13.6 eV/*n*2. The *n* = 1 state is called ground state. In hydrogen atom the ground state energy is –13.6 eV. Higher values of *n* correspond to excited states (*n* > 1). Atoms are excited to these higher states by collisions with other atoms or electrons or by absorption of a photon of right frequency.
9. de Broglie's hypothesis that electrons have a wavelength □ □ *h*/*mv* gave an explanation for Bohr's quantised orbits by bringing in the waveparticle duality. The orbits correspond to circular standing waves in which the circumference of the orbit equals a whole number of wavelengths.
10. Bohr's model is applicable only to hydrogenic (single electron) atoms. It cannot be extended to even two electron atoms such as helium. This model is also unable to explain for the relative intensities of the frequencies emitted even by hydrogenic atoms.

POINTS TO PONDER

1. Both the Thomson's as well as the Rutherford's models constitute an unstable system. Thomson's model is unstable electrostatically, while Rutherford's model is unstable because of electromagnetic radiation of orbiting electrons.
2. What made Bohr quantise angular momentum (second postulate) and not some other quantity? Note, *h* has dimensions of angular momentum, and for circular orbits, angular momentum is a very
relevant quantity. The second postulate is then so natural!

3. The orbital picture in Bohr's model of the hydrogen atom was inconsistent with the uncertainty principle. It was replaced by modern quantum mechanics in which Bohr's orbits are regions where the electron may be found with large probability.
4. Unlike the situation in the solar system, where planet-planet gravitational forces are very small as compared to the gravitational force of the sun on each planet (because the mass of the sun is so
much greater than the mass of any of the planets), the electron-electron electric force interaction is comparable in magnitude to the electronnucleus electrical force, because the charges and distances are of the same order of magnitude. This is the reason why the Bohr's model with its planet-like electron is not applicable to many electron atoms.
5. Bohr laid the foundation of the quantum theory by postulating specific orbits in which electrons do not radiate. Bohr's model include only one quantum number *n*. The new theory called quantum mechanics supportes Bohr's postulate. However in quantum mechanics (more generally accepted), a given energy level may not correspond to just one quantum state. For example, a state is characterised by four quantum numbers (*n*, *l*, *m*, and *s*), but for a pure Coulomb potential (as in hydrogen atom) the energy depends only on *n*.
6. In Bohr model, contrary to ordinary classical expectation, the frequency of revolution of an electron in its orbit is not connected to the frequency of spectral line. The later is the difference between two orbital energies divided by *h*. For transitions between large quantum numbers (*n* to *n* – 1, *n* very large), however, the two coincide as expected.
7. Bohr's semiclassical model based on some aspects of classical physics and some aspects of modern physics also does not provide a true picture of the simplest hydrogenic atoms. The true picture is quantum mechanical affair which differs from Bohr model in a number of fundamental ways. But then if the Bohr model is not strictly correct, why do we bother about it? The reasons which make Bohr's model still useful are:
(i) The model is based on just three postulates but accounts for almost all the general features of the hydrogen spectrum.
(ii) The model incorporates many of the concepts we have learnt in classical physics.
(iii) The model demonstrates how a theoretical physicist occasionally must quite literally ignore certain problems of approach in hopes of being able to make some predictions. If the predictions of the theory or model agree with experiment, a theoretician then must somehow hope to explain away or rationalise the problems that were ignored along the way.

NUCLEI

1. An atom has a nucleus. The nucleus is positively charged. The radius of the nucleus is smaller than the radius of an atom by a factor of 104. More than 99.9% mass of the atom is concentrated in the nucleus.
2. On the atomic scale, mass is measured in atomic mass units (u). By definition, 1 atomic mass unit (1u) is 1/12th mass of one atom of 12C; 1u = 1.660563 × 10–27 kg.
3. A nucleus contains a neutral particle called neutron. Its mass is almost the same as that of proton.
4. The atomic number *Z* is the number of protons in the atomic nucleus of an element. The mass number *A* is the total number of protons and neutrons in the atomic nucleus; *A* = *Z*+*N*; Here *N* denotes the number of neutrons in the nucleus. *A* nuclear species or a nuclide is represented as X *A*
Z , where X is the chemical symbol of the species. Nuclides with the same atomic number *Z*, but different neutron number *N* are called *isotopes*. Nuclides with the same *A* are *isobars* and those
with the same *N* are *isotones*. Most elements are mixtures of two or more isotopes. The atomic mass of an element is a weighted average of the masses of its isotopes. The masses are the relative abundances of the isotopes.
5. A nucleus can be considered to be spherical in shape and assigned a radius. Electron scattering experiments allow determination of the nuclear radius; it is found that radii of nuclei fit the formula *R* = *R*0 *A*1/3, where *R*0 = a constant = 1.2 fm. This implies that the nuclear density is independent of *A*. It is of the order of 1017 kg/m3.
6. Neutrons and protons are bound in a nucleus by the short-range strong nuclear force. The nuclear force does not distinguish between neutron and proton.
7. The nuclear mass *M* is always less than the total mass, ▫*m*, of its constituents. The difference in mass of a nucleus and its constituents is called the *mass defect*, ▫*M* = (*Z mp* + (*A* – *Z*)*mn*) – *M*
Using Einstein's mass energy relation, we express this mass difference in terms of energy as ▫*Eb* = ▫*M c2*. The energy ▫*Eb* represents the *binding energy* of the nucleus. In the mass number range *A* = 30 to 170, the binding energy per nucleon is nearly constant, about 8 MeV/nucleon.
8. Energies associated with nuclear processes are about a million times larger than chemical process.

9. The *Q*-value of a nuclear process is *Q* = final kinetic energy – initial kinetic energy. Due to conservation of mass-energy, this is also, *Q* = (sum of initial masses – sum of final masses)*c*2
10. Radioactivity is the phenomenon in which nuclei of a given species transform by giving out □ or □ or □ rays; □-rays are helium nuclei; □-rays are electrons. □-rays are electromagnetic radiation of wavelengths shorter than *X*-rays;
11. Law of radioactive decay : *N* (*t*) = *N*(0) e–□*t* where □ is the decay constant or disintegration constant. The half-life *T*1/2 of a radionuclide is the time in which *N* has been reduced to one-half of its initial value. The mean life □ is the time at which *N* has been reduced to *e*–1 of its initial value ½ ln2 *T* □ ln2
12. Energy is released when less tightly bound nuclei are transmuted into more tightly bound nuclei. In fission, a heavy nucleus like 235 92 U breaks into two smaller fragments, e.g., 235 1 133 99 1 92 0 51 41 0 U+ n □ Sb □ Nb + 4 n.
13. The fact that more neutrons are produced in fission than are consumed gives the possibility of a chain reaction with each neutron that is produced triggering another fission. The chain reaction is uncontrolled and rapid in a nuclear bomb explosion. It is controlled and steady in a nuclear reactor. In a reactor, the value of the neutron multiplication factor *k* is maintained at 1.
14. In fusion, lighter nuclei combine to form a larger nucleus. Fusion of hydrogen nuclei into helium nuclei is the source of energy of all stars including our sun.

POINTS TO PONDER
1. The density of nuclear matter is independent of the size of the nucleus. The mass density of the atom does not follow this rule.
2. The radius of a nucleus determined by electron scattering is found to be slightly different from that determined by alpha-particle scattering. This is because electron scattering senses the charge distribution of the nucleus, whereas alpha and similar particles sense the nuclear matter.
3. After Einstein showed the equivalence of mass and energy, *E* = *mc*2, we cannot any longer speak of separate laws of conservation of mass and conservation of energy, but we have to speak of a unified law of conservation of mass and energy. The most convincing evidence that this principle operates in nature comes from nuclear physics. It is central to our understanding of nuclear energy and harnessing it as a source of power. Using the principle, *Q* of a nuclear process (decay or reaction) can be expressed also in terms of initial and final masses.
4. The nature of the binding energy (per nucleon) curve shows that exothermic nuclear reactions are possible, when two light nuclei fuse or when a heavy nucleus undergoes fission into nuclei with intermediate mass.
5. For fusion, the light nuclei must have sufficient initial energy to overcome the coulomb potential barrier. That is why fusion requires very high temperatures.
6. Although the binding energy (per nucleon) curve is smooth and slowly varying, it shows peaks at nuclides like 4He, 16O etc. This is considered as evidence of atom-like shell structure in nuclei.
7. Electrons and positron are a particle-antiparticle pair. They are identical in mass; their charges are equal in magnitude and opposite. (It is found that when an electron and a positron come together, they annihilate each other giving energy in the form of gamma-ray photons.)
8. In â--decay (electron emission), the particle emitted along with electron is anti-neutrino (□). On the other hand, the particle emitted in □+- decay (positron emission) is neutrino (□). Neutrino and anti-neutrino are a particle-antiparticle pair. There are anti particles associated with every particle. What should be antiproton which is the anti particle of the proton?
9. A free neutron is unstable (n □ p □ e– □ □). But a similar free proton decay is not possible, since a proton is (slightly) lighter than a neutron.
10. Gamma emission usually follows alpha or beta emission. A nucleus in an excited (higher) state goes to a lower state by emitting a gamma photon. A nucleus may be left in an excited state after alpha or beta emission. Successive emission of gamma rays from the same nucleus (as in case of 60Ni, Fig. 13.4) is a clear proof that nuclei also have discrete energy levels as do the atoms.
11. Radioactivity is an indication of the instability of nuclei. Stability requires the ratio of neutron to proton to be around 1:1 for light nuclei. This ratio increases to about 3:2 for heavy nuclei. (More neutrons are required to overcome the effect of repulsion among the protons.) Nuclei which are away from the stability ratio, i.e., nuclei which have an excess of neutrons or protons are unstable. In fact, only about 10% of knon isotopes (of all elements), are stable. Others have been either artificially produced in the laboratory by bombarding □,

p, d, n or other particles on targets of stable nuclear species or identified in astronomical observations of matter in the universe.

SEMICONDUCTOR ELECTRONICS: MATERIALS, DEVICES AND SIMPLE CIRCUITS

FASTER AND SMALLER: THE FUTURE OF COMPUTER TECHNOLOGY

The *Integrated Chip* (IC) is at the heart of all computer systems. In fact ICs are found in almost all electrical devices like cars, televisions, CD players, cell phones etc. The miniaturisation that made the modern personal computer possible could never have happened without the IC. ICs are electronic devices that contain many transistors, resistors, capacitors, connecting wires – all in one package. You must have heard of the *microprocessor*. The microprocessor is an IC that processes all information in a computer, like keeping track of what keys are pressed, running programmes, games etc. The IC was first invented by Jack Kilky at Texas Instruments in 1958 and he was awarded Nobel Prize for this in 2000. ICs are produced on a piece of semiconductor crystal (or chip) by a process called *photolithography*. Thus, the entire Information Technology (IT) industry hinges on semiconductors. Over the years, the complexity of ICs has increased while the size of its features continued to shrink. In the past five decades, a dramatic miniaturisation in computer technology has made modern day computers *faster and smaller*. In the 1970s, Gordon Moore, co-founder of INTEL, pointed out that the memory capacity of a chip (IC) approximately doubled every one and a half years. This is popularly known as *Moore's law*. The number of transistors per chip has risen exponentially and each year computers are becoming more powerful, yet cheaper than the year before. It is intimated from current trends that the computers available in 2020 will operate at 40 GHz (40,000 MHz) and would be much smaller, more efficient and less expensive than present day computers. The explosive growth in the semiconductor industry and computer technology is best expressed by a famous quote from Gordon Moore: "If the auto industry advanced as rapidly as the semiconductor industry, a Rolls Royce would get half a million miles per gallon, and it would be cheaper to throw it away than to park it".

1. Semiconductors are the basic materials used in the present solid state electronic devices like diode, transistor, ICs, etc.
2. Lattice structure and the atomic structure of constituent elements decide whether a particular material will be insulator, metal or semiconductor.
3. Metals have low resistivity (10–2 to 10–8 □m), insulators have very high resistivity (>108 □m–1), while semiconductors have intermediate values of resistivity.
4. Semiconductors are elemental (Si, Ge) as well as compound (GaAs, CdS, etc.).
5. Pure semiconductors are called 'intrinsic semiconductors'. The presence of charge carriers (electrons and holes) is an 'intrinsic' property of the material and these are obtained as a result of thermal excitation. The number of electrons (*ne*) is equal to the number of holes (*nh*) in intrinsic conductors. Holes are essentially electron vacancies with an effective positive charge.
6. The number of charge carriers can be changed by 'doping' of a suitable impurity in pure semiconductors. Such semiconductors are known as extrinsic semiconductors. These are of two types (n-type and p-type).
7. In n-type semiconductors, *ne* >> *nh* while in p-type semiconductors *nh* >> *ne*.
8. n-type semiconducting Si or Ge is obtained by doping with pentavalent atoms (donors) like As, Sb, P, etc., while p-type Si or Ge can be obtained by doping with trivalent atom (acceptors) like B, Al, In etc.
9. *nenh* = *ni* 2 in all cases. Further, the material possesses an *overall charge neutrality*.
10. There are two distinct band of energies (called valence band and conduction band) in which the electrons in a material lie. Valence band energies are low as compared to conduction band energies. All energy levels in the valence band are filled while energy levels in the conduction band may be fully empty or partially filled. The electrons in the conduction band are free to move in a solid and are responsible for the conductivity. The extent of conductivity depends upon the energy gap (*Eg*) between the top of valence band (*EV*) and the bottom of the conduction band *EC*. The electrons from valence band can be excited by heat, light or electrical energy to the conduction band and thus, produce a change in the current flowing in a semiconductor.
11. For insulators *Eg* > 3 eV, for semiconductors *Eg* is 0.2 eV to 3 eV, while for metals *Eg* □ 0.
12. p-n junction is the 'key' to all semiconductor devices. When such a junction is made, a 'depletion layer' is formed consisting of immobile ion-cores devoid of their electrons or holes. This is responsible for a junction potential barrier.

13. By changing the external applied voltage, junction barriers can be changed. In forward bias (n-side is connected to negative terminal of the battery and p-side is connected to the positive), the barrier is decreased while the barrier increases in reverse bias. Hence, forward bias current is more (mA) while it is very small (□A) in a p-n junction diode.
14. Diodes can be used for rectifying an ac voltage (restricting the ac voltage to one direction). With the help of a capacitor or a suitable filter, a dc voltage can be obtained.
15. There are some special purpose diodes.
16. Zener diode is one such special purpose diode. In reverse bias, after a certain voltage, the current suddenly increases (breakdown voltage) in a Zener diode. This property has been used to obtain *voltage regulation*.
17. p-n junctions have also been used to obtain many photonic or optoelectronic devices where one of the participating entity is 'photon':
(a) Photodiodes in which photon excitation results in a change of reverse saturation current which helps us to measure light intensity; (b) Solar cells which convert photon energy into electricity; (c) Light Emitting Diode and Diode Laser in which electron excitation by a bias voltage results in the generation of light.
18. Transistor is an n-p-n or p-n-p junction device. The central block (thin and lightly doped) is called 'Base' while the other electrodes are 'Emitter' and 'Collectors'. The emitter-base junction is forward biased while collector-base junction is reverse biased.
19. The transistors can be connected in such a manner that either C or E or B is common to both the input and output. This gives the three configurations in which a transistor is used: Common Emitter (CE), Common Collector (CC) and Common Base (CB). The plot between *IC* and *VCE* for fixed *IB* is called output characteristics while the plot between *IB* and *VBE* with fixed *VCE* is called input characteristics. The important transistor parameters for CE-configuration are: input resistance & output resistance,
20. Transistor can be used as an amplifier and oscillator. In fact, an oscillator can also be considered as a self-sustained amplifier in which a part of output is fed-back to the input in the same phase (positive feed back). The voltage gain of a transistor amplifier in common emitter
Configuration where *RC* and *RB* are respectively the resistances in collector and base sides of the circuit.
21. When the transistor is used in the cutoff or saturation state, it acts as a switch.
22. There are some special circuits which handle the digital data consisting of 0 and 1 levels. This forms the subject of Digital Electronics.
23. The important digital circuits performing special logic operations are called logic gates. These are: OR, AND, NOT, NAND, and NOR gates.
24. In modern day circuit, many logical gates or circuits are integrated in one single 'Chip'. These are known as Intgrated circuits (IC).

POINTS TO PONDER
1. The energy bands (*EC* or *EV*) in the semiconductors are space delocalized which means that these are not located in any specific place inside the solid. The energies are the overall averages. When you see a picture in which *EC* or *EV* are drawn as straight lines, then they should be respectively taken simply as the *bottom* of conduction band energy levels and *top* of valence band energy levels.

2. In elemental semiconductors (Si or Ge), the n-type or p-type semiconductors are obtained by introducing 'dopants' as defects. In compound semiconductors, the change in relative stoichiometric ratio can also change the type of semiconductor. For example, in ideal GaAs the ratio of Ga:As is 1:1 but in Ga-rich or As-rich GaAs it could respectively be Ga1.1 As0.9 or Ga0.9 As1.1. In general, the presence of defects control the properties of semiconductors in many ways.
3. In transistors, the base region is both narrow and lightly doped, otherwise the electrons or holes coming from the input side (say, emitter in CE-configuration) will not be able to reach the collector.
4. We have described an oscillator as a positive feedback amplifier. For stable oscillations, the voltage feedback (*Vfb*) from the output voltage (*Vo*) should be such that after amplification (*A*) it should again become *Vo*. If a fraction □ □is□ feedback, then *Vfb* = *Vo*. □ □and after amplification
its value *A*(*vo*.□ □) should be equal to *Vo*. This means that the criteria for stable oscillations to be sustained is *A* □ □=□1. This is known as Barkhausen's Criteria.
5. In an oscillator, the feedback is in the same phase (positive feedback). If the feedback voltage is in opposite phase (negative feedback), the gain is less than 1 and it can never work as oscillator. It will be an amplifier with reduced

gain. However, the negative feedback also reduces noise and distortion in an amplifier which is an advantageous feature.

COMMUNICATION SYSTEMS

1. Electronic communication refers to the faithful transfer of information or message (available in the form of electrical voltage and current) from one point to another point.
2. Transmitter, transmission channel and receiver are three basic units of a communication system.
3. Two important forms of communication system are: Analog and Digital. The information to be transmitted is generally in continuous waveform for the former while for the latter it has only discrete or quantized levels.
4. Every message signal occupies a range of frequencies. The bandwidth of a message signal refers to the band of frequencies, which are necessary for satisfactory transmission of the information contained in the signal. Similarly, any practical communication system permits transmission of a range of frequencies only, which is referred to as the bandwidth of the system.
5. Low frequencies cannot be transmitted to long distances. Therefore, they are superimposed on a high frequency carrier signal by a process known as modulation.
6. In modulation, some characteristic of the carrier signal like amplitude, frequency or phase varies in accordance with the modulating or message signal. Correspondingly, they are called Amplitude Modulated (AM), Frequency Modulated (FM) or Phase Modulated (PM) waves.
7. Pulse modulation could be classified as: Pulse Amplitude Modulation (PAM), Pulse Duration Modulation (PDM) or Pulse Width Modulation (PWM) and Pulse Position Modulation (PPM).
8. For transmission over long distances, signals are radiated into space using devices called antennas. The radiated signals propagate as electromagnetic waves and the mode of propagation is influenced by the presence of the earth and its atmosphere. Near the surface of the earth, electromagnetic waves propagate as surface waves. Surface wave propagation is useful up to a few MHz frequencies.
9. Long distance communication between two points on the earth is achieved through reflection of electromagnetic waves by ionosphere. Such waves are called sky waves. Sky wave propagation takes place up to frequency of about 30 MHz. Above this frequency, electromagnetic
waves essentially propagate as space waves. Space waves are used for line-of-sight communication and satellite communication.
10. If an antenna radiates electromagnetic waves from a height h_T, then the range d_T is given by $2 T R h$ where R is the radius of the earth.
11. Amplitude modulated signal contains frequencies (□ □□ □), *c m* □c and ( ). *c m* □ □ □ □
12. Amplitude modulated waves can be produced by application of the message signal and the carrier wave to a non-linear device, followed by a band pass filter.
13. AM detection, which is the process of recovering the modulating signal from an AM waveform, is carried out using a rectifier and an envelope detector.

ELECTRIC CHARGES AND FIELDS

1. Electric and magnetic forces determine the properties of atoms, molecules and bulk matter.
2. From simple experiments on frictional electricity, one can infer that there are two types of charges in nature; and that like charges repel and unlike charges attract. By convention, the charge on a glass rod rubbed with silk is positive; that on a plastic rod rubbed with fur is then negative.
3. Conductors allow movement of electric charge through them, insulators do not. In metals, the mobile charges are electrons; in electrolytes both positive and negative ions are mobile.
4. Electric charge has three basic properties: quantisation, additivity and conservation. Quantisation of electric charge means that total charge (q) of a body is always an integral multiple of a basic quantum of charge (e) i.e., $q = n e$, where $n = 0, \pm1, \pm2, \pm3, ...$ Proton and electron have charges $+e$, $-e$, respectively. For macroscopic charges for which n is a very large number, quantisation of charge can be ignored. Additivity of electric charges means that the total charge of a system is the algebraic sum (i.e., the sum taking into account proper signs) of all individual charges in the system. Conservation of electric charges means that the total charge of an isolated system remains unchanged with time. This means that when bodies are charged through friction, there is a transfer of electric charge from one body to another, but no creation or destruction of charge.
5. *Coulomb's Law*: The mutual electrostatic force between two point charges q_1 and q_2 is proportional to the product $q_1 q_2$ and inversely proportional to the square of the distance r_{21} separating them.

In SI units, the unit of charge is coulomb. The experimental value of the constant ε_0 is $\varepsilon_0 = 8.854 \times 10^{-12}$ C^2 N^{-1} m^{-2} The approximate value of *k* is $k = 9 \times 10^9$ N m^2 C^{-2}
6. The ratio of electric force and gravitational force between a proton and an electron.
7. *Superposition Principle*: The principle is based on the property that the forces with which two charges attract or repel each other are not affected by the presence of a third (or more) additional charge(s). For an assembly of charges q_1, q_2, q_3, ..., the force on any charge, say q_1, is the vector sum of the force on q_1 due to q_2, the force on q_1 due to q_3, and so on. For each pair, the force is given by the Coulomb's law for two charges stated earlier.
8. The electric field E at a point due to a charge configuration is the force on a small positive test charge *q* placed at the point divided by the magnitude of the charge. Electric field due to a point charge *q* has a magnitude $|q|/4\pi\varepsilon_0 r^2$; it is radially outwards from *q*, if *q* is positive, and radially inwards if *q* is negative. Like Coulomb force, electric field also satisfies superposition principle.
9. An electric field line is a curve drawn in such a way that the tangent at each point on the curve gives the direction of electric field at that point. The relative closeness of field lines indicates the relative strength of electric field at different points; they crowd near each other in regions of strong electric field and are far apart where the electric field is weak. In regions of constant electric field, the field lines are uniformly spaced parallel straight lines.
10. Some of the important properties of field lines are: (i) Field lines are continuous curves without any breaks. (ii) Two field lines cannot cross each other. (iii) Electrostatic field lines start at positive charges and
end at negative charges —they cannot form closed loops.
11. An electric dipole is a pair of equal and opposite charges *q* and –*q* separated by some distance 2*a*. Its dipole moment vector p has magnitude 2*qa* and is in the direction of the dipole axis from –*q* to *q*.
12. Field of an electric dipole in its equatorial plane (i.e., the plane perpendicular to its axis and passing through its centre) at a distance *r* from the centre: In a uniform electric field E, a dipole experiences a torque τ given by τ = p × E but experiences no net force.
14. The flux $\Delta\phi$ of electric field E through a small area element ΔS is given by $\Delta\phi$ = E.ΔS The vector area element ΔS is ΔS = ΔS ˆn where ΔS is the magnitude of the area element and ˆn is normal to the area element, which can be considered planar for sufficiently small ΔS.

POINTS TO PONDER

1. You might wonder why the protons, all carrying positive charges, are compactly residing inside the nucleus. Why do they not fly away? You will learn that there is a third kind of a fundamental force, called the strong force which holds them together. The range of distance where this force is effective is, however, very small ~10^{-14} m. This is precisely the size of the nucleus. Also the electrons are not allowed to sit on top of the protons, i.e. inside the nucleus, due to the laws of quantum mechanics. This gives the atoms their structure as they exist in nature.
2. Coulomb force and gravitational force follow the same inverse-square law. But gravitational force has only one sign (always attractive), while Coulomb force can be of both signs (attractive and repulsive), allowing possibility of cancellation of electric forces. This is how gravity, despite being a much weaker force, can be a dominating and more pervasive force in nature.
3. The constant of proportionality *k* in Coulomb's law is a matter of choice if the unit of charge is to be defined using Coulomb's law. In SI units, however, what is defined is the unit of current (A) via its magnetic effect (Ampere's law) and the unit of charge (coulomb) is simply defined by (1C = 1 A s). In this case, the value of *k* is no longer arbitrary; it is approximately 9×10^9 N m^2 C^{-2}.
4. The rather large value of *k*, i.e., the large size of the unit of charge (1C) from the point of view of electric effects arises because (as mentioned in point 3 already) the unit of charge is defined in terms of magnetic forces (forces on current-carrying wires) which are generally much weaker than the electric forces. Thus while 1 ampere is a unit of reasonable size for magnetic effects, 1 C = 1 A s, is too big a unit for
electric effects.
5. The additive property of charge is not an 'obvious' property. It is related to the fact that electric charge has no direction associated with it; charge is a scalar.
6. Charge is not only a scalar (or invariant) under rotation; it is also invariant for frames of reference in relative motion. This is not always true for every scalar. For example, kinetic energy is a scalar under rotation, but is not invariant for frames of reference in relative motion.
7. Conservation of total charge of an isolated system is a property independent of the scalar nature of charge noted in point 6. Conservation refers to invariance in time in a given frame of reference. A quantity may be scalar but not

conserved (like kinetic energy in an inelastic collision). On the other hand, one can have conserved vector quantity (e.g., angular momentum of an isolated system).
8. Quantisation of electric charge is a basic (unexplained) law of nature; interestingly, there is no analogous law on quantisation of mass.
9. Superposition principle should not be regarded as 'obvious', or equated with the law of addition of vectors. It says two things: force on one charge due to another charge is unaffected by the presence of other charges, and there are no additional three-body, four-body, etc., forces which arise only when there are more than two charges.
10. The electric field due to a discrete charge configuration is not defined at the locations of the discrete charges. For continuous volume charge distribution, it is defined at any point in the distribution. For a surface charge distribution, electric field is discontinuous across the surface.
11. The electric field due to a charge configuration with total charge zero is not zero; but for distances large compared to the size of the configuration, its field falls off faster than $1/r2$, typical of field due to a single charge. An electric dipole is the simplest example of this fact.

ELECTROSTATIC POTENTIAL AND CAPACITANCE

1. Electrostatic force is a conservative force. Work done by an external force (equal and opposite to the electrostatic force) in bringing a charge *q* from a point R to a point P is $VP - VR$, which is the difference in potential energy of charge *q* between the final and initial points.
2. Potential at a point is the work done per unit charge (by an external agency) in bringing a charge from infinity to that point. Potential at a point is arbitrary to within an additive constant, since it is the potential difference between two points which is physically significant. If potential at infinity is chosen to be zero; potential at a point with position vector **r** due to a point charge *Q* placed at the origin is given is given by
3. The electrostatic potential at a point with position vector **r** due to a point dipole of dipole moment **p** placed at the origin is The result is true also for a dipole (with charges –*q* and *q* separated by 2*a*) for $r >> a$.
4. For a charge configuration *q*1, *q*2, ..., *qn* with position vectors **r**1,**r**2, ... **r**n, the potential at a point P is given by the superposition principle where *r*1P is the distance between *q*1 and P, as and so on.
5. An equipotential surface is a surface over which potential has a constant value. For a point charge, concentric spheres centered at a location ofthe charge are equipotential surfaces. The electric field **E** at a point is perpendicular to the equipotential surface through the point. **E** is in the direction of the steepest decrease of potential.
6. Potential energy stored in a system of charges is the work done (by an external agency) in assembling the charges at their locations. Potential energy of two charges *q*1, *q*2 at **r**1, **r**2 is given by where *r*12 is distance between *q*1 and *q*2.
7. The potential energy of a charge *q* in an external potential *V*(**r**) is *qV*(**r**). The potential energy of a dipole moment **p** in a uniform electric field **E** is –**p.E**.
8. Electrostatics field **E** is zero in the interior of a conductor; just outside the surface of a charged conductor, **E** is normal to the surface given by where is the unit vector along the outward normal to the surface and s is the surface charge density. Charges in a conductor can reside only at its surface. Potential is constant within and on the surface of a conductor. In a cavity within a conductor (with no charges), the electric field is zero.
9. A capacitor is a system of two conductors separated by an insulator. Its capacitance is defined by $C = Q/V$, where *Q* and –*Q* are the charges on the two conductors and *V* is the potential difference between them. C is determined purely geometrically, by the shapes, sizes and relative positions of the two conductors. The unit of capacitance is farad:, 1 F = 1 C V –1. For a parallel plate capacitor (with vacuum between the plates), C = where *A* is the area of each plate and *d* the separation between them.
10. If the medium between the plates of a capacitor is filled with an insulating substance (dielectric), the electric field due to the charged plates induces a net dipole moment in the dielectric. This effect, called polarisation, gives rise to a field in the opposite direction. The net electric field inside the dielectric and hence the potential difference between the plates is thus reduced. Consequently, the capacitance *C* increases from its value *C*0 when there is no medium (vacuum), $C = KC0$ where *K* is the dielectric constant of the insulating substance.
11. For capacitors in the series combination, the total capacitance *C* is given by In the parallel combination, the total capacitance *C* is: $C = C1 + C2 + C3 + ...$ where *C*1, *C*2, *C*3... are individual capacitances.
12. The energy *U* stored in a capacitor of capacitance *C*, with charge *Q* and voltage *V* is The electric energy density (energy per unit volume) in a region with electric field is (1/2)e0E2.

13. A Van de Graaff generator consists of a large spherical conducting shell (a few metre in diameter). By means of a moving belt and suitable brushes, charge is continuously transferred to the shell and potential difference of the order of several million volts is built up, which can be used for accelerating charged particles.

POINTS TO PONDER

1. Electrostatics deals with forces between charges at rest. But if there is a force on a charge, how can it be at rest? Thus, when we are talking of electrostatic force between charges, it should be understood that each
charge is being kept at rest by some unspecified force that opposes the net Coulomb force on the charge.
2. A capacitor is so configured that it confines the electric field lines within a small region of space. Thus, even though field may have considerable strength, the potential difference between the two conductors of a capacitor is small.
3. Electric field is discontinuous across the surface of a spherical charged shell. It is zero inside and outside. Electric potential is, however continuous across the surface, equal to *q*/4□e0*R* at the surface.
4. The torque **p × E** on a dipole causes it to oscillate about **E**. Only if there is a dissipative mechanism, the oscillations are damped and the dipole eventually aligns with **E**.
5. Potential due to a charge *q* at its own location is not defined – it is infinite.
6. In the expression *qV*(**r**) for potential energy of a charge *q*, *V*(**r**) is the potential due to external charges and not the potential due to *q*. As seen in point 5, this expression will be ill-defined if *V*(**r**) includes potential due to a charge *q* itself.
7. A cavity inside a conductor is shielded from outside electrical influences. It is worth noting that electrostatic shielding does not work the other way round; that is, if you put charges inside the cavity, the exterior of the conductor is not shielded from the fields by the inside charges.

1. *Current* through a given area of a conductor is the net charge passing per unit time through the area.
2. To maintain a steady current, we must have a closed circuit in which an external agency moves electric charge from lower to higher potential energy. The work done per unit charge by the source in taking the charge from lower to higher potential energy (i.e., from one terminal of the source to the other) is called the electromotive force, or *emf*, of the source. Note that the emf is not a force; it is the voltage difference
between the two terminals of a source in open circuit.
3. *Ohm's law*: The electric current *I* flowing through a substance is proportional to the voltage *V* across its ends, i.e., *V* ∝□*I* or *V* = *RI*, where *R* is called the *resistance* of the substance. The unit of resistance is ohm: 1□ ≡ 1 V A–1.
4. The *resistance R* of a conductor depends on its length *l* and constant cross-sectional area *A* through the relation, where r, called *resistivity* is a property of the material and depends on temperature and pressure.
5. *Electrical resistivity* of substances varies over a very wide range. Metals have low resistivity, in the range of 10–8 □ m to 10–6 □ m. Insulators like glass and rubber have 1022 to 1024 times greater resistivity. Semiconductors like Si and Ge lie roughly in the middle range of resistivity on a logarithmic scale.
6. In most substances, the carriers of current are electrons; in some cases, for example, ionic crystals and electrolytic liquids, positive and negative ions carry the electric current.
7. *Current density* **j** gives the amount of charge flowing per second per unit area normal to the flow, **j** = *nq* **v**d where *n* is the number density (number per unit volume) of charge carriers each of charge *q*, and **v**d is the *drift velocity* of the charge carriers. For electrons *q* = – *e*. If **j** is normal to a cross-sectional area **A** and is constant over the area, the magnitude of the current *I* through the area is *ne*vd *A*.
8. Using *E* = *V*/*l*, *I* = *nevd A*, and Ohm's law, one obtains The proportionality between the *force eE* on the electrons in a metal due to the external field *E* and the drift velocity *vd* (not acceleration) can be understood, if we assume that the electrons suffer collisions with ions in the metal, which deflect them randomly. If such collisions occur on an average at a time interval t, *vd* = *a*t = *eE*t/*m* where *a* is the acceleration of the electron. This gives
9. In the temperature range in which resistivity increases linearly with temperature, the *temperature coefficient of resistivity* a is defined as the fractional increase in resistivity per unit increase in temperature.
10. Ohm's law is obeyed by many substances, but it is not a fundamental law of nature. It fails if
(a) *V* depends on *I* non-linearly.
(b) the relation between *V* and *I* depends on the sign of *V* for the same absolute value of *V*.
(c) The relation between *V* and *I* is non-unique.
An example of (a) is when r increases with *I* (even if temperature is kept fixed). A rectifier combines features (a) and (b). GaAs shows the feature (c).
11. When a source of emf e is connected to an external resistance *R*, the voltage *Vext* across *R* is given by *Vext* = *IR* = + where *r* is the *internal resistance* of the source.

12. (a) Total resistance *R* of *n* resistors connected in *series* is given by $R = R1 + R2 + ... + Rn$
(b) Total resistance *R* of *n* resistors connected in *parallel* is given by
13. *Kirchhoff's Rules* –
(a) *Junction Rule:* At any junction of circuit elements, the sum of currents entering the junction must equal the sum of currents leaving it.
(b) *Loop Rule:* The algebraic sum of changes in potential around any closed loop must be zero.
14. The *Wheatstone bridge* is an arrangement of four resistances – R1, R2, R3, R4 as shown in the text. The null-point condition is given by using which the value of one resistance can be determined, knowing the other three resistances.
15. The *potentiometer* is a device to compare potential differences. Since the method involves a condition of *no* current flow, the device can be used to measure potential difference; internal resistance of a cell and compare emf's of two sources.

CURRENT ELECTRICITY

1. Current is a scalar although we represent current with an arrow. Currents do not obey the law of vector addition. That current is a scalar also follows from it's definition. The current *I* through an area of cross-section is given by the scalar product of two vectors: *I* = **j .** ▫**S** where **j** and ▫**S** are vectors.
2. Refer to *V-I* curves of a resistor and a diode as drawn in the text. A resistor obeys Ohm's law while a diode does not. The assertion that $V = IR$ is a statement of Ohm's law is not true. This equation defines resistance and it may be applied to all conducting devices whether they obey Ohm's law or not. The Ohm's law asserts that the plot of *I* versus *V* is linear i.e., *R* is independent of *V*. Equation **E** = r **j** leads to another statement of *Ohm's* law, i.e., a conducting material obeys Ohm's law when the resistivity of the material does not depend on the magnitude and direction of applied electric field.
3. Homogeneous conductors like silver or semiconductors like pure germanium or germanium containing impurities obey Ohm's law within some range of electric field values. If the field becomes too strong, there are departures from Ohm's law in all cases.
4. Motion of conduction electrons in electric field **E** is the sum of (i) motion due to random collisions and (ii) that due to **E**. The motion due to random collisions averages to zero and does not contribute to *vd* (Chapter 11, Textbook of Class XI). *vd* , thus is only due to applied electric field on the electron.
5. The relation **j** = r **v** should be applied to each type of charge carriers separately. In a conducting wire, the total current and charge density arises from both positive and negative charges: **j** = r+ **v**+ + r- **v**- r = r+ + r- Now in a neutral wire carrying electric current, r+ = – r- Further, *v*+ ~ 0 which gives r = 0 **j** = r- **v** Thus, the relation **j** = r **v** does not apply to the total current charge density.
6. Kirchhoff's junction rule is based on conservation of charge and the outgoing currents add up and are equal to incoming current at a junction. Bending or reorienting the wire does not change the validity of Kirchhoff's junction rule.

MOVING CHARGES AND MAGNETISM

MAGNETISM AND MATTER

ELECTROMAGNETIC INDUCTION

1. The magnetic flux through a surface of area A placed in a uniform magnetic field B is defined as, ▫B = BiA = *BA* cos ▫ where ▫ is the angle between B and A.
2. Faraday's laws of induction imply that the emf induced in a coil of *N* turns is directly related to the rate of change of flux through it.
Here ▫ ▫is the flux linked with one turn of the coil. If the circuit is closed, a current *I* = ▫/*R* is set up in it, where *R* is the resistance of the circuit.
3. Lenz's law states that the polarity of the induced emf is such that it tends to produce a current which opposes the change in magnetic flux that produces it. The negative sign in the expression for Faraday's law indicates this fact.
4. When a metal rod of length *l* is placed normal to a uniform magnetic field *B* and moved with a velocity *v* perpendicular to the field, the induced emf (called motional emf) across its ends is ▫ = *Bl v*
5. Changing magnetic fields can set up current loops in nearby metal (any conductor) bodies. They dissipate electrical energy as heat. Such currents are called eddy currents.
6. Inductance is the ratio of the flux-linkage to current. It is equal to *N*▫/*I*.

7. A changing current in a coil (coil 2) can induce an emf in a nearby coil (coil 1).
The quantity *M*12 is called mutual inductance of coil 1 with respect to coil 2. One can similarly define *M*21. There exists a general equality, *M*12 = *M*21

8. When a current in a coil changes, it induces a back emf in the same coil.
L is the self-inductance of the coil. It is a measure of the inertia of the coil against the change of current through it.
9. The self-inductance of a long solenoid, the core of which consists of a magnetic material of permeability □r, is given by *L* = *□r □0 n2 Al* where *A* is the area of cross-section of the solenoid, *l* its length and *n* the number of turns per unit length.
10. In an ac generator, mechanical energy is converted to electrical energy by virtue of electromagnetic induction. If coil of *N* turn and area *A* is rotated at □ revolutions per second in a uniform magnetic field *B*, then the motional emf produced is □ = *NBA* (2□ □) sin (2□ □t) where we have assumed that at time *t* = 0 s, the coil is perpendicular to the field.

POINTS TO PONDER

1. Electricity and magnetism are intimately related. In the early part of the nineteenth century, the experiments of Oersted, Ampere and others established that moving charges (currents) produce a magnetic field. Somewhat later, around 1830, the experiments of Faraday and Henry demonstrated that a moving magnet can induce electric current.
2. In a closed circuit, electric currents are induced so as to oppose the changing magnetic flux. It is as per the law of conservation of energy. However, in case of an open circuit, an emf is induced across its ends. How is it related to the flux change?
3. The motional emf discussed in Section 6.5 can be argued independently from Faraday's law using the Lorentz force on moving charges. However, even if the charges are stationary [and the *q* (v × B) term of the Lorentz force is not operative], an emf is nevertheless induced in the presence of a time-varying magnetic field. Thus, moving charges in static field and static charges in a time-varying field seem to be symmetric situation for Faraday's law. This gives a tantalising hint on the relevance of the principle of relativity for Faraday's law.
4. The motion of a copper plate is damped when it is allowed to oscillate between the magnetic pole-pieces. How is the damping force, produced by the eddy currents?

ALTERNATING CURRENT

6. In a purely inductive or capacitive circuit, cos□ = 0 and no power is dissipated even though a current is flowing in the circuit. In such cases, current is referred to as a *wattless current*.
7. The phase relationship between current and voltage in an ac circuit can be shown conveniently by representing voltage and current by rotating vectors called *phasors*. A phasor is a vector which rotates about the origin with angular speed □. The magnitude of a phasor represents the amplitude or peak value of the quantity (voltage or current) represented by the phasor. The analysis of an ac circuit is facilitated by the use of a phasor diagram.
8. An interesting characteristic of a series RLC circuit is the phenomenon of *resonance*. The circuit exhibits resonance, i.e., the amplitude of the current is maximum at the resonant frequency. *CR* is an indicator of the sharpness of the resonance, the higher value of *Q* indicating sharper peak in the current.
9. A circuit containing an inductor *L* and a capacitor *C* (initially charged) with no ac source and no resistors exhibits *free oscillations*. The charge *q* of the capacitor satisfies the equation of simple harmonic motion:
The energy in the system oscillates between the capacitor and the inductor but their sum or the total energy is constant in time.
10. A transformer consists of an iron core on which are bound a primary coil of *Np* turns and a secondary coil of *Ns* turns.
If the secondary coil has a greater number of turns than the primary, the voltage is stepped-up (*Vs* > *Vp*). This type of arrangement is called a *stepup transformer*. If the secondary coil has turns less than the primary, we have a *step-down transformer*.

POINTS TO PONDER

1. When a value is given for ac voltage or current, it is ordinarily the rms value. The voltage across the terminals of an outlet in your room is normally 240 V. This refers to the *rms* value of the voltage. The amplitude of this voltage is 2 2(240) 340V *m v* □ *V* □ □ □
2. The power rating of an element used in ac circuits refers to its average power rating.
3. The power consumed in an circuit is never negative.
4. Both alternating current and direct current are measured in amperes. But how is the ampere defined for an alternating current? It cannot be derived from the mutual attraction of two parallel wires carrying ac currents, as the dc ampere is derived. An ac current changes direction with the source frequency and the attractive force would average to zero. Thus, the ac ampere must be defined in terms of some property that is independent of the direction of the current. Joule heating is such a property, and there is one ampere of *rms* value of alternating current in a circuit if the current produces the same average heating effect as one ampere of dc current would produce under the same conditions.

5. In an ac circuit, while adding voltages across different elements, one should take care of their phases properly. For example, if *VR* and *VC* are voltages across *R* and *C*, respectively in an *RC* circuit, then the total voltage across *RC* combination is 2 2 *VRC* □ □*VR* □ □*VC* and not *VR* + *VC* since *VC* is □/2 out of phase of *VR*.
6. Though in a phasor diagram, voltage and current are represented by vectors, these quantities are not really vectors themselves. They are scalar quantities. It so happens that the amplitudes and phases of harmonically varying scalars combine mathematically in the same way as do the projections of rotating vectors of corresponding magnitudes and directions. The 'rotating vectors' that represent harmonically varying scalar quantities are introduced only to provide us with a simple way of adding these quantities using a rule that we already know as the law of vector addition.
7. There are no power losses associated with pure capacitances and pure inductances in an ac circuit. The only element that dissipates energy in an ac circuit is the resistive element.
8. In a *RLC* circuit, resonance phenomenon occur when *XL* = *XC*.
For resonance to occur, the presence of both *L* and *C* elements in the circuit is a must. With only one of these (*L* or *C*) elements, there is no possibility of voltage cancellation and hence, no resonance is possible.
9. The power factor in a *RLC* circuit is a measure of how close the circuit is to expending the maximum power.
10. In generators and motors, the roles of input and output are reversed. In a motor, electric energy is the input and mechanical energy is the output. In a generator, mechanical energy is the input and electric energy is the output. Both devices simply transform energy from one form to another.
11. A transformer (step-up) changes a low-voltage into a high-voltage. This does not violate the law of conservation of energy. The current is reduced by the same proportion.
12. The choice of whether the description of an oscillatory motion is by means of sines or cosines or by their linear combinations is unimportant, since changing the zero-time position transforms the one to the other.

ELECTROMAGNETIC WAVES

1. Maxwell found an inconsistency in the Ampere's law and suggested the existence of an additional current, called displacement current, to remove this inconsistency. This displacement current is due to time-varying electric field and acts as a source of magnetic field in exactly the same way as conduction current.
2. An accelerating charge produces electromagnetic waves. An electric charge oscillating harmonically with frequency □, produces electromagnetic waves of the same frequency □. An electric dipole is a basic source of electromagnetic waves.
3. Electromagnetic waves with wavelength of the order of a few metres were first produced and detected in the laboratory by Hertz in 1887. He thus verified a basic prediction of Maxwell's equations.
4. Electric and magnetic fields oscillate sinusoidally in space and time in an electromagnetic wave. The oscillating electric and magnetic fields, **E** and **B** are perpendicular to each other, and to the direction of propagation of the electromagnetic wave. For a wave of frequency □, wavelength □, propagating along *z*-direction, we have *E* = *Ex* (*t*) = *E*0 sin (*kz* – □ *t*).
5. The speed *c* of electromagnetic wave in vacuum is related to □0 and □0 (the free space permeability and permittivity constants) as follows: 0 0 *c* □ 1/ □ □ . The value of *c* equals the speed of light obtained from optical measurements. Light is an electromagnetic wave; c is, therefore, also the speed of light. Electromagnetic waves other than light also have the same velocity c in free space. The speed of light, or of electromagnetic waves in a material medium is given by *v* □ 1/ □ □ where □ is the permeability of the medium and □ its permittivity.
6. Electromagnetic waves carry energy as they travel through space and this energy is shared equally by the electric and magnetic fields. Electromagnetic waves transport momentum as well. When these waves strike a surface, a pressure is exerted on the surface. If total energy transferred to a surface in time *t* is *U*, total momentum delivered to this surface is *p* = *U*/*c*.
7. The spectrum of electromagnetic waves stretches, in principle, over an infinite range of wavelengths. Different regions are known by different names; □-rays, X-rays, ultraviolet rays, visible rays, infrared rays, microwaves and radio waves in order of increasing wavelength from 10–2 Å or 10–12 m to 106m.
They interact with matter via their electric and magnetic fields which set in oscillation charges present in all matter. The detailed interaction and so the mechanism of absorption, scattering, etc., depend on the wavelength of the electromagnetic wave, and the nature of the atoms and molecules in the medium.

POINTS TO PONDER

1. The basic difference between various types of electromagnetic waves lies in their wavelengths or frequencies since all of them travel through vacuum with the same speed. Consequently, the waves differ considerably in their mode of interaction with matter.

2. Accelerated charged particles radiate electromagnetic waves. The wavelength of the electromagnetic wave is often correlated with the characteristic size of the system that radiates. Thus, gamma radiation, having wavelength of 10–14 m to 10–15 m, typically originate from an atomic nucleus. X-rays are emitted from heavy atoms. Radio waves are produced by accelerating electrons in a circuit. A transmitting antenna can most efficiently radiate waves having a wavelength of about the same size as the antenna. Visible radiation emitted by atoms is, however, much longer in wavelength than atomic size.
3. The oscillating fields of an electromagnetic wave can accelerate charges and can produce oscillating currents. Therefore, an apparatus designed to detect electromagnetic waves is based on this fact. Hertz original 'receiver' worked in exactly this way. The same basic principle is utilized in practically all modern receiving devices. High frequency electromagnetic waves are detected by other means based on the physical effects they produce on interacting with matter.
4. Infrared waves, with frequencies lower than those of visible light, vibrate not only the electrons, but entire atoms or molecules of a substance. This vibration increases the internal energy and consequently, the temperature of the substance. This is why infrared waves are often called *heat waves*.
5. The centre of sensitivity of our eyes coincides with the centre of the wavelength distribution of the sun. It is because humans have evolved with visions most sensitive to the strongest wavelengths from the sun.