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PHYSICS

Class 9th (KPK)

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Chapter No: 1
PHYSICAL QUANTITIES AND MEASUREMENT
Comprehensive Questions

Q#1: Define Physics. How Physics play a crucial role in science, technology and society.

Ans: Physics:

Physics is the branch of science that involves the study of physical universe: energy, matter, and how they are related.

Explanation

The study of physics is to understand the world around us, the world inside us and the world beyond us. Physics covers a wide range of phenomena, from the smallest sub-atomic particles to the largest galaxies and universe.

Physics and Science

Physics is at the root of every field of science. Most of the major developments in Chemistry, Biology, Geology, Agricultural, Environmental science, Astronomy, Engineering and even in medicine have been made by physicists.

Physics, Technology and its impact on our Society:

Physics is concerned with gathering knowledge and organizing it. Technology lets humans use that knowledge for practical purposes. Physical phenomenon is there behind every technology and therefore physics has a key role in the progress of humankind and in the improvement of quality of living.

Example # 1:

Physics provide basic understanding for developing new instrumentation for medic al applications such as CT Scan, MRI and laser technology.

Example # 2:

The use of physics in information technology has improved the standard of communication. Mobile cell phones are commonly used even by illiterates. Hologram technology is a three-dimensional image.

Example # 3:

Physics investigate the motion of electrons and rockets, the energy in sound waves and electric circuits, the structure of the proton and of the universe.

Q#2: What is SI? Name SI base quantities and their units?

Ans: International System of Units:

In 1960, an international conference was held near Paris in France. In this conference, it was decided to introduce a system which could be used all over the world. It was given the name of system international. The international system of unit's is abbreviated as SI units. In this system seven quantities were chosen as basic quantities. The units of these quantities are defined and they are known as Base units, from which all other units are derived.

The seven basic physical quantities, their SI base units and symbols are given in table.

Base Quantity	SI Base Unit	Symbol of SI Unit
Length	Meter	m
Mass	Kilogram	kg
Time	Second	s
Electric current	Ampere	A

Temperature	Kelvin	K
Amount of substance	Mole	mol
Luminous intensity	Candela	cd

Q#3: What are physical quantities? Distinguish between base and derived physical quantities.

Ans: <u>Physical Quantities:</u>

All those quantities which can be measured are called physical quantities.

Example:

Length, mass, time, density and temperature etc.

Difference between base and derived physical quantities:

Base Quantities	**Derived Quantities**
Minimum number of physical quantities selected and their units are defined and standardized such that in terms of these all other physical quantities can be expressed are called base quantities.	The physical quantities defined in term of base quantities are called derived quantities.
These are seven in number.	These are infinite, having no fix number.
Examples: Length, mass, time, electric current, temperature, amount of substance and intensity of light.	**Examples:** Speed, area, volume , density, work and momentum etc.

Q#4: What is standard form or scientific notation?

Ans: Scientific Notation:

Scientific notation is a way of writing numbers that are too big or too small to be easily written in decimal form.

Explanation:

A large or small number 'N' can be expressed in terms of a number 'M' and a power of 10 like

$$\mathbf{N=M \times 10^n}$$

Where 'M' represents a number whose first digit is non-zero digit and 'n' represent the power of 10 which may be positive or negative.

Example:

The mass of moon is approximately 70,000,000,000,000,000,000,000kg, which in standard form or scientific notation is 7×10^{22} kg.

Similarly, the diameter of atomic nucleus is about 0.000000000000001m, which in standard form or scientific notation is 1×10^{-14} m.

Q#5: What are prefixes? Explain with examples.

Ans: Prefixes:

A mechanism through which a very small or very large number is expressed in terms of power of 10 by giving a proper name to it is called prefixes.

Explanation:

Prefixes are used before a standard unit to show how much larger or smaller the given physical quantity is as compared to the standard unit of that quantity.

Prefixes make standard form to be written even more easily. Large numbers are simply written in more convenient prefix with units.

Examples:

The thickness of a paper can be written conveniently in smaller units of millimeter instead of meter.

Similarly, the long distance between two cities may be expressed better in a bigger unit of distance, i.e. kilometer. A useful set of prefixes are given in table:

Decimal multiplier	Prefix	Symbol	Decimal multiplier	Prefix	Symbol
10^{18}	Exa	E	10^{-1}	deci	d
10^{15}	Peta	P	10^{-2}	centi	c
10^{12}	Tera	T	10^{-3}	milli	m
10^{9}	Giga	G	10^{-6}	micro	μ
10^{6}	Mega	M	10^{-9}	nano	n
10^{3}	Kilo	K	10^{-12}	pico	p
10^{2}	Hecto	H	10^{-15}	femto	f
10^{1}	Deca	Da	10^{-18}	atto	a

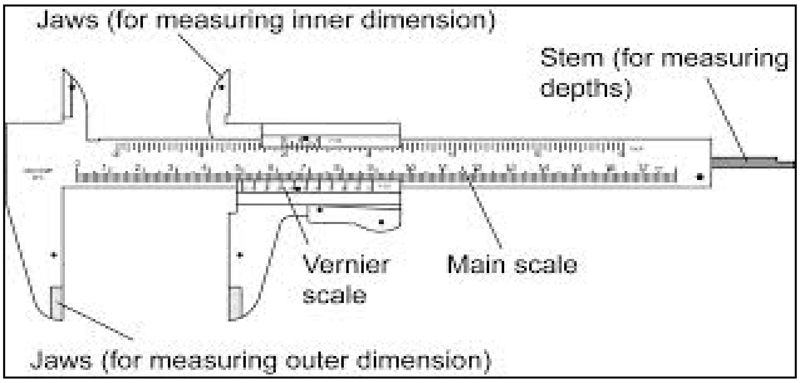
Q#6: Describe the construction and use for measurement of the following instruments:

a. Vernier Calliper

b. Screw Gauge

Ans(a): Vernier Calliper:

A device used to measure a fraction of smallest scale division by sliding another scale over it is called vernier calliper.



Construction:

There are two scales on vernier calipers.

1. **Main Scale:**

A main scale which has markings of usually of 1mm each and it contains jaw A on its left end.

2. **Vernier Scale:**

A vernier (Sliding) scale which has markings of some multiple of the marking on the main scale. The vernier scale usually has length of 9mm and is divided equally into 10 divisions. The separation between two lines on vernier scale is $\frac{9}{10}$ mm = 0.9mm. Vernier scale contains jaw B on its left end.

Vernier Constant or Least Count:

Minimum length which can be measured accurately with the help of a vernier callipers is called vernier constant or least count of vernier callipers. The least count of vernier callipers is calculated b:

$$\text{Least count} = \frac{\text{Smallest division on main scale}}{\text{Total no. of divisions on vernier scale}}.$$

If the smallest main scale division is 1mm and vernier scale division has 10 divisions on it then the least count is:

$$\text{Least count} = \frac{1\text{mm}}{10}$$
$$= 0.1\text{mm}$$
$$= 0.01\text{ cm}$$

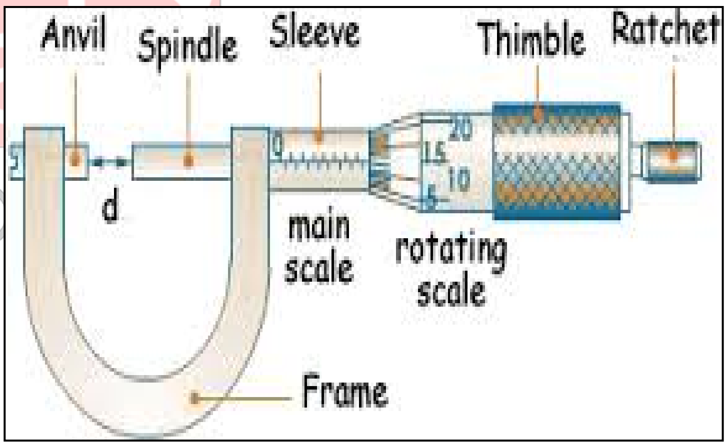
Uses of Vernier Calliper:

Vernier calliper is an instrument used to measure small length accurately upto 0.1mm or 0.01 cm. It can be used to measure the thickness, diameter or width of an object and the internal, external diameter of hollow cylinder.

(b). Screw Gauge:

A device used to measure a fraction of smallest scale division by rotatory motion of circular scale over it is known as screw gauge.

Construction:



A screw gauge consists of a "U" shaped frame, which is attached to a hollow cylindrical tube on one end. The hollow tube has a uniformly threaded nut inside it. A long stud with a plane face is fitted into this nut. Exactly on the opposite side of this nut and on -the other end of "U" shaped frame, a smaller stud with a plane face is also attached. Faces of both the studs are exactly parallel to each other. The smaller stud is known as the anvil and the longer one is known as the spindle. The anvil is fixed part of device, whereas the spindle moves. The object to be measured is held between the anvil and the spindle.

Least Count of Screw Gauge:

The minimum length which can be measured accurately by a screw gauge is called least count of screw gauge. The least count of screw gauge is found by dividing its pitch (pitch is the distance travelled by the circular scale on linear scale in one rotation) by the total number of circular scale division.

$$\text{Least count} = \frac{\text{Pitch of Screw Gauge}}{\text{Total no.of division on circular scale}}$$

If the pitch of the screw gauge is 0.5mm and the number of divisions on circular scale is 50 then

Least Count = $\frac{0.5 \text{ mm}}{50}$

= 0.01 mm

or

= 0.001 cm

Uses of Screw Gauge:

The screw gauge is used to measure very short lengths such as the thickness of metal sheet or diameter of a wire up to 0.01 mm or 0.001cm.

Q#7: What is meant by the significant figures of measurement? What are the main points to be kept in mind while determining the significant figures of measurement?

Ans: Significant Figures:

The number of accurately known figures and the first doubtful figure are known as significant figures.

Explanation:

There are two types of values, exact and measured. Exact values are those that are counted clearly. For example, while reporting 3 pencils or 2 books, we can indicate the exact number of these items.

On the other hand, values associated with measurements of any kind are uncertain to some extent. For example, if we want to measure the length of a pencil with an ordinary meter ruler having least count of 1mm and we note that the length of the pencil is greater than 67 mm and less than 68 mm. We can estimate that the length of the pencil is 67.5 mm. This length is accurate in mm upto 67, but the last fraction of mm has been guessed. There is a chance of error in the last figure. It is known as the doubtful figure.

General Rules For Significant Figures:

1. Non-zero digits are always significant. That is all the digits from 1 to 9 are significant. For example, the number of significant figures in 47.73 is four.
2. Zero in between two significant digits is always significant. For example, the number of significant figures in 32.50063 is seven.
3. Zeros to the left of significant figures are not significant. For example, the number of significant figures in 0.00467 is three.
4. Zeros to the right of the significant figure may or may not be significant. In decimal fractions zero to the right of a decimal fraction are significant. For example, in 7.400 there are four significant figures. For example, in number 80,000 we may have 1, 2 or even 5 significant figures.
5. In scientific notation or standard form, the figures other than power of ten are all significant, for example mass of electrons is 9.11 x 10^{-31}kg. There are three significant figure in it.

Rules for Rounding Off Significant Figures:

a. If the last digit is less than 5 then it will be ignored. e.g. 2.6573 is rounded to 2.657.
b. When the dropping digit is greater than 5 then the last retained digit increased by 1. e.g. 2.6578 is rounded to 2.656.
c. When the dropping digit is 5 and the last retained digit is even then the last digit i.e. 5 will be dropped without affecting the next one e.g. 2.6585 is rounded to 2.658.
d. If the last digit is 5 and the 2^{nd} last is an odd digit then the 2^{nd} last digit is increased by 1 in order to round off 5. e.g. 2.6575 is rounded to 2.658.

TOPIC WISE QUESTIONS

Q.8 Discuss the contribution of Muslim scientists in the development of physics?

Ans. Scientists of the Islamic world contributed in the development of physics. Few of the notable scientists are;

YAQUB KINDI (800-873 AD)

He was born in Basra, Iraq. He had done valuable work in the field of meteorology, specific gravity and on tides. His most important work was done in the field of optics, especially on reflection of light.

IBNAL HAITHAM (965-1039 AD)

He was born in Basra, Iraq. He was great scholar of his time. His greatest work is the book on optics named Kitab-ul-Manazir. He is also considered as the inventor of the pin-hole camera.

AL-BERUNI (973-1048 AD)

He was an Afghan scholar and wrote 150 books on physics, cosmology, geography, culture, archeology and medicine. Al Beruni discussed the shape of earth the movement of the sun, moon and the phases of moon.

Q.9 **Discuss the work of famous Pakistani physicists?**

Ans:

Dr. Abdus Salam (1926-1996)

He was born in Jhang in 1926. He was a Pakistani theoretical physicist. He shared the 1979 Nobel prize in physics with Sheldon Glashow and Steven Weinberg for his contribution to the electroweak unification theory. He was the first Pakistani to receive a Nobel prize in Science.

Dr. Abdul Qadeer Khan

He was born in Bhopal, India in 1936. He is a Pakistani nuclear physicist and a metallurgical engineer, who founded the uranium enrichment program for Pakistan's atomic bomb project. He founded and established the Kahuta Research Laboratories (KRL) in 1976, and served as both its senior scientist and Director- General until he retired in 2001.

Q.10 **What is Physics? Describe main branches of physics.**

Ans. **Physics:**

Physics is the branch of science which deals with the properties of matter, energy and their mutual relationship.

Branches of Physics:

1. Mechanics:

The branch of physics which deals with the motion of material objects under the action of forces.

Examples:

Falling objects, friction, weight, spinning objects.

2. **Heat and Thermodynamics:**

The branch of physics which deals with the heat and temperature and their relation to energy. It also deals with the transformation of heat energy into other forms of energy.

Examples:

Melting and freezing processes, engines, refrigerators.

3. **Oscillations and Waves:**

The branch of physics which deals with the study of to and fro motion and various properties of waves.

Examples:

Mass-spring system, water waves, sound waves etc.

4. **Optics:**

The branch of physics which deals with the nature of light, its propagation, reflection, refraction, dispersion and the wave properties of light.

Examples:

Mirrors, lenses, telescopes, Eye.

5. **Electricity and Magnetism:**

The branch of physics which deals with the study of static as well as moving charges and associated physical phenomena.

Examples:

Electrical charge, circuitry, magnets, electromagnets.

6. **Atomic And Nuclear Physics:**

The branch of physics which deals with the structure and properties of individual atoms and nuclei of an atom.

Examples:

X-rays, lasers, nuclear reactor, MRI, CT scan, PET Scan.

7. **Relativity:**

The branch of physics which deals with the objects moving with very high speed and gravitation.

Examples:

Particle accelerators, Nuclear energy.

8. **Quantum Physics:**

Quantum Physics is that branch of physics which deals with discrete, indivisible units of energy called quanta as describe by quantum theory.

Examples: The atom and its parts.

9. **Particle Physics:**

It is the branch of physics in which we study the nature of the particles that constitute matter and radiation.

Examples:

Quarks, Leptons, photons, Bosons etc.

10. **Cosmology and Astrophysics:**

It deals with the study of the origin, evolution and eventual fate of the universe.

Examples:

Stars, galaxies and black holes.

11. **Biophysics and Medical Physics:**

It deals with the study of physical interactions of biological processes and application of physics health processes such as prevention, diagnosis and treatment.

Examples:

MRI, CT scan, Radiotracers and conduction in living cells.

Q11: What are physical quantities? Discuss its types.

Ans:

PHYSICAL QUANTITIES:

All those quantities which can be measured are called physical quantities.

Examples:

Length, mass, time, density and temperature etc.

TYPES OF PHYSICAL QUANTITIES:

There are two types of physical quantities which are given below;

1. Base physical quantities
2. Derived physical quantities

BASE PHYSICAL QUANTITIES:

Minimum number of physical quantities selected and their units are defined and standardized such that in terms of these all other physical quantities can be expressed are called base quantities.

There are seven base quantities which are mass, length, time, current, temperature, intensity and amount of substance.

BASE UNITS:

In **SI,** seven physical quantities are chosen as base and their units are defined, standardized and are called base units.

OR

The units of base quantities are known as base units.

The seven base physical quantities, their SI base units and symbols are given in table.

Base Quantity		SI Base Unit	
Name	**Symbol**	**Name**	**Symbol**
Length	L	Meter	m
Mass	m	Kilogram	kg
Time	T	Second	s
Electric charge	I	Ampere	A
Temperature	T	Kelvin	K
Luminous intensity	I	Candela	cd
Amount of substance	N	Mole	mol

DERIVED PHYSICAL QUANTITIES

The physical quantities defined in terms of base quantities are called derived physical quantities.

Examples:

work, area, volume, speed, power etc.

DERIVED UNITS

Units derived from multiplying and dividing base units are termed as derived units. In SI units for all other physical quantities can be derived from seven base units.

Some derived quantities with derived units are given in the table.

Derived Quantity		Derived Unit	
Name	**Symbol**	**Name**	**Symbol**
Area	A	Square meter	m^2
Speed	V	Meter per second	ms^{-1}
Force	F	Newton	$N=kgms^{-2}$
Energy	E,U	Joule	$J=kgm^2s^{-2}$
Pressure	P	Pascal	$Pa=kgm^{-1}s^{-2}$

Q.12 What is system of units?

Ans. SYSTEM OF UNITS:

A complete set of units for all physical quantities is called system of units.

There are several system of units.

For example;

Meter kilogram second system (MKS)

Foot pound second system (FPS)

But the system which is used internationally is system International (SI).

Q.13 What are measuring instruments?

Ans. MEASURING INSTRUMENTS:

Measuring instruments are devices to measure physical quantities.

Physicists use large number of measuring instruments. These range from simple objects such as rulers and stopwatches to Atomic Force Microscope (AFM) and Scanning Tunneling Electron microscope (STEM). All measuring instruments have some measuring limitations.

LEAST COUNT:

Least count is the minimum value that can be measured on the scale of a measuring instrument.

Q.14 What is meter rule?

Ans. Meter rule is used to measure the length of objects or the distance between two points.

Rulers are made from different materials and in a wide range of sizes.

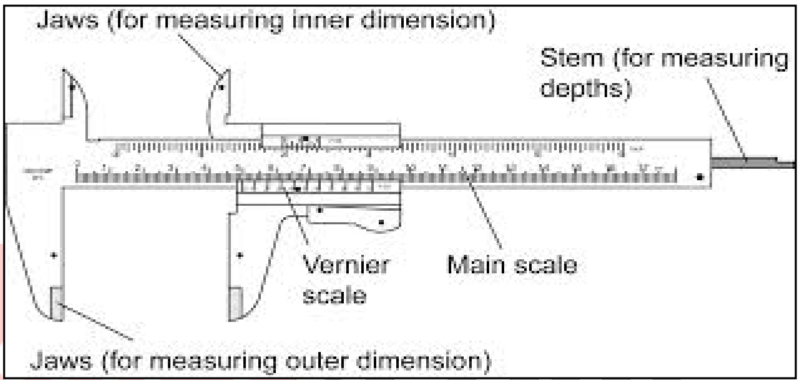
Q.15 Describe the purpose, construction and use for measurement of vernier caliper?

Ans. VERNIER CALLIPERS:

A device used to measure a fraction of smallest scale division by sliding another scale over it is called vernier caliper.

PURPOSE:

Vernier calliper is used to measure the length, thickness, diameter or width of an object and the internal, external diameter of hollow cylinders and the depths.



CONSTRUCTION:

There are two scales on vernier calliper;

1. Main Scale
2. Vernier Scale

MAIN SCALE:

A main scale which has markings of usually 1mm each and it contains jaw A on its left end.

VERNIER SCALE:

A vernier scale (sliding) scale which has markings of some multiple of the markings on the main scale. The vernier scale usually has length of 9mm and is divided equally into 10 divisions. The separation between two lines on vernier scale is 9/10 mm=0.9mm. Vernier scale contains jaw B on its left end.

VERNIER CONSTANT OR LEAST COUNT:

Minimum length which can be measured accurately with the help of a vernier callipers is called vernier constant or least count of vernier calipers. The least count of vernier callipers is calculated by

$$\text{Least Count} = \frac{\text{smallest division on main scale}}{\text{total no.of divisions on vernier scale}}$$

If the smallest main scale division is 1mm and vernier scale division has 10 division on it then the least count i.e.

$$\text{Least count} = \frac{1\text{mm}}{10}$$

$$= 0.1 \text{ mm}$$

$$= 0.01 \text{ cm}$$

ZERO ERROR:

On closing the jaws of the callipers, the zero of the vernier scale may or may not coincide with the zero of the main scale. If their zero does not coincide, there is zero error in the instrument.

POSITIVE ZERO ERROR:

When the zero of the vernier scale remains right to the zero of the main scale, such error is called positive zero error.

NEGATIVE ZERO ERROR:

When the zero of the vernier scale is left of the zero of the main scale, such error is called negative zero error.

HOW TO FIND ZERO ERROR:

Bring the jaws of vernier calliper towards each other so that they touch each other. Now note the division of vernier scale which exactly coincides with any division of the main scale. Note it as "n" and multiply it with the least count.

ZERO CORRECTION:

If the error is positive this value (n×L.C) is subtracted from the actual reading. If the error is negative, the value is added to the actual reading.

MEASUREMENT WITH VERNIER CALLIPERS:

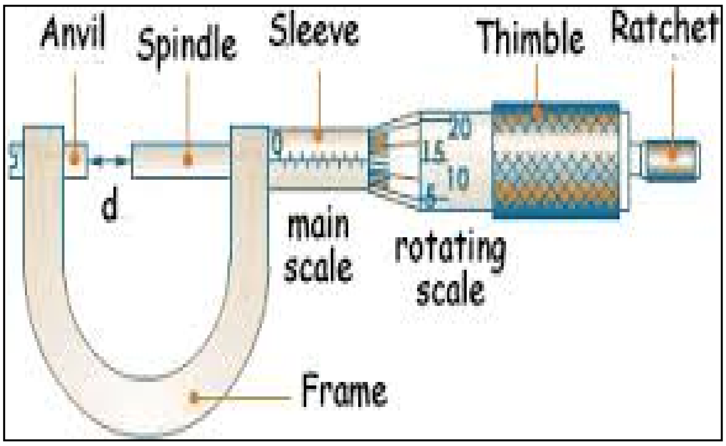
Suppose we want to measure the diameter of a small solid cylinder with the vernier calipers, we will use the following method;

1. First of all check the zero error of the vernier callipers.
2. Now place the object between the jaws of vernier calipers and tight them.
3. Now note the reading on main scale. Let this reading be represented by "x".
4. Now note a division on the vernier scale which coincides with any division of main scale. Now multiply this division of vernier scale with least count. Let this reading be "y".
5. Now add "x" and "y" (x+y) which is measurement of the given object.
6. In case of zero error, add negative error with (x+y) and in case of positive error subtract the error from (x+y).
   i.e Accurate Measurement= (x+y)± zero error.

Q.16 Describe the purpose, construction and use for measurement of screw gauge?

Ans. SCREW GAUGE:

A device used to measure a fraction of smallest scale division by rotatory motion of circular scale over it is known as screw gauge.



CONSTRUCTION:

A screw gauge consists of a "U" shaped frame, which is attached to a hollow cylindrical tube on one end. The hollow tube has a uniformly threaded nut inside it. A long stud with a plane face is fitted into this nut. Exactly on the opposite side of this nut and on the other end of

"U" shaped frame, a smaller stud with a plane is also attached. Faces of both the studs are exactly parallel to each other. The smaller stud is known as the anvil and the longer one is known as the spindle. The anvil is fixed part of device, whereas the spindle moves. The object to be measured is held between the anvil and the spindle.

PITCH OF SCREW GAUGE:

The distance travelled by the circular scale on linear scale in one rotation is called the pitch of screw gauge.

LEAST COUNT OF SCREW GAUGE:

The minimum length which can be measured accurately by a screw gauge is called least count of screw gauge. The least count of screw gauge is found by dividing its pitch by the total number of circular scale divisions.

$$\textbf{Least count}= \frac{\textbf{pitch of screw gauge}}{\textbf{total number of divisions on circular scale}}$$

If the pitch of the screw gauge is 0.5mm and the number of divisions on circular scale is 50 then

$$\text{Least count}= \frac{0.5\text{ mm}}{50}$$

$$= 0.01\text{ mm}$$

$$\text{or} \quad = 0.001\text{ cm}$$

ZERO ERROR:

Turn the thimble until the anvil and spindle meet. If the zero mark on the thimble scale does not lie directly opposite the datum line of the main scale, we say that there is zero error.

POSITIVE ZERO ERROR:

If the zero of the circular scale remains below the horizontal line then such zero error is called positive zero error.

NEGATIVE ZERO ERROR:

If the zero of the circular scale remains above the horizontal line of the linear scale then such zero error is called negative zero error.

HOW TO FIND ZERO ERROR:

Bring the bolt towards the stud by rotating cap of the screw, so that they touch each other. Note the division on the circular scale that exactly coincides with the horizontal line of the linear scale. Multiply this division "n" with the least count to get the zero error.

ZERO CORRECTION:

If there is zero error, then for correct measurement, we add the negative error or subtract the positive error from the actual reading.

MEASUREMENT WITH SCREW GAUGE:

Suppose we want to measure the diameter of a small sphere by using screw gauge we will use the following method;

1. First of all check the screw gauge for zero error.
2. Place the object between anvil and spindle and tight the sphere by rotating the thimble.
3. Now note the reading on linear scale and denote it by "x".

4. Now note a division on circular scale which coincides with the horizontal line of the linear scale. Now multiply this division with the least count. Let this reading be denoted by“y”.
5. Now add “x” and “y” (x+y) to get the result.
6. In case of zero error, to get the actual measurement, subtract positive zero error an add negative zero error to (x+y).
   i.e Accurate Measurement = (x+y)± zero error

Q.17 What is physical balance?

Ans. <u>PHYSICAL BALANCE:</u>

It is a device which is used for measuring the mass of a body.

<u>EXPLANATION:</u>

Physical balance is a common balance where there are two pans and we measure weight of an object by putting it in one pan and a known weight in the other.

A physical balance is a very sensitive common balance which can measure weight in milligram order. It is placed in a protective glass case so that even dust and wind can not affect the accuracy of the instrument.

Q.18 What is stop watch? Discuss its types and their working?

Ans. <u>STOP WATCH:</u>

It is a device which is used for measuring specific intervals of time.

There are two main types of stop watch;

1. Mechanical or Analogue Stop Watch
2. Digital Stop Watch

<u>MECHANICAL/ ANALOGUE STOP WATCH:</u>

It consists of two hands a small minute hand and a long second hand. Scales for each hand are marked on a circular dial.

<u>WORKING:</u>

To note the time both the hands are set at zero by pressing and releasing the knob. As the knob is pressed and released again, the watch starts.

When the second’s hand completes two rotations of 30 seconds each, the minute hand advances by one division. When it is required to be stopped, again the same knob is pushed, the watch stops, and time can be noted.

<u>DIGITAL STOP WATCH:</u>

A digital clock is a type of clock with a digital display.

OR

Digital Stopwatch shows the time in the form of digits.

<u>WORKING:</u>

The timing functions in digital stopwatch are usually controlled by two buttons on the case. Pressing the top button starts the timer running, and pressing the button a second time stops it, leaving the elapsed time displayed.

A press of the second button then resets the stopwatch to zero. The second button is also used to record split times or lap times. When the split time button is pressed while the watch is running, the display freezes, allowing the elapsed time to that point to be read, but the watch mechanism continues running to record total elapsed time. Pressing the split button a second time allows the watch to resume display of total time.

Q.19 Discuss the purpose, construction and working of measuring cylinder.

Ans. MEASURING CYLINDER:

Measuring cylinder is a device with the help of which we can determine the volume of a liquid as well as volume of irregular solid body such as key.

CONSTRUCTION:

It is made of transparent plastic or glass and it has a vertical scale in milliliter (ml) or cubic centimeter (cm^3).

WORKING:

Water is poured into a measuring cylinder until the cylinder is about half full. Note the volume of water.

Now an irregular shaped object is lowered gently into the cylinder such that it is immersed completely and note the volume of water again. The final volume is the sum of volume of water and volume of the object.

The volume of the object is found by subtracting the first reading from the second.

Conceptual Questions:

Q#1: How technology is shaped by physics?

Ans: Physics and technology are closely related. Physics is concerned with gathering knowledge and organizing it. So, Physical phenomenon is there behind every technology.

For example:

1. Buses, cars, motorcycles etc. are the important means of transport in modern technologies which are based on the principle of mechanics.
2. Heat engines work on the principle of thermodynamics.
3. Computer is used in the modern technology which works on the principle of physics.
4. The discovery of laws of electromagnetic induction enabled the engineers to develop electric generators.
5. The discovery of nuclear fission led to the development of nuclear power plant which produce huge amount of energy for use.
6. Physics helps in the development of new instruments for medical applications such as CT scan, MRI and LASER etc.

From the above discussion, it is clear that physics has played an important role in the development of various technologies.

Q#2: Physics and biology are considered different branches of science, how physics links with biology?

Ans: Physics helps biology to great extent for example:

i. Physics leads us to great invention like microscope, electron microscope, Computer Tomography (CT scan), Ultrasonic Machines, X-rays etc.
ii. Physics has invented concave and convex lenses which are widely used to correct short and long sightedness.
iii. The movement of muscles and bones are studied and followed by the principles of physics (lever and its types).
iv. Physics has helped a lot to understand photosynthesis by describing the nature of light.

Q#3: Why are measurements important?

Ans: Measurement is one of the most basic concepts in science. Physics deals with physical quantities which can be measured. So, measurement provides a standard for everyday things and processes.

Examples:

Some examples from daily life have shown the importance of measurement.

1. Without the ability to measure, it would be difficult for scientists to conduct experiments.
2. Without measurements, there would be no concept of freezing point, boiling point and density etc.
3. Without measurements, patients are unable to take correct dose of medicines.
4. Without measurements, buying and selling of things are impossible.
5. It is also essential in farming, engineering, construction, and manufacturing etc.
6. From weight, temperature, length, even time is a measurement and it does play a very important role in our lives.

Q#4: Why area is a derived quantity?

Ans: A derived quantity is the combination of various base quantities. Thus, area is a derived quantity because in area the same base quantity "length" occurs twice (in the form of length and breadth).

As we know that

Area = Length x breadth

Area = ι x ι

= ι^2

As unit of length is "m"

So,

Unit of area is **'m^2'.**

Q#5: Name any four derived units and write them as their base units?

Ans: Four derived units are newton, pascal, joule and ohm.

Derived units in term of base units are given below:

Derived Quantities	**Derived Units**	**Derived unit in term of base unit**
Volume	Cubic meter	m^3
Acceleration	Meter per second square	ms^{-2}
Force	Newton (N)	$kg\ ms^{-2}$
Pressure	Pascal (Pa)	$kg\ m^{-1}\ s^{-2}$

Q#6: Why in physics we need to write in scientific notation?

Ans: Scientific notation is an easy way of writing numbers that are very big or very small. In physics we need to write number in scientific notation because with the help of scientific notation we can express very large or very small number easily. A large or small number "N" can be expressed in term of a number "M" and a power of 10. e.g.;

$$N = Mx10^n$$

Where "M" represents a number whose first digit is non-zero digit and "n" represent the power of 10 which may be positive or negative.

For example:

150, 000,000,000 m is expressed in terms of scientific notation as **$1.5x10^{11}$m.**

Q#7: What is least count? How least count for vernier caliper and screw gauge are defined?

Ans: Least Count:

Least Count is the minimum value that can be measured on the scale of measuring instrument.

Least Count of Vernier Calliper:

The minimum length which can be measured accurately with the help of vernier caliper is called least count of vernier calliper.

Least count can be obtained from dividing the value of smallest division on main scale by total number of divisions on vernier scale.

$$\text{Least Count} = \frac{\text{smallest division on main scale}}{\text{total no.of dividion on vernier scale}}$$

If smallest main scale division is 1mm and vernier scale division has 10 divisions then the least count is

$$\text{Least Count} = \frac{1\text{mm}}{10} = 0.1\text{mm}$$

Least Count of Screw Gauge: The minimum length which can be measured accurately by a screw gauge is called least count of the screw gauge.

The least count can be obtained by dividing its pitch by the total number of circular scale division:

$$\text{Least count} = \frac{\text{Pitch of the screw gauge}}{\text{total no.of divisions on circular scale}}$$

If the pitch of the screw gauge is 0.5mm and the number of divisions on circular scale is 50 then

$$\text{Least count} = \frac{0.5\text{mm}}{50} = 0.01\text{mm}$$

Q#8: How can we find the volume of a small pebble with the help of measuring cylinder?

Ans: Take a measuring cylinder and put some water into it about half full. Note the initial volume of water. i.e. Initial volume $=V_i$

Now a pebble is lowered gently into the cylinder such that it is immersed completely and note the final volume. The final volume is the sum of volume of water and volume of pebble which is V_f.

Now, find the difference "ΔV" in volume which is the volume of the pebble.

Volume of the pebble = $\Delta V = V_f - V_i$

ASSIGNMENTS

1.1 The mass of earth is 5,980,000,000,000,000,000,000,000 kg. Write this number in standard form/ scientific notation.

DATA:

Mass of earth = 5,980,000,000,000,000,000,000,000 kg

FIND:

Standard form=?

SOLUTION:

As we know that

$$N = M\times10^n$$

So,

5,980,000,000,000,000,000,000,000kg= 5.98×10^{24}kg

Therefore, mass of earth in scientific notation is 5.98×10^{24}kg.

1.2 Calculate the number of seconds in a week. Express the number in power of 10 notation.

Data:

Number of seconds in a week=?

SOLUTION:

No. of days in1 week =7 days

No. of hours in 1 day =24 hours

No. of minutes in 1 hour =60 min

No. of seconds in 1 min=60 sec

So,

1 week=$1\times7\times24\times60\times60$

1 week= 604800 sec

In scientific notation,

$N=M\times10^n$

1 week = 6.048×10^5 sec

1.3 Adult housefly (Musca domestica) is having a mass of only about 0.0000214kg. Express this number in standard form/ scientific notation.

DATA

Mass of housefly= 0.0000214 kg

SOLUTION

As we know that

$N=M\times10^n$

So,

0.0000214kg=2.14×10^{-5}kg

Therefore, mass of housefly in scientific notation is 2.14×10^{-5}kg.

1.4 The smallest bird is the bee hummingbird. Males measure only 0.057m, convert this number to standard form and write this number in millimeters.

DATA:

Size of bee in meter= 0.057m

FIND:

a. Standard form=?

b. Size of bee in millimeter=?

SOLUTION:

a. In scientific notation, we know that

$\mathbf{N=M\times10^n}$

0.057= $5.7\text{x}10^{-2}$m

b. Now, to convert in "mm"we also know that

1m=10^{-3}mm

So, Size of bee =$5.7\text{x}10^{-2}$ x10^{-3}mm

=$5.7\text{x}10^{-2+3}$m

=$5.7\text{x}10^{1}$mm

=$57\text{x}10^{1-1}$mm

=$57\text{x}10^{0}$ mm

Size of bee =57mm

So, the size of bee in millimeter is 57mm.

1.5 Calculate the distance from Peshawar to Lahore in millimeters.

DATA:

Distance from Peshawar to Lahore=489km

FIND:

Distance from Peshawar to Lahore in millimeter=?

SOLUTION:

Distance from Peshawar to Lahore=489km

$=489\times10^{3}$m (because kilo=10^3)

$=489\times10^{3}\times10^{3}$mm (because 1m=$10^3$mm)

$=489\times10^{3+3}$mm

$= 489\times10^{6}$mm

$=4.89\times10^{2}\times10^{6}$mm

$=4.89\times10^{2+6}$mm

$=4.89\times10^{8}$mm

Therefore, distance from Peshawar to Lahore in millimeters is 4.89×10^{8}mm.

1.6 Which of the following is the accurate device for measuring length;

a. A vernier calipers with main scale of 1mm marking and 50 divisions on sliding scale.

b. A screw gauge of pitch 1mm and 25 divisions on the circular scale.

DATA

Smallest division on main scale of vernier callipers= 1mm

Total no. of divisions on vernier scale= 50

Pitch of screw gauge= 1mm

Total no. of divisions on circular scale= 25

SOLUTION

a. Least count of vernier callipers is given by

$$\text{Least count} = \frac{\text{Smallest division on main scale}}{\text{total no.of divisions on vernier scale}}$$

$$= \frac{1\text{mm}}{50}$$

=0.02 mm

b. Least count of screw gauge is given by

$$\text{Least count} = \frac{\text{Pitch of screw gauge}}{\text{total no.of divisions on circular scale}}$$

$$\text{Least count} = \frac{1\text{mm}}{25}$$

=0.04 mm

As the least count of vernier calliper is smaller than that of screw gauge, so in this case vernier calipers will give more accurate result for measuring length.

1.7 A breaker contains 200ml of water, what is the volume of water in cm^3 and m^3.

DATA:

Volume of water in ml=200ml

FIND:

Volume of water in cm^3=?

Volume of water in m^3=?

SOLUTION:

Volume of water =v= 200ml

a. As V=200ml------------(1)

And we know that

1ml=$1cm^3$

So eq (1) becomes

$V=200x1ml$
$=200x1cm^3$
$V=200cm^3$--------------(2)

b. <u>Now find the volume of water in m^3</u>

As we know that
1m=100cm
Taking cube on both sides
$(1m)^3=(100cm)^3$
$1m^3=(100)^3\ cm^3$
$= 100x100x100\ cm^3$
$1m^3=1000000\ cm^3$
$\frac{1m^3}{1000000} = \frac{1000000}{1000000}cm^3$
$\frac{1}{10^6}m^3= 1cm^3$
$10^{-6}m^3 = 1cm^3$
Or
$1cm^3 = 10^{-6}m^3$
So eq (2) becomes
$V=200\ cm^3$
$=200x1\ cm^3$
$V=200x10^{-6}m^3$ (because $1cm^3= 10^{-6}m^3$)
$=2.0 \times 10^2 x\ 10^{-6}\ m^3$
$=2.0x10^{2-6}m^3$
$V=2.0x10^{-4}m^3$

NUMERICAL QUESTIONS

1. Write the number in prefix to power of ten,
- **a. Mechanical nano-oscillators can detect a mass change as small as 10^{-21}kg.**
- **b. The nearest neutron star (a collapsed star made primarily of neutrons) is about $3.00x10^{18}$m away from Earth.**
- **c. Earth to sun distance is 149.6 million km.**

SOLUTION;

a. Mass = 10^{-21}kg
Mass = 10^{-21}x 1kg $\because 1kg = 10^3\ g$
$=10^{-21}x\ 10^3g$
$=10^{-21+3}g$
$=10^{-18}g$
$=1x10^{-18}g$ ($\because 10^{-18}$ = atto)
Mass = 1 atto g
Or
Mass = 1 ag

b. Distance of nearest neutron from earth = $3.00x10^{18}$m
Distance = $3.00x10^{18}$m
=3.00 Exa. m (because 10^{18}= Exa)
Or Distance =3.00 Em

c. Earth to sun distance = 149.6 million km
$=149.6x10^6$km (because million=10^6)
$=149.6x10^6x10^3$m (because kilo= 10^3)

$=149.6x10^{6+3}m$
$=149.6x10^{9}m$
$=149.6$ Giga.m (because 10^9= Giga)

Earth to sun distance = 149.6 Gm

2. An angstrom (symbol A*) is a unit of length (commonly used in atomic physics), defined as $10^{-10}m$ which is of the order of the diameter of an atom.

a. How many nanometers are in 1.0 angstrom?

DATA:

1 angstrom = $10^{-10}m$

SOLUTION:

1 angstrom = $10^{-10}m$
$=10^{-1-9}m$ (because $a^{m+n}=a^m.a^n$)
$=10^{-1}x10^{-9}m$ ($\because 10^{-9}$ =1nano)
$=10^{-1}$nano. m
$=10^{-1}$nm
$=\frac{1}{10}$nm
=0.1 nm

1 angstrom= 0.1nm

b. How many femtometers or fermis (the common unit of length in nuclear physics) are in 1.0 angstrom?

SOLUTION:

1.0 angstrom= $10^{-10}m$

Multiplying 10^{-5} on both sides:

$1.0x10^{-5}$ angstrom = $10^{-10}x\ 10^{-5}m$
$1.0x10^{-5}$angstrom= $10^{-10-5}m$ (because $a^m.a^n= a^{m+n}$)
$1.0x10^{-5}$angstrom=$10^{-15}m$
$1.0x10^{-5}$angstrom= Femto.m (because 10^{-15}= 1 Femto)

Multiplying 10^5 on both sides :

$1.0x\ 10^{-5}\ x\ 10^5$angstrom= 10^5 femto m
$1.0x10^{-5+5}$ angstrom = 10^5 femto. m
$1.0\ x\ 10^0$ angstrom= 10^5fm

So,

1.0 angstrom= 10^5fm

c. How many angstroms are in 1.0m?

SOLUTION:

1 angstrom=$10^{-10}m$
1 angstrom = $\frac{1}{10^{10}}$ m

Multiplying 10^{10} on both sides:

$1x10^{10}$angstrom=$10^{10}x\frac{1}{10^{10}}m$
10^{10}angstrom= 1m

Or

1m=10^{10} angstrom

3. The speed of light is c= 299,792,458m/s.

a. Write this value in scientific notation.

DATA:

speed light is c= 299,792,458m/s

FIND:

Standard form=?

SOLUTION:

For scientific notation we have

$N=Mx10^n$-----------(1)

Then eq (1) becomes

$299792458m/s= 2.99792458x10^8m/s$

So, the speed of light in scientific notation is $2.99792458x10^8m/s$.

b. Express the speed of light to

i. Five significant figures

ii. Three significant figures

SOLUTION

i. As $c=2.99792458x10^8m/s$

Now, round off "c" upto five significant figures

$c= 2.99792458\ x10^8m/s$

$c=2.9979246x10^8m/s$

$c=2.997925x10^8m/s$

$c=2.99793x10^8m/s$

$c=2.9979x10^8m/s$

ii. As $c=2.9979246x10^8$ m/s

Now, round off "c" upto three significant figures

$c = 2.9979246x108m/s$

$c = 2.997925x108m/s$

$c = 2.99793x108m/s$

$c = 2.9979x108m/s$

$c = 2.998x108m/s$

$c = 3.00x108m/s$

4. Express the following in terms of power of 10

a. 7 nanometer

As nano $=10^{-9}$

So 7 nanometer= $7x10^{-9}$ meter

b. 96 megawatt

As mega = 10^6

So 96 megawatt = $96x10^6$watt

c. 2 gigabite

As giga = 10^9

So 2 gigabites= $2x10^9$bite

d. 43 picofarad

As pico = 10^{-12}

So 43 picofarad = $43x10^{-12}$farad

e. 2 millimeter

As milli=10^{-3}

So 2 millimeter = $2x10^{-3}$meter

5. Write the following numbers in standard form;

a. Mass of Bacterial cell;0.000,000,000,005kg

DATA:

Mass =0.000,000,000,005kg

FIND:

Standard form=?

SOLUTION:

As we know that

$N=Mx10^n$ -------(1)

then eq (1) becomes

0.000,000,000,005kg=$5x10^{-12}$kg

So, mass of the bacterial cell in standard form is $5x10^{-12}$kg.

b. Diameter of sun; 1,390,000,000 m

DATA:

Diameter of sun =1,390,000,000m

FIND:

Standard form=?

SOLUTION

As we know that

$N=Mx10^n$ -------(1)

Then, equation (1) becomes

1,390,000,000m=$1.39x10^9$m

So, diameter of Sun in standard form is $1.39x10^9$m.

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PHYSICS

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Chapter # 02
Kinematics

Comprehensive questions:

Q#1. What is motion? Describe that motion is relative. How two observers in relative motion can have conflicting views about same object?

Ans: Motion:

A body is said to be in state of motion if it changes its position with respect to its surroundings (or an observer).

Examples:

1. A flying bird
2. A moving car
3. A running boy, etc

Rest and Motion are Relative:

The rest and motion are not absolute. Both are relative because they need specification of observer.

Explanation:

Objects can be at rest and in motion at the same time. Sometimes it happens that a body "A" will be at rest with respect to body "B" but at the same time it will be in motion with respect to body "C". So for same events two observers can have different observations.

Examples:

1. For example, a person travelling by train is at rest with respect to its fellow passenger but the same person is in motion with respect to all the bodies outside the train. Thus, the motion and rest are not absolute but relative. This means that we have to specify the observer while telling about the rest or motion of the body.

2. Similarly, in the classroom, when teacher changes her position while the students are sitting on their chairs. According to the student observation, teacher is in motion whereas, the teacher while moving also observes the students to move as well because the distance between teacher and students in classroom is changing with respect to each other. This shows that rest and motion are relative.

Q#2. Explain different types of motion and give an example of each.

Ans: Types of Motion:

In general, there are three types of motion which are described below:

1. Translatory Motion
2. Rotatory Motion
3. Vibratory Motion

1. **Translatory Motion:** That type of motion in which all particles of the body move parallel to each other along any path, straight or curved is called translatory motion.

Examples:

1. Motion of a ball
2. A moving car, train, bus etc
3. A running boy

2. Types of Translatory motion:

There are further three types of translatory motion which are as follow:

(i) Rectilinear Motion:

The straight line motion of a body is called rectilinear motion.

Example:

Motion of free falling bodies.

(ii) Curvilinear Motion:

The motion of a body along a curved path is called curvilinear motion.

Example:

Motion of cricket ball in air.

(iii) Random Motion:

The irregular motion of a body is called random motion.

Example:

- Motion of gas molecules.
- Flight of butterfly

2. Rotatory Motion:

That type of motion in which all particles of a body moves around a fixed point or axis is called rotatory motion.

Examples:

1. Motion of the blades of a fan
2. Motion of a wheel.
3. Motion of hands of a clock.

3. Vibratory Motion:

The back and forth motion of a body along the same path about its mean position is called vibratory motion.

Examples:

1. Motion of a swing
2. Motion of pendulum
3. Motion of the strings of a guitar.

Q#3. Define scalar and vector quantities. Explain with example the graphical representation of vector quantities.

Ans: Scalar Quantities:

Those physical quantities which are completely described by their magnitude only are called scalar quantities or scalars.

The scalars can be added, subtracted, multiplied and divided by ordinary mathematical method.

Examples:

Speed, distance, temperature, energy, volume, power etc. are the examples of scalar quantities.

Vector Quantities:

Those physical quantities which are completely described by their magnitude as well as direction are called vector quantities or vectors.

The vectors can be added, subtracted, divided and multiplied by graphical or geometrical method.

Examples:

Force, velocity, acceleration, displacement etc. are the examples of vector quantities.

Graphical Representation of Vector Quantities:

Graphically, a vector is represented by an arrow where the length of arrow shows the magnitude (under certain scale) and the arrow head shows the direction of the vector.

The direction of the vector can either be represented by **"Geographical" Coordinate System (NEWS)"** or **"Cartesian Coordinate System**".

Steps to represent a vector:

The following method is used to represent a vector.

1. Draw a coordinate system.
2. Select a suitable scale.
3. Draw a line in the specified direction. Cut the line equal to the magnitude of the vector according to the selected scale.
4. Put an arrow in the direction of the vector.

Example:

We can explain the graphical representation of a vector with the help of an example. Suppose a bus is moving towards east (direction) with a velocity of $50kmh^{-1}$ (magnitude).

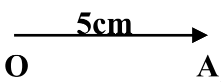
1. First of all, we specify the direction by drawing NEWS coordinate system as shown in figure.

Now, we select a suitable scale i.e.,

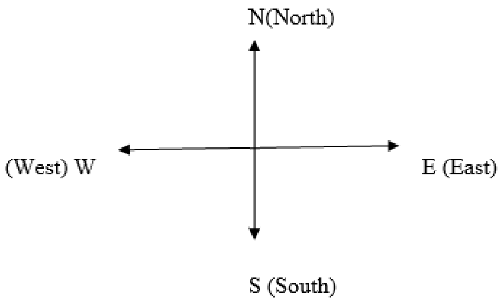
Let, $10km h^{-1}$= 1cm

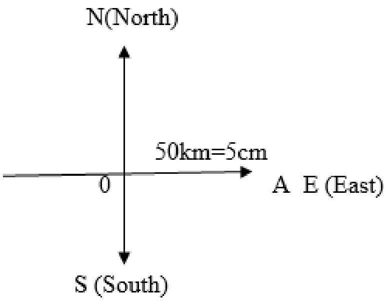
Then50$km h^{-1}$ =5cm

2. Now, we draw the representative line $\overrightarrow{OA}$ of 5cm towards east i.e.



In fig "B" the length of line $\overrightarrow{OA}$ represents the magnitude of the given vector (velocity) and arrow head indicates the direction of given vector. This vector is infact 50 kmh^{-1} and is directed towards East.

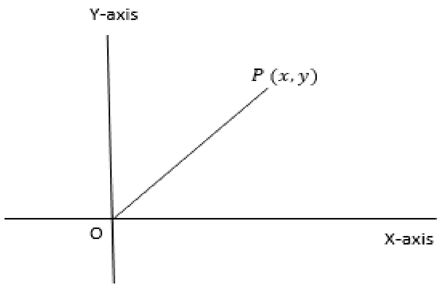




Q#4. What is position. Explain the difference between distance traveled, displacement, and displacement magnitude.

Ans: **Position:**

The location of an object relative to some reference point (origin) is known as position of that object.



Explanation:

Position of an object can be described in rectangular coordinate system where origin O can serve as a reference point. In the given figure, the position of an object at any point "P" is $P(x, y)$ where x and y are known as coordinates of point P.

1. Distance travelled:

The length of actual path traveled by a body between two positions is called distance travelled.

The value of distance is always positive. Distance is a scalar quantity because it has magnitude only. It has no direction. Distance is usually denoted by Δx, Δr, Δs, Δl, or Δd and its SI unit is meter (m).

2. Displacement:

The shortest directed distance between two positions is called displacement.

Or

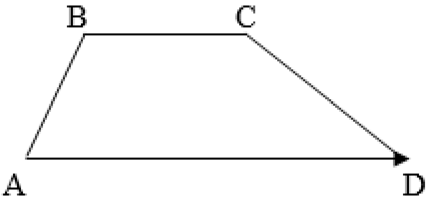
Straight distance from one point to another is called displacement.

The value of displacement can be positive, negative or even zero. It is a vector quantity because it has magnitude as well as direction. Displacement is usually denoted by $\Delta\vec{x}$, $\Delta\vec{r}$, $\Delta\vec{s}$, $\Delta\vec{l}$ or $\Delta\vec{d}$ and its SI unit is meter(m).

3. Displacement Magnitude:

The magnitude of displacement is the shortest distance between the two points.

The magnitude of displacement can be equal to the magnitude of distance when a body moves in a straight line. It is a scalar quantity rather than a vector because it has magnitude only and having no direction.



For example:

In the given figure, a body reaches from point "A" to 'D" through "B" and "C". So, path "ABCD" represents the total path travelled by the body during its motion i.e. distance. While AD represents the shortest distance between A and D. So, it is known as displacement.

Q#5. State and explain the terms:

a) Speed
b) Velocity
c) Acceleration

a. Speed:

The distance covered by a body in a unit time is called speed. It is denoted by "V".

Mathematical Form:

Mathematically, it can be written as:

$$\text{Speed} = \frac{distance}{Time}$$

Or

$$v = \frac{\Delta s}{\Delta t}$$

Or

$$v = \frac{s_f - s_i}{t_f - t_i}$$

Quantity and Unit:

Speed is a scalar quantity and its SI unit is meter per second (m/s or ms^{-1})

Example:

For example, a car is moving with a speed of 50m/s. This means that in every one second, it covers a distance of 50m.

Types of Speed:

The speed is categorized into following types:

1) Uniform Speed (Constant Speed):

If a body covers equal distances in equal intervals of time, then the body is said be moving with uniform speed or constant speed.

Mathematical Form:

$$\text{Uniform speed} = \frac{Equal\ distance\ covered}{equal\ interval\ of\ time}$$

Or $$v = \frac{S}{t}$$

2) Non-Uniform Speed (Variable Speed):

If a body covers unequal distances in equal interval of time, then the body is said to be moving with non-uniform speed or variable speed.

Mathematical Form:

$$\text{Variable Speed} = \frac{Unequal\ distance\ covered}{equal\ interval\ of\ time}$$

3. **Average Speed:**

The total distance covered by a body divided by total time taken is called Average speed. It is denoted by "$< v >$".

Mathematical Form:

$$\text{Average Speed} = \frac{Total\ \ distance}{Total\ Time}$$

Or $$< v > = \frac{s}{t}$$

4. **Instantaneous Speed:**

The speed of a body at any particular instant of time is called instantaneous speed.

For such speed, we take time interval "Δt" to be very small such that limit "Δt" approaches to zero i.e. limit $\Delta t \to 0$.

or

The speed for short time interval "Δt" is called instantaneous speed.

Mathematical Form:

Mathematically, it can be written as:

$$\text{Instantaneous Speed} = \lim_{\Delta t \to 0} \frac{short\ distance}{short\ time}$$

Or

$$v = \lim_{\Delta t \to 0} \frac{\Delta s}{\Delta t}$$

b. **Velocity:**

The displacement($\Delta\vec{s}$) covered by a body in a unit time (Δt)is called velocity. It is denoted by $\vec{v}$.

or

The speed of a body in a definite direction is called velocity.

Example:

For example, a car is moving with a velocity of 50m/s towards east. So, in case of velocity, we specify both magnitude (speed of car) and direction.

Quantity and Unit:

Velocity is a vector quantity and its SI unit is meter per second (m/s or ms^{-1}).

Mathematical Form:

Mathematically, it can be written as:

$$\text{Velocity} = \frac{displacement}{time}$$

Or $\vec{v} = \frac{\overrightarrow{\Delta s}}{\Delta t}$

Or

$$\vec{v} = \frac{\overrightarrow{s_f} - \overrightarrow{s_i}}{t_f - t_i}$$

Types of Velocity:

The velocity is categorized into following types.

1. **Uniform Velocity (constant velocity):**

If a body covers equal displacement in equal intervals of time, then the body is said to be moving with uniform velocity or constant velocity. In uniform velocity, the speed as well as direction of the body does not change with time.

Mathematical Form:

Mathematically, it can be written as:

Uniform Velocity = $\frac{Equal\ displacement\ covered}{Equal\ interval\ of\ time}$

2. **Non-uniform velocity (variable velocity):**

If a body covers unequal displacement in equal interval of time, then the body is said to be moving with non-uniform velocity or variable velocity.

In variable velocity, the speed or direction or both of a moving body changes with time.

Mathematical Form:

Mathematically, it can be written as:

Variable Velocity = $\frac{Unequal\ displacement\ covered}{Equal\ interval\ of\ time}$

3. **Average velocity:**

The total displacement covered by a body divided by the total time is called average velocity.

Mathematical Form:

Mathematically, it can be written as:

Average velocity = $\frac{Total\ displacement}{Total\ time}$

$$\vec{v} = \frac{\vec{S}}{t}$$

4. **Instantaneous velocity:**

The velocity of a body at any particular instant of time is called instantaneous velocity.

Or

The velocity for very short time interval Δt (very small such that limit "Δt" approaching to zero) is called instantaneous velocity.

Mathematical Form:

Mathematically, it can be written as:

$$\text{Instantaneous velocity} = \lim_{\Delta t \to 0} \frac{short\ displacemnt}{short\ time}$$

$$\vec{v} = \lim_{\Delta t \to 0} \frac{\vec{\Delta s}}{\Delta t}$$

c. Acceleration:

The measure of change in velocity"Δv" with the passage of time " Δt"is called acceleration.

Or

Time rate of change of velocity is called acceleration.

Mathematical Form:

Mathematically, it can be written as:

$$\text{Acceleration} = \frac{change\ in\ velocity}{time}$$

Or

$$\vec{a} = \frac{\overrightarrow{\Delta v}}{\Delta t}$$

Or

$$\vec{a} = \frac{v_f - v_i}{t_f - t_i}$$

Quantity and unit:

Acceleration is a vector quantity and its SI unit is meter per second squared ($\frac{m}{s^2}$ $or\ ms^{-2}$).

Type of Acceleration:

The acceleration is categorized into following types.

1. **Uniform Acceleration (constant Acceleration):**

A body is said to be moving with uniform acceleration, if equal change occurs in velocity in equal intervals of time.

2. **Non- uniform or variable acceleration:**

A body is said to be moving with variable acceleration, if unequal change occurs in velocity in equal intervals of time.

3. **Average Acceleration:**

The total change in velocity of a body divided by the total time is called average acceleration. It is denoted by "$< \vec{a} >$".

Mathematical Form:

Mathematically, it can be written as:

$$\text{Average Acceleration} = \frac{Total\ change\ in\ velocity}{Total\ time}$$

Or

$$< \vec{a} > = \frac{\vec{v}}{t}$$

4. **Positive Acceleration:**

If the magnitude of velocity increases with the passage of time, such type of acceleration is called positive acceleration. The positive acceleration is always in the direction of motion of a body.

Example:

For example, a car starts from rest and its speed increases along a straight line with the passage of time then the car is said to have positive acceleration.

5. **Negative Acceleration:**

If the magnitude of velocity decreases with the passage of time, such type of **acceleration is called negative acceleration**.

Negative acceleration is also called **Retardation or deceleration**. The negative acceleration is always in the opposite direction of motion of a body.

Example:

For example, when a car is moving with a certain speed then brakes are applied which decreases the speed of car, then the car is said to have negative acceleration.

6. **Instantaneous Acceleration:**

The Acceleration of a body at any particular instant of time is called instantaneous acceleration.

The value of instantaneous acceleration is obtained, if Δt is made smaller such that it approaches to zero.

Mathematical Form:

Mathematically, it can be written as:

$$\text{Instantaneous Acceleration} = \lim_{\Delta t \to 0} \frac{\textit{short change in velocity}}{\textit{short time}}$$

$$\vec{a} = \lim_{\Delta t \to 0} \frac{\Delta \vec{v}}{\Delta t}$$

Q#6. Use velocity time graph to prove the following equations of motion.

(a) $v_f = v_i + at$ (b) $s = v_i t + \frac{1}{2}at^2$ (c) $2as = v_f^2 - v_i^2$

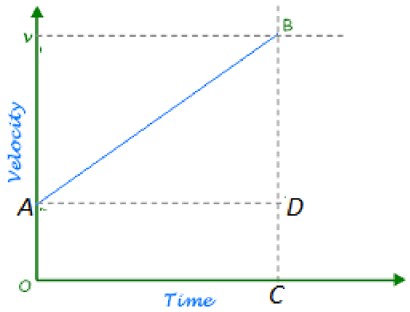
(a) Derive 1st equation of motion

OR

Prove that $v_f = v_i + at$

Ans: 1st equation of motion

Consider a body has initial velocity "v_i" at point "A" and then its velocity changes with uniform acceleration from "A" to "B" in time interval "t" and its final velocity becomes "v_f" as shown.



In the figure

Initial velocity = v_i = OA = DC
Final velocity = v_f = BC
Time = t = OC = AD
Acceleration = a = AB

From the graph

BC = BD + DC ------ (i)

Put the values of "BC" and "DC" in equation (i)

$V_f = BD + v_i$ -------- (ii)

As we know that the slope of velocity-time graph is equal to acceleration, then

$$AB = \frac{BD}{AD}$$

$$a = \frac{BD}{t}$$

$$at = BD$$

Put it in eq (ii)

$$V_f = at + V_i$$

$$V_f = V_i + at \qquad \text{(Proved)}$$

(b) Derive 2nd equation of motion

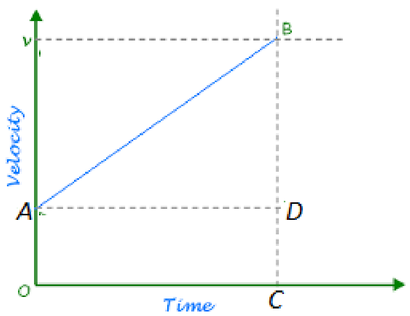
OR

Prove that $S = v_i t + \frac{1}{2} at^2$

Ans: 2nd equation of motion

Consider a body is moving with initial velocity "v_i" and covered distance "S" in time "t".

The distance covered by a body is equal to the area between velocity-time graph "AB" and time axis "OC" which is equal to the area of "OABC".



In the figure

Initial velocity = v_i = OA = DC
Final velocity = v_f = BC
Time = t = OC = AD
Acceleration = a = AB
Distance = S

From the figure

Distance travelled = Area of figure OABC

$$S = Area\ of\ Rectangle\ OADC + Area\ of\ Triangle\ ABD$$

$$S = (Length \times Breadth) + \frac{1}{2}(Lenght \times Breadth)$$

$$S = (OC \times OA) + \frac{1}{2}(AD \times BD)$$

By putting the values we get

$$S = (t \times v_i) + \frac{1}{2}(t \times BD) \text{ ------ (i)}$$

As

$$AB = \frac{BD}{AD}$$

$$a = \frac{BD}{t}$$

$$at = BD$$

Put it in eq (i)

$$S = + V_i t + \frac{1}{2}(t \times at)$$

$$S = v_i t + \frac{1}{2} at^2$$

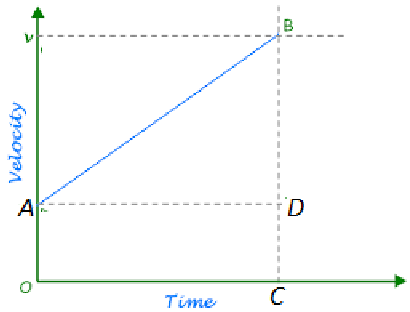
(Proved)

(c) Derive 3rd equation of motion

OR

Prove that $2aS = v_f^2 - v_i^2$

Ans: **3rd equation of motion**



Consider a body is moving with initial velocity "v_i" and covered distance "S" in time "t".

The distance covered by a body is equal to the area of "OABC" which is known as Trapezium.

In the figure

Initial velocity = v_i = OA = DC

Final velocity = v_f = BC

Time = t = OC = AD

Acceleration = a = AB

Distance = S

From the figure

Distance travelled = Area of figure OABC

S = Area of Trapezium OABC

$$S = \frac{(\textbf{Sum of parallel sides}) \times \textbf{hieght}}{\mathbf{2}}$$

$$S = \frac{(\boldsymbol{OA+BC}) \times \boldsymbol{OC}}{\mathbf{2}}$$

$$S = \frac{(\boldsymbol{v_i + v_f}) \times \boldsymbol{t}}{\mathbf{2}}$$

$$S = \frac{(\boldsymbol{v_f + v_i})}{\mathbf{2}} \times t \text{ ------ (i)}$$

As from 1st equation of motion

$$V_f = V_i + at$$

OR

$$\boldsymbol{t} = \frac{\boldsymbol{v_f - v_i}}{\boldsymbol{a}}$$

Put it in eq (i)

$$S = \left(\frac{\boldsymbol{v_f + v_i}}{\boldsymbol{2}}\right)\left(\frac{\boldsymbol{v_f - v_i}}{\boldsymbol{a}}\right)$$

$$S = \frac{\boldsymbol{v_f^2 - v_i^2}}{\boldsymbol{2a}}$$

$$2aS = \boldsymbol{v_f^2} - \boldsymbol{v_i^2} \quad \text{(proved)}$$

Q#7. What is free fall? what is its value near the surface of earth. Explain with example that rock and sheet of paper will fall at the same rate without air resistance.

Ans: Free Fall:

The motion in which air resistance is neglected and the acceleration is nearly constant is known as free-fall.

Explanation:

The acceleration produces in a freely falling body due to attraction of earth is called acceleration due to gravity or gravitational acceleration. It is denoted by "g".

According to famous scientist Galileo, In the absence of air resistance, when bodies of different masses (light or heavy) are dropped at the same time from the same height then they fall towards earth with the same acceleration.

Furthermore, if the distance of the fall is small compared to the radius of earth, the acceleration can be considered constant throughout its fall.

Value of "g":

The value of "g" near the earth's surface is approximately "9.8 m/s^2" or "32.2Ft/s^2" and its value is constant for all bodies. It is directed downward towards the centre of the earth.

Example:

If we drop a rock and sheet of paper from the top of tube at the same time. It is found that in the presence of air resistance, rock is falling faster than a sheet of paper. The effect of air resistance is responsible for slower fall of the paper. When air is removed from the tube, both the rock and the paper have exactly the same acceleration due to the gravity. So, in the absence of air, the rock and the paper fall freely as shown in figure.

Acceleration due to gravity and three equations of motion:

For freely falling bodies, we can use the equations of motion by replacing "a" with "g" and distance "S" with height "h". Then, the equations become:

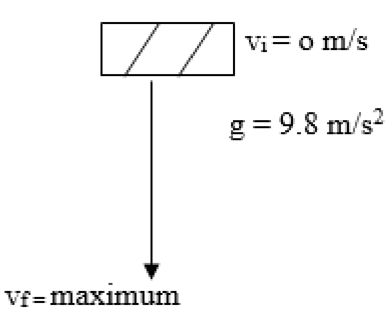
$v_f = v_i + gt$ – (i)

$h = v_i t + \frac{1}{2} g t^2$ – (ii)

$2gh = v_f^2 - v_i^2$ – (iii)

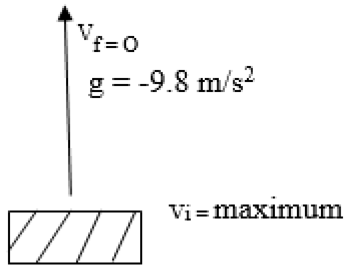
Conditions: While using these equations of motion there are two conditions.

1. If a body is thrown vertically downward, its initial velocity (v_i) will be zero and the value of "g" will be positive.



(a) Vertically downward

2. If a body is thrown vertically upward, its final velocity "v_f" will be zero and the value of "g" will be negative because with altitude, the value of "g" decreases.



(b) Vertically upward

TOPIC WISE QUESTIONS

Q#1. Define Kinematics.

Ans: Kinematics:

Kinematics is the branch of physics which deals with the study of motion without going into detail of what causes the motion.

Q#2. Define Rest.

Ans: Rest:

When a body does not change its position with respect to its surrounding (or an observer), then the body is said to be in the state rest.

Examples:

1. A bird sitting on a branch of a tree.
2. A student sitting on a chair.

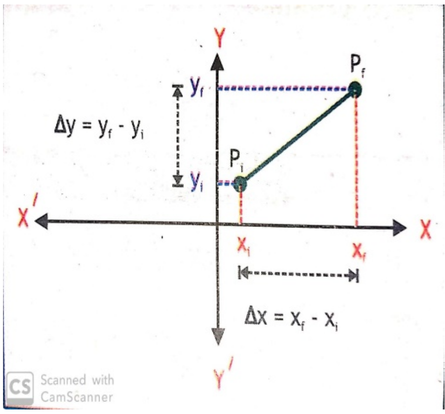
Q#3. What is meant by graph and discuss how the slope of a graph can be calculated?

Ans: Graph:

A graph is a straight or curved line which shows a relationship between two physical quantities.

Explanation:

Usually, a graph contains horizontal and vertical lines at equal distances and coordinate systems to show relationship in various quantities. The horizontal lines are called x-axis while the vertical lines are called y-axis. The point of intersection of these two lines are called origin "O".



Slope of Graph:

The slope of graph means vertical coordinate difference divided by horizontal coordinate difference.

Mathematical Form:

Mathematically, it can be written as:

$$\text{Slope} = \frac{\Delta y}{\Delta x}$$

Or

$$\text{Slope} = \frac{y_f - y_i}{x_f - x_i}$$

Calculation of slope of a graph:

The slope of a graph in Cartesian coordinate system can be calculated as,

1. Pick two points P_i and P_f on the line.
2. Determine the coordinates i.e. P_i (x_i, y_i) and P_f (x_f, y_f) by drawing perpendicular on x and y-axis from both points.
3. Determine the difference between x-coordinates ($\Delta x = x_f - x_i$) and y-coordinates ($\Delta y = y_f - y_i$.)
4. Dividing the difference in y-coordinates by difference in x-coordinates gives slope. i.e.

Slope = $\frac{\Delta y}{\Delta x} = \frac{y_f - y_i}{x_f - x_i}$

Q#4. Discuss the distance time graph with different cases.

Ans: **Distance- Time Graph:** The graph plotted between distance (s) and time (t) is called distance-time graph.

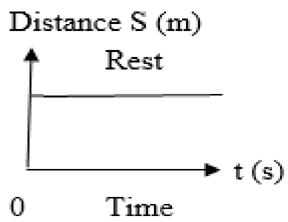
Explanation: In this graphical analysis, the distance is plotted along vertical axis (y-axis) and time along horizontal axis (x-axis). Distance time graph is always in the positive xy plane, as with the passage of time, distance never goes to negative axis, irrespective of the direction of motion. The slope of distance time curve only gives speed.

Slope = $\frac{\Delta S}{\Delta t}$ Or

Slope = $\frac{S_f - S_i}{t_f - t_i}$

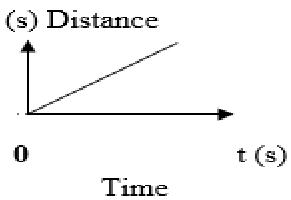
Distance time graph with different cases:

1. **When there is no motion (zero speed):**

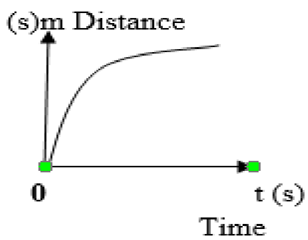


When there is no change in distance with the passage of time, then the body is at rest. So, the speed is zero. In such conditions, graph will be a straight horizontal line as shown in figure.

When the body is moving with uniform speed: When a body covers equal distance in equal interval of time, then the body is said to be moving uniform speed, In such conditions the graph will be a straight line with a constant slope. i.e. the higher is the slop, greater will be the speed.



When the body is moving with variable speed: When a body covers unequal distance in equal interval of time, then it is said to be moving with variable speed. In such conditions, the slope does not remain constant as shown in figure.



Q#5. Define speed-time graph? Show that how

(a) Slope or gradient of speed-time graph gives magnitude of acceleration?

(b) Area under the gives distance travelled?

Ans: **Speed-Time Graph:** The graph plotted between speed (v) and time (t) is called speed-time graph.

In this graphical analysis, the speed is plotted along vertical axis (y-axis) and time along horizontal axis (x-axis).

(a) Slope of speed-time graph gives magnitude of acceleration: The slope of speed-time graph will give the magnitude of acceleration i.e.

$$\text{Slope} = \frac{\Delta v}{\Delta t} = \frac{v_f - v_i}{t_f - t_i}$$

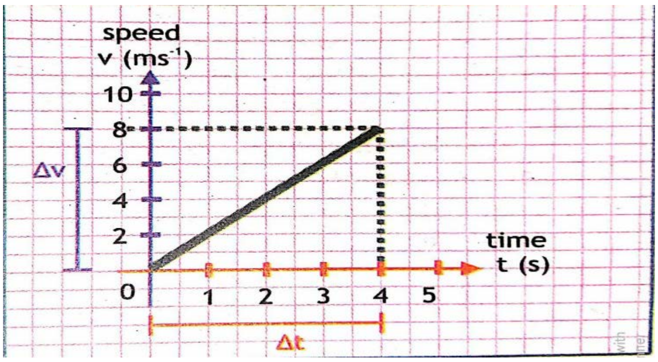
Explanation: Consider the motion of the object which speeds up from 0 m/s to 8m/s in 4 seconds.

Now, the slope of the graph is given by:

$$\text{Slope} = \frac{\Delta v}{\Delta t}$$

Whereas, $\Delta v = v_f - v_i$ And $\Delta t = t_f - t_i$

$$\text{Slope} = \frac{v_f - v_i}{t_f - t_i}$$



So, eq (i) becomes

Slope = Magnitude of acceleration |a|

So,

$$a = \frac{8-0}{4-0}$$

$$a = \frac{8}{4}$$

$$a = 2\text{m/s}^2$$

Thus, the slope of speed time graph gives the magnitude of acceleration.

(b) Area under speed time graphs represent the distance travelled: In speed time graph, the area enclosed by the speed time curve and the time axis gives us the distance travelled by the body.

As we know that,

$$\text{Speed} = \frac{distance}{time}$$

Or

$$v = \frac{\Delta s}{\Delta t}$$

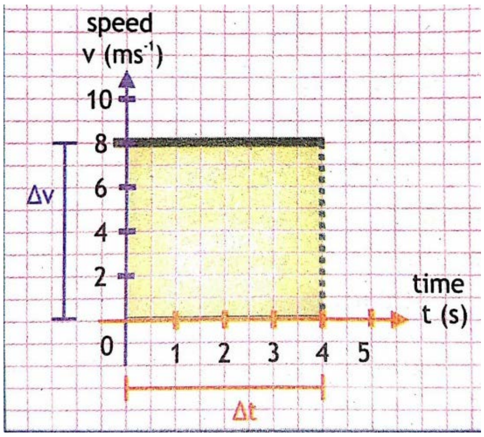
By cross-multiplication

$$\Delta s = v \times \Delta t \text{ – (i)}$$

Now, to find out the distance travelled by calculating the area of rectangle for the speed time graph, consider the motion of the object which speeds up from 0 m/s to 8 m/s in 4 sec.

As,

Distance travelled = Area of Rectangle – (ii)



And we know that

Area of Rectangle = length x width

Area of Rectangle = l x w

So, eq (i) becomes,

Area of Rectangle = Δx Δt

Where as $\Delta t = t_f - t_i$, $\Delta v = v_f - v_i$

So,

Area of rectangle = $(t_f - t_i)$ x ($v_f - v_i$)

By putting values,

Area of rectangle = (4-0) x (8-0)

= 4x8

Area of Rectangle = 32m

This shows that area under the graph gives us distance travelled.

Q#6. Discuss the slopes of speed-time graph in following cases.

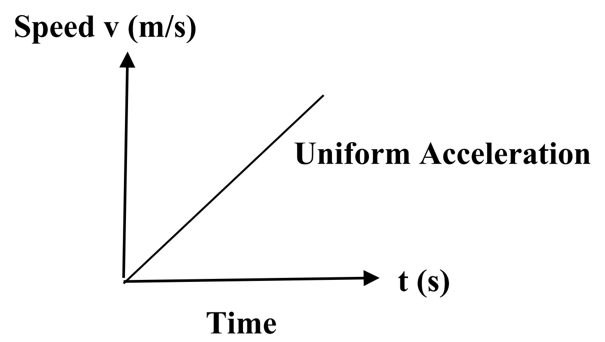
(a). When Acceleration is uniform

(b). When Acceleration is variable (non-uniform)

(c). When there is no Acceleration.

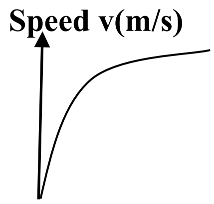
a. <u>When Acceleration is uniform:</u>

When the speed of a moving body increases by equal amounts in equal intervals of time then the speed-time graph of the body will be straight line with a constant slope as shown in figure. The slope of straight line shows uniform acceleration of the moving body.



<u>b. When acceleration is variable (non-uniform):</u>

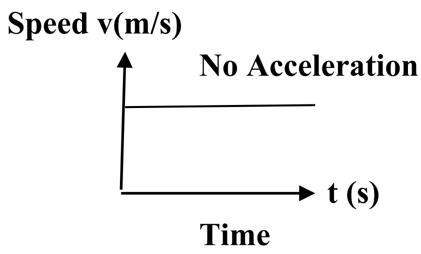
When a body covers unequal distance in equal intervals of time then the body is said to be moving with variable speed. In such case, variable acceleration is produced and the slope of the body is a curved lined. So, the curved line shows the variable acceleration of the moving body as shown in figure.



Variable Acceleration

C. <u>When there is no Acceleration:</u>

When the speed of a moving body does not change with the passage of time then there is no acceleration produced in it. So, the speed remains constant and in such condition, the graph will be a straight horizontal line as shown in figure.



<u>"CONCEPTUAL QUESTIONS"</u>

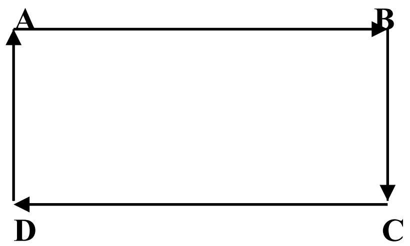
Give a brief response to the following questions.

Q#1. Is it possible that displacement is zero but not the distance? Under what condition displacement will be equal to distance.

Ans:(a)

Yes, it is possible that the displacement is zero but not the distance if the initial and final point of a moving body are at the same place.

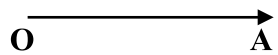
<u>For example:</u>



In figure ABCD, displacement is zero because starting and ending point is same i.e. "A" but distance covered by the body is ABCD which is the actual path of the body.

(b) The magnitude of distance and displacement will be equal when a body moves in a straight line because displacement is the shortest distance between two points in a straight line.

<u>For Example:</u>



In the given figure, a body moves from point "O" to "A". Now, in this case distance and displacement are equal.

Q#2. Does a speedometer measure a car's speed or velocity?

Ans: As we know that speed is a scalar quantity. It has magnitude only but having no direction while velocity is a vector quantity and it has magnitude as well as direction. The speedometer of a car displays only magnitude i.e. speed of a car but it does not tell us about the direction of the car. Thus, the speedometer measures only the speed of the car but not its velocity.

Q#3. Is it possible for an object to be accelerating and at rest at the same time? Explain with example.

Ans: Yes, it is possible for an object to be accelerating and at rest at the same time.

For example:

If a body of mass "m" is thrown vertically upwards with initial velocity "v_i" then it comes to rest after reaching at highest point. So, at that point, its final velocity "v_f" becomes zero but forces acting on it will not be zero and still the body possess certain acceleration which is known as acceleration due to gravity i.e. $g = -9.8\, m/s2$. In such case, the acceleration will be negative because it is opposite to the direction of velocity.

Q#4. Can an object have zero acceleration and non-zero velocity at the same time? Give example.

Ans: Yes, an object can have zero acceleration and non-zero velocity at the same time.

As we know that

$$\vec{a} = \frac{\Delta\vec{V}}{t} \text{ - (i)}$$

Eq (i) shows that acceleration depends upon rate of change in velocity of a body. If there is no charge in velocity then, body will have zero acceleration but its velocity is not zero.

Example:

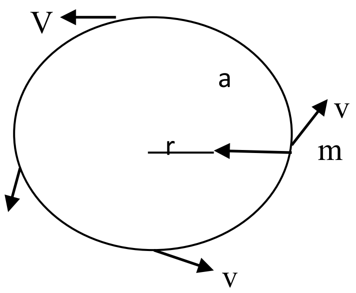
For example, if a car of mass "m" is moving along a smooth straight path "AB" with uniform velocity. In this case, the acceleration of the car is zero but its velocity is non zero.

Q#5. A person standing on a roof of a building throws a rubber ball down with a velocity of 8.0 m/s. What is the acceleration (magnitude and direction) of the ball?

Ans: When a person throws a ball from the top of a building, the ball will fall towards earth due to force of gravity. According to famous scientist Galileo, all bodies falling towards earth with a constant acceleration of $g=9.8m/s^2$. So, if we ignore the air resistance, then the ball will fall freely with acceleration due to gravity "g". Its magnitude will be $9.8\ m/s^2$ and it will be directed towards earth.

Q#6. Describe a situation in which speed of an object is constant while velocity is not.

Ans: A situation in which the speed of an object is constant while the velocity is not constant may be that of circular motion. For example, a body moving along a circular path may have a constant (uniform) speed. But its velocity is not constant because the direction of velocity changes at each point continuously during circular motion.



Q#7. Can an object have a northward velocity and a southward acceleration? Explain.

Ans: Yes, it is possible for an object to have northward velocity and a southward acceleration in the following situations.

1. When a body is coming to the rest.
2. When the speed of a body is decreasing.

Example:

If a car is moving towards north and gradually its velocity decreases by applying breaks. Then, negative acceleration (deceleration) will produce which is opposite to the direction of the velocity. In this case, the acceleration produced will be acting towards south.

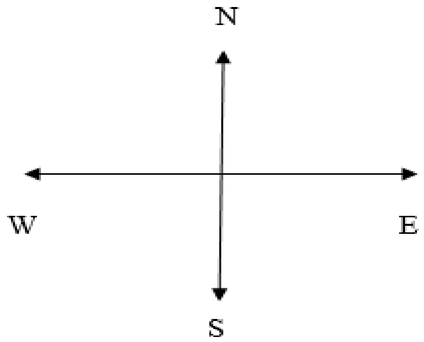
Q#8. As a freely falling object speeds up, what is happening to its acceleration does it increase, decrease, or stay the same?

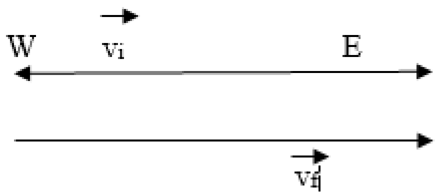
Ans: In the absence of air resistance, all bodies falling towards earth with a constant acceleration. So, for freely falling objects, the speed of the body increases uniformly at the rate of 9.8 m/s^2. Thus, the acceleration of the body does not increase, or decrease but remains constant during free-fall motion. i.e. we take $g=9.8\ m/s^2$ as a constant value for free-fall objects.

Q#9. A ball is thrown upward with an initial speed of 5m/s. What will be its speed when it returns to starting point?

Ans: If a ball is thrown vertically upward with an initial speed of 5m/s, then in the absence of air resistance, the ball will return back to its starting point with the same speed of 5m/s. Because, in upward and a downward, the only force acting on ball is gravitational pull of earth.

"NUMERICAL QUESTIONS"





1. **A squash ball makes contact with a squash racquet and changes velocity 15m/s west to 25m/s east in 0.10s. Determine the vector acceleration of the squash ball.**

Data:
Initial velocity (west) = $\vec{v}_i$ = - 15m/s (negative sign is used with $\vec{v}_i$ because it is opposite to $\vec{v}_f$)
Final velocity (East) = $\vec{v}_f$ = 25m/s
Time = t = 0.10s
Find:
Acceleration = $\vec{a}$ =?
Solution:
As, we know that

$$\vec{a} = \frac{V_f - V_i}{t}$$

By putting values

$$\vec{a} = \frac{25-(-15)}{0.10}$$

$$\vec{a} = \frac{25+15)}{0.10}$$

$$\vec{a} = \frac{40}{0.10}$$

$$\vec{a} = 400 \text{ m/s}^2$$

Result:
So, the acceleration produced by squash ball is 400 m/s^2 in the direction of east.

2. **A golf ball that is initially traveling at 25m/s hits a sand trap and slows down with an acceleration of -20m/s^2. Find its displacement after 2.0s.**

Data: Initial velocity = v_i = 25m/s

Acceleration = a = -20m/s^2 (deacceleration)

Time = t = 2s

Find: Displacement = S = ?

Solution: By using second equation of motion

$$S = v_i t + \frac{1}{2} at^2$$

By putting values,

$$S = 25x2 + \frac{1}{2} x(-20) \times (2)^2$$

$$S = 25x2 + \frac{1}{2} x -20 \times 4$$

$$S = 50 + \frac{1}{2} x -20 \times 4$$

$$S = 50 + \frac{1}{2} x - 80$$

$$S = 50 - 40$$

$$\mathbf{S = 10m}$$

3. **A bullet accelerates the length of the barrel of a gun 0.750m long with a magnitude of 5.35x 10^5 m/s^2. With what speed does the bullet exit the barrel?**

Data: Initial velocity = v_i = 0 m/s

Distance covered = S = 0.750m

Acceleration = $\vec{a}$ =5.35 x 10^5 m/s^2

Find: Final velocity = v_f= ?

Solution:

By using 3rd equation of motion

$$2aS = v_f^2 - v_i^2$$

Or

$$v_f^2 = 2aS + v_i^2$$

By putting values

$$v_f^2 = 2x5.35x10^5 \times 0.750 + (0)^2$$

$$v_f^2 = 8.025x10^5 + 0$$

$$v_f^2 = 8.025x10^5$$

Taking square root on both sides

$$\sqrt{v_f^2} = \sqrt{8.025x10^5}$$

$$v_f = \sqrt{80.25x10^{-1}\, x10^5}$$

$$v_f = \sqrt{80.25x10^{5-1}}$$

$$v_f = \sqrt{80.25x10^4}$$

$v_f = \sqrt{80.25} \text{ x } \sqrt{10^4}$

$v_f = \sqrt{80.25}\text{x } \sqrt{(10^2)^2}$

v_f =8.958 x 10^2 m/s

v_f = 8.96 x 10^2 m/s

Or

v_f = 896 x 10^{-2} x 10^2 m/s

v_f = 896 x 10^{-2+2}

v_f =896 m/s

4. A driver is travelling at 18m/s when she sees a red light ahead. Her car is capable of decelerating at a rate of 3.65 m/s². If she applies brakes when she is only 20.0m from the intersection when she sees the light, will she be able to stop in time.

Data:

Initial velocity = v_i = 18 m/s

Find velocity = v_f = 0m/s   Acceleration = a = -3.65m/s^2 (negative sign shows deceleration because velocity of car decreases)

Distance b/w car and red light = S_1 = 20m

Find:

Actual distance covered = S_2 = ?

Further distance covered=S=?

Solution: First, we calculate actual distance covered "S_2" with deceleration by using 3rd equation of motion.

$$2aS_2 = v_f^2 - v_i^2$$

Or

$$S_2 = \frac{v_f^2 - v_i^2}{2a}$$

$$S_2 = \frac{(O)^2 - (18)^2}{2x - 3.65}$$

$$S_2 = \frac{O - 324}{-7.3}$$

$$S_2 = \frac{-324}{-7.3}$$

S_2 = 44.38m

Or

S_2 = 44.4m

Here the distance covered by the car with given deccleration is 44.4m which is greater than the remaining distance i.e 20m between the car and red light.

Thus, the driver will unable to stop the car with in 20m.

Now, For finding further distance covered "S"

$S = S_2 - S_1$

$S = 44.4 - 20$

$S = 24.4m$

So, she will go 24.4m past the light.

Q#5. An antelope moving with constant acceleration $2m/s^2$ covers crosses a point where its velocity is 5m/s. After 6.00s how much distance it has covered and what is its velocity.

Data:

Acceleration = a = $2m/s^2$

Initial velocity = v_i = 5m/s

Time = t = 6s

Find:

Distance covered = S = ?

Final velocity = v_f = ?

Solution:

For finding "S", we use 2nd equation of motion

$S = v_i t + \frac{1}{2} at^2$

By putting values

$S = 5x6 + \frac{1}{\not 2} x \not 2 x (6)^2$

$S = 30 + \frac{1}{2} x 2 x 36$

$S = 30 + 36$

$S = 66m$

Now, for finding "v_f", we use 1st equation of motion

$v_f = v_i + at$

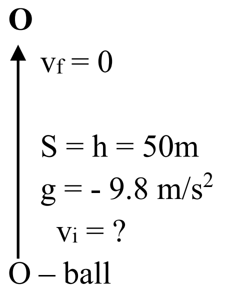
By putting values

$v_f = 5 + (3x6)$

$V_f = 5 + 12$

$V_f = 17 m/s$

Q#6. With what speed must a ball be thrown vertically from ground level to rise a maximum height of 50m?



Data:

Final velocity = $v_f = 0$ m/s

Height = h = 50m

Acceleration due to gravity = g = -9.8 m/s^2 [for upward motion, g is -9.8 m/s^2]

Find:

Initial velocity = v_i= ?

Solution:

By using 3rd equation of motion

$2gh = v_f^2 - v_i^2$

By putting values

$2 \times (-9.8) \times 50 = 0 - V_i^2$

$-980 = - v_i^2$

$980 = v_i^2$

Or

$v_i^2 = 980$

Taking square root on both sides

$\sqrt{v_i^2} = \sqrt{980}$

$v_i = 31.3$ m/s

ASSIGNMENTS

Assignment 2.1:

In 2009, a Jamaican sprinter Usain Bolt created a world record in Berlin by running 100m in just 9.58s. What is his average speed?

Data: Distance covered = S = 100m

Time taken = t = 9.58s

Find:

Average speed = <v>=?

Solution:

As, we know that

$< v > = \frac{S}{t}$

By putting values

$$< v > = \frac{100}{9.58}$$

$$< v > = \mathbf{10.43\ m/s}$$

Assignment 2.2:

A runner makes one lap around a 270m circular track in 30s. What is his (a) average speed (b) average velocity.

Data:

Distance covered = S = 270m

Time taken = t = 30s

Find:

(a) Average speed = $< v >$= ?

(b) Average velocity = $< \vec{v} >$ = ?

Solution:

(a) For finding average speed $< v >$, we know that

$$< v > = \frac{S}{t}$$

By putting values

$$< v > = \frac{270}{30}$$

$$< v > = \mathbf{9m/s}$$

(b) Now, for finding average velocity, we know that

$$< \vec{v} > = \frac{\text{Total displacement}}{\text{Total time}}$$

$$< \vec{v} > = \frac{\vec{s}}{t}$$

As we know that displacement in a circular track is zero. i.e, $\vec{S}$ = 0, So,

$$< \vec{v} > = \frac{0}{30}$$

$$< \vec{v} > = \mathbf{0\ m/s}$$

Assignment 2.3:

If in the same experiment you take the readings of the speedometer of the car as 20km/h in the 4^{th} second and 32 km/h in the 9^{th} second. What is the acceleration of your car in this interval?

Data:

Initial velocity = v_i = 20km/h

$= v_i = \frac{20x1000}{3600}$

$= v_i = \frac{200}{36}$ => 5.5 m/s

Final velocity = v_f = 32km/h

$v_f = \frac{32x1000}{3600}$

v_f = 8.8 m/s

Initial time = t_i = 4s

Final time = t_f = 9s

Find:

Acceleration = a =?

Solution:

As we know that

$$\vec{a} = \frac{\Delta\vec{v}}{\Delta t}$$

Or

$$a = \frac{\vec{V}_f - \vec{V}_i}{t_f - t_i}$$

By putting values

$$\vec{a} = \frac{8.8-5.5}{9-4}$$

$$\vec{a} = \frac{3.3}{5}$$

$$\vec{a} = 0.66\ m/s^2$$

Assignment2.4:

A cyclist increases his speed from zero to $8ms^{-1}$ in 10s. Then he moves with uniform speed for the next 20 seconds and then its speed decreases uniformly to zero in the next 20 seconds. The graph is plotted for the journey, use this graph to calculate the total distance covered.

(Graph on page no.48)

Data:

Length of 1^{st} parallel side = 30-10 = 20m

Length of 2^{nd} parallel side = 50-0 = 50m

Height of trapezium = 8m

Find:

Total Distance covered = S = ?

Solution:

For finding "S", using formula

Distance covered = Area under the graph

So, S = Area of Trapezium OABC …………(i)

As we know that

$$\text{Area of Trapezium OABC} = \frac{\text{sum of two parallel sides x height}}{2}$$

So, eq (i) becomes

$$S = \frac{\text{Sum of two parallel sides X height}}{2}$$

By putting values

$$S = \frac{(20+50)\text{x}\ 8}{2}$$

$S = \frac{(70) x 8}{2}$

$S = \frac{560}{2}$

S = 280m

Assignment 2.5:

A cyclist is moving with uniform acceleration of 1.2m/s². How much time will it require to change his velocity form 6m/s to 12 m/s.

Data:

Initial velocity = v_i = 6m/s

Final velocity = v_f = 12m/s

Acceleration = a = $1.2 m/s^2$

Find:

Time t = ?

Solution:

By using 1st equation of motion

$v_f = v_i + at$

Or

$$\mathbf{t} = \frac{V_f - V_i}{a}$$

By putting values

$t = \frac{12 - 6}{1.2}$

$t = \frac{06}{1.2}$

t = 5s

Assignment 2.6:

On Motorway M_1, a car is moving at speed limit of 120km/h. By applying brakes the car comes to rest after covering a distance of 30m. What is the deceleration of the car?

Date:

Initial velocity = v_i = 120km/h

$v_i = \frac{120x1000}{3600}$

v_i = 33.33m/s

Final velocity = v_f = 0 m/s

Distance covered = S = 30m

Find:

Deceleration of car = a = ?

Solution:

Using 3rd equation of motion

$2aS = v_f^2 - v_i^2$

Or

$$\mathbf{a} = \frac{v_f^2 - V_i^2}{2S}$$

By putting values

$$a = \frac{(o)^2 - (33.33)^2}{2x30}$$

$$a = \frac{0 - 1110.8}{60}$$

$$a = \frac{-1110.8}{60}$$

$$\mathbf{a = -18.5 m/s^2}$$

Assignment 2.7:

In a cricket ball go straight up with a velocity of 40m/s. Calculate

(a) Maximum height ball will reach.

(b) Time to reach that height.

O

$v_f = 0$, $t = ?$

$g = -9.8\ m/s^2$

$h = ?$

$v_i = 40m/s$

O Cricket ball

Data:

Initial velocity = $v_i = 40m/s$

Final velocity = $v_f = 0m/s$

Acceleration due to gravity = $g = -9.8\ m/s^2$ (For upward motion, value of g is negative)

Find:

(a) Maximum height = h = ?

(b) Time = t = ?

Solution:

For finding "h" we use 3rd equation of motion

$2gh = v_f^2 - v_i^2$

Or

$$\mathbf{h} = \frac{v_f^2 - v_i^2}{2g}$$

By putting values

$$h = \frac{(o)^2 - (40)^2}{2\ x - 9.8}$$

$$h = \frac{0 - 1600}{-19.6}$$

$$h = \frac{-1600}{-19.6}$$

$$\mathbf{h = 81.6m}$$

(b) Now for finding "t", we use 1st equation of motion.

$v_f = v_i - gt$

Or

$$\mathbf{t} = \frac{v_f - v_i}{g}$$

By putting values

$$t = \frac{0 - 40}{-9.8}$$

$$t = \frac{-40}{-9.8}$$

$$t = 4.08s$$

or

t = 4s

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PHYSICS

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Chapter # 3
Dynamics

Q.1: What is force? What are its unit. Distinguish between contact and non-contact forces?

Ans: Forces:

Definition:

Force is a physical quantity which moves or tends to move a body, stops or tends to stop a moving body or which tends to change the speed and directions of a moving body.

Mathematical Form:

When a force acts on a body of mass "m", it produces acceleration "a" in the body in the direction of force. Mathematically, it can be written as:

Force = mass x acceleration

Or $F = m \times a$

$F = ma$

Quantity and Unit:

Force is a vector quantity. The SI unit of force is "newton" and it is denoted by symbol "N".

So, one newton is defined as the force that produces acceleration of 1 m/s^2 in a body of mass 1 kg. i.e.

$$1\ N = 1\ kg \times 1 m/s^2$$

or

$$1\ N = kg\ m/s^2 \text{ or } kgms^{-2}$$

Types of Force:

There are two types of forces based on the interaction between objects.

1. Contact forces
2. Non – contact forces (Action at a distance forces)

Contact Forces:

Contact forces are those types of forces which result when the two bodies are physically contact with each other.

Example:

Friction forces, push or pull forces etc. are examples of contact forces. e.g. push a cart or drag a chair on floor etc.

Non-contact Forces:

Non- contact forces are those forces which result when the two bodies are not in physical contact with each other. They are also known as "action-at-a-distance forces".

Examples:

Gravitational forces, electric forces and magnetic forces are examples of non-contact forces. E.g. if we release a ball from certain height towards earth surface, then after releasing, earth's surface is not in contact with the ball, it falls down due to force of gravity, such force is called non-contact force.

Q.2: State and explain Newton's three laws of motion. Give one example of each.

Ans: <u>Newton's Laws of Motion:</u>

Isaac Newton formulated three laws based on the observation about the motion of objects. These laws express the relationship among force, mass and the motion of an object which are described below:

<u>Newton's First Law of Motion</u>:

Statement:

If the net (external) force acting on an object is zero, the object will maintain its state of rest or of uniform motion with constant velocity.

Or

If there is no external force acting on an object, a body at rest will remains at rest and a body in motion will continue its motion with constant velocity.

Mathematically:

Mathematically, first law can be written as:

$$\text{If } \vec{F}_{net} = 0 \,,$$
$$\text{Then} \,,\ \vec{a} = 0, \text{ or } \Delta\vec{v} = 0$$

Explanation:

The first law of motion consists of two parts. The first part of the law is for the "Bodies at rest" and the second part is for the "bodies in motion'.

Bodies at Rest:

The first part of the law states that a body at rest will remain at rest if no net force acts on it.

Example:

A chair lying in a room will stationary and will not start moving by itself unless someone moves it by applying a net force.

Bodies in Motion:

The second part of the law states that a body in motion will continue to move in a straight line with uniform speed if no net force acts on it.

Example:

If we roll a ball on the surface of earth, it comes to rest after sometime due to friction and air resistance. But if we remove all the forces acting on that ball, then it will move forever with uniform velocity.

Newton's First law is also known as "Law of Inertia". Inertia is the property of a body which resists any change in its state of rest or of uniform motion. In other words, we can say that all the bodies try to maintain its state of rest or continue its uniform motion due to inertia.

Example:

When a bus starts motion, suddenly the passengers experience a push in the backward direction. It is because, when the bus starts motion suddenly, then the lower parts of the passengers also comes into motion, while the upper parts are still at rest and wants to be at rest due to inertia. So, they fall in the backward direction. Conversely, if a moving bus suddenly stops, the passenger falls forward.

<u>Newton's Second Law of Motion:</u>

Statement:

The net force "F' on a body is equal to the product of the body's mass "m" and its acceleration "a".

Or

When a net force acts on a body, it produces an acceleration "a" in the body in its own direction. This acceleration is directly proportional to the net force and inversely proportional to the mass of the body.

Explanation:

Newton's Second law of motion establishes a relationship between net force, mass and acceleration. As we know that greater force applied to a body produces greater acceleration. Thus, the acceleration is directly proportional to the force i.e. a αF.

Now if the same amount of force is applied to different masses, it will produce different acceleration. A heavier body will acquire lesser acceleration than a lighter body. This means that the acceleration is inversely proportional to the mass of the body. i.e. $a \propto \frac{1}{m}$

Mathematical Form:

$$a \propto F \text{ ------------- } (i)$$

$$a \propto \frac{1}{m} \text{------------- } (ii)$$

combining eq (i) and (ii), we get

$$a \propto \frac{F}{m}$$

or

$$a = \text{constant. } F/m$$

$$a = k\frac{F}{m}$$

In SI units, k =1 then,

$$a = 1 \times \frac{F}{m}$$

$$a = \frac{F}{m}$$

or

F = ma ....(3)

Eq(iii) represents the mathematical form of Newton's second law of motion.
Thus, Newton's second law tells us that acceleration "a" will be largest when force "F" is large and mass "m" is small.

Example:

It is easier to push an empty shopping cart than a full one, because the full shopping cart has more mass than the empty one. This means that more force is required to push the full shopping cart.

Newton's Third Law of Motion:

Statement:

"To every action there is always an equal and opposite reaction".

Explanation:

According to Newton's third law of motion, when one object exerts a force on a second object, the second object exerts a force of the same magnitude and opposite direction on the first object. So, when an object "A" exert force on object B written as F_{AB}, object "B" also exert equal force on object A written as F_{BA} but in opposite direction. i.e.

$$\vec{F}_{AB} = -\vec{F}_{BA}$$

Here, the negative sign shows that force F_{BA} is opposite to the force F_{AB}.
So, this law described these two forces as action reaction pair. Action and reaction always occur in pair because they act on different bodies i.e. action is on one body and its reaction is on another body.

Example:

1. For example, when a football is kicked, the foot exerts the force "F_{AB}" on the football and as a reaction to that, a football exerts an equal and opposite force F_{BA} on the foot. i.e. $F_{AB} = - F_{BA}$

2. When a bullet is fired from a gun, it moves on forward direction due to the action of gases which are produced due to the burning of chemicals while in reaction, the bullet pushes the gun in backward direction.

3. The jet airplanes also work on the principle of action and reaction. In action, the fuel in airplane's engines burns and hot gases rush out of the rear end (backward direction) of the airplane with very high speed. While in reaction the backward going gases exert equal and opposite force on the airplane. So, the airplane moves forward with a great speed.

Q.3: What is weight? Differentiate between mass and weight.

Ans: **Weight:**

The weight of a body is the force with which it is attracted towards the centre of the earth. It is denoted by symbol "W".

Mathematical Form:

Mathematically, weight of a body is the product of its mass and acceleration due to gravity.

Weight = mass x acceleration due to gravity

Or $W = m \times g$

$$\mathbf{W = mg}$$

Quantity and Unit:

Weight is a vector quantity and its SI unit is newton (N).

Difference Between Mass and Weight:

Mass	Weight
The quantity of matter in a body is called mass.	The force of attraction of the earth on a body is called its weight
Mass is denoted by "m".	Weight is denoted by "W".
The S.I unit of mass is kilogram (kg).	The SI unit of weight is newton (N).
Mass is a scalar quantity because it has no direction.	Weight is a vector quantity because it has a direction(downward).
Mass is a constant quantity because its value remains the same at different distances from the centre of the earth .	Weight is a variable quantity because it is different at different distances from the centre of the earth.
Mass can be measured by beam balance	Weight can be measured by spring balance .
Mass can be found by formula : **m=F/a**	Weight can found by formula: **W= mg**
Mass cannot be zero.	Weight can be zero.
Mass is the measure of inertia .	Weight is a force of gravity.

Q.4: Define momentum. Relate force to change in momentum.

Ans: **Momentum:**

The quantity of motion in a body is called momentum.

Or

The product of object's mass and linear velocity is called momentum. It is denoted by symbol "P".

Mathematical Form:

Mathematically, it can be written as

Momentum = Mass x velocity

$$\vec{P} = m\,x\,\vec{v}$$

Or $$\boldsymbol{\vec{P} = m\ \vec{v}}$$

Quantity and Unit:

Momentum is a vector quantity where its direction is same as that of velocity of the body and the SI unit of momentum is kilogram-meter per second ($kgms^{-1}$) or Newton-second(Ns).

Relation of force with change in momentum:

Statement:

The time rate of change of linear momentum of a body is equal to the net force acting on the body.

Mathematically, it can be written as:

$$\mathbf{F} = \frac{\Delta \vec{\mathbf{P}}}{\Delta \mathbf{t}}$$

Derivation:

According to the Newton's 2nd law of motion, when a net force "F" is applied on body having mass "m", it produces acceleration "a" in the direction of net force which is directly proportional to the force and inversely proportional to mass of the body. Mathematically, it can be written as:

$$\vec{F} = m\vec{a} \text{ .... (i)}$$

Where the acceleration "a" is defined as the time rate of change of velocity.

$$\vec{a} = \frac{\vec{v}_f - \vec{v}_i}{\Delta t}$$

Putting the value of "a" in eq (i)

$$\vec{F} = m\left(\frac{\vec{v}_f - \vec{v}_i}{\Delta t}\right)$$

$$\vec{F} = \frac{m\vec{v}_f - m\vec{v}_i}{\Delta t} \text{.............(2)}$$

As $\vec{P} = m\vec{v}$, therefore $\vec{P}_f = m\vec{v}_f$ and $\vec{P}_i = m\vec{v}_i$, So, eq (2) becomes

$$\vec{F} = \frac{\vec{P}_f - \vec{P}_i}{\Delta t} \text{ ....(3)}$$

As $\Delta\vec{P} = \vec{P}_f - \vec{P}_i$

So eq (3) becomes

$$\vec{\boldsymbol{F}} = \frac{\Delta\vec{\boldsymbol{P}}}{\Delta \boldsymbol{t}} \text{....................(4)}$$

Eq (4) shows the relation between net force and change of momentum of a body. Thus, the time rate of change of momentum of a body is equal to the net force acting on it.

Q.5: Define Isolated system. Explain the law of conservation of momentum.

Ans: Isolated System:

An isolated system is a collection of particles that can interact with each other but whose interactions with the environment outside the collection have a negligible effect on their motions.

Example:

The gas molecules enclosed in a container can be considered as an isolated system of interacting bodies in which the gas molecules collide with each other and with the walls of the container. Other forces, such as gravitational force etc. are considered to have a negligible effect on the motions of the gas molecules and container. So, in isolated system, the bodies exert forces on each other which are very large as compared with external forces.

Law of Conservation of Momentum:

Statement:

If there is no external force applied to a system of particles (Isolated system) then the total momentum of that system remains constant.

i.e. $\Delta \boldsymbol{P} = \boldsymbol{0}$

Or

In the absence of an external force (isolated system), the initial momentum (P_i) of the system must be equal to the final momentum (P_f).

i.e. $\overrightarrow{\boldsymbol{P_i}} = \overrightarrow{\boldsymbol{P_f}}$

Mathematical Derivation:

As we know that:

$$\boldsymbol{F} = \frac{\Delta \overrightarrow{\boldsymbol{P}}}{\Delta \boldsymbol{t}}$$

For an isolated system, there is no net force acting i.e. F=0. Therefore, Newton's Second law in terms of momentum can be written as:

$$0 = \frac{\Delta \vec{P}}{\Delta t} \text{ ...... (1)}$$

As $\Delta \vec{P} = \overrightarrow{P_f} - \overrightarrow{P_i}$, so eq (1) becomes

$$0 = \frac{\overrightarrow{P_f} - \overrightarrow{P_i}}{\Delta t}$$

By cross Multiplication:

$$0 \times \Delta t = \overrightarrow{P_f} - \overrightarrow{P_i}$$

$$0 = \overrightarrow{P_f} - \overrightarrow{P_i}$$

$$0 + P_i = \overrightarrow{P_f} - \overrightarrow{P_i} + P_i$$

$$\overrightarrow{\boldsymbol{P_i}} = \overrightarrow{\boldsymbol{P_f}} \text{ .... (2)}$$

Eq (2) shows that the initial momentum of system is equal to the final momentum in the absence of an external force which satisfies the law of conservation of momentum.

Examples:

1. Collision of objects
2. Firing of a gun
3. Explosion of bombs
4. Propulsion of rockets etc.

In all the above examples, the systems are initially at rest. Therefore, their initial momentum is zero i.e. $\overrightarrow{P_i} = 0$. Let all these systems consist of two parts of masses "m_1" and "m_2" with velocities "v_1" and "v_2" then their final momentum is given by

$$\overrightarrow{P_f} = m_1 v_1 + m_2 v_2$$

Now, by the law of conservation of momentum

$$\vec{P_i} = \vec{P_f}$$

$$0 = m_1v_1 + m_2v_2$$

$$\text{Or } -m_1v_1 = m_2v_2$$

So, both parts of the system will have an equal but opposite momentum. However, if we add up the momentum of both parts, the sum of total momentum will be zero.

Q.6: Define collision and explosion. Explain change in momentum in terms of collision and explosion.

Ans: Collision:

An event during which particles come close to each other and interact by means of forces is called collision.

Change in momentum in term of collision:

The forces due to the collision are assumed to be much larger than any external forces present.

Consider a system consisting of two objects A and B of masses "m_1" and "m_2" moving with velocities "u_1" and "u_2" respectively as shown in figure. The total momentum of the system before collision is given by,

$$\vec{P_i} = m_1u_1 + m_2u_2$$

Let "v_1" and "v_2" be the velocities of the masses after collision. Then, the total momentum of the system after collision is given by,

$$\vec{P_f} = m_1v_1 + m_2v_2$$

Now, by law of conservation of momentum,

$$\vec{P_i} = \vec{P_f} \text{ -------------- (1)}$$

Therefore, eq (1) becomes

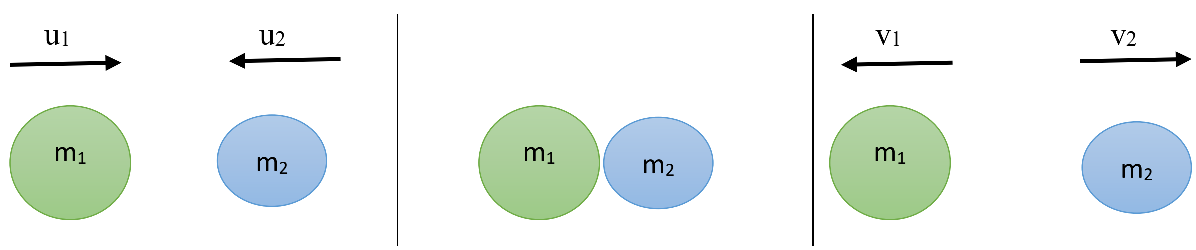
$$\mathbf{m_1u_1 + m_2u_2 = m_1v_1 + m_2v_2} \text{--------------- (2)}$$

OR

Initial momentum= final momentum

Before collision after collision

Eq(2) shows that the total initial momentum of the system before collision is equal to the total final momentum of the system after collision. Thus, the total momentum during the collision will be conserved in an isolated system, by the law of conservation of momentum.



Before Collision	During Collision	After Collision

Explosion:

The process in which the particles of the system move apart from each other after an intense interaction is known as explosion.

Change in Momentum in terms of Explosion:

If the system is isolated, its total momentum during the explosion will be conserved, by the law of conservation of momentum. Explosion is the opposite of collision.

Consider an isolated system of bullet of mass "m_1" and gun of mass "m_2". Before firing, the velocity of the bullet as well as that of gun is zero. Therefore, the total momentum of both objects before firing is zero. So, we have,

$$P_i=0$$

After firing, the bullet moves with velocity "v_1" in one direction and the gun recoils with velocity ''v_2" in the other direction. Therefore, the total momentum of the system after firing is given by

$$\vec{P_f}= m_1\vec{v_1} + m_2\vec{v_2}$$

Now, by law of conservation of momentum

$$\vec{P_i} = \vec{P_f}$$

$$\mathbf{0 = m_1\vec{v_1} + m_2\vec{v_2}}$$

Hence, both gun and bullet will have an equal but opposite momentum. However, if we add up the momentum of both gun and bullet, the sum of total momentum will be zero.

Q7: **What is friction? What are microscopic basis of friction? What is normal force, how it affects friction.**

Friction:

The force which always opposes the motion of one body over another body in contact with it is called force of friction.

It is denoted by "f".

Examples:

Friction exists between,

1. The ground and the wheels of a car
2. Water and fish swimming through it.
3. A flying cricket ball and air etc.

Quantity and unit:

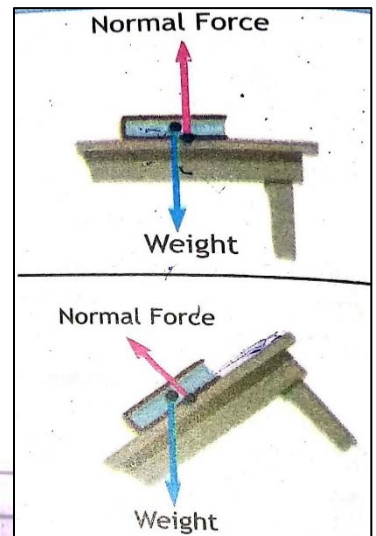
Friction is a vector quantity and its SI unit is newton(N).

Microscopic description of friction:

Every object has a rough surface, even surfaces that appear to be very smooth to the naked eye can actually look quite rough when examined under a microscope. Thus, if different surfaces are observed under microscope, it can be seen that there are ups and downs (irregularities) on these surfaces. Whenever the surfaces are rolled or slide over one another, their ups and downs are interlocked with each other that opposes the relative motion of each surface and gives rise to friction force. So, the main cause of friction is the roughness of the surface. The more rough and uneven surface, the more will be the cause of friction.

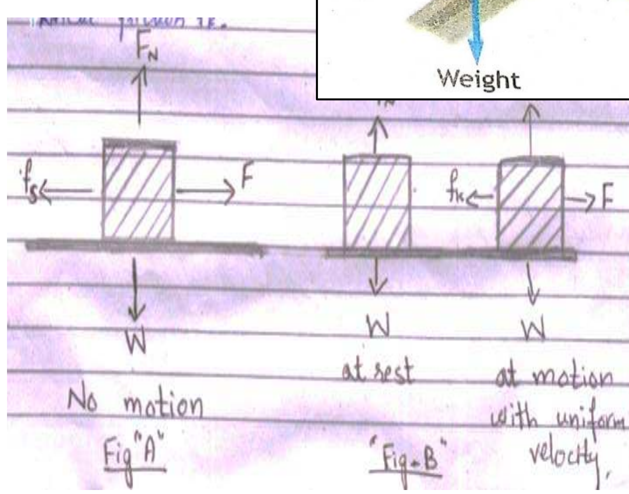
Normal force (F_N)

A contact force perpendicular to the contact surface that prevents two objects from passing through one another is called normal force (F_N).



Consider a book is placed on a horizontal table's surface. By Newton's third law, the book exerts the force on the table due to its weight that is acting downward and as a reaction, table also exerts a force on the book in upward direction i.e. a normal force (F_N) of table. If no other vertical forces act, then the normal force on the book by table is equal in magnitude to the book's weight i.e. F_N=W

But if the surface of the table is not horizontal, then the normal force is not vertical and is not equal in magnitude of the book. In this case a book slightly moves on an inclined plane of the table and become stop after covering some distance due to force of friction.



Even on a horizontal surface, if there are other vertical forces acting on the book then the normal force is not equal in magnitude to the weight of the book. In this case, normal force on the book increases that further increases the frictional force.

As we know that, $f=\mu F_N$…………(i)

According to equation(i), friction is directly proportional to the normal force. Greater is the normal force, F_N greater will be the force of friction "f". i.e.

$f \alpha F_N$ and vice versa.

Q8. Differentiate between static and kinetic friction by giving an example. Find the expression for the coefficient of kinetic and static friction.

Static friction:

The maximum force of friction that is opposite to the applied force and prevents the body from moving is called static friction. It is denoted by "f_s".

Mathematical form:

$$f_s = \mu_s F_N$$

Kinetic friction:

The force of friction that acts against during motion of an object in a direction opposite to the direction of motion is called kinetic friction. It is denoted by "f_k".

Mathematical form:

$$f_k = \mu_k F_N$$

Example:

When we slide a wooden block placed on a table, then the following four forces acts on the block at the same time. i.e.

1. The weight "W" of the body is acting downward.
2. The normal force "F_N" which is acting upward.
3. The applied force "F".
4. The force of static friction "f_s" which is acting in opposite direction to the applied force as shown in figure A.

The weight "W" and normal force "F_N" balance each other. Now when the applied force "F" acts on the block, still the block does not move. Such force of friction at this stage is called static friction "f_s".

If we increase the applied force further gradually, the static friction also increases and finally a stage comes when the static friction reaches to its maximum value. Such maximum value of static friction is called maximum static friction or limiting friction "$f_{s,\,max}$".

The maximum static friction does not increase further more and the block begins to move due to maximum applied force. The friction is still present while the block is moving due to applied force. Such force of friction during the motion of the body is called kinetic friction "f_k". Usually, kinetic friction is always less than static friction ($f_k < f_s$).

Coefficient of static friction (μ_s):

As we know that, the static friction "f_s" is directly proportional to the normal force "F_N" acting on the body i.e.,

$$f_s \alpha\ F_N$$

Or

$$\mathbf{f_s = \mu_s F_N}$$

Where "μ_s" is a constant of proportionality known as the coefficient of static friction and depends on the nature of surfaces in contact before sliding.

Thus, the coefficient of static friction "μ_s" can be written as

$$\mu_s = \frac{f_s}{F_N}$$

Coefficient of kinetic friction(μ_k):

Similarly, the kinetic friction "f_k" is directly proportional to the "F_N". i.e.,

$$f_k \alpha F_N$$

or

$$\mathbf{f_k = \mu_k F_N}$$

Where "μ_k" is known as coefficient of kinetic friction and depends on the nature of surfaces in contact during sliding.

Thus, the coefficient of kinetic friction "μ_k" can be written as:

$$\mu_k = \frac{f_k}{F_N}$$

As "μ" is the ratio of forces (two similar quantities), therefore it has no unit.

Q9: What are the advantages and disadvantages of friction? Also give methods to reduce and improve friction.

Ans: **Advantages of friction:**

Some advantages of friction are given below:

1. We can walk on the ground with the help of friction between the soles of our shoes and the ground.
2. The nails remain fixed in the walls and wood due to friction.
3. The lighting of a match stick is another useful application of friction.
4. The moving vehicles can be stopped by applying brakes due to friction.
5. Friction enables us to write on paper.

Disadvantages of friction:

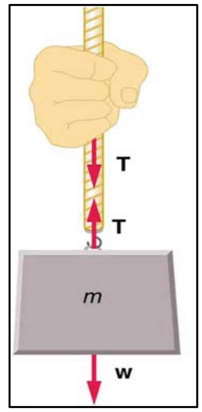
Some disadvantages of friction are given below:

1. The friction can produce heat in various parts of running machine.
2. Friction reduces the speed of moving vehicles to a great extent.
3. The various parts of machines become useless due to friction.
4. Cars, buses, trains, machines etc lose a part of their energy in overcoming friction due to which their efficiency decreases.

Methods of reducing friction:

Some methods of reducing friction are given below:

1. If we polish the rough surfaces, they become smooth and friction is reduced.
2. Friction can be reduced by applying lubricants (oils or grease) between the parts of machinery or any rough surface.
3. Friction can be reduced by converting sliding friction into rolling friction by using ball bearings
4. To reduce air friction, the front portions of cars and airplanes are made oblong in shape.



Q10: What is tension? If two connected bodies of masses m_1 and m_2 are hanging from the ends of a string which is passing over a pulley, find the values of tension and acceleration in it.

Ans: **Tension:**

The pulling force exerted by a stretched rope, string or cable on an object to which it is attached is called a tension force. It is denoted by "T".

Explanation:

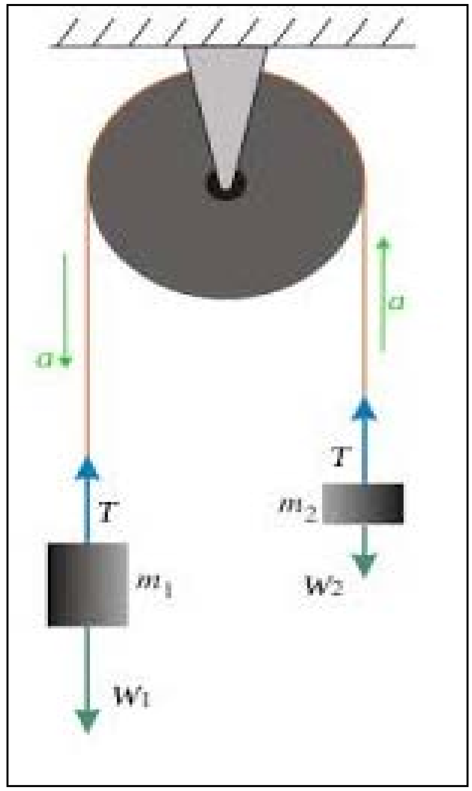
Tension is always a pull force. Hence, the direction of a tension force is always the direction in which one would pull the object with a string or rope. Suppose a person is holding an object of mass "m" at rest with the help of a string as shown in figure. The object exerts a force on the hand through the string in downward direction due to its weight "W". By Newton's third law, the force which is exerted by the string on hand is called the tension in the string. As the object is at rest, the magnitude of tension is equal to that of weight of the object i.e., T=W

Acceleration and Tension in Atwood's machine:

Consider, motion of two bodies "A" and "B" having masses m_1 and m_2 (with m_1 is greater than m_2) are suspended by an extensible string which passes over a frictionless pulley. Such arrangement is known as Simplified Atwood's machine. In such an arrangement ($m_1>m_2$), m_1 will move downward and m_2 will move upward. Since, tension "T" and acceleration "a" will be same for both bodies.

Mathematical form:

In order to find acceleration and tension in the string, be proceed as follows.



Two forces acting on mass "m_1" are:

1. Weight acting downward= $W_1 = m_1g$
2. Tension in the string acting upward = T

So, the net force acting on "m_1" is given by:

$F_{net} = m_1a$

$W_1 + (-T) = m_1a$

$W_1 - T = m_1a$ $\qquad \therefore W_1 = m_1g$

$m_1g - T = m_1a$ ....(i)

Similarly, two forces acting on mass "m_2" are:

1. Weight acting downward = $W_2 = m_2g$
2. Tension in the string (upward) = T

Now, the net force acting on "m_2" is given by,

$F_{net} = m_2a$

$T + (-W_2) = m_2a$

$T - W_2 = m_2a$ $\qquad \therefore W_2 = m_2g$

$T - m_2g = m_2a$ (ii)

For finding acceleration:

Adding eq(i) and eq (ii)

$m_1g - T + T - m_2g = m_1a + m_2a$

$m_1g - m_2g = m_1a + m_2a$

$(m_1 - m_2)g = (m_1 + m_2)a$

Divide ($m_1 + m_2$) on both sides

$$\frac{(m_1-m_2)}{(m_1+m_2)} g = \frac{(m_1+m_2)}{(m_1+m_2)} a$$

$$\frac{(m_1-m_2)}{(m_1+m_2)} g = a$$

Or

$$a = \frac{(m_1-m_2)}{(m_1+m_2)} g \text{ ... ...iii}$$

For finding tension in string:

Dividing eq (i) and eq (ii)

$$\frac{m_1g - T}{T - m_2g} = \frac{m_1a}{m_2a}$$

$$\frac{m_1g - T}{T - m_2g} = \frac{m_1}{m_2}$$

By cross multiplication

$m_2(m_1 g - T) = m_1(T - m_2 g)$

$m_1 m_2 g - m_2 T = m_1 T - m_1 m_2 g$

$m_1 m_2 g + m_1 m_2 g = m_1 T + m_2 T$

$2m_1 m_2 g = (m_1 + m_2)T$

Divide $(m_1 + m_2)$ on both sides

$$\frac{2m_1 m_2 g}{m_1 + m_2} = \frac{(m_1 + m_2)T}{m_1 + m_2}$$

$$\frac{2m_1 m_2 g}{m_1 + m_2} = T$$

Or

$$T = \frac{2m_1 m_2 g}{m_1 + m_2} \qquad \text{(iv)}$$

Equation (iv) represents the Tension "T" in the string.

Q11: What is uniform circular motion? What are the factors on which magnitude of acceleration (centripetal acceleration) in uniform circular motion depends.

Ans: Uniform circular motion:

"If a body moves in a circular path with a uniform speed, its motion is called uniform circular motion."

Or

"When the speed of a moving object does not change as it travels in the circular path, it is called uniform circular motion.

Examples:

1. Motion of earth around the sun.
2. Motion of electrons around the nucleus.
3. Motion of fan etc.

Centripetal acceleration:

The acceleration which is produced by changing the direction of motion of a body moving in a circular path with constant (uniform) speed is called centripetal acceleration. It is denoted by "a_c".

Explanation:

We know that during the circular motion, the direction of velocity of the body changes at every point continuously due to which an acceleration is produced which is known as centripetal acceleration. It is perpendicular to the velocity of the body and is directed towards the center of the circle.

Mathematical form:

Mathematically it can be written as:

$$a_c = \frac{v^2}{r} \qquad (i)$$

Unit:

The SI unit of centripetal acceleration is meter per second square (m/s^2 or ms^{-2}).

Factors:

According to eq (i) the centripetal acceleration "a_c" depends on the following two factors in uniform circular motion.

1. Velocity of the body (v)
2. Radius of circle (r)

Eq (i) shows that the centripetal acceleration is directly proportional to the square of velocity of the body which means greater is the speed of the body, greater will be the centripetal acceleration. Also, centripetal acceleration is inversely proportional to the radius of the circle (r) which means smaller is the radius of circular path, greater will be the centripetal acceleration.

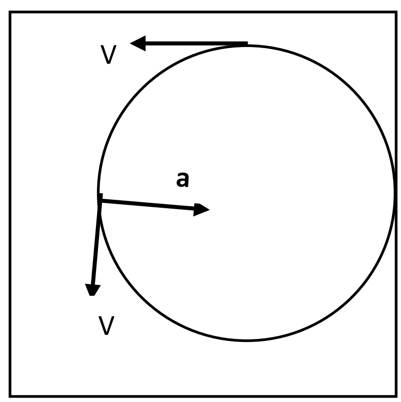
Q12: What is centripetal force? Explain how centripetal force is used in banking of roads and centrifugation.

Centripetal force:

The force which compels a body to move in a circular path is called centripetal force. It is denoted by "F_c".

Mathematical form:

$$F_c = \frac{mv^2}{r}$$



Where "m" is the mass of the body, "v" is the velocity of the body and "r" is the radius of the circle.

Explanation

We know that in circular motion, the direction of velocity of the body changes at every point continuously. Thus, acceleration is produced during such motion and the force required for the production of centripetal acceleration is known as centripetal force which is directed forwards the centre of the circle.

Applications of centripetal force:

The centripetal force plays an important role in our daily life. Some of the useful applications of centripetal force are given below:

1. **Banking of road:**

To make the outer edge of a curved road is a little higher than the its inner edge is known as banking of road.

When a car takes a turn along a round track, sufficient centripetal force is required. In the absence of this force, the car will skid off the road to the outward direction due to inertia. The force of friction between tyres and the road provides this centripetal force and keeps the car moving on the curved path. However, if the road is slippery due to rain or snow, this reduces the friction which in turn reduces centripetal force of taking turn.

In this case, we use a technique "banking of road curves" in order to provide sufficient centripetal force to the turning vehicles by making the outer edge of a round track is slightly higher than that of the inner edge. In this case the normal force 'F_N' of the road is resolved into two components i.e. 'F_{Nx}' and 'F_{Ny}'.

The horizontal component 'F_{Nx}' balances the weight of a car whereas the vertical component 'F_{Ny}' of normal force increases the friction which provides sufficient centripetal force due to which the vehicles take a safe turn.

Centrifuge:

Centrifuge is a device which is used for the separation of liquids of unequal densities. Its operation depends upon centripetal force.

Construction and working:

A simplest type of centrifuge consists of a wheel which rotates horizontally and some buckets are attached to the wheel vertically. Now, if a mixture of unequal densities are introduced into the buckets and the wheel is allowed to rotate rapidly, the liquid becomes separate that is the heavy liquid remains farther from the axis of rotation while the lighter liquids remains nearer to it. This means that the heavier liquids are at the bottom of the buckets when the centrifuge is stopped.

Examples:

The same centrifuge principle can be used in some commonly used devices in our daily life i.e. cream separator and washing machine dryer are the examples of centrifuge.

TOPIC WICE QUESTION

Q1. Describe various type of friction.

Ans. Types of friction:

There are two types of frictional forces which are given below

1. Sliding friction
2. Rolling friction

1. Sliding friction:

The force which opposes the sliding of one solid body over the surface of another solid body is called sliding friction. This kind of friction is caused by the roughness of surfaces in contact.

Types of sliding friction:

Sliding friction is of two types which are given below;

a. Static friction
b. Kinetic friction

a. Static friction:

The minimum force of friction that is opposite to the applied force and prevents the body from moving is called static friction. It is denoted by f_s.

b. Kinetic friction:

The frictional force that acts against during motion of an object in a direction opposite to the direction of motion is called kinetic friction. It is denoted by f_k.

Example:

Whenever a wooden cart is dragged over a road then the friction produced is called sliding friction.

2. Rolling friction:

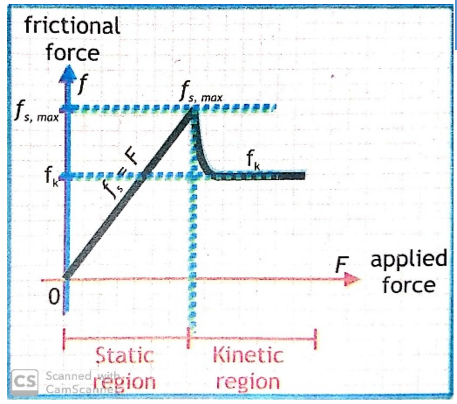
When a body rolls over a surface, the force of friction is called rolling friction.

Explanation:

It is commonly observed that a body with wheels move easily as compared to a body of same size without wheels. Thus, rolling friction is much less than a sliding friction because the contact surface area is much less in rolling than in sliding friction.

Example:

Whenever a ball is rolled over the ground the friction produced is called rolling friction because small surface area of both ball and ground are in contact with each other that offer less resistance.



Q2. Discuss the graphical interpretation of friction.

Ans. <u>Graphical interpretation of friction:</u>

The graph between applied force 'F' and frictional force 'f' shows that when the applied force increases the static frictional force 'f_c' also increases until it reaches a certain maximum value called limiting friction 'f_s max'.

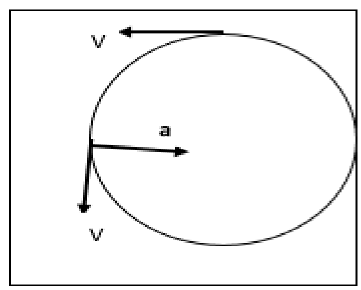
At this point the object starts moving and frictional force rapidly decreases to a smaller kinetic friction 'f_k' value, which nearly remains constant.

Q3. Define and explain centripetal force.

Ans. <u>Centripetal force:</u>

The force which compels a body to move in a circle is called centripetal force. It is denoted by 'F_c'.

<u>Explanation:</u>



We know that in circular motion, the direction of velocity of body changes continuously. Thus, acceleration is produced during such motion. The force required for the production of centripetal acceleration is known as centripetal force and it is always directed towards the centre of circle. In the absence of centripetal force, the object will travel in a straight line. Hence, the effect of centripetal force is to continuously change the direction of moving object, forcing it to move in a circle.

<u>Mathematical form:</u>

Let 'm' be the mass of an object which is compelled to move in a circle of radius 'r' with the constant speed 'v'. Centripetal force 'F_c' produces centripetal acceleration 'a_c' in the body which can be written as:

$a_{c} = = \frac{v2}{m}$

Now, according to the Newton second law of motion:

$F_c = ma_c$ (i)

Putting value of a_c in eq (i):

$F_c = \frac{mv2}{r}$ (ii)

<u>Quantity and Unit:</u>

The centripetal force is a vector quantity and its SI unit is Newton (N).

Factors on which it depends:

According to eq (ii), the centripetal force depends upon the following three factors:

1. Mass of the body
2. Velocity of the body
3. Radius of the circle

Greater the mass and velocity of the body, greater will be the centripetal force. Also, smaller is the radius of circular path, greater will be the centripetal force.

Example:

The moon revolves around the earth because of centripetal force which is provided by the gravitational force between moon and the earth.

Q4. Write a note on cream separator.

Ans. <u>Cream separator:</u>

A cream separator is a centrifugal device which is used to separate cream from milk. It works on the principle of centrifuge.

<u>Construction:</u>

It consists of a set of blades connected to an axis by means of a metallic rod which is driven by an electric motor.

<u>Working:</u>

As milk is a mixture of light and heavy particles, the turning blades of this device spins the milk due to which the light and heavy particles of milk are separated. The light particles (cream) gather near the axis of rotation while the heavy particles of milk go away from the axis of rotation. In this way, cream is separated from milk.

Q5. Write a note on washing machine dryer.

Ans. <u>Washing machine dryer:</u>

A washing machine dryer is a device which is used to dry the wet clothes quickly. It works on the principle of centrifuge.

<u>Construction:</u>

It consists of a cylinder having small holes on its wall and a rotor which is driven by an electric motor.

<u>Working:</u>

When wet clothes are placed in this cylinder and it is rotated rapidly. Due to this, water moves outward to the wall of cylinder and is drained out through the holes. In this way, the clothes become dry quickly.

CONCEPTUAL QUESTIONS

Q1. Why does dust fly off, when a hanging carpet is beaten with a stick?

Ans. When we beat a carpet with a stick, the carpet is set into motion while the dust particles inside the carpet are at rest and tends to remain at rest due to inertia. As the dust particles do not move with the carpet, so they get removed from the carpet.

Q2. If your hands are wet and no towel is handy, you can remove some of the excess water by shaking them, why does this work?

Ans. We can remove some of the excess water from our wet hands by shaking them due to inertia. When we shake our hands, the hands come into state of motion while the drops of water are at rest and tend to remain at rest due to inertia. As a result, these drops are removed from our hands.

Q3. Why a balloon filled with air move forward when its air is released?

Ans. When air is released from balloon, the balloon exerts an action force on the air and pushes it out in the backward direction. While the rushing out air exerts an equal reaction force on the balloon in forward direction. As a result, the balloon moves forward.

We can also explain this in terms of the law of conservation of momentum. The air and balloon forms an isolated system whose total momentum is initially zero. Now, when air is released, it rushes out with great momentum in the backward direction. Now to conserve the momentum, the balloon moves forward with the same momentum.

Q4. Why does a hosepipe tend to move backward when the fire man directs a powerful stream of water towards fire?

Ans. It is an example of Newton's third law as well as law of conservation of momentum. By Newton's third law of motion, when the fire man directs a hose pipe towards fire, the water shoots out from the pipe in forward direction which is an action on water. While as a reaction, the water also exerts the same force on the pipe in backward direction. As a result, the house pipe moves backward.

Similarly, it can be explained by the law of conservation of momentum, the water and pipe forms an isolated system whose total momentum is zero. Now, when the water is released from the pipe it comes out with great momentum in the forward direction. Now, to conserve the momentum, the pipe moves in backward direction.

Q5. Your car is stuck in wet mud. Some students on their way to class see your predicament and help out by sitting on the trunk of your car to increase its traction. Why does it help?

Ans. When a car stuck in wet mud, the friction between tyres and mud decreases. As a result, the car cannot move. Now, when the students sit on the trunk of the car, the weight of car increases due to which the normal force 'F_N' on the car also increases.

As we know that:

$$\mathbf{f = \mu F_N}\text{..........eq (i)}$$

According to eq (i), force of friction (f) is directly proportional to the normal force (F_N) which means that greater the normal force, greater will be the force of friction. Thus, the increase in friction helps the car to come out of the mud easily.

Q6. How does friction help you walk? Is it kinetic friction or static friction?

Ans. A frictional force exists between the ground and sole of our shoes. When we walk forward, we push the ground with feet in the backward direction while in reaction, the ground also exerts a force (friction) in forward direction which moves us forward. Because of this frictional force, we are able to walk on the ground. Without friction, it is not possible for us to walk on the ground.
This is **static friction** because when we walk on the ground, our feet are at rest for a moment which provides the static friction between our feet and ground. Hence, we walk due to static friction instead of kinetic friction.

Q7. The parking brake on a car causes the air wheels to lockup. What would be the likely consequence of applying the parking brake in a car that is in rapid motion?

Ans. While driving fast on a road, if the parking brake (hand brake) is applied, the rear wheels of the car will be lock up. But the front wheels are in motion and according to inertia, the front wheels try to maintain their state of motion. As a result, the car will skid in such situation.

Q8. Why is the surface of a conveyor belt made rough?

Ans. The surface of a conveyor belt is made rough just to increase the force of friction between the belt and the objects which are placed on the surface of belt. Because on rough surface, irregularities are more due to which area of contact increases the force of friction. As a result, the things lying on the belt remain safe from falling down.

Q9. Why does a boatman tie his boat to a pillar before allowing the passengers to step on the river bank?

Ans. When the passengers jump from the boat on the river bank, they actually push the boat with their feet in the backward direction. In this way, the boat would move away from the bank and the passengers may fall in water. So, to avoid the backward push of the boat, it is first tied to the pillar before allowing the passengers to step on the river bank.

Q10. In uniform circular motion, is the velocity constant? Is the acceleration constant? Explain.

Ans. In uniform circular motion, the velocity does not remain constant because the direction of velocity of the body changes continuously from point to point and this direction of velocity is always tangent to circle at each point. Whereas, the centripetal acceleration is directed towards the centre of circular path and its direction remain unchanged. Due to uniform circular motion, the centripetal acceleration remains constant throughout the motion.

Q11. You tie a brick to the end of the rope and whirl the brick around you in a horizontal circle. Describe the path of the brick after you suddenly let go of the rope.
Ans. According to Newton's third law of motion, for every action there is an equal and opposite reaction. When we tie a brick to the end of a rope and whirl it in a circle of radius 'r', we provide centripetal force to the brick through the rope. Whereas the brick also exerts centrifugal force on our hands through the rope in a direction away from the centre of the circle. So, the reaction of the centripetal force is centrifugal force. Now, if we let go the rope suddenly then the brick will move in a straight line away from the centre of the circle due to centrifugal force.

Q12. Why the posted speed for a turn is lower than the speed limit on most highways?
Ans. When a car takes a turn, the necessary centripetal force v is provided by the force of friction between the road and tyres. We know that the centripetal force 'F_c' is given by:

$F_{c\,=} = \frac{mv^2}{r}$ .... eq (i)

eq (i) shows that higher the speed of the car, greater amount of centripetal force is required to move along a circular path. At higher speed, it is not possible for the frictional force to provide necessary centripetal force for the car to take a safe turn. As a result, the car will skid away due to insufficient centripetal force. So, to avoid such risky situation, the driver should keep the speed of the car lower while taking a turn.

NUMERICAL QUESTIONS

Q1. 1580kg car is travelling with a speed of 15.0 m/s. what is the magnitude of the horizontal net force that is required to bring the car to a halt in a distance of 50.0m.

Data:

Mass = m = 1580kg

Initial velocity = vi = 15m/s

Final velocity = vf = 0m/s

Distance covered = s = 50m

Find:

Force required to stop the car = F =?

Solution:

As we know that

F = ma……………. eq (i)

First, we find 'a' by using 3rd equation of motion

$$2as = v_f^2 - v_i^2$$

Or

$$a = \frac{v_f^2 - v_i^2}{2s}$$

By putting values:

$$a = \frac{(0)-(15)2}{2\times50}$$

$$a = \frac{0-225}{100}$$

$$a = \frac{-225}{100}$$

$$\mathbf{a = -2.25 m/s^2}$$

The negative sign shows deceleration.

Now, putting value of 'a' in eq(i)

$$F = ma$$

$$F = 1580 \times -2.25$$

$$F = -3555N$$

$$F = -3.555 \times 10^3 \text{ N}$$

Or

$$\mathbf{F = -3.55 \times 10^3 \text{ N}}$$

Q2. A bullet of mass 10g is fixed with a rifle. The bullet takes 0.003s to move through barrel and leaves with a velocity of 300m/s. What is the force exerted by the rifle?

Data:

Mas = m = 10g

$$m = \frac{10}{1000}$$

m = 0.01kg

Time = t = 0.003s

Initial velocity = v_i = 0m/s

Final velocity = v_f = 300m/s

Find:

Force = F =?

Solution:

We know that

$$\mathbf{F = ma} \quad \ldots\ldots\ldots\ldots \quad \text{eq (i)}$$

1st we find 'a' by using formula

$$\mathbf{a} = \frac{v_f - v_i}{t}$$

By putting values

$$a = \frac{300-0}{0.003}$$

$$a = \frac{300}{0.003}$$

$$\mathbf{a = 100{,}000\ m/s^2}$$

Now, putting value of 'a' in eq (i)

$$F = ma$$

$$F = 0.01 \times 100{,}000$$

$$\mathbf{F = 1000N}$$

Q3. A 2200 kg vehicle travelling at 94km/h(26m/s) can be stopped in 21s by gently applying the barkers. It can be stopped in 3.8s. if the driver slams on the brakes. What average force is exerted on the vehicle in both of these stops.

Data: -

Mass = m =2200kg

Initial velocity = v_i = 94km/hr

$$v_i = \frac{94 \times 1000}{3600}$$

$$v_i = 26m/s$$

Time taken in 1st case = t_1 = 21s

Time taken in 2nd case = t_2 = 3.8s

Final velocity = v_f = 0m/s

Find:

Force required in 1st case = F_1 =?

Force required in 2nd case = F_2 =?

Solution; -

As we know that

$$\mathbf{F_1 = ma_1} \text{ .... (i)}$$

1st we find "a_1" by using formula

$$a_1 = \frac{v_f - v_i}{t_1}$$

by putting values

$$a_1 = \frac{0-26}{21}$$

$$a_1 = \frac{-26}{21}$$

$$\mathbf{a_1 = -1.23 m/s^2}$$

Now, putting value of a_1 in eq (i)

$$F_1 = ma_1$$

$$F_1 = 2200 \times (-1.23)$$

$$F_1 = -2706N$$

$$F_1 = -2.706 \times 10^3 N$$

OR

$$\mathbf{F_1 = -2.7 \times 10^3 N}$$

For finding F_2, we know that

$$F_2 = ma_2 \text{ .... (ii)}$$

1st we find "a_2" by using formula

$$a_2 = \frac{V_f - v_i}{t_2}$$

By putting values

$$a_2 = \frac{0-26}{3.8}$$

$$a_1 = \frac{-26}{3.8}$$

$$\mathbf{a_2 = -6.84 m/s^2}$$

Now, putting value of a_2 in eq (ii)

$$F_2 = ma_2$$

$$F_2 = 2200 \times (-6.84)$$

$$F_2 = -15048N$$

$$\mathbf{F_2 = -1.5 \times 10^4 N}$$

For finding average force "F":

$$F = \frac{F_1 + F_2}{2}$$

$$F = \frac{(-2.7 \text{ x } 10^3) + (-1.5 \times 10^4)}{2}$$

$$F = \frac{-2.7 \times 10^3 - 1.5 \times 10^4}{2}$$

$$F = \frac{-2.7 \times 10^3 \quad -0.15 \times 10^3}{2}$$

$$F = \frac{-2.85 \times 10^3}{2}$$

$$\mathbf{F = -1.42 \times 10^3\ N}$$

Q4. You want to move a 500N crate across a level floor. To start the crate moving, you have to pull with a 230N horizontal force. Once the crate "breaks loose" and starts to move, you can keep it moving at constant velocity with only 200N. What are the co-efficient of static and kinetic friction?

Data: -

Normal force = weight of crate

$F_N = W$

$F_N = 500N$

Static friction = f_s = 230N

Kinetic friction = f_k = 200N

Find

Co-efficient of static friction = μ_s =?

Co-efficient of kinetic friction = μ_k =?

Solution

For finding μ_s, using formula

$$\mu_s = \frac{f_s}{F_N}$$

$$\mu_s = \frac{230}{500}$$

$$\boldsymbol{\mu_s = 0.46}$$

For finding μ_k, using formula

$$\mu_k = \frac{f_k}{F_N}$$

$$\mu_k = \frac{200}{500}$$

$$\boldsymbol{\mu_k = 0.4}$$

Q5. Two bodies of masses 3kg and 5kg are tied to string which is passed over a pulley. If the pulley has no friction, find the acceleration of the bodies and tension in the string.

Data:

Mass of 1st body = m_1 = 5kg

Mass of 2nd body = m_2 = 3kg

Acceleration due to gravity = g = 9.8m/s^2

Find

Acceleration = a=?

Tension in the string =T=?

Solution:

1st we find "a", by using formula

$$\mathbf{a = \left(\frac{m_1 - m_2}{m_1 + m_2}\right)g}$$

$$a = \left(\frac{5-3}{5+3}\right) \times 9.8$$

$$a = \left(\frac{2}{8}\right) \times 9.8$$

$$a = 0.25 \times 9.8$$

$$\mathbf{a = 2.45 m/s^2}$$

For finding T, using formula

$$\mathbf{T = \left(\frac{2m_1 m_2}{m_1 + m_2}\right)g}$$

$$T = \frac{2 \times 5 \times 3}{5+3} \times 9.8$$

$$T = \frac{30}{8} \times 9.8$$

$$T = 3.75 \times 9.8$$

$$\mathbf{T = 36.75N}$$

Q6. Determine the magnitude of the centripetal force exerted by the rim of a car's wheel on a 45.0 kg tire. The tire has 0.408 meter radius and is rotating at a speed of 30.0 m/s.

Data:

Mass = m = 45 kg

Radius= r = 0.480m

Speed= v = 30 m/s

Find:

Centripetal force = F_c = ?

Solution:

We know that

$$\mathbf{F_c = \frac{mv^2}{r}}$$

By putting values

$$F_c = \frac{45 \times 30^2}{0.480}$$

$$F_c = \frac{45 \times 900}{0.480}$$

$$F_c = \frac{40500}{0.480}$$

$$F_c = 84375\ N$$

$$F_c = 8.4375 \times 10^4\ N$$

or

$$\mathbf{F_c = 8.44 \times 10^4\ N}$$

Q7. A motorcyclist is moving along a circular wooden track of a circus (death well) of radius 5m at a speed of 10m/s. If the total mass of motorcycle and the rider is 150 kg, find the magnitude of centripetal force acting on him?

Data:

Mass = m = 150 kg

Radius= r = 5m

Speed= v = 10 m/s

Find:

Centripetal force = F_c = ?

Solution:

We know that

$$\mathbf{F_c = \frac{mv^2}{r}}$$

By putting values

$$F_c = \frac{150 \times 10^2}{5}$$

$$F_c = \frac{150 \times 100}{5}$$

$$F_c = \frac{15000}{5}$$

$$\mathbf{F_c = 3000\ N}$$

Q8: A car of mass 1000kg is running on a circular motorway interchange near swabi with a velocity of 80m/s, the radius of circular motorway interchange is 800m. How much centripetal force is required?

Data:

Mass = m = 1000 kg

Radius= r = 800m

Velocity= v = 80 m/s

Find:

Centripetal force = F_c = ?

Solution:

We know that

$$\mathbf{F_c = \frac{mv^2}{r}}$$

By putting values

$$F_c = \frac{1000 \times 80^2}{800}$$

$$F_c = \frac{1000 \times 6400}{800}$$

$$F_c = \frac{64000}{8}$$

$$\mathbf{F_c = 8000\ N}$$

Assignment

Assignment 3.1

Find the acceleration produce in engine force of 3500N in car of mass 600 Kg and truck of mass 2400 kg.

Data:

Force = F = 3500 N

Mass of car = m_1 =600 kg

Mass of truck = m_2 = 2400 kg

Find:

Acceleration produced in car = a_1 = ?

Acceleration produced in truck = a_2 = ?

Solution:

For finding a_1, using formula

$$F = ma$$

Or

$$F = m_1 a_1$$

$$\mathbf{a_1 = \frac{F}{m_1}}$$

By putting values

$$a_1 = \frac{3500}{600}$$

$$\mathbf{a_1 = 5.83\ m/s^2}$$

For finding a_2, using formula

$$F = m_2 a_2$$

or $$\mathbf{a_2 = \frac{F}{m_2}}$$

By putting values

$$a_2 = \frac{3500}{2400}$$

$$a_2 = 1.458\ m/s^2$$

Or

$$\mathbf{a_2 = 1.46\ m/s^2}$$

Assignment 3.2

The weight of an astronaut and his space suit on the moon is only 250N. How much do they weigh on earth? What is the mass on the moon? On earth? (Take acceleration due to gravity for earth as g_E = 9.8m/s^2 and moon as g_M = 1.6m/s^2)

Data:

Weight of astronaut on moon = W = 250 N

Acceleration due to gravity on earth = g_E = 9.8 m/s^2

Acceleration due to gravity on moon = g_m = 1.6 m/s^2

Find:

a) Mass on moon = m_m = ?
b) b. Mass on earth = m_E = ?
c) c. Weight on earth = W_E =?

Solution

For finding m_m , using formula

$$W = mg$$
$$W = m_m g_m$$
$$\text{Or} \quad \mathbf{m_m = \frac{W}{g_m}}$$
$$m_m = \frac{250}{1.6}$$
$$\mathbf{m_m = 156\ kg}$$

(b) As mass is constant everywhere, so mass of astronaut on earth will be also 156kg. i.e.,

$$\mathbf{m_E = 156kg}$$

(c) For finding W_E, we know that

$$W_E = m_E g_E$$
$$W_E = 156 \times 9.8$$
$$W_E = 1528.8\ N$$
$$W_E = 1.528 \times 10^3 N$$
Or
$$\mathbf{W_E = 1.5 \times 10^3 N}$$

Assignment 3.3

The fastest recorded speed for a golf ball hit by a golfer is 75.8 m/s (273km/hr). If mass of golf ball is 46g, what is the magnitude of its momentum?

Data

Velocity = V = 75.8m/s
Mass = m = 46g

$$m = \frac{46}{1000} kg$$
$$m = 0.046kg$$

Find

Momentum = P = ?

Solution

We know that

$$\mathbf{P = mv}$$

By putting values

$$P = 0.046 \times 75.8$$
$$P = 3.4868Ns$$
Or $\quad$ **P = 3.49 Ns**

Assignment 3.4

Calculate the force required to stop a car of mass 1200 kg and a loaded truck of mass 9000kg in 2 second, if they are moving with same velocity of $10ms^{-1}$.

Data

Mass of car = m_1 = 1200 kg

Mass of truck = m_2= 9000kg

Time = t= 2s

Initial velocity = v_i =10 ms^{-1}

Final velocity = v_f= 0 ms^{-1}

Find

Force required to stop a car = F_1 = ?

Force required to stop a truck = F_2 = ?

Solution

As we know that

$$\mathbf{F_1 = m_1a} \qquad \text{(i)}$$

1st we find "a", by using formula

$$\mathbf{a= \frac{v_f - v_i}{t}}$$

By putting values

$$a = \frac{0-10}{2}$$

$$a = \frac{-10}{2}$$

$$\mathbf{a = -5ms^{-1}}$$

Now putting values of "a" in eq (i)

$$F_1 = m_1a$$

$$F_1 = 1200 \times -5$$

$$\mathbf{F_1 = -6000N}$$

For finding F_2, we know that

$$F_2 = m_2a$$

By putting values

$$F_2 = 9000 \times -5$$

$$\mathbf{F_2 = -45000N}$$

Assignment 3.5

In carrom board game the stricker of mass having mass 0.015kg sliding to the right at velocity of 0.40m/s makes head on collision with a disk having mass 0.005kg that is initially at rest. After the collision, stricker moves to the right along the direction of disk at 0.20m/s. Find the final velocity of the disk.

Data

Mass of stricker = m_1 = 0.015kg

Mass of disk = m_2 = 0.005kg

Initial velocity of stricker = u_1 = 0.40m/s

Final velocity of stricker = v_1 = 0.20m/s

Initial velocity of disk = u_2 = 0m/s

Find

Final velocity of disk = v_2 = ?

Solution

By using law of conservation of momentum

$$m_1u_1 + m_2u_2 = m_1v_1 + m_2v_2$$

$$m_1u_1 + m_2u_2 - m_1v_1 = \cancel{m_1v_1} - \cancel{m_1v_1} + m_2v_2$$

$$m_1u_1 + m_2u_2 - m_1v_1 = m_2v_2$$

Divide " m_2" on both sides

$$\frac{m_1u_1+m_2u_2-m_1v_1}{m_2} = \frac{\cancel{m_2}v_2}{\cancel{m_2}}$$

$$\frac{m_1u_1+m_2u_2-m_1v_1}{m_2} = v_2$$

Or

$$\mathbf{v_2 = \frac{m_1u_1+m_2u_2-m_1v_1}{m_2}}$$

$$v_2 = \frac{0.015\times0.40+0.005\times0-0.015\times0.20}{0.005}$$

$$v_2 = \frac{0.006+0-0.003}{0.005}$$

$$v_2 = \frac{0.003}{0.005}$$

$$\mathbf{v_2 = 0.6\ m/s}$$

Assignment 3.6

A 200kg cannon at rest contains a 10kg cannon ball. When fired, the cannon ball leaves the cannon with a speed of 90m/s. what is the recoil speed of cannon?

Data:

Mass of a cannon ball = m_1 = 10kg

Mass of a cannon = m_2 = 200kg

Velocity of cannon ball after fire = v_1 = 90m/s

Find:

Velocity of cannon after fire = v_2 = ?

Solution:

We know that

$$P_f = P_i \qquad \therefore P_i = 0$$

$$P_f = 0$$

$$m_1v_1 + m_2v_2 = 0$$

$$m_1v_1 - m_1v_1 + m_2v_2 = 0 - m_1v_1$$

$$m_2v_2 = - m_1v_1$$

Divide "m_2" on both sides

$$\frac{m_2v_2}{m_2} = \frac{-m_1v_1}{m_2}$$

$$\mathbf{v_2 = \frac{-m_1v_1}{m_2}}$$

$$v_2 = \frac{-(10 \times 90)}{200}$$

$$v_2 = \frac{-900}{200}$$

$$\mathbf{v_2 = -4.5m/s}$$

The negative sign shows that the cannon is pushed in opposite direction of cannon ball.

Assignment 3.7

A 5kg heavy leather bag is placed on a horizontal wooden plank. How much force is required to set it in motion if the coefficient of friction between the plank and bag is 0.1?

Data:

Mass of bag = m = 5kg

Acceleration due to gravity = g = 9.8m/s^2

Coefficient of friction = μ_k= 0.1

Find:

Normal force = F_N = ?

Force = f_k= ?

Solution:

As we know that

$$\mathbf{f_k = \mu_k F_N} \text{..........................(i)}$$

First we find F_N , we know that

$$F_N = \text{Weight of the bag}$$

$$F_N = W \qquad \therefore w = mg$$

$$F_N = mg$$

$$F_N = 5 \times 9.8$$

$$\mathbf{F_N = 49N}$$

Now, putting value of 'F_N' in eq (i)

$\mathbf{f_k = \mu_k F_N}$

$f_k = 0.1 \times 49$

$f_k = 4.9N$

Or

$\mathbf{f_k = 5N}$

Assignment 3.8

Two bodies of mass 3.5kg and 1.5kg are tied to ends of string which passes over a pulley. Find

a. **The acceleration of bodies**
b. **The tension in the string**

Data:

Mass of 1st body = m_1 = 3.5kg

Mass of 2nd body = m_2 = 1.5kg

Acceleration due to gravity = g = 9.8m/s^2

Find:

Acceleration = a = ?

Tension in string = T = ?

Solution;

For finding 'a' ,using formula

$$\mathbf{a = \left(\frac{m_1 - m_2}{m_1 + m_2}\right) g}$$

$$a = \left(\frac{3.5-1.5}{3.5+1.5}\right) 9.8$$

$$a = \left(\frac{2}{5}\right) 9.8$$

$$a = 0.4 \times 9.8$$

$$a = 3.92 \text{ m/s}^2$$

Or

$$\mathbf{a = 4 \text{ m/s}^2}$$

For finding 'T', using formula

$$\mathbf{T = \left(\frac{2m_1 m_2}{m_1 + m_2}\right) g}$$

$$T = \frac{2 \times 3.5 \times 1.5}{3.5+1.5} \times 9.8$$

$$T = \frac{10.5}{5} \times 9.8$$

$$T = 2.1 \times 9.8$$

T = 20.58N

T = 20.6N

Or

T = 21N

Assignment 3.9

A pilot is flying a small plane at 56.6m/s in a circular path with a radius of 188.5m. The centripetal force needed to maintain the plane's circular motion is 1.89×10⁴N. What is the plane's mass?

Data:

Velocity = v = 56.6m/s

Radius = r = 188.5m

Centripetal force = $F_c = 1.89\times10^4$N

Find:

Mass = m = ?

Solution:

We know that

$$F_c = \frac{mv2}{r}$$

Or

$$\mathbf{m = \frac{F_c \times r}{v^2}}$$

$$m = \frac{1.89\times10^4\times188.5}{(56.6)^2}$$

$$m = \frac{356.265\times10^4}{3203.56}$$

$$m = 0.11120 \times 10^4$$

$$m = 01112.0 \times 10^{-4} \times 10^4$$

$$m = 1112.0\ 10^{4-4}$$

Or

m = 1112kg

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TURNING EFFECTS OF FORCES

COMPREHENSIVE QUESTIONS:

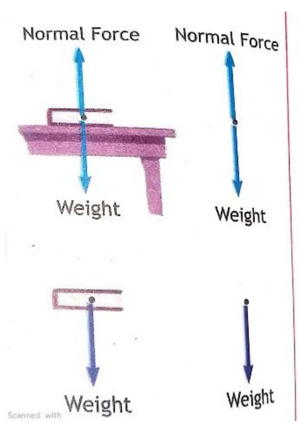
Q1. What are force diagrams? Define like and unlike parallel force with examples.

Ans. Force Diagrams:

In force diagrams, the objects on which force are shown is reduced to a dot at its centre and the force acting on the object are represented by arrows pointing away from it.

Explanation:

If we were to draw a force diagram of a book (object) placed at rest on table, we would reduce book to a dot and draw two arrows representing forces acting on it. There are two forces acting on a book, one is the weight of the book, pulling it downward and the other force is normal force due to the table pushing the book upward. Both forces are equal in magnitude but opposite in direction. These two forces are an example of balanced force where they cancel out each other and the book (object) remains in state of equilibrium.

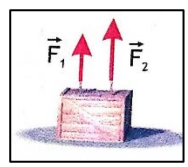


In case of free fall object:

In case of freefall objects, the force due to gravity on the book is unbalanced and the book accelerates downward, in this case the force diagram of a free fall book (object).

Like parallel force:

Like parallel force are those forces which are parallel to each other and having the same direction. They may have same or different magnitude.



Example:

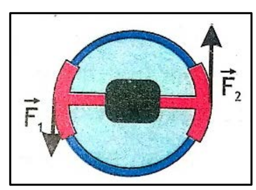
When we lift a box with double support we are applying like parallel force from each support. These forces may not equal but parallel and act in the same direction as shown in fig.

Unlike parallel forces:

Unlike parallel forces are those force which are parallel to each other but they are opposite in direction.

For Example:

When we apply force with our both hands on steering wheel of a car to turn it. The force from one hand may be greater than other. Here, we are applying unlike parallel forces as shown in fig.



Q2. Explain the addition of forces, in connection with head to tail rules.

Ans. Addition of Forces:

Addition of forces is a process of obtaining a single force (Resultant force) which produces the same effect as produced by number of forces acting together.

Explanation:

Forces are vector quantities and may be added geometrically by drawing them to common scale and placing them head to tail.

The addition of forces is simple for parallel force. In case of like parallel forces, add the magnitude of vectors (forces) and in case of unlike parallel forces, subtract the magnitude of vectors.

Addition of Non – Parallel Forces:

When the forces are non-parallel that are acting at angle other than 0^{o} and 180^{o} Then for addition of such vectors (forces), we apply a special method called Head to tail rule in order to find their resultant force (Vector)

Head to tail rule:

According to head to tail rule, we will get a resultant force (vector) by drawing the representative lines of the given forces in such a way that the tail of first force vector joins with the head of last force vector.

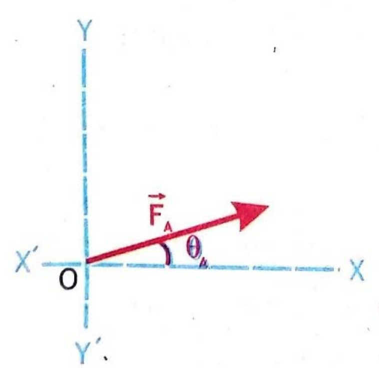
Resultant force:

A resultant force is the sum of two or more forces which is obtained by joining the tail of first force vector to the head of last one. It is represented by "F_R". This method of adding forces is known as "head to tail rule" of addition of forces.

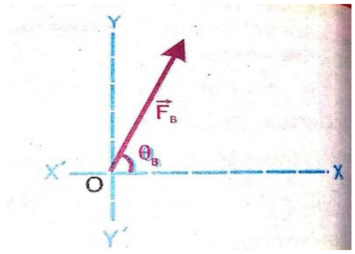
Example:

Consider two persons pulling a cart such that their force vectors are drawn to same scale to calculate the net or resultant force applying on a cart, the following steps must be followed to add the vectors by head to tail rule.

1. Draw a first force vector "F_A" which shows that the force exerted by first person on the cart and making an angle θ_A with x – axis.

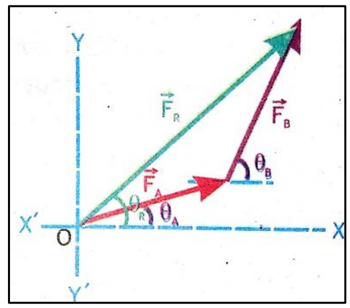


Draw a second force "F_B" which shows that the force exerted by second person on the cart and making an angle θ_B with x – axis



2. Join the tail of second force vector "F_B" with the head of first force vector (F_A) in the given direction.

3. Now, the net or resultant force "F_R" can be obtained by joining the tail of first vector "F_A" to the head of the last force vector "F_B".
Mathematically, the magnitude of resultant vector can be written as:
$\mathbf{F_R = F_A + F_B}$
This rule for vector addition can be extended to any number of forces.



Q3. Define moment of a force. Give its mathematical description and elaborate the factors on which it depends?

Ans: <u>Torque or Moment of force:</u>

The turning effect produced in a body about a fixed point due to applied force is called torque or moment of force.

<u>Explanation:</u>

Torque is the cause of changes in rotational motion and is similar to force, which causes changes in translational motion. For example, opening a door or tightening a nut with spanner etc. Torque may rotate an object in clock wise or anticlock wise direction.

<u>Mathematical Form:</u>

Torque is equal to the product of applied force "F" and the moment arm "d" which is the perpendicular distance from the axis of rotation to the line of action of rotation. Mathematically, it can be written as:

Torque = Force × moment arm (perpendicular distance)

Or

$\tau = F \times d$

<u>Quantity and Unit:</u>

Torque is a vector quantity and its S.I unit is "Newton meter (Nm)"

<u>Factors Affecting Torque:</u>

Torque depends upon the following two factors

1. Magnitude of force (F)
2. Moment arm or perpendicular distance (d)

1. **Magnitude of Applied Force (F):**

Torque is directly proportional to the force applied "F" which means greater is the magnitude of force, greater will be the torque produced. If the force is applied near the axis of rotation, moment arm will be small and turning effect will be poor. But if the force is applied at the pivot point then it will cause no torque since the moment arm would be zero i-e d = 0

2. **Moment Arm (d):**

Moment arm plays an important role in producing torque and it is directly proportional to the torque. Greater is the moment arm, greater will be the torque produced by applying less effort and vice versa.

Example:

To open the door, force 'F' is applied at perpendicular distance "d" from the axis of rotation. By increasing the moment arm 'd' or applied force 'F', torque '$\mathcal{T}$' will also increases. So, the closer you are to the door hinges (i-e the smaller 'd' is), the harder it is to push. That is why, the door's handle is made at the maximum distance from the hinges.

Q4. What is resolution of forces? Explain with an example how force can be resolved into rectangular components.

Ans: RESOLUTION OF FORCES:

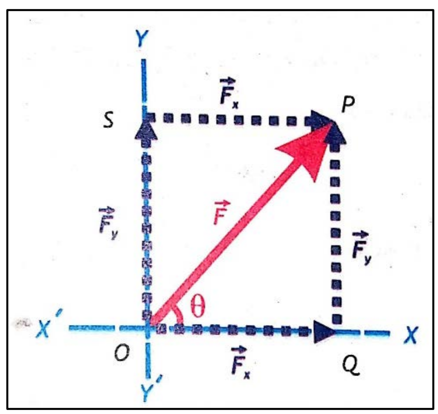
The process of splitting a force vector into two or more force vectors is called resolution of forces.

RECTANGULAR COMPONENTS:

A vectors (Force) is resolved into two components which are mutually perpendicular to each other, such components are called rectangular components of a force vector i. e horizontal component and vertical component.

Example:

Consider a force vector 'F' which is represented by line $\overrightarrow{OP}$ making an angle θ with x-axis.



Resolution of force (F):

To resolve the force vector $\vec{F}$ into its components, draw a perpendicular PQ on axis from point "P". Suppose $\overrightarrow{OQ}$ and $\overrightarrow{QP}$ represents two forces i-e $\vec{F}_x$ and $\vec{F}_y$. So,

i. Force 'OQ' is along x-axis i-e $\vec{F}_x$ represents horizontal component.

ii. Force 'QP' is along y-axis i-e $\vec{F}_y$ represents vertical components.

By applying head to tail rule, we see that sum of vector $\vec{F}_x$ and $\vec{F}_x$ is equal to resultant force vector $\vec{F}$ i-e

$$\vec{F} = \vec{F}_x + \vec{F}_y$$

Therefore, $\vec{F}_x$ and $\vec{F}_y$ are the rectangular components of force vector $\vec{F}$.

For Finding Magnitude of Rectangular Components:

The magnitude of $\overrightarrow{F_x}$ and $\overrightarrow{F_y}$ can be determined by using trigonometric ratios.

For Horizontal Component $\overrightarrow{F_x}$:

Now considering the right angle triangle ΔOPQ , we use the ratio $\cos\theta$ in order to find the value of $\overrightarrow{F_x}$

$$\text{Cos}\theta = \frac{Base}{Hypotenuse}$$

$$\text{Cos}\theta = \frac{OQ}{OP} \qquad :.\ OQ = F_x\ ,\ OP = F$$

$$\text{Cos}\theta = \frac{\overrightarrow{F_x}}{F}$$

By cross multiplication, we get

$$\overrightarrow{F_x} = F\cos\theta \text{ ---- (i)}$$

For Vertical Component F_y:

To find the value of F_y, we use the ratio sin θ

$$\text{Sin}\theta = \frac{Perpendicular}{Hypotenuse}$$

$$\text{Sin}\theta = \frac{QP}{OP} \qquad :.\ QP = F_y,\ OP = F$$

$$\text{Sin}\theta = \frac{F_y}{F}$$

By cross Multiplication, we get

$$F_y = F\,\text{Sin}\theta \text{ ---------- (ii)}$$

So, we can calculate the magnitude of $\overrightarrow{F_x}$ and $\overrightarrow{F_y}$ components of force vector by using eq (i) and (ii)

For finding magnitude of force $\vec{F}$:

If the values of rectangular components F_x and F_y of a force vector are known, we can determine the magnitude of Resultant force $\vec{F}$

According to Pythagoras theorem

$$(Hyp)^2 = (Base)^2 + (Perpendicular)^2$$

$$F^2 = F_x^2 + F_y^2$$

Taking square root on both side:

$$\sqrt{F^2} = \sqrt{F_x^2 + F_y^2}$$

$$F = \sqrt{F_x^2 + F_y^2}$$

For Direction θ:

The direction (θ) of $\vec{F}$ in right angle triangle $\triangle$OPQ is determined by using trigonometric ratio of tanθ.

$$\tan\theta = \frac{Perpendicular}{Base}$$

$$\tan\theta = \frac{QP}{OQ}$$

$$\tan\theta = \frac{F_y}{F_x}$$

$$\theta = \tan^{-1}\frac{F_y}{F_x}$$

Q5. What is Couple? Explain with examples.

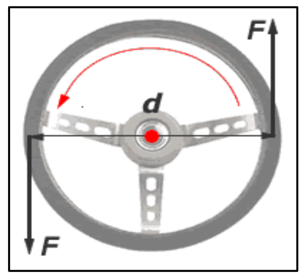
Ans. Couple:

Two equal and opposite parallel forces acting along different lines on a body is called a couple.

Explanation:

Couple does not produce any translational motion but only rotational motion. In other words, the resultant force of a couple is zero but the resultant of a couple is not zero. It is a pure moment. The shortest distance between two couple forces is called couple arm.

Example:



Consider an example of steering wheel gripped by two hands is often a couple. Each hands grips the wheel at points on opposite sides of the shaft. When both hands apply a force F_1 and F_2 that is equal in magnitude but opposite in direction, the wheel rotates. So, a pure couple always consists of two opposite forces equal in magnitude. If both hands apply a force in same direction, the wheel will not rotate

Other Example:

Similarly, in our daily life, we come across many object which work on the principle of couple. e.g.

1. Exerting force on bicycle pedals
2. Winding up the spring of a toy car
3. Opening and closing the cap of a bottle
4. Turning of a water tap etc.

Q6. Define equilibrium. Explain its types and state the two conditions of equilibrium

Equilibrium:

Definition:

The state of a body in which under the action of several forces acting together, there is no change in translational motion as well as rotational motion is called equilibrium.

Or

If there is no change in state of rest or of uniform motion of a body, the body is said to be in state of equilibrium.

Type of Equilibrium:

There are two type of equilibrium which are as follow.

1. Static equilibrium
2. Dynamic equilibrium

1. Static equilibrium:

When a body is at rest under the action of several forces acting together and several torques acting, the body is said be in static equilibrium

Example:

For example, a book is resting on the table and two forces are acting on it i-e weight of book and reaction force of table. Both forces are equal in magnitude but opposite in direction. So, the net force is zero and the book is said to be in state of static equilibrium.

2. Dynamic Equilibrium:

When a body is moving at uniform velocity under action of several forces acting together, the body is said to be in dynamic equilibrium.

The dynamic equilibrium is further divided into two types

1. Dynamic Translational equilibrium
2. Dynamic Rotational Equilibrium

1. Dynamic Translational Equilibrium:

When a body is moving with uniform linear velocity, the body is said to be in dynamic translational equilibrium.

Example: For example, a paratrooper falling down with constant velocity is in state of dynamic translational equilibrium

2. Dynamic Rotational Equilibrium:

When a body is moving with uniform rotation, the body is said to be in dynamic rotational equilibrium.

Example: For example, a Compact disk (CD) rotating in CD player with constant angular velocity is in state of dynamic rotational equilibrium

Conditions of Equilibrium:

There are two conditions of equilibrium which are necessary for a body to be fulfilled

First Condition of Equilibrium:

When the sum of all the forces acting on the body is Zero, then first condition of equilibrium is satisfied

Mathematically: Mathematically, if $\vec{F}_{net}$ is the sum of force $\overrightarrow{F_1}, \overrightarrow{F_2}, \overrightarrow{F_3} \ldots\ldots\ldots\ldots.. \overrightarrow{F_n}$ then

$$\vec{F}_{net} = \overrightarrow{F_1} + \overrightarrow{F_2} + \overrightarrow{F_3} \ldots\ldots\ldots\ldots.. + \overrightarrow{F_n}$$

Or

$$\vec{F}_{net} = \sum \vec{F} = 0$$

Where $\sum$ represents the sigma or summation.

Second Condition of Equilibrium:

When the sum of all the torques acting on the body is zero then the second condition of equilibrium is satisfied.

Mathematically:

Mathematically , if τ_{net} is the sum of forces $\tau_1, \tau_2, \tau_3 \ldots \ldots \ldots \ldots \ldots \tau_n$, then

$$\overrightarrow{\tau_{net}} = \overrightarrow{\tau_1} + \overrightarrow{\tau_2} + \ldots\ldots\ldots \overrightarrow{\tau_n} = 0$$

Or

$$\overrightarrow{\boldsymbol{\tau_{net}}} = \sum \vec{\boldsymbol{\tau}} = \mathbf{0}$$

First condition is valid up to translational motion while the second condition is up to rotational motion. Thus, for complete equilibrium both the first and second conditions of equilibrium must be satisfied by a body.

Q7. State and explain principle of moments with example.

Ans. Principle of Moments:

Statement:

For an object to be in equilibrium the sum of the clockwise torque taken about the pivot must be equal to the sum of anti – clock wise torque taken about the same pivot this principle is known as principle of moments.

i.e. sum of Anti clock wise Torque = Sum of Clock Wise Torque

$$\Sigma\, \tau_1 = \Sigma\, \tau_2$$

Second condition of equilibrium is also called principle of moments.

Examples:

In the given figure, a rod is balance about pivot. Here torque produced by "w1" and "w2" is anti-clockwise and torque produced by "w3" is clockwise.

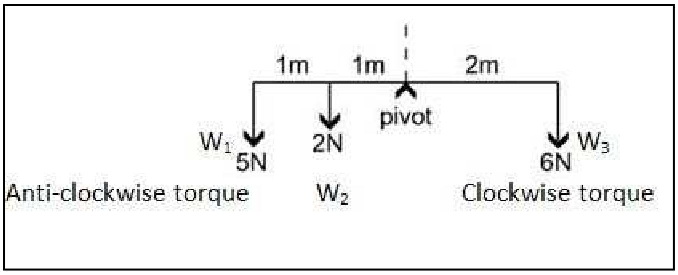
Mathematically

Clockwise torque = Anti-clockwise torque

$$\boldsymbol{\Sigma\, \tau_3 = \tau_1 + \Sigma\, \tau_2}$$

$$(6 \times 2) = (5 \times 2) + (2 \times 1)$$

$$12 = 12$$



Hence, there is only one clock wise moment about the turning point, but two anti-clock wise moments add up to balance it.

For second condition of equilibrium, the sum of all these torques must be zero.

$$\boldsymbol{\tau_1 + \Sigma\, \tau_2 + \tau_3 = 10\, Nm + 2Nm - 12Nm}$$

$$\boldsymbol{\tau_1 + \Sigma\, \tau_2 + \tau_3 = o\, Nm}$$

Q8. What is centre of mass Or centre of gravity Explain how CM/CG can be determined? Is there any difference between CM and CG?

Ans: <u>Centre of Mass (CM):</u>

The centre of mass of the body is the point about which mass is equally distributed in all direction. It is denoted by "CM".

The identification of this point is possible by applying a force at this point which will produce linear acceleration.

<u>Center of Gravity (CG):</u>

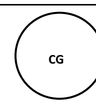
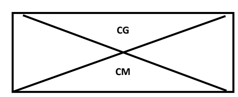
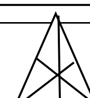
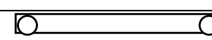
The Centre of gravity of the body is a point inside or outside a body at which whole weight of the body appears to act. It is denoted by "CG"

<u>Explanation:</u>

Everybody has a centre of mass (CM) where whole mass of a body is located and the CM is also the point at which the force of gravity is acting vertically downward i-e "CG". For most of the time, these two points are lie at the same position in an object.

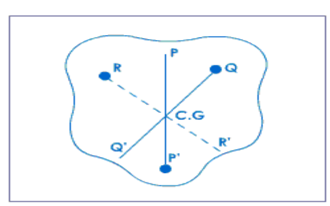
<u>Determination of CG and CM for regular shaped bodies:</u>

The centre of gravity "CG" and centre of mass "CM" of regular shaped bodies is located at the geometrical centre of the body. So the CG and CM of different symmetric bodies are shown in following table.

	Name of Object	**Position of CM& CG**	**Shapes of objects**
1	Circle	Centre of circle	
2	Square or Rectangular plate	Intersection of diagonals	
3	Triangular Plate	Intersection of medians	 CG & CM
4	Uniform rod	Centre of rod	 CG & CM

<u>Determination of CG and CM for irregular shaped bodies:</u>

The CG or CM of irregular shaped bodies can be determined with the help of plumb line. If we take an irregular shaped object and make up a plumb line, then suspend it randomly from at least three different points and trace the plumb lines location. So, the point of intersection of all three plumb lines is the CG or CM of an object.



Difference between CG and CM:

The CG is based on weight of a body where as the CM is based on mass of a body. Also, CG depends on the gravitational field whereas CM does not depend upon the gravitational field. So, when the gravitational field across an object is uniform, the centre of mass and centre of gravity are in exactly the same position. However, near the surface of earth or on the surface of earth, the gravitational force is uniform, therefore CM and CG are present at the same point inside or outside a body. However, when gravitational field is non – uniform, the CM and CG does not lie at same point in an object. The CG will move closer to regions of the object in a stronger gravitational field, where as CM is unmoved.

Q9. Explain the stability of the objects with reference to position of centre of mass.

Stability:

The stability of an object refers to the ability of an object to come back in its original position after removing the force which was applied for its disturbance.

Or

Stability is a measure of how hard it is to displace on object or system from equilibrium

Explanation:

The degree of stability depends on how the position of centre of mass (CM) or centre of gravity (CG) of an object change when disturbed by some external force and how much it has the tendency to come back to its original position.

States of Equilibrium:

On the basis of stability of an object, there are three states of equilibrium which are as follow

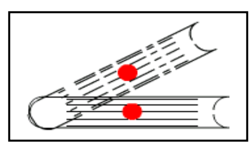
1. Stable Equilibrium
2. Unstable Equilibrium
3. Neutral Equilibrium

1. Stable Equilibrium:

When a body in equilibrium is slightly disturbed, its CM moves up and after removing external force, the CM of a body comes to its original position and regain its stability This state of equilibrium is called stable equilibrium.

Example:

It is observed that if a book lifted from its edge, the CM of the book raised and when released, it comes back to its original position because the vertical line of action of weight passing through CM of body still falls inside the base and the torque caused by the weight of the body brings back the body to its original position.



Book

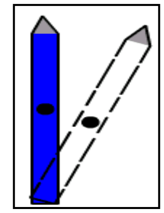
Other examples of stable equilibrium are table, chair, box and brick lying on the floor.

2. Unstable Equilibrium:

When a body in equilibrium is slightly disturbed and its CM moves down and cannot come back to its original position after removing external force. This state of equilibrium is called unstable equilibrium.

Example:

A pencil is made to stand on its tip in equilibrium state. If it is slightly disturbed from its position, its CM will lower and it will not come back to its original position. Because the vertical line of weight passing through CG/CM of the body falls outside the base of the body and the torque caused by weight of pencil topples it rather than bring it back to its original position.



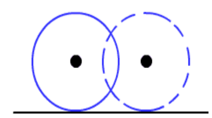
Other example of Unstable equilibrium are vertically standing cylinder cones and funnels etc.

3. Neutral Equilibrium:

When a body is slightly disturbed and its CM does not change from its original position. This state of equilibrium is called neutral equilibrium.

Example:

For example, when a ball is kicked to roll, its CM is neither raised nor lowered. This means the CM is at the same height as below and vertical line of action of weight always remain within the base of the body.



Topic Wise Questions

Q1. Explain the process of force for like and unlike parallel forces.

Ans. Addition of Forces:

Addition of forces is a process of obtaining a single force which produces the same effect as produced by a number of forces acting together

Addition of like parallel forces:

The addition of like parallel force can be done by adding the magnitudes of vectors.

For Example:

1. 5N → + 5N → = 10N →
2. 5N → + 10N → = 15N →

Where the length of arrow line shows the magnitude of force and the arrow head shows the direction of force.

Addition of Unlike Parallel Forces:

The addition of unlike parallel forces can be done by subtracting the magnitude of vectors.

For Example:

1. ↓ -5N ↑ +5N = 0N
2. ↓ -5N ↑ 10N = ↑ 5N
3. ↓ -10N ↑ 5N = ↓ -5N

By following these rules, we can add or subtract the parallel forces.

Q2. Define rotational motion and discuss the terms that cause the rotational motion in an object.

Ans. **Rotational Motion:**

Motion where all the points of an object moves about a single fixed axis is called rotational motion.

Examples:

The motion of a top, the wheel of a bicycle and car, the hands of clock and the blades of fan are the examples of rotational motion.

Terms that causes Rotational Motion:

There are the following terms that help to produce rotational motion in an object.

1. Rigid Objects
2. Axis of Rotation

1. Rigid Objects:

Rigid objects are objects of fixed form that do not distort or deform (change shape) as they move. For rotational motion, objects should be rigid because all particles are fixed and distance between particles does not change after applying an external force in rigid bodies.

2. Axis of Rotation:

Another term that causes rotational motion in an object is the axis of rotation. Axis of rotation is the line about which rotation takes place. This line remains at rest during rotational motion of the extended object while the other points of the body move in circles about this line. It may be a pivot, hinges or any other support around which all particles of an object can rotate.

Q3. Define the types of torque or Define the senses of rotation.

Ans. **Types of Torque:**

There are two types of torque which are as follow:

1. Clockwise torque
2. Anticlockwise torque

1. Clockwise torque:

If the object rotates in clockwise direction, the torque is known as clockwise torque. The clockwise torque is always taken negative.

2. Anti-Clockwise torque:

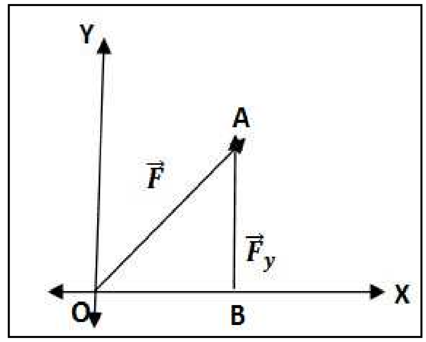
If the object rotates in anticlockwise direction, the torque is known as anticlockwise torque. The anticlockwise torque is always taken positive.

CONCEPTUAL QUESTIONS

Q1. Can the rectangular component of the vector be greater than vector itself? Explain

Ans. No, the magnitude of rectangular components cannot be greater than the magnitude of vector itself.

Reason:



In the given figure, "F_x" and "F_y" represents the rectangular components of a vector "F" which is given by:

$F_x = F\cos\theta$ ----(i)

And $F_y = F\sin\theta$ -----(ii)

As the values of sinθ and cosθ may be equal to "1" but cannot be greater than"1". So, according to eq (i) and (ii), "F_x" and "F_y" may be equal to "F" or will be less than "F" but cannot be greater than "F".

Q2. Explain why door handles are not put near hinges?

Ans. The door handles are not put near the hinges because in this way more turning effect is produced by applying less effort. As we know that torque depends upon force applied and moment arm. Greater is the moment arm, greater will be the torque produced by applying small force and the door will open easily.

Conversely by putting the door's handle near hinges, moment arm will be small and turning effect will be poor and the door will not open easily. That is why the handles are not put near the hinges.

Q3. Can a small force ever exert a greater torque than a larger force? Explain.

Ans. Yes, a small force can exert a greater torque than a larger force, if the small force has a large enough moment arm.

As we know that,

$\tau = \mathbf{F} \times \mathbf{d}$ -------(i)

Eq (i) clearly shows that torque depends on both applied force and moment arm. Moment arm also plays an important role in producing torque. If the moment arm at which small force is acting is greater than the moment arm at which large force is acting, then the torque produced by small force will be greater than the larger force.

For example,

Let $F_1 = 2N$ and $d_1 = 10m$

Then , $\tau_1 = F_1 \times d_1$

$\tau_1 = 2 \times 10$

$\tau_1 = 20\ Nm$

And

Let $F_2 = 5N$ and $d_2 = 2m$

Then, $\tau_2 = F_2 \times d_2$

$\tau_2 = 5 \times 2$

$\tau_2 = 10Nm$

It is clear from this example that $\tau_1 > \tau_2$. Thus, torque produced by smaller force is greater than larger force by taking large value of moment arm.

Q4. Why it is better to use a long spanner rather than a short one to loosen rusty nut?

Ans. As we know that torque depends upon force applied and moment arm. As torque is directly proportional to the moment arm which means greater is the moment arm, greater will be torque produced So, it is easier to loosen a rusty nut by using a long spanner rather than a short spanner because more turning effect is produced on the nut by increasing the moment arm with less effort.

Q5. The gravitational force acting on a satellite is always directed towards the center of the earth. Does this force exert torque on satellite?

Ans. The gravitational force is always directed towards the centre of the earth. In this situation, the line of gravitational force is passing through the centre of gravity of the satellite and the moment arm is equal to zero ($\theta=180^0$). Therefore, this force cannot exert torque on the satellite.

We can also prove it mathematically,

As we know that

$\boldsymbol{\tau = dF\sin\theta}$ ---------(i)

Here, the angle $\theta = 180^0$ between d and F. So, eq (i) becomes

$\tau = d\,F\sin 180^0$:. $\sin 180^0 = 0$

$\tau = dF(0)$

$\boldsymbol{\tau = 0}$

Hence, it shows that no torque is exerted on satellite by gravitational force.

Q6. Can we have situations in which an object is not in equilibrium, even though the net force on it is Zero? Give two examples.

Ans. As we know that for a complete equilibrium, the following two conditions must be satisfied i-e

(i) $\Sigma F = 0$

(ii) $\Sigma \tau = 0$

Now if ΣF is equal to zero but $\Sigma \tau$ is not equal to zero, then the body will rotate and will not be in state of complete equilibrium.

Example1:

When a steering wheel of a car is rotated with two equal and opposite forces, then it will not be in state of equilibrium. Here the net force is zero but the net torque is not zero. Hence, the wheel is not in state of equilibrium.

Exqample2:

When the pedals of a bicycle are rotated, the net force is equal to zero but the net torque exists in the system. Therefore, due to net torque, the pedals are not in state of equilibrium.

Q7. Why do tightrope walkers carry a long, narrow rod?

Ans: A tightrope walker uses long narrow rod for getting balanced condition and prevent himself from falling over the rope. For example, if the walker leans towards right and produces clockwise torque then he moves the rod in such a way to create anticlockwise torque. Both torques will cancel the effect of each other and thus, he will remain in state of equilibrium. The long and balancing rod also lowers the centre of gravity (CG) of walker which helps in maintaining the stability while walking over the tightrope

Q8. Why does wearing high – heeled shoes sometimes cause lower back pain?

Ans. Wearing high – heeled shoes causes lower back to arch more than normal because it pushes the body weight in the forward direction which exerts more pressure on the ball of the foot. So, the position of centre of gravity (CG) of a body is also shifts forward. As heel height increases, stability decreases. Now, to maintain the balanced condition, the body tries to change its positions and posture in order to oppose the forward push. In doing so, the back muscles become tense and over used and that can cause the lower back pain.

Q9. Why it is more difficult to lean backwards. Explain?

Ans: We know that the degree of stability of a body depends on how the position of centre of gravity (CG) changes when disturbed by applying force. So, when a person leans backward, the position of centre of gravity (CG) of the body changes in such a way that increase the instability. As a result, it becomes difficult for a body to remain in state of equilibrium. That's why it is more difficult to lean backward.

Q10. Can a single force applied to a body change both its translational and rotational motion Explain?

Ans. Yes, a single force applied to a body can change both its translational and rotational motion. As we know that a force applied at the centre of mass will cause translational motion and a torque will cause rotational motion. So, if the force is applied at the centre of mass of a body, it will perform translational motion only. But, if the force is applied at a point other than centre of mass (CM), the body will also rotate along with translational motion. For example, if a football is kick off, it will perform both translational and rotational motion because football will rotate as it moves forward.

Q11. Two forces produce the same torque Does it follow that they have the same magnitude? Explain Describe the path of the brick after you suddenly let go of the rope.

Ans. If two forces produce the same torque, then it does not necessary that they have the same magnitude. They may or may not have the same magnitude depending upon the values of both force and moment arm. Because torque depends upon forces as well as moment arm i .e $\tau = F \times d$.

Case1:

Let $F_1 = 5N$ and $d_1 = 1m$

then , $\tau_1 = F_1 \times d_1$

$\tau_1 = 5 \times 1$

$\tau_1 = 5$ Nm

And $F_2 = 5$ N and $d_2 = 1$ m

then , $\tau_2 = F_2 \times d_2$

$= 5 \times 1$

$= 5$ Nm

In case 1, we can get the same torque for two same forces by taking the same value of moment arm.

Case 2:

Let, $F_1 = 5N$ and $d_1 = 2m$

then, $\tau_1 = F_1 \times d_2$

$= 5 \times 2 \Rightarrow 10Nm$

and, $F_2 = 10N$ and $d_1 = 1m$

then, $\tau_2 = F_2 \times d_2$

$= 10 \times 1$

$= 10Nm$

In case 2, we can also get the same torque for two different forces by taking different values of moment arm.

CHAPTER: 04
NUMERICAL QUESTION

1. To open a door force of 15N is applied at 30^0 to the horizontal, find the horizontal and vertical components of force.

Data:

Force Applied = F = 15N

Angle = $\theta = 30^0$

Find:

(a) Horizontal component of force = F_x = ?

(b) Vertical Component of force = F_y = ?

Solution:

(a) For finding "Fx", we know that

$\mathbf{F_x = F\cos\theta}$

$F_x = F\cos 30^0$:. $\cos 30^0 = 0.866$

$F_x = 15 \times 0.866$

$F_x = 12.99N$

Or

$\mathbf{F_x = 13N}$

(b) For finding "Fy", we know that

$\mathbf{F_y = F\sin\theta}$

$Fy = 15 \sin 30^0$ $\quad$ $\therefore \sin 30^0 = 0.5$

$Fy = 15 \times 0.5$

$Fy = 7.5$ N

2. A bolt on a car engine needs to be tightened with a torque of 40Nm. you use a 25 cm long wrench and pull on the end of the wrench perpendicularly. How much force do you have to exert?

Data:

Torque = τ = 40Nm

Moment arm = d = 25cm

$d = \frac{25}{100}$

d = 0.25 m

Find:

Force Applied = F = ?

Solution:

As we know that

$\tau = F \times d$

Or

$$\mathbf{F} = \frac{\tau}{d}$$

Putting values

$$F = \frac{40}{0.25}$$

F = 160N

R.W

$\tau = F\times d$

$\frac{\tau}{d} = \frac{F\times d}{d}$

$\frac{\tau}{d} = F$

or $F = \frac{\tau}{d}$

3. Sana whose mass is 43 kg, sits 1.8m from the centre of a see saw. Faiz whose mass is 52 kg, wants to balance Sana. How far from the centre of see saw should Faiz sit?

Data:

Mass of Sana = m_1 = 43 kg

Sana's moment arm = d_1 = 1.8 m

Mass of Faiz = m_2 = 52 kg

Find:

Faiz's moment arm = d_2 = ?

Weight of Sana = W_1 = ?

Weight of Faiz = W_2 = ?

Solution:

For finding "W_1", using formula

$$\mathbf{W_1 = m_1 g}$$

$W_1 = 43 \times 9.8$

W_1 = 421.4N

For finding "W_2", using formula

$$\mathbf{W_2 = m_2 g}$$

$W_2 = 52 \times 9.8$

$W_2 = 509.6N$

Now, For finding "d_2" using the principle of moment.

Anticlockwise Torque= clockwise torque

$$\tau_1 = \tau_2$$

$$W_1 \times d_1 = W_2 \times d_2$$

$$\frac{W1 \times d1}{W_2} = \frac{\cancel{W2} \times d2}{\cancel{W_2}}$$

$$\frac{W1 \times d1}{W_2} = d_2$$

Or

$$\mathbf{d_2 = \frac{W1 \times d1}{W_2}}$$

$$d_2 = \frac{421.4 \times 1.8}{509.6}$$

$$d_2 = \frac{758.52}{509.6}$$

$$d_2 = 1.48m$$

or **$d_2 = 1.5m$**

Hence, Faiz should sit at a distance of 1.5 m from the centre of seesaw.

4. Two kids of weighing 300N and 350N are sitting at the ends of 6m long seesaw. The seesaw is pivoted at its centre. Where would a third kid sit so that the seesaw is in equilibrium in the horizontal position? The weight of 3rd kid is 250N (Ignore the weight of seesaw).

Data:

Weight of 1st Kid = W_1 = 300N

Moment arm of 1st Kid = d_1 = 3m

Weight of 2nd kid = d_1 = 350N

Moment arm of 2nd kid = d_2 = 3m

Weight of 3rd kid = w_3 = 250N

Find: Moment arm of 3rd kid = d_3 = ?

Solution:

For finding "d_3" using the principle of moment

Sum of anticlockwise torque = Sum of clockwise torque

$$\tau_1 + \tau_3 = \tau_2$$

$$W_1 \times d_1 + W_3 \times d_3 = W_2 \times d_2$$

Subtract "$W_1 \times d_1$" on both sides

$$\cancel{W_1 \times d_1} - \cancel{W_1 \times d_1} + W_3 \times d_3 = W_2 \times d_2 - W_1 \times d_1$$

$$W_3 \times d_3 = W_2 \times d_2 - W_1 \times d_1$$

Divide "W_3" on both sides

$$\frac{\cancel{W_3} \times d_3}{\cancel{W_3}} = \frac{W_2 \times d_2 - W1 \times d1}{W_3}$$

$$d_3 = \frac{W_2 \times d_2 - W_1 \times d_1}{W_3}$$

By putting values

$$d_3 = \frac{350 \times 3 - 300 \times 3}{250}$$

$$d_3 = \frac{1050 - 900}{250}$$

$$d_3 = \frac{150}{250}$$

$$\mathbf{d_3 = 0.6m}$$

5. Two children push on opposite sides of a door during play. Both push horizontally and perpendicular to the door. One child pushes with a force of 20N at a distance of 0.60m from the hinges, and the second child pushes at a distance of 0.50m. What force must the second child exert to keep the door from moving? Assume friction is negligible.

Data:

Force of 1st child = F_1 = 20N

Moment arm of 1st child = d_1 = 0.60m

Moment arm of 2nd child = d_2 = 0.50m

Find:

Force of 2nd child = F_2 = ?

Solution:

By using formula

$$\tau_1 = \tau_2$$

$$F_1 \times d_1 = F_2 \times d_2$$

Divide "d_2" on both sides

$$\frac{F_1 \times d_1}{d_2} = \frac{F_2 \times \cancel{d_2}}{\cancel{d_2}}$$

$$\frac{F_1 \times d_1}{d_2} = F_2$$

Or

$$\mathbf{F_2 = \frac{F_1 \times d_1}{d_2}}$$

Putting value

$$F_2 = \frac{20 \times 0.60}{0.50}$$

$$F_2 = \frac{12}{0.50}$$

$$\mathbf{F_2 = 24N}$$

6. A construction crane lifts building material of mass 1500 kg by moving its crane arm, calculate moment of force when moment arm is 20m. After lifting the crane arm, which reduces moment arm to 12 m, calculate moment.

Data:

Mass = m = 1500kg

Moment arm = d = 20 m

Find:

Torque = τ = ?

Solution:

Using formula

$$\tau = F \times d \text{ --------(i)}$$

As we know that

$F = W$:. $W = mg$

$F = mg$

Putting values

$F = 1500 \times 9.8$

$\mathbf{F = 14700\ N}$

Now, putting the value of "F" in eq (i)

$\tau = F \times d$

$\tau = 14700 \times 20$

$\mathbf{\tau = 294000\ Nm}$

Data:

Force = F = 14700 N

Moment arm = d = 12m

Find:

Torque = τ = ?

Solution:

As we know that

$\tau = F \times d$

$\tau = 14700 \times 12$

$\mathbf{\tau = 176{,}400\ N}$

Assignments

4.1 Two force are applied one force is 25 N (20^0 with x – axis) and the other force is 10N (60^0 with x-axis). Find the net resultant force.

Data:

Force = F_1 = 25 N

Angle 1 = $\theta_1 = 20^0$ with x – axis

Force 2 = F_2 = 10N

Angle 2 = $\theta_2 = 60^0$ with x-axis

Find:

Resultant Force = F_R = ?

Solution:

1st we select a suitable scale

Let 5N = 1cm

Then, F_1 = 25N = 5cm
And, F_2 = 10N = 2cm

Now, for finding the resultant, we add $\vec{F}_2$ with $\vec{F}_1$ by head to tail rule.

Finally, we combine the tail of $\vec{F}_1$ with the head of $\vec{F}_2$ which gives us the resultant force "F_R" .

Thus, $\overrightarrow{OB}$ = F represents the resultant force. Now, by measuring the length of vector "F_R" by meter rod, we get,

$$\mathbf{F_R = 6cm}$$

Now, according to given scale, 6cm will be equal to 30N. i-e, $6 \times 5 = 30N$

So, the magnitude of resultant force "F_R" = 30N And to measure the angle "θ" with protector i-e 30^0 with x-axis.

Hence,

$$\mathbf{F_R = 30N,\ \theta = 30^0 \text{ with x-axis}}$$

4.2 While tilling your garden, you exert a force on the handles of the tiller that has components Fx = 85 N and F_y = 13N. The x-axis is horizontal and y-axis points up. What are the magnitude and direction of this force?

Data:

Horizontal component of force = Fx = 85N

Vertical components of force = Fy = 13N

Find:

Magnitude of force = F = ?

Direction of force = θ = ?

Solution:

For finding the "F", using formula

$$\mathbf{F} = \sqrt{F_x^2 + F_y^2}$$

$$F = \sqrt{(85)^2 + (13)^2}$$

$$F = \sqrt{7225 + 169}$$

$$F = \sqrt{7394}$$

$$F = 85.9N$$

Or F = 86N

Now, for finding direction "θ", using formula

$$\theta = \tan^{-1} \frac{Fy}{Fx}$$

$$\theta = \tan^{-1} \frac{13}{85}$$

$$\theta = \tan^{-1} 0.1529$$

$$\theta = 8.695^0$$

Or $\mathbf{\theta = 8.7^0}$

4.3 20Nm torque is required to open a soda bottle. A boy with a bottle opener apply a force perpendicularly at 0.1m, what is the magnitude of force required.

Data:

Torque = τ = 20Nm

Moment arm = d = 0.1m

Find:

Force applied = F=?

Solution:

As we know that

$$\tau = F \times d$$

Or

$$\mathbf{F = \frac{\tau}{d}}$$

$$F = \frac{20}{0.1}$$

$$\mathbf{F = 200N}$$

4.4 With a beam two masses m_1 and m_2 are suspended at distance 0.4m and 0.5m respectively from suspension point as shown in figure. Ignoring the weight of the balance, if m_2 = 1.6kg, what is the mass m_1?

Data:

Moment arm at left = d_1 = 0.4m

Moment arm at right = d_2= 0.5m

Mass at right =m_2 = 1.6kg

Find:

Mass at left = m_1 = ?

Weight at right = W_2 = ?

Weight at left = W_1 = ?

Solution:

As we know that

$$\mathbf{W_2 = m_2 g}$$

$$W_2 = 1.6 \times 9.8$$

$$\mathbf{W_2 = 15.68N}$$

For finding W1, using formula of principle of moment

$$\mathbf{\tau_1 = \tau_2}$$

$$W_1 \times d_1 = W_2 \times d_2$$

Divide "d_1" on the both sides

$$\frac{W_1 \times \cancel{d_1}}{\cancel{d_1}} = \frac{W_2 \times d_2}{d_1}$$

$$W_1 = \frac{W2 \times d2}{d_1}$$

$$W_1 = \frac{15.68 \times 0.5}{0.4}$$

$$\mathbf{W_1 = 19.6N}$$

Now, for finding "m_1" we know that

$$W_1 = m_1 g$$

Or

$$\mathbf{m_1 = \frac{W_1}{g}}$$

$$m_1 = \frac{19.6}{9.8}$$

$$\mathbf{m_1 = 2kg}$$

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PHYSICS

Class 9th (KPK)

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Gravitation

COMPREHENSIVE QUESTIONS:

1. State and explain the law of universal Gravitation. Also show that the law obeys Newton's third law of motion.

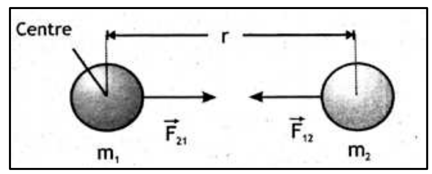
Ans. Law of universal Gravitation:

Statement:

Everybody in the universe attracts every other body with a force which is directly proportional to the product of their masses and inversely proportional to the square of the distance between their centers.

Derivation:

Consider two spherical bodies of masses 'm_1' and 'm_2' separated by distance 'r' as shown in fig.



According to the Newton's law of universal gravitation, the force of gravity 'Fg' between them is:

$$F_g \propto m_1 m_2 \quad \text{---------(i)}$$

And $$F_g \propto \frac{1}{r^2} \quad \text{----------(ii)}$$

Combining eq(i) and (ii), we get

$$F_g \propto \frac{m_1 m_2}{r2}$$

$$F_g = \frac{Gm_1 m_2}{r2}$$

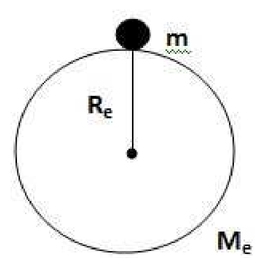
Where 'G' is the constant of proportionality and is known as universal gravitational constant. The value of 'G' is 6.67×10^{-11} Nm^2 kg^{-2}. It does not depend on the medium between the two bodies.

Newton's third law of motion and universal gravitation:

The law of universal gravitation also obeys the Newton's third law of motion. We can see that the force acting on mass 'm_2' due to mass m_1 is F_{12}. Also the force acting on mass m_1 due to mass "m_2" is same force 'F_{21}', Both these forces are equal but opposite in direction. Therefore, we can say that the forces acting on two bodies due to gravitation force is the example of action and reaction i-e

$$F_{12} = - F_{21}$$

2. Determine the mass of earth by applying the law of gravitation.



Ans. Determination of Mass of Earth:

The mass of the earth can be determined with the help of law of universal gravitation. Let an object of mass 'm_0' be placed on the surface of the earth. The distance between the centre of the body and the earth is equal to the radius of earth 'r_E'. If the mass of earth is 'm_E' then the force 'F_g'

with which the earth attracts the body towards its centre is given by law of gravitation.

$$\mathbf{F_g = G\frac{m_o m_E}{r_E^2}}$$

Also, we know that force of gravity (F_g) is equal to the weight of the body (W). i-e

$$F_g = W$$

So,

$$W = G\frac{m_o m_E}{r_E 2}$$

We know that $W = m_o g$

$$m_o g = G\frac{m_0 m_E}{r_E 2}$$

$$g = G\frac{m_E}{r_E 2}$$

By cross Multiplication, we get

$$Gm_E = gr_E^2$$

Divide 'G' on both sides,

$$\frac{Gm_E}{G} = \frac{gr_E^2}{G}$$

$$\boldsymbol{m_E = \frac{gr_E^2}{G}} \text{ ------ (i)}$$

By putting the values of g, r_E^2 and G in eq (i) we will obtain value of m_E.

Gravitational constant = G= 6.67×10^{-11} $Nm^2\ kg^{-2}$

Acceleration due to gravity = g = 9.8 ms^{-2}

And, radius of earth $r_E = 6.4 \times 10^6 m$

Now,

$$m_E = \frac{9.8 \times (6.4 \times 10^6)^2}{6.67 \times 10^{-11}}$$

$$m_E = \frac{9.8 \times 40.96 \times 10^{12}}{6.67 \times 10^{-11}}$$

$$m_E = \frac{401.40 \times 10^{12}}{6.67 \times 10^{-11}}$$

$$m_E = \frac{401.40 \times 10^{12} \times 10^{11}}{6.67}$$

$$m_E = 60.18 \times 10^{12+11}$$

$$m_E = 60.18 \times 10^{23}$$

$$m_E = 6.018 \times 10^{23+1}$$

$$\boldsymbol{m_E = 6 \times 10^{24}\ Kg}$$

Thus, the mass of earth is approximately 6×10^{24}kg.

3. What is gravitational field and gravitational field strength Show that weight of an object changes with location.

Ans. <u>Gravitational Field (Gravity as a field force):</u>

Gravitational field is region surrounding the earth in which another object feels force of attraction toward its centre According to the field theory; every mass creates a gravitational field composed of field lines that permeates outward into space. The earth creates a gravitational field that pulls objects towards its centre by force of gravity. At any point, earth's gravitational Field can be described by the gravitational field strength (g).

The gravitational field or gravitational field strength is defined as a measure of gravitational force (F_g) exerted on a per unit mass (m) of an object.

Mathematical Form:

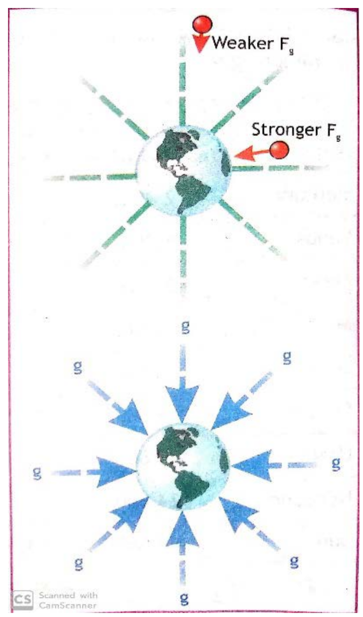
$$\text{Gravitational Field} = \frac{Gravitational\ force}{unit\ mass}$$

Or

$$g = \frac{\boldsymbol{F_g}}{\boldsymbol{m}}$$

Quantity and Unit:

The gravitational field (g) is a vector quantity and its unit is Newton per kilogram i-e Nkg^{-1}



Gravitational Field strength:

The gravitational field strength tells us how strong a gravitational field is. The gravitational field is represented by field lines as shown in figure, which shows the strength of gravitational field decreases, as the distance from the earth increase. The gravitational field strength of earth near its surface is equal to the acceleration of free fall (g) at its surface i-e $g = 9.8\ ms^{-2}$

According to Newton's second law, a = F/m. As gravitational field strength (g) is defined as $\frac{F_g}{m}$, so the value of 'g'at any given point is equal to the acceleration due to gravity. For this reason, the gravitational field strength is 9.8 Nkg^{-1} means 9.8N force is exerted on every 1 kg mass of an object. Therefore, the acceleration is same for any object, regardless of mass.

Weight changes with location:

As we know that weight is the magnitude of force due to gravity i-e $W = m_o g$. Now we can refine our definition of weight as mass time gravitational field strength this new definition helps to explain why our weight changes with our location in the universe by calculating the value of g i-e.

$$\mathbf{g} = \frac{\boldsymbol{Gm_E}}{\boldsymbol{r_E^2}}$$

This equation shows that gravitational field strength depends only on mass of earth 'm_E' and radius of earth 'r_E'. Greater will be the value of 'g' if lesser the distance from earth's centre. Therefore, on the surface of any planet, the value of earth's centre varies as we change location. 'g' as well as our weight will depends on the planet's mass and radius.

4.How is the Value of 'g' changing by going to higher altitude? Write the relevant formula.

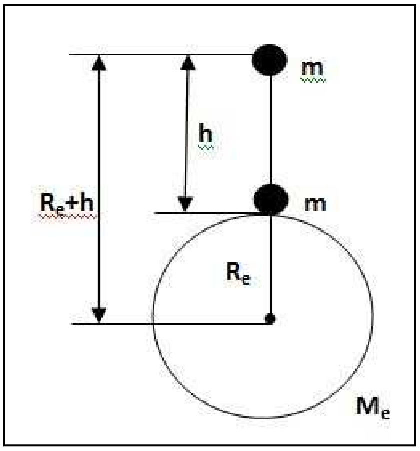
Ans. <u>Variation of 'g' with altitude:</u>

The value of 'g' doesn't depend upon the mass of the body. It means that light and heavy bodies should fall towards the centre of earth with constant acceleration. However, the value of 'g' depends upon the distance of the body from the centre of the earth. Greater the distance from the centre of the earth, smaller will be the value of 'g'. That is why the value of 'g' at the poles is greater than at equator because earth is not a perfect square; its equatorial radius is greater than the radius at the poles.

<u>Derivation:</u>

Consider a body of mass 'm_o' placed on earth's surface, as shown in the figure, now we know that law of universal gravitation is given by.

$$F_g = G\frac{m_o m_E}{r_E^2}$$



As,

$F_g = W = m_0 g$

So, $$m_0 g = G\frac{m_o m_E}{r_E^2}$$

$$g = G\frac{m_E}{r_E^2} \;\ldots\ldots\ldots\ldots (i)$$

If we lift the body to a height "h", then the value of "g" at the height is given by

$$g = G\frac{M_e}{(R_e+h)^2}$$

From equ(i), $Gm_E = gr_E^2$

So,

$$g = G\frac{gr_E^2}{(R_e+h)^2} \;\ldots\ldots\ldots\ldots \text{equ(ii)}$$

Both eq (i) and (ii) shows that 'g' is inversely proportional to the square of distance of the body from the earth centre. Thus, the value of 'g' decreases with altitude (height).

5.Derive the formula for the orbital speed of an artificial satellite.

Ans: <u>Satellites:</u>

Satellites are the objects revolving around the planet in fixed orbits. Artificial satellites are man-made objects that revolve around the earth or other planets in different orbit with uniform speed due to gravitational force.

A satellite requires a centripetal force (F_c) to revolve around the earth and this necessary centripetal force is provided by the gravitational force of attraction between the earth and satellite.

Derivation:

Consider a satellite of mass 'm_s' revolving in a circular orbit with uniform velocity 'v' from earth of mass 'm_E' Let 'r' be the distance between the centre of earth and centre of satellite as shown in figure.

Now, the gravitational force by Newton's law of universal gravitation is:

$$\mathbf{F_g}=\frac{\boldsymbol{Gm_E m_S}}{\boldsymbol{r^2}} \quad \text{.........eq (i)}$$

The necessary centripetal force 'Fc' required for uniform circular motion is given by:

$$F_c=\frac{m_s v^2}{r} \quad \text{.........eq (ii)}$$

As Centripetal force is provided by gravitational force, therefore

$$F_c = F_g \quad \text{.........eq (iii)}$$

Now, putting the value of F_g and F_c in eq (iii),
We get

$$\frac{m_s v^2}{r} = \frac{G m_s m_E}{r^2}$$

$$v^2 = \frac{G m_E}{r}$$

Taking square root on both sides

$$\sqrt{v^2} = \sqrt{\frac{G m_E}{r}}$$

$$v = \sqrt{\frac{G m_E}{r}}$$

Where $r = r_E + h$, so

$$\boldsymbol{v} = \sqrt{\frac{\boldsymbol{G m_E}}{\boldsymbol{r_E + h}}}$$

This equation represents the orbital speed of satellite where h is the height of satellite from surface of earth and 'r_E'is the radius of earth. So, the orbital of satellite speed depends upon the mass of earth and the distance from the centre of the earth to the centre of mass of the satellite and doesn't depend upon mass of satellite.

Topic Wise Question

7. Derive a formula to calculate the value of g.

Value of g:

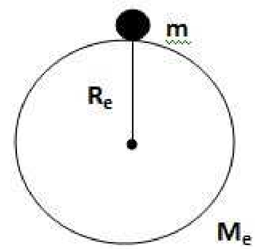
The Newton's law of Universal gravitation shows that value of g depends on mass of all reacting bodies and distance to it. So the value of 'g' can be determined by using law of gravitation.

Consider an object of mass 'm_o' placed on the surface of earth and r_E is the distance between their centers as shown in figure The gravitational force between the object and earth is as follow.

$$F_g = G\frac{m_o m_E}{r_E^2} \text{ ---------- (i)}$$

As, we know that

$$F_g = W = m_o g \text{ ----------- (ii)}$$



Comparing eq (i) and (ii)

$$m_o g = G\frac{m_o m_E}{r_E^2}$$

$$\mathbf{g = G\frac{m_E}{r_E^2}}$$

By putting the values of G, m_E & r_E, we will obtain the value of g

As,

$m_E = 6 \times 10^{24}$ kg

$r_E = 6.4 \times 10^6$ m

$G = 6.67 \times 10^{-11}$ Nm^2 kg^{-2}

$$g = \frac{6.67 \times 10^{-11} \times 6 \times 10^{24}}{(6.4 \times 10^6)^2}$$

$$g = \frac{40.02 \times 10^{-11+24}}{40.96 \times 10^{12}}$$

$$g = \frac{40.02 \times 10^{13}}{40.96 \times 10^{12}}$$

$$g = \frac{40.02 \times 10^{13} \times 10^{-12}}{40.96}$$

$g = 0.977 \times 10^1$

$g = 9.77 \times 10^{1-1}$

$g = 9.77 \times 10^0$ (..10^0=1)

$g = 9.77$

or

$\mathbf{g = 9.8ms^{-2}}$

This is value of 'g' at the surface of earth.

CONCEPTUAL QUESTIONS:

Q1. If there is an attractive force between all objects, why don't we feel ourselves gravitating toward nearby massive buildings?

Ans. Gravitational force pulls us to massive buildings but the forces are relatively small due to the small masses of us and buildings when compared to the mass of the earth. Therefore, the attractive force would be almost unnoticeable.

Q2. Does the sun exert a larger force on the Earth than that exerted on the sun by the earth? Explain.

Ans. By Newton's third law, the force exerted on the Sun by the Earth is exactly equal to the force the Sun exerts on the Earth but in opposite direction.

Q3. What is the importance of gravitational constant 'G'? Why is it difficult to calculate?

Ans. Constant always play an important in bringing the equality in the dimensions on both sides of an equation and its value depends upon the factors relating the interaction between the two bodies similar is the case with gravitational constant 'G' here it maintains the equality on both sides of the universal gravitational law's equation. It's difficult to calculate it because there's no theoretical derivation to it is just an experimentally measured value.

Q4. If Earth somehow expanded to a larger radius, with no charge in mass, how would your weight be affected? How would it be affected if earth instead shrunk?

Ans: According to law of universal Gravitation

$$F = \frac{Gmm_E}{r_E^2} \quad \text{------------ (i)}$$

As we know that

F=W=mg

So eq (i) becomes

$$mg = \frac{Gmm_E}{r_E^2}$$

$$g = \frac{Gm_E}{r_E^2} \quad \text{------------ (ii)}$$

From eq (ii), we say that force of gravity is inversely proportional to the radius of earth. So if radius of Earth gets larger weight would get smaller. If the earth shrunk, the radius of earth decreases and as a result weight gets increases.

Q5. What would happen to your weight on earth if the mass of the earth doubled but its radius stayed the same?

Ans: As we know that

$$g = \frac{Gm_E}{r_E^2} \quad \text{------------ (i)}$$

Above eq (i) shows that value of 'g' depends on mass of earth 'm_E' and radius of earth 'r_E'. If we only double the mass of earth the value of 'g' becomes double and weight depends on the value of 'g'. i.e.

W= mg ------------ (ii)

Eq (ii) shows that if value of 'g' is doubled, the weight will also double.

Q6. Why lighter and heavier objects fall at the same rate toward the earth?

Ans: Because value of 'g' does not depend upon the mass of the body, it depends only on mass of earth and radius of earth. Therefore, lighter and heavier bodies fall towards earth with same acceleration.

Q7. The value of 'g' changes with location on earth, however we take the same value of 'g' as 9.8ms^{-2} for ordinary calculations why?

Ans: The value of 'g' depends upon the distance from the centre of earth. Greater the distance from the centre of earth, smaller will be the value of 'g' and vice versa. The change in the value of 'g' is significant only at very large distance. Therefore, we take same value of 'g' for ordinary calculation.

Q8. Moon is attracted by the earth, why it does not fall on earth?

Ans: The moon is natural satellite of the earth. It revolves around the earth in a specific orbit. The earth attracts the moon towards itself with gravitational force. The gravitational force of earth provides necessarily centripetal force which compels the moon to move in the circular path. Because of this orbital motion moon does not fall on earth.

Q9. Why for some height larger and smaller satellites must have same orbital speeds?

The orbital speed depends upon the mass of earth and distance from the centre of earth to the centre of mass of satellite and does not depend upon the mass of satellite. Therefore, for some particular distance from the centre of earth, all the satellites have the same orbital speed irrespective of the size of satellite.

Chapter No 05
Assignments

5.1 The mass of earth is 6×10^{24} kg and that of the moon is 7.4×10^{22} kg. If the distance between the earth and the moon is 3.84×10^5 km, calculate the force exerted by the earth on the moon,

Data:

Mass of earth = m_1 = 6×10^{24} kg

Mass of moon = m_2 = 7.4×10^{22} kg

Distance = r = $3.84 \times 10^5 km$

= $3.84 \times 10^5 \times 10^3$m

= 3.84×10^8cm

Gravitational constant = G = $6.67 \times 10^{-11} Nm^2 kg^{-2}$

Gravitational force = F_g = ?

Solution:

By using formula

$$\mathbf{F_g = G\frac{m_1 m_2}{r^2}}$$

Putting Values

$$= \frac{6.67\times10^{-11}\times6\times10^{24}\times7.4\times10^{22}}{(3.84\times10^{8})^2}$$

$$= \frac{6.67\times6\times7.4\times10^{-11+24+22}}{14.7456\times10^{16}}$$

$$= \frac{296.148\times10^{35}}{14.7456\times10^{16}}$$

$$= 20.083\times10^{35-16}$$

$$= 20.083\times10^{19}\ \text{N}$$

$F_g = 2.008\times10^{20}$N

F_g = $\mathbf{2\times10^{20}}$N

5.2 If the radius of the moon is 1.74×10^{6} m and have acceleration due to gravity on its surface as $1.6ms^{-2}$. Calculate the mass of moon.

Data:

Radius of Moon = r = 1.74×10^{6} m

Acceleration due to gravity on moon = g = $1.6ms^{-2}$

Gravitational constant = G = 6.67×10^{-11} N$m^2\ kg^{-2}$

Find: Mass of moon = m = ?

Solution:

By using formula

$$\mathbf{m = \frac{gr^2}{G}}$$

Putting Values

$$= \frac{1.6\times(1.74\times10^{6})^2}{6.67\times10^{-11}}$$

$$= \frac{1.6\times3.027\times10^{12}}{6.67\times10^{-11}}$$

$$= \frac{4.843\times10^{12}}{6.67\times10^{-11}}$$

$$= 0.726\times10^{12+11}$$

$$= 0.73\times10^{23}\ \text{kg}$$

m = $\mathbf{7.3\times10^{22}}$ kg

5.3 An astronaut of mass 65.0 kg (weighting 637N on earth) is walking on the surface of the moon, which has a mean radius of 1.74 $\times 10^6$m and a mass of 7.35 $\times 10^{22}$kg. What is the weight of the astronaut on moon? What is the free – fall acceleration at the surface of the moon?

Data:

mass of astronaut = m = 65kg

Radius of moon = r_M = 1.74×10^6m

Mass of moon = $m_M = 7.35 \times 10^{22}$ kg

Gravitational constant = G = 6.67×10^{-11} Nm^2kg^{-2}

Find:

Weight of astronaut = W= ?

Free – fall acceleration on moon = g_M= ?

Solution:

By Using Formula

$$g = \frac{Gm_M}{r_M^2}$$

Putting values

$$= \frac{6.67 \times 10^{-11} \times 7.35 \times 10^{22}}{(1.74\times10^6)^2}$$

$$= \frac{6.67 \times 7.35 \times 10^{-11+22}}{3.027\times10^{12}}$$

$$= \frac{49.02 \times 10^{11}}{3.027\times10^{12}}$$

$$= 16.19 \times 10^{11-12}$$

$= 16.19 \times 10^{-1}$ m/s^2

$= 16.2 \times 10^{-1}$ m/s^2

g = 1.62 m/s^2

Now we find weight of Astronaut

As we know that

W = mg

Putting values

= 65 $\times$ 1.62 N

= 105.3 N

W = 105 N

5.4 Calculate the value of 'g' at 1000 km and 35900 km above the earth surface

i. Calculate value of 'g' at 1000 km.

Data:

Radius of earth = $r_E = 6.4 \times 10^6$m

Acceleration due to gravity = g= $9.8 ms^{-2}$

Height above earth surface = h= 1000km

$= 1000 \times 10^3 m$

$= 10^3 \times 10^3$m

$= 10^{3+3}$m

$= 1\times10^6$m

FIND:

Value of 'g' at height h = g_h =?

SOLUTION:

By using formula

$$g_h = \frac{g r_E^2}{(r_E+h)^2}$$

Putting Values

$$= \frac{9.8\times(6.4\times10^6)^2}{(6.4\times10^6 + 1\times10^6)^2}$$

$$= \frac{9.8\times40.96\times10^{12}}{(7.4\times10^6)^2}$$

$$= \frac{401.408\times10^{12}}{54.76\times10^{12}}$$

$= 7.33 \times10^{12-12}$ m/s^2

g_h = 7.33 m/s^2

ii. Calculate value of 'g' at 35900 km

Data:

Radius of earth = r_E= 6.4×10^6m

Acceleration due to gravity = g = 9.8 ms^{-2}

Height above earth surface = h = 35900 km

$= 35900 \times 10^3$m

$=35.9\times10^3 \times10^3$m

$= 35.9 \times10^6$m

FIND:

Value of 'g' at height h = g_h= ?

SOLUTION:

By using formula

$$g_h = \frac{g r_E^2}{(r_E+h)^2}$$

Putting Values

=

$\boldsymbol{g_h}$**= 0.22 m/s^2**

5.5 If a satellite orbits the earth at 2,000 km above sea level, how fast must the orbiting satellite travel to maintain a circular orbit?

Data:

Height of satellite above earth surface = h = 2000 km

$= 2000\times10^3$m

$= 2.0 \times 10^3 \times10^3$m

= 2 $\times 10^6$m

Mass of Earth = $m_E = 6 \times10^{24}$kg

Radius of Earth = r_E= 6.4×10^6m

Gravitational constant = G = 6.67×10^{-11}Nm^2kg^2

Find: Orbital Speed = v = ?

Solution:

By using formula

$$\mathbf{v} = \sqrt{\frac{Gm_E}{r_E+h}}$$

$$= \sqrt{\frac{6.67\times10^{-11}\times6\times10^{24}}{6.4\times10^6+2\times10^6}}$$

$$= \sqrt{\frac{40.02\times10^{-11+24}}{8.4\times10^6}}$$

$$= \sqrt{\frac{40.02\times10^{13}}{8.4\times10^6}}$$

$$= \sqrt{4.76} \times 10^{13-6}$$

$$= \sqrt{4.76} \times 10^7$$

$$= \sqrt{47.6} \times 10^6$$

$$= 6.899 \times 10^3\text{m/s}$$

v = 6.899 x 10³ m/s

Numericals

1.Pluto's moon Charon is unusually large considering Pluto's size, giving them the character of a double planet. Their masses are 1.25 × 10^{22}kg and 1.9 ×10^{21}kg, and their average distance from one another is 1.96 × 10^4km. What is the gravitational force between them?

Data:

Mass of Pluto's Moon= $m_1 = 1.25\times10^{22}$kg

Mass of Pluto's = $m_2 = 1.9\times10^{21}$kg

Distance between Pluto's and Pluto's Moon = r = 1.96×10^4km

$= 1.96 \times 10^4 \times 10^3$m

$= 1.96 \times10^{4+3}$m

$= 1.96 \times 10^7$m

Gravitational constant = G = $6.67 \times 10^{-11} Nm^2 kg^{-2}$

FIND:

Gravitational force = F_g = ?

Solution:

$$F_g = G\frac{m_1 m_2}{r^2}$$

$$= \frac{6.67\times10^{-11}(1.25\times10^{22})(1.9\times10^{21})}{(1.96\times10^{7})^2}$$

$$= \frac{6.67\times1.25\times1.9\times10^{-11+22+21}}{3.84\times10^{14}}$$

$$= \frac{15.84\times10^{32}}{3.84\times10^{14}}$$

$$= 4.12 \times 10^{32-14} N$$

$$F_g = 4.12 \times 10^{18} N$$

2.The mass of Mars is 6.4×10^{23}kg and having radius of 3.4×10^6m. Calculate the gravitational field strength (g) on Mars surface.

Data:

Mass of Mars = $m_M = 6.4 \times 10^{23}$kg

Radius of Mars = $r_M = 3.4\times10^6$m

Gravitational constant = G = 6.67×10^{-11} $Nm^2 kg^{-2}$

Gravitational strength on Mars = g_M = ?

Solution:

By using formula

$$g_M = \frac{Gm_M}{r_M^2}$$

$$= \frac{6.67\times10^{-11}\times6.4\times10^{23}}{(3.4\times10^6)^2}$$

$$= \frac{6.67\times6.4\times10^{-11+23}}{11.56\times10^{12}}$$

$$= \frac{42.68\times10^{12}}{11.56\times10^{12}}$$

$$= 3.69\times10^{12-12}\ m/s^2$$

$$g_m = 3.69\ m/s^2$$

3.Titan is the largest moon of Saturn and the only moon in the solar system known to have a substantial atmosphere. Find the acceleration due to gravity on Titan's surface, given that its mass is 1.35×10^{18} and its radius is 2570km.

DATA:

Mass of Titan = $m_T = 1.35\times10^{18}$kg

Radius of Titan = r_T = 2570km

$= 2570 \times 10^3$m

$= 2.57 \times 10^3 \times 10^3$ m

$= 2.57 \times 10^6$ m

Gravitational constant = G = 6.67×10^{-11} Nm^2kg^{-2}

FIND:

Gravity on Titan's surface = g_T = ?

SOLUTION:

By using Formula

$$g_T = \frac{Gm_T}{r_T^2}$$

$$= \frac{6.67\times10^{-11}\times1.35\times10^{18}}{(2.57\times10^6)^2}$$

$$= \frac{6.67\times1.35\times10^{-11+18}}{6.6049\times10^{12}}$$

$$= \frac{9.0045\times10^7}{6.6049\times10^{12}}$$

$$g_T = 1.36 \times10^{7-12}\ m/s^2$$

$$\mathbf{g_T = 1.36 \times 10^{-5}\ m/s^2}$$

4.At which altitude above Earth's surface would the gravitational acceleration be 4.9m/s²

Data:

Gravitational acceleration at height = g_h= $4.9m/s^2$

Acceleration due to gravity = g = $9.8m/s^2$

Radius of Earth = r_E= 6.4×10^6m

Find:

Altitude above earth's Surface = h = ?

Solution:

By Using Formula

$$g_h = \frac{g\, r_E^2}{(r_E+h)^2}$$

Rearrange the formula

$$(r_E+h)^2 = \frac{gr_E^2}{g_h}$$

$$r_E + h = \sqrt{\frac{gr_E^2}{g_h}}$$

$$\mathbf{h = \sqrt{\frac{gr_E^2}{g_h}} - r_E}$$

Putting Value

$$= \sqrt{\frac{9.8\times(6.4\times10^6)^2}{4.9}} - 6.4\times10^6$$

$$= \sqrt{\frac{9.8\times40.96\times10^{12}}{4.9}} - 6.4\times10^6$$

$$= \sqrt{\frac{401.408\times10^{12}}{4.9}} - 6.4\times10^6$$

$= \sqrt{81.92 \times 10^{12}} - 6.4 \times 10^6$

$= 9.05 \times 10^6 - 6.4 \times 10^6$

$= (9.05 - 6.4) \times 10^6$

h $= 2.65 \times 10^6$ m

or

h $= 2.6 \times 10^6$ m

5.Assume that a satellite orbits Earth 225km above its surface. Given that the mass of Earth is 6×10^{24} kg and the radius of Earth is $6.4 \times 10^6 m$, What is the satellite's orbital speed?

Data:

Height above earth surface=h=225km

$= 225 \times 10^3$m

$= 0.225 \times 10^3 \times 10^3$m

$= 0.255 \times 10^6$m

Mass of Earth = $m_E = 6 \times 10^{24}$kg

Radius of Earth = $r_E = 6.4 \times 10^6$m

Gravitational Constant = G = 6.67×10^{-11} Nm^2 kg^{-2}

Find:

Satellite's orbital speed =v=?

Solution:

By using formula

$$v = \sqrt{\frac{Gm_E}{r_E + h}}$$

Putting values

$$v = \sqrt{\frac{6.67 \times 10^{-11} \times 6 \times 10^{24}}{6.4 \times 10^6 + 0.225 \times 10^6}}$$

$$v = \sqrt{\frac{6.67 \times 6 \times 10^{-11+24}}{(6.4 + 0.225) \times 10^6}}$$

$$v = \sqrt{\frac{40.02 \times 10^{13}}{6.625 \times 10^6}}$$

$$v = \sqrt{6.040 \times 10^{13-6}}$$

$$v = \sqrt{6.040 \times 10^7}$$

$$v = \sqrt{60.4 \times 10^6} \text{ m/s}$$

v= 7.77×10^3m/s

6.The distance from centre of earth to centre of moon is 3.8×10^{8}m. Mass of earth is 6×10^{24}kg. What is the orbital speed of moon?

Data:

Mass of earth = m_E = 6 × 10^{24}kg

Distance between Earth and moon = r = 3.8× 10^{8}m

Gravitational constant = G = 6.67 × 10^{-11}Nm^{2}kg^{-2}

FIND:

Orbital speed of moon = v= ?

Solution:

By using formula

$$v = \sqrt{\frac{Gm_E}{r}}$$

Putting values

$$v = \sqrt{\frac{6.67 \times 10^{-11} \times 6 \times 10^{24}}{3.8 \times 10^8}}$$

$$v = \sqrt{\frac{40.02 \times 10^{-11+24}}{3.8 \times 10^8}}$$

$$v = \sqrt{\frac{40.02 \times 10^{13}}{3.8 \times 10^8}}$$

$$v = \sqrt{10.53 \times 10^{13-8}}$$

$$v = \sqrt{10.53 \times 10^5}$$

$$v = \sqrt{105.3 \times 10^4}\ m/s$$

v= 10.26 ×10^2 m/s

v = 1.026×10^3 m/s

v = 1.02 ×10^3 m/s

7.The Hubble space telescope orbits Earth (m_E=6× $10^{24}kg$) with an orbital speed of 7.6× 10^{3}m/s. Calculate its altitude above Earth's Surface.

Data:

Mass of Earth = m_E = 6× $10^{24}kg$

Radius of Earth = r_E = 6.4× 10^6m

Gravitational constant = G = 6.67 × 10^{-11}Nm^{2}kg^{-2}

Orbital speed = v = 7.6 ×10^{3}m/s

Find:

Altitude = h = ?

Solution:

By using Formula

$$\mathbf{v} = \sqrt{\frac{Gm_E}{r_E + h}}$$

Taking square on both sides

$$v^2 = \left(\sqrt{\frac{Gm_E}{r_E + h}}\right)^2$$

$$v^2 = \frac{Gm_E}{r_E + h}$$

Rearranging equation

$$r_E + h = \frac{Gm_E}{v^2}$$

$$h = \frac{Gm_E}{v^2} - r_E$$

Putting Values

$$h = \frac{6.67 \times 10^{-11} \times 6 \times 10^{24}}{(7.6 \times 10^3)^2} - 6.4 \times 10^6$$

$$h = \frac{6.67 \times 6 \times 10^{-11+24}}{57.76 \times 10^6} - 6.4 \times 10^6$$

$$h = \frac{40.02 \times 10^{13}}{57.76 \times 10^6} - 6.4 \times 10^6$$

$$h = 0.6928 \times 10^{13-6} - 6.4 \times 10^6$$

$$h = 00.6928 \times 10^7 - 6.4 \times 10^6$$

$$h = 6.928 \times 10^6 - 6.4 \times 10^6$$

$$h = (6.928 - 6.4) \times 10^6$$

$$h = 0.5286 \times 10^6$$

$$h = 528.6 \times 10^{6-3}$$

$$h = 528 \times 10^3$$

$$h = 528 \times 10^3\ m$$

$$h = 528\ km \qquad \therefore 10^3 = \text{kilo}$$

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PHYSICS

Class 9TH (KPK)

Chapter # 6

Work and Energy

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Chapter # 6

Chapter # 06
Work and Energy

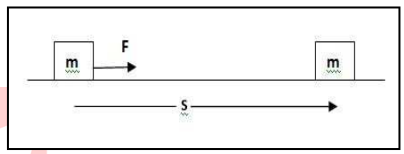
COMPREHENSIVE QUESTIONS

Q1: Define work and explain how work is calculated if force is applied at an angle.
Ans: Work:
Work is said to be done when a force displaces a body in its own direction.
Or
The product of force and displacement is called work.
Explanation:
In our daily life, when someone hold a body in state of rest no work is done because it does not cover any displacement. In the scientific sense, work is said to be done, when a force acts on a body, there must be motion or displacement by a body in the direction of the force.
Mathematically:
When an object moves distance "S" in the direction of applied force "F" then work done is given as:

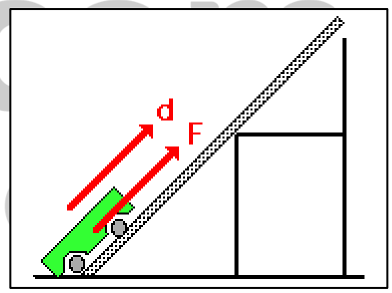
Work = force × Displacement

$$W = \vec{F} \times \vec{S}$$

Or $$W = FS$$



Force making at Angle θ:
Sometime force is not perfectly applied in the direction of motion. In that case, the direction of force and the direction of motion of a body is not same. So, when a body is moving in horizontal direction and force "F" is applied making certain angle "θ" with the horizontal. In such situation, the force is resolved into its rectangular components. According to definition of work, horizontal component of force "F_x" i-e cosθ displaces a body through distance "S" horizontally. So, mathematically work done can be written as:



$W = F_x \times S$ $\quad$ ∵ $F_x = F\cos\theta$
$W = F\cos\theta \times S$
Or, $W = FS\cos\theta$

Quantity and Unit of work:
Work done is a scalar quantity and the SI unit of work is Joule, denoted by "J" and can be defined as:
$W = FS$
So, $1J = 1N \cdot 1m$
Or, **$1J = 1Nm$**

Q2: Define Kinetic Energy. Derive the expression used for kinetic energy.
Ans: Kinetic Energy:
The energy possessed by a body due to its motion is called kinetic energy.
Examples:
All moving objects have kinetic energy i-e.
1. Moving car or train
2. Blowing wind
3. Flowing water etc.

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Explanation:

The object mass and its speed are contributing to its kinetic energy. When the body is at rest, there is no kinetic energy present in it. It means the velocity of a body is zero, its kinetic energy is also zero. So, greater the mass or velocity of a body, greater will be the kinetic energy. It is denoted by **"E_K".**

Mathematical Form:

Mathematical, kinetic energy is one half the product of an object's mass "m" and the square of its velocity "v".

$$E_k = \frac{1}{2} mv^2$$

Quantity and Unit:

Kinetic energy is a scalar quantity and the SI unit of "E_k" is Joule (J)

Derivation of formula:

Consider a body of mass "m" which is placed on a smooth surface. As the body is at rest, so its initial velocity "v_i" is zero. A force "F" is applied on the body and the body moves from point "A" to "B" after covering the distance "S". At point "B" final velocity "v_f" of the body becomes "v".

We know that when a force "F" is applied on a body and it covers some distance "S" then work "W" can be written as:

$$W = F \times S$$

This is the work done by the body due to its motion. So, it appears as the kinetic energy i-e.

$$W = E_K$$

$$F \times S = E_k$$

Or $$E_K = F \times S \text{ ------------eq (i)}$$

According to Newton's second law of motion

$$F = ma$$

In order to find distance "S" covered by the body, we use third equation of motion.

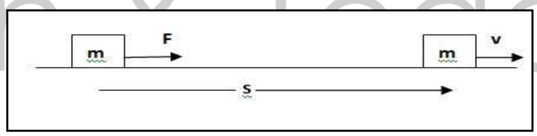
$$2aS = v_f^2 - v_i^2$$

As $v_f = v$ & $v_i = 0$, By putting the values

$$2aS = (v^2) - (0)^2$$

$$2aS = v^2 - 0$$

$$2aS = v^2$$



Divide "2a" on both sides

$$\frac{2aS}{2a} = \frac{v^2}{2a}$$

$$s = \frac{v^2}{2a}$$

Now, putting the value of "F" And "S" in Eq (i)

$$E_k = F \times S$$

$$E_k = ma \times \frac{v^2}{2a}$$

Or $$E_k = \frac{1}{2} mv^2$$

This equation shows the relation between kinetic energy of a moving object with its mass and velocity.

Q3: What is potential Energy? Prove that gravitational potential energy of a body of mass "m" at a height "h" above the surface of earth is given by mgh.

Ans: Potential Energy:

The energy possessed by a body due to its position or configuration in a force field is called potential energy.

Explanation:

Potential energy can be produced by changing the position of a body horizontally or vertically that is said to be elastic potential energy. For example, doing work on an elastic band by stretching it stores potential energy in the elastic bond. Also a battery contains both chemical and electrical potential energy. When an object raised above the ground, it has gravitational potential energy due to its raised position.

Gravitational Potential Energy:

When a body is taken to a height with respect to earth, here work is done against the force of gravity then potential energy stored in a body will be termed as gravitational potential energy. It is denoted by “$E_{GP.E}$”. If we release the body from that height, it will accelerate and gain kinetic energy as its velocity increases. Thus “$E_{GP.E}$” can be released and have the ability to do useful work.

Mathematical Form:

Mathematically, gravitational potential energy is the product of mass “m”, the acceleration due to gravity “g” and the change in height “h”.

$$E_{GP.E} = mgh$$

Derivation of Gravitational Potential Energy:

Consider a body of mass “m” is taken to certain height “h” due to applied force “F”. The work done can be written as.

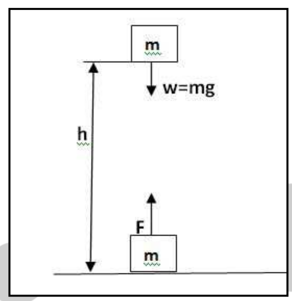
$$W = F \times S \quad \text{----------------- (i)}$$

This is the work done by the body due to its height. So, it is considered as gravitational potential energy then eq (i) becomes

$$W = E_{GPE}$$

$$F \times S = E_{GPE}$$

Or, $$E_{GPE} = F \times S$$



As we know that,

Force “F” is equal to weight of body i-e F = W and S = h

$$E_{GPE} = W \times h$$

As we know, $$W = mg$$

$$E_{GPE} = mg \times h$$

Or, $$E_{GPE} = mgh$$

Q4: State the law of conservation of energy and mass energy conversion relation.

Ans: Law of Conservation of Energy:

Statement:

The law of conservation of energy states that:

“Energy can neither be created nor destroyed in any process. It can be converted from one from to another but the total amount of energy remains constant”.

Examples:

- In radio, electrical energy is converted into sound energy.
- In light bulb, electrical energy is converted into heat and light energy.
- In electric motor, electrical energy is converted into mechanical energy.

Mass Energy Equivalence / Equation:

According to Einstein’s mass energy equation “The energy “E” of a physical system is numerically equal to the product of its mass “m” and the speed of light “c” squared. It is also known as mass energy equivalence.

Mathematical Form:

Mathematical, mass energy equation can be written as:

$$\text{Energy} = \text{mass X the speed of light squared}$$

$$E = m \times c^2$$

Or $$E = mc^2$$

Where the speed of light is constant having value of $3 \times 10^8 \, ms^{-1}$, however this value needs to be squared.

This equation shows the relationship between mass and energy that mass and energy are same physical entities and can be changed into each other.

Chapter # 6

Q5: Explain briefly major sources of energy. Such fossil fuels, wind, solar, biomass, nuclear and thermal energy.

Ans. Major sources of energy:

The major sources of energy are described below:

1. Fossil Fuels:

Coal, oil and natural gas are called fossil fuels because they are non – renewable resources that formed when prehistoric plants and animals died and were gradually buried by layers of rock. Over million of years, different types of fossil fuels i-e coal, oil or gas are formed.

Coal is most abundant fossil fuel in world, with an estimated reserve of one million metric tons.

Crude oil is refined into many different types of energy products i-e gasoline, jet fuel and heating oil. Oil produces more energy than same amount of Coal.

Natural gas is often a byproduct of oil; it is the mixture of gases the most common of which is methane. The main advantage of natural gas is that it is easy to transport.

Most of the energy that we use comes from fossil fuels which are burned in power stations, factories, homes and vehicles etc. It is consumed in more than 80 % of the world demand for energy. The disadvantage is that burning of fossil fuels caused atmospheric pollution.

2. Wind Energy:

The kinetic energy of the wind is currently used in many parts of the world to generate electricity. It is a renewable resource that can be used again and again. It is ecofriendly source of energy but require very large open space.

3. Solar Energy:

Solar energy is the energy obtained from sunlight. The energy from direct sun light can be used to produce electricity. Today, solar cells are used to power everything from calculators and watches to small cities. The energy obtained from sunlight is 100% free and very eco-friendly. It doesn't cause any pollution. However, just like wind energy, huge land area is required to produce electricity.

4. Bio – mass:

"Bio" means life so bio – mass is the energy from living things. The term "bio mass" refers to the material from which we get bio-energy. Biomass is produced when the sun's solar energy is converted into plant matter (carbohydrates) by the process of photosynthetic. Only green plants and photosynthetic algae, containing chlorophyll, are able to use solar energy. The simplest process employed to make use of this energy is eating. In this way, we are taking advantage of the energy stored as biomass.

5. Geothermal Energy:

Geo means "earth" and thermal means "heat". So, geothermal energy is the heat energy obtained from earth's core. The thermal energy contained within Earth's core result from energy trapped almost 5 billion years ago during the formation of planets. It is a natural renewable resource and doesn't cause any pollution. In many countries, geothermal energy is used to generate electricity.

6. **Nuclear Energy:**

Nuclear fission is the process of splitting large atoms i-e uranium into two or more pieces, which releases a huge amount of energy in the form of radiation or heat. The heat is used to boil water that is further used to produce electricity, In nuclear reactor, small quantities of fuel produce large amount of energy ($E=mc^2$). The advantage is that major portion of heat energy is used for useful purpose while some part of energy is wasted that can cause pollution and it is harmful for the humans.

Chapter # 6

Q6: Define and explain efficiency.

Ans. <u>Efficiency:</u>

Efficiency is the ratio of useful energy or work output to the total energy or work input.

Or

It is the ratio between work done by the machine and work done on the machine.

<u>Mathematical Form:</u>

$$\text{Efficiency} = \frac{useful\ output\ work}{input\ work}$$

$$\text{Efficiency} = \frac{\boldsymbol{W_0}}{\boldsymbol{W_i}}$$

or

$$\text{Efficiency} = \frac{useful\ energy\ output}{energy\ input}$$

$$\text{Efficiency} = \frac{\boldsymbol{E_o}}{\boldsymbol{E_i}}$$

<u>Percentage efficiency:</u>

Efficiency is always expressed in percentage. It is defined as the ratio of useful energy provided by a device to the energy required to operate the device or machine. Mathematically the percentage efficiency is calculated as follow.

$$\textbf{Efficiency} = \frac{E_o}{E_i} \textbf{ X 100\%}$$

Or

$$\textbf{Efficiency} = \frac{W_o}{W_i} \textbf{ X 100 \%}$$

Efficiency has no unit.

<u>Explanation:</u>

The efficiency of any machine describes the extent to which it converts the energy given as an input into the required form of energy obtained from a machine as an output. As we know, energy can neither be created nor destroyed. Like a light energy. While the bulb is transforming potential energy (Stored in it) into the required form of energy i.e. light energy while some part of its energy is lost or wasted. That lost energy is transformed into heat energy.

Thus it is not possible to have a machine with 100% efficiency because friction lowers the efficiency of a machine. So, work output is always less than work input.

<u>Examples:</u>

1. In light bulb 5% of the electrical energy transforms into light energy while the rest of given energy is wasted in the form of heat energy. So we say, the efficiency of light bulb is only 5% out of 100%.
2. If a petrol engine does 25 joule of useful work for every 100 joule of energy supplied to it, then its efficiency will be 25%.

Q7. Define and explain power.

Ans. <u>POWER</u>:

Power is defined as the time rate at which work is done or time rate at which energy is converted.

<u>Mathematical Form:</u>

Mathematically, power can be written as:

$$\text{Power} = \frac{work}{time}$$

$$\mathbf{P} = \frac{W}{t}$$

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Or **(in terms of energy)**

$$\text{Power} = \frac{Energy}{time}$$

$$\mathbf{P} = \frac{\boldsymbol{E}}{\boldsymbol{t}}$$

EXPLANATION:

As we know, power is a measure of how fast work is done or how fast energy is being converted from one form to another. Let suppose, there are two persons 'A' and 'B'. They both are having equal masses. Person 'A' runs 5 meters in 1 min while person 'B' also runs 5 meter in 3 mins. So, it shows that person 'A' is more powerful than person 'B' because both have performed the same work but person 'A' takes less time to cover a distance of 5 m than person 'B' and he has performed work faster than 'B'. Also his energy is quickly converted from one form to another. So, we relate work or energy with time which shows how much power is consumed in given time period.

QUANTITY AND UNIT:

Power is a scalar quantity. The SI unit of power is watt (W) where as 1 watt is equal to 1 Joule (J) per 1 second (s). i-e

$$\mathbf{1\ W = 1Js^{-1}}$$

OTHER UNITS OF POWER:

A larger unit is often used for power is the "horse power (hp)" where as one horse power is equal to 746 W. i-e

$$\mathbf{1hp = 746\ W}$$

Another commercial unit of power is "kilowatt hour (kWh)" where as one kilowatt hour is the energy converted or consumed in 1 hour at constant rate of 1000 Js^{-1} or 1kW. I-e

$$1kWh = 1000 \times 3600$$

$$1kWh = 3600000$$

or $$\mathbf{1kWh = 3.6 \times 10^6\ J}$$

TOPIC WISE QUESTIONS

Q1: Define energy and explain different types of energy.

Ans: Energy:

Energy is defined as the ability to do work.

SI Unit:

The SI Unit of energy is Joule (J).

Types / Forms of Energy:

There are different types of energy which are as follow:

1. **Kinetic Energy:**

The energy possessed by a body due to its motion is called kinetic energy. If an object is moving, it has kinetic energy i.e. a person running, a river flowing, or a car traveling on a road are the examples of kinetic energy.

2. **Potential energy:**

The energy possessed by a body due to the position, arrangement or state of the object is called potential energy. It is the energy that is stored in an object that has potential to do work. So, when the position, arrangement or state of the object changes, the stored energy will be released.

For example, chemical potential energy is stored in the food you eat or the energy stored in stretched elastic band.

3. **Chemical Energy:**

Chemical energy is the stored energy in the bonds of chemical compounds such as atoms and molecules. These bonds can take many different forms, like it is the energy stored in food, gasoline in chemical combination. For example, striking a match stick or breaking light sticks releases chemical energy.

4. **Heat Energy:**

Heat energy is also known as thermal energy. Heat is a transfer of energy from one part of a substance to another or from one object to another due to difference in temperature. For example, burning of fire transfer the energy to keep room warm.

5. **Electrical Energy:**

The energy produced by electrons moving through a substance is called electrical energy. We mostly see electric energy in batteries and from the outlets in our homes. It lights our homes, and runs all our appliances. Electrical energy is major source of energy that is used in homes, offices, schools, industries etc.

6. **Sound Energy:**

Sound energy is produced when an object is made to vibrate. Sound energy travels out as waves in all directions. Sound needs a medium to travel through such as air, water, Woods etc. For example, voices, whistles, horns and musical instruments produced sound energy.

7. **Nuclear Energy:**

Nuclear energy is the energy that is released when the nuclei of atoms are spilt (fission) or fused together (fusion). Nuclear energy is used in nuclear power plants to generate electricity. It is also used in sun and atomic bonds.

8. **Radiant energy:**

Radiant energy is a combination of heat and light energy. It travels as an electromagnetic wave. Light energy like sound energy travels in all direction in waves. For example, the microwave cooks food on the basis of radiant energy. Other examples of radiant energy are the glowing coils on a toaster, the sun and even headlights on cars.

CONCEPTUAL QUESTIONS:

1. Can a centripetal force ever do work on an object? Explain.

Ans. The centripetal force is always perpendicular to the direction of motion of an object. Only the component of the force in the direction of motion can do work. The centripetal force has no such component, so it can never do work on an object.

2. What happens to the kinetic energy of a bullet when it penetrates into a sand bag?

Ans: When a bullet penetrates into a sand bag its kinetic energy works against the frictional force of sand particles up to a short distance and becomes in state of rest. In this the energy of the bullet is transferred to sand particles, some energy is converted into heat and sound energy.

3. A meteor enters into earth's atmosphere and burns. What happens to its kinetic energy?

Ans: When meteor enters into earth's atmosphere its kinetic Energy works against the frictional force of gases therefore the meteor burns and its kinetic energy is converted into light and heat energy.

4. Two bullets are fired at the same time with the same kinetic energy. If one bullet has twice the mass of the other which has the greater speed and by what factor? Which can do the most work?

Ans: Kinetic energy of a particle is

$$E_K = \frac{1}{2} mv^2$$

Kinetic energy of the first bullet is,

$$E_{K_1} = \frac{1}{2} m_1 v_1^2$$

Here m_1 is the mass of first bullet and v_1 is the speed of the first bullet.
Kinetic energy of the second bullet is,

$$E_{K_2} = \frac{1}{2} m_2 v_2^{\ 2}$$

Here m_2 is the mass of the second bullet and v_2 is the speed of the second bullet.
Since, kinetic energy of both the bullets are same.

$$E_{K_1} = E_{K_2}$$

$$\frac{1}{2} m_1 v_1^2 = \frac{1}{2} m_2 v_2^2 \quad \text{———————— (i)}$$

Since mass of one bullet is twice the mass of the other bullet. So, put $m_1 = 2m_2$ in eq (i)

$$\frac{1}{2} (2m_2)\, v_1^2 = \frac{1}{2} m_2 v_2^2$$

Rearrange the equation

$$m_2 v_1^2 = \frac{1}{2} m_2 v_2^2$$

$$=> \quad v_1^2 = \frac{1}{2} v_2^2$$

Multiplying 2 on both sides

$$2v_1^2 = 2 \times \frac{1}{2} v_2^2$$

$$2v_1^2 = v_2^2$$

$$=> \quad v_2^2 = 2v_1^2$$

Taking square root on both sides

$$\sqrt{v_2^2} = \sqrt{2v_1}^2$$

$$\mathbf{v_2 = \sqrt{2}v_1}$$

Thus, the second bullet travels with greatest speed with a factor of $\sqrt{2}$. Both the bullets have the same kinetic energies therefore they can do the same work.

5. Can an object have different amounts of gravitational potential energy if it remains at the same elevation?

Ans: We know that

$$\mathbf{E_p = mgh} \quad \text{———————— (i)}$$

Eq (i) shows that gravitational potential energy is directly proportional to the mass of object and height of object.

If the objects have same masses and remain at the same elevation then gravitational potential energy of the objects remains same.

If the objects have different masses and remains at the same elevation then object with greater mass has greater potential energy and the object with lighter mass has less gravitational potential energy.

6. Why do roads lead to the top of a mountain wind back and forth?

Ans: The reason is that most vehicles don’t have the ability to exert enough force, fast enough to climb up a steep slope. By making vehicle go up a longer, but less steep slope, the vehicle has to exert less power over a longer period of time.

Also, going down those steep slopes may cause more accidents that the winding mountain road. Therefore, to reduce the incline of the road, we make road longer by putting curves in it.

Chapter # 6

7. Which would have a greater effect on the kinetic energy of an object, doubling the mass or doubling the velocity?

Ans. We know that

$E_k = \frac{1}{2} mv^2$

If m = 2m

Then

$E_{K_1} = \frac{1}{2}(2m)\, v^2$

$= \frac{1}{2}(2)mv2$

$E_{K_1} = 2\,(\frac{1}{2} mv^2)$

$\mathbf{E_{K_1} = 2\, E_k}$ ———— (i)

Eq (i) shows that if we double the mass the kinetic energy will also be double

Now

$E_{K_2} = \frac{1}{2} mv^2$

If v = 2v

Then

$E_{K_2} = \frac{1}{2} m(2v)^2$

$= \frac{1}{2} m\,(4v^2)$

$= 4\,(\frac{1}{2} mv^2)$

$\mathbf{E_{K_2} = 4E_k}$ ---------- (ii)

Eq(ii) shows that if we double the velocity the kinetic energy will be increases four times.

Therefore, doubling the velocity has greater effect on the kinetic energy of the object than doubling the mass.

8. If the speed of a particle triples, by what factor does its kinetic energy increases?

Ans. As we know that

$E_k = \frac{1}{2} mv^2$

If v = 3v

Then

$E_{K_1} = \frac{1}{2} m\,(3v)^2$

$= \frac{1}{2} m\,(9)v^2$

$= 9\,(\frac{1}{2} mv^2)$

$\mathbf{E_{K_1} = 9\, E_k}$ **- (i)**

Eq (i) shows that if we triple the speed of the particle then the kinetic energy of the particle increases the factor nine.

9. The motor of a crane uses power P to lift a steel beam. By what factor must the motor's power increase to lift the beam twice as high in half the time.

Ans. We know that

$\mathbf{P = \frac{W}{t}}$ --------------- (i)

Here work done is due to gain in potential energy. So,

W = mgh

Eq (i) becomes

$P = \frac{mgh}{t}$

If h = 2h and t = $\frac{1}{2}$ t

$P = \frac{mg(2h)}{\frac{1}{2}t}$

$= \frac{2mgh}{\frac{1}{2}t}$

$= \frac{2 \times 2mgh}{t}$

$P = \frac{4mgh}{t}$

$P = 4(\frac{mgh}{t})$

P = 4 P – (ii)

Eq (ii) shows that power 'P' will increases by factor 4, if we lift the beam twice as high in half the time.

ASSIGNMENTS

6.1 During a tug – of – war, team A pulls on team B by applying a force of 1100 N to the rope between them. The rope remains parallel to the ground. How much work does team A do if they pull team B towards them a distance of 2.0 m?

Given data:

Force = F = 1100N

Distance = S = 2m

Find:

Work done = W = ?

Solution:

As we know that

W = F × S

= 1100 × 2

W = 2200 J

Or **W= 2.2 × 10^3J**

6.2 A bullet of mass 30g travels at a speed of $400ms^{-1}$. Calculate its kinetic energy.

Given Data:

Mass = m = 30g

$= \frac{30}{1000} kg$

= 0.03 kg

Speed = v = 400m/s

Find:

Kinetic Energy = E_k = ?

Solution:

As we know that

$\mathbf{E_k = \frac{1}{2} mv^2}$

Putting values

$= \frac{1}{2}(0.03)(400)^2$

$E_k = (0.5)(0.03)(400)^2$

$E_k = 0.5 \times 0.03 \times 160000$

$\mathbf{E_k = 2400\ J}$

Chapter # 6

6.3 An object of mass 10 kg is lifted vertically through a height of 5m at a constant speed. What is the gravitational potential energy gained by the object?

Given Data:
Mass = m = 10 kg
Height = h = 5m
Acceleration due to gravity = g = 9.8 m/s^2

Find:
Gravitational potential energy = E_p = ?

Solution:
As we know that

$$\mathbf{E_p = mgh}$$

Putting values

$$E_p = 10 \times 9.8 \times 5$$

$$\mathbf{E_p = 490\ J}$$

6.4 How much energy is generated when mass of 1 g is completely converted into energy?

Given Data:
Mass = m = 1 g

$$= \frac{1}{1000}\ kg$$

$$= 0.001\ kg$$

Speed of light = c = 3×10^8 m/s

Find:
Energy = E = ?

Solution:
By Einstein equation

$$\mathbf{E = mc^2}$$

Putting value

$$E = (0.001)(3\times10^8)^2$$

$$= 0.001\times9\times10^{16}$$

$$= 0.009 \times 10^{16}$$

$$= 9 \times 10^{-3} \times 10^{16}\ J$$

$$= 9 \times 10^{-3+16}\ J$$

$$\mathbf{E = 9 \times 10^{13}\ J}$$

6.5 An electric heater is heated at 250W. Calculate the quantity of heat generated in 10 minutes.

Given Data:
Power = P = 250 W
Time = t = 10 min

$$= 10 \times 60\ sec$$

$$= 600\ sec$$

Find:
Quantity of heat is work done = W = ?

Solution:
As we know that

$$P = \frac{W}{t}$$

or $\mathbf{W = P \times t}$

Putting values

$$W = 250 \times 600\ J$$

$= 150000\ J$

$= 150 \times 10^3\ J$

W = 150 kJ

NUMERICALS

1.Determine the work done in each of the following cases:

a.Kicking a soccer ball forward with a force of 40 N over a distance of 15 cm.

Given data:

Force = F = 40 N

Distance = S = 15 cm = $\frac{15}{100}$m = 0.15 m

Find:

Work done = W = ?

Solution:

As we know that

$$\mathbf{W = F \times S}$$

$$= 40 \times 0.15$$

$$\mathbf{W = 6J}$$

b. Lifting a 50 kg barbell straight up 1.95 m

Given data:

Mass of barbell = m = 50 kg

Acceleration due to gravity = g = 9.8 m/s^2

Distance = S = 1.95m

Find:

Work done = W = ?

Solution:

By using formula

$$\mathbf{W = F \times S} \text{ – (i)}$$

As we know that

$$F = mg$$

Putting value

$$= 50 \times 9.8$$

$$\mathbf{F = 490\ N}$$

Now putting values in eq (i)

$$\mathbf{W = F \times S}$$

$$= 490 \times 1.95$$

$$W = 955.5J$$

$$= 9.55 \times 10^2\ J$$

$$\mathbf{W = 9.6 \times 10^2\ J}$$

2.Calculate the velocity of a 1.2 kg falling star (meteorite) with 5.5 × 10^8 J of energy.

Given data:

Mass = m = 1.2 kg

Energy = E = 5.5×10^8 J

Find:

Velocity = v = ?

Solution:

As we know that

$$\mathbf{E_K = \frac{1}{2} mv^2}$$

Rearranging the formula

$$2E_K = mv^2$$

$$\frac{2E_k}{m} = v^2 \quad \text{or} \quad v^2 = \frac{2E_k}{m}$$

Taking square root on both sides

$$\sqrt{v^2} = \sqrt{\frac{2E_k}{m}}$$

$$\mathbf{v} = \sqrt{\frac{2E_k}{m}}$$

Putting values

$$= \sqrt{\frac{2\times5.5\times10^8}{1.2}}$$

$$= \sqrt{\frac{11\times10^8}{1.2}}$$

$$= \sqrt{\frac{11}{1.2}\times 10^8}$$

$$= \sqrt{9.16\times10^8} \text{ m/s}$$

$$v = 3.02\times10^4 \text{ m/s}$$

or

$$\mathbf{v = 3\times10^4 \ m/s}$$

3. Calculate the gravitational potential energy of a 2000 kg piano.
a.Resting on the floor.
Given data:
Mass = m = 2000 kg
Height = h = 0 m
Acceleration due to gravity = g = 9.8 m/s^2
Find:
Gravitational potential energy = E_p = ?
Solution:
As we know that

$$\mathbf{E_p = mgh}$$

Putting value

$$= 2000 \times 9.8 \times 0$$

$$\mathbf{E_p = 0\ J}$$

b. With respect to the basement floor, 1.9m below.
Given data:
Mass = m = 2000 kg
Height = h = 1.9m
Acceleration due to gravity = g = 9.8 m/s^2
Find:
Gravitational potential energy = E_p = ?
Solution:
As we know that

$$\mathbf{E_p = mgh}$$

Putting values

$$= (2000) \times 9.8 \times 1.9$$

$$E_p = 37240 \text{ J}$$

$\mathbf{E_p = 3.7 \times 10^4\ J}$

4.An elevator weighting 5000 N is raised to a height of 15.0m in 10.0s, how much power is developed?

Given data:

Weight of elevator = W= mg = 5000 N

Height = h = 15 m

Time = t = 10 Sec

Find:

Power = P = ?

Solution:

As we know that

$$\mathbf{P = \frac{E_P}{t}} \text{ ---------- (1)}$$

For finding E_P, we know that

$$E_p = mgh$$
$$= 5000 \times 15$$
$$E_p = 75000\ J$$

Putting value of E_P in eq 1

$$\mathbf{P = \frac{E_P}{t}}$$
$$= \frac{75000}{10}\ W$$
$$\mathbf{P = 7500\ W}$$

5.What power is required for a ski – hill chair lift that transports 500 people (average mass 65 kg) per hour to an increased elevation of 1200 m?

Given data:

Average mass of one person = 65 kg

Mass of 500 peoples = m = 500 × 65 kg

m= 32500 kg

Height = h = 1200m

Acceleration due to gravity = 9.8 m/s^2

Time = 1 hour

= 1 × 60 × 60 sec

= 3600 sec

Find:

Power = P = ?

Solution:

As we know that

$$\mathbf{P = \frac{E_P}{t}} \text{ ------- (i)}$$

So,

$$E_p = mgh$$
$$= 32500 \times 9.8 \times 1200$$
$$\mathbf{E_p = 382200000\ J}$$

Eq(i) =>

$$P = \frac{E_P}{t}$$

Putting values

$$= \frac{382200000}{3600}\ W$$
$$= 106166.6\ W$$

$= 1.06166 \times 10^5$ W

$P = 1.06 \times 10^5 W$

6.How long will it take a 2750 – W motor to lift a 385 – kg sofa set to a sixth - story window 16.0 m above?

Give Data:

Power = P =2750 W
Mass = m = 385 Kg
Height = h = 16.0m
Acceleration due to gravity = g = 9.8 m/s^2
Time = t = ?

Solution:

As we know that

$$\mathbf{P = \frac{W}{t}} \text{ ------------------(i)}$$

Here

$$W = E_p = mgh$$

Putting values

$$W = 385 \times 9.8 \times 16 \text{ J}$$
$$W = 60368 \text{ J}$$

Now eq (i) becomes

$$P = \frac{W}{t}$$
$$\Rightarrow \mathbf{t = \frac{W}{P}}$$

Putting Value

$$t = \frac{60368}{2750} \text{ sec}$$
$$= 21.9 \text{ Sec}$$

Or

t = 22 Sec

7. How much work can a 2.0 hp motor do in 1.0h?

Data:

Power = P = 2hp
= 2 × 746 W   :. 1hp = 746 W
= 1492 W
Time = t= 1 hour
= 1 hour
= 1 × 60 × 60 Sec
= 3600 Sec

Find:

Work done = W = ?

Solution:

As we know that

$$\mathbf{P = \frac{W}{t}}$$

or $W = P \times t$

$= 1492 \times 3600$

$= 5371200$ J

$= 5.37 \times 10^6$ J

$W = 5.4 \times 10^6$ J

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Chapter # 8
Thermal Properites of Matter

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Chapter # 08
Thermal Properties of matter
Comprehensive Questions

Q1: Explain the term internal energy and temperature. Use kinetic theory to distinguish between heat, internal energy and temperature.

Ans: Internal Energy:

Internal energy is the sum of the kinetic and potential energies associated with the motion of the atoms of the substance.

Explanation:

When we touch a hot body, internal energy flows in the form of heat into our body, so it appears to be hot. On the other hand, when we touch a cold object internal energy flows as heat from our body into the cold object, so it appears to be cold.

Temperature:

The measure of the degree of hotness or coldness of a body with respect to some standard is called temperature.

Or

The temperature can also be defined as: "The average kinetic energy of molecules of a body."

Explanation:

Temperature is a measure of the average kinetic energy of particles. The kinetic energy may be in the form of translational, vibrational and rotational kinetic energy. As atoms or molecules of the material are in constant motion, at high temperature the kinetic energy of molecules is more and at lower temperatures, it is less. Temperature also affects the physical states (shape, size) of material. For example, water at low temperature is ice (a solid), at a high temperature it is water (a liquid) and still at higher temperature it is steam (a gas).

Distinguishing Temperature, Heat & Internal Energy:

Using the kinetic theory, we make a clear distinction between temperature, heat and internal energy. Temperature is a measure of the average kinetic energy of individual molecules. Internal energy refers to the total energy of all the molecules within the object. Thus two equal mass hot ingots of iron may have the same temperature, but two of them have twice as much internal energy as one does. Heat, finally, refers to a transfer of energy from one object to another because of a difference in temperature.

Q2: How do we measure temperature? Explain liquid in glass thermometer.

Ans: Measurement of temperature:

Temperature could be measured in a simple way by using our hand to sense the hotness or coldness of an object. However, the range of temperatures that our hand can bear is very small and our hand is not precise enough to measure temperature correctly. The branch of physics which deals with the measurements of temperature is called thermometry. For scientific work, we need some reliable device or instrument to measure temperature accurately. Such an instrument is called thermometer.

Liquid in glass thermometer:

The liquid in glass thermometer utilizes the variation in volume of a liquid in temperature.

Construction or working:

The fluid is contained in a sealed glass bulb, and its expansion is measured using a scale etched in the stem of the thermometer. The thermometer utilizes the variation of length of liquid with temperature. In this type the liquid in a glass bulb expands up a capillary tube when the bulb is heated. The liquid must be easily seen and must expand (or contract) rapidly and by a large amount over a wide range of temperature. The tube has a constriction just beyond the bulb. When the thermometer is removed, the liquid in the bulb cools and contracts breaking the liquid (mercury) thread at the constriction. The liquid beyond the constriction stays in the tube and shows the temperature. It must not stick to the inside of the tube. Liquids commonly used include mercury and alcohol.

Q3: What are various temperature scales. Derive mathematical expressions to convert between various scales of temperature.

Ans: Temperature Scales:

The scale which is made for the measurement of temperature is called temperature scale or thermometric scale. The scale comprises of two reference points, called fixed points. There are freezing point (ice point) and boiling point (steam point). The interval between these point is divided arbitrarily into equal divisions. There are three scales of temperature which are the following.

1. Centigrade or Celsius scale.
2. Fahrenheit scale.
3. Kelvin or absolute scale.

1. Centigrade or Celsius scale:

i. This scale was introduced by a Swedish astronomer Anders Celsius.
ii. It is denoted by ‘^{o}C’.
iii. Its ice point is marked as 0^{o}C.
iv. Its steam point is marked as 100^{o}C.
v. The interval between ice point and steam point is divided into 100 equal parts (divisions).
vi. Each part is called degree centigrade.

2. Fahrenheit Scale:

i. This scale was introduced by German physicist Daniel Gabriel Fahrenheit.
ii. It is denoted by ^{o}F.
iii. Its ice point is marked as 32^{o}F.
iv. Its steam point is marked as 212^{o}F.
v. The interval between ice point and steam point is divided into 180 equal parts (divisions).
vi. Each part (division) is called degree Fahrenheit.

3. Kelvin or absolute scale:

i. This scale was introduced by William Thomson, (Lord Kelvin). He named this scale as absolute scale.
ii. It is denoted by K.
iii. Its ice point is marked as 273 K.
iv. Its steam point is marked as 373 K.
v. The interval between ice point and steam point is divided into 100 equal parts.
vi. The lowest temperature at which the molecular movement of matter ceases is called Kelvin zero or absolute zero. Its magnitude on the Celsius scale is -273 ^{o}C or (0K).
vii. Kelvin is the S.I unit of temperature.

Relationship Between Different Scales of temperature

A Temperature measured on one scale sometimes, needs conversion to another scale. A general relation for the conversion of temperature from one scale to the other is

$$\frac{Temp\ on\ one\ scale - ice\ point}{No. of\ division\ b/w\ fixed\ points} = \frac{Temp\ on\ other\ scale - ice\ point}{No. of\ divisions\ b/w fixed\ point}$$

A. Conversion between centigrade and Fahrenheit scale:

Using the general relation, we have

$$\frac{T_{^\circ C} - 0}{100} = \frac{T_{^\circ F} - 32}{180}$$

$$\frac{T_{^\circ C}}{100} = \frac{T_{^\circ F} - 32}{180}$$

$$T_{^\circ C} = 100 \text{ x } [\frac{T_{^\circ C} - 32}{180}]$$

$$T_{^\circ C} = \frac{100}{180}(T_{^\circ F} - 32)$$

$$T_{^\circ C} = \frac{10}{18}(T_{^\circ F} - 32)$$

$$\mathbf{T_{^\circ C} = \frac{5}{9}(T_{^\circ F} - 32)}$$

Or

$$T_{^\circ C} = \frac{5}{9}(T_{^\circ F} - 32)$$

$$\frac{9}{5}T_{^\circ C} = T_{^\circ F} - 32$$

$$\frac{9}{5}T_{^\circ C} + 32 = T_{^\circ F}$$

Or $$\mathbf{T_{^\circ F} = \frac{9}{5}T_{^\circ C} + 32}$$

B. Conversion between centigrade and Kelvin scale:

Using the general relation, we have

$$\frac{T_{^\circ C} - 0}{100} = \frac{T_K - 273}{100}$$

$$\frac{T_{^\circ C}}{100} = \frac{T_K - 273}{100}$$

$$\mathbf{T_{^\circ C} = T_K - 273}$$

Or

$T_{°C} = T_K - 273$

$T_{°C} + 273 = T_K$

$\mathbf{T_K = T_{°C} + 273}$

Q4: What is meant by linear thermal expansion and volume thermal expansion of solids?

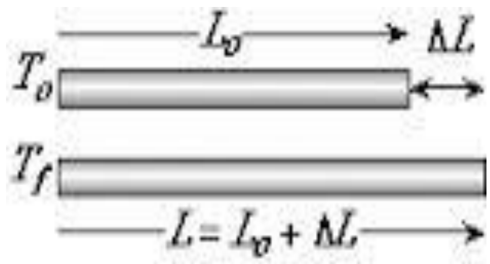
Ans: <u>Linear Thermal Expansion of Solids:</u>

<u>Definition:</u>

The increase in length of a substance due to rise in temperature is called linear thermal expansion.

<u>Mathematical Derivation:</u>

Consider a metal rod having an original length "l_o" at temperature "T_o". After heating metal rod to temperature "T", the rod expands to its new length "l_T". This means for the change in temperature ΔT (where $\Delta T = T - T_o$) there is corresponding change in length Δl (where $\Delta l = l_T - l_o$).



The change in length Δl of almost all solids is directly proportional to the change in temperature ΔT as long as is not too large. This means by changing temperature the length also changes, more the change in temperature more is the change in length and vice versa.

$$\Delta l \propto \Delta T \text{.........(i)}$$

The change in length Δl is also directly proportional to original length l_o of the object.

i.e. $\Delta l \propto l_o$ .....(ii)

Combining eq (i) and eq (ii), we get

$$\Delta l \propto l_o \Delta T$$

Changing proportionality into equality.

$$\mathbf{\Delta l = \alpha\, l_o\, \Delta T} \text{ .....(iii)}$$

Were "α" the proportionality constant is called the coef ficient of linear thermal expansion for the particular material.

Since $\Delta l = l_T - l_o$, we can write eq(iii) as

$$l_T - l_o = \alpha\, l_o\, \Delta T$$

$$l_T = l_o + \alpha\, l_o\, \Delta T$$

Taking l_o common

$$\mathbf{l_T = l_o (1 + \alpha \Delta T)}$$

If the temperature change $\Delta T = T - T_o$ is negative, then $\Delta l = l_T - l_o$ is also negative; the length shortens as the temperature decreases.

<u>Coefficient of linear thermal expansion:</u>

From eq(iii), we can define coefficient of linear thermal expansion "α" of a substance as the increase in length per unit length of the solid per Kelvin "K" rise in temperature

$$\boldsymbol{\alpha = \frac{\Delta l}{l_o \Delta T}}$$

In simple words, α is numerically the increase in 1m long wire for 1 degree rise of temperature. The value of α depends upon the nature of material and is different for different materials.

Unit:

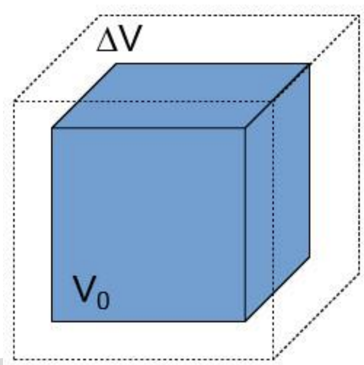
The coefficient of linear thermal expansion has units of $^oC^{-1}$ and in SI as K^{-1}.

Volume (cubical) Thermal Expansion of Solids:

Definition:

The increase in volume of a substance due to rise in temperature is called volume thermal expansion.

Explanation:



Consider a metal block having an original volume "V_o" at temperature "T_o". After heating metal block to temperature "T", the block expands to its new volume "V_T". This means for the change in temperature ΔT (where $\Delta T = T - T_o$), there is corresponding change in volume ΔV (where $\Delta V = V_T - V_o$).

The increase in volume of a metal block on heating is directly proportional to original volume of the metal block and rise in temperature. Mathematically,

$$\Delta V \propto \Delta T \quad .....(i)$$

and $$\Delta V \propto V_o \quad .....(ii)$$

combining eq(i) & eq(ii), we get

$$\Delta V \propto V_o \Delta T$$

Changing proportionality in equality

$$\mathbf{\Delta V = \gamma V_o \Delta T} \quad ....(iii)$$

Where "γ" is the proportionally constant is called the coefficient of volume thermal expansion for the particular material.

Since $\Delta V = V_T - V_o$ we can write eq(iii) as

$$V_T - V_o = \gamma V_o \Delta T$$

$$V_T = V_o + \gamma V_o \Delta T$$

Taking V_o common

$$\mathbf{V_T = V_o (1 + \gamma \Delta T)} \quad .....(iv)$$

Eq (iv) represents the final volume of the object after expansion.

Coefficient of volume thermal expansion:

From eq(iii), we can define coefficient of volume thermal expansion (γ) of a substance as the change in volume per unit volume per Kelvin change in temperature.

$$\gamma = \frac{\Delta V}{V_o \Delta T}$$

The volume of γ depends upon the nature of material and is different for different materials.

Unit:

The coefficient of volume thermal expansion has unit of $^oC^{-1}$ and in SI as K^{-1}.

This is general rule for solids that they expand to the same extent in three directions. It can be proved that all the coefficient of volume thermal expansion of solids γ is about three times the coefficient of linear thermal expansion 'α' of solids i.e.

$$\gamma = 3\alpha$$

so, eq 3 becomes

$$\Delta V = 3\alpha V_o \Delta T$$

Q5: What is thermal expansion of liquid? Why we have real and apparent thermal expansion in liquids. Illustrate with the help of an experiment.

Ans: <u>Thermal Expansion of Liquids:</u>

The increase in the volume of a liquid due to the thermal effect of heating is called thermal expansion of liquids. Since heat affects both the liquid and the container the real expansion of a liquid cannot be detected directly. In case of liquids, we have two kinds of thermal expansion.

1. Real expansion
2. Apparent expansion

1. <u>Real expansion of liquid:</u>

A real increase in the volume of a liquid that take place due to increase of temperature is called real expansion (V_R) of liquid. This expansion is independent of the expansion of the container.

2. <u>Apparent expansion of liquid:</u>

An apparent increase in the column of a liquid that takes place due to increase of temperature is called apparent expansion (V_A) of liquid. When a liquid is taken in a container and heated, both the liquid and the container expand at same time. The difference of these expansions is called apparent expansion. If V_R is the expansion in the volume of the liquid (called real expansion) and V_C is the expansion in the volume of container on heating, then the apparent expansion V_A is given by as;

$$V_A = V_R - V_C$$

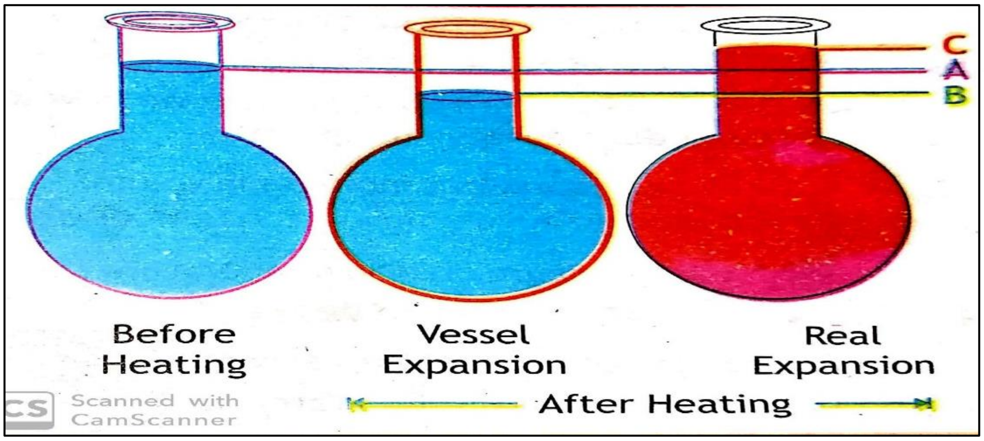
<u>Experiment:</u>

Let a vessel has water up to level A. If heat is applied, the vessel will first expand which will produce an illusion that the water has fallen. This is due to the expansion of the vessel and is given by the levels i.e. AB. On further heating the heat energy will start reaching the liquid. The liquid will then start expanding rapidly, according to its nature exceeding its previous level to reach up to level C. So the measurement of BC gives the true (real) expansion of the liquid only. An observer presents at the start and at the end will see the whole process as just the expansion of the liquid from A to C. So AC measures the apparent expansion of the liquid. Mathematically,

$$BC = AC + AB$$

Real expansion of liquid = Apparent expansion of liquid + Vessel Expansion.

Since there are two different types of expansion of liquids their coefficients of expansion should also be defined differently.



Coefficient of real expansion "γ_R":

It is defined as the apparent increase in volume of liquid per unit original volume per unit degree rise in temperature.

$$\gamma R = \frac{\text{real increase in volume}}{\text{original volume x rise in temperature}}$$

Its unit is per degree rise in temperature i.e. $^oC^{-1}$ or K^{-1}

Coefficient of apparent expansion "γ_A":

It is defined as the apparent increase in volume of liquid per unit original volume per unit degree rise in temperature.

$$\gamma R = \frac{\text{apparent increase in volume}}{\text{original volume x rise in temperature}}$$

Its unit is per degree rise in temperature i.e. $^oC^{-1}$ or K^{-1}.

Q6: Define heat capacity and specific heat capacity of a substance. Explain the importance of high specific heat capacity of water.

Ans: Heat Capacity (Thermal Capacity):

The quantity of heat required to raise the temperature of a substance of mass (m) by 1 ^OC or 1 K is called the heat capacity (c_m) of that substance.

Mathematically:

If ΔQ is the change in heat and ΔT is the change in temperature, then

$$c_m = \frac{\Delta Q}{\Delta T}$$

The value of "c_m" depends upon.

1. The nature of the material of the substance.
2. The mass of the material of the substance.
3. The rise in temperature.

Unit:

The S.I unit of heat capacity is joule per Kelvin which is expressed as JK^{-1}.

Specific heat capacity (specific heat):

The quantity of heat required to raise the temperature of unit mass (1.0 kg) of the substance by 1°C or 1K is called specific heat capacity of that substance.

Mathematically:

$$C = \frac{c_m}{m} \qquad \therefore c_m = \frac{\Delta Q}{\Delta T}$$

Putting value of c_m

$$\mathbf{C = \frac{\Delta Q}{m\Delta T}}$$

Unit:

The S.I unit of specific heat capacity or specific heat is joule per kilogram per Kelvin which is expressed as $JKg^{-1}\ K^{-1}$.

Importance of the high specific heat capacity of water:

The specific heat capacity of water is equal to 4190 $JKg^{-1}\ K^{-1}$. It has some important implications.

1. **Moderate climate of sea shore:**

The specific heat of sand is about 800 $JKg^{-1}K^{-1}$. A certain mass of water needs five times more heat than the same mass of solid for its temperature to rise by 1°C or 1 K. Hence, the land gets heated much more easily than water. Also it cools down much easily hence a large difference in temperature is formed that gives rise to land breeze and sea breeze. It keeps the climate of the coastal areas moderate moon soon in Pakistan is also due to the difference in temperature between the land and the surrounding sea.

2. **As a coolant:**

Water is used as an effective coolant. By allowing water to flow in radiator pipes of the vehicles, heat energy from such part is removed. Thus, water extracts much heat without much rise in temperature.

Q7: What is meant by the latent heat of fusion and latent heat of vaporization of a substance?

Ans: Latent Heat of Fusion:

The amount of heat energy is required to convert a given mass of a substance from the solid state to the liquid state (melt) without any rise in temperature is called its latent heat of fusion. Liquids release the same amount of heat when they solidify (freeze).

Specific latent heat of fusion:

The amount of heat energy required to convert unit mass (1 kg) of solid at its melting point of liquid (or liquid into solid) without any change in temperature is called its specific latent heat of fusion of the solid.

Explanation:

If "ΔQ" is the amount of heat energy needed to melt mass "m" of a solid to liquid (or freeze liquid to solid), then mathematically.

$$\Delta Q = mL_f$$

Where L_f is the latent heat of fusion of substance and is given as

$$L_f = \frac{\Delta Q}{m}$$

Unit:

The S.I unit of specific latent heat of fusion is joule per kilogram which is expressed as JKg^{-1}. Different substances have different specific latent heat of fusion.

Latent heat of vaporization:

The amount of heat energy required to convert a given mass of a substance from liquid state to the gaseous state (boil) without any rise in temperature is called its latent heat of vaporization. Gases release the same amount of heat when they liquify (condense).

Specific latent heat of vaporization:

The amount of heat energy required to convert unit mass (1 Kg) of the liquid at it boiling point to gas, (or gas into liquid) without any change in temperature is called its specific latent heat of vaporization of the solid.

Explanation:

If "ΔQ" is the amount of heat energy needed to vaporize mass "m" of a liquid to gas (or condense gas to liquid), then mathematically.

$$\Delta Q = m L_v$$

Where L_v is the latent heat of vaporization such that

$$L_v = \frac{\Delta Q}{m}$$

Unit:

The S.I unit of specific heat of vaporization is joule per kilogram which is expressed as JKg^{-1}. Different substances have different specific latent heat of vaporization.

Q8: What is meant by evaporation? On what factors the evaporation of liquid depends. Explain how cooling is produced by evaporation. Differentiate between boiling and evaporation.

Ans: Evaporation of liquid:

The process by which a liquid slowly changes into its vapors at any temperature (below its boiling point) without the aid of any external source of heat is called evaporation of liquids.

Explanation:

Liquid starts to boil if they are heated to their boiling temperatures. The liquid starts to transform into vapors' but the change of liquids into vapors goes on even when the temperature is below the boiling point. For example, a spread wet cloth on being exposed to the air becomes dry in a short time due to evaporation of water. Water left in open dish also disappears due to evaporation. We know that the molecules of a liquid move with wide of range of instantaneous velocities and they have different kinetic energies ranging from minimum to a very high value. Some of the molecules having sufficient kinetic energy to overcome the forces of attraction leave the surface of the liquid and escape out in the form of vapors. We call this escaping of high energy molecules as evaporation.

Factors on which evaporation of liquid depends:

Evaporation of liquids depends on the following factors.

1. **Nature of liquid:**

Liquid with low boiling points evaporates more rapidly than those with higher boiling points. For example, the rate of evaporation of alcohol is higher than that of water.

2. **Temperature of liquid:**

Due to higher temperature, molecules of liquid at the surface will have more kinetic energy and chances of escaping will increase and evaporation will be fast. This can be seen while ironing clothes. Under a hot iron wet clothes dry out quickly as the water evaporates quickly.

3. **Temperature of surrounding:**

The higher the temperature of the surrounding, the higher is the rate of evaporation. It is for this reason that wet clothes dry rapidly in summer than in winter.

4. **Presence of water vapor in Air:**

The more the amount of water vapor present in air, the less is the rate of evaporation. It is for this reason that wet clothes dry slowly in rainy season as a lot of water vapor are present in the air.

5. **Area of the exposed surface of liquid:**

Increased surface area gives the molecules a greater chance of escaping. Wet roads dry out quickly because the rain water is spread over large area.

6. **Movement of Air:**

The more rapid the flow of air the higher is the rate of evaporation. It is for this reason that wet clothes dry more rapid on a windy day compared on a calm day.

7. **Dryness of Air:**

Drier the air, the more rapid is the evaporation. Presence of water vapor reduces the rate of evaporation. Desert room coolers are more effective in cooling by evaporation in the dry month of June than it is in the humid month of August.

8. **Air Pressure on the surface of the liquid:**

The lower the pressure on the surface of the liquid, higher is the rate of evaporation.

Evaporation causes cooling:

A liquid needs latent heat for its evaporation. If the liquid is not being heated by an external source, the heat required for evaporation of liquid must come from the liquid itself. Since the molecule is taking heat with it as its leaving, this has a cooling effect on the surface left behind. For example, spirit spilled on your palm quickly evaporates. As a result, your palm feels cold. You can feel the chilling effect of the evaporation of water if you sit under a fan and wearing wet clothes. Perspiration in a human body helps to cool the body and to maintain a stable body temperature. The kinetic theory explains the cooling caused by evaporation. During evaporation, more energetic molecules escape from the liquid surface. Molecules that remain in the liquid have lower kinetic energy. A liquid with molecules of less kinetic energy has a lower temperature. Thus evaporation produces cooling.

Evaporation Vs Boiling:

Vaporization of an element or compound is a phase transition from the liquid phase to vapor. There are two types of vaporization: evaporation and boiling.

Evaporation:

Evaporation is a phase change from the liquid phase to vapor that occurs at temperatures below the boiling temperature at a given pressure. Evaporation usually occurs on the surface.

Boiling:

Boiling is a phase transition from the liquid phase to gas phase that occurs at or above the boiling temperature as opposed to evaporation, occurs below the surface.

Some Important Questions

Q9: Define and explain heat?

Ans: Heat:

Heat is a form of energy transferred from a hotter body to a colder body.

OR

The form of energy which is transferred from one body to another body due to the difference in temperature is called heat.

Explanation:

When two objects with different temperature are placed in thermal contact, the temperature of the warmer object decreases with the temperature of the cooler object increases. With time they reach a common equilibrium temperature somewhere in between their initial temperatures. During this process we say that energy is transferred from the warmer object to the cooler one. For example, water in a kettle can be heated by placing it on flame. The water gradually becomes warmer and eventually starts boiling. Something must have transferred from the hot flame to the cold water. This something which flows from hotter body to the colder body till the temperature of two bodies becomes equal is called heat. In general temperature of any object can be raised by placing it in thermal contact with another hotter object.

Q10: Define and explain thermometric property?

Ans: Thermometric Property:

The particular property of a substance that increases and decreases uniformly with temperature and can be used for the measurement of temperature is called thermometric property.

Explanation:

In order to construct a thermometer, we make use of a certain physical property of matter that increases or decreases uniformly with rise and fall in temperature. This particular property of substance is called thermometric property. The commonly used thermometric property is the thermal expansion of materials. This property makes use of the fact that matter (solid, liquid or gas) expands on heating and contracts on cooling. Thus, the degree of expansion or contraction of matter can be calibrated on suitable scale to record temperature. For example, mercury and alcohol are the substances which contain this property and therefore used in thermometer for the measurement of temperature.

Q11: Define and explain thermal expansion?

Ans: <u>Thermal Expansion:</u>

The increase in size of a substance on heating is called thermal expansion.

Explanation:

Most substances expand when heated and contract when cooled. However, the amount of expansions or contraction varies depending on the material, the change in temperature and the original size of the substance. Thermal expansion is different for different states e.g. solid, liquid or gas of the same substance. It is experienced that gases expand more than liquids and liquids expand more than solids.

Thermal expansion of solids:

A solid substance can undergo three types of expansion:

1. Expansion in length is known as linear thermal expansion. When a metal rod is heated it will expand in length, so it will be linear thermal expansion.
2. Expansion in area is known as superficial thermal expansion. When a metal sheet is heated, it will expand in length and breadth, so it will be superficial thermal expansion.
3. Expansion in volume is called volume or cubical thermal expansion. When a metal block is heated, it will expand its length, Breadth and height. So, it will be volume or cubical thermal expansion.

Q12: Discuss practical applications of thermal expansion?

Ans: Following are a few applications of thermal expansion of solids.

i. Railway lines:

When railway tracks are laid, the engineers leave a small gap between two rails. If two railway tracks are laid together without any gap between them they will push against each other when they expand with the rise of temperature. This may cause them to bend or tracks may also break free from one another. Such a situation result in the derailment of the trains causing major accidents and loss of lives. So, the railway engineers always leave a small gap between two rails to compensate for the expansion of the rails during the not summer and contraction during cold winter.

ii. Opening a tight jar lid:

When the lid of a glass jar is too tight to open, holding the lid under hot water for a short time will often make it easier to open. The top expand before the heat reaches the bottle but even if not, metals generally expand more than glass for the same temperature change.

iii. Transmission lines:

Transmission lines in the summer sag more as compared to winter.

iv. Shrink-fitting of axles into gear wheels:

The axles have been shrunk by cooling in liquid nitrogen at-196°C until the gear wheels can be slipped on to them. On regaining normal temperature, the axles expand to give a very tight fit.

v. Expand fitting iron ring to a cart wheel:

An iron ring can be tightly fixed into the wooden wheel of a Tonga. At room temperature, the diameter of the iron ring is slightly less than the diameter of the wooden wheel. The ring expands on heating and can be placed around the wooden wheel. When the ring comes to room temperature, it contracts and produces a tight fit.

vi. Expansion joints:

Most large bridges include expansion joints, which look rather like two metal combs facing one another, their teeth interlocking. When heat causes the bridge to expand during the sunlight hours of a hot day, the two sides of the expansion joint move toward one another; then as the bridge cool down after dark they being gradually to retract. Thus, the bridge has a built-in safety zone; otherwise, it would have no room for expansion or contraction in response to temperature changes.

vii. Bimetallic strip:

A Bimetallic strip is used to convert a temperature change into mechanical displacement. The strip consists of two strips of different rates as they are heated. When their temperature increases, the unequal amounts of expansion cause the bimetallic strip to bend. For example, if equal length of two different metals such as copper and iron are riveted together so that they cannot move separately, they form a bimetallic strip. When heated, copper expands more than iron and to allow the strip bends with copper on the outside. Bimetal strips have many uses, like fire alarm and thermostat.

Q13: Explain the anomalous expansion of water?

Ans: Anomalous expansion of water:

Liquids expand on heating except water between 0^oC and 4^oC. Water is unusual in its expansion characteristics. When water at 0^oC is heated, its volume decreases up to 4^oC and from 4^oC, its volume increases with the increase of temperature. This peculiar behavior of water is called anomalous expansion of water. Due to the formation of more number of hydrogen bonds, water has anomalous expansion. As the temperature increases from 0^oC to 4^oC, the density increases and as the temperature further increases, the density decreases. Hence water has maximum density at 4^oC. This is why ice floats on water we can see this when we put ice cubes in water to cool it or icebergs floating in ocean.

Q14: Explain latent heat and phase change?

Ans: Latent Heat:

The heat required to change the physical state of a substance (solid into a liquid or vapour, or a liquid into a vapour) but does not change its temperature is called latent heat of that substance.

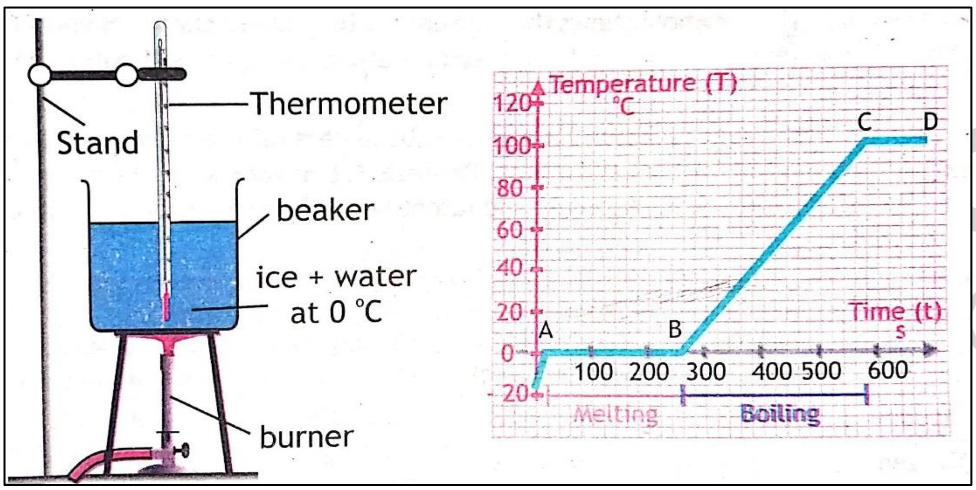
Explanation:

A substance usually undergoes a change in temperature with transfer of energy (heat). In some cases, however the transfer of energy doesn't result in a change in temperature. This can occur when the physical characteristics of the substance change from one from to another, commonly referred to as a phase change. Some common phase changes are solid to (melting), liquid to gas (boiling), liquid to solid (freezing) and gas to liquid (condensation). Energy used to cause a phase change does not cause a temperature change. When ice melts at 0°C it becomes water at 0°C, when water boils at 100°C, it becomes steam at 100°C. The same is true in reverse, when water at 0°C freezes it becomes ice at 0°C, when steam at 100°C condenses it becomes water at 100°C.

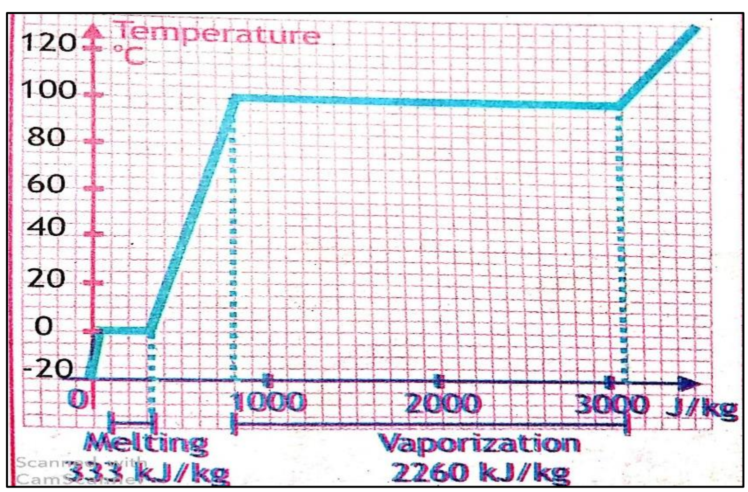
Q15: Explain experiment for ice-water phase change and temperature-time graph on heating ice?

Ans: Experiment for ice-water phase change:

Take a beaker and place it over a stand. Put small pieces of ice in the beaker and suspend a thermometer in the beaker to measure the temperature. Place a burner under the beaker. The ice will start melting. The temperature of the mixture containing ice and water will not increase above 0°C until all the ice melts. Note the time which the ice takes to melt completely in to water at 0°C. Continue heating the water at 0°C in the beaker. It temperature will start to increase. Note the time which the water in the beaker takes to reach its boiling point at 100 °C.



Explanation of temperature-time graph on heating ice:



From the graph we can see that at curve "AB" even we were providing heat to the ice water mixture but the temperature remained constant at 0 °C. At point B, all the ice has melted to form water. Now, on heating beyond point "B", the temperature of water started rising as shown by the slope line "BC" in the graph. Since the heat absorbed during the change of state of a substance does not raise its temperature, it is called latent heat or hidden heat. The graph also shows when water is boiling and changing into steam, the temperature remains constant at 100°C through heat is being given continuously to water. This heat which is going into water but not increasing its temperature is the energy required to convert the water from the liquid state to the vapour state. Since this heat does not show its presence by producing a rise in temperature, it is called latent heat of vaporization of water.

Q16: Discuss the applications of cooling by evaporation:

Ans: <u>Applications of cooling by evaporation:</u>

i. <u>Cooling by Fans:</u>

We use fans in the hot season because the moving air increases the rate of evaporation or perspiration from our bodies. Hence we get a cooling sensation. As discussed earlier, perspiration helps in cooling the body and regulating its temperature.

ii. <u>Fever Control:</u>

Wet towel is applied on the forehead of a person running high fever. It is because, as the water evaporates, it takes heat from the head. Thus the temperature of the head remains within the safe limits and the patient does not suffer any brain damage.

iii. <u>Refrigerator:</u>

The cooling effect is many refrigerators is produced by the evaporation of a volatile liquids called Freon. The liquid Freon evaporates in the pipes of freezer compartment. As the Freon evaporates, it draws the necessary latent heat from the food inside the refrigerators.

Q17: What is refrigerator? Discuss its principle, construction and working?

Ans: <u>Refrigerator:</u>

It is a device which produces cooling effect and thus the food items kept inside it remains in safe conditions.

<u>Working principle:</u>

The working principle of refrigerator is evaporation and compression.

<u>Construction:</u>

There are six parts of a refrigerator.

a. <u>Heat exchanging pipes:</u>

These coils are present on the inside and the outside of the fridge, they carry the refrigerant from one part of the fridge to another.

b. <u>Refrigerant:</u>

This is the substance which evaporates in the fridge causing freezing temperatures.

c. <u>Expansion Values:</u>

The expansion value which is made up of a thin copper coil reduces the pressure on the liquid refrigerant.

d. <u>Compressor:</u>

A compressor is a metal object which compresses the refrigerant thus raising the pressure and in turn the temperature of the gas.

e. <u>Condenser:</u>

A condenser condenses, that is, it converts the refrigerant into liquid from, reducing its temperature.

f. Evaporator:

An evaporator absorbs the heat in the refrigerator with assistance of the evaporating liquid refrigerant.

Working:

Refrigerator has a pipe that is partly inside a refrigerator and partly outside it, and sealed so it is a continuous loop. The pipe is filled with a refrigerant. Inside the refrigerator, we make the pipe gradually get wider, so the refrigerant expands and cools as it flowed through it. Outside the refrigerator, we have a pump (compressor) to compress the gas and release its heat. As the gas flow round and round the loop, expanding when it is inside the refrigerator and compressing when it is outside, it constantly picks up heat from the inside and carry it to the outside.

CONCEPTUAL QUESTIONS

Q1: Ordinary electric fan increases the kinetic energy of the air molecules caused by the fan blades pushing them means the air temperature increase slightly rather than cool the air? Why use it.

Ans. For cooling, we usually use electric fans. But the electric fan does not actually cool the air inside the room. It increases the kinetic energy of air molecules due to which the temperature of molecules increases. Such high speed molecules touch our body and evaporate water molecules from our body. The evaporated water molecules absorb heat of vaporization from our body and as a result we feel cool.

Q2: Why are small gap left behind the girders mounted in walls?

Ans: Small gaps are left behind the girders mounted in walls because to allow for the expansion of the girders during summer usually one end of the iron structure is fixed and the other end is allowed to expend in summer into the left out gap. If there is no gap left, then the expansion will cause the girders to buckle.

Q3: Why you should not put a closed glass jar into a campfire. What could happen if you tossed an empty glass jar, with the lid on tight, into a fire?

Ans: When we put a closed glass jar into a campfire, the inside of the glass jar is not empty. It is filled with air. As the fire heats the air inside, its temperature rises and as a result the pressure inside the jar increases. Due to high internal pressure the jar may explode and turn into pieces. Also if we tossed an empty glass jar into a fire, then due to high internal pressure in jar may cause it crack. So we should not throw a close glass jar into a campfire.

Q4: Explain why it is advisable to add water to an overheated automobile engine only slowly, and only with the engine running.

Ans: It is advisable to add water to an overheated automobile engine slowly and only with the engine running it is because if we add water quickly to an overheated engine, water will come into contact with the hot metal part of the engine. Some area of metal part will cool down very rapidly, while other part will not. Some part of the water will quickly turn to steam and will rapidly expand which can result a cracked engine block or radiator.

Q5: Explain why burns caused by steam at 100 ^oC on the skin are often more severe than burns caused by water at 100 ^oC.
Ans: When the temperature of water rises at 100^{o}C, water is converted to steam. At this point the temperature remains constant. Although heat is being given to water. Heat equal to latent heat of vaporization i.e. 2.26 x 10^6 J Kg^{-1} K^{-1} is added to steam. The steam while leaving the container carries this extra amount of heat which produces more severe burns as compared to water at 100^{o}C.

Q6: Explain why cities like Karachi situated by the ocean tend to have less extreme temperatures than inland cities at the same latitude.
Ans: Coastal areas like Karachi have moderate temperature than inland areas because of the high specific heat capacity of water of the sea. During the day, the sun shines equally on land and sea. The land heats up more quickly than the sea because of high specific heat of water. The hot air over the land rises and the cold air from the sea blows to replace it. Thus there is a sea breeze during the day. At night the reverse occurs, the land cools more quickly than the sea because the sea water has absorbed a huge quantity if heat throughout the day. So the hot air over the sea rises and cool air from the land blows to replace it. Thus, there is a land breeze during the night. So the temperature of coastal area like Karachi remains at moderate level i.e. not too hot in summer and not too cold in winter than inland cities at the same latitude.

Q7: An iron rim which is fixed around a wooden wheel is heated before its fixture. Explain why?
Ans: An iron rim which is fixed around a wooden wheel is heated before its fixture because at room temperature the diameter of the iron rim is made slightly less than the diameter of wooden wheel. The rim expands on heating and can be placed around wooden wheel. When the rim comes to room temperature, it contracts and produces tight fit.

Q8: Why is ice at 0^{o}C a better coolant of soft drink than water at 0 ^{o}C?
Ans: The ice when absorb heat, it melts. During melting the temperature of ice remains constant at 0°C. When the ice is put in the soft drink, it absorbs heat from the drink. So, its temperature falls and become cool. But in case of water at 0^{o}C when it absorbs heat its temperature rises. Therefore, ice is the better coolant than water at 0^{o}C.

Q9: Why we feel cool after perspiration?
Ans: We feel cool after perspiration because for evaporation there is need of heat energy. When the sweat drops evaporate from our body it absorbs heat from our body and as a result we feel cool due to decrease in temperature of our body.

ASSIGNMENTS

8.1: Temperature of an object is 250 K, Find its temperature in centigrade.

Data:

$T_k = 250\ K$

Find:

$T\ ^oC = ?$

Solution:

As we know that

$$T_{^\circ C} = T_K - 273$$

Putting values

$$T_C = 250 - 273$$

$$T_C = -23^oC$$

8.2: The length of a bar of certain metal is 60 cm. When the bar is heated from 8ºC to 100 ºC, its length becomes 60.127 cm. Calculate the coefficient of linear thermal expansion of the metal.

Data:

Initial length of bar $= l_o = 60cm$

$= \frac{60}{100} m$

$= 0.6\ m$

Final length of bar $= l_T = 60.127\ cm$

$= \frac{60.127\ m}{100}$

$= 0.60127\ m$

Change in length $= \Delta l = l_L - l_o$

$= (0.60127 - 0.60)\ m$

$= 0.00127\ m$

Initial temperature $= T_o = 8\ ^oC$

Final temperature $= T = 100\ ^oC$

Change in temperature $= \Delta T = T - T_o$

$= 100\ ^oC - 8\ ^oC$

$= 92\ ^oC$

Find:

Co-efficient of linear thermal expansion $= \alpha = ?$

Solution:

We know that

$$\boldsymbol{\alpha = \frac{\Delta l}{l_o \Delta T}}$$

Putting values $\alpha = \frac{0.00127}{0.6\ x\ 92}$

$= \frac{0.00127}{55.2}$

$\alpha = 0.000023$

$\boldsymbol{\alpha = 2.3 \times 10^{-5}\ ^oC^{-1}}$

Or

Data:

Initial length of bar = l_o = 60 cm

Final length of bar = l_T = 60.127 cm

Change in length = $\Delta l = l_T - l_o$

= (60.127 – 60) cm

= 0.127 cm

Initial temperature = T_o = 8 ^oC

Final Temperature = T = 100 ^oC

Change in temperature = $\Delta T = T - T_o$

= 100 ^oC – 8 ^oC

= 92 ^oC

Find:

Co-efficient of linear thermal expansion = α = ?

<u>Solution:</u>

We know that $\boldsymbol{\alpha = \frac{\Delta l}{l_o \Delta T}}$

Putting value $\alpha = \frac{0.127}{60 \times 92}$

$\alpha = \frac{0.127}{5520}$

$\alpha = 0.000023$

$\boldsymbol{\alpha = 2.3 \times 10^{-5}\ ^oC^{-1}}$

8.3: A 200 cm^3 piece of lead (γ= 87 x 10^{-6} K^{-1}) is at 10 ^oC. If it is heated to a temperature of 40 ^oC, find the change in volume of the lead.

Data:

Initial volume = V_o = 200 cm^3

Initial temperature = T_o = 10 ^oC

Final temperature = T = 40 ^oC

Change in temperature = $\Delta T = T - T_o$

=40 ^oC -10 ^oC

= 30 ^oC

= 30 K

Coefficient of volume thermal expansion = $\boldsymbol{\gamma}$ = 87 x 10^{-6} K^{-1}

Find:

Change in volume = ΔV = ?

Solution:

We know that

$$\boldsymbol{\Delta V = \gamma V_o \Delta T}$$

Putting value

$$\Delta V = 87 \times 10^{-6} \times 200 \times 30$$
$$\Delta V = 522000 \times 10^{-6}$$
$$= 0.522 \times 10^{6} \times 10^{-6}$$
$$= 0.522 \times 10^{6-6}$$
$$= 0.522 \times 10^{o}$$
$$\mathbf{\Delta V = 0.522\ cm^3}$$

8.4: If petrol at 0°C occupies 250 liters. What is its volume at 50°C? For petrol take $\gamma = 9.6 \times 10^{-4}\ K^{-1}$.

Data:

Initial volume = V_o = 250 liters

Initial temperature = T_o = 0 °C

Final Temperature = T = 50 °C

Change in temperature= $\Delta T = T - T_o$

= 50 °C - 0°C

= 50 °C

= 50 K

Coefficient of volume thermal expansion = $\gamma = 9.6 \times 10^{-4}\ K^{-1}$

Find:

Final volume = V_T = ?

Solution:

As we know that

$$\mathbf{V_T = V_o (1 + \gamma \Delta T)}$$

Putting values

$$V_T = 250 (1 + 9.6 \times 10^{-4} \times 50)$$
$$= 250 (1 + 480 \times 10^{-4})$$
$$= 250 (1 + 0.0480) \text{ liters}$$
$$= 250 (1.0480) \text{ liters}$$
$$\mathbf{V_T = 262\ liters}$$

8.5: If 117.60 J of heat is required to raise the temperature of 10g of silver through 50 °C. Calculate the specific heat of sliver.

Data:

Heat required = ΔQ = 117.60 J

Mass = m = 10g

$= \frac{10}{1000}$kg (1 Kg = 1000g)

= 0.01 Kg

Rise in temperature = ΔT = 50°C

Find:

Specific heat of silver = c = ?

Solution:

We know that

$$c = \frac{\Delta Q}{M\Delta T}$$

Putting values

$$c = \frac{117.6}{0.01 \times 50} \text{ JKg}^{-1} \text{ K}^{-1}$$

$$= \frac{117.60}{0.5} \text{ JKg}^{-1} \text{ K}^{-1}$$

$$\mathbf{c = 235.2 \text{ J Kg}^{-1} \text{ K}^{-1}}$$

8.6 Find the amount of heat for evaporating 2.8 kg of water at 45°C? (Latent heat of vaporization of water $L_v = 2.3 \times 10^6$ J/Kg and specific heat of water c = 4190 J Kg^{-1} K^{-1}.)

Data:

Mass of water = m = 2.8 Kg

Latent heat of vaporization for water = $L_v = 2.3 \times 10^6$ J Kg^{-1}

Specific heat of water = C = 4190 J Kg^{-1} K^{-1}

Initial temperature = T_o= 45 °C

Final temperature = T = 100 °C

Change in temperature = $\Delta T = T - T_o$

= 100- 45= 55 °C

Find:

Heat required = ΔQ = ?

Solution:

Heat required by water at 45 °C to attain the temperature of 100 °C

$$\mathbf{\Delta Q_1 = c\ m\ \Delta T}$$

Putting the value

$$\Delta Q_1 = 4190 \times 2.8 \times 55$$

$$= 645260 \text{ J}$$

$$\mathbf{\Delta Q_1 = 0.65 \times 10^6 \text{ J}}$$

Now we will find heat required for vaporization of water at 100 °C

$$\mathbf{\Delta Q_2 = mLv}$$

Putting values

$$= 2.8 \times 2.3 \times 10^6$$

$$\mathbf{\Delta Q_2 = 6.44 \times 10^6 \text{ J}}$$

Amount of heat required for evaporation of water at 45 °C

$$\mathbf{\Delta Q = \Delta Q_1 + \Delta Q_2}$$

$$= 0.65 \times 10^6 \text{ J} + 6.44 \times 10^6 \text{ J}$$

$$= (0.65 + 6.44) \times 10^6 \text{ J}$$

$$\Delta Q = 7.09 \times 10^6 \text{ J}$$

$$\mathbf{\Delta Q = 7.1 \times 10^6 \text{ J}}$$

NUMERICAL QUESTIONS

1. Perform the temperature conversions

a). Temperature difference in the body. The surface temperature of the body is normally about 7 °C lower than the internal temperature. Express this temperature difference in kelvins and in Fahrenheit degrees.

b). Blood storage. Blood stored at 4.0°C lasts safely for about 3 weeks, whereas blood stored at -160 °C lasts for 5 years. Express both temperatures on the Fahrenheit and Kelvin scales.

a). **Data:**

Temperature in °C = $T_{1°C}$ = 37 °C

Temperature in °C = $T_{2°C}$ = 37 – 7

= 30 °C

Find:

Temperature difference in kelvin = $(\Delta T)_K$ = ?

Temperature difference in Fahrenheit = $(\Delta T)_F$ = ?

Solution:

To find $(\Delta T)_K$, we first convert $T_{1°C}$ and $T_{2°C}$ in Kelvin.

So,

T_{1C} = 37 °C

We know that

$T_{1k} = T_{1°C} + 273$

Putting values

$T_{1k} = 37 + 273$

$\mathbf{T_{1k} = 310\ K.}$

And $T_{2°C}$ = 30 °C

We know that $T_{2k} = T_{2°C} + 273$

Putting value

$= 30 + 273$

$\mathbf{T_{2k} = 303\ K}$

Now $(\Delta T)_k = T_{1k} - T_{2k}$

Putting value

$= (310 - 303)$ K

$\mathbf{(\Delta T)_k = 7\ K}$

To find $(\Delta T)_F$ we first convert t_{1C} and T_{2C} in Fahrenheit.

So,

T_{1c} = 37 °C

We know that $T_{1F} = \frac{9}{5} T_{1C} + 32$

Putting value $= \frac{9}{5}(37) + 32$

$= \frac{333}{5} + 32$

$= 66.6 + 32$

$\mathbf{T_{1F} = 98.6\ °F}$

And $T_{2C} = 30\ ^oC$

We know that

$$T_{2F} = \frac{9}{5} T_{2c} + 32$$

Putting value

$$T_{2F} = \frac{9}{\cancel{5}_1} (\cancel{30}^6) + 32$$

$$= 9 \times 6 + 32$$

$$= 54 + 32$$

$$\mathbf{T_{2F} = 86\ ^oF}$$

Now $(\Delta T)_F = T_{1F} - T_2F$

$$= 98.6\ ^oF - 86\ ^oF$$

$(\Delta T)_F = 12.6\ ^oF$

$(\Delta T)_F = 13\ ^oF$

b). **Data:**

(i) Temperature in $^oC = T_{1C} = 4\ ^oC$

(ii) Temperature in $^oC = T_{2C} = -160\ ^oC$

Required:

(i) $T_{1k} = ?$

$T_{1F} = ?$

(ii) $T_{2k} = ?$

$T_{2F} = ?$

Solution:

(i) Temperature in $^oC = T_{1c} = 4\ ^oC$

Now to convert T_{1C} in T_{1k} and T_{1F}

For $T_{1C} = 4^oC$

We know that $T_{1k} = T_{1c} + 273$

Putting value $= 4 + 273$

$T_{1k} = 277$ K

For $T_{1C} = 4\ ^oC$ We have

We know that

$T_{1F} = \frac{9}{5} T_{1C} + 32$

Putting value of T_{1C}

$T_{1F} = \frac{9}{5}\ (4 + 32)$

$$= \frac{36}{5} + 32$$

$$T_{1F} = 7.2 + 32$$

$T_{1F} = 39.2\ ^oF$

(ii) Temperature in $^oC = T_{2C} = -160\ _oC$

We have to convert T_{2C} in T_{2k} and T_{2F}

FoT$_{2C} = -160\ _oC$

We know that $T_{2k} = T_{2C} + 273$

Putting value

$$= -160 + 273$$

$$\mathbf{T_{2k} = 113\ K}$$

For $T_{2C} = -160\ ^oC$

We know that $T_{2F} = \frac{9}{5} T_{2c} + 32$

$$= \frac{9}{5}(-160^{32}) + 32$$

$$= 9\,(-32) + 32$$

$$T_{2F} = -\,288 + 32$$

$$\mathbf{T_{2F} = -\,256\ ^oF}$$

2. Consider a meter – stick composed of platinum (the coefficient of linear expansion for platinum is $\alpha = 8.8 \times 10^{-6}\ K^{-1}$). By what amount does the length of this meter – stick change if the temperature increases by 1.0 K?

Data:

Length of meter - stick $= L_o = 1m$

Coefficient of linear thermal expansion $= \alpha = 8.8 \times 10^{-6}\ K^{-1}$

Change in temperature $= \Delta T = 1.0\ K$

Find:

Change in length $= \Delta L = ?$

Solution:

We know that

$$\mathbf{\Delta L = \alpha\, l_o\, \Delta T}$$

Putting values

$$\Delta L = 8.8 \times 10^{-6} \times 1 \times 1.0$$

$$\mathbf{\Delta L = 8.8 \times 10^{-6}\ m}$$

3. A railway line made of iron is 1200 km long and is laid at 25 °C. By how much will it contract in winter when the temperature falls to 15 °C? By how much will it expand when the temperature rises to 40 °C in summer? (the coefficient of linear expansion for iron is $\alpha = 12 \times 10^{-6}\ K^{-1}$).

Data:

Length of railway line $= L_o = 1200$ km

$= 1200 \times 1000$ m (1km = 1000 m)

$= 1200000$ m

Initial temperature $= T = 25\ ^oC$

Temperature in winter $= T_w = 15\ ^oC$

Temperature difference $= \Delta T = 25° - 15°$

$= 10\ ^oC$

Temperature in summer $= T_s = 40\ ^oC$

Temperature difference $= \Delta T = 40 - 25$

$= 15\ ^oC$

Coefficient of linear thermal expansion = $\alpha = 12 \times 10^{-6}\ K^{-1}$

Find:

Length in winter = L_w = ?

Length in summer = L_s = ?

Solution:

In winter

$$\mathbf{L_w = L_o (1 + \alpha\, \Delta T)}$$

Putting values

$$L_w = 1200000 (1 + 12 \times 10^{-6} \times 10)$$
$$= 1200000 (1 + 120 \times 10^{-6})$$
$$L_w = 1200000 (1 + 0.000120)$$
$$= 1200000 (1.00012)\ m$$
$$\mathbf{L_w = 1200144\ m}$$

So, $\Delta L = L_w - L_o$

$$= 1200144 - 1200000$$
$$\mathbf{\Delta L = 144\ m}$$

In summer:

$$L_s = L_o (1 + \alpha\, \Delta T)$$

Putting values

$$L_s = 1200000 (1 + 12 \times 10^{-6} \times 15)$$
$$= 1200000 (1 + 180 \times 10^{-6})$$
$$= 1200000 (1.000180)$$
$$L_s = 1200000 (1.00018)\ m$$
$$\mathbf{L_s = 1200216\ m}$$

So, $\Delta L = L_s - L_o$

$$= 1200216 - 1200000$$
$$\mathbf{\Delta L = 216\ m}$$

4. The volume of a brass ball is 800 cm^3 at 20 ^oC. Find out the new volume of the ball if the temperature is raised to 52 ^oC. The coefficient of volumetric expansion of brass is 57 x $10^{-6}\ K^{-1}$.

Data:

Initial Volume of brass = V_o = 800 cm^3

Initial temperature = T_o = 20 ^oC

Final temperature = T = 52 ^oC

Coefficient of volumetric expansion of brass= r = 57 x $10^{-6}\ K^{-1}$

Temperature difference = $\Delta T = T - T_o$

$$= 52\ ^oC - 20\ ^oC$$
$$= 32\ ^oC$$

Find:

Final volume of brass = V_T = ?

Solution:

Using formula

$$\mathbf{V_T = V_o (1 + \gamma \Delta T)}$$

Putting value

$$V = 800 (1 + 57 \times 10^{-6} \times 32)$$
$$= 800 (1 + 1824 \times 10^{-6})$$
$$= 800 (1 + 0.001824)$$
$$= 800 (1.00\ 1824)\ cm^3$$
$$V = 801.459\ cm^3$$

Or

$$\mathbf{V = 801.5\ cm^3}$$

5. What is the specific heat of a metal substance of 135 KJ of heat is needed to raise 4.1 Kg of the metal from 18.0 °C to 37.2 °C?

Data:

Heat supplied = ΔQ = 135 KJ

= 135×10^3 J

= 135000 J

Initial temperature = T_o = 18 °C

Final temperature = T = 37.2 °C

Change in temperature = $\Delta T = T - T_o$

= 37.2 °C – 18 °C

$\Delta T = 19_o\ 2$ °C

Or

ΔT = 19.2 K

Mass of metal = m = 4.1 Kg

Find:

Specific heat of metal = c = ?

Solution:

We know that

$$\mathbf{c = \frac{\Delta Q}{m\Delta T}}$$

Putting values

$$c = \frac{135000}{4.1 \times 19.2}$$
$$= \frac{135000}{78.72}$$
$$c = 1714.93\ J\ Kg^{-1}\ K^{-1}$$

Or

$$\mathbf{c = 1715\ J\ Kg^{-1}\ K^{-1}}$$

6. How much heat is needed to melt 23.50 Kg of silver that is initially at 25 ^oC? (Specific heat of silver is C = 230 J Kg^{-1} K^{-1}. Latent heat of fusion for silver is L_F = 8.82 K 10^4)

Data:

Mass of silver = m = 23.50 Kg

Specific heat of silver = c = 230 J Kg^{-1} K^{-1}

Latent heat of fusion for silver = L_F = 8.82 x 10^4 J Kg^{-1}

Initial temperature = T_o = 25 ^oC

Final temperature or melting point of silver = T = 961 ^oC

Change in temperature = $\Delta T = T - T_o$

$= 961\ ^oC - 25\ ^oC$

$\Delta T = 936\ ^oC$

Or

$\Delta T = 936$ K

Find:

Heat required = ΔQ = ?

Solution:

Heat required to raise the temperature of silver from 25 ^oC to 961 ^oC

$$\mathbf{\Delta Q_1 = mc\Delta T}$$

Putting values

$$\Delta Q_1 = 23.50 \times 230 \times 936 \text{ J}$$

$$= 5059080 \text{ J}$$

$$\mathbf{\Delta Q_1 = 5.059080 \times 10^6 \text{ J}}$$

Heat required to melt silver

$$\Delta Q_2 = mL_F$$

Putting values

$$\Delta Q_2 = 23.50 \times 8.82 \times 10^4 \text{ J}$$

$$\Delta Q_2 = 207.27 \times 10^4 \text{ J}$$

$= 2.0727 \times 10^2 \times 10^4$ J

$= 2.0727 \times 10^{2+4}$ J

$$\mathbf{\Delta Q_2 = 2.0727 \times 10^6 \text{ J}}$$

Heat required to melt silver at 25 ^oC

$\Delta Q = \Delta Q_1 + \Delta Q_2$

$= 5.059080 \times 10^6 + 2.0727 \times 10^6$

$= (5.059080 + 2.0727) \times 10^6$ J

$\Delta Q = 7.13178 \times 10^6$ J

$\mathbf{\Delta Q = 7.1 \times 10^6 \text{ J}}$

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PHYSICS

Class 9th (KPK)

NAME: ______________________________

F.NAME: _____________________________

CLASS:_____________ SECTION: _________

ROLL #: ______ SUBJECT: ______________

ADDRESS: ____

____

SCHOOL: ____

TRANSFER OF HEAT
COMPREHENSIVE QUESTIONS

Q1. Explain conduction of heat and its mechanism. Describe its practical applications.

Ans: - Conduction of Heat:

The process by which heat energy is transferred from particle to particle by collision is called conduction of heat.

Mechanism of Heat Conduction:

The mechanism of heat conduction can be explained by the behavior of atoms within the material.

There are two ways by which heat is transferred

(i) Vibration of atoms in the metals
(ii) Motion of free electrons present in the metals.

Vibration of atoms in the metals:

A metal rod consists of large number of closely packed atoms. These atoms vibrate about their mean position inside the material.

Now if we supply heat to the one end of the rod, then due to this heat the vibration of atoms increases as a result the kinetic energy and amplitude of vibration of atoms increases. These atoms collide with their neighbor atoms and transfer their heat to the neighboring atoms. In this way, heat is transferred from one end of the metal rod to the other end easily. Such type of heat transfer is known as conduction of heat.

Motion of Free Electrons in the Metals:

The metals also consist of large number of free electrons. These free electrons play an important role in the transfer of heat from one point to another by conduction.

Example:

When one end of the metal rod is heated, the atoms in the heated part vibrate more with greater speeds. The free electrons that collide with these atoms gain kinetic energy and move faster. They diffuse into the colder part of the metal where collisions with other free electrons and atoms occur which result in the transfer of energy. In this way heat is transferred from one location to another location such type of heat transfer is known as conduction of heat.

Practical applications of Heat Conduction:

i. **Cooking pots and pans:** cooking pots and pans are made of metals which are good thermal conductors. They conduct heat readily to the food inside and to spread it evenly.
ii. **Plastic Foam:** Plastic foam and fiberglass (plastic material containing glass fiber) are good insulators because they contain tiny pockets of trapped air. These materials are used in the walls and ceilings of our homes to keep them cool in summer and warm in winter season.
iii. **Wire Gauze:** Wire gauze is often placed over a flame to conduct heat outwards from flame. A glass beaker can safely be heated on the gauze because this protects it from the concentrated heat of the flame.

iv. **Pot Holders and Table Mats:** Pot holders and table mats for hot pans are made of poor conductors such as clothes and wood. The uses of poor conductors avoid burning of hands and table top.

v. **Woolen Clothes:** Woolen clothes have fine pores filled with air. Air and wood are bad conductors of heat. Thus the heat from our body does not flow out and our body remains warm in winter.

vi. **Igloos:** Igloos type of shelter (house or hut) built of snow. Igloos are constructed from ice and snow to provide protection from wintery conditions. One reason that igloos do their job so well is that the ice and snow act as a thermal insulation and minimize the loss of heat from the inside due to conduction.

vii. **Ice box:** Ice box has a double wall made of tin or iron. The space between the two walls is filled with cork which is the poor conductor of heat.
The cork prevents the flow of outside heat into the box, thus keeping the ice from melting.

viii. **Soldering:** During soldering objects are in direct contact, such as the soldering iron and the circuit board, heat is transferred by conduction

Q2. Explain thermal conductivity of a substance and its mathematical description.

Ans: - Thermal Conductivity: -

The thermal conductivity of a substance is a measure of the ability of the substance to conduct heat energy.

Explanation: -

Consider a rod of length "L" having area of cross section 'A' and let "ΔT" be the temperature difference.

Now the amount of heat 'Q' that flows across the rod depends upon the following factors.

i. **Temperature Difference:**

The amount of heat 'Q' flows is directly proportional to the temperature difference "ΔT".

i.e. $Q \;\alpha\; \Delta T$ …….. eq (1)

ii. **Area of Cross-Section:**

The amount of heat 'Q' flows is directly proportional to the cross-sectional area 'A 'of the rod

i.e. $Q \;\alpha\; A$ ……. eq (2)

iii. **Time Interval: -**

The amount of heat 'Q' flows is directly proportional to the time interval 't'

i.e. $Q \;\alpha\; t$ …….. eq (3)

iv. **Thickness/Length: -**

The amount of heat 'Q' flows is inversely proportional to the length 'L' of the rod.

i.e. $Q \;\alpha\; \frac{1}{L}$ …….. eq (4)

By combining equations (1), (2), (3) and (4), we get

$$Q \;\alpha\; \frac{\Delta T A t}{L}$$

$$Q \;\alpha\; \frac{A t \Delta t}{L}$$

$$Q \;\alpha\; \frac{At(T_1 - T_2)}{L} \qquad (\because \Delta T = T_1 - T_2)$$

$$Q = \frac{kAt(T_1 - T_2)}{L} \quad \text{........ eq (5)}$$

Where "k" is the constant of proportionality and is known as thermal conductivity of the substance. Its value depends upon the nature of the material. Such that

$$k = \frac{Q.L}{At(T_1 - T_2)}$$

Special Case: -

If $L = 1m$, $A = 1m^2$, $T_1 - T_2 = 1^\circ C$ or 1 K and $t = 1s$, then equation (5) becomes

$$Q = k$$

Thus the thermal conductivity 'k' of a substance is defined as "The quantity of heat which flows through one square meter of area of the substance in one second when a temperature difference of one Kelvin is maintained across a thickness of one meter.

Unit: - The S.I unit of thermal conductivity is $JK^{-1}m^{-1}s^{-1}$.

Since Js^{-1} is equal to watt

i.e. Js^{-1} = watt

The thermal conductivity is also express in unit $\mathbf{WK^{-1}m^{-1}}$.

Q3. Explain convection of heat and its mechanism. Explain its practical applications.

Ans. Convection of Heat: -

The transfer of heat from one place to another by the actual motion of the heated particles is called convection of heat.

Mechanism of Heat Convection: -

The mechanism of convection of heat can be explained by the behavior of the medium between the hot and cold objects. Convection occurs only in fluids (liquid and gases). Convection cannot occur in solids as the atoms in a solid are located in fixed positions and cannot change place.

Let us examine the heating of water in a beaker by the process of heat-convection.

The heated portion of water at the bottom of the beaker expands and becomes less dense. Being less dense, the warm water moves upward. It is replaced by the cold and dense water around it. The cold water flowing to the point of heating in its turn absorbs heat energy, expands and is pushed upward. Thus a continuous circulatory flow is established from the bottom to the top of the water in the beaker.

Practical Applications of Heat Convection: -

i. Heating Water:

If it were not for convection currents, it will be very difficult to boil water. The lower layers of water in an electric kettle are warmed first. This heated water expands and move upward to the top because its density is lowered. Meanwhile dense cool water replaces the warm water at the bottom of the kettle so that it can also be heated.

ii. Sea Breeze:

Convection causes coastal breeze. During the day the land heats up more quickly than the sea. The hot air over the land rises and the cold air from the sea blows to replace it. Thus there is a sea breeze during the day. At night, the reverse happens. The land cools more quickly than the sea.

The hot air over the sea rises and the cold air from the land blows to replace it. This movement of air is called the land breeze.

iii. Riding on Thermals:

Thermals are streams of hot air rising in the sun. They are convection currents. Birds are able to fly for hours on thermals without flapping their wings. Similarly, glider airplanes are able to rise by riding on the thermals.

iv. Refrigerator:

In a refrigerator, convection is used to circulate cold air around the food. Air is cooled by the freezer compartment the top of the refrigerator. As it sinks, it is replaced by warmer air rising from the below. The circulating air carries heat energy away from all the food in the fridge.

v. Ventilation:

Convection currents are used in ventilation classrooms or rooms in houses have ventilators installed near the ceiling. The warm and stale air inside the room rises and escapes through the openings near the ceiling. Fresh and cold air is drawn into the room through the doors and windows. Similarly, smoke and hot gas from the fires in houses and factories rise up and escape through the chimneys.

Q4. Explain radiation of heat and its mechanism. Describes any three of its practical applications.

Ans: <u>Radiation of heat: -</u>

The heat transfers from a hotter place to a colder place with or without having material medium in between is called radiation of heat.

<u>Mechanism of Radiation of heat: -</u>

The mechanism of radiation is energy transfer by electromagnetic waves. Electromagnetic radiation comes from accelerating electric charges. Unlike conduction and convection transfer of heat by radiation, does not necessarily require a material medium. Heat energy transferred through radiation is as familiar as the light; in fact, it is the light but not visible or barely visible. Electromagnetic waves can transfer energy via vacuum or empty space as well as via a material medium like glass.

Every object around us is continually radiating, unless its temperature is at absolute zero (0) K.

Example:

A scoop of ice cream has temperature of about 237K, therefore it radiates. Even we radiate all the time, but that radiation isn't visible as light because it's in the infrared part of spectrum.

<u>Practical application of radiation of heat:</u>

(i). Colouring materials: -

The cooling fins on the heat exchanger at the back of a refrigerator are painted black so that they lose heat more quickly. By contrast, saucepans that are polished are poor emitters and keep their heat longer. In general, surfaces that are good absorbers of radiation are good emitters when hot.

(ii). Texture of the surface: -

One type of radiant barrier material, ARMA foil, produced by Energy Efficient solutions.

(iii). Satellite Protective coating: -

The highly reflective metal foil covering the satellite minimizes the temperature changes.

(iv). Thermos flask: -

The vessel which is used to prevent heat transfer due to conduction, convection and radiation is called thermos flask.

It consists of a double-walled glass vessel silvered on the inside. The purpose of the silvering is to reflect all radiant heat trying to enter or leave the vessel. The space between the walls is highly evacuated to prevent convection. The glass, being a poor conductor minimizes conduction of heat.

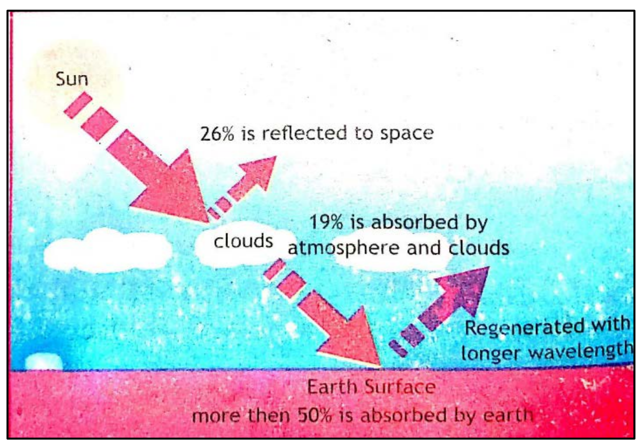
The heat loss through the flask is so small that a hot liquid placed in the flask will remain hot for a very long time. A cold thing placed in the flask will remain cold for a long time because flow of heat from the outside will also be very small.

Q5. Discuss the greenhouse effect. Explain its importance and global warming concern.

Ans: <u>Greenhouse Effect:</u>

The greenhouse effect is the process by which radiation from a planet's atmosphere warms the planet's surface to a temperature above what it would be without its atmosphere.

<u>Mechanism of Greenhouse Effect:</u>



Earth receives energy from the sun in the form of ultraviolet, visible and near infrared radiation. Of the total amount of solar energy available at the top of the atmosphere, about 26% reflected to space by the atmosphere and clouds and 19% is absorbed by the atmosphere and clouds. More than 50% of the remaining energy or short wavelengths radiations from the sun are absorbed at the surface of earth.

Because the earth's surface is colder than the photosphere of the sun, it radiates at wavelength that are much longer than the wavelengths that were absorbed. Most of this thermal radiation is absorbed by the atmosphere, thereby warming it. In addition to the absorption of solar and thermal radiation, the atmosphere gains heat by latent heat fluxes from the surface.

The atmosphere radiates energy both upwards and downwards, the part radiated downwards is absorbed by the surface of earth. This leads to higher the temperature of earth.

<u>Importance of Greenhouse Effect:</u>

Greenhouse effect is important for the survival of life on earth. Earth atmosphere containing naturally occurring greenhouse gases (water vapour, CO_2, CH_4, and O_3) causes air temperature near the surface to be about 33°C warmer. Without the Earth's atmosphere, the Earth's average temperature would be well below the freezing temperature of water.

Concerns of Global Warming:

Human activity has increased the amount of greenhouse gases in the atmosphere leading to the global
warming (increase in the temperature of earth). Due to human activities in the period from 1880 to 2012, the global average temperature has increased by 0.85°C.

The largest human influence has been the emission of carbon dioxide from factories and motor vehicles. Currently, about half of the carbon dioxide released from burning of fossil fuels is not absorbed by the vegetation and the oceans and remains in the atmosphere.

Now in order to decrease global warming we have to reduce the emission of greenhouse gases and to plant more vegetation to absorb the produced carbon dioxide.

IMPORTANT TOPIC WISE QUESTIONS

Q6: What are good and bad conductors?

Ans: Good Conductor:

Some materials allow heat to pass through them easily. They are called heat conductor or good conductors.

Examples:

Metals such as silver, iron, copper and aluminum etc. are the best heat conductors.

Bad Conductor or Insulator:

Some materials do not allow heat to pass through them easily. They are called heat insulator or bad conductor.

Examples: Wood, rubber, plastic, paper etc.

Q7. Discuss the conduction of heat in solids, liquids and gases?

Ans: Conduction in solids:

The metallic solid contains closely packed atoms and free electrons. These atoms and free electrons play an important role in the conduction of heat from one location to another. Thus the metallic solids are good thermal conductors. Non-metallic solids like plastic, wood glass etc. are poor conductors of heat because they do not have free electrons.

Conduction in liquids:

In liquids the inter-molecular distance is larger as compare to solids. Thus the rate of conductive collision in liquids is smaller than that of metallic solids. Thus the liquids are poor conductor of heat. So water is a poor conductor of heat.

Conduction in gases:

In gases the separation between particles is very large. Thus the rate of conductive collision in gases is very smaller as compare to solids and liquids. Thus the gases are the poorest conductor of heat. The conductivity of air is twenty times smaller than that of water. Many materials such as, wood, cloth, fiberglass and plastic foam etc. are poor conductors because they contain tiny packets of trapped air.

Q8. What are good and bad absorbers?

Ans: <u>Good Absorber (good radiator):</u>

The body which absorbs all radiation or maximum radiation fall upon it is called good absorber.

Example:

i. A dull black kettle absorbs heat better than a silver kettle.

ii. Standing in the sun, a black car warms up more quickly than any other.

iii. Black or dark coloured clothes are worn in cold climates, because black or dark colour is good absorber.

A perfectly black body absorbs all radiations falling on it. It does not reflect any radiation striking it.

<u>Bad Absorber (poor radiator):</u>

The body which absorbs minimum radiation and reflects maximum radiation falling upon it is known as bad absorber.

Example:

i. Silver mirror like surface are poor absorber, which reflect almost all the radiations falling on it.

ii. White clothes are worn in hot climates because white is a good reflector and a poor absorber.

CONCEPTUAL QUESTIONS:

Q1. Why white clothes are preferred wearing in summer? Explain briefly.

The white and light coloured clothes are most suitable in summer because they reflect maximum sun radiation and absorb minimum sun radiation and thus keep our body cool. That's why we feel comfort by wearing white clothes in summer.

Q2. Why is the freezer compartment kept at the top of a refrigerator? Explain briefly.

The freezer compartment kept at the top of a refrigerator, because it cools the surrounding air and makes it denser as compare to the air at the bottom. Convectional currents are used to circulate cold air in a refrigerator. The cool denser air moves down while the warmer air at the bottom moves up, where it is cooled. That is why, the freezer compartment is kept at the top of a refrigerator.

Q3. A black car standing in the sun warms up more quickly than any other. Why?

A black car standing in the sun warms up more quickly than any other car because the black surface is a good absorber of heat radiations than any other surface.

Q4. Why a tile floor feels colder to bare feet than a carpeted floor?

A carpet is a bad conductor of heat as compared to tile floor. When bare feet are put on the tile floor more heat is lost by the feet which is absorbed by the tile floor and as a result we feel cool. If we put the feet on a carpeted floor, we feel less coldness because in this case our feet losses no heat or very less amount of heat to the carpet. That is why a tile floor feels colder to bare feet than a carpeted floor.

Q5. How woolen sweaters keep us warmer in winter?
Woolen sweaters have fine pores filled with air. Air and wool are bad conductors of heat. Thus heat from our body does not flow out to atmosphere. Thus woolen sweaters keep our body warm in winter.

Q6. In certain places, birds can fly for hours without flapping their wings, Explain.
In certain places, there are streams of hot air which are arising from the sun such streams of hot air is known as thermals. Thermals are convection currents. The birds can fly for hours on thermals without flapping their wings. And this phenomenon occurs due to the convection of heat.

Q7. Good quality thermos bottle is double walled and evacuated between these walls, and the internal surfaces are like mirrors with a silver coating. How does this configuration combat heat loss for all three transfer methods and keep the bottle's contents your coffee hot?
Ans:-A thermos bottle consists of a double walled glass vessel silvered on the inside. The silvered surface reflects all the radiant heat trying to enter or leave the vessel by radiation. The space between the walls is highly evacuated to prevent convection. The glass being a poor conductor minimizes the conduction of heat. That is why a liquid placed in the thermos bottle will remain hot for a long time.

Q8. A piece of wood lying in the sun absorbs more heat than a piece of shiny metal. Yet the metal feels hotter than the wood when you pick it up. Explain.
Ans:-A material with high thermal conductivity will transfer heat at a much faster rate than a body with lower thermal conductivity. So, the metal has a high thermal conductivity and the wood has a low thermal conductivity. Even though the piece of wood lying in the sun absorbs more heat than a piece of shiny metal, but on touching the metal feels hotter than the wood. This is because the heat flows from metal to our hand more quickly due to its high thermal conductivity. On the other hand, wood is bad conductor of heat. When it is touched, heat flows slowly to our hand. So the metal feels hotter than the wood due to the difference of their thermal conductivities.

Q9. Some pot handles remain cool during cooking while others become unpleasantly hot. What determine which handles remain cool and which become hot?
Ans:-The thermal conductivity of the material of handles determines which handle remain cool and which become hot. When a pot handle is made of material which has high value of thermal conductivity such as metal, then it becomes hot quickly.

On the other hand, if the pot handle is made of material which has low thermal conductivity such as wood, then it does not get hot. Thus the handle of good conductors becomes hot and the handles of bad conductors remain cool.

Q10. When sunlight warms the land beside a cool body of water, a breeze begins to blow from the water towards the land. Explain.

Ans: Convection causes coastal breeze. During the day the sun shines equally on land and sea. The land heats up more quickly than the sea. The hot air over the land rises and the cold air from the sea blows to replace it. Thus there is a sea breeze during the day time.

ASSIGNMENT

9.1). Find the amount of heat transferred in one hour through a concrete wall of area 6.9m^2 and 0.20m thick. One side of the wall is held at 20^{o}C and the other side is at 5^{o}C. The thermal conductivity of concrete is 1.3JK^{-1}m^{-1}s^{-1}.

Data:

Area of concrete wall = A = 6.9m^2

Thickness off concrete wall = L = 0.20m

Temperature of one side of wall = T_h = 20^{0}C

Temperature of other side of wall = T_c = 5^{0}C

Thermal conductivity of concrete wall = k = 1.3JK^{-1}m^{-1}s^{-1}

Time taken = t = 1hour

$= 1 \times 60min$

$= 1 \times 60 \times 60\ sec$

= 3600sec

Find:

The amount of heat transferred through a concrete wall = Q = ?

Solution: -

By using formula

$$\mathbf{Q = \frac{kAt\ T_h - T_c}{L}}$$

putting Values

$$Q = \frac{(1.3)(6.9(3600)(20-5)}{0.20}$$

$$Q = \frac{(1.3)(6.9(3600)(15)}{0.20}$$

$$Q = \frac{484380}{0.20}$$

Q = 2421900 J

Q = 2.4 × 10^6 J

NUMERICAL QUESTIONS

1. A person's body is covered with 1.6m^2 of wool clothing. The thickness of the wool is 2.0× 10^{-3} m. The temperature at the outside surface wool is 11^{0}C, and the skin temperature is 36^{0}C. How much heat per second does the person lose due to conduction? Thermal conductivity of wool is k = 0.04 Wm^{-1}K^{-1}.

Data: -

Area = A = 1.6m^2

Thickness = L = 2.0×10^{-3}m

Inside Temperature = T_h = 36^{0}C

Outside temperature = T_c = 11^{0}C

Temperature difference = $T_h - T_c$ = (36-11)^{0}C

= 25^{0}C

Thermal conductivity of wool = k = 0.04 Wm^{-1}K^{-1}

Find:

Rate of flow of heat = $\frac{Q}{t}$ = ?

Solution: -

By using formula:

$$Q = \frac{kAt\,(T_h - T_c)}{L}$$

Or $$\frac{\mathbf{Q}}{\mathbf{t}} = \frac{\mathbf{kA(T_h - T_c)}}{\mathbf{L}}$$

putting values

$$\frac{Q}{t} = \frac{(0.04)(1.6)(25)}{2.0\ \times 10^{-3}}$$

$$\frac{Q}{t} = \frac{1.6}{2.0\ \times 10^{-3}}$$

$$\frac{Q}{t} = \frac{1.6}{2.0} \times 10^{3}$$

$$\frac{Q}{t} = 0.8\ \times 10^{3}$$

$$\frac{Q}{t} = 8\ \times 10^{-1}\ \times 10^{3}\ \text{J/s} \qquad \therefore \mathbf{J/s\ =\ watt}$$

$$\frac{Q}{t} = 8\ \times 10^{3-1}$$

$$\boldsymbol{\frac{Q}{t} = 8\ \times 10^{2}\ W}$$

2. The external wall of a brick house has an area of $16m^2$ and thickness 0.3m. The temperatures inside and outside the house are respectively 20^0C and 0^0C. Calculate the rate of heat loss through the wall. Thermal conductivity of brick is $k = 0.84Wm^{-1}K^{-1}$

Data: -

Area of wall = A = $16m^2$

Thickness = L = 0.3m

Inside Temperature = $T_h = 20^0C$

Outside Temperature = $T_c = 0^0C$

Temperature difference = $T_h - T_c = (20 - 0)^0C$

$= 20^0C$

Thermal conductivity of brick = $k = 0.84Wm^{-1}K^{-1}$

Find:

Rate of heat loss = $\frac{Q}{t}$ = ?

Solution: -

By using formula:

$$\frac{Q}{t} = \frac{kAt\,(T_h - T_c)}{L}$$

$$\frac{Q}{t} = \frac{kA(T_h - T_c)}{L}$$

putting values

$$\frac{Q}{t} = \frac{(0.84)(16)(20)}{0.3}$$

$$\frac{Q}{t} = \frac{268.8}{0.3}\ J/s$$

$$\frac{Q}{t} = \mathbf{896\ W}$$

3. Window glass has thermal conductivity of $0.8 Wm^{-1}K^{-1}$. Calculate the rate at which heat is conducted through a window of area is $2.0 m^2$ and thickness 4.0mm. The temperature inside an air-conditioned room is 20^0C. The outdoors temperature is0^0C 35^0C.

Data: -

Thermal conductivity = k = $0.8 Wm^{-1}K^{-1}$

Area = $2.0 m^2$

Thickness = L = 4.0mm

= 4.0×10^{-3}m

Inside Temperature = $T_c = 20^0C$

Outside Temperature = $T_h = 35^0C$

Temperature difference = $T_h - T_c = (35 - 20)^0C$

= 15^0C

Find:

Rate of heat conduction = $\frac{Q}{t} = ?$

Solution: -

By using formula:

$$\frac{Q}{t} = \frac{kA(T_h - T_c)}{L}$$

putting values

$$= \frac{(0.8)(2.0)(15)}{4.0 \times 10^{-3}}$$

$$= \frac{24}{4.0 \times 10^{-3}} \text{ J/s}$$

$$= \frac{24}{4.0} \times 10^3 \text{ J/s}$$

$$\frac{Q}{t} = 6 \times 10^3 \text{ J/s}$$

$$\boldsymbol{\frac{Q}{t} = 6 \times 10^3 \text{ W}} \qquad (\therefore \text{J/s} = \text{watt})$$