APPENDIX-I

INSTRUCTIONAL MATERIAL

Topic 1 : SPEED AND VELOCITY

CLASSROOM LEARNING MATERIAL (CLM)

Task analysis

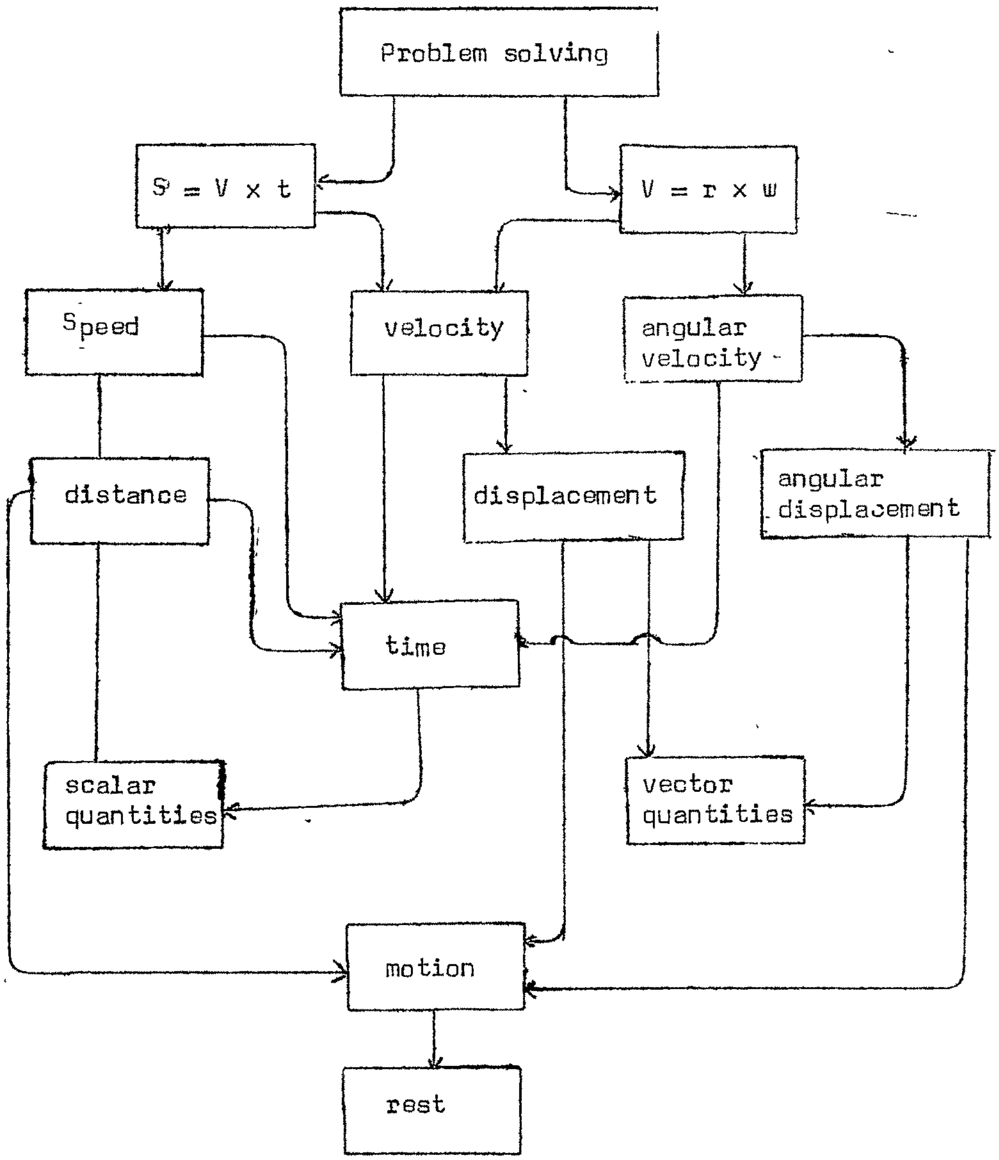


Fig. 1.1 Task analysis map - speed and velocity

Topic 1: SPEED & VELOCITY (CLM)

Learning hierarchy

The following are the learning objectives in the learning hierarchy shown in Fig.No.1.2.

When the topic is completed the students should be able to :

I. A. define rest and give examples.
   B. recognize that rest is not absolute but only relative.

II. A. define motion and give examples.
   B. recognize that motion is not an absolute event but relative.
   C. appreciate the fact that the bodies can be said to be in motion as well as at rest at the same time.
   D. define uniform motion and non-uniform motion and give examples.

III. A. define scalar quantities and give examples.

IV. A. define vector quantities and give examples.
   B. differentiate between vector and scalar quantities.
   C. state and illustrate triangle law of velocities.
   D. state and illustrate parallelogram law of velocities
   E. state and illustrate polygon law of velocities.
   F. determine graphically the resultant of two velocities.

V. A. measure time and give its unit.

VI. A. define distance and give its unit.
   B. measure distance.

VII. A. define displacement and give its unit.
   B. give the limitation of the concept.
   C. differentiate between distance and displacement.

VIII. A. define angular displacement and give its units.

IX. A. define speed.
   B. derive an expression for speed.
   C. derive the unit for speed.
   D. calculate the speed of a body from the given data.

Learning hierarchy

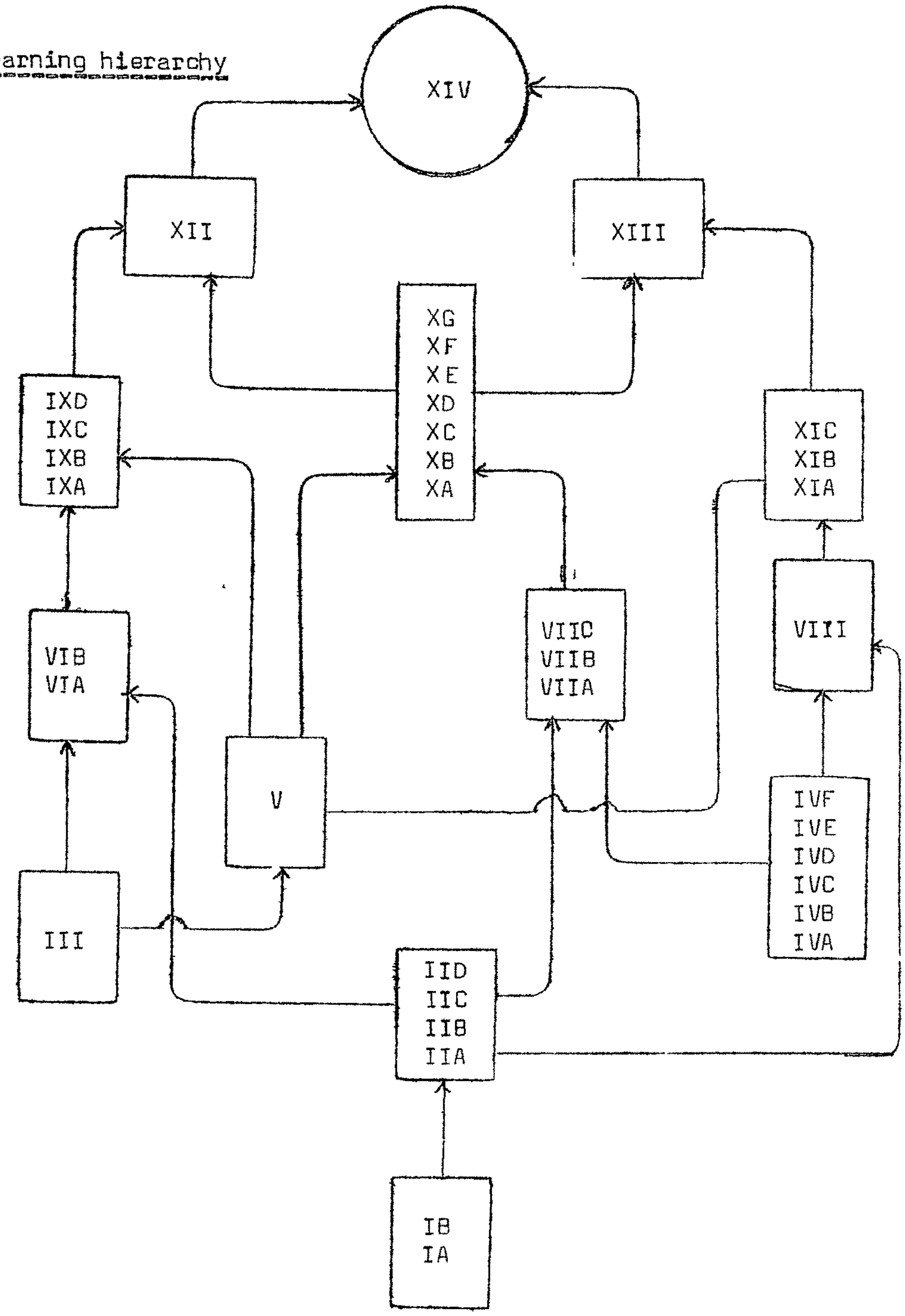


Fig. 1.2 Learning hierarchy – Speed and velocity

X. A. define velocity.
   B. derive an expression for velocity.
   C. derive the unit for measuring velocity.
   D. derive an expression for average velocity.
   E. distinguish between speed and velocity.
   F. define uniform velocity.
   G. calculate the value of velocity and average velocity from a given data.

XI. A. define angular velocity.
   B. derive an expression for angular velocity.
   C. state the unit in which angular velocity is measured.

XII. A. derive the . . relation between displacement velocity and time.

XIII. A. derive the relation between linear velocity and angular velocity.

XIV. A. solve problems on speed and velocity.

I. Rest

When a body does not change its position with the lapse of time with respect to its axis or some other object, the body is considered to be fixed, is called at rest.

A body, say a book, kept on the table remains there at the same position even after some time, we may say the book has not changed its posi ion not only with respect to time but also with respect to the table in this case. The book is at rest; fixed at its position.

There is no body in this universe which can be considered to be fixed in absolute terms. The idea of absolute rest is futile. Since the earth is rotating about its axis and also revolving round the sun, we cannot have reference points as trees, houses etc., to be bodies at absolute rest. Our reference points themselves are not at rest.

However, we define the bodies at rest on the surface of earth taking stationary objects such as trees, houses etc. assuming the earth itself to be at rest.

Thus, we must be clear of the fact that rest is not an absolute term, but relative. With reference to one object, a body can be at rest but with respect to asecond one, it need not be.

Evaluation

1. What do you mean by absolute rest?
2. Can any body be at absolute rest? If not, why?
3. Is it possible to have bodies at absolute, rest at any other part of the universe?
4. Define rest.

II. Motion

When a body changes its position with the passage of time with respect to its axis or some other object taken as fixed, then the body is said to be in motion.

The idea of absolute motion is also futile similar to that of absolute rest. Assuming the earth as stationary, we define all motions of the surface of earth.

Motion can either be uniform or non-uniform. Any object that moves through equal distances in equal interval of time, however small the time may be, is said to be in uniform motion. Any body that moves through unequal distances in any equal intervals of time, it is said to be in non-uniform motion. Motion can be linear, angular or circular depending upon the path it describes.

Two physical quantities have to be specified to completely describe motion.

i. The change in the position in space, with respect to a reference-point.

ii. The period of time over which the change of position occurs.

Evaluation

i. Define motion, uniform motion, non-uniform motion.
ii. Why we cannot speak of absolute motion?
iii. Give examples for- (1) lenear motion, (2) circular motion.
iv. Give an example for uniform motion.

III. Scalar Quantities

Scalar- A quantity that has only magnitude.

Examples- Mass, time, density, temperature, electric charge, distance.

Written Representation- A single magnitude written as either;

(i) a real-number multiple of a standard or well-defined unit (e.g. 6.5 kg., 9s. 136 g cm^{-3}, 273 K, 2°C);

OR

(ii) A diagrammatic representation of an absolute or a relative magnitude (Fig. 1.3 and 1.4).

Fig.1.3: Diagrammatic representation of absolute value. The sorter line is 1 cm long and represents an absolute length of 1 cm. The longer line is similarly 4 cms long.

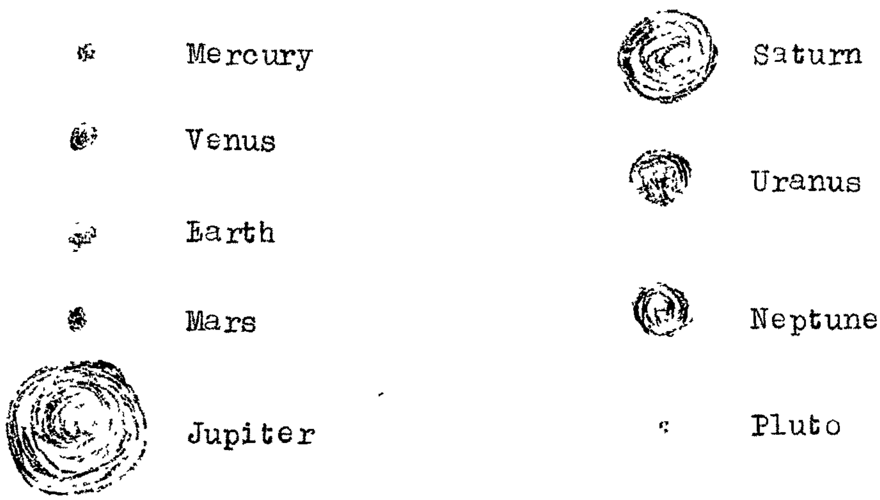


Fig.1.4: Pictorial representation of the relative size of the planets. Size of the planet is proportional to the area of the circle.

Evaluation

1. What are the conditions for a quantity to be scalar?
2. List a few examples for scalar quantities.

IV. Vector Quantities

Vector- A quantity that has m gnitude as well as direction.

Examples- Linear displacement, linear velocity, force, linear momentum, electric current.

Written Representation- One of the following:

i. a single letter of the alphabet printed in italic with an arrow over it.

(e.g. $\vec{r}$ $\vec{v}$, $\vec{F}$, $\vec{P}$, $\vec{I}$)

OR

ii. a single letter of the alphabet printed in bold. (e.g. **Y**, **V**, **F**, **P**, **I**)

OR

iii. a pair of capital letters of the alphabet, printed in italic with an arrow over it.

(e.g. $\overrightarrow{OA}$, $\overrightarrow{MN}$)

Specification

(i) Magnitude: Numerically specified by a scalar quantity (e.g., the magnitude of the force F is 2.5 N). Algebraically, the magnitude of a vector M is denoted by the same symbol in italic. *M* (e.g. the magnitude of the displacement r is *r*).

((ii) Direction: Specified verbally mathematically or pictorially with reference to a known reference-direction or co-ordinate system (e.g., the velocity of this car is directed due north).

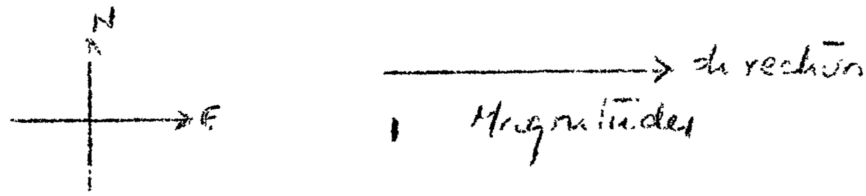
Pictorial Representation

A straight line with an arrow head (Fig.1.5).

(i) Magnitude: Pictorially represented by the length of the straight line from base to tip of arrowe head drawn to scale (Fig. 1.5).

(ii) Direction: Pictorially represented by the arrowhead with reference to a marked reference-direction or coordinate-system (Fig.1.5).

Fig.1.5:



<u>Fig.1.5</u>: Arrow representing vector quantity. Length of arrow is proportional to the magnitude of the vector quantity; arrowhead points in the direction of the vector quantity. To specify magnitude, a scale is necessary; for direction, a reference direction is necessary.

If we analyse some of the quantities known, like temperature or time we see that they are represented only by magnitude i.e., expressed by degree celsius or seconds, and as such they are scalar quantities. But in the case of force not only its magnitude but also its direction must be known to get a sensible idea. This makes force a vector quantity.

Scalar quantities like 5 gms and 2 gms can be added up easily to give 5+2=7gms vector quantities, however, cannot be added up like that since both direction as well as magnitude are involved. This can be done only in accordance with certain well formulated laws, called the laws of vector addition, and their addition is referred to as the composition of vectors or the composition of vector quantities, the sum of a number of vector quantities being spoken of as their resultant.

Thus, the resultant of a number of vector quantities is a quantity which, taken alone, will produce the same effect as is done by all those quantities taken together.

There are three laws of vector addition, viz., (i) the parallelogram law of vectors, (ii) the triangle law of vectors, and (iii) the polygon law of vectors.

(i) <u>The Parallelogram Law of Vectors</u>: If there be two vectors impressed simultaneously on a particle, such that they can be represented in magnitude as well as direction by the two adjacent sides of a parallelogram, their resultant is represented, both in magnitude and direction, by the diagonal of the parallelogram, passing through their point of interaction.

Thus, if u and ve be the two vectors, impressed simultaneously on a particle O, (Fig.1.6(a), such that they can be represented in magnitude as well as direction by the two adjacent sides AB and AD of the parallelogram ABCD (Fig.1.6(b), their resultant R is represented, both in magnitude and direction, by the

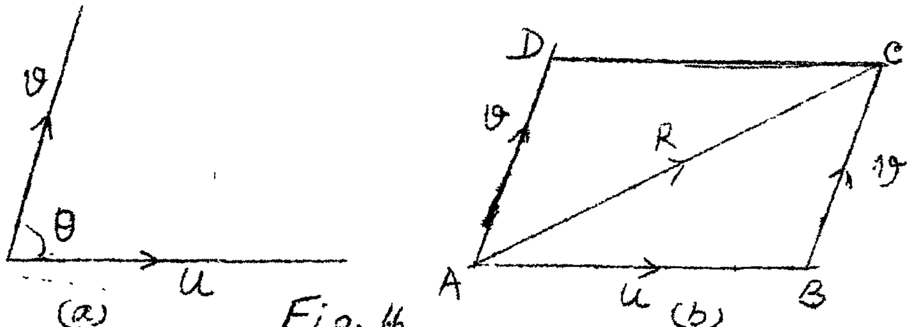


Fig. 16

diagonal AC of the parallelogram, passing through their point of intersection A.

(ii) <u>The Triangle Law of Vectors</u>: If there be two vectors impressed simultaneously on a particle, such that they can be represented in magnitude as well as direction by the two sides of a triangle, taken in order, their resultant is represented fully by the third side of the triangle taken in the opposite order.

Thus, if u and v be the two vectors impressed simultaneously on a particle O, (Fig.1.6(a)), such that they can be represented in magnitude as well as direction by the two sides AB and BC of the triangle ABC (Fig.1.6(b)), taken in order, their resultant is represented completely by the third side AC of the triangle, taken in the opposite order, (i.e., in the direction A to C).

(iii) <u>The Polygon Law of Vectors</u>: If there be a number of vectors impressed simultaneously on a particle, such that they can be represented in magnitude as well as direction by the sides of a polygon, taken in order, their resultant is represented completely by the closing side of the polygon, taken in the opposite order.

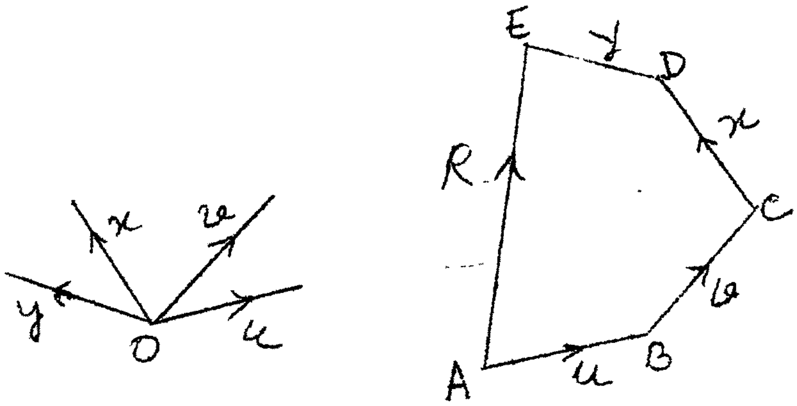


Fig. 1.7

If we have four vectors u, v, x and y, acting simultaneously on the object O, then this can be represented by ABCDE in magnitude and direction taken in order. Then their resultant is given by R (AE) in magnitude and direction.

NOTE: If two vectors are acting in the same direction then resultant is given by their sum (magnitude) and direction being the same as the components.

Evaluation

1. What are the requirements to make a quantity vector?
2. In what way vector quantities differ from scalars?
3. Classify the following as scalar/vector quantity:

i. Speed_ _ _ _ _ _
ii. Velocity_ _ _ _ _
iii. Acceleration_ _ _ _
iv. Force_ _ _ _ _ _
v. Work_ _ _ _ _ _
vi. Energy_ _ _ _ _
vii. Distance_ _ _ _ _
viii. Displacement_ _ _
ix. Time_ _ _ _ _ _
x. Density_ _ _ _ _
xi. Temperature_ _ _ _
xii. Momentum_ _ _ _ _
xiii. Mass_ _ _ _ _ _

4. If two vectors A and B (both acting southwards) are applied to a body what will be their resultant.
5. What will be the resultant of two vectors A southwards and B northwards acting on a body?

V. Time

The measure of an action, event or process that enables us to estimate the change.

Type of quantity: Scalar

Written representation: t

Specification: Magnitude: It is measured in seconds. Bigger units like minute (60 seconds) and hour (3600 seconds) are also used.

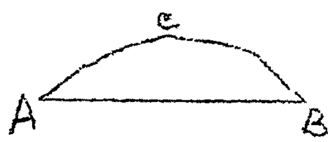
Dimensional representation: T

Demonstration of stopwatch to measure time.

Evaluation

1. Name some of units (other than the ones mentioned above), used to measure time.
2. How many seconds make one day?
3. What is one year?

VI. Distance



It is a measure of length between two points. The distance between two points may be different depending upon the path taken. Distance between A & B can be ACB or ADB.

Limitation: The distance need not be measured along a straight line and as such may not represent the shortest distance between two points.

Specification: 1. Being measured only by its magnitude, it is a scalar quantity. 2. Unit metre, kilometre, etc.

Dimensional representation: L

Evaluation

i. Name some of the units by which distances are measured.
ii. What makes distance a scalar quantity?

VII. Displacement

Linear Displacement (or, simply, Displacement): The change in the position of a physical body in a particular direction.

Type of Quantity: Vector

Written Representation: d

Dimensional Representation: L

Specification: (i) Magnitude: Straight line distqnce between initial and the final position; measured in metre (m). (ii) Direction: As that when moving from the initial to the final position, along a straight line.

Pictorial Representation: A straight line joining the initial to the final position with arrowhead at the final position. (See Fig. 1.8).

Limitation of the Concept: The displacement vector gives no indication of the actual path of motion of the body. (See Fig. 1.8).

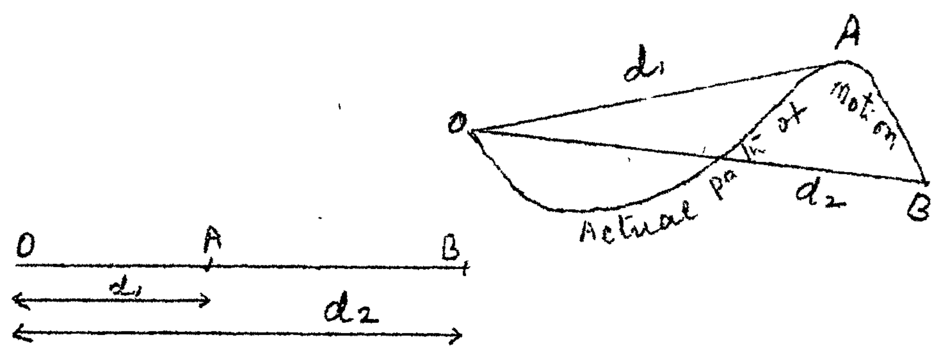


Fig.1.8: Displacement (a) for a body moving in a straight line, (b) for a body moving in a curved path d_1 is the displacement of the body at position A with respect to the reference point O and d_2 is the displacement of the body at position B with respect to the reference point O.

Evaluation

1. How does displacement differ from distance?
2. What are the units by which we can measure displacement?
3. Why the units of displacement and distance are the same?

VIII. Angular Displacement

We have seen earlier linear displacement. But for a body describing ciruclar motion the displacement will be angular or angular displacement, which is measured in terms of angle.

If a body moves from A to B then its angular displacement is equal to θ.

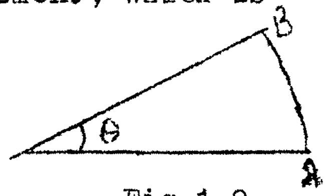


Fig. 1.9

Written representation: θ

Type of quantity: Vector

Specification: Angular displacement is measured in degrees or radians.

It may be noted that 180° = radians

Dimensional representation = ∠° (or dimensionless)

Evaluation

i. Can the angular displacement be same with varying linear displacement?

ii. If so, under what conditions?

iii. What is the advantage of using radian as the unit of angular displacement?

IX. Speed

Average speed (or simply, speed) - A measure of how fast a body is moving.

Type of Quantity: Scalar

Written Representation: u, v, u_i, u_f

Specification:

$$\text{Speed} = \frac{\text{actual distance travelled}}{\text{time elapsed}}$$

OR $$u = \frac{s}{t}$$

Magnitude: The scalar ratio (s/t), measured in metre per second (ms^{-1}).

Note: If the speed of a body changes, its initial speed is denoted by ui and its final speed by uf.

Dimensional equation: LT^{-1}

A demonstration of the movement with the help of marbles of different sizes will clearly show the difference speed of the marbles due to the varying time taken by them to cover the same distance. One another unit of speed is km/hr usually used by automobiles.

$$1 \text{ km/hr} = \frac{1000 \text{ m}}{60 \times 60 \text{ sec}} = \frac{10}{36} \text{ m/sec}$$

Evaluation

1. Name few units by which speed can be expressed.
2. What type of quantity is speed?
3. When a body covers 10 metres in 2 seconds, what is its speed?
4. Convert 36 km/hr to m/sec.

X. Velocity

Now let us again look at the movement of marbles.

A^{x} B^{x}

Let the two points be marked on the table. Unless the marble is pushed in a particular direction it will not reach B. Thus to describe the motion of a body the direction is also important.

Average Linear Velocity - (or, simply, velocity). The rate of displacement of a body from an initial to a final position.

Type of Quantity: Vector
Written Representation: v, v_i, v_f, u

Specification:

$$\text{Velocity} = \frac{\text{Displacement}}{\text{Time Elapsed}}, \text{ OR } \quad v = \frac{d}{t}$$

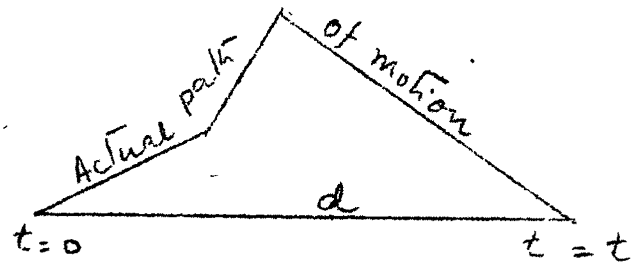


Fig.1.10: For a displacement d taking place in time t the velocity $v = d/t$

(i) Magnitude: The scalar ratio (d/t) measured in metre per second (ms^{-1}).

(ii) Direction: Same as that of the displacement vector.

Dimensional equation: LT^{-1}

Notes: (i) If the velocity of a body changes, its initial velocity is denoted by u and its final velocity by v.
(ii) In the case of changing velocity, the average velocity is given by

$$V_{av} = \frac{v + u}{2}$$

Calculation :

i. If a body covers 100 m in 5 seconds then its velocity will be

$$\frac{100 \text{ m}}{5\text{s}} = 20 \text{ m/s}$$

ii. If the body changes its initial velocity from 10 m/s to 20 m/s then

$$V_{av} = \frac{10+20}{2} = 15 \text{ m/s}$$

Uniform Velocity: If a body covers equal distances in equal intervals of time in a particular direction then the body is said to be moving with uniform velocity.

Evaluation:

1. Distinguish between speed and velocity.
2. What are the units of velocity?
3. Why does the unit of velocity is the same as that of speed?
4. Why velocity is a vector quantity?
5. Can two velocities be added up as that of speed?
6. If a body covers 100 m in the first 10 sec and 50m in the next 8 sec, what will be its average velocity?

XI. Angular Velocity

If a body moves from A to B in time t then its angular displacement is equal to θ. Angular displacement per unit time is known as angular velocity.

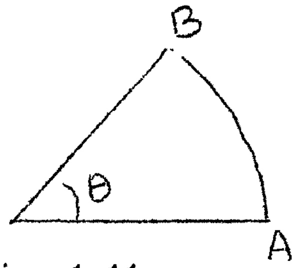


Fig. 1.11

Written representation: w
Type of quantity: Vector

Specification:

$$\text{Angular Velocity} \qquad w = \frac{\text{Angular Displacement } \theta}{\text{time } t}$$

$$\text{OR} \qquad w = \frac{\theta}{t} \text{ radians/sec}$$

Dimensional equation = $\angle^{\circ} T^{-1}$

Evaluation

1. Can the linear velocity have different values for the same angular velocity.
2. Is the angular velocity same for a body moving with constant speed?
3. Calculate the angular velocity in radians/s for a body describing 60° angular displacement in 5s time.

XII. Relation Between Displacement and Velocity

We have seen that the average velocity is the distance travelled in unit time. We can represent the same as

$$V_{av} = \frac{s}{t}$$

$$\text{OR} \qquad s = V_{av} \times t$$

where s = displacement

V_{av} = average velocity

t = time

i.e.,

$$s = \frac{v+u}{2} t \qquad \text{OR simply} \quad s = V \times t$$

Evaluation

1. What are the factors on which the distance travelled depends?
2. What is average velocity?
3. Why do we take average velocity instead of actual velocity in the above equation?

XIII. Relation Between Angular Velocity and Lenear Velocity

We know that the angular velocity $w = \frac{\theta}{t}$

Here, we can draw out a relation between linear velocity and angular velocity.

We know that

$$\theta = \frac{Arc}{radius}$$

$$= \frac{AB}{r}$$

OR $AB = r\theta$

When a body moves from A to B in time t then linear velocity or simply velocity is -

$$Velocity = \frac{Displacement}{Time}$$

$$v = \frac{AB}{t} = r\frac{\theta}{t} = r.w$$

i.e. $v = rw$

Evaluation

i. Under what conditions the linear velocity and angular velocity be same.

ii. Can the unit of angular velocity be

$$w = \frac{v}{r} = \frac{m/s}{m} = 5^{-1} ?$$

XIV. Problem Solving

(a) A car covers a 150 kms with a speed at the rate of 50 kms/hr and another 80 kms at the rate of 40 kms/h^{-1}. Calculate the average speed for the whole journey.

(i) S_1 = 150 km $\qquad$ S_2 = 80 km

$V_1 = 50$ km h^{-1} $\qquad$ $V_2 = 40$ km h^{-1}

(ii) Average speed?

(iii) $\text{Average speed} = \dfrac{\text{Total Distance Covered}}{\text{Total Time Taken}}$

$S = S_1 + S_2 \qquad t = t_1 + t_2$

(iv) $S_1 = 150$

$V_1 = 50$ km h^{-1}

$$t_1 = \frac{S_1}{V_1} = \frac{150}{50} = 3 \text{ hrs}$$

$$t_2 = \frac{S_2}{V_2} = \frac{80}{40} = 2 \text{ hrs}$$

$$S = S_1 + S_2 = 150 + 80 = 230 \text{ kms}$$

$$t = t_1 + t_2 = 3 + 2 = 5 \text{ hrs}$$

(v) $\text{Average speed} = \dfrac{S}{t} = \dfrac{230}{5} = 46$ km/h

(b) A man is walking on foot. He covers 5 kms in an hour. We say that he is moving at a speed of 5 kms per hour ($\frac{5 \text{ kms}}{h}$). This speed can be expressed in several ways. In one minute this man moves a distance given by :

$$\frac{5 \text{ kms}}{1 \text{ h}} = \frac{5 \text{ kms}}{60 \text{ min}} = \frac{(5)1000 \text{ m}}{60 \text{ min}} = \frac{83.3 \text{ m}}{\text{Min}}$$

We can still express this rate of change of distance (speed) as the distance the man moves in the second:

$$\frac{5\ kms}{1\ h} = \frac{5 \times 1000\ m}{(1) \times (60 \times 60)s} = 1.4\ \frac{m}{s} \text{ or } 1.4\ ms^{-1}$$

(c) A merry-go-round of 10 m radius with children sitting on it, is revolving at the rate of 1 rev. per minute. Calculate the speed of children sitting on it. (All India Secondary Examination, 1979).

(1) radius = 10 m

rate = 1 rev. per minute

(2) Speed of the children?

(3) To determine the speed of the children we must know the distance travelled by them.

$$V = \frac{Distance}{Time}$$

$$= \frac{2 \pi r}{t}$$

(4) $V = \frac{2 \times 22 \times 10}{7 \times 60}$

(5) $V = 1.047\ ms^{-1}$

Evaluation

1. A car travels a certain distance with a speed of 50 km h^{-1} and returns with a speed of 40 km h^{-1}. Calculate the average speed for the whole journey.

(Delhi Secondary Examination, 1979)

2. If a body covers 25 kms with a speed of 5 km/h and next 30 km at the rate of 6 km/h calculate the average speed.

Topic 1: SPEED & VELOCITY

Self Learning Material

(SLM)

We come across a large number of thing around us. Of these some move and others do not move. A body is said to be moving when its position keeps changing with respect to a fixed body taken as reference. The passengers sittings in a moving bus are moving as their position keeps changing with respect to the objects on the road. The tree, electric poles and several other bodies, by the side of the road, don't change their position and therefore are at rest.

When a body changes its position with the passage of time with respect to its axis of some other body taken as fixed, is said to be in.............. ....(1)

When a body does not change its position with the lapse of time with respect to its axis or some other, body considered to be fixed, then the body is said to be at.............. ....(2)

In our daily life, we come across with the measurements of various physical quantities. We measure mass in kilograms, length in metres, volume in litre, time in second and speed in metre/second. The measurement of these quantities only involve magnitude.

Such quantities which are represented by magnitude only are called........... ....(3)

In order to get complete idea about the motion of a body, we must know besides its speed (magnitude), the direction in which it moves. The measurement of velocity of a body involve magnitude (as in SPEED) and the direction of motion. Similarly measurement of displacement of a moving body involve, magnitude (as in distance moved by the body) and the direction in which the distance is moved.

If a pilot is to take off an aeroplane from Delhi for Madras, he is to be told the distance and direction of destination. Similarly, there are other quantities as well which need both magnitude and direction.

All such quantities which are represented by magnitude and direction are called....... ....(4)

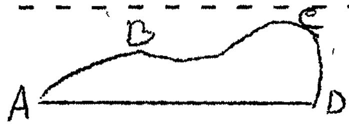
The distance between two given points may be different or same along different paths taken. It has only magnitude.

It is known as a.........quantity. ....(5)

The displacement between two given points will always be same and minimum because it is the distance in one direction.

It is known as a...........quantity. ....(6)

Now let us look at the figure. A body travels through the path ABCD to reach D from A.



Displacement between the points A & D is......... (AD/ABCD) ....(7)

Distance covered between the points A & D is............ ....(8)

The distance travelled by a body in a unit time is called speed.

The speed does not refer to any direction. The distance travelled by a body may be along a straight path or a curved path. The speed is a scalar quantity.

Speed = $\frac{\dots\dots\dots\dots}{\dots\dots\dots\dots}$ ....(9)

If a body moves with non-uniform speed, its speed cannot be easily determined at every moment, so it is convenient to know its average speed

If a non-uniform motion, the average speed of a body is determined as the total distance travelled by the body divided by the total time taken by it.

Average Speed = $\frac{\dots\dots\dots}{\dots\dots\dots}$ ....(10)

Many objects move with different speed and some examples are given below:

Object	Speed	
Man walking on foot	1.5 m/s	(Approx)
Mail Train	30 m/s	"
Aeroplane	220 m/s	"
Sound in air at 0°C	332 m/s	"
Bullet from a rifle	860 m/s	"
Sound in water	1500 m/s	"
Moon round the earth	1 km/s	"
Earth round the sun	29.9 km/s	"
Light and radio waves	3×10^5 km/s	"

Do these values represent actual speed or average speed? ....(11)

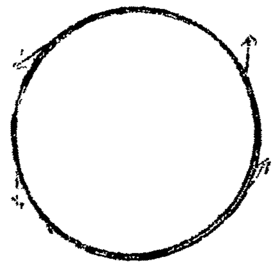
The terms speed and velocity are often used synonymously. However, speed gives an idea of the slow or fast motion of a body, but it does not tell about the direction of motion. Many problems in astronomy, transportations, artillary, navigation and other fields of science and engineering are solved more conveniently when some specific direction is assigned to speed. Thus, a specific direction assigned to speed gives a new physical quantity known as velocity which is a vector quantity.

Velocity may be defined as the distance travelled by a body in unit time in some specific direction.
OR
Rate of change in position with time in a particular direction is called velocity.
OR
Rate of change of displacement is called velocity.

Velocity = $\frac{..............}{..............}$ ....(12)

The unit of velocity is............ ....(13)

Next, let us consider a body moving with a constant speed along a circular path. Its direction will keep on changing continuously.



Direction of a body moving along a circle changes continuously.

The body is said to be moving with .... velocity. (constant/varying) ....(14)

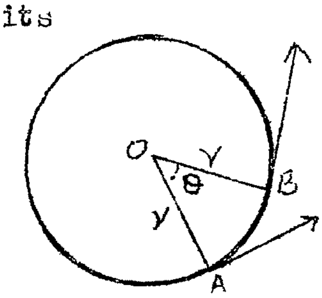
From the above example, we can say that even when the speed is same the velocity can be...... ....(15) (same/different)

As the velocity is a measure of displacement in unit time the displacement can be written as displacement is .... x ....(16)

The same can also be written as

S = ... x . . . .(17)

Let us take the case of uniform circular motion of a particle. Suppose it moves from A to B (distance s apart) in time t (Fig.). Its speed will be s/t. We can also express its motion in another form. It has moved an angle subtended at the centre O of the circle. It has described an angle θ radius in a time t. When the displacement is measured in terms of angles the velocity can be termed as angular velocity.



Angular velocity = $\frac{\text{Angle in radians}}{\text{............}}$ ....(18)

This can be represented by

$w = \frac{\theta}{t}$ where θ is angle in radians t in seconds and w angular velocity.

The unit of angular velocity is...... ....(19)

When we consider the total angle around a point it is equal to 360° which is equal to 2π radius. Then

One degree = _ _ _ _ _ _ radius. ....(20)

- -

We know that

Angular velocity $w = \frac{\theta}{t}$

By the knowledge of geometry we can write Angle substended by the Arc AB at the centre of circle.

θ = Arc (AB)/radius of the circle (r)

OR $\theta = \frac{AB}{OA} = \frac{S}{r}$ (∴ AB=S and OA=r)

$$w = \frac{\theta}{t}$$

$$= \frac{S}{r} \times \frac{1}{t} = \frac{S}{t} \times \frac{1}{r}$$

$$= \frac{v}{r}$$

OR $v = rw$

It is interesting to know that all the particles on a rotating disc will have the same angular velocity but their linear velocity will differ as the distance moved by different particles will differ for the same interval of time. This is evident if we look at the equation $v = rw$.

Even when w is constant v change as the value of r changes.

- -

A body placed on a rotating disc is allowed to go to its centre and it rotates. Then its linear velocity goes on_ _ _ _ _ _ (increasing/decreasing) ....(21)

- -

A motor car is moving with a uniform speed of 40 km/h. Calculate its distance travelled in 6 hours.

Solution: Here, v = 40 km/h, t=6h s=?

$v = s/t$ $s = vt$

= _ _ _ _ _

*

= _ _ _ _ _ ....(22)

- -

An aeroplane is flying at a uniform speed. It travels a distance of 200 km in 1.25 hours, calculate its speed in km/h and m/s.

Solution: s = 200 km. t=1.25 h, v=?

$$v = \frac{s}{t} = \frac{200\ km}{1.25\ h} = \ldots\ldots\ldots \quad \ldots\ldots(23)$$

Speed in m/s?

$$v = \frac{160\ km}{1\ h} = \frac{160 \times 1000m}{60\ minutes} = \frac{160 \times 1000m}{(60x60)s}$$

$$= \ldots\ldots\ldots \quad \ldots\ldots(24)$$

Topic 1: SPEED & VELOCITY

Self Evaluation Material (SEM)

I. Complete the following statements:

a. Speed is a........quantity since it has magnitude only.

b. Velocity is a vector quantity since it indicates.........as well as magnitude.

c. A physical quantity is termed as........if magnitude and direction are indicated.

d. Average speed = $\frac{.............}{\text{Total time taken}}$

e. A toy can starts from a point in a circle of 5 metres and comes back to the same point. Then

Distance covered = ...

Displacement = ...

II. Encircle the most suitable word which join the statement given.

a. In order to detect motion you need

i. a change in speed
ii. to be isolated from all other objects
iii. to be within a vehicle
iv. a point of reference.

b. The rate at which the object moves in a given direction is called-

i. speed
ii. motion
iii. magnitude
iv. velocity

III. An object is moving with a constant velocity of 50 m/sec. How far will it travel in 20 seconds?

- -
- -
- -

IV. Classify the following into scalar and vectors:

10 kms, speed, velocity, 20 kms towards sky, 10 kgs, 1 hour, 15 sq.cm, 10 cu.metres.

Scalar	Vector
......	......
......	......
......	......

V. Which of the following is a vector?

a. Temperature
b. Mass
c. Volume
d. Speed
e. Displacement

VI. Calculate the angular velocity of the rotation of the earth.

- -
- -
- -

VII. Explain whether a fly which is riding round on the edge of a playing record is moving with constant speed or constant velocity.

- -
- -
- -

VIII. A certain space satellite always move at 3000 metres per second. Explain this is its constant speed or its constant velocity.

- -
- -
- -
- -

KEY TO SLM

1. Motion (2) rest
2. Rest
3. Scalar
4. Vector quantities
5. Scalar
6. Vector
7. AD
8. ABCD
9. $\frac{\text{Distance travelled}}{\text{Time Taken}}$
10. $\frac{\text{Total Distance Travelled}}{\text{Total Time Taken}}$
11. Average speed
12. $\frac{\text{Displacement}}{\text{Time}}$
13. m/s
14. Varying
15. Different
16. Velocity x Time
17. $S = v \times t$
18. Time taken
19. Radians/sec
20. π /180
21. Decreasing
22. 240 kms
23. 160 km/h
24. 14.44 m/s

KEY TO SEM

I. a. Scalar
   b. Direction
   c. Vector
   d. Total distance
   e. 10m, 0

II. a. iv
   b. iv

III. 100 m

IV. Vectors Velocity
   20 kms ------> Sky

V. Displacement

VI. $\frac{2}{24 \times 60 \times 60}$

VII. Constant speed

VIII. Constant speed

Topic 1: SPEED & VELOCITY

Assessment Material (AM)

Section A

I. Match the expressions in B by selecting the MOST closely related express one from A.

A	B	(R)
a. Rate of displacement	Speed	(✗)
b. Continuous change of location	Displacement	( )
c. Rate of motion	Linear motion	( )
d. Sum of component velocities	Velocity	( )
e. Quantities with magnitude and direction	Scalar	( )
	Angular Velocity	( )
f. Motion in a straight line	Vectors	( )
g. Rate of angular displacement	Motion	( )
h. 10 metres	Radians	( )
i. Angular displacement	Distance	( )
j. A measure of length between two points	Radians	( )

II. In the blank space at the right of each statement write the word on expression which BEST completes the meaning.

1. If the velocity of an object is constant the motion is said to be..1.. ....(1)

2. Since the velocity has both magnitude and..2a.. it is a..2b..quantity ....(2a) ....(2b)

3. A physical quantity is termed as ..3.. if it has only magnitude. ....(3)

4. Temperature is a ..4.. quantity. ....(4)

Section-B

III. Write the answers in the blanks provided.

1. Keeping the time constant if the velocity of a moving body is doubled what happens to the displacement. ....(1)

2. If the velocity and time are doubled what happens to the displacement. ....(2)

3. If the displacement is expressed in terms of kilometres and time in hours what will be the unit of measurement of velocity. ....(3)

4. If the angular velocity of a rotating body increases what happens to its linear velocity. ....(4)

5. A fly which is riding round on the edge near centre of a playing record moves towards its edge. What happens to its linear velocity? ....(5)

(increases/decrease)

Section C

IV. Convert 3 km/per to m/sec.

- -
- -
- -

V. If a body is moving with a velocity of 3 m/sec for 30 minutes, what will be the displacement?

- -
- -
- -

VI. A truck moved 10 km at the rate of 50 km/hr and then 20 km at the rate of 40 km/h. Calculate the average velocity.

- -
- -
- -

Topic 2 : ACCELERATED MOTION

CLASSROOM LEARNING MATERIAL (CLM)

TASK ANALYSIS

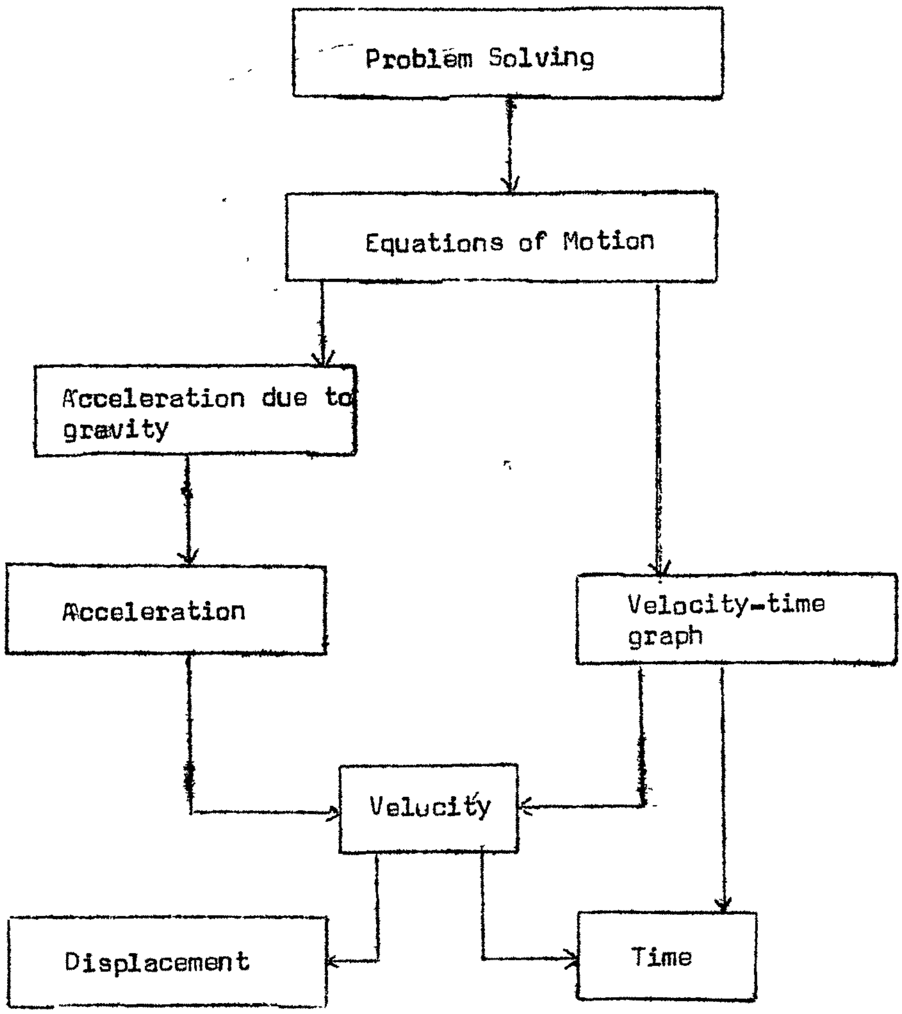


Fig. 2.1 Task analysis map - accelerated motion

Topic 2: Accelerated Motion

Learning hierarchy

The following are the learning objectives in the learning hierarchy shown in Fig.No.2.2.

When the topic is completed the student should be able to:

I. recall the concept displacement.

II. recall the concept time.

III. recall the concept velocity.

IV. A. define acceleration.
B. derive an expression for acceleration.
C. derive the unit for expressing acceleration.
D. recognize retardation as negative accelera[illegible]

V. A. plot a graph between velocity and time.
B. interpret the graph with respect to-
i. uniform motion
ii. uniformly accelerated motion
iii. uniformly decelerated motion
and iv. irregular motion

VI. A. define free fall
B. define acceleration due to gravity

VII. A. derive $v = u+at$ algebraically
B. derive $s = ut + \frac{1}{2} at^2$ algebraically
C. derive $v^2 = u^2 + 2as$ algebraically
D. derive $v = u+at$ graphically
E. derive $v = ut + \frac{1}{2} at^2$ graphically
F. state the equations for vertical motion

VIII. A. calculate velocity, acceleration and dista[illegible] from velocity time graphs
B. solve the problems involving equations of motion.

Concept Revision

I. Displacement
II. Time
III. Velocity

Learning hierarchy

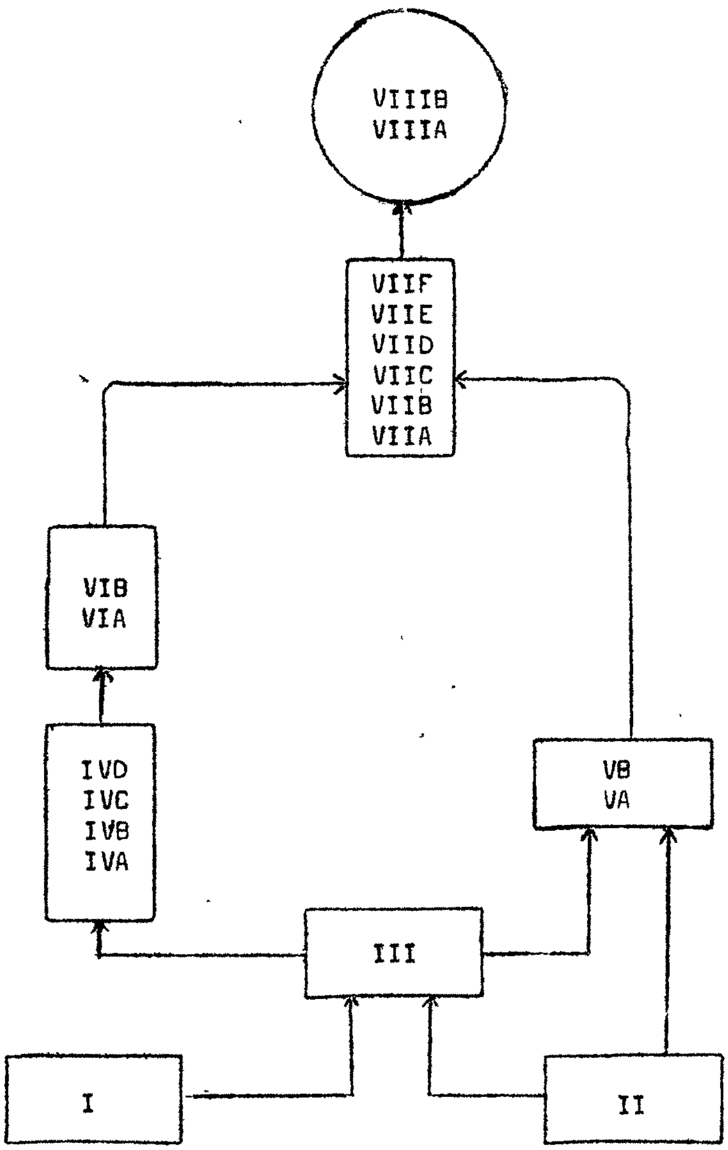


Fig. 2.2 Learning map - accelerated motion

Evaluation

1. Differentiate between distance and displacement?
2. What are the units in which time is measured?
3. How does the velocity differ from speed?
4. Can the velocity of a body change when the body is moving with constant speed?
5. When does the velocity change?

IV. Acceleration

The rate of change of velocity of a body in motion.

Type of Quantity: Vector
Written Representation: a
Specification:

$$\text{Acceleration} = \frac{(\text{final velocity}) - (\text{initial velocity})}{\text{Time elapsed}}$$

If u is the initial velocity and v the final velocity and t the time taken,

$$a = \frac{v - u}{t}$$

The change mentioned in the above definition can either increase or decrease depending upon the value of v & u.

(i) Magnitude: Measured in metre per second per second (ms^{-2}) acceleration =

$$\frac{m/s}{s} = \frac{m}{s^2} = ms^{-2}$$

(ii) Direction: Same as that of the velocity and the displacement vectors of the body.

Dimensional Equation: LT^{-2}

Deceleration (or Retardation)

The inverse acceleration acting on a body, the rate of decrease of the velocity of a body in linear motion.

Examples: (i) When the brakes are applied on a moving car, the vehicle decelerates.
(ii) When a ball is thrown upwards, it decelerates

Type of Quantity: Vector
Written Representation: a
Specification: In the case of deceleration u
so a is negative.

(i) Magnitude: Measured in metre per second per second (ms^{-2}) or (m/s^2).

(ii) Direction: Opposite to that of the velocity and the displacement vectors.

Note: Retardation is actually negative acceleration.

Evaluation

1. What is the acceleration of a body moving with constant velocity? (D.S.E. 1980).
2. A body goes round the sun with constant speed in a circular orbit. Is the motion uniform or accelerated? (Delhi Secondary Examination, 1978)
3. Does the earth move round the sun with a uniform velocity? (Delhi Secondary Examination, 1979)
4. Define a uniformly accelerated motion and give one example of it. (Delhi Secondary Examination, 1977)
5. Define the term 'acceleration'.

V. Velocity-Time Graph

We can plot a graph between the velocity (on Y-axis) and time (on X-axis) for the motion and obtain a velocity-time graph.

1. For Uniform Motion: Suppose the velocity is 10 metres/sec which remains unchanged throughout. Initially the velocity is 10 metres/sec, at the end of 1 second again the velocity is 10 metres/sec, at the end of 2 sec also the velocity is 10 metres/sec and so on. Thus, we get a graph as shown in Fig.1. If the body was in motion for 6 seconds then the graph will be the straight line AB parallel to the X-axis.

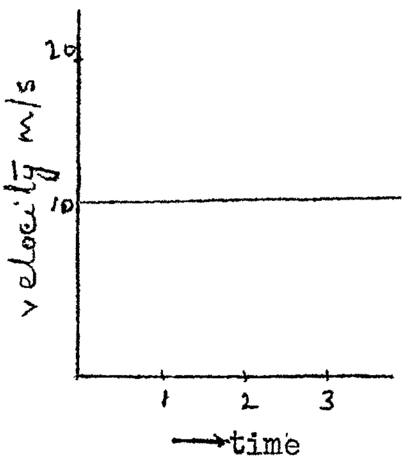


Fig.1 uniform motion -moving with constant velocity

2. For Uniformly Accelerated Motion: Suppose the body starts from rest and the acceleration is 3 metres/sec^2 throughout the motion. We can plot a graph between its velocity and time for the first 6 seconds of its motion.

Plotting the graph between the two quantities, we get the straight line OP which is inclined to the X-axis.

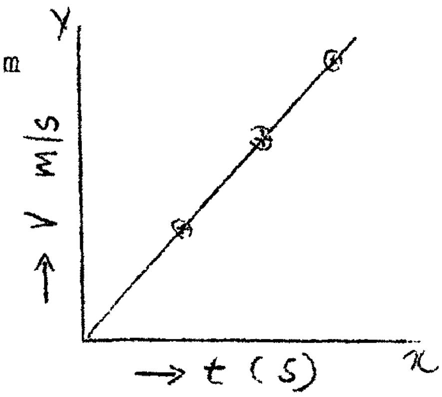


Fig.2. Graph Between Velocity and Time (Motion with a Uniform Acceleration).

3. For Uniformly Decelerated Motion: Suppose the driver of a train applies to bring it to a stop. If we plot a graph between velocity and time we get a graph as shown in Fig.3.

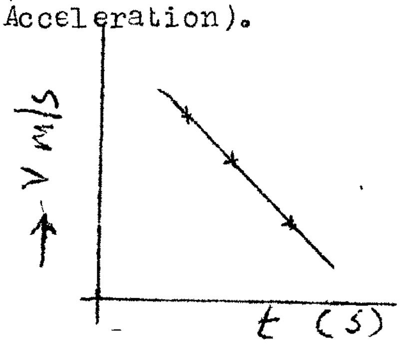


Fig.3: The graph of the velocity versus time of a body subjected to uniform retardation. The velocity of the body is not zero when retardation starts.

4. When the velocity of the moving body varies in an irregular way, the graph is like the curve as shown in Fig.4.

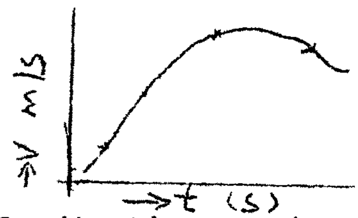


Fig.4: Velocity-time graph when acceleration is not constant.

NOTE: 1. Speed is the magnitude of velocity for uniform linear motion. You can as well plot the speed vs time.

2. The area under the velocity time graph, which is in fact is the product of velocity and time, is a measurement of the distance travelled by the body.

3. The slope of the velocity time graph at any instant gives the value of acceleration.

$$\text{i.e.,} \quad a = \frac{Y}{X}$$

Evaluation

1. What does the slope of a velocity-time graph indicate? (Delhi Secondary Examination, 1980)
2. When the velocity-time graph is a straight line with a +ve slop, what can you about its acceleration?
3. How will you find out the distance travelled by a body from the velocity time graph?
4. What type of motiom is represented in the following graphs:

VI. Acceleration Due to Gravity

Free Fall

All bodies, large or small, on the surface of the earth, if lifted to a certain height and then released, are found to fall on the earth's surface. But we usually find that heavier bodies like steel ball, stone, brick etc. fall faster than the ligher bodies like a piece of paper, feather etc.

Take a piece of paper and a one rupee coin. Drop the two from a certain height and observe the fall. You will find that the coin falls faster than the piece of paper and also reaches the ground earlier. Now fold the paper so that its area may be minimum and drop the folded piece of paper and the coin from the same height. What do you find now? This time you will find that the coin falls slightly faster than the folded piece of paper, but the difference in the rate of falling is very small. This simple experiment illustrates that it is not the mass of the bodies on which rate of fall depends, but the resistance caused by the air decreases the rate of fall of lighter bodies having greater surface area.

Aristotle, a Greek philosopher had also the false concept about the falling bodies. But Galileo for the first time said that all bodies, large or small, would fall at the same rate if there is no air resistance. Later on Newton verified Galileo's idea by an experiment known as Feather and Guinea Experiment.

A long glass tube containing a feather and a silver coin was taken. When the tube was turned upside down, the feather and the coin were found to fall but with different rates of fall.

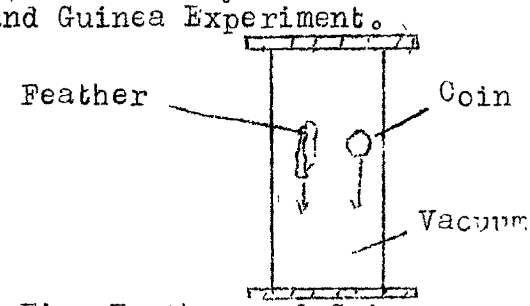


Fig. Feather and Guinea Experiment

When the experiment was repeated after evacuation, it was found that both th- feather and the coin fell at the same rate and strike the bottom together.

All bodies, large or small fall with the same acceleration, if there is no air resistance. This is known as free fall.

OR

Free fall is the motion of bodies subjected only by the force of gravity.

Acceleration Due to Gravity (g)

Bodies falling freely are accelerated uniformly due to the gravitational attraction of the earth. The acceleration is same at a place for all falling bodies.

The acceleration due to gravity is defined as the acceleration produced in a body during free fall due to attraction of the earth.

The acceleration due to gravity is not the same at all places. It varies from place to place. It has maximum value at sea level. The value of g decreases as we go up the mountain etc. Therefore the value of 'g' will be minimum on the top of Everest.

Evaluation

1. Define acceleration due to gravity.
2. What is the unit of 'g'?
3. What do you think, the value of g in space?
4. Do you think the value of g will be same as on the surface of different planets?

VII. Equations of Motion

Equations of Linear Motion: The linear motion of a a uniformly accelerated or uniformly decelerated ~~by~~ body can be described quantitatively. This quantitative description is given the form of three equations, which relate velocity, acceleration, displacement and time.

In the case of a non-uniform motion, let us consider a body travelling along a straight line. The body starts with an initial velocity (u) and attains a velocity (v) in a time (t), the uniform acceleration (a) will be given by -

$$a = \frac{v - u}{t}$$

or

$$at = v - u$$

or $$v = u + at$$

By now, we have already got a relation between initial velocity (u), final velocity (v), time (t) and the uniform acceleration (a) of a moving body :

$$v = u + at \qquad \text{.....(A)}$$

Let us find out the average velocity of such a body. As the average velocity (V_{av}) of a body is the average of its velocities in this case the initial and final velocities.

$$V_{av} = \frac{u + v}{2} \qquad \text{.....(B)}$$

Thus, distance (s) travelled by this body in the time (t) will be given by the relation

$$s = V \times t$$

$$s = \frac{(u + v)}{2} t \qquad \text{.....(C)}$$

Combining the relations (A) & (C), we get -

$$s = \frac{(u + u + at)t}{2}$$

$$= ut + 1/2\ at^2 \qquad \text{.....(D)}$$

Some time another relation between u, v, s and a is helpful. We can write the relation (A) as $v - u = at$ and the relation (C) as

$$v - u = at \qquad \text{......(1)}$$

$$v + u = \frac{2s}{t} \qquad \text{......(2)}$$

Multiplying the relation (1) and (2), we get

$$(v-u)(v+u) = at \frac{2s}{t} \text{ or } v^2 - u^2 = 2as \qquad \text{.....(E)}$$

Equations A, D and E are known as equations of motion.

Equations of Motion by Graphical Method

(a) $v = u + at$

Let a body start with an initial velocity 'u' represented by OP in figure 2.51. Suppose the body is moving with uniform acceleration 'a', then the velocity time graph is a straight line PQ. Suppose the point Q on the graph PQ, gives the velocity 'y' and time 't'. Draw a perpendicular QA from Q at X-axis. Then QA = t and QA = v.

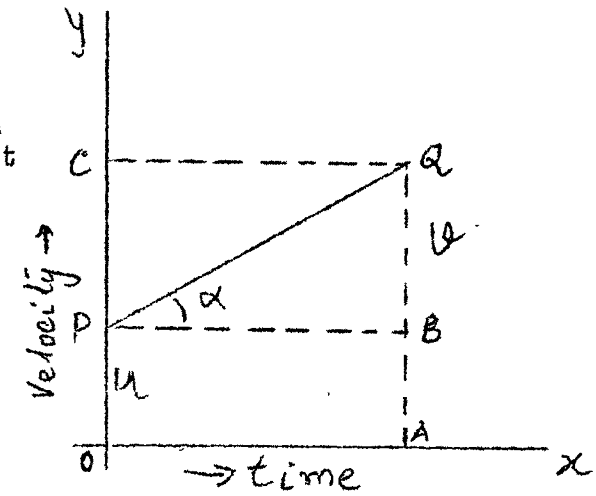


Fig.2.51: Velocity-time Graph of Motion of a Body

The slope of the velocity-time graph PQ gives acceleration 'a'.

Then $a = \tan \alpha = \frac{QB}{PB}$

OR $QB = a \times PB$

$= a \times t$

But $QA = AB + BQ$

Therefore $v = u + at$ .....(1)

(b) $s = ut + 1/2at^2$

Suppose distance travelled by the body in time 't' is 's'. Then

s = area of OPQA

s = Area of rectangle OABP + Area of triangle PBQ

$s = (OA \times AB) + (1/2PB \times QB)$

$s = t \times u + 1/2 \times at$

Therefore $s = ut + 1/2at^2$ .....(2)

(c) $v^2-u^2 = 2as$

From (1) $t = \frac{v - u}{a}$

Substituting the value of t in (2)

$$s = u\frac{v-u}{a} + \frac{1}{2} a \frac{v-u}{a}^2$$

$$s = \frac{uv-u^2}{a} + \frac{v^2-2uv+u^2}{2a}$$

$$s = \frac{2uv-2u^2+v^2-2uv+u^2}{2a}$$

$$2as = v^2-u^2$$

OR $v^2-u^2 = 2as$ .....(3)

NOTE:

(i) The three equations of motion involve only scalar quantities.

(ii) The equations can be applied only to a body moving with unfform acceleration or deceleration along a straight-line path. For deceleration, replace a by -a.

(iii) Since the equations are applicable only to uniformly accelerated or decelerated inear motion, the magnitude of velocity can be replaced by the speed of the body, and the displacement can be replaced by the actual distance covered by the body in motion.

Equations for Vertical Motion

Obviously the equations of motion i.e., A, D & E (Section VI) about the accelerated motion are all applicable in the case of a body falling freely under the action of gravity. For this we have to replace 'a' by 'g' and height (h) for the distance (s), the value of 'g' and 'h' are taken positive in the downward direction. Thus, for the motion of freely falling body, the equations (A), (D) and (E) can be re-written by making the required changes.

$v = u + gt$ .....(A')

$h = ut + 1/2gt^2$ .....(D')

$v^2 - u^2 = 2gh$ .....(E')

NOTE: If the body is dropped from rest its initial velocity u=0 and the equations (A),(D) and (E) take new form:

$v = gt$ .....(A")

$h = 1/2gt^2$ .....(D")

$v^2 = 2gh$ .....(E")

Evaluation

1. Rewrite the equations of motion for a body moving upwards freely.
2. Are these equations of motion valid if the body is moving with constant velocity?
3. Write the equation for a body thrown up vertically, for the maximum height it reached.
4. If a body is thrown up vertically with a velocity v; what will be its velocity when it is abcut to touch the ground on its return?

VIII. Problem Solving

1. A scooter acquires a velocity of 36 km h^{-1} in 5s just after start. Calculate the acceleration of the scooter. (All India Secondary Examination, 1979).

$u = 0$
$v = 36$ km/h
$= 36 \times \frac{10}{36}$
$= 10$ m/sec
$t = 5$ sec

$$a = \frac{v-u}{t}$$

$$= \frac{10-0}{5}$$

$$= 2 \text{ m/sec}^2$$

2. A bus starting from rest moves with a uniform acceleration of 0.1 m/s^2 for 2 minutes. Find (a) the speed acquired, (b) the distance travelled.

(a) $u = 0$
$v = ?$
$a = 0.1 m/s^2$
$t = 2mt$ (Minutes)
$= 120s$

$v = u+at$
$= 0+0.1x120$
or $v = 12m/s$

(b) We know
$s = ut+\frac{1}{2}at^2$

$= 0+\frac{1}{2} x \frac{1}{10} x 120x120$

$= 720m$

$s = 720m$

3. A train is travelling at a speed of 90 km per hour. The brakes are applied so as to produce a uniform acceleration of $-0.5m/s^2$. Find how far the train goes before it is brought to rest.

$u = 90$ km/hr $= 25$ m/s

$v = 0$

$a = -0.5m/s^2$

$s = ?$

$V^2 = u^2+2 as$

$0 = (25x25)-1xs$

OR $s = 25x25$

OR $s = 625$ m

4. In the figure is shown the position of a body at different times. Calculate the speed of the body as it moves from A to B, B to C and C to D.

What is the distance travelled by the body in the last four seconds. (Delhi Secondary Examination, 1977)

- - - - - - - - - - - - - -
- - - - - - - - - - - - - -
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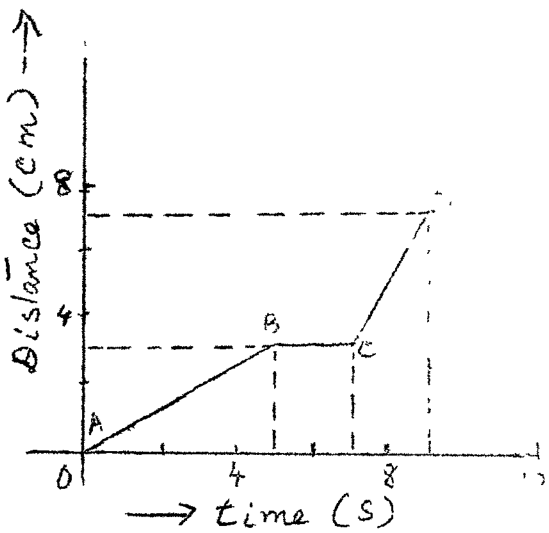
(km s^{-1}, 0 cms^{-1}, 2cms^{-1})



A ball thrown vertically upwards is caugh b the thrower in 5 seconds. Calculate the highest poi reached and also its initial velocity. You may take of acceleration due to gravity to be $10\frac{m}{s^2}$.

Here magnitude of the initial velocity u v=0 at the highest point where the ball reaches an

$$t = \frac{5}{2}s \quad h = ?$$

and $$g = 10\frac{m}{s^2}$$

By using the relation A" i.e. v=u-gt, we ge

$$0 = u - \frac{(10m)}{s^2}\ \frac{5}{2}\ s$$

OR

$$u = \frac{25m}{s}$$

Next we can use the relation $h= ut-1/2gt^2$

Thus, $$h = 25\frac{m}{s} \times \frac{5}{2}\ s - \frac{1}{2}\ \frac{10m}{s}\ \left(\frac{5s}{2}\right)^2$$

$$= \frac{125}{}m - \frac{125}{4} = \frac{125}{4}\ m = 31.25m$$

Hence the highest point reached by the ball i 31.25m and the initial velocity is $\frac{25m}{s}$ vertically up.

Evaluation

1. A bus was moving with a speed of 54 km h^{-1}. On applying brakes it stopped in 8s. Calculate the acceleration. (Delhi Secondary Examination, 1981)

2. A body starts to slide over a horizontal surface with an initial velocity of 0.5 ms^{-1}. Due to friction its velocity decreases at the rate of 0.05 ms^{-2}.

(Hint-Acceleration = -0.05 ms^{-2})

How much time will it take for the body to stop? (Delhi Secondary Examination, 1978).

3. A ball thrown vertically upwards is caught back by the thrower after 4 seconds. Find the velocity with which the ball was thrown up.

Topic 2: Accelerated Motion

Self Learning Material (SLM)

To Students:

In the previous topic we have discussed speed and velocity. We often hear of an accelerator in a car or even accelerating motion. Acceleration tells us how quickly the velocity is changing. Without the knowledge of acceleration we cannot describe the motion of a body completely. We have studied in the class all about acceleration. Here let us look at it little more minutely. While trying to answer the exercises given, you may refer back the classroom teaching/learning material supplied to supplement your knowledge of a particular concept as and when required or when any difficulty arises.

Most of the motions we come across in our daily life situations are non-uniform motion. A car starting from rest constantly increases its speed till it acquires the required speed.

When brakes are applied by the driver of a bus, the magnitude of the velocity of bus decreases with time. Similarly while taking a turn, driver decreases the speed of the bus. In this case, magnitude of the velocity (Speed) and also the direction of the velocity changes with time.

To represent the changing velocity we make use of an important physical quantity called acceleration. It is defined as the rate of change of velocity with time or in simple words change of velocity in unit time.

$$\text{i.e., acceleration} = \frac{\dots\dots\dots\dots}{\text{Time taken}} \qquad \dots(1)$$

If 'v' represents final velocity, 'u' initial velocity and 't' the time taken and 'a' the acceleration then acceleration can be represented as

$$a = \frac{\dots\dots\dots}{\dots\dots\dots} \qquad \dots(2)$$

Velocity is represented by metre/sec while time by seconds. Therefore the unit of acceleration will be as follows:

$$a = \frac{\dots\dots\dots}{\dots\dots\dots} = \dots\dots\dots / \dots\dots\dots \qquad \dots(3)$$

In the definition of acceleration, the word change, implies an alteration in magnitude or in direction or in magnitude as well as in direction. After all change in velocity is also velocity as change in rupees is also rupees.

Therefore acceleration is a ....quantity. ....(4)

As we have seen earlier in the case of the bus when the brakes are applied the velocity of the bus goes down to zero; meaning thereby the change is negative. Therefore acceleration can be negative known as retardation.

Retardation = ...acceleration. ....(5)

Unit of retardation = ...(6)

Positive Acceleration: If the velocity increases with time, the acceleration is said to be +ve acceleration.

Negative Acceleration: If the velocity decreases with time, the acceleration is said to be -ve acceleration.

Zero Acceleration: If a body is at rest or moving with uniform velocity, the body is said to have zero acceleration or no acceleration

Sometimes it is possible that the change in velocity remains the same throughout. That is, if a car changes its velocity from 5 m/sec to 10 m/sec in first second and then from 10 m/sec to 15 m/sec in the 2nd second the change in first as well as in the second is 5 m/sec each. That is, the change is same. In that case we may say that the body is moving with uniform acceleration.

When a body moves with non-uniform velocity such that there is equal change in velocity in equal intervals of time, however small the time interval may be, the body is said to be moving with uniform acceleration.

Now let us take the case of a train. It starts slowly from rest from a railway station and takes some time to catch speed. After some time it moves with a uniform speed say on a straight track.

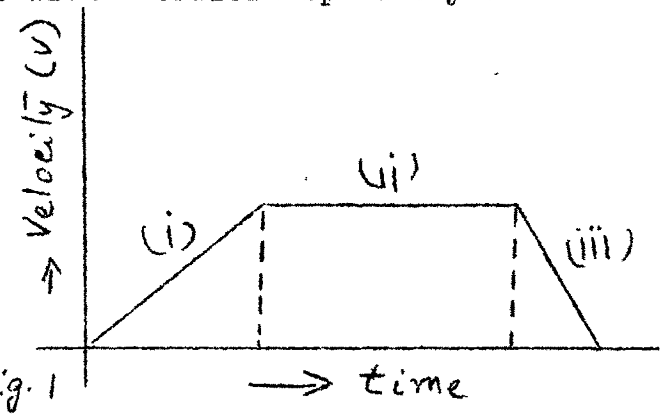


Fig. 1

Again this train starts loosing speed soon before reaching another station. This time a negative acceleration acts and finally the train stops. We can plot a graph (Fig.1) between velocity and time for this complete motion as described here. Three distinct stages (i), (ii) and (iii) of motion can be viewed at a glance from the graph.

In the first stage velocity x increases, inthe second stage, it remains constant and in the third stage, velocity goes on decreasing.

For stage I acceleration = ___ (+ve/0/-ve) ....(7)

For " II " = ___ (") ....(8)

For " III " = ___ (") ....(9)

These type of graphs are called velocity time graphs. The velocity time graph of a uniform motion is a straight line parallel to the time axis.

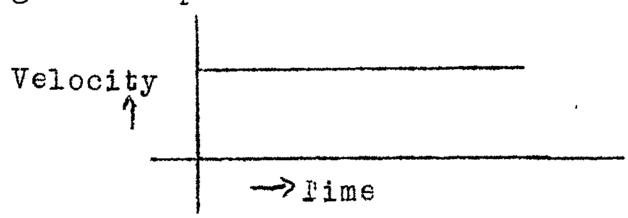


Fig.2

The velocity time graphs have a very important application. We have already learned in the first topic that the distance travelled = velocity x time taken.

If we now look at the graph carefully, we see that the product of velocity and time is actually equal to the area under the graph. That is, we come to conclusion that distance travelled is equal to area under the velocity time graph.

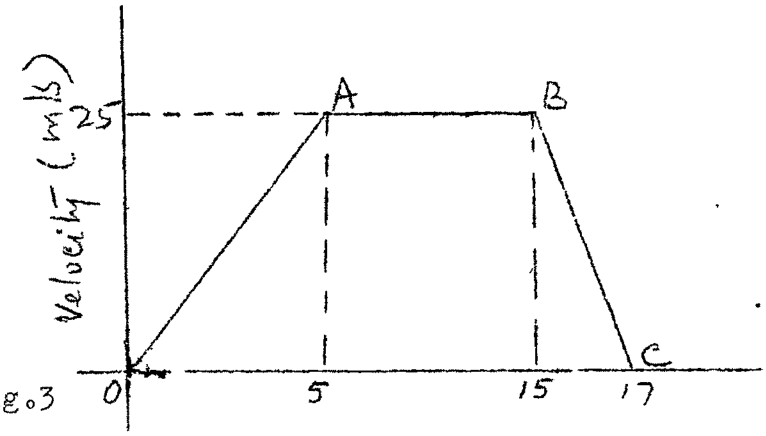


Fig.3

In the graph shown here the distance covered is equal to the area of the trapezium 1 OABC.

- -

$$\therefore \text{ distance travelled } = \frac{AB + OC}{2} \, AE$$

$$= \frac{\cdots\cdots}{\cdots\cdots} \times \cdots\cdots$$

$$= \cdots\cdots \qquad \cdots\cdots(10)$$

- -

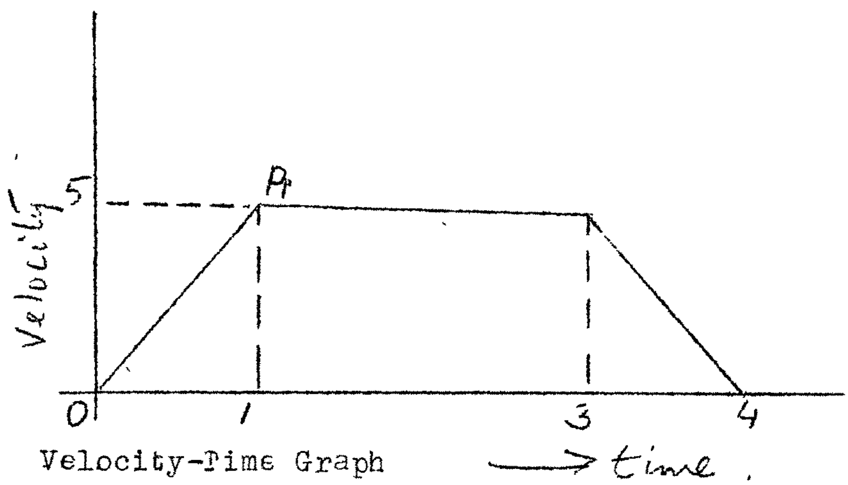


Fig.4: Velocity-Time Graph

In the graph given above the distance travelled

in the first second
= Area of Triangle ABE
= $\frac{1}{2}$ base x height
= ....(11)

The distance travelled in
the 2nd and 3rd second = ...(12)

From the velocity time graph, we can also determine the acceleration of the body. It is given by the slope (gradient) of the graph line. Scope of a straight line graph is given by

$$m = \frac{y}{x}$$

i.e., the value along y axis divided by corresponding value along x axis.

In the graph above for the Ist stage

Acceleration = $\frac{.....}{.....}$ = 5 m/sec^2 ....(13)

It is our common experience that when a body let free in the air falls to the ground. It is due to the force of attraction exerted by the earth on that body. The acceleration thus gained by the body is known as acceleration due to gravity. (Refer to 2.4 of Classroom Materials).

Therefore we can define acceleration due to gravity as:.......................
....(14)

The unit of acceleration due to
gravity is............. ....(15)

When a body is thrown up vertically its velocity goes on decreasing giving rise to uniform retardation while the descending bodies gain velocity gradually.

Therefore ascending bodies have..........
acceleration. ....(16)

Descending bodies have........
acceleration. ....(17)

The motion of a body can be thoroughly studied using the following equations of motion. Refer to 2.5 classroom materials for direction.

$v = u + at$	$v = u + gt$
$s = u + \frac{1}{2} at^2$	$s = u + \frac{1}{2} gt^2$
$v^2 = u^2 + 2as$	$v^2 = u^2 + 2gh$

The first set describes linear motion along a horizontal plane while second set describes the motionof bodies under acceleration due to gravity in a vertical plane.

Rewrite the second set of equations for body moving upwards.

$v =$ .....
$s =$ .....
$v^2 =$ ....(18)

Which equation can be used to determine the value of a where initial velocity, final velocity and time are given.

....(19)

Rewrite the equations of motion for a body in motion, starting from rest.

$v =$ ......
$s =$ ......
$v^2 =$ ....(20)

The final velocity of an object starting from rest is equal to

a/b/c/d ....

a. product of acceleration and time
b. division of distance by time
c. division of acceleration by time
d. none of these. ....(21)

A car travelling at 80 km/h is slowed down to 44 km/h in 15 seconds; calculate the acceleration.

Given Final velocity v = 44 km/h
Initial velocity u = 80 km/h
Time taken t = 15 seconds

To find a = ?

Solution:

$$a = \frac{\text{Change of velocity}}{\text{Time taken for change}}$$

$$= \frac{\text{Final velocity - Initial Velocity}}{\text{Time Taken}}$$

$$= \frac{v - u}{t}$$

$$= \frac{(44-80)\ km/h}{15\ seconds} = \qquad \ldots\ldots(22)$$

The velocity of a body undergoing uniform acceleration increases from 20 m/s to 40 m/s while it travels 100 metres. Work out its acceleration and the time taken to travel 100m.

Given $u = 20$ m/s
$v = 40$ m/s
$s = 100$ m

To find $a = ?$
$t = ?$

Solution:

$$v^2 - u^2 = 2as$$

$$\therefore a = \frac{v^2 - u^2}{2s} = \frac{\ldots\ldots}{\ldots\ldots} = \ldots\ldots \qquad \ldots\ldots(23)$$

As $v = u + at$

or $t = \frac{v-u}{a}$

$$= \frac{\ldots\ldots}{\ldots\ldots}$$

$$= \ldots\ldots \qquad \ldots\ldots(24)$$

By the application of brakes a car running at 54 km/h is brought to rest in 10 seconds. Find the acceleration produced and the distance covered after the application of brakes.

Given $u = 54$ km/h

$= \frac{5400 \text{ m}}{3600 \text{ s}}$

$= 15$ m/s

$v = 0$

$t = 10$ seconds

To find $a = ?$

$s = ?$

$a = ...$

$s = ...$ .....(26)

Topic 2: Accelerated Motion

Self Evaluation Material (SEM)

I. Directions: In the blank sp ce at the right of each statement, write the word or expression which BEST completes the meaning.

1. The rate of change of velocity is called....... 1

2. If the velocity of a body is constant, its acceleration is.... 2

3. When the velocity of a body increases or decreases the same amount in successive units of time, the acceleration is.... 3

4. Motion of this kind is described as......accelerated motion. 4

5. An object which moves linearly 2.0 m during the first second, 6.0 m during the second second, and 10.0 m during the third second has an acceleration of.... 5

6. In terms of x s and t, acceleration is expressed as... 6

7. The acceleration due to gravity (is constant, varies)......over the earth's surface. 7

8. In air, den. objects fall (slower than, at the same speed as, faster than)...... objects of lower density. 8

II. Directions: Write the answers to the following in the spaces provided. Where appropriate, make complete statements.

9. What algebraic relationship expresses the displacement of an object in terms of its average velocity and elapsed time of travel? 9

10. In cases of uniformity accelerated motion, how may the final velocity be expressed in terms of initial velocity, acceleration, and elapsed time? 10

11. During any interval of time in which the initial and final velocities are known, how is the average velocity expressed algebraically? 11

12. A car accelerates uniformly from a speed of 36 km/hr to 72 km/hr in 30 minutes.

a. What is its acceleration? 12a
b. How much distance will it cover? 12b

13. A proton travelling at 5×10^6 m/sec is retarded by an electric field at the rate of 10^4 m/sec^2.

a. What time is required to bring the proton to rest? 13a

b. How far does the proton travel? . . . 13b

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14. A stone is dropped from the top of a house and is found to reach the ground in one second. How high is the house? 14

- - - - - - - - - - - - - - - - - - -
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Topic 2: Accelerated Motion

Key to S.L.M.

1. Change in velocity
2. $\frac{v-u}{t}$
3. $\frac{m}{s^2} = m/s^2$
4. Vector
5. Negative
6. m/s^2
7. +ve
8. Zero
9. -ve
10. $\frac{10+17}{2} \times 25$
11. $\frac{1}{2} \times 1 \times 5 = 2.5$
12. $2 \times 5 = 10$
13. $\frac{5-0}{1} = 5$
14. Acceleration due to the gravitational attraction.
15. m/s^2
16. -ve
17. +ve
18. $v = u - gt$
    $s = u + \frac{1}{2}gt^2$
    $v^2 = u^2 - 2gh$
19. $v = u + at$
20. $v = at$
    $s = \frac{1}{2}at^2$
    $v^2 = 2as$
21. a
22. $-0.67\ m/s^2$
23. $6\ m/s^2$
24. 3.33s
25. $-1.5\ m/s^2$
26. 75

Key to SEM

1. Acceleration
2. Zero
3. Uniform
4. Uniformly
5. $4m/s^2$
6. s/t^2
7. Varies
8. Faster than
9. $d = V_{av} \times t$
10. $v = u + at$
11. $V_{av} = \frac{u+v}{2}$
12. $72\ km/hr^2$, 27 km
13. 5×10^{-8} sec, 0.125 m
14. 4.9 m

Topic 2: Acceleration Motion

Assessment

Section A

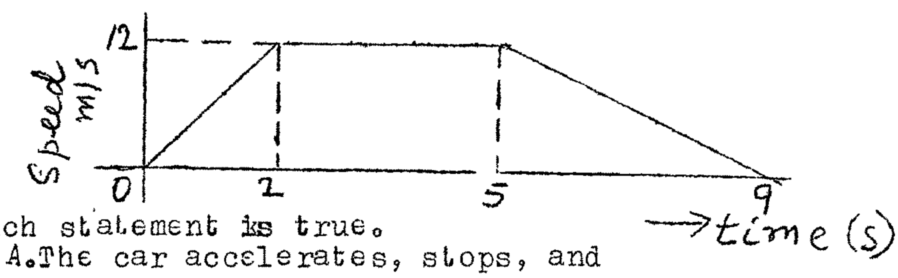
1. Select the most appropriate from the choices given (A/B/C/D).

a. Acceleration is the rate of change of.......
A. direction   C. velocity
B. speed   D. none of these.

b. A body moving with uniform speed along a circular path. . . . .
A. has no acceleration
B. has a variable velocity
C. has some acceleration
D. none of these

c. When a body is thrown up its velocity goes on......
A. increasing   C. remains constant
B. decreasing   D. none of these

d. The graph represents the motion of a car.



Which statement is true.
A. The car accelerates, stops, and reverses.
B. The car accelerates at 6 m/s^2 for 2 sec.
C. The car is moving for a total time of 12 seconds
D. The car decelerates at 12 m/s^2 for 4 sec.

2. Fill in the blanks.

a. Negative acceleration is called.......
b. When a body is thrown up vertically velocity at the highest points is..........
c. What is the acceleration of a body moving with uniform velocity?........
d. Can the direction of velocity change when the acceleration is constant?. ....

e. What is the S.I. Unit of acceleration?........
f. What is the standard value of g?.. ....
g. when a body is descending is the value of g negative or positive?........
h. Two bodies of different masses m_1 and m_2 ($m_1 \gg m_2$) dropped from the same height in vacuum which one will strike the ground earlier........
i. What is the S.I. Unit of g?........

3. Define the following:

a. Acceleration:
- -
- -

b. Acceleration due to gravity (g):
- -

c. Uniform acceleration:
- -

Section B

4. Select the most suitable statement A/B/C/D.

a. The distance travelled by a body starting from rest and moving with uniform acceleration is........
  A. directly proportional to the square of time
  B. inversely proportional to square of time
  C. directly proportional t time
  D. inversely proportional to time.

b. Final velocity of a body starting from rest is equal to........
  A. product of acceleration and time
  B. division of distance by the time
  C. division of acceleration by the time
  D. none of these

c. You observe an object covering distances in direct proportion to the squafe of time elapsed. What conclusion might ydu draw about its acceleration?........
  A. Increasing
  B. Decreasing
  C. Zero
  D. Constant

5. Derive the following relations:

a. $v = u + at$ (analytical method)

b. $S = ut + \frac{1}{2} at^2$ (graphical method

c. $v^2 = u^2 + 2as$ (analytical method)

Section C

6. A car starting from rest covers a distance of 100 km in 2 hours with a uniform acceleration. Calculate its acceleration.

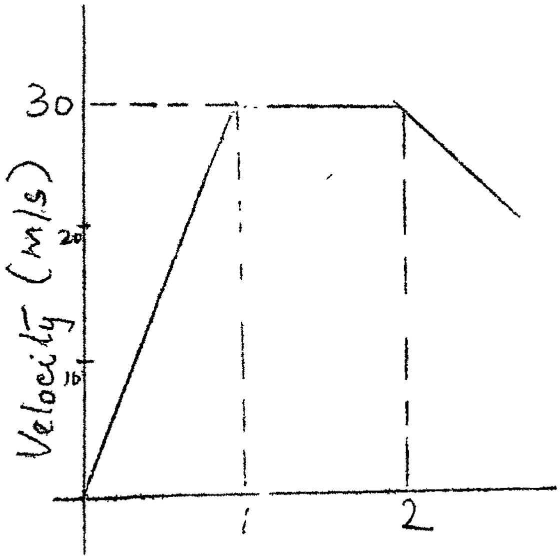
7. An electron moving with a velocity of 5×10^4 m/s enters an electric field and attains an acceleration of 10^{15} m/s^2 in the direction of its original motion. In how much time will the velocity of the electron become twice its original velocity?

8. The graph represents the velocity time graph of the motion of a car.

Calculate:

i. acceleration in the first second.

ii. distance travelled in the first two seconds



9. A ball thrown up is caught by the thrower after 6 seconds.

Calculate:

i. with what velocity was it thrown at?

ii. how high did it go?

Topic 3 : NEWTON'S LAWS I & II

CLASSROOM LEARNING MATERIAL (CLM)

Task analysis

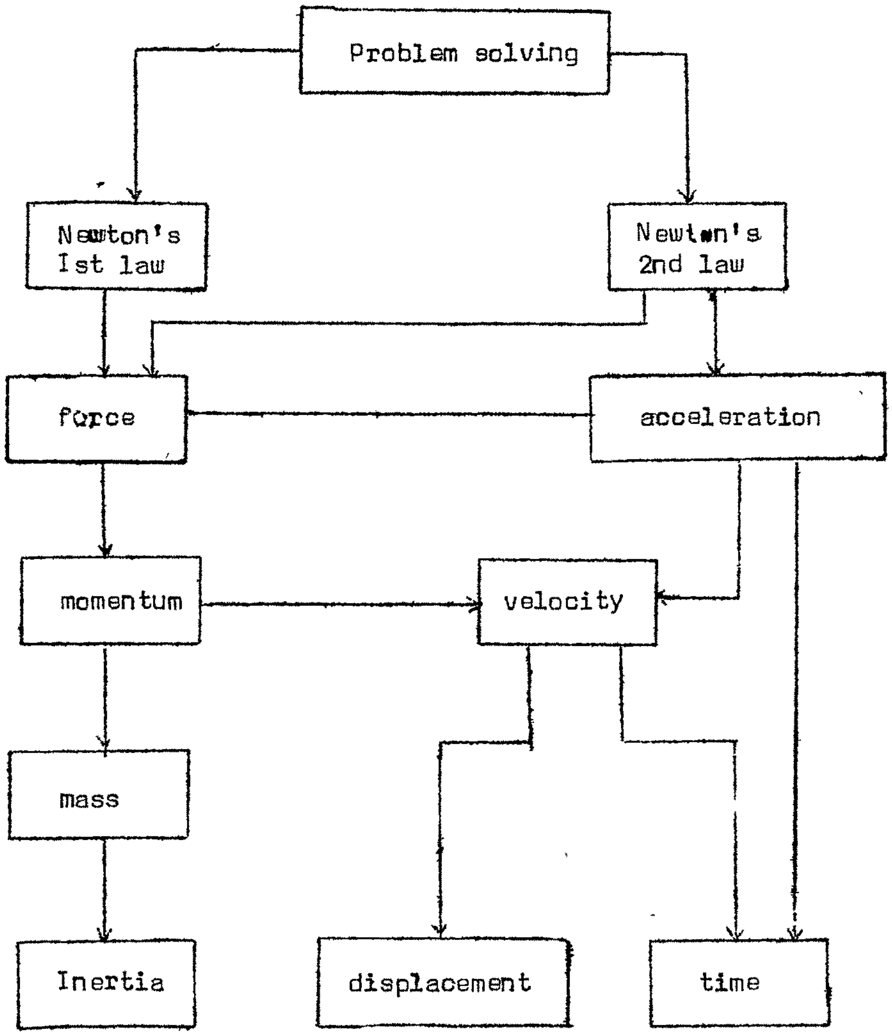


Fig. 3.1 Task analysis map.– Newton's laws I & II

Topic 3: Newton's Laws I & II

Learning hierarchy

The following are the learning objectives in the learning hierarchy shown in Fig.3.2.

When the topic is completed the student should be able to:

I. recall the measurement of time

II. recall displacement

III. recall velocity

IV. recall acceleration

V. A. define inertia
   B. recognize the difference in the inertia experienced by different bodies
   C. define inertia of rest and give examples
   D. define inertia of motion and give examples

VI. A. define mass and give its unit
   B. recognize the fact that mass remain constant for a body at different places.

VII. A. define momentum
   B. express momentum as the product of mass and velocity
   C. derive the unit of momentum
   D. give the conditions under which the momentum of a body change.
   E. recognize the applications for the change in momentum

VIII. A. define force and give its unit
   B. explain the relation between Newton and Dyne.
   C. describe the various types of forces viz. muscular force, gravitational force, magnetic force and electrostatic force.

IX. A. state Newtons first law
   B. give examples to explain Newton's first law.

Learning hierarchy

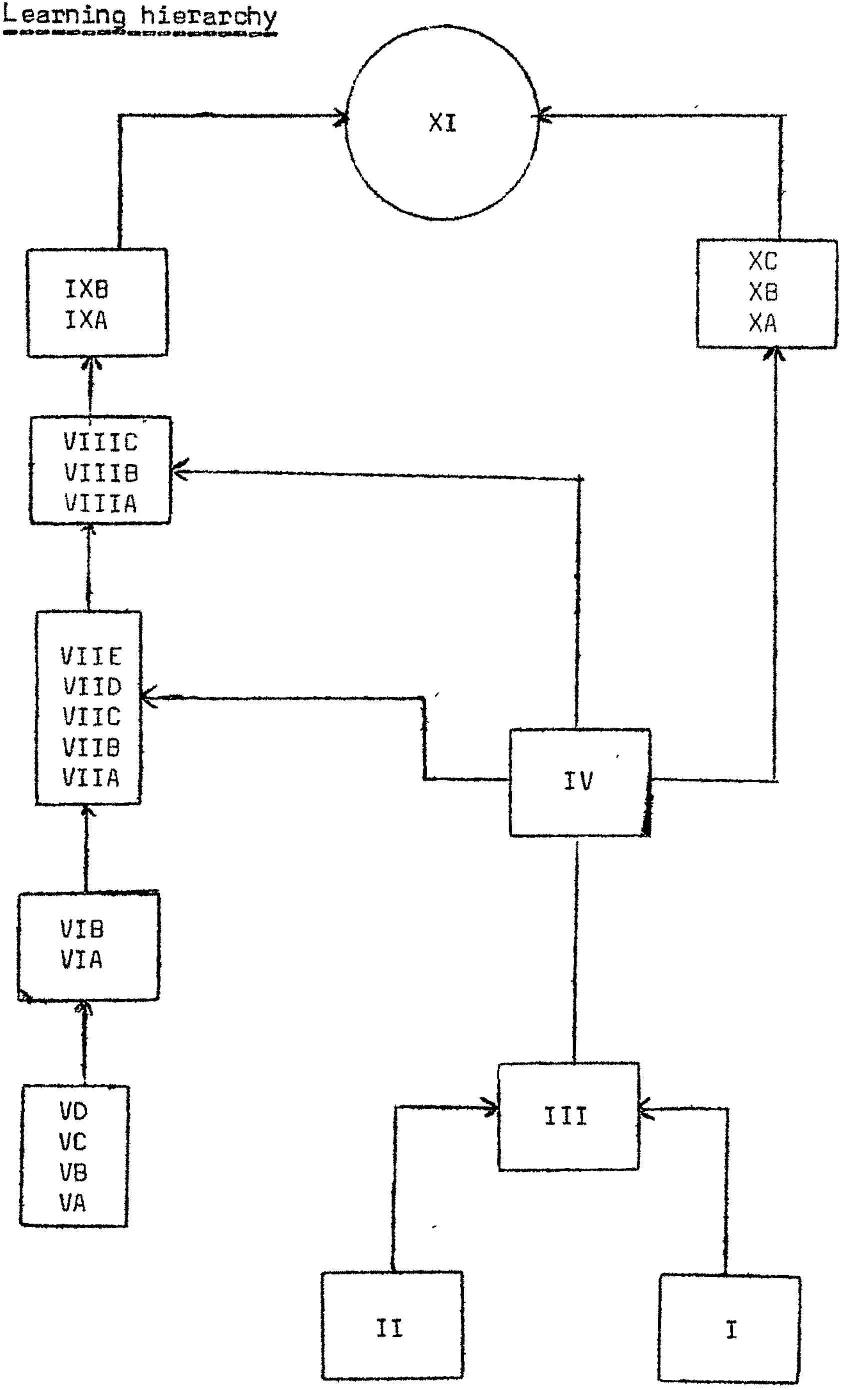


Fig. 3.2 Learning hierarchy map - Newton's I & II law

X. A. state Newton's second law
B. derive the expression f = ma
C. give examples to explain the application of Newton's 2nd law

XI. solve problems based on Newton's first and second laws.

Concept Revision

I. Time
II. Displacement
III. Velocity
IV. Acceleration

Evaluation

i. Will the direction of velocity be the same as that of displacement?
ii. Define acceleration
iii. You observe an object covering distances in direct proportion to the square of the time elapsed. What conclusion can be drawn about its acceleration?
iv. What is the expression for acceleration?
v. If the velocity decreases, what happens to acceleration?
vi. A cyclist moves along a circular path and covers 15 metres in every second. Is it moving with constant velocity?

V. Inertia

Although two objects can look the same, it might be more difficult to move one than the other. A fullbox is much more difficult to move than an empty box. This is becase of a property known as Inertia.

The property of all material bodies due to which they naturally tend to continue in a state of rest or of uniform linear motion is known as inertia.

As is seen above heavier bodies possess more inertia compared to lighter bodies.

Depending on whether the body is at rest or in motion the inertia can be of two types.

(a) Inertia of Rest

If the body is at rest, its inertia is called the inertia of rest.

e.g.,

1. A bullet fired on a window glass pane makes a clear hole without breaking the remaining part of the glass. The greater inertia of motion of the bullet takes out the part of the glass and the remaining part tends to remain at rest due to its inertia of rest.

2. A coin placed on a post-card which rests on a tumbler, falls into the tumbler, when the post-card is suddenly knocked with the finger. The coin tends to remain at rest due to inertia of rest. Thus, due to this unbalanced motion the person tends to fall backward.

(?) Inertia of Motion

Inertia of a moving body is called the inertia of motion.

e.g.,

1. A running person does not stop instantaneously. It is due to the inertia of motion.

2. A person in getting down from a moving bus tends to fall forward. When the bus is in motion, the person in the bus is also in motion. As he gets down, his feet come to rest almost immediately due to friction between the feet and the ground, while x his upper portion tends to move in the direction of the motion of the bus. Thus, due to this unbalanced motion, the person tends to fall forward.

3. A cricket bowler runs for some distance before bowling. By doing so he tends to increase the inertia of motion of the ball.

4. An athletete can take a longer jump after running as compared to the jump that he takes after standing.

NOTE: If a body has large inertia, it will resist a change in its state of rest or of uniform motion to a much greater extent than will a body with a small inertia.

Evaluation

1. Define inertia.
2. Give examples for inertia from daily life.
3. Differentiate between inertia of rest and inertia of motion.
4. Explain why
   - i. a man sitting in a moving car leans forward when the car suddenly comes to rest;
   - ii. a person alighting from a moving train should keep running on the platform for some distance before stopping;
   - iii. a bullet pierces through a windowpane and makes a small hole, while a stone hitting it into small pieces;
   - iv. a man riding a galloping horse keeps his thighs pressed hard against the belly of the horse.

VI. Mass

It is a measure of the quantity of inertia of a body or its resistance to acceleration.

Type of quantity: Scalar
Written Representation: m
Specification Magnitude: Measured in kilogram (kg).

The mass of a body can be considered to be an intrinsic property of the body. Its resistance to acceleration would be same at the surface of earth, at the surface of Mars, or at the surface of Jupiter.

Dimensional Representation: M

NOTE: Under ordinary circumstances the mass of the body is unchanged. At very high speeds comparable to that of the speed of light mass changes.

Evaluation

1. What is the smaller unit of mass?
2. Will the mass of a person change as he moves from earth to space and then to moon.
3. What are the bigger units of mass? How are they related to kg?

V
VII. Momentum (Linear Momentum)

It is a measure of the linear motion possessed by a body and is measured as the product of mass and velocity of the moving body.

Type of Quantity: Vector
Written Representation: P
Specification: Obtained as the product of the mass of the body and its linear velocity.

$$P = mv$$

(i) Magnitude: Measured in kilogram-metre per second (kg m s^{-1}).

(ii) Direction: Same as that of the linear velocity of the body.

Dimensional Equation: MLT^{-1}

NOTE: 1. If the momentum changes, its initial value is denoted by P_i and final momentum by P_f.

2. A heavier moving body possesses a greater quantity of motion (or momentum) than a lighter moving body.

3. Momentum changes with the change in mass or velocity or both.

Change in Momentum = mv − mu

Where m = mass of the body
v = final velocity
u = initial velocity

e.g., (Application)

1. It is difficult to catch a cricket ball as compared to a tennis ball moving with the same velocity. The mass of tennis ball is less than that of a cricket ball. Therefore, the change in momentum is less in the case of tennis ball than that of cricket ball. Consequently less force is needed to catch tennis ball and more force is required to catch the cricket ball.

Evaluation

1. Define momentum.
2. When the measurements are taken in gms, cms, and seconds what will be the unit of momentum?
3. What type of quantity is momentum?
4. If the velocity of a body is doubled what happens to its momentum?
5. If the velocity and mass are doubled what happens to momentum?

VIII. Force

Any action which alters or tends to alter the state of rest or of uniform linear motion of a body is called force.

Type of Quantity: Vector
Written Representation: F

The cause or agency which produces a change in the state of motion or change in the shape of a body is usually a push or pull which can generally be called a force.

Magnitude:

Force = Mass x Acceleration
or $f = ma$

Dimensional Equation: MLT^{-2}

Unit: Newton

One Newton is that much force which when acting on a body of mass one kg produces in it an acceleration of 1 ms^{-2}.

Thus, 1 Newton = 1 kg x 1 ms^{-2}

Written Representation: N

NOTE: Force (Dynes) = Mass (Grams) x Acceleration(cm/sec^2)

1 Newton (N) = 1 kg x 1 m/sec^2

= 1000 gm x 100 cm/sec^2

= 10^5 dynes.

e.g.,

1. We can set a hand cart in motion by merely pushing it.
2. We can change direction of motionof a tennis ball by pushing it.
3. We can change the shape of a plastic mug by simply pressing it.
4. We can elongate a rubber band by pulling it.
5. We can stop the motion of a cricket ball with our hands.

There are various types of forces of which we can discuss a few.

Muscular Force: The push and pull that we exert on a body can be termed as muscular forces.

e.g., 1. Pushing the door open
2. Throwing a cricket ball
3. Pulling the chain
4. Lifting the box

Gravitational Forces: A body released from a height falls to the ground; the earth seems to exert a force on the body. This happens because of some constant force exerted by the earth on the body. These forces are called gravitational forces.

e.g., 1. A mango released from the tree falls down.
2. Similar falling bodies.

Magnetic Forces: Two magnets placed at a distance interact with each other. Similar poles repel each other while disimilar poles attract each other.

e.g., 1. North pole of one magnet repels the north pole of another magnet.
2. North and south poles attract each other.

Electrostatic Forces: Two electrified bodies placed at a distance, interact with each other, Similar changes repel each other while disimilar charges attract each other.

e.g., 1. If you rub a plastic comb on your sleeve and hold it near to water trickling from a tap, the water under the influenze of a force, will bend towards the comb.
2. The same comb if brought near pieces of small paper it will pick up a few.

Evaluation

1. What is force?
2. How is force related to motion?
3. Does the motion of a body depend on force?
4. Give examples for different types of forces.
5. When the acceleration is doubled what happens to the force?
6. What is the unit of force? Define.

IX. Newton's First Law (Law of Inertia)

Every body continues in its state of rest or of uniform linear motion unless an external force acts upon it.

Examples:

1. A duster lying on the table will not move unless we apply force.
2. The table remains at rest in the absence of any force acting on it.
3. A ball moving straight keeps on its direction unless we apply some force to change its direction, by kicking it.
4. A marble moves straight, it changes the direction only when we apply some force on it.

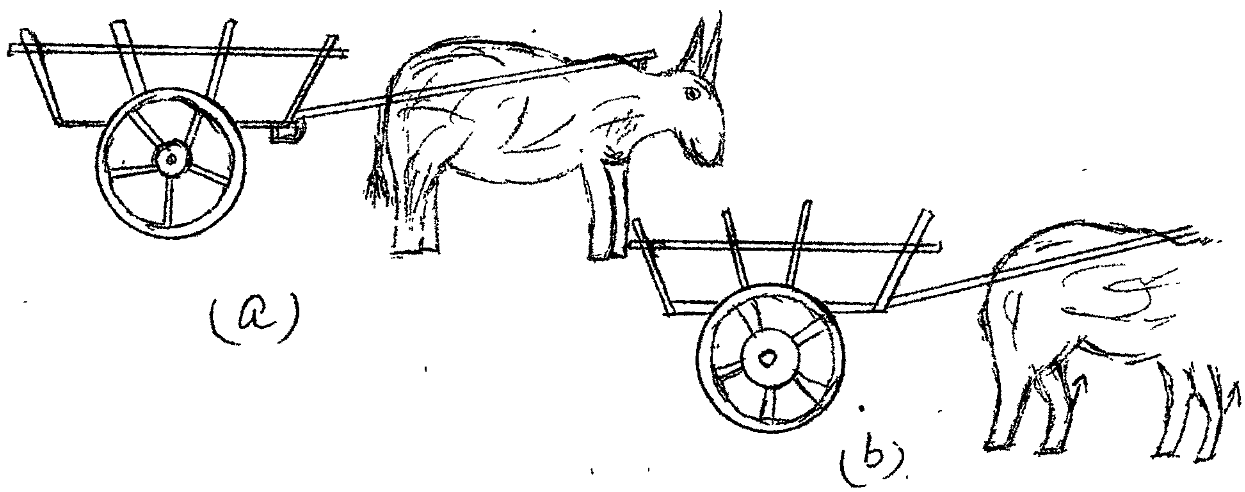


Fig. 3.5: A force is required to change the state of motion.

(a) Since the bullockis not applying a force on the cart, it will not move.

(b) The bullock bends its leg and applies a force on the cart. This force changes the state of motion, i.e. from rest to moving.

Evaluation

1. Define Newton's first law.
2. How does the first law help us to define force?
3. Can the law be called 'law of inertia'? If so, why?

X. Newton's 2nd Law

The rate of change of momentum with time is directly proportional to the applied force and takes place in the direction in which the force acts.

Suppose a body of mass m is moving with velocity u and a force f acts on it for t seconds and the velocity becomes v. Then change of momentum produced in t seconds

$$= mv - mu$$

Rate of change of momentum

$$= \frac{mv - mu}{t}$$

According to the second law

$$f \propto \frac{mv - mu}{t}$$

Or $$f \propto m \frac{v-u}{t}$$

But $$\frac{v-u}{t} = \text{acceleration } (a)$$

$$\therefore \quad f \propto ma$$

or $$f = kma \qquad \ldots\ldots(i)$$

Where k is a constant of proportionality.
The units of F, m and a are so chosen that

$$k = 1$$

Suppose f = 1, when m = 1 and a = 1, then from equation (i), we have

$$1 = k \times 1 \times 1$$

or $$k = 1$$

Thus, by putting k = 1 in equation (i), we get

$$f = ma$$

NOTE: The main points in this are :

(i) The external force acting on a body, its mass and acceleration are interrelated.
(ii) The acceleration of a body is directly proportional to the unbalanced external force acting on it.
(iii) The acceleration of a body is inversely proportional to its mass.

e.g.,

1. A cricket player while catching a ball moves his hands backwards with the ball. A retarding force is needed to stop the ball. Since $f = ma$ and $a = \frac{v-u}{t}$, therefore, he tends to increase the time interval to stop the ball and thus succeeds in reducing the retarding force. Otherwise he gets hurt.

2. A person falling on a cemented floor gets hurt. The person has some initial momentum mu which becomes zero when he comes to halt. Since the mass comes to rest within very short time, a very large force is called into action in order to produce a definite change of momentum (from mu to zero).

Evaluation

1. How does the 2nd law defined force quantitatively?
2. State Newton's 2nd Law.
3. Can you derive the unit of force from Newton's 2nd Law?

XI. Problem

1. Find the momentum of a mass of 10 kg moving with a velocity of 5 m/sec.

Here $m = 10$ kg
$v = 5$ m/sec

Momentum $P = mv$
$= 10 \times 5$
$= 50$ kg m/sec

2. A mass of 1 kg which can slide on a frictionless surface is to be imparted an acceleration of 10 cm/sec^2. What is the magnitude of the force required?

Formula $f = m \times a$

Now $m = 1$ kg

$a = 10 \text{ cm/sec}^2 = 0.1 \text{ m/sec}^2$

$\therefore$ $f = 1 \text{ kg} \times 0.1 \text{ m sec}^{-2}$

$= 0.1$ Newton

3. What force must be applied on a motorcycle of mass 100 kg so that, starting from rest, it covers a distance of 1000 m in 60.0 s?

Solution $u_i = 0$, $t = 60$ s, and $s = 1000$

From the second equation of motion

$$s = u_i t + \frac{1}{2} at^2$$

or

$$a = \frac{2s}{t^2} = \frac{2 \times 1000 \text{ m}}{(60 \text{ s})^2} = \frac{5 \text{ ms}^{-2}}{9}$$

$f = ma$

$= 100 \text{ kg} \times 5/9 \text{ ms}^{-2}$

$= 55.6$ N

Evaluation

1. Find the momentum of a cycle rider of mass 150 kg moving at 6 ms^{-1} due east.

2. What force is required to give a car of mass 1225 kg an acceleration of 2 m s^{-1} ?

3. A motor car of mass 2000 kg is moving with a velocity of 36 km per hour. By the application of brakes it is brought to rest in a distance of 40 metres. Find the average force resisting the motion.

Topic 3: Newton's Laws (I & II)

Self Learning Material (SLM)

To
Students:

History of Newton's laws is a long one. The world created by his 'Principia' were inhabited mentally by philosophers and scientists alike.

In the absence of forces, Galileo and Descartes had proposed that a particle continues in uniform motion or remains at rest; this was incorporated by Newton as the first law of motion. In the presence of forces, Newton, generalising the suggestion of Galileo, proposed 2nd law: the force is equal to mass times acceleration.

These are the raw materials of the Newtonian world. Is it really possible to construct from these few stones a building diverse enough to encompass the marvellous variety of our experience?

It is our everyday experience that objects left alone will continue stay in the position of rest. They can't move on their own. This is due to a property known as Inertia. The same thing is right in the case of moving bodies. They keep on moving in a straight line unless some force disturbs them to change the direction of motion.

- -

Thus, the property of all material bodies due to which they naturally tend to continue in a state of rest or of uniform linear motion, is called.......   .....(1)

- -

As we have seen above the property of inertia is associated with bodies at rest as well as in motion. The inertia involved when the bodies are in motion are called Inertia of motion whereas the bodies are at rest it is called inertia of rest. Inertia will be more in the case of heavier bodies.

Suppose a coin is put on a card which is placed over a glass tumbler. If now the card is flipped quickly then the coin falls into the tumbler. This due to the inertia of rest of the coin.

Standing passengers jerk forward when a bus stops suddenly. This is because the upper portion of the body tends to remain in motion even though the lower portion in contact with the floor of the bus has come to rest as the bus comes to a halt. This is due to inertia of motion of the upper portion of the body.

We run a short distance with a moving bus before getting into it.

This is to provide the body with.........so that when we get into the bus we may not fall down. ....(2)

A passenger jumping out of a rapidly moving train falls forward with his face downwards if he does not run forward. This is due to the fact that his feet on touching the ground are brought to rest whereas the upper part of his body tends to move forward due to.... ....(3)

We have already seen that it will be difficult to move a heavier body compared to a lighter one. Conversely we can think that the body having more inertia will be a heavy body. Thus the measure of inertia becomes important and is known as mass. Mass of a body can also be thought of as its resistance to acceleration. Mass is a quantity expressed in magnitude only.

So we can say that mass is ......quantity. ....(4)

Mass is measured in kilograms. Mass of a body does not change.

Therefore, mass remains........throughout and it does not........from place to place. ....(5)

Let us imagine that a tennis ball and a cricket ball are falling from the same height. Common experience tells us that it is easier to catch the tennis ball than the cricket ball. Why? The balls are falling from the same height and as such have the same velocity on reaching the hand. But the cricket ball is heavier than the tennis ball. Thus, the quantity of motion contained in a body depends upon its mass.

Again consider two cricket balls, one falling from a height of 100 m and the other from 25 m. On reaching the hand the velocity of the first ball will be

$2gh = 2 \times 9.8 \times 100 = 43.4$ m/sec and that of the second ball will be $2 \times 9.8 \times 25 = 23.3$ m/sec. It will be difficult to catch the former as it has greater velocity than the latter.

Thus the motion contained in a body depends upon its mass and velocity. The quantity of motion contained in a body can be termed as the momentum.

Thus the momentum of a body is defined as.........
....
....(6)

Momentum is measured by the product of mass and velocity.

The unit of momentum, then, can be. . . . .(7)

If we push a ball it starts rolling. If we leave it without disturbing it will remain at the same place. It is a matter of common experience that an object like a book once placed on a table remains on the table for ever. This means that to make any body move certain action must take place.

The external agency which make a body move can be called........ ....(8)

We know that if we throw a cricket ball it will move in a straight direction. If we apply a force using a bat we can make it move in a different path altogether.

Force not only makes a body move but it may also change its........of motion. ....(9)

Any body in motion can be brought to rest by applying a force in the reverse direction.

Thus, anything which causes a body to start moving when it is at rest, or stop it when it is moving, or deflect it once it is moving can be called..... ....(10)

We have already learned about mass and acceleration. Force is measured as the product of mass and acceleration.

Therefore, Force = ... x .....

or f = ...(11)

The unit of force is Newton. The unit of mass is kg and that of acceleration is m/s^2.

Therefore Newton = ... x ....(12)

Force has magnitude as well as direction.

Thus, force is a .....quantity. ....(13)

. . . .

When we think about forces, we probably think first of all of the forces we can exert with our own bodies-by our muscles.

Such forces are called..... ....(14)

Perhaps the most familiar force of all is that of gravity - the force which pulls things towards the earth. It certainly is a force, because if you let something go, it starts to move to fall.

This force is called..... ....(15)

Have you ever handled a magnet? If you have, then you must have noticed that the north and north poles repel and north and south poles attact.

The forces involved are called..... ....(16)

It is to our common experience that a plastic comb after combing the hair is brought near small pieces of paper it picks them up. This can happen only if a force is exerted by the comb on the pieces of paper. It is evident that while combing, it got charged up.

These forces are called...... ....(17)

For a body which is under force of gravity the acceleration will be acceleration due to gravity g.

So far we have been discussing about & bodies at rest and bodies in motion. We have seen clearly that the bodies will not move unless a force is applied on it, or we can say that "Every body continues in its state of rest or of uniform linear motion unless an external force acts upon it."

This is known as Newton's First Law (Law of Inertia).

This law can be restated as "Every body preserves its velocity unless acted upon by an external force." Since velocity is constant either when the body is at rest or when it is moving uniformly in a straight line, this law implies that both these states are preserved due to inertia.

The importance of First Law lies in the fact that -

i. it defines......qualitatively.

ii. it explains the property of...... ....(18)

The first law tells us that a force is required to move a body. How much the body will move? In what direction it will move; all depend on the force. This can be seen in Newton's 2nd law which states that the rate of change of momentum of a body is directly proportional to the force acting on the body and is in the same direction.

Thus, we find that the first law gives us the qualitative definition of force while the second law gives us the quantitative definition of force.

i.e., $f = ma$.

The first law also can be said to be a special case of 2nd law.

- -

A car of mass 500 kg accelerates from 10 metres per second to 20 metres per second in 20 seconds. Calculate the force making it accelerate.

We know that $f = ma$

but, $a = \frac{v-u}{t}$ or $f = m\frac{v-u}{t}$

Substitute the values and calculate force.

. . . .
. . . .
. . . .(19)

- -

A bullet of mass 0.005 kg, travelling at a speed of 40 m s^{-1}, penetrates 0.2 m of wood. What is the resistive force offered by the wood, if the retardation is uniform?

- -

We know resistive force $f = ma$ in the opposite direction. The velocity will reduce from 40 m/sec to zero when it stops.

$f = ma$ but $a = \frac{V^2-u^2}{2s}$ $(v^2 = u^2 + 2as)$

or $f = m \frac{v^2-u^2}{2s}$ substitute and calculate.

. . . .
. . . .
. . . .(20)

- -

The momentum of a particle moving at a speed of 45 km h^{-1} is 100 kg m s^{-1}. What is the mass of the particle?

We know that momentum $p = mv$
or we can write mass $m = \frac{p}{t}$

Substitute the values and calculate.

. . . .
. . . .(21)

Topic 3: Newton's Laws I & II

Self Evaluation Material (SEM)

In the blank space provided write the word or expression which BEST completes the meaning.

1. A body continues in its state of..(1a).. or.(1b)..unless a..(1c)..acts on it. ......1a ......1b 1c

2. The state of a body in which there is no change in its position is called..(2).. 2

3. Newton's first law of motion describes the requirement for the motion of a body in..(3).. 3

4. The property of matter that is responsible for the first law of motion is..(4).. 4

5. Mass is a measure of..(5).. 5

6. The objects with equal inertias must have equal..(6).. 6

7. If an object is stationary, its inertia tends to keep it at..(7).. 7

8. If an object is in motion its inertia tends to keep it..(8).. 8

9. What is meant by force? How is it related to other physical quantities? Name and define the absolute unit of force in the S.I. system.
_ _ _ _ _ _ _ _ _ _ ....(9
_ _ _ _ _ _ _ _ _ _ _ _

10. What will be the acceleration of a car of mass 1,000kg if an unbalanced force of 800 N is applied to it?
_ _ _ _ _ _ _ _ _ _ _ _ _
_ _ _ _ _ _ _ _ _ _ _ _ _ 10
_ _ _ _ _ _ _ _ _ _ _ _ _
_ _ _ _ _ _ _ _ _ _ _ _ _

11. An unbalanced force of 150N is applied to a boat which is accelerated at 0.50 m/s^2. What is the mass of the boat?

12. State Newton's first law of motion. What do you mean by inertia? Why is the first law also named as the law of inertia?

Key to SLM

1. Inertia 2. Inertia of motion 3. Inertia of motion 4. Scalar 5. Constant, change 6. The quantity of motion contained in a body. 7. kg m/s 8. Force 9. Direction 10. Force 11. Mass x Acceleration = In a. 12. kg x m/sec^2 13. Vector 14. Muscular forces 15. Gravitational force 16. Magnetic forces 17. Electrostatic forces 18. Force, inertia 19. 250N 20. 20 N 21. 8 kg

Key to SBM

1a. Rest 1b. Motion 1c. Force 2. Rest 3. Rest 4. Inertia 5. Inertia 6. Mass 7. Rest 8. In motion 10. 8 m/s^2 11. 300 kgs

Topic 3: Newton's Laws I & II

Assessment

Section A

I. In the blank space provided write the word ~~of~~ which BEST completes the meaning :

1. The product of mass and velocity is called..(1).. 1

2. If the acceleration is doubled the force becomes..(2)..times. 2

3. When a moving bus suddenly stops the passengers are jerked forward due to..(3).. 3

4. A person sitting on a trolley falls backward when it is being pushed forward by some one because of..(4). 4

5. Newton is the unit of..(5).. 5

6. ...(6)...is defined as the resistance to acceleration. 6

7. Heavy bodies posses..(7).. amount inertia. 7

II. Define the following :

a. Inertia : ________________
____

b. Force : ________________
____

c. Newton : ________________
____

III. Explain why a bullet moving fast pierces through a windowpane making a small hole without shattering it.

____
____
____

Section B

I. In the blank space provided write the word which BEST completes the meaning.

1. The property of matter that is responsible for the Ist law of motion is called..(1).. 1

2. Newton's Ist law of motion describes the requirement for the motion of a body in..(2).. 2

3. Force is directly proportional to..(3a).. . . . . ..3a in momentum and inversely proportion to ..(3b).. . . . . . .3b

II. State Newton's 2nd law. How can this be used to measure force? Explain.

- -
- -
- -

Section C

I. Find the momentum of a cycle rider of mass 150 kg moving at 6 ms^{-1} due east.

- -
- -

II. The momentum of a particle moving at a speed of 45 km h^{-1} is 100 kg ms^{-1}. What is the mass of the particle?

III. A force 2N acts on a body of mass 2 kg at rest for 6 seconds. Calculate the velocity acquired by it.

- -
- -

IV. A cyclist moves with a velocity 4 m/s. The mass of the cyclist including his bicycle is 128 kg. Find the force needed to stop his bicycle in 10 s.

- -
- -
- -
- -

Topic 4 : Newton's III law of motion

CLASSROOM LEARNING MATERIAL (CLM)

Task analysis

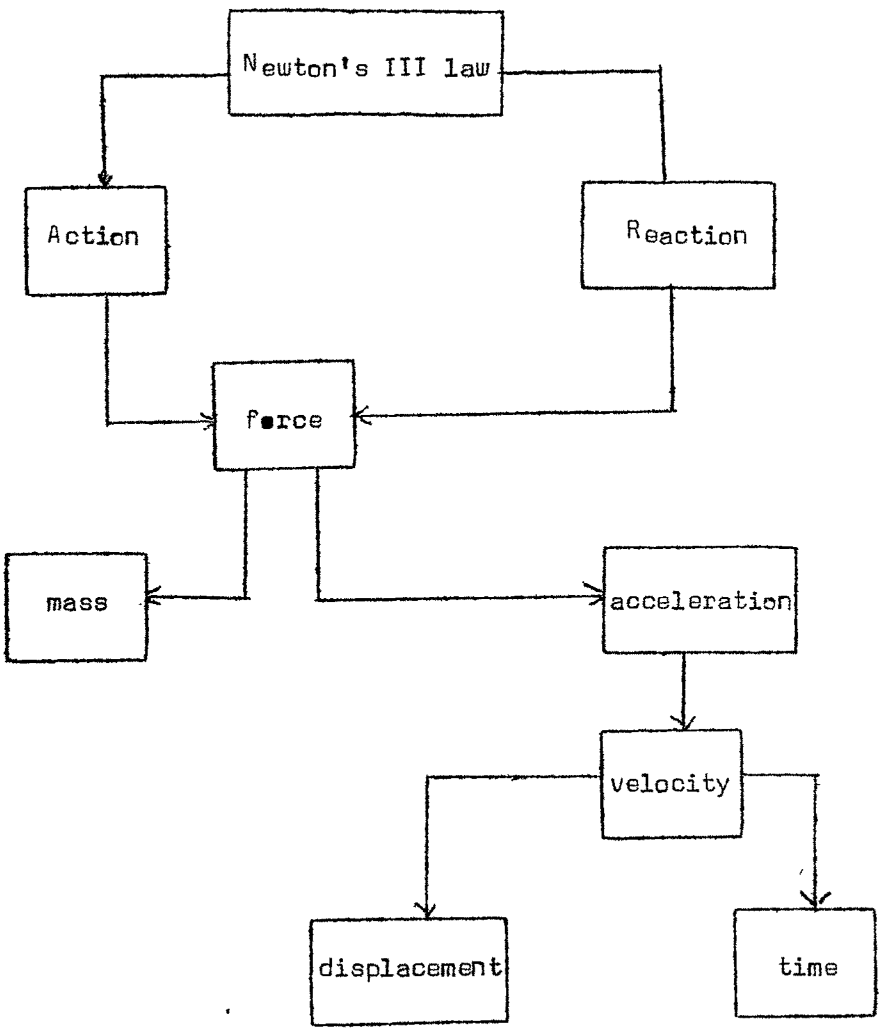


Fig 4.1 Task analysis map - Newton's third law

Topic 4: Newton's IIIrd Law of Motion

Learning Hierarchy

The following are the learning objectives in the learning hierarchy shown in Fig.4.2.

When the topic is completed the students should be able to :

I. recall displacement

II. recall time

III. recall velocity

IV. recall acceleration

V. recall mass

VI. recall force

VII. define reaction

IX. A. state the Newton's IIIrd law
B. differentiate between action and reaction with respect to IIIrd law.
C. give illustrations for Newton's IIIrd law

Concept Revision

I. Displacement
II. Time
III. Velocity
IV. Acceleration
V. Mass
VI. Force

Evaluation

i. What happens to the force if the mass of the moving body doubled.

ii. Define mass in terms of force and acceleration.

Learning hierarchy

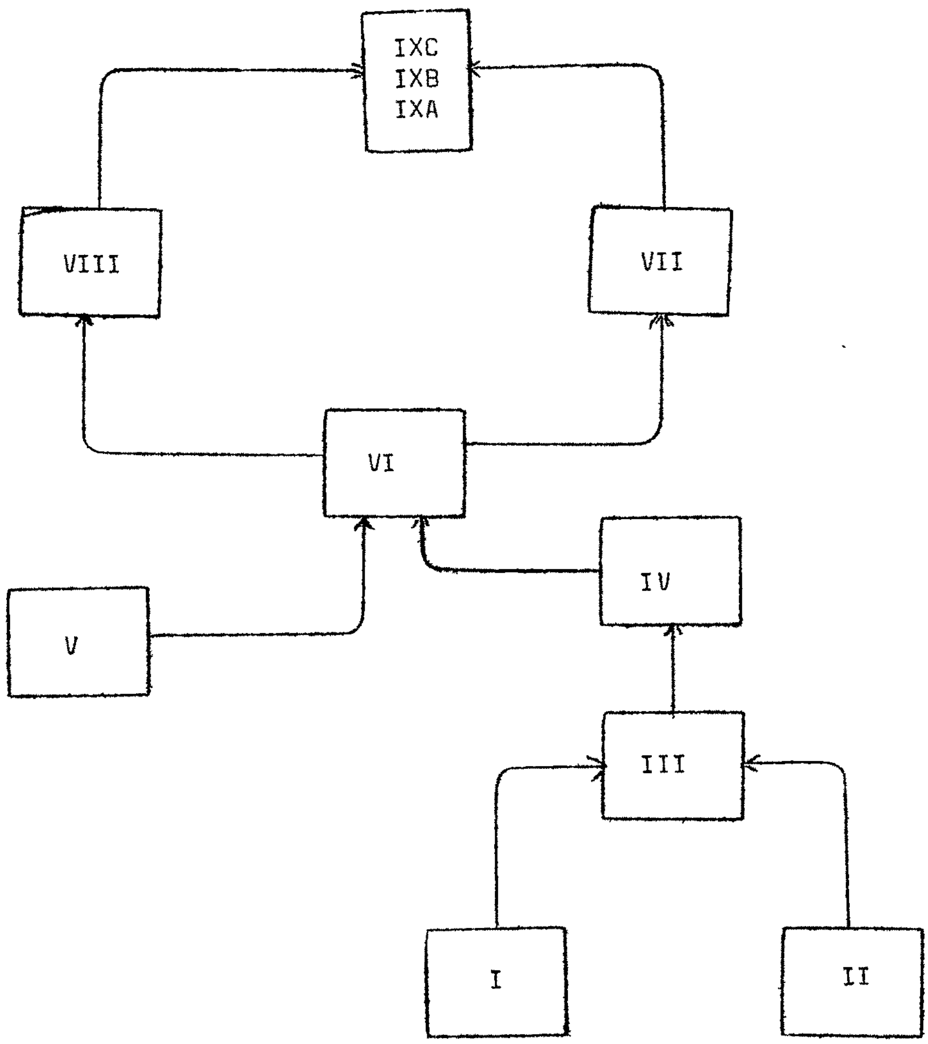


Fig. 4.2 Learning hierarchy map - Newton's third law

iii. What will happen to the velocity of a body if the force applied is doubled.

iv. Bring out a relation between displacement and force.

<u>Action:</u> Suppose we take objects A and B and let A exert a force on B; then the force that the first object (A) exerts on the second is known as action.

<u>Reaction:</u> The force that the second object exerts on the first is known as reaction. Of course one may note that any object can be taken as the first object.

Evaluation

1. What is force?
2. What are Action and Reaction? Define.
3. Do action and reaction act on the same body?

Newton's IIIrd Law

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

Here, action = − (Reaction).

The negative sign shows that the reaction is in the opposite direction.

NOTE:

i. The action and reaction are forces.
ii. The action and reaction always act along the same straight line but in opposite directions
iii. The action and reaction never act on the same body but always act on different bodies.
iv. The action and reaction are always equal in magnitude.
v. The forces always exist in action reaction pairs.

It is a common experience that if a person hits another person with his palm, the former also experiences a pain. Harder the hit, greater is the pain.

Here hitting the person is action while the pain is experienced due to reaction.

It should be borne in mind that there is no formal proof of Newton's third law of motion. Through discussions it could be easily concluded that existence of an isolated force is not possible as for every action (i.e. force). There is always an equal and opposite reaction (i.e. force). Hence forces always exist in action reaction pairs.

However with the help of spring balance experiment it can be established that action and reaction are always equal in magnitude.

Let us consider a spring balance a being pulled by another spring balance B as shown in the Fig.4.1. Both the spring balances read equally. This shows that when the balance B pulls the balance A, the balance A also pulls balance B in the opposite direction. The

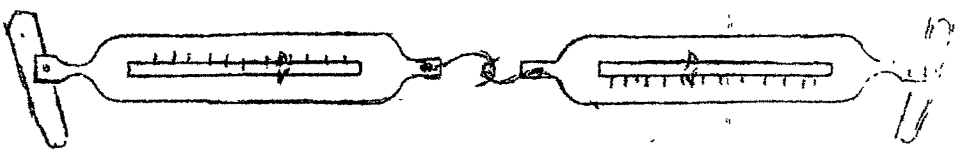


Fig. 4.1

force with which balance B pulls balance A is equal and opposite to the force with which balance A pulls balance B. The force exerted by balance B on balance A on balance B may be termed as 'reaction'. Thus we see that "for every action there is equal and opposite reaction."

Illustrations

1. Whenever a person steps out from a rowing boat, he pushes backwards on the boat (the action) which moves accordingly whilst the boat pushes the person forward (the reaction) the forces are equal in size, opposite in direction and act simultaneously on the person and the boat.

2. While swimming, a swimmer throws water in a backward direction (action) where as the reaction of the water moves the swimmer in the forward direction.

3. The birds while flying, push the air downwards with their wings (action). The air exerts an equal and opposite force on the birds in the upward direction (reaction).

4. In rotating fountain, a central pipe is fitted with four small pipes having fine nozzles at the ends (Fig.4.2). Water rushes out of the nozzles ~~at~~ (action). The pipes move in the opposite direction (reaction). This principle is used in the fountain to sprinkle water around.

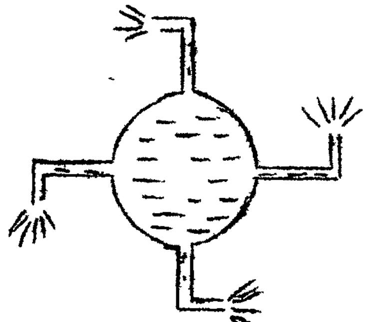


Fig. 4.2

5. When a bullet is fired from a rifle with a certain force (action), there is an equal and opposite force exerted on the rifle in the backward direction (reaction).

6. When we walk on the ground, our feet press the ground backward (action) and the reaction of the ground on our feet moves us in the forward direction.

7. A boatman in order to go away from bank, pushes the bank with a pole (action). The bank pushes the boat away as result of reaction.

<u>Evaluation</u>

1. If action, and reaction are equal then how does a body move.

2. Explain with the help of 3rd law the action during the lift off of a rocket.

3. Explain what happens when air from a ballon is allowed to rush out quickly.

Topic 4: Newton's IIIrd Law of Motion

Self Learning Material (SLM)

To Students:

What happens when two bodies collide is a very old problem. In 1668, the Royal Society of London proposed an investigation of the question of collisions; the solutions were produced by the mathematician John Wallis; the architect of St.Paul's, Sir Christopher Wren; and the Dutch physicist Christian Hugens. Some of their conclusions and experiments are discussed by Newton in Principia. And Newton also provides the solution - the same solution as proposed by the others. What he achieved was to unite what seemed like a separate problem with the other problems of motion, and he was able to solve all using the three postulates of motion.

Prior to this significant contributions were made by Descartes proposing the principle of inertia and Galileo who contributed extensively to the study of forces.

Those of us who had the experience of rowing by boat know that to get out from the row-boat to the deck one needs a force to accelerate himself. For this he pushes the boat pushes the man in turn in the opposite direction with the help of which he reaches the rock and this force is reaction.

So we can say that action and reaction are...............but they act in........direction. ...(1)

While talking about action and reaction, we should realise that they act along the same straight line.

We have discussed in the class about Newton's third law, which says that action and reaction are equal but act in the opposite direction.

Here, we are confronted with a problem. Taking that action and reaction are two forces and for every action there is an equal and opposite reaction. I am inclined to think them, why should the body move? Don't they cancel each other?

Here, we are confused because we have not yet fully understood the nature of these forces. Action and reaction act on different bodies giving no change to cancel each other.

- -

If A hits B than action acts on........and reaction acts on....... . ...(2)

- -

To increase reaction, we should increase....... . ...(3)

- -

<u>Key to SLM</u>

1. Equal, Opposite

2. B, A

3. Action

Topic 4: Newton's IIIrd Law of Motion

Assessment

1. Newton's third law of motion deals with

   a. one object and two forces.
   b. two objects and two forces.
   c. action and reaction. ....

2. When an automobile is accelerated forward

   a. the tires exert a forward action.force on the road.
   b. the road exerts a forward reaction force on the tires.
   c. the tires exert a rearward action on the road.
   d. the road exerts a rearward reaction force on the tires. ....

3. Can action-reaction be produced on a single body?

   . . . .
   . . . .

4. Can you set a steel toy car in motion with the help of a magnet suspended through a support attached to the car itself?

   . . . .
   . . . .
   . . . .

5. Explain the action and reaction in case of the following :

   a. While swimming.

      . . . .
      . . . .

   b. The birds while flying.

      . . . .
      . . . .

Topic 5 : CONSERVATION OF MOMENTUM

CLASSROOM LEARNING MATERIAL (CLM)

Task analysis

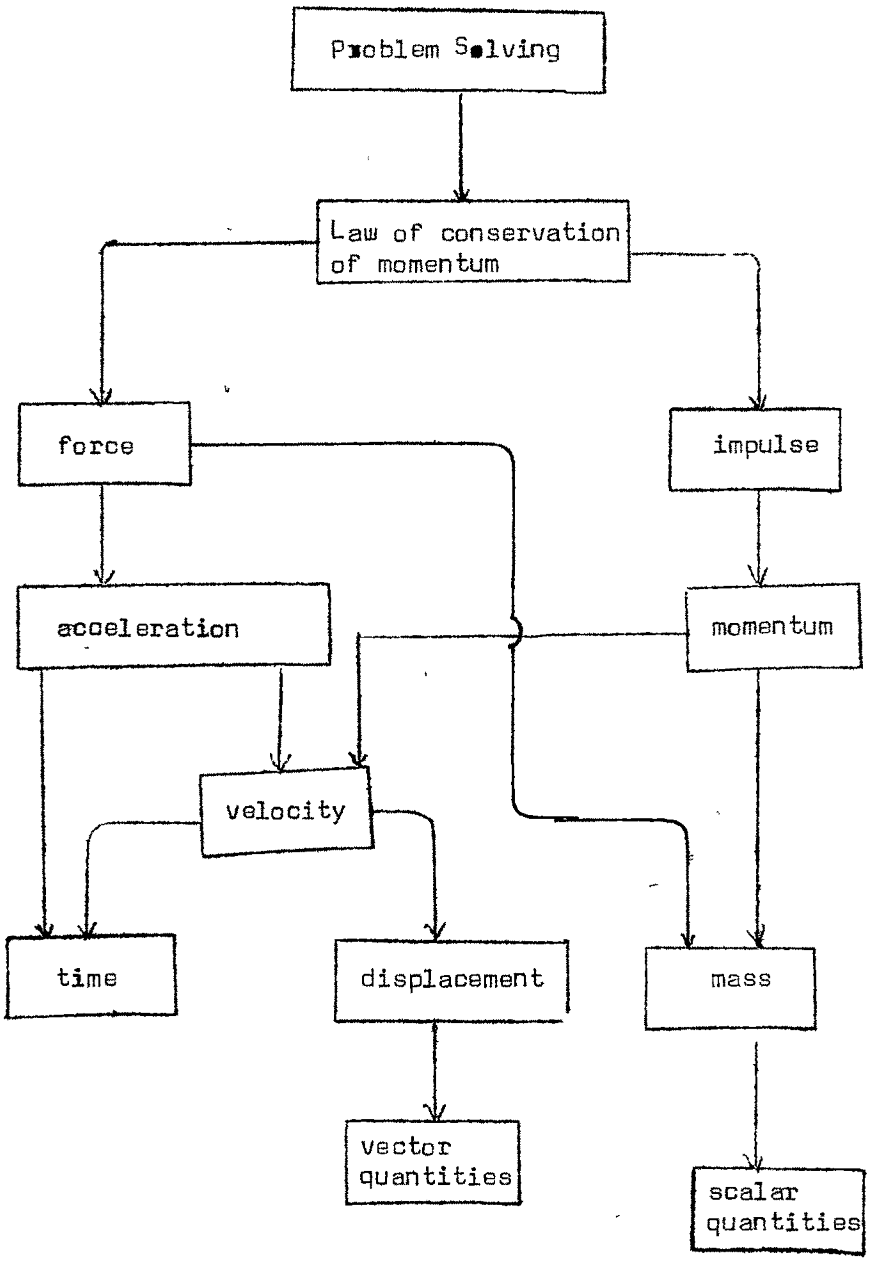


Fig. 5.1 Task analysis map - Conservation of momentum

Topic 5: Conservation of Momentum

Learning Hierarchy

Classroom Learning Material (CLM)

The following are the learning objectives in the learning hierarchy shown in Fig.5.2.

At the end of the topic the students should be able to :

I. recall scalar quantities

II. recall vector quantities

III. recall mass

IV. recall time

V. recall displacement

VI. recall velocity

VII. recall momentum

VIII. recall acceleration

IX. recall force

X. A. define impulse
B. express it as

$$I = f \times t$$

C. give its units.
D. calculate impulse from the given data.

XI. A. state the law of conservation of mementum.
B. derive the expression

$$m_1u_1 + m_2u_2 = m_1v_1 + m_2v_2$$

C. explain the significance of the law.

XII. A. solve problems.

Learning hierarchy

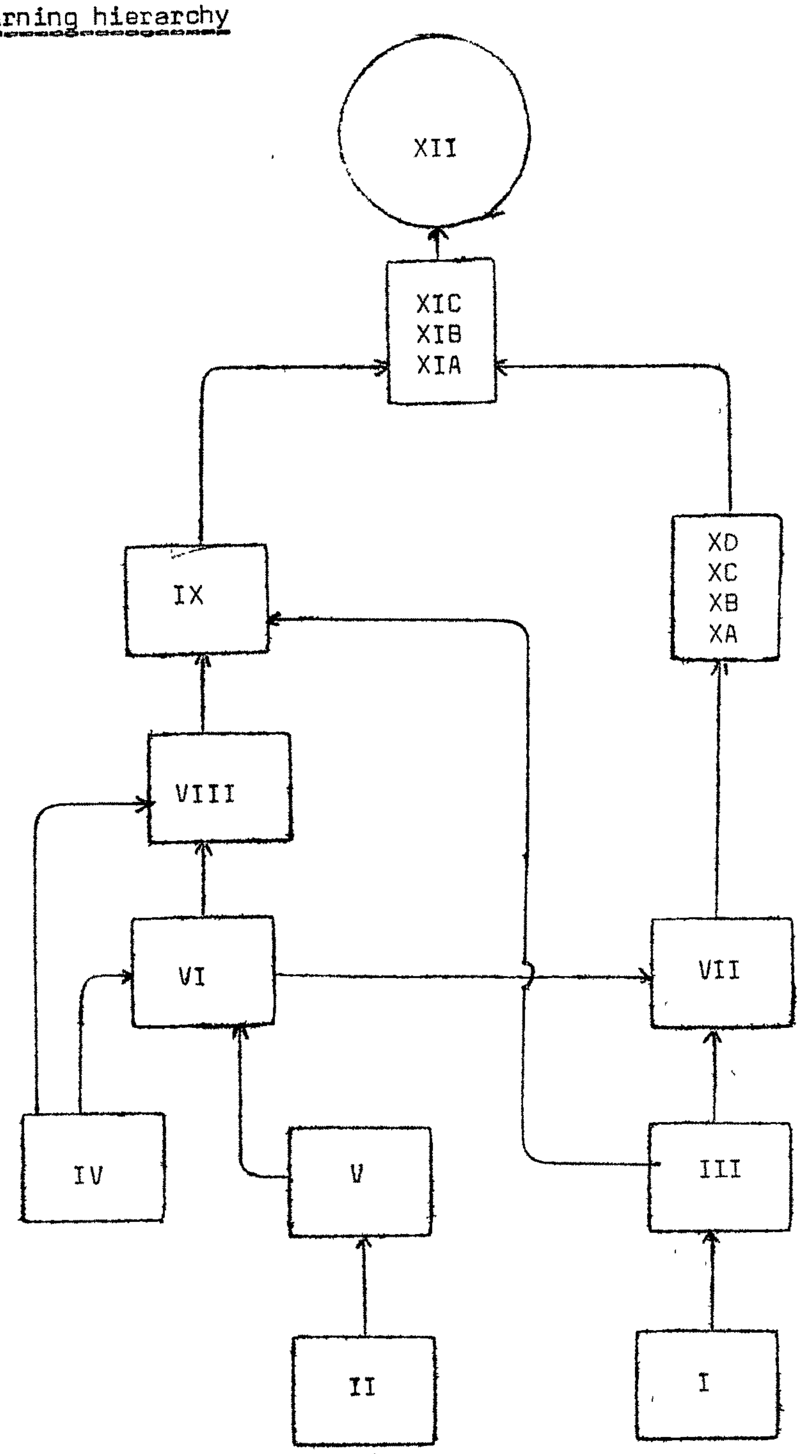


Fig. 5.2 Learning hierarchy map - Conservation of momentum

Reviewing Concepts

I. Scalar quantities
II. Vector quantities
III. Mass
IV. Time
V. Displacement
VI. Velocity
VII. Momentum
VIII. Acceleration
IX. Force

Evaluation

1. Define force quantitatively.
2. Define momentum.
3. How force and momentum are related?
4. What happens to the momentum of a body if the force is increased?
5. Select the scalar quantities and vector quantities from those concepts mentioned above?
6. What happens to the momentum if the mass and velocity are doubled?

X. Impulse

The motion of a body on the application of a force will depend upon two factors :

(1) Magnitude of force, and
(2) Time duration for which it acts.

This total effect of force is called impulse.

Type of quantity: Vector.
Specification: Measured by the change in momentum produced in a body.

unit - kg m/sec

Impulse = change of momentum
= final momentum - initial momentum
$= mv - mu$
$= m(v-u)$
$= m.at$
$= f.t$
= force x time

$\therefore \quad v = u + at$

$\therefore \quad f = m.a$

Impulse may, therefore, also be defined as the product of force and time during which it acts.

Dimensional Equation: MLT^{-1}

Illustrations

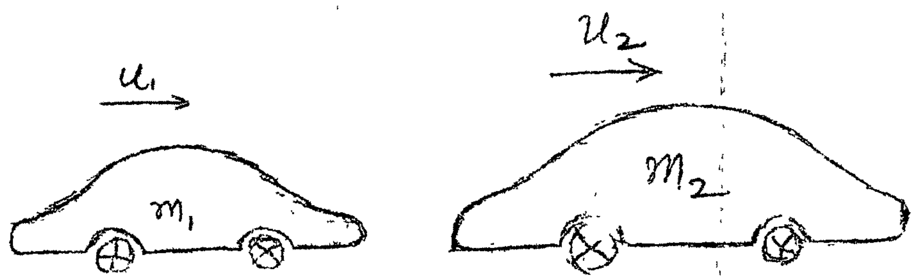
Impulse shows the total effect of force. A cricket player lowers his hands while catching a fast moving cricket ball. This is to increase the time and hence to reduce the force that he has to exert to stop it.

Evaluation

1. What physical quantity corresponds to the change in momentum?
2. Define impulse.
3. How is it measured.

XI. Law of Conservation of Momentum

We discussed about the momentum in the previous topic i.e., $p = mv$.



Suppose we have two bodies A & B of mass m_1 and m_2 move with velocities u_1 and u_2 respectively. Suppose the two bodies interact for a time interval of t second, let their velocities, after collision, be v_1 and v_2. Let the force exerted by A on B be f_1 and that by B on A be f_2.

By Newton's 2nd law

$$f_1 t = m_1(v_1 - u_1)$$

(Force experienced by A is f_2)

$$f_2 t = m_2(v_2 - u_2)$$

For the same time interval

$$f_1 t - f_2 t$$

i.e.. $$m_2(v_2-u_2) = -m_1(v_1-u_1)$$

$$m_2v_2-m_2u_2 = m_1v_1+ m_1u_1$$

or $$m_2v_2- m_2v_1 = m_1u_1+ m_2u_2$$

or $$m_1u_1+ m_2u_2 = m_1v_1+ m_2v_2$$

i.e., Total momentum before collision = Total momentum after collision

We can generalise this by the following :

In a system of bodies interacting with one another, the total linear momentum of the system in any given direction remains unaltered, unless an external force acts on the system in that direction.

This is known as the law of conservation of momentum.

Illustrations:

1. Suppose let us take 3 marbles keep two together as shown at rest. Using the third one between the marble nearest to it, i.e. (2), we will see that marble No.(1) moves away with the same speed u as that of 3 and comes to rest. This is a perfect example of law of conservation of momentum. (NOTE that this is also an example of law of conservation of energy which we will study later).

2. A bullet fired from gun: (i) Before firing, both the bullet and the gun are at rest, so the momentum of the bullet = 0 and the momentum of the gun = 0

$\therefore$ Total momentum of (Rifle + Bullet) = 0 ...(i)

Let m be the mass of the bullet and M be the mass of rifle and v and V be the velocities of the bullet and rifle respectively after the bullet has been fired, then

(ii) After firing

Momentum of the bullet = mv (taken as +ve, being in forward direction)

Momentum of the Rifle = -MV (taken as -ve, being in backward direction)

$\therefore$ Total momentum of (Bullet+Rifel) = mv -MV ...(ii)

Now according to the law of conservation of momentum we have,

Total momentum before firing = Total momentum after firing

Thus, we get from equations (i) and (ii)

$$mv - MV = 0$$
$$\text{or} \quad mv = MV$$

Since $M \gg m$, $\therefore V \ll v$

It means that the velocity V with which rifle recoils in the backward direction is much smaller than the velocity v of the bullet because rifle is much heavier than the bullet. Thus the recoil of the gun sometimes is not noticeable.

Evaluation

1. We discussed the conservation of momentum in a two particle system. How will you rewrite the equation if there are n particles?

2. State the law of conservation of momentum.

XII. Problem Solving

1. A force of 2 newton is acting on a body of mass 5 kg for 4 seconds. Calculate the impulse developed.

Here, $f = 2N$
$m = 5kg$
$t = 4$ sec

Impulse $f \times t = 2 \times 4 = 8$ kg m/sec.

2. A body of mass 10 kg changes its velocity from 5 m/sec to 8 m/sec on the application of a force for 3 seconds. Calculate the impulse developed.

$$\begin{aligned} \text{Impulse} &= \text{Change in mementum} \\ &= mv - mu \\ &= 10 \times 8 - 10 \times 5 \\ &= 80 - 50 \\ &= 30 \text{ kg m/sec} \end{aligned}$$

3. A cricket player is able to stop a cricket ball of mass 360 g moving with a velocity of 200 cm s^{-1} in 0.3s. Find the impulse on the ball and the retarding force applied by the player.

Solution given $m = 360$ g
$u = 200$ cm s^{-1}
$v = 0$
$t = 0.3$ s

Impulse = ?
f = ?

$$\begin{aligned} \text{Impulse} &= m(v-u) \\ &= 360(0-200) = -72000 \text{ dyme} \quad \ldots(i) \end{aligned}$$

But also we have, Impulse = Force x Time
$= f \times t = f \times 0.3 \quad \ldots(ii)$

$\therefore$ From eqns(i) and (ii) we get
$f \times 0.3 = -72000$
or $f = -240000$ dyne or $f = -2.4N$

$(\because 10^5 \text{dynes} = 1N)$

Negative sign here simply shows that the force is retarding one.

4. A 50 gm cannon ball is fired from a gun weighing 4 kg with a velocity of 40 m/sec. If the gun is free to move with what velocity will it move with what velocity will it move backwards?

Solution:

Here, mass of the ball = $m_1 = 50gm = \frac{50}{1000}$ kg

$= \frac{1}{20}$ kg

Velocity of the of the ball = $v_1 = 40$ m/sec

$\therefore$ momentum of the ball = $m_1 v_1$

$= \frac{1}{20} \times 40$

= 2 kg m/sec

Mass of the gun = $m_2 = 4$ kg

Velocity of the gun = $v_2 = ?$

According to the Principle of conservation of momentum,

$$m_1 v_1 = m_2 v_2$$

$\therefore$ Velocity of the gun = $v_2 = \frac{m_1 v_1}{m_2}$

$= \frac{2}{4} = \frac{1}{2}$ m/sec

= 50 cm/sec

<u>Evaluation</u>

1. A force 10 newton produces an impulse of 40 kg m/sec on a body. Calculate time duration of the application of force.

2. A canon fires a shell of mass 50 kg. Find the muzzle velocity of the shell if the recoil velocity of the canon is 4 ms^{-1}. You are given that the mass of the canon is 6000 kg.

3. A railway wagon travelling due north at a speed of 10ms^{-1} collides with an identical wagon at rest. Both the wagons move together after the collision. Calculate the final speed of the wagons.

Topic 5 : Conservation of Momentum

Self Learning Material (SLM)

To
Students:

We may note that as an immediate consequence of Newton's third law concerning the nature of forces, we have one of the most famous theorems of mechanics - conservation of momentum. The idea of momentum conservation is so deep that it pervades physics even when the Newtonian form of mechanics is no longer used. This is one of the several instances in which a result obtained as a relatively special theorem is found later to be more important and more general than the postulates from which it come.

The theorem stating momentum conservation is more fundamental than third law, on which is based history often decides the original order in which propositions come to life but it does not necessarily place them in the order of their final importance.

In the earlier topic, we studied about momentum. The momentum depends on mass and its velocity.

Momentum = ... x ....(1)

Newton's 2nd law deals with forces and its impact on the motion of bodies. When a force of considerable amount acts on a body what we notice is motion or simple a change in its velocity and hence a change in its momentum.

Newton's 2nd law can be mathematically be stated as -

$$f = \frac{m \times (v-u)}{t} = \frac{mv-mu}{t}$$

or ft = ... - ....(2)

On the left side of the equation, the quantity ft = the product of a force and the time during which it acts - is called impulse.

Thus, impulse can be defined as. . . . . . .

. . . .(3)

On the right hand side of the equation (2) is the change in the bodies momentum.

i.e., Impulse = Change in momentum

Thus, the impulse can be measured in

.......units. ...(4)

Impulse is ....quantity

The fact that the impulse given by a body equals its change in momentum leads us directly to the very important concept of conservation of momentum.

Consider two marbles colliding on a smooth table. Each exerts a force on the other that will change its speed and direction. From Newton's third law, we know that these forces are at all times exactly equal and opposite in direction, and the time during which these collision forces act is obviously identical for each marble. Thus, each marble during the collision, receives an impulse equal to the impulse received by the other marble, but in the opposite direction.

It follows, then, that each marble undergoes a change in momentum equal and opposite to the change in momentum of the other marble.

Hence we can say that

Change in mementum of first marble = Change momentum of 2nd marble.

If m is the mass of first marble and the velocity changes from u_1, v_1 and m_2 the mass of 2nd marble and the velocity changes from u_2 v_2

Then we can write this as

$$m_1v_1 - m_1u_1 = -(m_2v_2 - m_2u_2)$$

The negative sign indicates that the impulse of 2nd is in a direction opposite to that of first.

Simplyfying

$$m_1v_1 - m_1u_1 = -m_2v_2 + \ldots\ldots\ldots \qquad \ldots(5)$$

$$\text{or} \quad m_1u_1 + m_2u_2 = \ldots\ldots\ldots \qquad \ldots(6)$$

The left hand side indicates the total momentum before collision and the right hand side the total momentum after collision.

i.e., we can say that the total momentum before and after collision is conserved.

or the law of conservation of momentum states that

. . . .

. . . .(7)

We have shown here that a quantity called total momentum remains constant, no matter what happens. If bodies collide, if an object explodes - no matter what happens, the total momentum remains the same.

This we can illustrate with the example of firing a gun.

Before firing since both the gun and the bullet are at rest total momentum = 0 + 0 = 0.

After firing bullet (m) moves forward with a velocity v and the gun (M) moves backward with a velocity (V).

i.e., total momentum after firing = mv-MV.

(-ve sign shown both are in opposite direction).

By law of conservation of momentum, we can write

$$0 = \ldots\ldots\ldots - \ldots\ldots\ldots \qquad \ldots(8)$$

$$\text{or} \quad MV = \ldots\ldots\ldots \qquad \ldots(9)$$

Topic 5 : Conservation of Momentum

Self Evaluation Material (SEM)

Directions:

In the parentheses at the right of each words or expression in the second column, write the letter of the expression in the first column which is MOST closely related.

a. Rate of displacement	displacement	( )	1
b. Its graph is a curved line	motion	( )	2
c. Rate of motion	linear motion	( )	3
d. Distance with direction	speed	( )	4
e. Continuous change of location	velocity	( )	5
f. Motion along a curved path	uniform velocity	( )	6
g. Sum of component velocities	variable velocity	( )	7
h. Motion in a straight line	circular motion	( )	8
i. Motion about an axis	velocity vector	( )	9
j. Represents the magnitude and direction of a velocity	resultant velocity	( )	10
k. Its graph is a straight line			

Directions

In the blank space at the right of each statement, write the word or expression which BEST completes the meaning.

11. If the velocity of an object is constant, the motion is said to be..(11).. 11

12. If either the rate or direction of motion of an object is changing, the motion is said to be..(12).. 12

13. Since velocity has both magnitude and direction, it is a (n)..(13).. quantity. 13

14. If two component velocities are known, the resultant velocity may be found by completing the velocity..(14a).. and determining the length of its..(14)b)..
. . . . . . .14a
. . . . . . .14b

15. An object which moves along a straight path 3.0m during 1.0sec, 6.0m during 2.0sec, and 9.0m during 3.0sec has a velocity of ..(15).. 15

16. The product of the mass of a moving body and its velocity is called..(16) 16

17. The product of a force and the time interval during which it acts is called..(17).. 17

18. Momentum is a vector quantity because it is the product of a (scalar, vector)..(18a).. . . . . .18a
quantity, mass, and a (scalar, vector)..(18b)..quantity, velocity. 18b

19. Impulse is a vector quantity because it is the product of a (scalar, vector)..(19a)..quantity, ...19a
force, and a (scalar, vector).. ..(19b)..quantity, time. 19b

20. The relationship between impulse and change of momentum is that they are..(20).. 20

21. When no..(21a)..forces are acting 21a
on a system of..(21b)..objects, the 21b
total..(21c)..of the system.. . . . . .21c
..(21d).. . . . . .21d

Directions

Place the answers to thefollowing problems in the spaces provided at the right.

22. The distance from Baroda to Bombay 400 km, (a) if the 22a
driving time is 8 hr, what is the average speed, (b) what is 22b
is the direction of this displacement?

23. What is the momentum of an automobile, mass 1500 kg, moving at a velocity of 20.0 m/sec northward? 23

24. For how many seconds must a force of 750 n northward act to impart the momentum to the automobile of No. 28? 24

25. A ball, mass 25.5 g, velocity 30.0 cm/sec southward, collides with another ball, mass 10.0 g, moving along the same ~~x~~ line with a velocity of 15.0 cm/sec southward. After collision, the 25.0 g ball has a velocity of 22.0 cm/sec southward. What is the velocity of the 10.0 g ball? 25

<u>Key to SLM</u>

1. mass x velocity 2. mv-mu 4. kg m/sec
5. m_2u_2 6. $m_1v_1 + m_2u_2$ 8. mv-MV 9. mv=MV

<u>Key to SEM</u>

1. d 2. e 3. h 4. e 5. a 6. k 7. b 8. i 9. j 10. g 11. uniform
12. non-uniform 13. vector 14. a diagram 14b. last side
15. 3 m/s 16. momentum 17. impulse 18a. scalar 18b. vector
19a. vector 19b. scal r 20. equal 21a. external
21b. moving 21c. momentum 21d. is constant 22a. 50 km/hr
22b. Baroda Bombay 23. 30000 kg m/sec
24. 40 sec 25. 35 cm/sec

Topic 5: Conservation of Momentum

Assessment Material (AM)

Section A

I. Fill in the blanks using the most appropriate word/s.

a. Momentum is a..(1a)..quantity. . . . .(1a)

b. If the velocity is doubled the momentum..(1b).. . . . . (1b)

c. When the mass is increased to 3 times the momentum increases by..(1c).. . . . . (1c)

d. The product of mass and velocity is called..(1d).. . . . . (1d)

e. The unit of momentum is..(1e).. . . . . (1e)

f. The product of force and ..(1f)..is called impulse. . . . . (1f)

g. Impulse can also be thought of as the change in..(1g).. . . . . (1g)

h. Impulse is a..(1h).. quantity. . . . . (1h)

II. Define:

(a) Momentum: _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _
_ _
_ _

(b) Impulse: _
_ _
_ _

Section B

III. a. State and explain the law of conservation of momentum.

b. Give two illustration to show the consequence of conservation of momentum.

Section C

IV. A cricket ball weighing 2N moving with a velocity of $2ms^{-1}$ is brought to rest by a player in 2 sec. Calculate the impulse of the ball.

V. A bullet of mass 30 gram leaves the rifle with a velocity of 100 ms^{-1}. If the mass of the rifle is 4 kg, find the velocity of recoil.

Topic 6 : LAW OF GRAVITATION

CLASSROOM LEARNING MATERIAL (CLM)

Task analysis

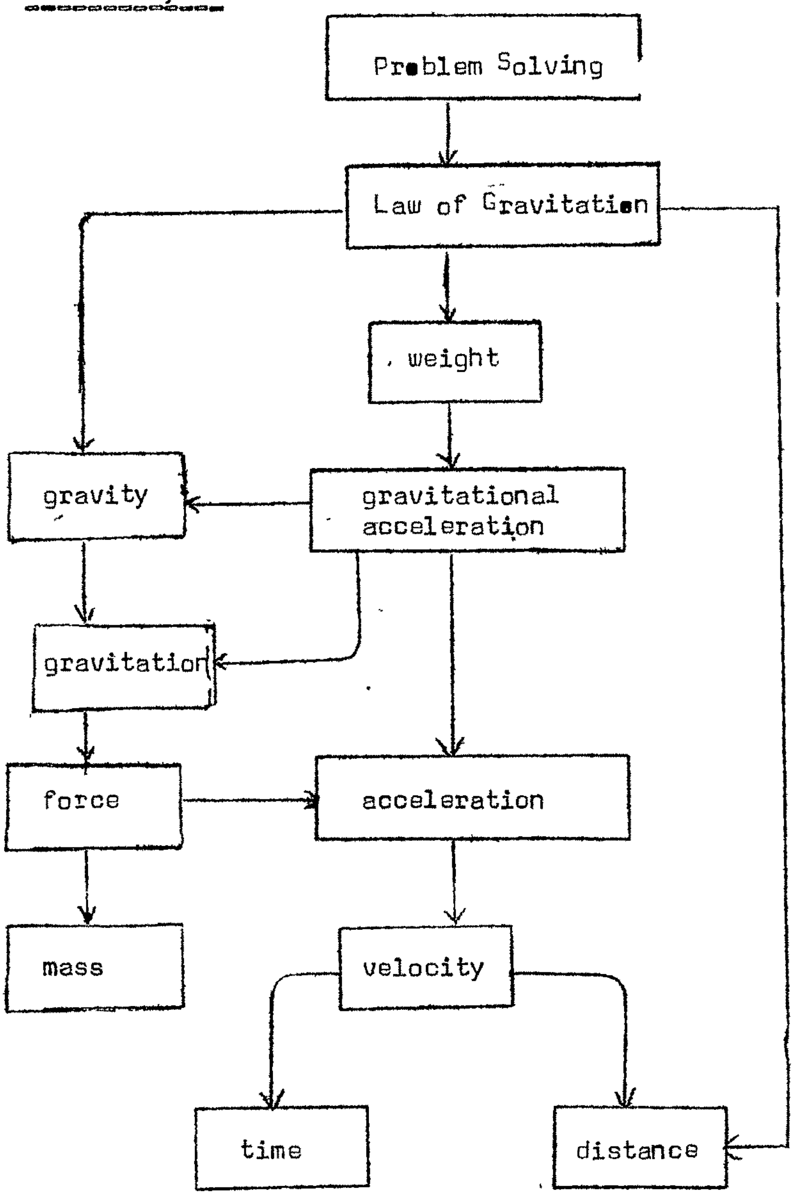


Fig. 6.1 Task analysis map - law of gravitation

Topic 6: Gravitation

Learning Hierarchy

The following are the learning objectives in the learning hierarchy shown in Fig.6.2.

At the end of the topic the students should be able to :

I. recall time measurement
II. recall distance
III. recall velocity
IV. recall acceleration
V. recall mass
VI. recall force
VII. A. define gravitation
B. explain the effect of gravitation
VIII. A. define gravity
B. explain the difference in the usage of gravitation and gravity
IX. define gravitational acceleration
X. A. define weight and give its unit
B. appreciate the limitations of the concept weight
C. differentiate between mass and weight
D. recognize the misconception in the usage of the unit in which weight is expressed.
XI. A. state Newton's law of gravitation
B. derive $F = \frac{G m_1 m_2}{r^2}$
C. derive $g = \frac{GM}{r^2}$
XII. solve the problems using the law of gravitation.

Reviewing Concepts

I. Time
II. distance
III. velocity
IV. acceleration
V. mass
VI. force

Learning hierarchy

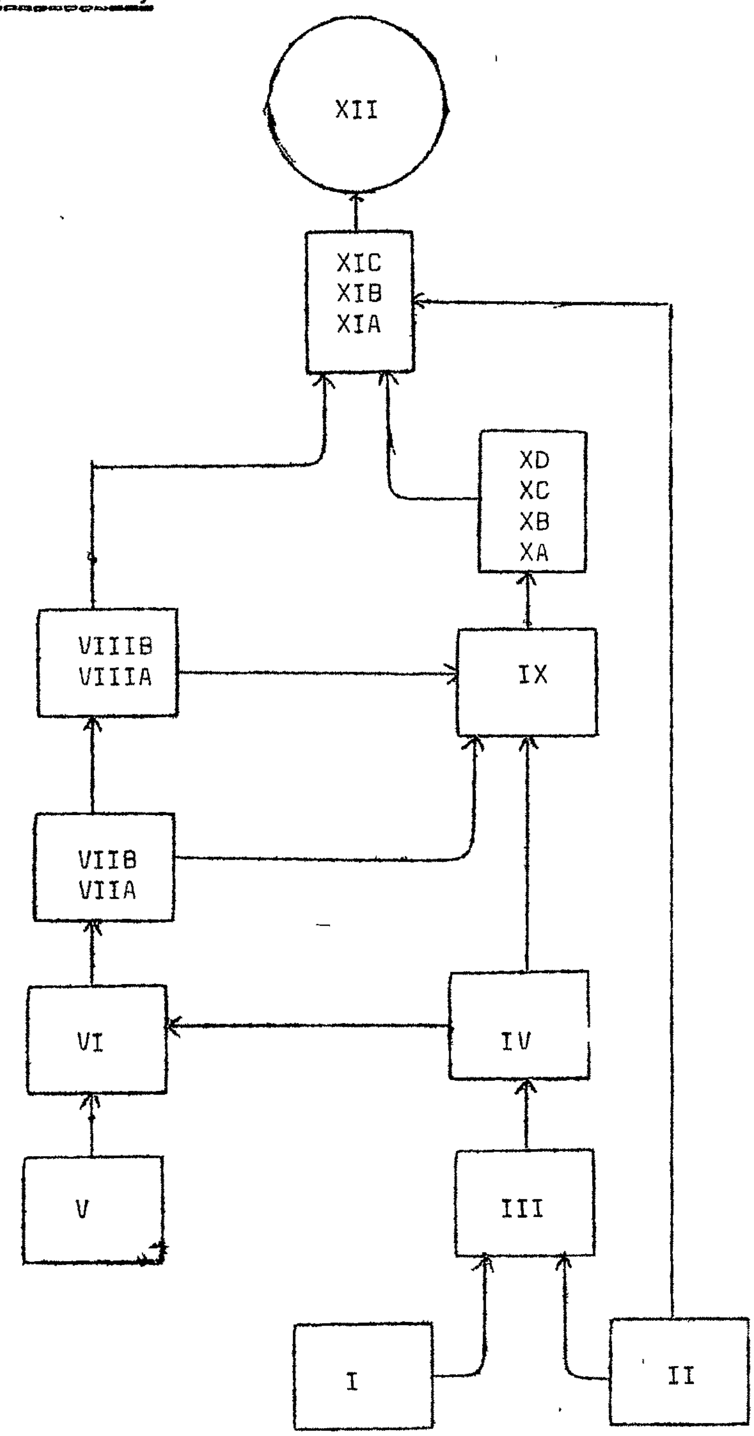


Fig. 6.2 Learning hierarchy map - law of gravitation

Evaluation

1.How is the mass related to force?
2.What happens to the force if the time of application is doubled?
3.What happens to the acceleration if the time of application is doubled keeping the force constant?
4.What is free fall?
5.When the bodies fall down does the force remain constant?

VII.Gravitation

We are quite aware of the fact that a body allowed to fall freely i.e. when body is dropped from a height it fall towards the earth. This happens because of the gravitational attraction between the object and the earth. This force of attraction between the objects is responsible for holding planets or satellites in their orbits around the sun. The tides in the sea are caused due to the force of attraction that the moon and the sun exerts on the water surface of the earth.

Gravitation is the phenomenon of attraction of one body by another body common to all physical bodies in the universe.

NOTES:

1.Bodies attract each other by means of gravitational force.

2.The earth exerts a gravitational (attractive) force on every other body in the universe.

3.Bodies which have a mass that is small compared to the mass of the earth and are near the surface of the earth, 'fall down' because of the gravitational attraction.

Evaluation

1.Why does a small body at a height falls down to earth taking that force of attraction is the same between both?

2.If two bodies attract each other why don't then it move towards each other on the surface of earth?

3.What type of quantity is force of attraction?

VIII. Gravity

Gravity: The gravitational force between the earth (or other planet or satellite) and a body near its surface.

NOTES:

1. This gravitational force (gravity) is measured as the weight of the body on that planet (the earth).

2. The term 'gravity' must be used in a different sense from that of the term 'gravitation'. Gravitation is a phenomenon which gives rise to a force of attraction between all bodies. Gravity is the measureable effect of the phenomenon of gravitation between a body and a planet or satellite i.e. when we talk of gravitation as gravity the attraction is between a body and a planet or a body and a satellite (e.g. moon).

Evaluation

1. How does the term 'gravity' differ from 'gravitation'?
2. Does the value of gravity remains constant always?
3. Does 'gravity' refer to force of attraction with respect to a planet only?

IX. Gravitational Acceleration

Acceleration due to gravity: The acceleration experienced by a body near the earth's surface due to the earth's gravitational force acting on the body.

Example: A stone falling vertically from a height is accelerated by the force exerted on it by the earth.

Type of Quantity: Vector but in practice always treated as scalar (see specification below).

Written Representation: g

Specification: (i) Magnitude: For any body near the earth's surface, the magnitude of g is almost constant; usually taken to be $9.8\ ms^{-2}$.

(ii) Direction: The gravitational acceleration vector for any body near the earth's surface is always directed towards the earth's centre. Hence, the direction is 'fixed' and need not be considered in all calculations.

Evaluation

1. What type of quantity is gravitational acceleration?
2. Why it is treated as a scalar?
3. Does the gravitational attraction remains the same always?

X. Weight

The force by which the given body is attracted by the earth.

Example: See Fig.

Types of Quantity: Vector, but in practice usually treated as a scalar (see specification below).

Written Representation: W

Specification: (i) Magnitude: Given by the relation applied to gravitational force and gravitational acceleration of body.

OR $W = mg$

measured in newton (N).

(ii) Direction: Always towards the centre of the earth; hence 'fixed' and need not be considered in all calculations.

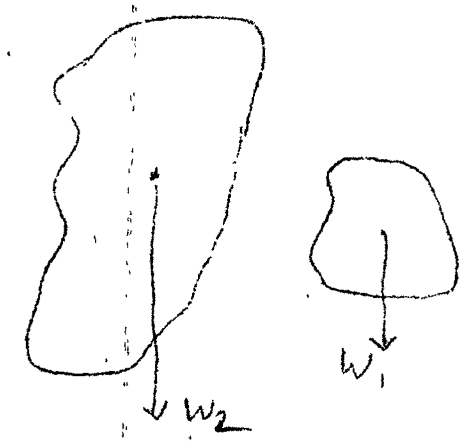


Fig.: Weight is a vector quantity. Its magnitude is the object's mass times the acceleration due to gravity. It is directed towards the centre of the earth.

Dimensional Formula: MLT^{-2}

Limitations of the Concept: (i) The above definition is also valid for any planet or celestial body other than the earth e.g. Mars, Venus, the Moon, but the value of g is different in each case (e.g., g of Mars = $3.92 ms^{-2}$; g of Venus = $8.82 ms^{-2}$; g of Moon = $1.67 ms^{-2}$)

NOTE: 1. Sometime unit of weight is also expressed in kilogram weight (kg.wt). At a place, where value of "g" is taken as 9.8 m/s, the newton and kg.wt are related by the relation 1 kg.wt = 9.8N.

Limitation: This unit and its value in newton are defined only for measurements on earth. Further, as g varies from place to place on earth. 1 kg.wt. is not a constant unit; its magnitude depends on the place.

(2) The weight of a body in space, where g = 0, is zero. This explains the weightlessness experienced by astronaughts. Though the bodies experience weightlessness their mass remains unaltered.

Misconception: Weight is often used synonymously with the concept mass which is erroneous. For example, the weight of a person is always expressed as 50 kgs. Kg being ~~the~~ the unit of mass. Rightly it should be mentioned as 50 x 9.8 = 490 Newton or 50 kg wt.

Evaluation

1. What type of quantity is weight?
2. What is the relation between one kg.wt. and one newton?
3. Do the weight remain constant throughout the surface of earth?
4. If not, why does it vary?
5. What are the differences between mass and weight?

XI. Newton's Law of Gravitation

Every body in the universe attracts every other body at all distances with a force directly proportional to the product of their masses and inversely proportional to the square of the distance between them.

If two bodies of masses m_1 and m_2 are kept at a distance r from each other. These attract each other with a force f.

Then $f \propto m_1 \times m_2$

And also $f \propto \frac{1}{r^2}$

$$\therefore f = G \frac{m_1 \times m_2}{r^2}$$

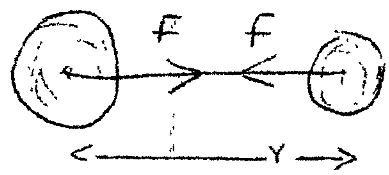


Fig.: Gravitational force between two bodies

G is called the universal gravitaional constant. The present accepted value of G in SI system is :

$$6.67 \times 10^{-11} Nm^2/kg^2$$

Illustration

We have noted in the earlier section that while gravitation refers to gravitational force between any two bodies in the universe gravity is in reference to earch only.

We know that on earth $f = mg$

by Newton's law of gravitation $f = \frac{GMm}{r^2}$

Where M = mass of earth
m = mass of the body

i.e., $mg = \frac{GMm}{r^2}$

or $g = \frac{GM}{r^2}$

The immediate consequence of this is that we come to a conclusion the g varies inversely as r^2. The value of g will be zero at large distances and hence the weight mg will also be zero, which explains the weightlessness in space.

Evaluation

1. What holds the bodies on earth?
2. Why there is no atmosphere on moon where the value of g is 1/6th of that on earth.
3. What holds all the objects in the universe in their respective places?

XII. Problem Solving

1. Calculate the mass of the earth from the following data:

$$G = 6.67 \times 10^{-11} nm^2/kg^2$$

Radius of the earth $r = 6.4 \times 10^6 m$,

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

Solution: $f = mg$ and also $f = \frac{GMm}{r^2}$

$$\frac{GMm}{r^2} = mg$$

$$M = \frac{gr^2}{G}$$

$$= \frac{9.8 \times (6.4 \times 10^6)^2}{6.67 \times 10^{-11}}$$

$$= 6 \times 10^{24} kg$$

2. In the hydrogen atom, an electron of mass 9.11×10^{-32}kg is at a distance of about 5.30×10^{-10}m from a proton of mass 1.67×10^{-27}kg. Calculate the gravitational force between the electron and the proton.

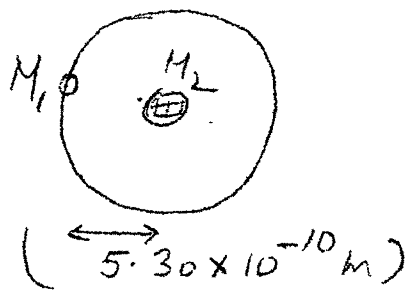


Fig. An Electron Revolving Round a Proton

Solution: $M_1 = 9.11 \times 10^{31}$kg, $M_2 = 1.67 \times 10^{-27}$kg and

$$r = 5.3 \times 10^{-10} m$$

$$f = \frac{GM_1M_2}{r^2}$$

$$= 6.67 \times 10^{-11} Nm^2kg^{-2} \times 9.11 \times 10^{-31}$$

$$\frac{kg \times 1.67 \times 10^{27} kg}{(5.30 \times 10^{-10} m)^2}$$

$$= \frac{6.67 \times 9.11 \times 1.67}{5.30 \times 5.30} \times 10^{-49} N$$

$$= 3.61 \times 10^{-49} N,$$

Evaluation

1. Suppose you are 10^{12}km from a certain star and observe that the force of attraction between your spaceship and the star is 50N. What will be the force when the distance of the star is reduced to 10^{9}km?

(ANS. 5×10^{7} N)

2. Calculate the mass of the earth from the following data :

$g = 9.80$ m/sec^2

$G = 6.67 \times 13^{-11}$ SI units

$R = 6.34 \times 10^{6}$m

Here 'g' is acceleration due to gravity, G is the gravitational constant and R is the radius of the earth.

(ANS. 60×10^{23}kg)

Topic 6: Gravitation

Self Learning Material (SLM)

Newton reflected (perhaps in his garden when the apple fell) that the earth exerts an inward pull on nearby objects causing them to fall. He then speculated whether the same force of gravity might not extend out farther to pull on the moon and keep it in orbit. His speculation and thought in this direction helped us to know more about gravitation.

Every body attracts every other body in the universe. This phenomenon of attraction is called gravitation.

Gravitation can be defined as. . . . . . . (1)

Gravitational force is between two bodies on the. . . . . (earth/universe) (2)

Earth being a member of the universe. This force of attraction exists here also. This force of attraction will depend upon mass of earth and the body. If the mass of one is much greater than the other then the smaller one is pulled towards the bigger.

This force of the attraction between two objects on earth is feeble and cannot cause any motion of the bodies. But for the earth and another body, this force is quite appreciable because of the huge mass of the earth. Hence bodies when projected upwards will fall back to its surface. The special name given to this force for the earch and object is called force of gravity.

When we refer to this gravitational force between earth and any other object on it only we call it 'gravity'.

Therefore gravity can be defined as. . . . . .

. . . .

. . . . (3)

Gravity refers to the force of attraction between one object and.........only. (4)

This gravitational f.r.e on the earth felt by an object is called its weight.

Thus, weight can be defined as..............
.... (5)

The essential difference between force of gravitation and force of gravity is that in gravity one of the object must be a........while in gravitation it need not be so. (6)

Acceleration of bodies called by.......... is called acceleration due to gravity. (7)

Weight of a body depends on a body, mass and acceleration due to gravity.

The expression for weight $w = ... \times g$ (8)

The unit of weight is.......... (9)

The force of attraction due to gravitation depends on the masses of bodies and the distance between them. If m_1 and m_2 are the masses separated by a distance r then force of gravitation

$$f = g. \frac{m_1 m_2}{r^2}$$

Where g is universal gravitation constant.

This law is known as Newton's universal law of gravitation.

We can write this as: Every body in this universe attracts every other body with a force directly proportional to the product of their.... ....and inversely proportional........... . (10)

The value of G is $6.67 \times 10^{-11} Nm^2/kg^2$. From this law it is very clear that as the distance increases the r value of this force also k helps on decreasing, when the distance becomes infinitely large the value of this force reduces to zero. Let us solve some problems.

(i) What is the weight of a body on earth whose mass is 6 kg?

We know that weight of body

$$w = mg$$

where m is the mass and g acceleration due to gravity.

Here

$$m = 6 \text{ kg} \quad \text{and} \quad g = 9.8 \text{ m/sec}^2$$

$\therefore$ $w = mg$

= ..... x ..... = ...N (11)

(ii) Compute the gravitational force of attraction between two 5 kg balls 3 metres apart.

We know that $f = G. \dfrac{m_1 m_2}{1^2}$

Here, $g = 6.67 \times 10^{-11} Nm^2/kg^2$

$m_1 = 5$ kg

$m_2 = 5$ kg

$r = 3m$

$\therefore$ $f = G. \dfrac{m_1 m_2}{r^2}$

= ..... x $\dfrac{\text{..... x .....}}{\text{......}}$

= ..... (12)

Topic 6: Gravitation

Self Evaluation Material (SEM)

1. A body is taken from the earth to the moon. Will its (i) mass, (ii) weight increase, decrease or remain constant?

. . . .
. . . .
. . . .

2. What instruments can be used to measure the (iii) mass (iv) weight on the moon?

. . . .
. . . .
. . . .

3. State Newton's Law of Gravitation.

. . . .
. . . .
. . . .

4. What is the nature of motion (uniform or accelerated) of a body thrown in a vertical direction on the surface of the earth?

. . . .
. . . .
. . . .

5. Give reasons in support of your answer.

. . . .
. . . .
. . . .

6. Two objects placed close to each other do not move any closer. Although a force of attraction exists between them. Explain why do they not move?

. . . .

. . . .

. . . .

Key to SLM

1. Attraction of one body on another
2. Universe
3. Force of attraction between a body and a planet or satellite
4. Planet (e.g. earth) or satellite
5. Gravitational pull experienced by the body (or is the product of mass and acceleration due to gravity)
6. Planet or satellite
7. Gravitational attraction
8. m
9. Newton
10. Masses, to the square of their distance
11. 6 x 9.8 = 58.8N

Key to SEM

1. Decrease
2. Common balance, spring balance
4. Accelerated
5. Force of attraction very feeble

Topic 6: Gravitation

Assessment Material (AM)

Section A

I. Complete the following sentences by suitable word or words:

1. The type of force of attraction that exists between any two bodies in the universe is called..(1).. ....(1)

2. The force with which a body is attracted by the earth is called..(2).. ....(2)

3. Acceleration of an object due to the earth's gravity is..(3).. ....(3)

4. Gravity is the force of attraction between..(4)..and any other object on or around it. ....(4)

5. Weight is a ..(5a).. and is measured as the product of mass and ..(5b).. ....(5a) ....(5b)

6. Gravity and gravitation differ in the sense that in gravity one object should be..(6).. ....(6)

Section B

II. Select the proper word and fill in the blanks:

1. Every material body exerts a force of ..(1)..towards every other material body (attraction/repulsion). ....(1)

2. Force of gravitation between two bodies is directly proportional to the ..(2).. of their masses (sum, square, product). ....(2)

3. Force of gravitation between two bodies is inversely proportional to the ..(3a)..of distance between ..(3b).. (square/product) . . . . . . (3a) . . . . . . (3b)

4. $f = G \times \dfrac{M_1 \times \ldots(4a)\ldots}{\ldots(4b)\ldots}$ . . . . . . (4a) . . . . . . (4b)

5. $g = G \times \dfrac{M}{\ldots(5)\ldots}$ . . . . . . (5)

6. The value of G ..(6).. from place to place (remains constant/varies) . . . . . . (6)

7. A body lying on the surface of earth and suppose earth looses its power of attraction them (A/B/C/D) ...(7)... . . . . . . (7)

A = mass of body becomes zero
B = weight of the body will become zero
C = mass will remain same but weight will vanish
D = weight will remain same but mass will vanish

III.

1. If the masses of two objects A & B are doubled what happens to gravitational attraction? . . . . . . (1)

2. If the distance between the centres of the objects A & B is doubled what happens to gravitational attraction? . . . . . . (2)

Section C

1. Calculate the weight of a man of mass 60 kg

(i) on the earth ($g = 9.80 ms^{-2}$)

(ii) on the moon ($g = 1.70 ms^{-2}$) and

(iii) in a space vehicle in inter-planetary space ($g = 0$).

. . . .

. . . .

. . . .

2. Calculate the mass of the earth if radius of the earth = 6.38×10^{6}m ; $g = 9.8 ms^{-2}$

and $G = 6.67 \times 10^{-11} Nm^{2}/kg^{2}$.

3. The mass of the sun is 2×10^{30}kg and of the planet Jupiter is 2×10^{27}kg. The mean distance between the sun and the Jupiter is 7.8×10^{11}m. Calculate the value of the universal gravitational constant if the force of attraction between the Sun and the Jupiter is 4.276×10^{23}N.

Topic 7 : FRICTION

CLASSROOM LEARNING MATERIAL (CLM)

Task analysis

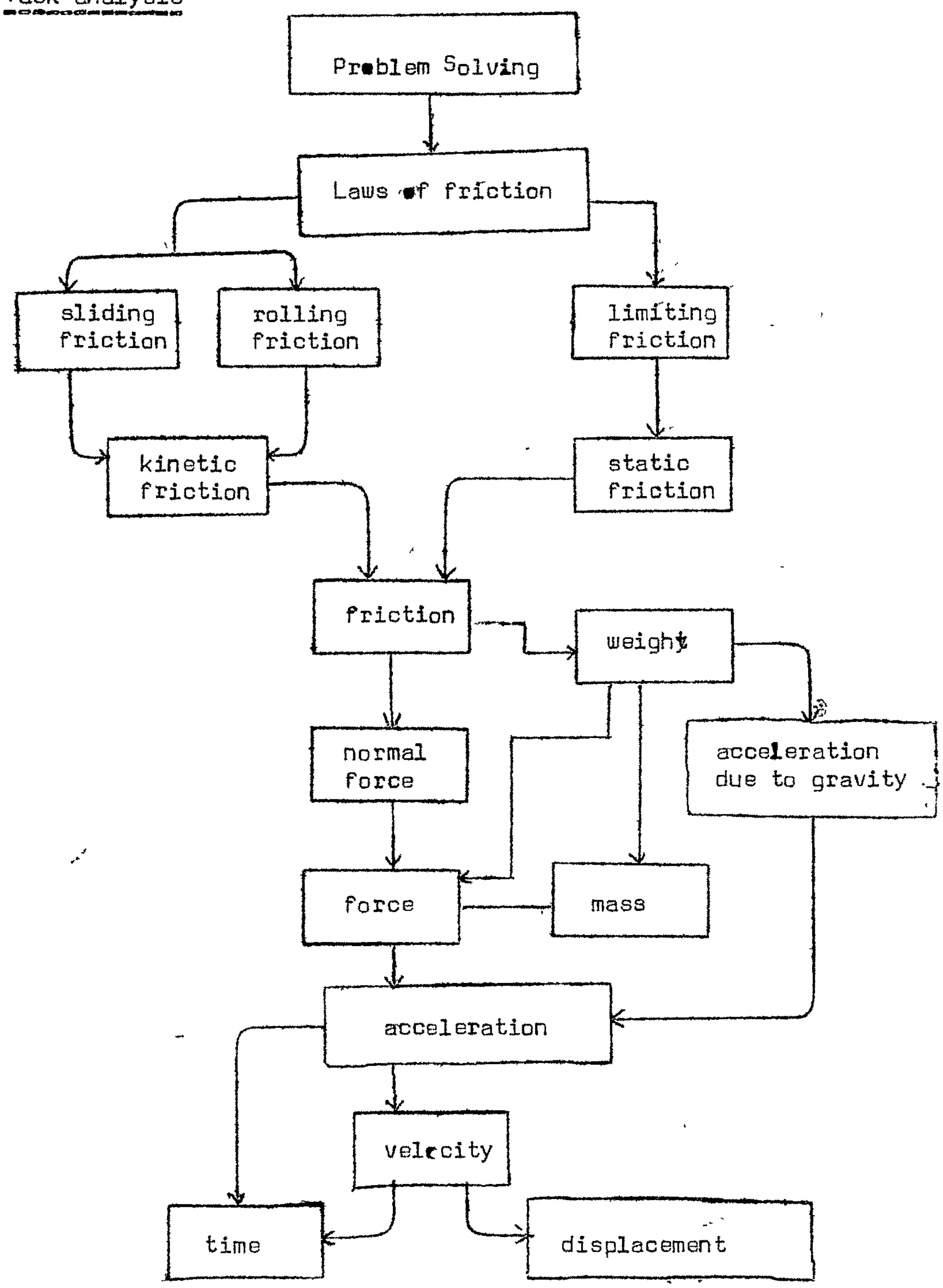


Fig. 7.1 Task analysis map - friction

Topic 7: Friction

Learning Hierarchy

The following are the learning objectives in the learning hierarchy shown in Fig. 7.2.

When the topic is completed the student should be able to :

I. recall the measurement of time
II. recall displacement
III. recall velocity
IV. recall acceleration
V. recall acceleration due to gravity
VI. recall mass
VII. recall force
VIII. recall weight

IX. A. define normal force
B. recognize the changes in the value of normal force on an inclined plane
Ø

X. A. define friction
B. explain the origin of friction
C. appreciate the effects of friction

XI. define static friction

XII. define limiting friction

XIII. A. define kinetic friction
B. give examples for kinetic friction
C. differentiate between kinetic and sliding friction.

XIV. A. define sliding friction
B. illustrate sliding friction with examples

XV. A. define rolling friction
B. Illustrate rolling friction with examples

XVI. A. state the laws of friction
B. derive $F = \mu R$

XVII. A. justify the need of friction
B. describe the methods to reduce friction

XVIII. solve problems.

Learning hierarchy

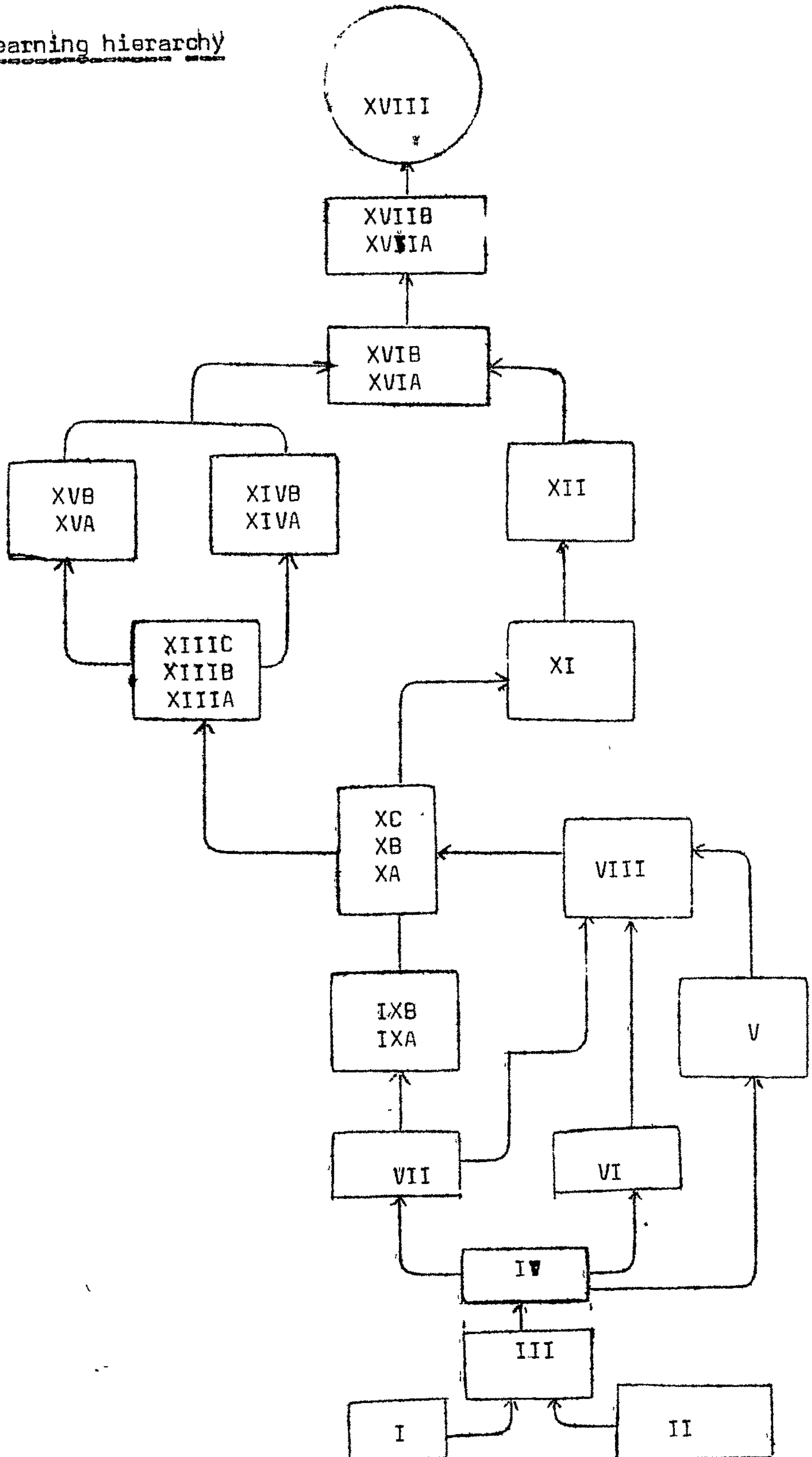


Fig. 7.2 Learning hierarchy map – friction

Reviewing Concepts

I. Time
II. Displacement
III. Velocity
IV. Acceleration
V. Acceleration due to gravity
VI. Mass
VII. Force
VIII. Weight

Evaluation

1. Differentiate between mass and weight.
2. How does the force vary as the velocity changes?
3. What is the unit of weight?
Does it differ from that of force?
4. Why the direction of weight is fixed?
5. Does the force gravitation between two bodies depends upon the distance between them?
If so, how?
6. Define mass.

IX. Normal Force

Forces which act perpendicular to the surfaces in contact. For example, a body lying on the floor its weight will be acting normally to the surface of the floor which is its normal force.

Here, mg is the normal force acting on the surface AB

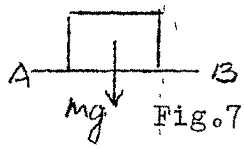


Fig. 7.1

If the surface is inclined to the horizontal then the normal force =mgCosθ again normal to the surfaces in contact i.e., N=mgCosθ .

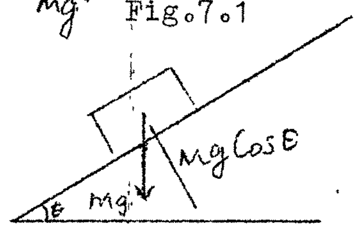


Fig. 7.2

Normal force is the force perpendicular to the surface in contact.

Type of Quantity: Vector

Written Representation: R

Specification: (i) Magnitude: Equal to the magnitude of the components of the force perpendicular to the two surfaces in contact. Measured in Newton (N).

(ii) Direction: Always perpendicular to the surfaces which are in contact.

Evaluation

1. Define normal force.
2. What is its unit?
3. Will the normal force is always equal to its weight?
4. When will be R = mg ?

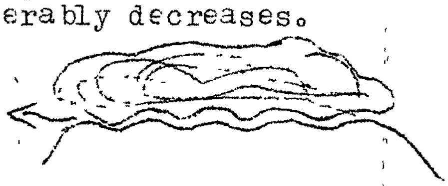
X. Friction

We daily observe that a bus or a car eventually comes to rest after its engine stops working. A cricket ball hit by a batsman stops moving on the ground after some time. A bicycle ultimately comes to rest when one stops peddling it. We see that generally all the moving bodies when left to themselves, ultimately come to rest. This is due to the fact that all the moving bodies are acted upon by an external force, which opposes their motion. The motion of an object moving on a surface or in air in general is opposed by the resistance of air or the force of friction.

Force of Friction (or simply friction): A force which opposes the relative motion between two surfaces in contact.

NOTE: Two bodies or two surfaces are said to be in relative motion when the position of one is constantly changing with respect to the position of the other.

The force of friction is caused by the interlocking of the irregularities of the surfaces in contact. The motion of one surface over the other requires the overcoming of interlocking obstacles which may be achieved by the slight lifting of the moving body or the smoothening of the irregular projections or the filling up of the irregularities by a suitable lubricant. If the surfaces are polished, the force of friction between them considerably decreases.

Interlocking  Fig. 7.3

Evaluation

1. What is friction or force of friction?
2. Why does interlocking between the surfaces happen?
3. Will the friction b. less or more along smooth surfaces?
4. Can we over come friction?
5. Is there any friction when the body starts moving?

XI. Static Friction

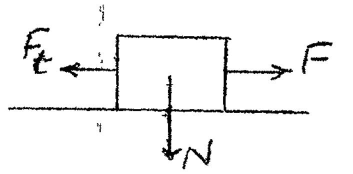
When there is no relative motion between the two surfaces the friction involved is static and is known as static friction.

Static friction is the force which opposes an applied force when one solid tends to slide over another solid.

Type of Quantity: Vector.

Written Representation: Fs

Magnitude: Any value between 0 and F_L (see below), equal to the component of the applied force perpendicular to the normal force.



Direction: Perpendicular to the normal force and direct to oppose the applied force.

Evaluation

1. What do you mean by the term 'static'?
2. What type of quantity is static friction?
3. Define static friction.
4. What will be direction of the frictional force w.r.t. to the applied force?

XII. Limiting Friction

The force of friction is a self-adjusting force. It increases with the force tending to produce motion as much of it being brought into play as is just sufficient to prevent motion but in no case does it exceed a maximum value. This maxim value attained by friction is known as limiting friction. Limiting friction is the force which opposes the applied force when one solid is just about to slide over another solid.

Limiting friction is the maximum value of static friction.

Type of Quantity: Vector
Written Representation: F_t
Direction: Same as static friction.

Evaluation

1. When we say friction is a self adjusting force and it keeps on increasing with the applied force; will it increase to infinitly large values?
2. What is the name given to the maximum value of static friction?
3. What is the unit in which limiting friction can be measured?
4. What can you say about the direction of limiting friction?

XIII. Kinetic Friction

We have seen that there is a limit to static friction. When the applied force is increased to greater than this limiting friction the body starts moving or rather sliding.

The force of friction involved when the body is in motion, is called kinetic friction or dynamic friction.

Kinetic friction will always be less than static friction.

A car before being pushed forward is moved to and fro to create a motion this reducing the friction. It is of common experience that a moving body can be pushed easily compared to the one at rest. It is a vector quantity represented by F_k.

Evaluation

1. What is kinetic friction?
2. Illustrate with examples to show that kinetic friction is less than static friction.

3. What is the difference between static and kinetic friction?
4. Why has a horse to pull a cart harder during the first few feet of its motion than later on?

XIV. Sliding Friction

When the surface of one body slides over the surface of another body, then the force of friction acting between the two surfaces is known as force of sliding friction. The friction acting on the following cases is sliding friction :

a. A book pushed or pulled on a table.

b. Walking on the ground.

c. Sking.

d. Fixing a nail in wooden furniture.

The sliding friction depends on the smoothness of the two surfaces in contact. Smoother the surfaces, less is the sliding friction and vice versa. Sking is done on ice and not on the ordinary ground because sliding firction in the case of ski shoes and smooth surface of ice is much less as compared to ski shoes and rough ground surface.

It is a vector quantity and is represented by F_s.

Evaluation

1. What will be the direction of sliding friction?
2. Does the sliding friction reduce when the surfaces are smooth?
3. Give few illustrations to show sliding friction.

XV. Rolling Friction

When the surfce of one body rolls over the surface of another body, the force of friction acting between the two surfaces is known as force of rolling friction. The friction acting in the following cases is rolling friction.

i. A cricket ball moving on the ground.
ii. Wheels of an automobile moving on the ground.
iii. Skating on a smooth surface.

It may be of common experience that the pulling of heavy boxes become easy when wheels are used with it. This is due to the fact that rolling friction is far less than sliding friction. When we pull a box it is the sliding friction involved but when wheels are used it is the rolling friction that comes into play.

It is a vector quantity and is represented by F_r.

Evaluation

1. Why roller bearings are used in machines?
2. How does rolling friction differ from sliding friction?
3. Can the value of rolling friction be reduced by applying lubricants?

XVI. Laws of Friction

Experimental results show that the friction follows three laws.

(i) The direction of friction is always opposite to the direction in which a body moves or tends to move.

(ii) The limiting friction is independent of the area of contact and depends upon the nature of the surfaces of contact.

(iii) The limiting friction is directly proportional to the normal force.

The third law can be represented as follows :

$F \propto R$ Where F is the limiting friction and R is normal force.

OR $F = \mu R$ Where μ is constant known as coefficient of friction.

...1

The equation can be rewritten as -

$F_s = \mu_s R$ ...2

$F_k = \mu_k R$ To represent static as well as kinetic friction. ...3

Coefficient of friction $\mu = \frac{F}{R}$ can be thought of as a constant measure of friction depending upon the nature and condition surfaces in contact (i.e., roughness, wetness lubrication, etc.) but is independent of normal reaction.

Table for μ (Only For Reference)

Values of Coefficient of Friction for Various Materials

Material	μ_s	μ_k	μ_r
Rubber tyre on dry concrete	1.0	0.7	0.04
Rubber tyre on wet concrete	0.7	0.5	
Wood on wood, dry	0.5	0.3	
Wood on wood, soapy	0.2		
Wood on steel	0.5	0.25	
Wood on leather, dry	0.56		
Wood on leather, oily	0.15		
Metalon metal	0.15		
Steel wheel on steel rail			0.0045
Steel ball on steel surface			0.0025

NOTES:

(i) Every force of friction is directly proportional to the normal force.

(ii) The magnitude of each force of friction is measured in newton (N).

(iii) The force of friction is independent of the area of the two surfaces in contact.

(iv) When no external force acts on the body, $F_s=0$.

(v) If the applied force F parallel to the displacement is greater than F_k, then the effective force is $F - F_k$. If $F = F_k$, then $a = 0$, or the body moves along a straight line at constant speed.

(vi) For small speeds, F_k is independent of the speed of the sliding body.

Evaluation

1. Is it correct to say that friction acts only when a body is acted upon by a force?

2. Will the value of coefficient of friction change on wetting the surfaces of contact?

3. What are the factors on which the value of limiting friction depends?

4. If a force of F is applied on a body and the value of kinetic friction is F_k what is the effective force with which the body is moving?

XVII. Effects of Friction

(A) Justify the statement 'friction is a necessary evil'.

Friction an important part in our daily life. In many of the cases we find that friction is a necessity but an evil necessit..

(i) Without friction between the feet and the ground it will not be possible to walk.

(ii) Without friction we cannot fix nails, climb trees.

(iii) Without friction it will not be possible to write on a paper.

(iv) Friction causes wear and tear of moving parts of different machinery and is, therefore, an evil only in this case.

(v) The energy wasted to overcome friction is converted into heat energy and causes additional damage to the machines etc.

So we see here though friction appears as a force which opposes motion it has certain definite advantages and disadvantages. We cannot think of a friction free world as life will become impossible. Thus friction is rightly called a necessary evil.

Evaluation

1. List instances where friction can be considered to be advantageous to us.

2. What are the disadvantages of thepresence of friction? List them.

3. Imagine you are in a friction free world. Can you describe how your life would be?

(B) The Ways of Reducing Friction.

(a) By Polishing the Surfaces: As the friction is due to interlocking of the surfaces it can be reduced by removing the unevenness of the surface by making it smooth.

(b) Using Lubricants: Lubricants such as oil, grease carbon powder etc. are being used to fill in the depressions on the surfaces lessening friction. Thick oils are always used.

(c) By Using Contact Ball Bearings: Ball bearings reduces the friction to a great extent as friction involved while rolling is less that while sliding.

(d) By Using Anti-Friction Materials: Use of anti-friction metals such as brass or bronze reduce friction considerably. It is found that friction between steel and steel is greater than steel and an anti-friction material.

Evaluation

1. List the methods by which friction can be reduced.

2. What happens when a lubricant is applied to the interface between the surfaces in contact?

3. Why the outside of an aeroplane is highly polished?

4. Why do we oil bicycles occasionally?

XVIII. Problems

(a) A metal box of mass 4 kg is placed on a horizontal floor, with a block of wood of mass 1 kg resting on top of it. A horizontal force of 19.6 N, applied on the metal box, is necessary to make the box just slide. Determine: (i) the normal force, (ii) the force of limiting friction and (iii) the coefficient of static friction, (iv) what will be the force of friction if the applied force is 3.0 N ?

Solution: The total mass resting on the horizontal floor is 4 kg + 1 kg = 5 kg.

(i) $W = 5 \text{ kg} \times 9.8 \text{ ms}^{-1} = 49.0 \text{ N}$.

Hence, the normal force = $R = W = 49.0$ N.

(ii) By definition, the force of limiting friction, F_t, is equal in magnitude to the applied force which causes the box to slide.

Hence $F_t = 19.6$ N

(iii) $F_s = \frac{F_t}{R} = \frac{19.6 \text{ N}}{49.0 \text{ N}} = 0.40$

(iv) The applied force, of magnitude 3 N is less than the force of limiting friction. The force of static friction can have any value upto F_t, but is equal to the applied force.

Hence, $F_s = 3.0$ N.

(b) A wooden block is being slide over a horizontal wooden table, the coefficient of friction being 0.35. A horizontal force of 7 N is just sufficient to maintain a uniform speed of the block. What is the weight of the block?

Solution: This is a numerical problem of kinetic friction.

$\mu_k = 0.35$ $F_k = 7$ Newton $W = ?$

Normal force, $R = \frac{F_k}{\mu_k} = \frac{7}{0.35} = 20$ Newtons

Weight of the block (W) = Normal force (R) = 20 N.

Evaluation

1. A book of mass 2 kg is placed on a table. A horizontal force of 5 N is applied on the book. Will the book move if the coefficient of static friction between its surface and that of the wooden table is 0.6 ?

2. If the force of sliding friction between the surfaces of a body and the ground is 40 N and the applied force is 50 N, will the body be accelerated? Determine the effective force producing the acceleration.

Topic 7: Friction

Self Learning Material (SLM)

Friction plays a very important role in our daily life. Whenever a body starts moving friction invariably comes into play and opposes the motion. A moving body ~~kx~~ left on its own, will come to rest after some time due to friction only.

Therefore, we can define friction as

. . . .

. . . . (1)

Friction being a force is. . . . . quantity and can be measured in. . . . . . . (2)

Friction depends upon the surfaces in contact. Between smooth surfaces it will be less as compared to rough ones.

One thing we should understand clearly is that friction comes into play only when a body is subjected to a force. As the applied force increases force of friction also increases till it reaches a maximum value known as limiting friction.

When the applied force is more than this limiting friction, the body starts moving.

Therefore the condition for a body to start moving is that the frictional force must be. . . . . (3)

There are many ways by which we can reduce friction. Applying lubricants like oil is one such method. These thick oil goes into unevenness of the surfaces smoothening it and reducing friction.

Use of ball bearings also help to reduce friction. You may have noticed that most of the rotating parts of a machine are supported by roller bearings. This is because the friction involved while rolling ~~s~~ is less than that involved in sliding.

Therefore, sliding friction is.......than rolling friction. (4)

We may also note that friction between two bodies of the same material is much more than that between two different objects. Thus to reduce friction anti-friction materials are also used.

Friction between steel and steel will be........ than steel and bronze. (5)

Depending upon whether the body is moving or not we can think of static as well as kinetic friction. Kinetic friction is always less than static friction.

The maximum value of static friction is known as................ . (6)

The value of limiting friction is directly proportional to normal force, i.e., the force acting perpendicular to the surfaces of contact. It does not depend upon the surface area in contact but depends on the nature of the surfaces in contact. We can write,

Force of limiting friction $F = \mu R$.

Where μ is the coefficient of friction.

i.e., $\mu = \frac{F}{....}$

being a ratio it has no unit. (7)

We can define coefficient of friction as the ratio of....... to .... (8)

Now let us solve a problem.

1. A block of 1.5 kg mass is resting on a surface. Calculate the force required to just slide it, when the coefficient of friction is 0.25 ($g=10\ m/s^2$). Once it starts moving, will the same force be required to keep it moving?

We know that force must be equal to limiting friction for the body to just slide.

$\therefore$ F = R

F = ?

= 0.25

R = mg = 1.5 x 10 = 15 N

F = R = .25 x 15 = 3.75 N.

A minimum of 3.5 N force is required to start it moving. Once it starts moving, we know that kinetic friction involved will be less than static friction and as such that much force (3.5 N) is not required to keep it moving.

2. A book of mass 2kg is placed on a table. A horizontal force of 5 N is applied on the book. Will the book move if the coefficient of static friction between its surface and that of the wooden table is 0.6 ?

. . . .

. . . .

. . . . (9)

---

3. A mass of 45 kg is resting on the rough horizontal surface and can be just moved by a force of 10 kg wt acting horizontally. Find the coefficient of sliding friction.

<u>Solution</u>: Let F be the limiting friction, R be the normal reaction and P be the external force applied (See Fig. 7.1).

Here, P = 10 kg wt; m = 45 kg

R = mg = 45 kg x g = 45 kg wt

$\therefore \quad \mu = \frac{F}{R} = \frac{P}{R} = \frac{P}{mg} =$ . . . . (10)

4. Find the distance travelled by a body before coming to rest if it is moving with a speed of 10 ms^{-1} and the coefficient of friction between the ground and the body is 0.4.

<u>Solution</u>

Here, $\mu = \frac{F}{R}$

$\therefore$ $F = \mu R$

But $F = ma$

where a = Retardation and $R = mg$

$\therefore$ $ma = mg\ \mu$

OR $a = \mu g = 0.4 \times 9.8 = \ldots\ldots$ (11)

Hence $v^2-u^2 = 2as$

$0-(10)^2 = 2(-3.92) \times 5$ ($\because$ a is retardation)

$\therefore$ $S = \ldots\ldots$ (12)

Topic 7: Friction

Self Evaluation Material (SEM)

Directions: In the blank space at the right of each statement, write the word or expression which BEST completes the meaning.

1. Friction is any force that..(1a).. the relative sliding or rolling ..(1b)..of objects that are..(1c).. each other. ____ 1a ____ 1b ____ 1c

2. Some physicists believe that friction is caused by surface.(2). ____ 2

3. If surfaces are made smooth, friction between them.(3). ____ 3

4. Other causes of friction may be..(4a)..and..(4b).. ____ 4a ____ 4b

5. Friction acts..(5a)...to the surfaces which are sliding over one another, and in the (same, opposite) ..(5b)..direction as the motion. ____ 5a ____ 5b

6. Friction depends upon the..(6a).. of the materials in contact and ..(6b).. ____ 6a ____ 6b

7. Static friction is (less than greater than)..(7)..sliding friction. ____ 7

8. Within the range of medium speeds, sliding friction is nearly independent of the..(8)...of the surfaces. ____ 8

9. Friction between a bullet and the gun barrel is (less than the same as, greater than)..(9)..the friction between slower-moving objects. ____ 9

10. Friction is (directly proportional to, independent of, inversely proportional to)..(10)..the force pressing the two surfaces together.(normal force) ____ 10

11. The ratio of the force needed to overcome friction to the normal force pressing the surfaces together is called the..(11).. _ _ _ _ _ _ _ _ _ _ 11

Directions: Write the answers to the following in the spaces provided. Where appropriate, make complete statements.

12. List four situations in which friction is a help.

a. _ _ _ _ _ _ _ _ _ _ _ _ _ _ _

b. _ _ _ _ _ _ _ _ _ _ _ _ _ _ _

c. _ _ _ _ _ _ _ _ _ _ _ _ _ _ _

d. _ _ _ _ _ _ _ _ _ _ _ _ _ _ _

13. List four situations in which friction is a hindrance.

a. _ _ _ _ _ _ _ _ _ _ _ _ _ _ _

b. _ _ _ _ _ _ _ _ _ _ _ _ _ _ _

c. _ _ _ _ _ _ _ _ _ _ _ _ _ _ _

d. _ _ _ _ _ _ _ _ _ _ _ _ _ _ _

14. List four ways in which friction may be increased.

a. _ _ _ _ _ _ _ _ _ _ _ _ _ _ _

b. _ _ _ _ _ _ _ _ _ _ _ _ _ _ _

c. _ _ _ _ _ _ _ _ _ _ _ _ _ _ _

d. _ _ _ _ _ _ _ _ _ _ _ _ _ _ _

15. List four ways in which friction may be decreased.

a. _ _ _ _ _ _ _ _ _ _ _ _ _ _ _

b. _ _ _ _ _ _ _ _ _ _ _ _ _ _ _

c. _ _ _ _ _ _ _ _ _ _ _ _ _ _ _

d. _ _ _ _ _ _ _ _ _ _ _ _ _ _ _

16. A block weighing 300 N moved uniformly on a horizontal surface by a force of 60 N. (Note here a = 0).

a. What is the force needed to overcome friction? _ _ _ _ _ _ _ 16a

b. What is the normal force pressing the surfaces together? _ _ _ _ _ _ _ 16b

c. What is the coefficient of friction? _ _ _ _ 16c

Key to S.L.M

2. Scalar, Newtons

3. equal to or less than applied force

4. greater

5. greater 6. limiting friction 7. R

8. force of limiting friction to normal reaction

9. F = .6 x 2 x 9.8 = N F and so it cannot be moved.

10. 0.22 11. 3.92 m/s^2 12. 12.75 m

Key to S.E.M.

1a. obstructs

1b. motion

1c. placed on 2. irregularities

3. decreases

4a. roughness

4b. wetness

5. parallel, opposite

6. surfaces normal force

7. greater than

8. area of contact

9. less than 10. directly proportional

~~10. less than~~ 11. coefficient of friction

Topic 7: Friction

Assessment

Section A

I. Complete the following statements with suitable word/s :

1. Static friction is..(1).. than dynamic friction. _ _ _ _ _ _ _1

2. Friction is a..(2a).. adjusting..(2b).. _ _ _ _ _ _ _2a _ _ _ _ _ _ _2b

3. Maximum value of friction called in to play is known as..(3).. _ _ _ _ _ _ _3

4. Friction can be reduced by..(4).. _ _ _ _ _ _ _4

5. Friction is both a necessity and an..(5).. _ _ _ _ _ _ _5

6. Friction always acts in direction that..(6)..motion. _ _ _ _ _ _ _6

7. Friction has..(7)..existance of its own (independent/no independent) _ _ _ _ _ _7

8. Rolling friction is..(8)..than sliding friction. _ _ _ _ _ _8

9. For a body lying on the ground its normal force is equal to its..(9).. _ _ _ _ _ _9

II. Define the following terms :

a. Limiting Friction: _ _ _ _ _ _ _ _ _ _ _ _ _ _

_ _

_ _

b. Rolling Friction: _ _ _ _ _ _ _ _ _ _ _ _ _ _

_ _

_ _

c. Sliding Friction: _

Section B

III. Use the most suitable word to complete the sentences

1. The limiting friction is..(1).. proportional to normal force. _ _ _ _ _ _ _ _1

2. F = m x ..(2).. _ _ _ _ _ _ _ _2

3. Coefficient of friction is defined as the ratio of..(3a)..to..(3b).. _ _ _ _ _ _ _3a _ _ _ _ _ _ _3b

4. Limiting friction is independent of..(4a)..and depends on..(4b).. _ _ _ _ _ _ _4a _ _ _ _ _ _ _4b

IV. State the three laws of friction.

_ _

V. Why it is more tiresome to walk on sand than on hard ground?

_ _

Section C

VI. A wooden crate of mass 20 kg rests on a horizontal road. What is the minimum force required to move the crate horizontally? The coefficient of static friction between two surfaces is 0.45.

_ _

VII. A horse of mass 7500N is able to exert a horizontal force of 6000 N on a level road. Determine the coefficient of static friction between the horse's hooves and the road.

_ _

Topic 8 : WORK

CLASSROOM LEARNING MATERIAL (CLM)

Task analysis

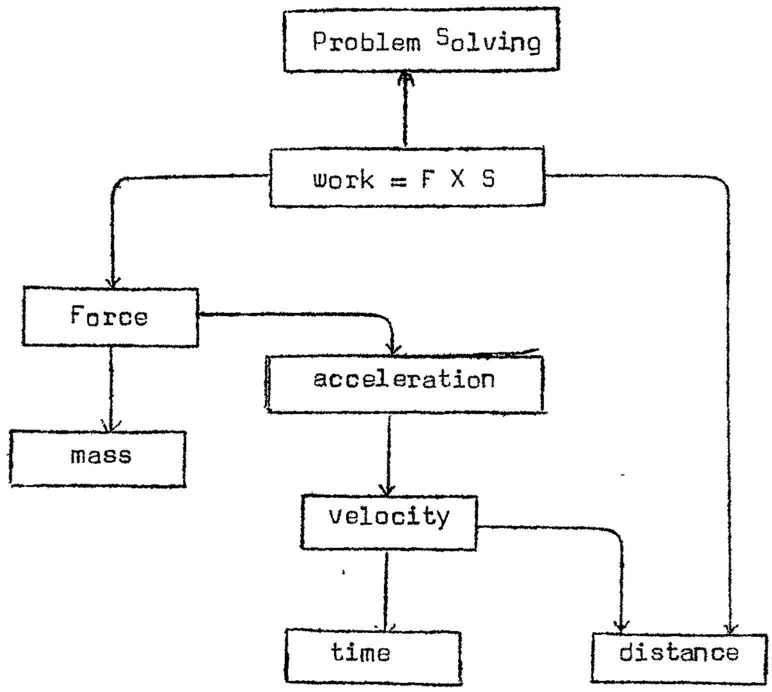


Fig. 8.1 Task analysis map - work

Learning hierarchy

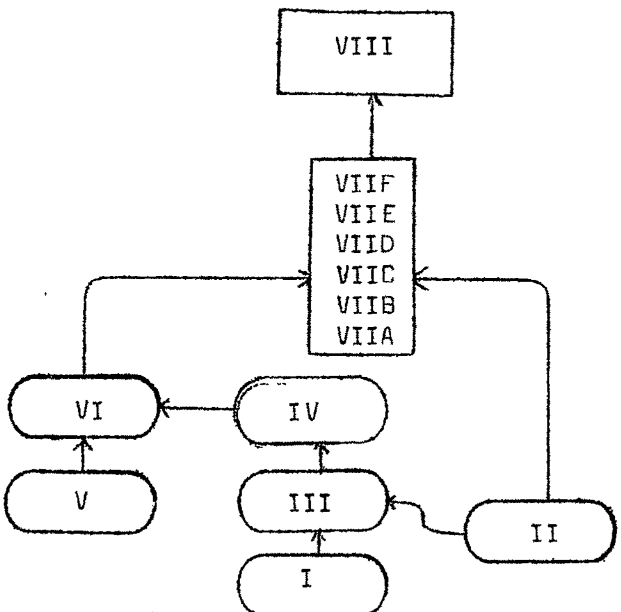


Fig. 8.2 Learning hierarchy map - work

Topic 8: Work

Learning Hierarchy

The following are the learning objectives in the learning hierarchy shown in Fig.8.2.

At the end of the topic the student should be able to :

I. recall the measurement of time
II. recall distance
III. recall velocity
IV. recall acceleration
V. recall mass
VI. recall force

VII. A. define work
B. express it as w = F x S
C. derive expression for work when the force is inclined to the direction of motion.
D. Find the work done when the force is acting against the direction of motion.
E. explain what is meant by positive work and negative work.
F. define joule.

VIII. solve problems based on work.

Reviewing Concepts

1. Distance
2. Time
3. Velocity
4. Acceleration
5. Mass
6. Force

Evaluation

1. Define the above concepts.
2. What are their units?
3. List out the vector quantities and scalar quantities among them.
4. If the body on the application of a force does not change its position what is the value of effective force?

7. Work

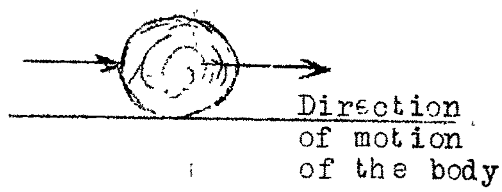
Whenever a force is applied on a body there can be a change in its shape, volume and position. In all cases, we speak of the work being done.

Work done by a force is a measure of the effect on a body or system on which it is acting.

Type of Quantity: Scalar
Written Representation: W
Specification: The amount of work done by a force is measured by the product of the force and the distance covered. It is measured in joule.

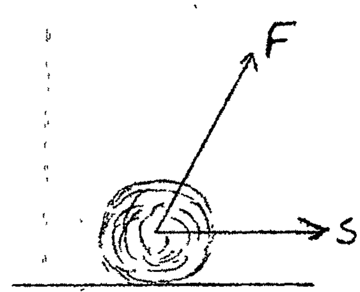
Mathematical Expression:

(i) From the definition
work done = force x distance
OR $W = F \times S$
Here force F must be in the direction of motion of the body.



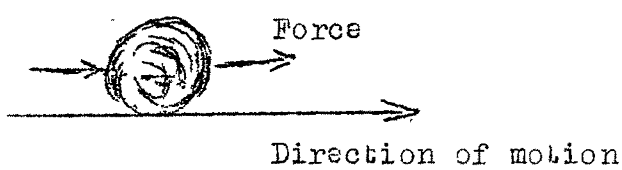
(ii) If the force F is acting in a direction θ inclined to the direction of motion of the body then the component of force in the direction of motion of the body is $F\cos\theta$ or the work done

$$W = F\cos\theta \times S$$
$$= F.S \cos\theta$$



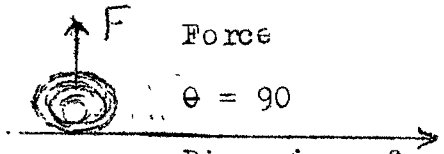
Three commonly encountered situations in which work is done by a constant force :

1. Force in the same direction as motion



Work done = F x S

2. Force perpendicular to motion



$$W = F.S \cos\theta$$
$$= F \times S.\cos 90°$$
$$= F \times S \times 0$$
$$= 0$$

3. Force opposed to direction of motion

$\theta = 180°$

Work done $W = F\ S \cos\theta$
$$= F\ S \cos 180$$
$$= -FS$$

From the definition we can construct a situation in which a force acts on a body and does not work. This will be true if the force is perpendicular to the direction of motion of the body.

When man is carrying a hand bag to the railway station and is walking on a level road scientifically he is doing no work because the force that he is applying against the weight of the bag is vertically upwards and his motion is in the horizontal direction and there is no motion in the direction of the force he is applying.

<u>Positive Work</u>: When the point of application of a force moves in the direction of the force, the force is said to perform +ve work. In other words, the work done by the body is called +ve work.

Negative Work: When the point of application of force moves in the opposite direction of the force, the force is said to perform -ve work. In other words, the work done on the body is called -ve work.

Joule

Unit of work is joule.

Written Representation: J

Specification: One joule is the quantity of work done when a force of magnitude one Newton moves its point of application through one metre along the direction of the force.

1 joule = 1 Newton x 1 metre

Or 1 = 1 Nm

A smaller unit 'erg' is also used to measure work.

1 erg = 1 dyne x 1 cm

1 joule = 10^7 ergs

Evaluation

1. Define work.
2. What type of quantity is work?
3. Define Joule.
4. Why is it that a man carrying a hand bag in his hand not doing any work?
5. Which is the physical quantity represented by the unit newton-metre?
6. If a body weighing mg lifted through a distancehL, what will be the work done?
7. Can you give a mathematical expression for work in terms of change in velocity?

8. Problem Solving

1. Calculate the work done when a body moves through a distance of 5 m on the application of a force of 6 N.

We know that $W = F.S$

Here, $F = 6$ N

$S = 5$ m

$W = F.S$

$= 6 \times 5$

$= 30$ joule.

2. Calculate the work done in lifting a weight of 8 kg through a vartical height of 10 metres. ($g = 9.8\ ms^{-2}$)

Solution: Work done = Force x Distance moved by force
= 44 x 9.8 x 10 Newton metres
= 392 joules

Hence work done = 392 J (Here $F = mg = 4 \times 9.8$).

3. A man pulls on 75 kg crate for 20 m across a level floor using a rope that is 60° above the horizontal. How much work does he perform, if he applied a force of 100 N.

$W = FS \cos\theta$
$= 100 \times 20 \times \cos 0°$
$= 1000$ J

Evaluation

1. What work does a man of 50 kg weight do when he climbs up the top of Qutab Minar? Take the height of Qutab Minar as 72 m.

2. Calculate the total amount of work done in moving a body of mass 100kg, with an acceleration of 5 ms^2 through a distance of 10 metres. (5000 Joules).

Topic 8: Work

Self Learning Material (SLM)

We know that forces can perform a number of different tasks, for example :

a. A body can be made to move with constant velocity.

b. Two or more forces can change the shape of an object.

c. A force can cause a body to undergo a change in velocity.

d. A force can cause rotation.

e. A force can support a body to remain at a certain height.

Well, all these tasks can be considered to be useful. However, they do not all constitute 'work' in the scientist's meaning of the work. A task being useful does not mean work being done.

Then, when can we consider work being done?

Work is said to be done when a body moves in the direction of the force.

This definition requires two things -

i. A force must be applied.

ii. The body should move in the direction of the force.

Mathematically we can represent it as $W = F.S.$

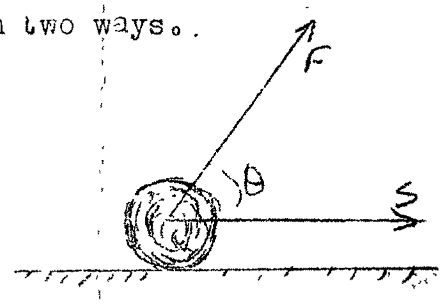
Here, W = ______________________

F = ______________________

S = ______________________ (1)

It is quite possible that the body need not move exactly in the direction of force. It can move in a direction inclined θ with the force.

In this case, we can compute in two ways.



(i) Force applied = F

Component of displacement in the direction of force = S Cos θ .

∴ Work done = F S Cos θ

(ii) Force in the direction of motion = F Cos θ

Distance covered = S

∴ Work done = F Cos θ x S = F S Cosθ

By both ways, we see that work done

W = F S Cosθ.

If the angle θ = 90°, the work done is_ _ _ _ (2)

If a person is holding a body for sometime without any movement then the work done by him is (note that distance moved = 0).

W = F.S. = _ _ _ _ _ (3)

In the tasks which can be performed by the force as mentioned earlier work is performed in cases_ _ _ _ _ _ _ _ _(a, b, c, d, e). (see page 1st, para 2). (4)

Work is not done in cases_ _ _ _ _(a,b,c,d,e) because_ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _
_ (5)

We have defined work as the product of force and distance.

The unit of force is _ _ _ _ _ _ _ _

AND the distance is measured in_ _ _ _ _ (6)

- -

$$W = F.S.$$

1 Joule = 1 Newton x 1 metre

One newton metre is called a joule. It can be defined as the work done when a body is moved through a distance of 1 metre on the application of a force of one newton.

Let us work out now a problem.

Calculate the work done to lift a mass of 5 kgs through distance of 2 metres.

- -

Now in this problem the value of force is not given. But we know the weight of the body = mg. To lift this body we have to exert a force equivalent to mg. i.e.,

$F = mg = 5 \times 9.8$ N

Distance moved in the direction of force

$S = 2$ m

$W = F\ S$

$= 5 \times 9.8 \times 2 = 9.8$ joule.

How much work is done by a force of 10N in moving an object through a distance of 1m in the direction of the force?

- -

- -

Compute the work done by a man weighing 60kgs in carrying a load of 40kgs at his back through a distance of 10m in (i)the vertical direction, (ii)horizontal direction and (iii)up a smooth inclined plane which rises 1 in 10.

(i)_ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _

_ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _

(ii)_ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _

(iii)_ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _

Topic 8: Work

Self Evaluation Material (SEM)

1. What is meant by the term 'work' in physics? How is it related to force responsible for doing work?

2. Explain the conditions under which no work is done even when a force is applied.

3. A body is moving with a uniform speed along the circumference of a frictionless circular path. Is any work being done on the body? Discuss.

4. A horizontal force of 25.0 Newtons is required to push a table of mass 50 kg across a room. How much work is done in pushing the table through 5 m?

5. A man ties a rope around a heavy rock and pulls it with a force of 50 kgf until he is tired, but fails to move the rock. Find the amount of work done on the rock.

6. A crane loads cars into a freighter. Each car weighs 1000 kg and must be lifted 20 m and then moved 10 m horizontally. Find the amount of work done.

KEY TO SLM

1. work done, force, displacement 2. zero 3. zero
4. a/b/c/d 5. e 6. Newton, metres 7. 10 J
8. 9800 J; 0 J; 980 J

KEY TO SEM

3. 250 J 5. 98.8 x 10 J 4. 0

Topic 9 : POWER

CLASSROOM LEARNING MATERIAL (CLM)

Task analysis

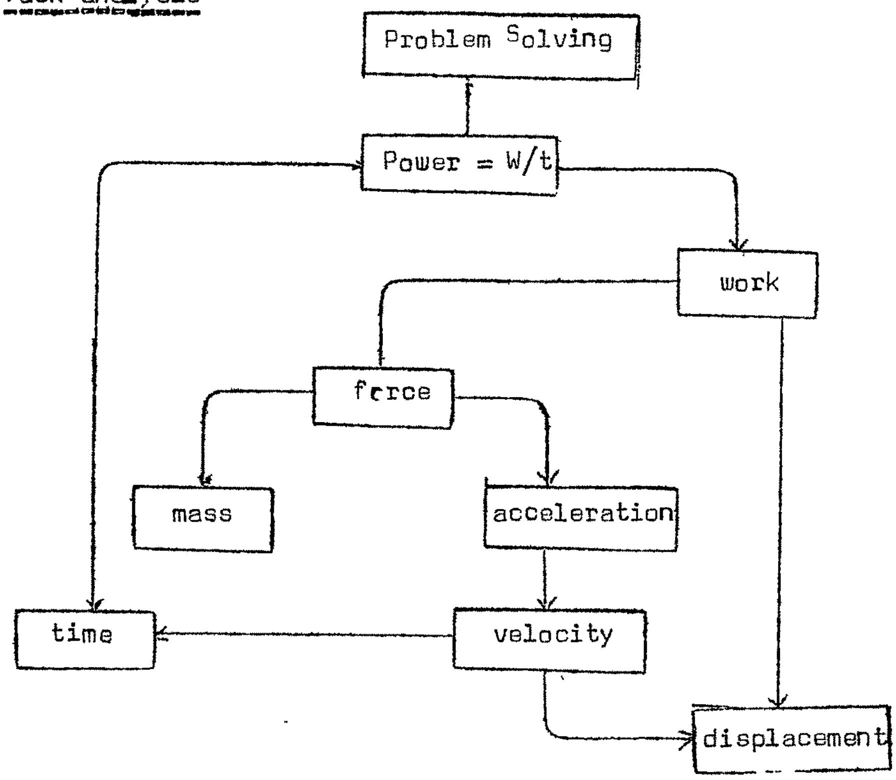


Fig. 9.1 Task analysis map - Power

Learning Hierarchy

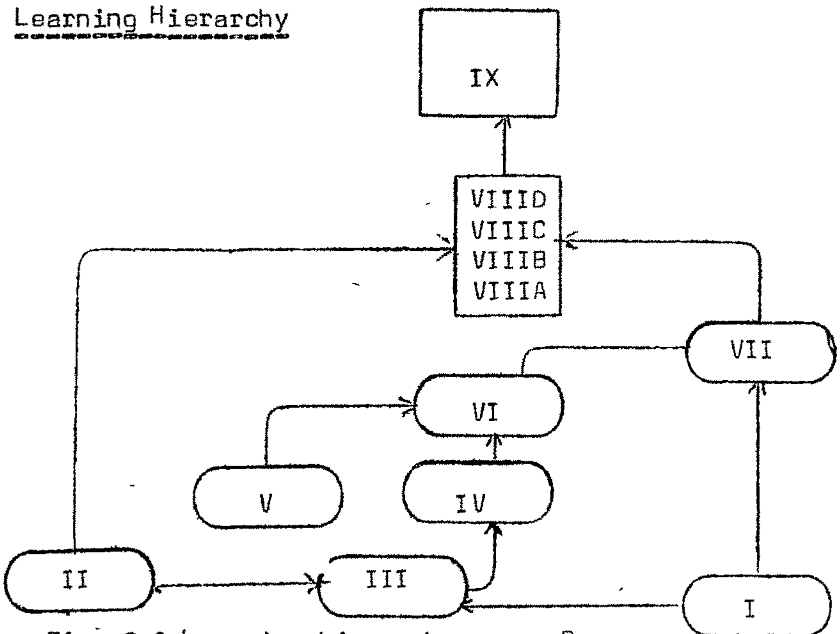


Fig. 9.2 Learning hierarchy map - Power

Topic 9: Power

Learning hierarchy

The following are the learning objectives in the learning hierarchy shown in Fig.9.2 .

When the topic is completed the students shou ld should be able to :

I. recall displacement
II. recall the measurement of time
III. recall velocity
IV. recall acceleration
V. recall mass
VI. recall force
VII. recall work

VIII. A. define power
B. express power as w/t
C. give the unit of power
D. recognise the effects of power

IX. solve problems

Revision of Concepts

1. Displacement
2. Time
3. Velocity
4. Acceleration
5. Mass
6. Force
7. Work

Evaluation

1. Define work, force, mass, acceleration.
2. What are the units of work, force, mass, acceleration, velocity, time and displacement?
3. Give the mathematical expression for force, work, acceleration and velocity.
4. In the above metnioned list which are vector quantities and which are scalar quantities?

8. Power

A measure of the rate at which work is done by a force.

Type of Quantity: Scalar
Written Representation: P

Specification: Magnitude. Obtained as the amount of work done by the force in one second. Measured in watt (W).

Mathematical Expression: The magnitude of power is obtained as the ratio of the total work done by a force to the time elapsed in doing the work.

$$\text{Power} = \frac{\text{Total work done}}{\text{Time taken}}$$

$$\text{Or} \quad P = W/t$$

Watt is the unit of power and is a measure of the power developed.

Written Representation: W

Specification: One watt is the quantity of power developed or expended when one joule of work is done in one second.

$$1 \text{ Watt} = \frac{1 \text{ Joule}}{1 \text{ Second}}, \quad \text{OR} \quad 1 \text{ W} = 1 \text{ Js}^{-1}$$

Larger units like kilowatt (1KW=1000W) and Megawatt (1MW=1000,000W) are also used.

e.g., a particular machine is said to be more powerful than another, if it does the same amount of work in less time or does more work in the same time.

Suppose a man first climbs a staircase slowly; on reaching the top he does not feel exhausted. Second time he climbs the same staircase rapidly and feels exhausted on reaching the top. In both cases the work done by him is the same; however, in the first case the power developed is less since time taken is more, and in the second case the power developed is more.

Note: There is also another unit used usually by Engineers known as Horse Power.

$$1 \text{ H.P.} = 746 \text{ W}$$

Evaluation

1. What is the S.I. unit of Power?
2. Define Power.
3. For doing the same work if the time is reduced to half what happens to the power?
4. What is the relation between watts and joules/sec?
5. Can the power of two machines be different when the work done by the two are the same?

9. Problem Solving

Example:

1. How much power is needed to lift a 30 kgs load of bricks to a height of 20m on a building under consideration in 10s?

$$\text{Work done} = mgh$$
$$= 30 \times 9.8 \times 20 J$$
$$\text{Power} = W/t$$
$$= \frac{30 \times 9.8 \times 20}{10}$$
$$= 588 \text{ W}$$

2. Find the power of an engine; which lifts 200,000 kgs of coal in two hours from a mine 360 metres deep. Given $g = 9.8 \text{ m/sec}^2$.

Solution:

Mass of the coal lifted by engine = 200,000 kgs
Time taken = 2 hours = 2 x 3600 = 7200 seconds
Depth of the mine = 360 metres
Engine has to do work against the force of gravity; in order to lift the coal the force which the engine has to apply is equal and opposite to the force of gravity or weight of the coal.

Topic 9: Power

Self Learning Material (SLM)

In the previous topic we discussed about the work done when a force is applied. How quick it can be done is also of prime importance to us.

Suppose two persons- one weak and another strong, draw water from a well. If both have drawn one bucket of water, they have done equal amount of work. The difference in doing so will be that the stronger one must have done the work in a shorter time compared to the weak one. We can say, then, the stronger one is more powerful or the power with which the work done is more.

Then what is power? It refers to work done with respect to time. For performing an amount of work if one takes more time then the power is less; on the contrary if the time taken is less then power is more.

Therefore, we can define power as ____________
____
____ (1)

The mathematical expression for power is ______
____
____ (2)

The unit of time is __________________________ (3)

The unit of work is __________________________ (4)

The Mathematical expression can be represented with help of unit as

$$P = \frac{W}{t} = \frac{\text{Joules}}{.....} = .../\text{sec} \qquad (5)$$

Therefore the unit of power is ________ (6)

This unit is also known as watt; bigger units like kilo watts and mega watts are also extensively used. We have seen that 1 watt = joules/sec

We can define one watt as_ _ _ _ _ _ _ _ _ _ _ _ _

_ (7)

_ _

Work is a_ _ _ _ _ _ _ _ _ _ _ _quantity.

Time is a _ _ _ _ _ _ _ _ _ _ _quantity. (8)

_ _

Power is also a_ _ _ _ _ _ _ _ _quantity. (9)

_ _

Let us now go to problem solving.

Find the power of a person weighing 30 kg when he works in climbing up a staircase having a height of 15 m in 25 seconds. Take the value of $g = 10 ms^{-2}$.

To calculate power, we must be able to find out the work done and the time taken.

Here in this case for climbing up he has to apply a force equal to his weight.

Weight of the person $F = mg$

Height covered = hm

$\therefore$ Work done $W = F \times S = \ldots\ldots\ldots$

$$\text{Power} = \frac{\ldots\ldots\ldots}{\ldots\ldots\ldots} = \frac{30 \times \ldots\ldots\ldots \times 15}{25}$$

$$= 180 \text{ watts.}$$

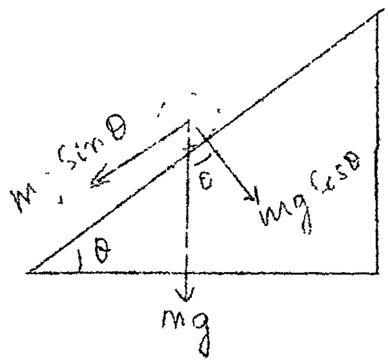
An automobile weighing 30,000 kg moves up an inclined plane rising 1 in 100 at the speed of 30 km/h. Calculate the power of the engine. Neglect friction and air resistance.

Take $g = 10 \text{ ms}^{-2}$

For an inclined plane rising 1 in 100 means that for even 100 units of length of the plane its height increases by one unit.

This means that $\text{Sin } \theta = \frac{\text{Height}}{\ldots} = \frac{1}{100}$

We know that when the force is inclined with the direction of movement then force = $F \cos\theta$. But here angle between the force and the plance of movement is $90 - \theta$ then force = $F \cos(90 - \theta)$ = $F \sin\theta$.



Here, F = mg

∴ Force required for the body to move = m x...x Sinθ

We know the equation for power

$$= \frac{W}{t}$$

$$= \frac{FS}{t}$$

But $V = \frac{S}{t}$

Thus,

we can write Power = F x ....

Now Substituting the values

$$P = \text{mg } \sin\theta \times V$$

= .... x ....

= 25000 W

= ....KW (10)

Topic 9: Power

Self Evaluation Material (SEM)

I. In the blank space at the right of each statement write the word or expression which BEST completes the meaning.

1. Mass is measured in..1.. ___________ 1

2. Velocity is the rate of change in..2.. ___________ 2

3. Velocity is measured in..3.. ___________ 3

4. The mathematical expresssion for acceleration is..4.. ___________ 4

5. Force is the product of ..5a..and..5b.. ___________ 5a ___________ 5b

6. Mass is a measure of..6.. ___________ 6

7. Work is the product of..7a.. and..7b.. ___________ 7a ___________ 7b

8. The unit of work is..8.. ___________ 8

9. Unit of time is..9.. ___________ 9

10. Power is the rate of doing..10.. ___________ 10

11. Power = $\frac{W}{...11...}$ ___________ 11

12. Unit of power is.. ..12 ___________ 12

13. 1 Joules/Sec = 1..13.. ___________ 13

14. 1 horse power = ..15..watts ___________ 14

KEY TO SLM

2. P = W/t 3. scalar 4. Joules 5. Joules/sec 6. Joules/sec 8. Vector, scalar 9. Scalar 10. 25KW

KEY TO SEM

1. kgs 2. displacement 3. m/s 4. m/s^2 5. mass and acceleration 6. Inertia 7. Force and displacement 8. Joule 9. sec 10. work 11. time 12. watts 13. watt 14. 746.

Topic 8 & 9: Work & Power

Assessment Materil (AM)

Section A

I. Complete the sentences using the most suitable word/s:

1. Work is ..1.. quantity. _ _ _ _ _ _ _ _ _ _ _1

2. The factors on which the work done depends are ..2a.. and ..2b.. _ _ _ _ _ _ _ _ _ _ _2a _ _ _ _ _ _ _ _ _ _ _2b

3. The product of mass and acceleration are ..3.. _ _ _ _ _ _ _ _ _ _ _3

4. Watt is the unit of ..4.. _ _ _ _ _ _ _ _ _ _ _4

5. The rate of doing ..5.. is known as power. _ _ _ _ _ _ _ _ _ _ _5

6. The unit of work in S.I. unit is ..6.. _ _ _ _ _ _ _ _ _ _ _6

7. Work is done only when an object is ..7.. in the direction of force. _ _ _ _ _ _ _ _ _ _ _7

II. Define the following:

a. Work: _
_ _

b. Watt: _
_ _

Section B

III. 1. The product of force and distance is ..1.. _ _ _ _ _ _ _ _ _ _ _1

2. The expression for work done when the displacement S is making an angle O with the direction of force is ..2.. _ _ _ _ _ _ _ _ _ _ _2

3. Even on application if the displacement is zero then the work done is ..3.. _ _ _ _ _ _ _ _ _ _3

4. What happens to the work done displacement is doubled..4.. _ _ _ _ _ _ _ _ _ _4

5. If the time is reduced to half for doing a work the power generated becomes..5.. _ _ _ _ _ _ _ _ _5

6. Power is also the product of..6a..and..6b.. _ _ _ _ _ _ _ _ _6a
_ _ _ _ _ _ _ _ _6b

IV. Indicate the most suitable choice.

1. In physics work is done when-

a. lifting an object from the floor to the table.
b. supporting an object on your shoulder.
c. in preparing school lessons.
d. pushing an object.

a/b/c/d _ _ _ _1

2. The two factors which determine the work done are :

a. force exerted and weight of the body.
b. distance moved by the object and time required.
c. displacement of the object and force in the direction of displacement.
d. magnitude of force displacement and time.

a/b/c/d _ _ _ _2

V. Does a man carrying a luggage on his head on a level road do any work? Justify your answer.

_ _
_ _
_ _
_ _

Section C

VI. A. What is the amount of work done when body is moved through 2 metres by the application of a force of 100N?

B. A man whose weight is 100 kg climbs up a tower 20 metres in height against the force of gravity. Calculate the amount of work done.

C. A boy of mass 40 kg runs up a staircase carrying 10 kg mass in 10s. The staircase has 25 steps each 20 cm high. Calculate his (a) total power and (b) useful power.

D. What is the power of a crane which lifts five 1000 kg girders in 30 s to a height of 15 m. Calculate the power of the crane in KW.