1. Details of Module and its structure

Module Detail	
Subject Name	Physics
Course Name	Physics 01 (Physics Part-1, Class XI)
Module Name/Title	Unit 3, Module 2, Newton's second law of motion Chapter 5, Laws of Motion
Module Id	Keph_10502_eContent
Pre-requisites	Kinematics, Vector algebra, Velocity, Acceleration, Inertia, Unbalanced forces, External force ,newtons first law of motion
Objectives	After going through this lesson, the learners will be able to: • Understand the concept of Momentum • Relate to Newton's Second Law of motion • Conceptualise the meaning of Impulse • Distinguish between constant and variable force
Keywords	Momentum, Impulse, Constant force, Variable force, second Law of motion

2. Development Team

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TABLE OF CONTENTS

1. UNIT SYLLABUS

Chapter 5: Laws of Motion

Intuitive concept of force, Inertia, Newton's first law of motion, momentum and Newton's second law of motion, Impulse; Newton's third law of motion.

Law of conservation of linear momentum and its applications.

Equilibrium of concurrent forces, Static and kinetic friction, laws of friction, rolling friction, lubrication.

Dynamics of uniform circular motion: Centripetal force, examples of circular motion (vehicle on a level circular road, vehicle on banked road).

2. MODULE-WISE DISTRIBUTION OF UNIT SYLLABUS 7 Modules

The above unit is divided into seven modules as follows:

Module 1	• Force • inertia • First law of motion
Module 2	• Momentum • Second law • Impulse • F=ma • Constant and variable force
Module 3	• Third law • Conservation of linear momentum and its applications
Module 4	• Types of forces (tension, normal, weight, …) • Equilibrium of concurrent forces • FBD
Module 5	• Friction • Coefficient of friction • Static friction • Kinetic friction • Rolling friction • Role of friction in daily life
Module 6	• Dynamics of circular motion • Centripetal force • Banking of roads
Module 7	• Using laws of motion to solve problems in daily life

MODULE 2

3. WORDS YOU MUST KNOW

- Rest: A body is said to be at rest if it does not change its position with time with respect to its surroundings.
- Motion: A body is said to be in motion if it changes its position with time with respect to its surroundings.
- Velocity: The time rate of change of displacement is called velocity.
- Uniform motion: When a particle has equal displacements, in equal intervals of time, (howsoever small this time interval may be) it is said to have a uniform motion. The acceleration for a particle in uniform motion would be zero.
- Momentum (**p**): An indicator of the impact capacity of a moving body. We have **p**= m**v**
- Acceleration: Time rate of change of velocity of a particle, equals its acceleration.
- Vector: A physical quantity that needs both a magnitude and a direction for its specification.
- Vector Algebra: The branch of mathematics that deals with computations involving addition, subtraction, and multiplication of vectors.
- Force: A body will continue in its state of rest, or uniform motion until and unless it is acted upon by an external unbalanced force.
- Inertia: An inherent property of all objects; an object continues in its state of rest or uniform motion unless and until a non-zero external force acts on it.
- **Newton's first law of motion** a body will continue in its state of rest or uniform motion unless and until acted upon by an unbalanced external force.
- **Unbalanced external force** a number of forces may act on a body, if they have a resultant which means forces are not balanced. This unbalanced force must act externally on the body.

4. INTRODUCTION

Let us start with recalling Newton's first law of motion according to it a body will continue in its state of rest or uniform motion unless and until acted upon by an unbalanced external force.

Whenever an unbalanced external force acts on a body it conditions of rest or uniform motion will change. We must remember when we argue that if a number of small forces having a resultant act on a body, yet the body continues in its state of rest, example some people applying force to move a truck with no result.

https://commons.wikimedia.org/wiki/File:Men_Pushing_Loaded_Truck_-_Phulbagan_-_Kolkata_20180223161038.jpg

Here,

We must remember that the weight of the truck and its load and forces or friction may not be accounted for in our consideration and hence our prediction will be incorrect.

Now let us understand how the external unbalanced force changes the state of rest or uniform motion of an object. Can we measure the force in terms of the effect or changes, it produces in the body.

The effect of force on motion of the bodies

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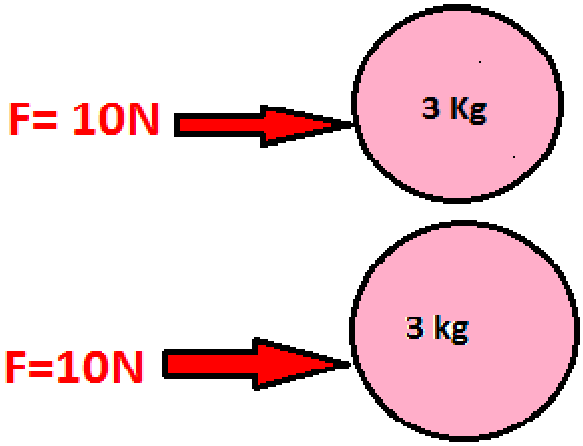
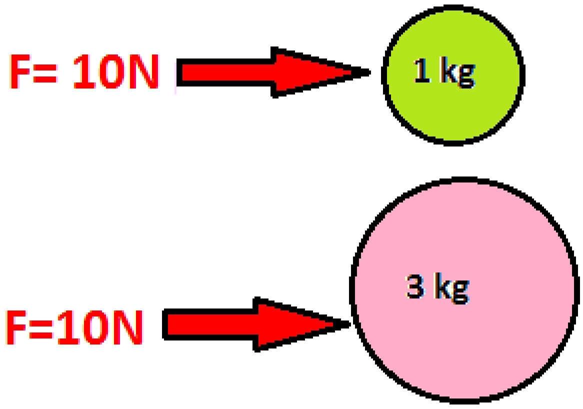
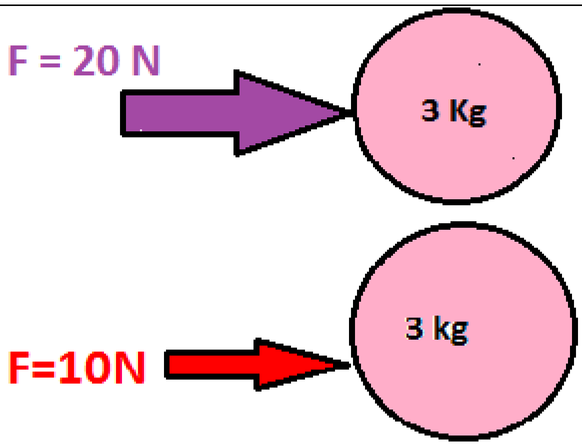
<tr><td>
</td><td>If forces of equal magnitude are applied on two bodies of equal masses, the bodies (initially at rest) start moving with the same speed.</td></tr>
<tr><td colspan="2"><u>Conclusion</u>: The effect of force on the motion of the two bodies (of same mass) can be same.</td></tr>
<tr><td>
</td><td>When forces of equal magnitude 'F= 10 N' are applied on two bodies of different masses. The lighter body (of mass 1 kg) moves with a greater speed in comparison to the heavier body of mass 3 kg.</td></tr>
<tr><td colspan="2"><u>Conclusion</u>: Mass is an important parameter in determining the effect of force on the motion of an object.</td></tr>
<tr><td>
</td><td>Here, forces of different magnitudes are applied on two bodies of same mass, say m = 3 kg each. The body, on which a greater force (F =20 N) is applied, moves with a greater speed in comparison to the body on which the magnitude of the applied force is smaller.</td></tr>
<tr><td colspan="2"><u>Conclusion</u>: The magnitude of the applied force is an important parameter to study the effect of force on the motion of an object.</td></tr>
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In this module, we will develop the concept of momentum and understand how to calculate momentum of objects. We will understand that rate of change of momentum is related to the magnitude of the force. We will study the effect of force on motion of objects and Newton's second law of motion.

We will study about impulsive forces and examples of constant and variable forces.

We will also visualize real life situations related to the concepts of impulse and momentum

LET US CONSIDER A FEW MORE EXAMPLES:

- **If two balls, one light (tennis ball) and the other heavy, (cricket ball) are dropped one by one from the top of the same building, a person on the ground will find it easier to catch the lighter ball 'easier on the hands' than the heavier ball.**
- **Brakes of a car have to be more powerful than the brakes of a bicycle; as greater force is required to stop a heavier body than a lighter body even when they are moving with the same speed.**
- **A tennis ball, hitting a person with a speed of 2 m/s, may not cause much harm, a car moving at a speed of 2 m/s can harm the person significantly.**
  (2m/s =7.5 km/h)

It follows then that the mass, as well as the speed, of the moving object need to be taken into account to assess the quantity of motion possessed by it.

The product of the mass and the velocity of an object is then an indicator of the quantity of motion possessed by it. This product is called the 'momentum' of the given object.

5. CONCEPT OF MOMENTUM

Momentum of a body is **defined as the product of its mass *m* and its velocity v; it is denoted by p. Thus,**

$$p = m\,v$$

Momentum is a vector quantity and its **direction is same as the direction of the velocity.**

The SI unit of momentum is kg m/s.

Physically it shows the impact capacity of a moving body, which means if a moving body were to strike something what will be its effect!!!, so greater the mass higher the impact, also greater the velocity greater is the impact.

We have observed this in games of cricket, or any ball game

EXAMPLE

A car and a scooter are moving with the same velocity. Which of the two has a greater momentum?

SOLUTION

Let 'M' be the mass of car and 'm' be the mass of scooter,

Let $\mathbf{p_c}$ and $\mathbf{p_s}$ be their respective momenta

Let $\mathbf{v}$ be the velocity of both the car and the scooter.

$\mathbf{p_c} = M\mathbf{v}$ and $\mathbf{p_s} = m\mathbf{v}$

As M > m , we have $\mathbf{p_c} > \mathbf{p_s}$.

The momentum of the car is greater than the momentum of the scooter.

Thus, for two bodies of different masses, moving with same velocity, the body with greater mass has more momentum.

Similarly, if two bodies, of same mass, move with different velocities (speed), the body with a greater velocity has a greater momentum.

EXAMPLE:

A 0.12 kg ball is moving with a velocity of 30m/s.

Find the magnitude of momentum of the ball.

SOLUTION:

p = m v

= (0.12kg) (30 m/s)

= 3.6 kg m/s.

6. FORCE AND MOMENTUM:

A force acting for a given amount of time will change an object's momentum.

If the force acts opposite to the object's velocity, it slows down the object. If a force acts in the same direction as that of object's velocity, the force speeds up the object. In either case, force changes the velocity of an object.

If the velocity of the object is changed, the momentum of the object gets changed.

SOME IMPORTANT POINTS ABOUT MOMENTUM:

- **Greater the change in momentum in a given time**, **greater is the force that was applied. Hence, for a given time interval Δt,**

  $F \propto \Delta p$

  FOR EXAMPLE

  A fielder feels a sharp and sometimes painful impact on the hand when she/he catches a ball that has been hit strongly. The impact is quite modest when a slow nicked ball is caught by the fielder.

Do it yourself

Take a water bottle

Ask a friend to catch it as you drop it to his/her hands

You will hear a sound plus the friend will be hurt

Now ask your friend to lower his/her hands as they catch the water bottle

No Sound? No hurt either?

- **Force is dependent not on the change in momentum, but on how fast that change has been brought about.**

  The same change in momentum, brought about in a shorter time, corresponds to a greater applied force. Thus, for a given change in momentum Δp,

  $$F \propto \frac{\Delta p}{\Delta t}.$$

  We can now understand the fielder's hand movement as seen in a cricket match, while catching a fast moving cricket ball, a player draws her/his hands backwards.

THINK ABOUT THESE

A) Suppose the mass of cricket ball is 250g i.e. 0.25 kg. If it falls from a height of 10 m, its final velocity can be calculated as follows:

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

$$\therefore v = 14 \text{m/s}$$

∴ **Change in momentum of the ball** = m (v- u) = 3.5 kg m/s.

Suppose the ball is brought to rest in $\frac{1}{10}$th of a second. If F is the force exerted by the player to catch the ball, we can calculate F as follows:

$$F\,\Delta t = \Delta p$$

$$\therefore F \times \frac{1}{10} = 3.5$$

$$\mathbf{F = 35\ N}$$

Now suppose, the same ball is brought to rest in $\frac{1}{2}$ second and F' is the force exerted by the player to catch the ball. Then, F' x $\frac{1}{2}$ = 3.5

$$\therefore \mathbf{F' = 7.0\ N}$$

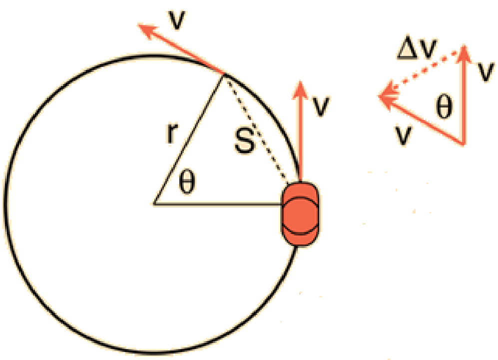
So, if the time duration increases five times, the force needed gets reduced to one-fifth.

By increasing the time, the player has to apply a less (average) force, and consequently, the ball also exerts a smaller force on the hands of the player.

The same force, acting for the same time, causes the same change in momentum for different bodies. For example: If same magnitude of force is applied for a fixed interval of time on two bodies of different masses (initially at rest), the lighter body picks up a greater speed than the heavier one. However, at the end of the time interval (for which the force is applied), each body acquires the same momentum. (Δp will be same in both the cases).

However**, the instantaneous momentum and change in momentum may or may not have the same direction.**

Consider an object in uniform circular motion, velocity and change in velocity do not have same directions. We know that, momentum is a vector quantity and its direction at any instant is same as direction of velocity at that instant.



Greater the rate of change of momentum $|\frac{\Delta p}{\Delta t}|$, greater is the force applied. Thus,

$$F \propto \frac{\Delta p}{\Delta t}.$$

EXAMPLE:

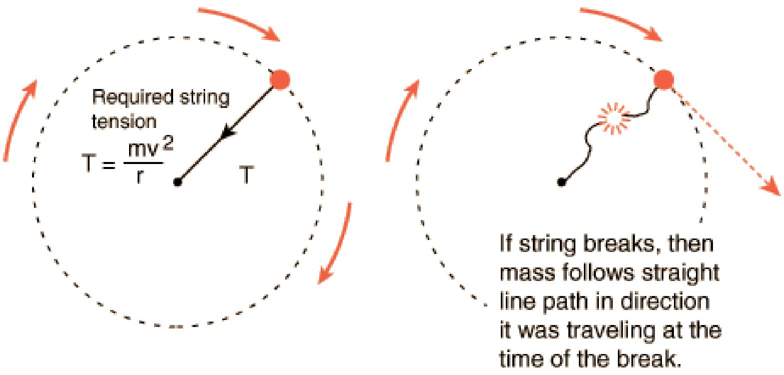
If a stone is rotated with uniform speed in a horizontal plane with the help of a string, the magnitude of momentum remains fixed but its direction changes at every instant. A force is needed to bring this change in momentum. This force is provided by our hand through the string. If we apply greater force to rotate the string, then it moves with greater acceleration.

Hence, the rate of change in momentum vector increases with an increase in the applied force.

$$\frac{\Delta \boldsymbol{p}}{\Delta \boldsymbol{t}} = \frac{\boldsymbol{m}\,(\boldsymbol{v}-\boldsymbol{u})}{\Delta \boldsymbol{t}} = \mathbf{m\ a}$$

Thus,

force is necessary for changing the direction of momentum, even when its magnitude is constant. The more force we apply, the faster it will be changing its direction.



All these observations lead us to statement of Newton's Second Law of motion.

7. NEWTON'S SECOND LAW OF MOTION:

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

If under the action of a force **F** acting for time interval Δt, the velocity of a body, of mass *m*, changes from **v** to v + Δ**v**,

its initial momentum $\mathbf{p_i} = m\,\mathbf{v}$ changes to $\mathbf{p_f} = m\,(\mathbf{v} + \Delta\mathbf{v})$.

According to the Second Law: $\mathbf{F}\ \alpha\ m\frac{\Delta v}{\Delta t} \propto \frac{\Delta p}{\Delta t}$

or

$$\mathbf{F} = \mathbf{k}\,\frac{\Delta \boldsymbol{p}}{\Delta \boldsymbol{t}}$$

where k is a constant of proportionality.

Taking the limit $\Delta t \to 0$, the term $\frac{\Delta \boldsymbol{p}}{\Delta t}$ becomes the derivative or differential co-efficient of **p** with respect to *t*; this is denoted by $\frac{d\boldsymbol{p}}{dt}$.

Thus, $\mathbf{F} = k\,\frac{d\boldsymbol{p}}{dt}$

For a body of constant mass m, $\frac{d\boldsymbol{p}}{dt} = \frac{d}{dt}(m\mathbf{v}) = m\,\frac{d\boldsymbol{v}}{dt} = m\,\mathbf{a}$

∴ **F= k m a,**

the force is proportional to mass and acceleration (for a body of constant mass).

In SI units, k = 1. Which means a mass of 1 kg is accelerated by 1 ms^{-2} under the action of 1 newton force

We can then write

$$\mathbf{F} = \frac{d\boldsymbol{p}}{dt} = m\,\mathbf{a}$$

Newton's Second law (for a body of constant mass) can also be expressed as:

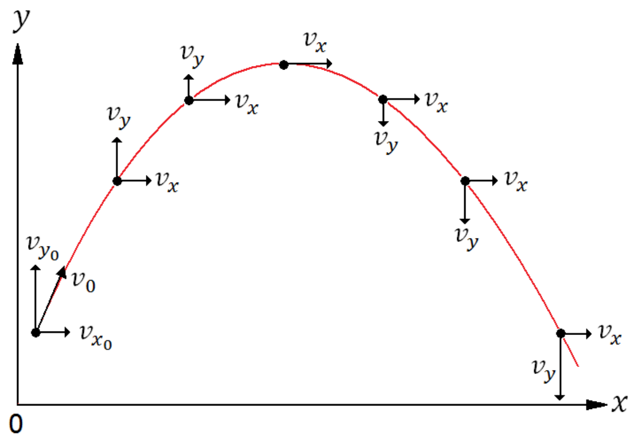
The net force acting on a body is equal to the product of body's mass and the resulting acceleration of the body.

SOME IMPORTANT POINTS ABOUT THE SECOND LAW:

(i) The second law is consistent with the First Law (F = 0 implies a = 0).

(ii) **The second law of motion is a vector law. It is equivalent to three scalar equations, one for each component of the vector:**

This means that if a force is not parallel to the velocity of the body, but makes some angle with it, it changes only the component of velocity along the direction of force. The component of velocity normal to the force remains unchanged. For example, in the motion of a projectile, under the (vertical) gravitational force, the horizontal component of velocity v_x remains unchanged, whereas it is only the vertical component v_y that changes.



(iii) **It is applicable to a particle, as well as to a finite size object or a system of particles.** In the latter case, **F** is the total external force on the system and **a** is the acceleration of the system as a whole.

(iv) **Force at a point, at a certain instant, determines the acceleration at the same point at that instant**. That is, the Second Law is a local law; acceleration at an instant is determined by force at that instant.

For example, if a child drops a stone from an accelerating train, then, once released, it would have only the vertical component of acceleration in air due to gravity (force of air resistance is neglected).

UNIT OF FORCE: This is defined in two ways: Absolute and gravitational.

The absolute unit of force remain the same throughout the universe. The gravitational unit of force, is however, not constant. This is because the gravitational unit of force depends upon the value of 'g' which is different at different places.

ABSOLUTE UNIT OF FORCE:

In SI units, the absolute unit of force is newton (N). One newton of force is the amount of force which produces an acceleration of 1 m/s^2 in a body of mass 1 kg.

In cgs system, the absolute unit of force is dyne. One dyne of force is the amount of force which produces an acceleration of 1 cm/s^2 in a body of mass 1g.

Relation between newton and dyne:

$1\ N = 10^5$ *dyne*

GRAVITATIONAL UNIT OF FORCE:

A gravitational unit of force is the amount of force which produces acceleration equal to g (acceleration due to gravity) in a body of unit mass.

In SI units, the gravitational unit of force is kg wt.

One kilogram weight is that much force which produces an acceleration of 9.8 m/s^2 in a body of mass 1 kg. (i.e. a body of mass 1kg is attracted towards the centre of the Earth)

In cgs system, gravitational unit of force is g wt. One gram weight is the amount of force which produces, on earth, an acceleration of 980 cm/s^2 in a body of mass 1 gram.

Dimensional formula for force is MLT^{-2}

EXAMPLE:

A body of mass 2kg is moving with an acceleration of 50 cm/s^2. Calculate the force acting on it.

SOLUTION

m= 2 kg,

a = 50 cm/s^2 = 0.5 m/s^2

Force: F = m a

= 2 X 0.5 N

$= 1\ N$

EXAMPLE:

A bullet of mass 0.04 kg moving with a speed of 90 m/s enters a heavy wooden block and is stopped after a distance of 60 cm. Find the average resistive force exerted by the block on the bullet.

SOLUTION

Using equation: $v^2 - u^2 = 2\ a\ s$,

we get

$a = -\ 6750\ m/s^2$

Retardation = $|-a| = 6750\ m/s^2$

$\therefore$ Retarding force = m a

$= 0.04\ kg \times 6750\ m/s^2$

$= 270\ N$

8. IMPULSE 'J'

The effectiveness of a force in producing motion or change in motion depends not only upon the magnitude of the force but also on the time for which the force acts.

Consider a situation when a ball hits a wall and bounces back. The force on the ball by the wall acts for a very short time when the two are in contact, yet the force is large enough to reverse the direction of the momentum of the ball.

The force and its time duration in these situations are difficult to find separately. However,

the product of force and time, which equals the change in momentum of the body, remains a measurable quantity. This product is called impulse.

A large force, acting for a short time, to produce a finite change in momentum is called an *impulsive force*. Impulsive force is like any other force except that it is large and acts for a short duration. Since the time of action of the force is very short, we can assume that there is no appreciable change in the position of the body during the action of an impulsive force.

Impulse = Force x time duration for which the force acts

= Change in momentum

$\sum \mathbf{F} = \mathbf{F}_{net} = m\mathbf{a}$, $\mathbf{a} = \frac{\Delta v}{\Delta t}$

Impulse = $\mathbf{F}\ \Delta t$

$\mathbf{F} = m \frac{\Delta v}{\Delta t}$

$\mathbf{F}\ \Delta t = m\ \Delta \mathbf{v} = m\ (\mathbf{v_f} - \mathbf{v_i}) = \Delta \mathbf{p}$

$\therefore$ Impulse = $\mathbf{F}\ \Delta t = \Delta \mathbf{p}$

Impulse and momentum have the same units; when an impulse is applied to an object, the momentum of the object change. The change in momentum is equal to the impulse.

SI unit for impulse is Ns.

And its dimensional formula is M L T^{-1}

9. CONSTANT FORCE AND VARIABLE FORCE

A constant force is a force which changes neither in magnitude nor in direction. A variable force is a force which changes either in magnitude, or in direction, or both.

Suppose a force **F** acts for a short time dt. The impulse of this force is given by:

$$d\mathbf{J} = \mathbf{F}dt$$

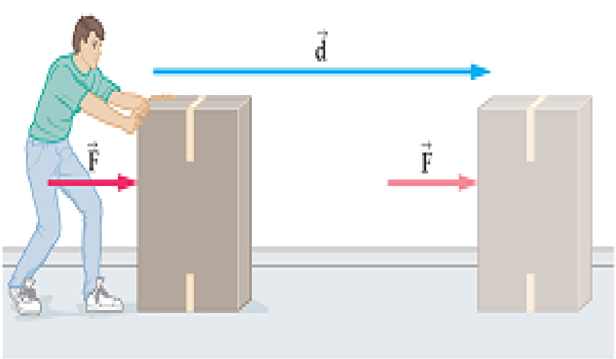
If a constant force acts for a given time duration (say from t_1 to t_2), the impulse is given by:

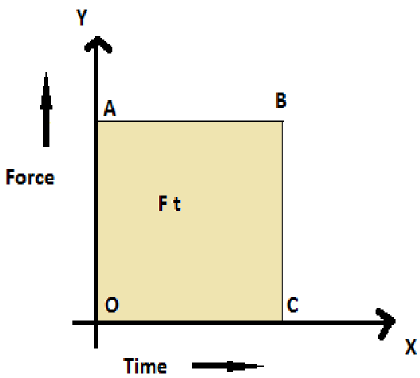
$$\mathbf{J} = \int_{t1}^{t2} F\ dt = \mathbf{F}\ [\ t\ ]_{t1}^{t2} = \mathbf{F}\ (t_2 - t_1)$$

$\mathbf{J} = \mathbf{F}\ \Delta\ t$ (direction of $\mathbf{J}$ is same as that of $\mathbf{F}$)

EXAMPLE:

Graph shown below is due to constant force applied on the block for a distance ‘d’ over a short time duration. The area of the rectangle OABC gives the magnitude of impulse of a constant force.





If we consider a **varying force** acting on an object over a finite interval of time, say from t_1 to t_2, then the impulse is given by: **J** = $\int_{t1}^{t2} \boldsymbol{F}\, dt$.

EXAMPLE:

The graph below is for a varying force, acting for a short duration.

The total area under the above curve will give the magnitude of impulse during the given time interval.

Impulse – Momentum Theorem:

Impulse is measured by the total change in momentum that the force produces in a given time.

According to Newton's Second Law: **F** = $\frac{d\boldsymbol{p}}{dt}$

Impulse of a varying force is given by: $\int_0^t \boldsymbol{F}\, dt$ **=** $p_2 - p_1$

Impulse of a constant force is given by: F t = $p_2 - p_1$

PRACTICAL APPLICATIONS OF IMPULSE:

Extending the duration of time over which a force acts in order to decrease the strength of the (needed) force is a common practice applicable in many areas:

1. Padding in shoes and seats are designed to allow the time to increase.
2. The front of automobiles is designed to crumple in an accident. This increases the time taken by the car to stop and hence decreases the (impact) force.
3. Airbags in cars serve as safety measure. In the absence of airbag, during sudden collision, a passenger may hit into the dashboard or windshield of the car and thus get injured. However, an airbag increases the time of over which the change in momentum occurs. The more time this change takes the less is the force on the passenger and the damage it may cause.
4. A cricket player lowers his hands while catching a fast moving ball.

10. EXAMPLES FOR BETTER UNDERSTANDING

EXAMPLE:

Calculate the impulse during the stopping of a 1500kg car moving at 90 km/h.

SOLUTION

Impulse = change in momentum

v = 0, u = 90 km/h = 25 m/s

Impulse = M v – M u = M (v- u)

Impulse = 1500 (0 – 25) N s

Impulse = - 37500 N s

EXAMPLE: What is the effect on acceleration of a particle if the net force on the particle is doubled?

SOLUTION

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

on doubling the force, the acceleration will also be doubled.

EXAMPLE:

If a 5 kg object experiences a 20 N force for duration of 0.10 second, find the change in momentum of the object.

SOLUTION :

Impulse $\mathbf{J} = \mathbf{F}\,\Delta t = \Delta \mathbf{p}$

$\therefore \Delta \mathbf{p} = 20 \text{ X } 0.10 = 2$ kg m/s

EXAMPLE:

A cricket ball of mass 500 g is moving with a speed of 36 km/h. It is reflected back with the same speed. Calculate the impulse.

SOLUTION:

Impulse = change in momentum

Final momentum = 0.5 X (-10) kg m/s = - 5 kg m/s (reflected back, let's say along negative x - axis)

Initial momentum = 0.5 X (10) kg m/s = 5 kg m/s (along positive x- axis)

Change in momentum ($\Delta \boldsymbol{p}$) = Final p – Initial p

= - (5 + 5) = -10 kg m/s (along negative x - axis)

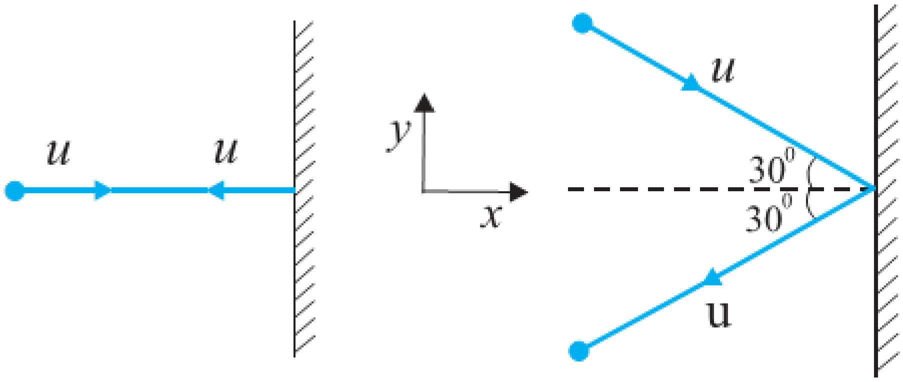
EXAMPLE:

Two identical billiard balls strike a rigid wall with the same speed but at different angles, and get reflected without any change in speed.

Find

(i) The direction of the force on the wall due to each ball.

(ii) The ratio of the magnitudes of impulses imparted to the balls in the two cases.



SOLUTION:

(i) Let u be the speed of each ball before and after collision with the wall. Let m be the mass of each ball. Choose the x and y axes as shown in the figure, and consider the change in momentum of the ball in each case:

Case (a)

p_x (initial) = m u , p_x (final) = - m u; p_y (initial) = 0 , p_y (final) = 0

Impulse = change in momentum vector = p_x (final) – p_x (initial) = - mu – mu = - 2 m u

x-component of impulse = - 2 m u

y-component of impulse = 0

Impulse and force are in the same direction. Clearly, from above, the force on the ball due to the ball is normal to the wall, along the negative x-direction. *Using Newton's third law of motion, the force, on the wall, due to the ball is normal to the wall along the positive x-direction*.

Case (b)

Resolving the components of initial and final speed 'u' along x- axis and y – axis, p_x(initial) = m u cos 30^0, p_x(final) = - m u cos 30^0

p_y(initial) = - m u sin 30^0 , p_y(final) = - m u sin 30^0 (y-component after collision doesn't change sign as it is along negative y-direction both before and after collision).

x-component of impulse = - 2 m u cos30^0

y- component of impulse = 0

The direction of impulse (and force) is the same as in case (i) and is normal to the wall along the negative x direction. *Using Newton's third law, the force, on the wall, due to the ball is normal to the wall along the positive x direction.*

(ii) The ratio of the magnitudes of impulses, imparted to the balls, by the wall is given by:

$$\frac{\textit{impulse in } (a)}{\textit{impulse in } (b)} = \frac{-2\,m\,u}{-2\,m\,u\cos 30} = \frac{2}{\sqrt{3}}$$

EXAMPLE:

Why is it less painful to fall on a mattress bed than on a concrete floor?

SOLUTION:

In one case, at floor level, there is a mattress and in another case there is concrete. We'll assume in each case, the initial velocity is same (close to zero) as the fall begins. The velocity v_1 with which one hits both the mattress and the concrete is the same, since the fall is through the same displacement.

Let's define velocity v_1 as the initial velocity of impact; the final velocity is zero, since the mattress and concrete bring the person to rest.

In each case, the change in velocity is the same as one is brought to rest, and the mass is the same, as well.

https://www.maxpixel.net/Air-Cushion-Bouncy-Castles-Bouncy-Castle-Inflatable-3567019

Therefore, the change in momentum (and therefore impulse) is the same in both cases.

https://www.maxpixel.net/Young-Jump-Man-Person-Jumping-Success-Happy-509437

BUT Since the mattress gets depressed, it will take more time for the mattress to bring you to rest than the concrete.

As we saw above, if the change in momentum is same, force gets decreased when it takes the longer to come to rest (for a given change in momentum Δp, F α $\frac{1}{\Delta t}$.

So it would be less painful when we fall on a mattress, instead of concrete floor

EXAMPLE:

A stone when thrown on a glass window smashes the windowpane to pieces, but a bullet from the gun can pass through, just making a hole in it.

SOLUTION

Due to its small speed, the stone remains in contact with the window pane for more time and thus transfers its momentum to the window breaking it into pieces. The shatter proof quality keeps the broken pieces together.

https://pxhere.com/en/photo/1248435

https://www.maxpixel.net/Blood-Bullet-Hole-Crime-Injury-Bullet-Glass-Shot-262105

The bullet, in fast motion, passes through making just a hole and leaving the (overall) glass pane almost undisturbed

11. SUMMARY

- The product of the mass and velocity of an object is called momentum; it is given by the equation **p**=m **v**. Momentum is a vector quantity that has the same direction as the velocity of the object
- Newton's Second law of motion: the time rate of change of momentum of a body is proportional to the applied force and the change of momentum takes place in the direction of the force. In the (usual from of) second law of motion **F** =*K m* **a**, **F** stands for the net force due to all agencies external to the body, **a** is the acceleration of the body (of constant mass).K the constant of proportionality is =1 in SI units

- According to Newton's first law, the velocity of an object cannot change unless a force is applied. If we wish to change the momentum of a body, we must apply force on it. The longer the force is applied; greater is the change in momentum.
- Force applied, multiplied by the time duration for which it acts, is called Impulse (J). Impulse is a vector quantity that has the same direction as the force.
- Momentum and impulse have the same units: kg m/s.
- The change of momentum of an object is equal to the impulse.

$\mathbf{J} = \mathbf{F}\, t = m\, \Delta\mathbf{v} = \Delta\mathbf{p}$