Chapter 2: FORCE and MOTION

Linear Motion

Linear motion is the movement of an object along a straight line.

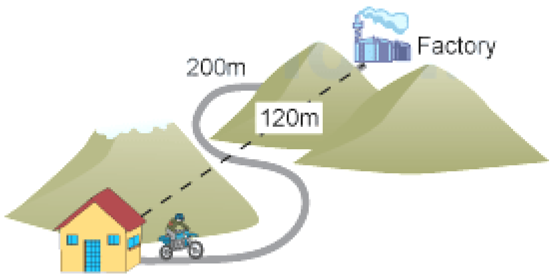
Distance

The **distance** traveled by an object is the **total length** that is traveled by that object.
Unit: **metre (m)**
Type of Quantity: **Scalar quantity**

Displacement

Displacement of an object from a point of reference, O is the **shortest distance** of the object from point O in a **specific direction**.
Unit: **metre (m)**
Type of Quantity: **Vector quantity**

Distance vs Displacement



Distance travelled = 200m
Displacement = 120 m, in the direction of Northeast
Distance is a scalar quantity,
Displacement is a vector quantity

Speed

Speed is the **rate of change** in distance.
Formula:

$$v = \frac{d}{t}$$

v = speed
d = distance travelled
t = time taken

Unit: ms^{-1}
Type of quantity: **Scalar quantity**

Velocity

Velocity is the rate of change in displacement.
Formula:

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

v = velocity
s = displacement
t = time taken

Unit: ms^{-1}
Type of quantity: **Vector quantity**

Acceleration

Acceleration is the **rate of velocity change.** Acceleration is a vector quantity
Formula:

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

a = acceleration
v = final velocity
u = initial velocity
t = time taken

Unit: ms^{-2}
Type of quantity: **Vector quantity**

Notes - Acceleration

- An object moves with a **constant velocity** if the **magnitude** and **direction** of the motion is always constant.
- An object experiences changes in velocity if
  - the **magnitude** of velocity changes
  - the **direction** of the motion changes.
- An object that experiences **changes in velocity** is said to have **acceleration**.
- An object traveling with a constant acceleration, ***a*,** if the velocity changes at a constant rate.

4. Equations of Uniform Acceleration

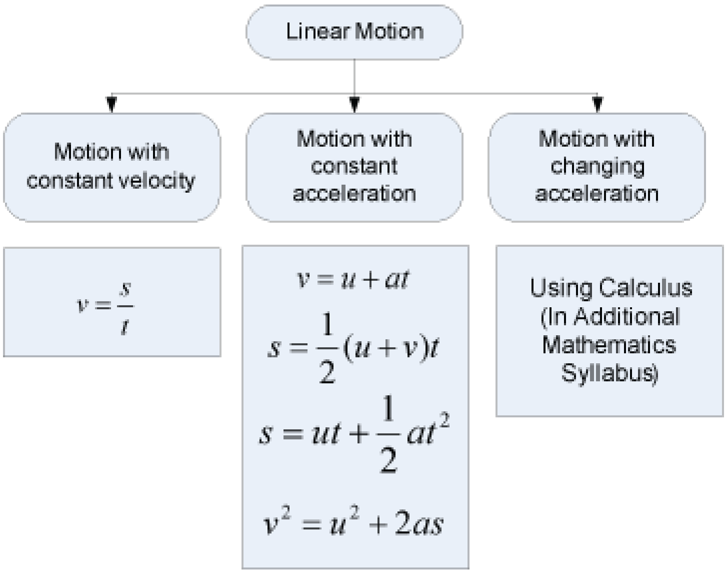
$$v = u + at \qquad s = ut + \frac{1}{2}at^2$$

$$s = \frac{1}{2}(u + v)t \qquad v^2 = u^2 + 2as$$

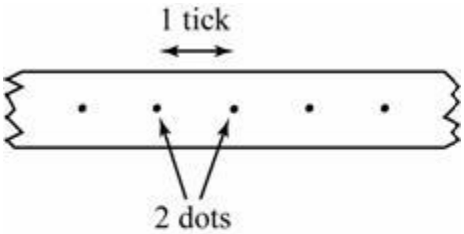
a = acceleration
v = final velocity
u = initial velocity
t = time taken
s = displacement

The above equation is for solving numerical problems involving uniform acceleration.

Summary

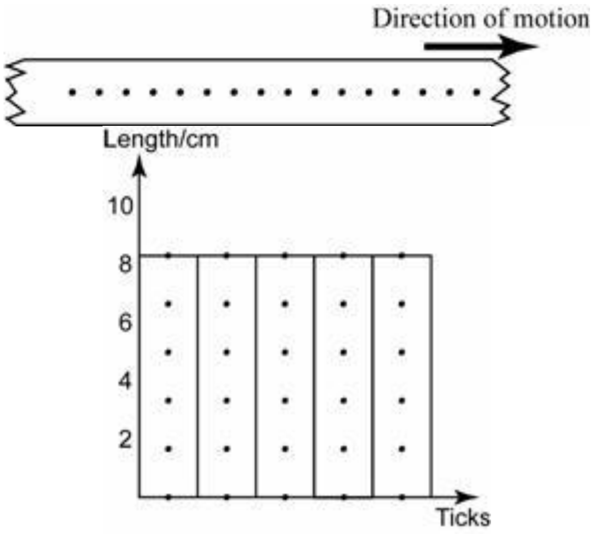


Ticker Timer



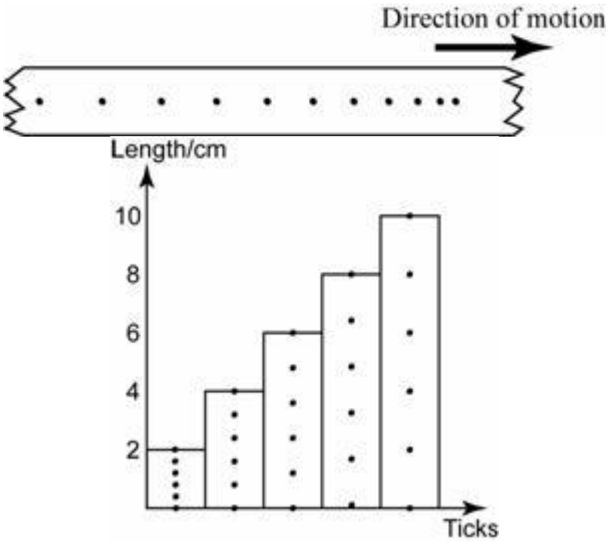
- A ticker-timer consists of an electrical vibrator which vibrates 50 times per second.
- This enables it to make 50 dots per second on a ticker-tape being pulled through it.
- The time interval between two adjacent dots on the ticker-tape is called one tick.
- One tick is equal to 1/50 s or 0.02 s.

Uniform Velocity



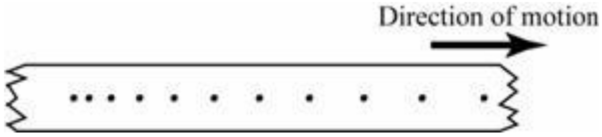
- The distance of the dots is equally distributed.
- All lengths of tape in the chart are of equal length.
- The object is moving at a uniform velocity.

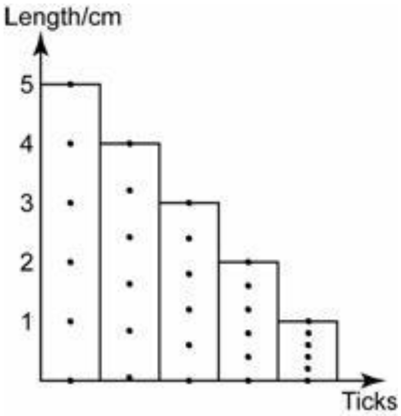
Uniform Acceleration



- The distance between the dots increases uniformly.
- The length of the strips of tape in the chart increase uniformly.
- The velocity of the object is increasing uniformly, i.e. the object is moving at a constant acceleration.

Uniform Deceleration





- The distance between the dots decreases uniformly.
- The length of the strips of tape in the chart decreases uniformly.
- The velocity of the object is decreasing uniformly, i.e. the object is decelerating uniformly.

Finding Velocity

Velocity of a motion can be determined by using ticker tape through the following equation:

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

v = velocity
s = displacement
t = time taken

Caution!!!
t is time taken from the first dot to the last dot of the distance measured.

Example 1

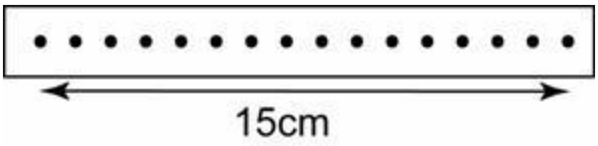


Diagram 2.4 shows a strip of ticker tape that was pulled through a ticker tape timer that vibrated at 50 times a second. What is the

a. time taken from the first dot to the last dot?
b. average velocity of the object that is represented by the ticker tape?

Answer

a. There are 15 ticks from the first dot to the last dot, hence
Time taken = 15 × 0.02s = 0.3s
b. Distance travelled = 15cm

Finding Acceleration

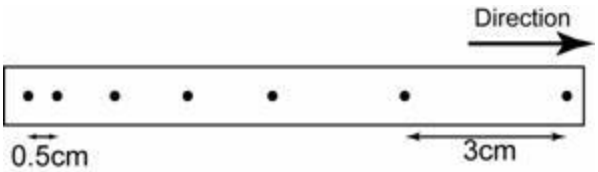
Acceleration of a motion can be determined by using ticker tape through the following equation:

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

a = acceleration
v = final velocity
u = initial velocity
t = time taken

Caution!!!
t is time taken from the initial velocity to the **final velocity**.

Example 2



The ticker-tape in figure above was produced by a toy car moving down a tilted runway. If the ticker-tape timer produced 50 dots per second, find the acceleration of the toy car.

Answer
In order to find the acceleration, we need to determine the initial velocity, the final velocity and the time taken for the velocity change.
Initial velocity,

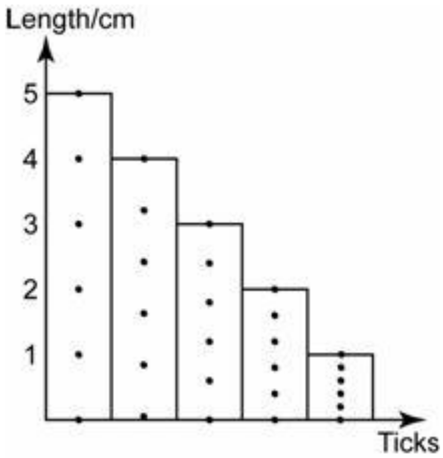
$$u = \frac{s}{t} = \frac{3cm}{0.02s} = 150cms^{-1}$$

$$v = \frac{s}{t} = \frac{0.5cm}{0.02s} = 25cms^{-1}$$

Time taken for the velocity change,
t = (0.5 + 4 + 0.5) ticks = 5 ticks
t = 5 × 0.02s = 0.1s

Acceleration, a =

Example 3



A trolley is pushed up a slope. Diagram above shows ticker tape chart that show the movement of the trolley. Every section of the tape contains 5 ticks. If the ticker-tape timer produced 50 dots per second, determine the acceleration of the trolley.

Answer
In order to find the acceleration, we need to determine the initial velocity, the final velocity and the time taken for the velocity change.
Initial velocity,

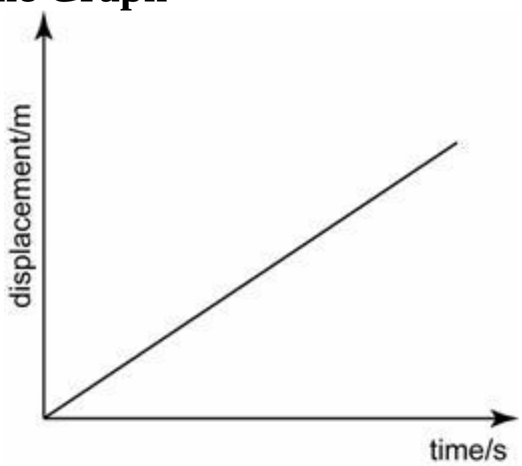
$$u = \frac{s}{t} = \frac{5cm}{5[?]0.02s} = 50cms^{-1}$$

$$v = \frac{s}{t} = \frac{1cm}{5[?][?]0.02s} = 10cms^{-1}$$

Time taken for the velocity change,
t = (2.5 + 5 + 5 + 5 + 2.5) ticks = 40 ticks
t = 40 × 0.02s = 0.8s

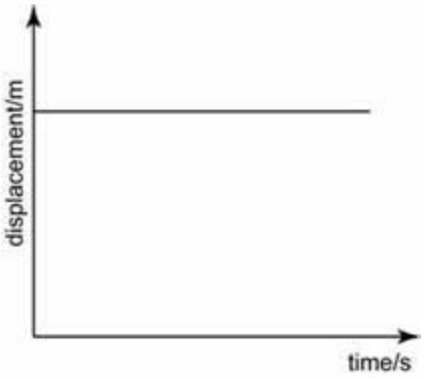
Acceleration, a:

Displacement - Time Graph

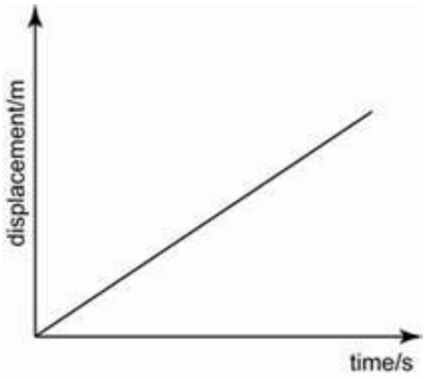


In a Displacement-Time Graph, the gradient of the graph is equal to the velocity of motion.

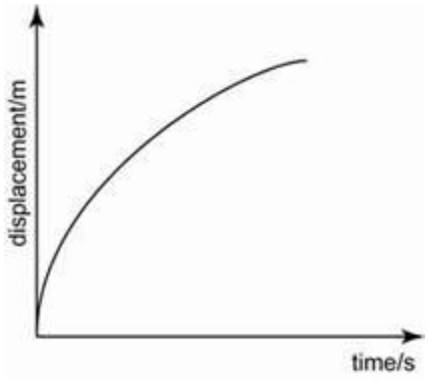
Analysing Displacement - Time Graph



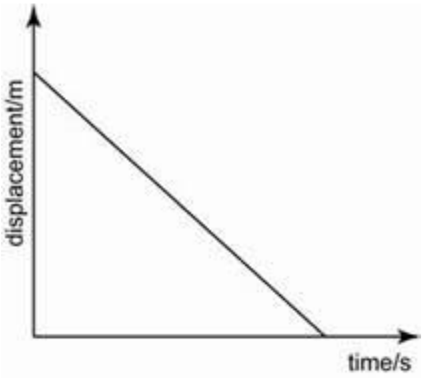
Gradient = 0
Hence, velocity = 0



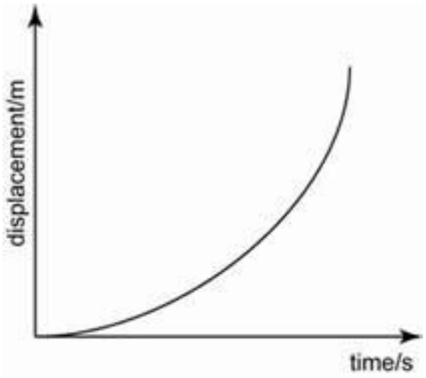
Gradient is constant, hence, velocity is Uniform



Gradient is decreasing, hence velocity is decreasing.

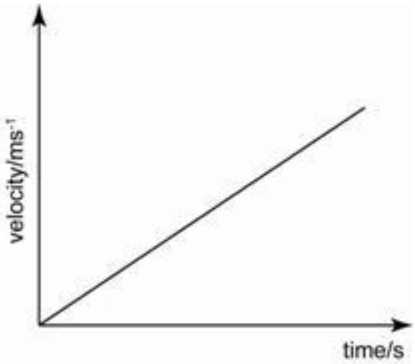


Gradient is negative and constant, hence velocity is uniform and in opposite direction



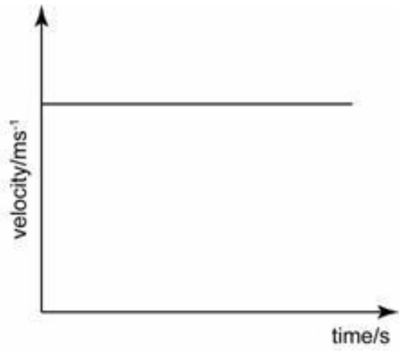
Gradient is increasing, hence velocity is increasing.

Velocity - Time Graph

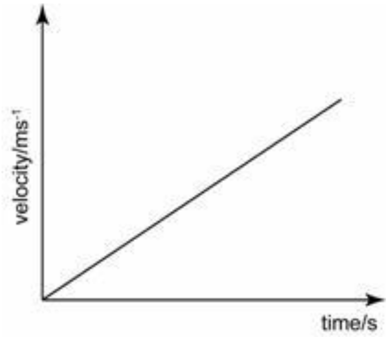


- The gradient of the velocity-time gradient gives a value of the changing rate in velocity, which is the acceleration of the object.
- The area below the velocity-time graph gives a value of the object's displacement.

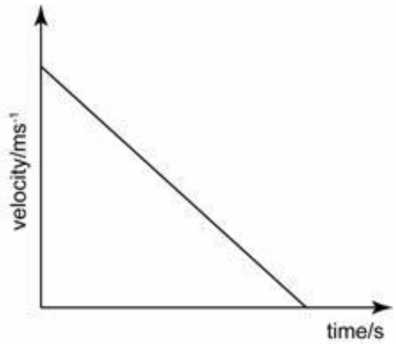
Analysing Velocity - Time Graph



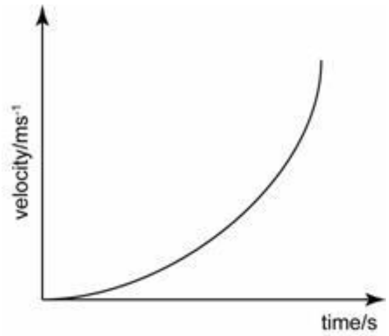
Uniform velocity



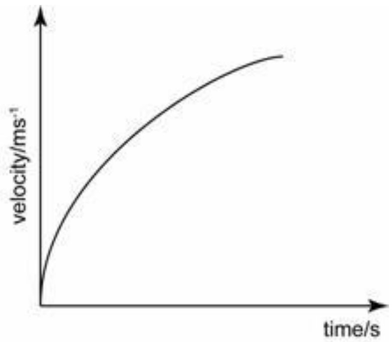
Uniform acceleration



Uniform deceleration



Increasing acceleration

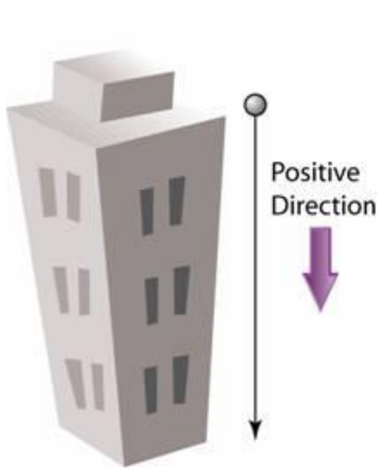
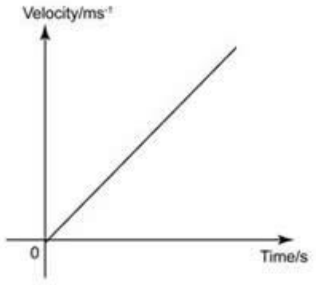
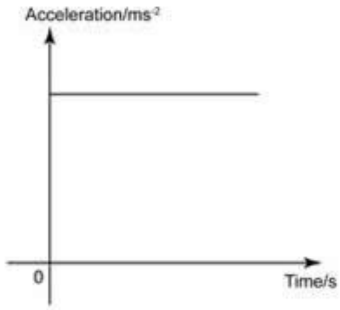


Increasing deceleration

Converting a Velocity-Time graph to Acceleration-Time graph

In order to convert a velocity-time graph to acceleration time graph, we need to find the gradient of the velocity time graph and plot it in the acceleration-time graph.

Dropping an object from high place

<table>
<tr><th></th><th>Velocity - Time Graph</th><th>Acceleration - Time Graph</th></tr>
<tr><td>
</td><td>
</td><td>
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Launching Object Upward

<table>
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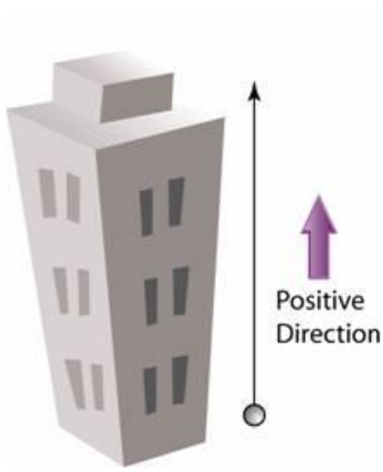
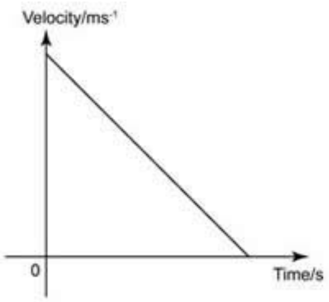
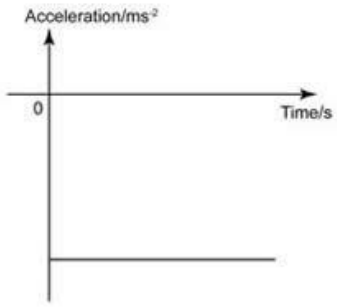
<tr><td>
</td><td>
</td><td>
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Object moving upward and fall back to the ground

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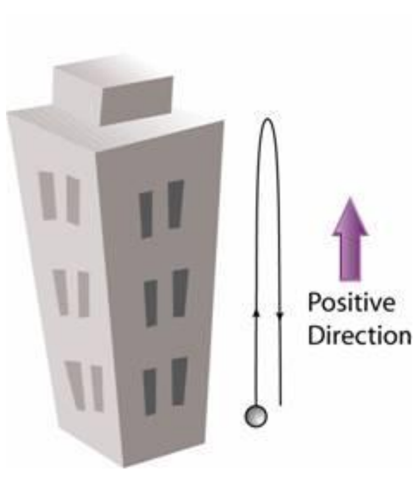
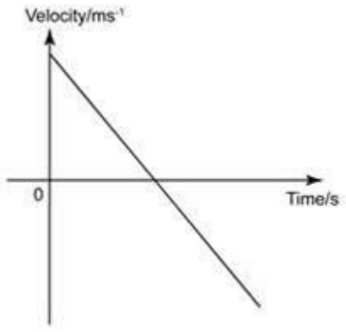
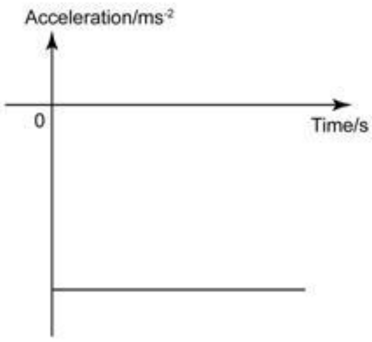
<tr><td>
</td><td>
</td><td>
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Object falling and bounces back

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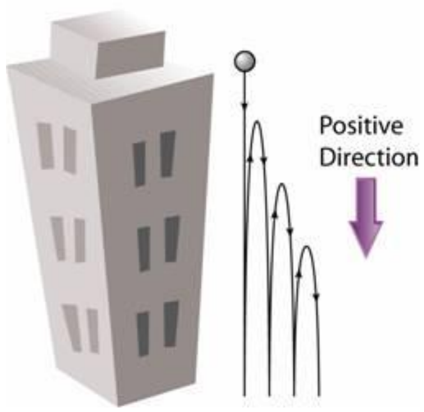
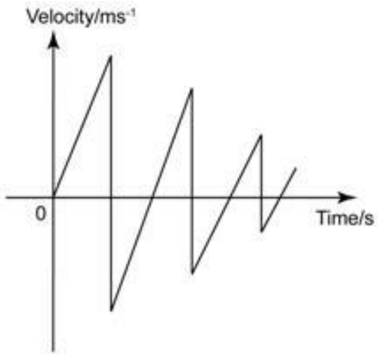
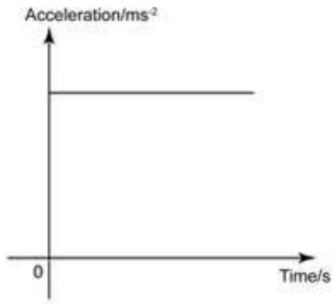
<tr><td>
</td><td>
</td><td>
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Mass

Mass is the amount of matter.
Unit: kilogram (kg)
Type of quantity: Scalar quantity

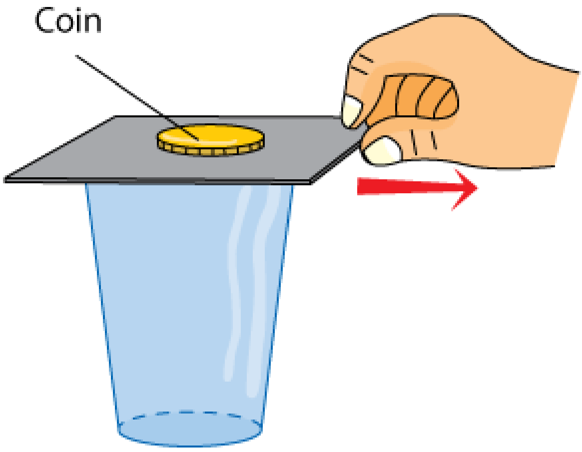
Inertia

Inertia is the property of a body that tends to maintain its state of motion.

Newton's First Law

In the absence of external forces, an object at rest **remains at rest** and an object in motion **continues in motion with a constant velocity** (that is, with a constant speed in a straight line).

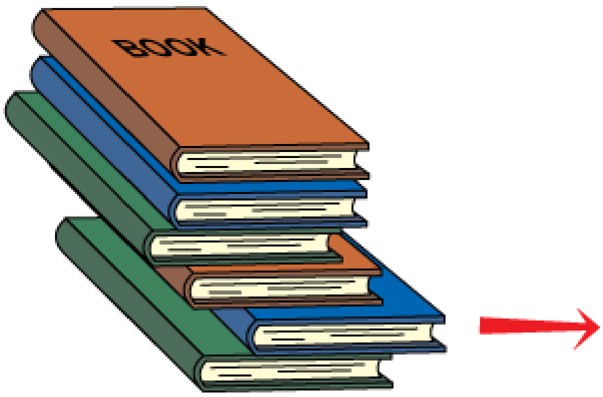
Jerking a Card



When the cardboard is jerked quickly, the coin will fall into the glass.
Explanation:

- The inertia of the coin resists the change of its initial state, which is stationary.
- As a result, the coin does not move with the cardboard and falls into the glass because of gravity.

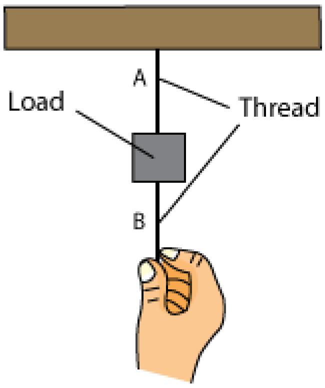
Pulling a Book



When the book is pulled out, the books on top will fall downwards.

Explanation
Inertia tries to oppose the change to the stationary situation, that is, when the book is pulled out, the books on top do not follow suit.

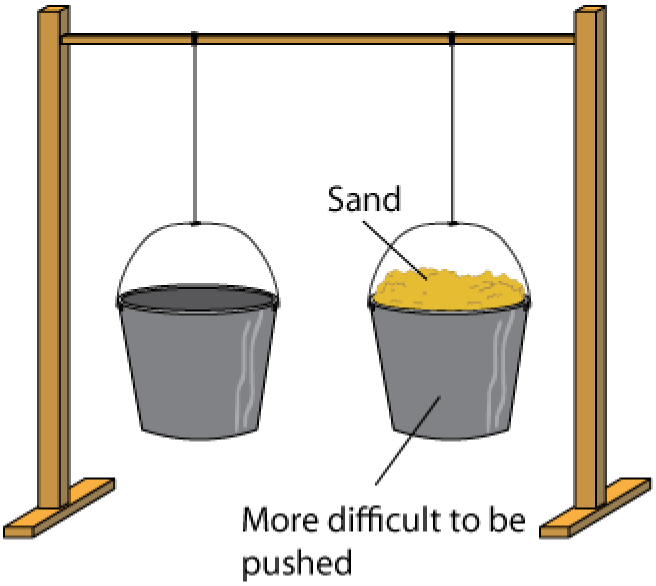
Pulling a Thread



Pull slowly - Thread A will snap.
Explanation:
Tension of thread A is higher than string B.
Tension at A = Weight of the load + Pulling Force
Yank quickly - Thread B will snap.

Explanation
The inertia of the load prevents the force from being transmitted to thread A, hence causing thread B to snap.

Larger Mass - Greater Inertia



Bucket filled with sand is more difficult to be moved. It's also **more difficult to be stopped** from swinging.

Explanation
Object with more mass offers a greater resistance to change from its state of motion.
Object with larger mass has larger inertia to resist the attempt to change the state of motion.

Empty cart is easier to be moved

An empty cart is easier to be moved compare with a cart full with load. This is because a cart with larger mass has larger inertia to resist the attempt to change the state of motion.

Momentum

Momentum is defined as the product of mass and velocity.
Formula:

$$p = mv$$

p = momentum
m = mass
v = velocity

Unit: kgms-1
Type of quantity: Vector

Example 1
A student releases a ball with mass of 2 kg from a height of 5 m from the ground. What would be the momentum of the ball just before it hits the ground?

Answer
In order to find the momentum, we need to know the mass and the velocity of the ball right before it hits the ground.
It's given that the mass, m = 2kg.
The velocity is not given directly. However, we can determine the velocity, v, by using the linear equation of uniform acceleration.
This is a free falling motion,
The initial velocity, u = 0
The acceleration, a = gravirational acceleration, g = 10ms-2
The dispacement, s = high = 50m.
The final velocity = ?
From the equation
v2 = u2 + 2as
v2 = (0)2 + 2(10)(5)
v = 10ms-1

The momentum,
p = mv =(2)(10) = 20 kgms-1

Principle of Conservation of Momentum

The principle of conservation of momentum states that **in a system** make out of objects that react (collide or explode), the total momentum is constant if **no external force** is acted upon the system.
Sum of Momentum Before Reaction = Sum of Momentum After Reaction

Formula

$$m_1u_1 + m_2u_2 = m_1v_1 + m_2v_2$$

m_1 = mass of the 1st object
m_2 = mass of the 2nd object
u_1 = initial velocity of the 1st object
u_2 = initial velocity of the 2nd object
v_1 = final velocity of the 1st object
v_2 = final velocity of the 2nd object

Example 2: Both objects are in same direction before collision.
A Car A of mass 600 kg moving at 40 ms-1 collides with a car B of mass 800 kg moving at 20 ms-1 in the same direction. If car B moves forwards at 30 ms-1 by the impact, what is the velocity, v, of the car A immediately after the crash?

Answer
m1 = 600kg
m2 = 800kg
u1 = 40 ms-1
u2 = 20 ms-1
v1 = ?
v2 = 30 ms-1

According to the principle of conservation of momentum,
m1u1 + m2u2 = m1v1 + m2v2
(600)(40) + (800)(20) = (600)v1 + (800)(30)
40000 = 600v1 + 24000
600v1 = 16000
v1 = 26.67 ms-1

Example 3: Both objects are in opposite direction before collision.

A 0.50kg ball traveling at 6.0 ms-1 collides head-on with a 1.0 kg ball moving in the opposite direction at a
speed of 12.0 ms-1. The 0.50kg ball moves backward at 14.0 ms-1 after the collision. Find the velocity of the second ball after collision.
Answer:
m1 = 0.5 kg
m2 = 1.0 kg
u1 = 6.0 ms-1
u2 = -12.0 ms-1
v1 = -14.0 ms-1
v2 = ?

(**IMPORTANT**: **velocity is negative when the object move in opposite siredtion**)

According to the principle of conservation of momentum,
m1u1 + m2u2 = m1v1 + m2v2
(0.5)(6) + (1.0)(-12) = (0.5)(-14) + (1.0)v2
-9 = - 7 + 1v2
v2 = -2 ms-1

Elastic Collision

Elastic collision is the collision where the kinetic energy is conserved after the collision.
Total Kinetic Energy before Collision = Total Kinetic Energy after Collision

Additional notes:
-In an elastic collision, the 2 objects seperated right after the collision, and
-the momentum is conserved after the collision.

Inelastic Collision

Inelastic collision is the collision where the kinetic energy is not conserved after the collision.

Additional notes:
-In a perfectly elastic collision, the 2 objects attach together after the collision, and
-the momentum is also conserved after the collision.

Example 4: Perfectly Inelastic Collision
A lorry of mass 8000kg is moving with a velocity of 30 ms-1. The lorry is then accidentally collides with a car of mass 1500kg moving in the same direction with a velocity of 20 ms-1. After the collision, both the vehicles attach together and move with a speed of velocity v. Find the value of v.

Answer
(**IMPORTANT**: **When 2 object attach together, they move with same speed.**)
m1 = 8000kg
m2 = 1500kg
u1 = 30 ms-1
u2 = 20 ms-1

v1 = v
v2 = v

According to the principle of conservation of momentum,
m1u1 + m2u2 = m1v1 + m2v2
(8,000)(30) + (1,500)(20) = (8,000)v+ (1,500)v
270,000 = 9500v
v = 28.42 ms-1

Rocket

1. Mixture of hydrogen and oxygen fuels burn in the combustion chamber.
2. Hot gases are expelled through the exhausts at very high speed .
3. The high-speed hot gas produce a high momentum backwards.
4. By conservation of momentum, an equal and opposite momentum is produced and acted on the rocket, pushing the rocket upwards.

Jet Engine

1. Air is taken in from the front and is compressed by the compressor.
2. Fuel is injected and burnt with the compressed air in the combustion chamber.
3. The hot gas is forced through the engine to turn the turbine blade, which turns the compressor.
4. High-speed hot gases are ejected from the back with high momentum.
5. This produces an equal and opposite momentum to push the jet plane forward.

Newton's Second Law

The **rate of change of momentum** of a body is directly proportional to the resultant force acting on the body and is in the same direction.

Implication:
When there is resultant force acting on an object, the object will accelerate (moving faster, moving slower or change direction).

Force

- A force is push or pull exerted on an object.
- Force is a vector quantity that has magnitude and direction.
- The unit of force is Newton (or kgms-2).

Formula of Force

From Newton's Second Law, we can derived the equation

$$F = ma$$

(IMPORTANT: F Must be the net force)

F = Net force
m = mass
a = acceleration

Summary of Newton's 1st Law and 2nd Law

Newton's First Law:
When there is no net force acting on an object, the object is either **stationary** or move with **constant speed in a straight line**.

Newton's Second Law:
When there is a net force acting on an object, the object will accelerate.

Example 1
A box of mass 150kg is placed on a horizontal floor with a smooth surface; find the acceleration of the box when a 300N force is acting on the box horizontally.

Answer
F = ma
(300) = (150)a
a = 2 ms-2

Example 2
A object of mass 50kg is placed on a horizontal floor with a smooth surface. If the velocity of the object changes from stationary to 25.0 m/s in 5 seconds when is acted by a force, find the magnitude of the force that is acting?

Answer
We know that we can find the magnitude of a force by using the formula F = ma. The mass m is already given in the question, but the acceleration is not give directly.
We can determine the acceleration from the formula

From the formula
F = ma = (50)(5) = 250N
The force acting on the box is 250N.

Effects of Force
When a force acts on an object, the effect can change the
- size,
- shape,
- stationary state,
- speed and
- direction of the object.

Impulse
Impulse is defined as the product of the **force** (F) acting on an object and the **time** of action (t).
Impulse exerted on an object is equal to the momentum change of the object.
Impulse is a vector quantity.

Formula of impulse

Impulse is the product of force and time.

$$\textbf{Impulse} = \textbf{F} \times \textbf{t}$$

Impulse = momentum change

$$\textbf{Impulse = mv - mu}$$

Example 1

A car of mass 600kg is moving with velocity of 30m/s. A net force of 200N is applied on the car for 15s. Find the impulse exerted on the car and hence determine the final velocity of the car.

Answer

Impulse = F × t = (200) × (15) = 300oNs
Impulse = mv - mu
(3000) = 600v - 600(30)
600v = 3000 + 18000
v = 21000/600 = 35 m/s
[500,000N]

Impulsive Force

Impulsive force is defined as the rate of change of momentum in a reaction.
It is a force which acts on an object for a very short interval during a collision or explosion.

Example 2
A car of mass 1000kg is traveling with a velocity of 25 m/s. The car hits a street lamp and is stopped in0.05 seconds. What is the impulsive force acting on the car during the crash?

Answer:

Effects of impulse vs Force

A force determines the acceleration (rate of velocity change) of an object. A greater force produces a higher acceleration.
An impulse **determines the velocity change** of an object. A greater impulse yield a higher velocity change.

Examples Involving Impulsive Force

- Playing football
- Playing badminton
- Playing tennis
- Playing golf
- Playing baseball

Long Jump

- The long jump pit is filled with sand to increase the reaction time when athlete land on it.
- This is to reduce the impulsive force acts on the leg of the atlete because impulsive force is inversely proportional to the reaction time.

High Jump

- During a high jump, a high jumper will land on a thick, soft mattress after the jump.
- This is to increase the reaction time and hence reduces the impulsive force acting on the high jumper.

Jumping

A jumper bends his/her leg during landing. This is to increase the reaction time and hence reduce the impact of impulsive force acting on the leg of the jumper.

Crumble Zone

- The crumple zone increases the reaction time of collision during an accident.
- This causes the impulsive force to be reduced and hence reduces the risk of injuries.

Seat Belt

Prevent the driver and passengers from being flung forward or thrown out of the car during an emergency break.

Airbag

The inflated airbag during an accident acts as a cushion to lessen the impact when the driver flings forward hitting the steering wheel or dashboard.

Head Rest

Reduce neck injury when driver and passengers are thrown backwards when the car is banged from backward.

Windscreen

Shatter-proof glass is used so that it will not break into small pieces when broken. This may reduce injuries caused by scattered glass.

Padded Dashboard

Cover with soft material. This may increases the reaction time and hence reduce the impulsive force when passenger knocking on it in accident.

Collapsible Steering Columns

The steering will swing away from driver's chest during collision. This may reduce the impulsive force acting on the driver.

Anti-lock Braking System (ABS)

Prevent the wheels from locking when brake applied suddenly by adjusting the pressure of the brake fluid. This can prevents the car from skidding.

Bumper

Made of elastic material so that it can increases the reaction time and hence reduces the impulsive force caused by collision.

Passanger Safety Cell

- The body of the car is made from strong, rigid stell cage.
- This may prevent the car from collapsing on the passengers during a car crash.