General Physics

Physical Quantities & Units
AS level

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Syllabus content

The table below shows which parts of the syllabus contain AS material and/or A2 material.

Section		AS	A2
I General Physics	1. Physical quantities and units	✓	✓
	2. Measurement techniques	✓	✓

Section I: General physics

Recommended prior knowledge
Candidates should be aware of the nature of a physical measurement, in terms of a magnitude and a unit. They should have experience of making and recording such measurements in the laboratory.

1. Physical quantities and units

Content	Learning outcomes
1.1 Physical quantities 1.2 SI Units 1.3 The Avogadro constant 1.4 Scalars and vectors	Candidates should be able to: *(a)* show an understanding that all physical quantities consist of a numerical magnitude and a unit *(b)* recall the following SI base quantities and their units: mass (kg), length (m), time (s), current (A), temperature (K), **amount of substance (mol)** *(c)* express derived units as products or quotients of the SI base units and use the named units listed in this syllabus as appropriate *(d)* use SI base units to check the homogeneity of physical equations *(e)* show an understanding of and use the conventions for labelling graph axes and table columns as set out in the ASE publication *Signs, Symbols and Systematics* (*The ASE Companion to 16–19 Science*, 2000) *(f)* use the following prefixes and their symbols to indicate decimal sub-multiples or multiples of both base and derived units: pico (p), nano (n), micro (μ), milli (m), centi (c), deci (d), kilo (k), mega (M), giga (G), tera (T) *(g)* make reasonable estimates of physical quantities included within the syllabus ***(h)* show an understanding that the Avogadro constant is the number of atoms in 0.012 kg of carbon-12** ***(i)* use molar quantities where one mole of any substance is the amount containing a number of particles equal to the Avogadro constant** *(j)* distinguish between scalar and vector quantities and give examples of each *(k)* add and subtract coplanar vectors *(l)* represent a vector as two perpendicular components.

Physical Quantities

Quantitative versus qualitative

- Most observation in physics are quantitative
- Descriptive observations (or qualitative) are usually imprecise

Qualitative Observations
How do you measure artistic beauty?

Quantitative Observations
What can be measured with the instruments on an aeroplane?

Physical Quantities

- A physical quantity is one that can be measured and consists of a magnitude and unit.

SI units are used in Scientific works

Measuring length

Physical Quantities

Are classified into two types:

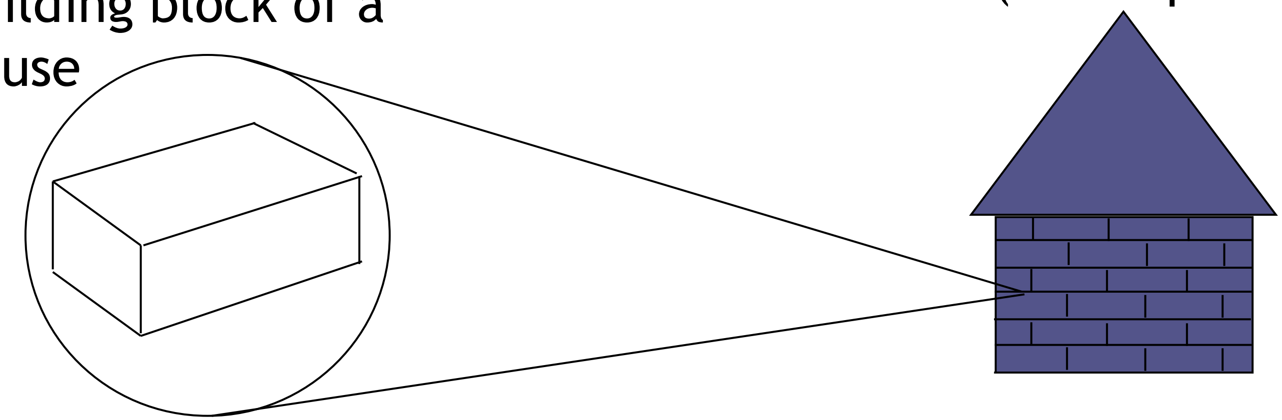
- Base quantities
- Derived quantities

Base quantity

For example : is like the brick – the basic building block of a house

Derived quantity

For example : is like the house that was build up from a collection of bricks (basic quantity)



Definitions :-

- Base quantities are the quantities on the basis of which other quantities are expressed.

- The quantities that are expressed in terms of base quantities are called derived quantities

SI Units for Base Quantity

- **SI Units** – International System of Units

Base Quantities	Name of Unit	Symbol of Unit
length	metre	m
mass	kilogram	kg
time	second	s
electric current	ampere	A
temperature	kelvin	K
amount of substance	mole	mol

Derived quantity & equations

- A derived quantity has an equation which links to other quantities.
- It enables us to express a derived unit in terms of base-unit equivalent.

  Example: $F = ma$; Newton = kg m s^{-2}

  $P = F/A$; Pascal = kg m s^{-2}/m^2 = kg m^{-1} s^{-2}

Some derived units

Derived quantity	Base equivalent units	Symbol
area	square meter	m^2
volume	cubic meter	m^3
speed, velocity	meter per second	m/s or m s^{-1}
acceleration	meter per second squared	m/s/s or m s^{-2}
density	kilogram per cubic meter	kg m^{-3}
amount concentration	mole per cubic meter	mol m^{-3}
force	kg m s^{-2}	Newton
work/energy	kg m^2 s^{-2}	Joule
power	kg m^2 s^{-3}	Watt
pressure	kg m^{-1} s^{-2}	Pascal
frequency	s^{-1}	Hertz

SI Units

1. Equation: area = length × width

In terms of base units: Units of area = m × m = m^2

2. Equation: volume = length × width × height

In terms of base units: Units of volume = m × m × m = m^3

3. Equation: density = mass ÷ volume

In terms of base units: Units of density = kg m^{-3}

SI Units

- Work out the derived quantities for:

1. Equation: $\text{speed} = \dfrac{\text{distance}}{\text{time}}$

In terms of base units: Units of speed = ms^{-1}

2. Equation: $\text{acceleration} = \dfrac{\text{velocity}}{\text{time}}$

In terms of base units: Units of acceleration = ms^{-2}

3. Equation: force = mass × acceleration

In terms of base units: Units of force = $kg\ ms^{-2}$

SI Units

- Work out the derived quantities for:

1. Equation: Pressure = $\frac{Force}{Area}$

In terms of base units: Units of pressure = $Kgm^{-1}s^{-2}$

2. Equation: Work = Force × Displacement

In terms of base units: Units of work = $Kgm^{2}s^{-2}$

3. Equation: Power = $\frac{Work\ done}{Time}$

In terms of units: Units of power = $Kgm^{2}s^{-3}$

SI Units - Fill in…

Derived Quantity	Relation with Base and Derived Quantities	Unit	Special Name
Momentum			
Electric Charge			
Potential Difference			
Resistance			

For you to know...

Physical quantity	Defined as	Unit	Special name
density	mass (kg) ÷ volume (m^3)	$kg\ m^{-3}$	
momentum	mass (kg) × velocity ($m\ s^{-1}$)	$kg\ m\ s^{-1}$	
force	mass (kg) × acceleration ($m\ s^{-2}$)	$kg\ m\ s^{-2}$	newton (N)
pressure	force ($kg\ m\ s^{-2}$ or N) ÷ area (m^2)	$kg\ m^{-1}\ s^{-2}$ ($N\ m^{-2}$)	pascal (Pa)
work (energy)	force ($kg\ m\ s^{-2}$ or N) × distance (m)	$kg\ m^2\ s^{-2}$ (N m)	joule (J)
power	work ($kg\ m^2\ s^{-2}$ or J) ÷ time (s)	$kg\ m^2\ s^{-3}$ ($J\ s^{-1}$)	watt (W)
electrical charge	current (A) × time (s)	A s	coulomb (C)
potential difference	energy ($kg\ m^2\ s^{-2}$ or J) ÷ charge (A s or C)	$kg\ m^2\ A^{-1}\ s^{-3}$ ($J\ C^{-1}$)	volt (V)
resistance	potential difference ($kg\ m^2\ A^{-1}\ s^{-3}$ or V) ÷ current (A)	$kg\ m^2\ A^{-2}\ s^{-3}$ ($V\ A^{-1}$)	ohm (Ω)

Reference Link – Physical quantities

- http://thinkzone.wlonk.com/Units/PhysQuantities.htm

KEY CONCEPTS

1. A **physical quantity** is a quantity that can be measured and consists of a numerical magnitude and a unit.
2. The physical quantities can be classified into **base quantities** and **derived quantities**.
3. There are seven base quantities: length, mass, time, current, temperature, amount of substance and luminous intensity.
4. The SI units for length, mass, time, temperature and amount of substance, electric current are metre, kilogram, second, kelvin, mole and ampere respectively.

Homogeneity of an equation

- An equation is homogeneous if quantities on BOTH sides of the equation has the same unit.
- E.g. $s = ut + \frac{1}{2} at^2$
- LHS : unit of s = m
- RHS : unit of ut = $ms^{-1} \times s = m$
- unit of $at^2 = ms^{-2} \times s^2 = m$
- Unit on LHS = unit on RHS
- Hence equation is homogeneous

Non-homogeneous

- $P = \rho g h^2$
- LHS ; unit of P = $Nm^{-2} = kgm^{-1}s^{-2}$
- RHS : unit of $\rho g h^2 = kgm^{-3}(ms^{-2})(m^2) = kgs^{-2}$
- **Unit on LHS $\neq$ unit on RHS**
- **Hence equation is not homogeneous**

Homogeneity of an equation

- Note: numbers has no unit
- some constants have no unit.
- e.g. π,

- A homogeneous eqn may not be physically correct but a physically correct eqn is definitely homogeneous

- E.g. $s = 2ut + at^2$ (homogenous but not correct)
- $F = ma$ (homogeneous and correct)

Magnitude

- **Prefix : magnitudes of physical quantity range from very large to very small.**
- **E.g. mass of sun is 10^{30} kg and mass of electron is 10^{-31} kg.**
- **Hence, prefix is used to describe these magnitudes.**

Significant number

- **Magnitudes of physical quantities are often quoted in terms of significant number.**
- **Can you tell how many sig. fig. in these numbers?**
- **103, 100.0 , 0.030, 0.4004, 200**
- **If you multiply 2.3 and 1.45, how many sf should you quote?**
- **3.19, 3.335 , 3.48**
- **3.312, 3.335, 3.358**

The rules for identifying significant figures

- The rules for identifying significant figures when writing or interpreting numbers are as follows:-

- All non-zero digits are considered significant. For example, 91 has two significant figures (9 and 1), while 123.45 has five significant figures (1, 2, 3, 4 and 5).
- Zeros appearing anywhere between two non-zero digits are significant. Example: 101.1203 has seven significant figures: 1, 0, 1, 1, 2, 0 and 3.
- Leading zeros are not significant. For example, 0.00052 has two significant figures: 5 and 2.

The rules for identifying significant figures (cont)

- Trailing zeros in a number containing a decimal point are significant. For example, 12.2300 has six significant figures: 1, 2, 2, 3, 0 and 0. The number 0.000122300 still has only six significant figures (the zeros before the 1 are not significant). In addition, 120.00 has five significant figures since it has three trailing zeros.

- **Often you will be asked to estimate some magnitudes of physical quantities around you.**

- **E.g. estimate the height of the ceiling, volume of an apple, mass of an apple, diameter of a strand of hair,**

Reference link :

http://www.xtremepapers.com/revision/a-level/physics/measurement.php

Estimates of physical quantities

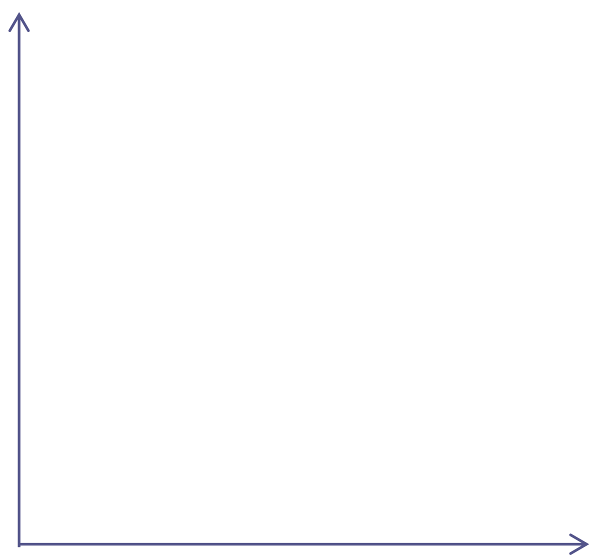
- When making an estimate, it is only reasonable to give the figure to 1 or at most 2 significant figures since an estimate is not very precise.

Physical Quantity	Reasonable Estimate
Mass of 3 cans (330 ml) of Pepsi	1 kg
Mass of a medium-sized car	1000 kg
Length of a football field	100 m
Reaction **time** of a young man	0.2 s

- Occasionally, students are asked to estimate the area under a graph. The usual method of counting squares within the enclosed area is used.

Convention for labelling tables and graphs

t/s	v/ms^{-1}
0	2.5
1.0	4.0
2.0	5.5



- The symbol / unit is indicated at the italics as indicated in the data column left.
- Then fill in the data with pure numbers.
- Then plot the graph after labelling x axis and y axis

[Illustration with sample graph on left]

Prefixes

- For very large or very small numbers, we can use standard prefixes with the base units.
- The main prefixes that you need to know are shown in the table. (next slide)

Prefixes

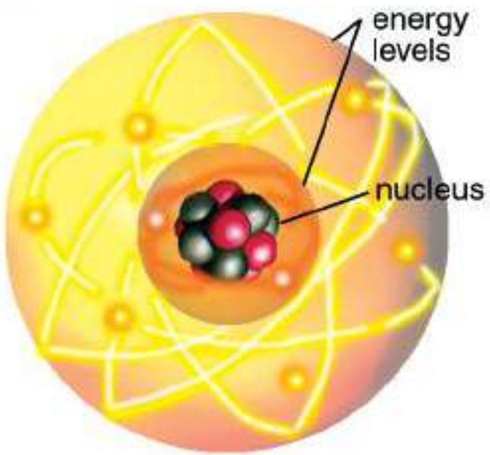
- Prefixes simplify the writing of very large or very small quantities

Prefix	Abbreviation	Power
nano	n	10^{-9}
micro	μ	10^{-6}
milli	m	10^{-3}
centi	c	10^{-2}
deci	d	10^{-1}
kilo	k	10^{3}
mega	M	10^{6}
giga	G	10^{9}
Tera	?	??

Prefixes

- Alternative writing method
- Using standard form
- $N \times 10^n$ where $1 \leq N < 10$ and n is an integer

This galaxy is about 2.5×10^6 light years from the Earth.

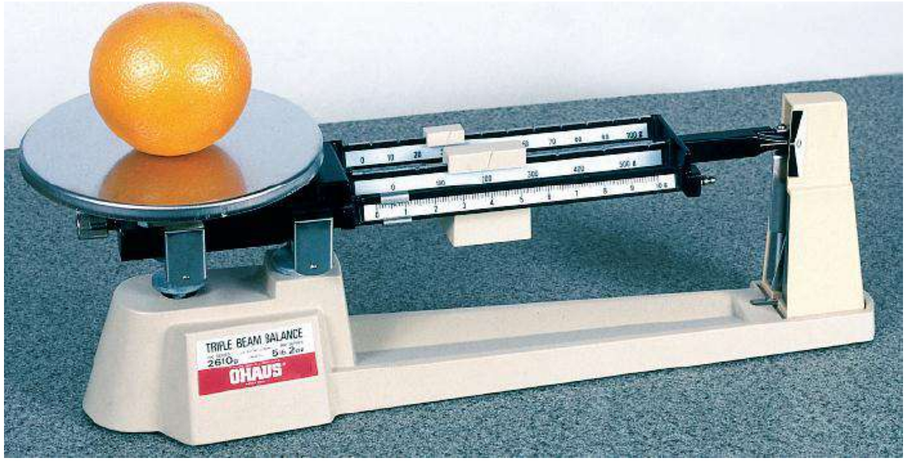


The diameter of this atom is about 1×10^{-10} m.

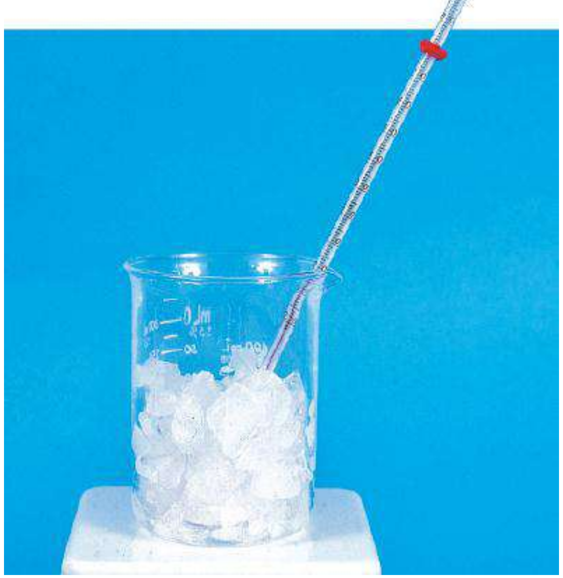
Scalars and Vectors

- **Scalar quantities** are quantities that have magnitude only. Two examples are shown below:

Measuring Mass



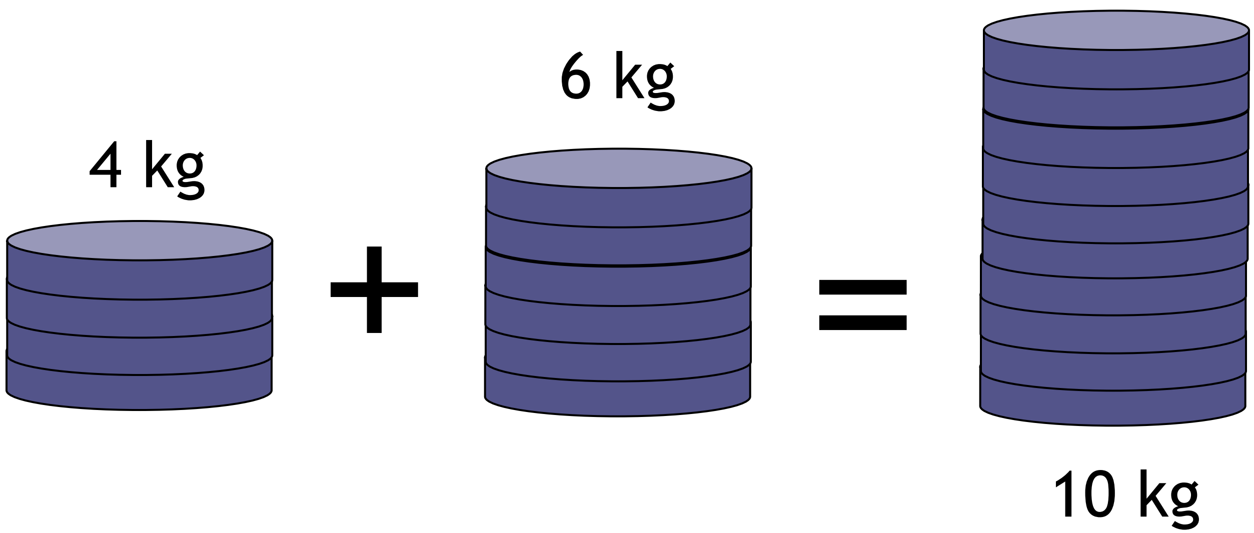
Measuring Temperature



Scalars and Vectors

- **Scalar quantities** are added or subtracted by using simple arithmetic.

  Example: 4 kg plus 6 kg gives the answer 10 kg



Scalars and Vectors

- **Vector quantities** are quantities that have both magnitude and direction

Magnitude = 100 N

Direction = Left

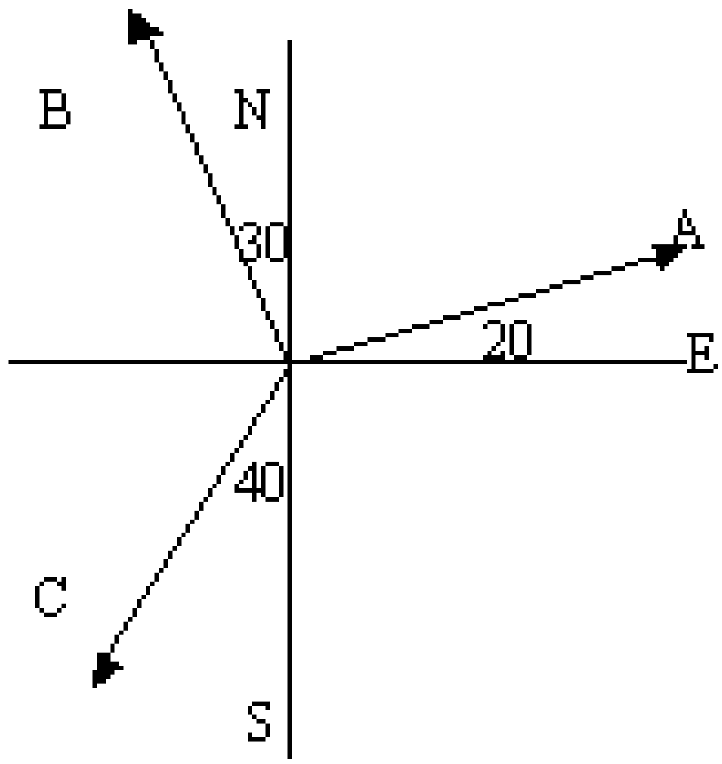
Scalars and Vectors

- Examples of scalars and vectors

Scalars	Vectors
distance	displacement
speed	velocity
mass	weight
time	acceleration
pressure	force
energy	momentum
volume	
density	

Direction of vector

e.g.



Vector A – E 20^0 N or N 70^0 E

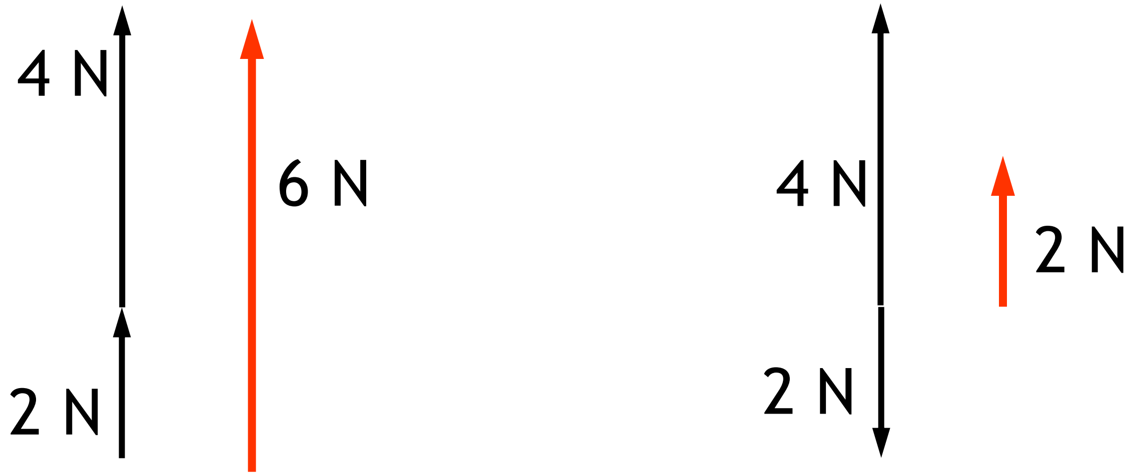
Vector B – N 30^0 W or W 60^0 N

Vector C -

Scalars and Vectors

Adding/Subtracting Vectors using Graphical Method

- Parallel vectors can be added arithmetically



Scalars and Vectors

Adding Vectors using Graphical Method

- Non-parallel vectors are added by graphical means using the parallelogram law
  - Vectors can be represented graphically by arrows

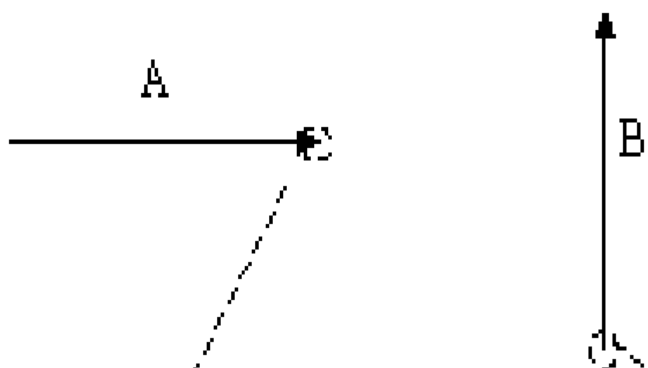
$$\overbrace{\xrightarrow{\hspace{6em}}}^{5.0\text{ cm} \equiv 20.0\text{ N}} \quad \text{Direction = right}$$

  - The length of the arrow represents the magnitude of the vector
  - The direction of the arrow represents the direction of the vector
  - The magnitude and direction of the resultant vector can be found using an accurate scale drawing

Vector addition

(a) Drawing method

E.g. Below are two vectors A and B.



What will be the result of adding them up? The resultant vector is the one that you get when you add two or more vectors together. It is a single vector that has the same effect as all the others put together.

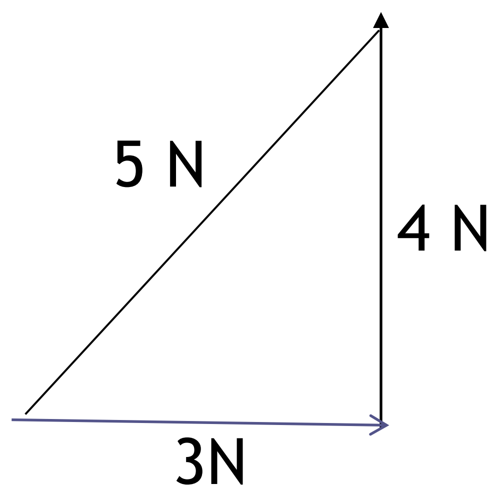
Let's describe the result as C.

So C = A + B

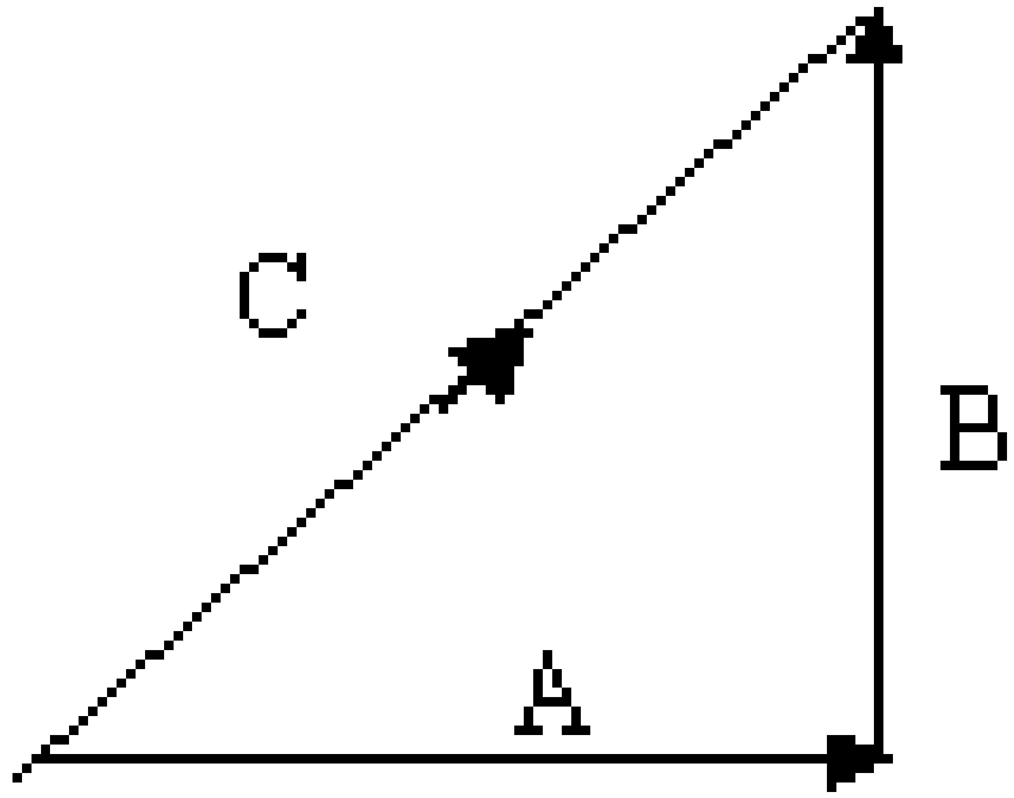
You will connect the two vectors in this manner. The tail of B connects to the head of A

Vector operation

- **Vector problem must be solved vectorically unlike scalar quantity.**
- **E.g. 3 N + 4 N = 5 N**



Addition using drawing method

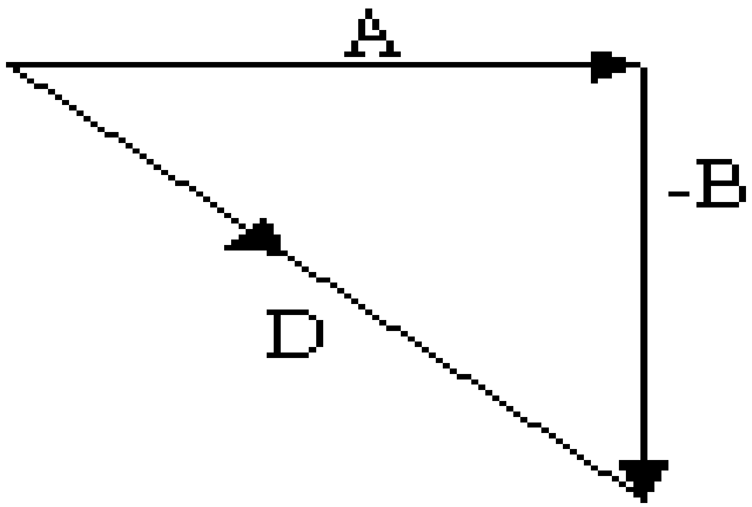


Reference link : Vector addition

- http://www.physicsclassroom.com/class/vectors/u3l1b.cfm

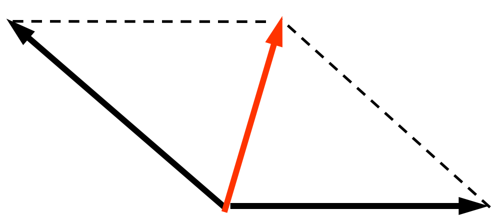
Subtraction using drawing method

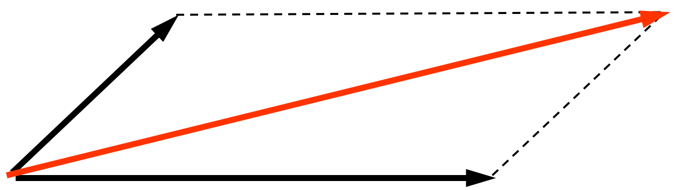
- if D = A – B

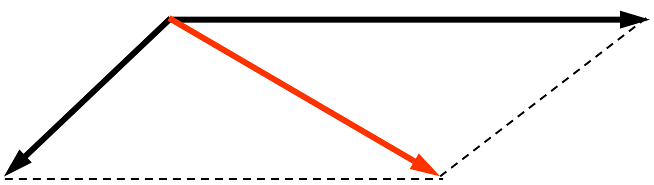


Scalars and Vectors

- The **parallelogram law of vector addition** states that if two vectors acting at a point are represented by the sides of a parallelogram drawn from that point, their resultant is represented by the diagonal which passes through that point of the parallelogram







Coplanar vectors

- When 3 or more vectors need to be added, the same principles apply, provided the vectors are all on the same plane i.e. coplanar
- To subtract 2 vectors, reverse the direction i.e. change the sign of the vector to be subtracted, and add

Change in a Vector

Case 1

- If an object changes it's direction but not speed, then velocity vector will only change its direction but not magnitude.

Case 2

- If an object changes it's direction and also speed, vector will change its direction as well as magnitude. So the change in the vector would be final minus initial.

Components of a Vector

- Any vector directed in two dimensions can be thought of as having an influence in two different directions. That is, it can be thought of as having two parts. Each part of a vector is known as a **component**.

- 2N + 4N = 6N (2N and 4N are the components of 6N)

- The components of a vector depict the influence of that vector in a given direction. The combined influence of the two components is equivalent to the influence of the single vector. The single vector could be replaced by the two components.

Components of a Vector

- Any vector can be thought of as having two different components. The component of a single vector describes the influence of that vector in a given direction.

- $\overrightarrow{3N} + \overrightarrow{4N} = \overrightarrow{7N}$ ($\overrightarrow{3N}$ and $\overrightarrow{4N}$ are the components of $\overrightarrow{7N}$)

Resolution of vectors

- **Resolving vectors into two perpendicular components**

- A vector can be broken down into **components**, which are perpendicular to each other, so that the vector sum of these two components, is equal to the original vector.

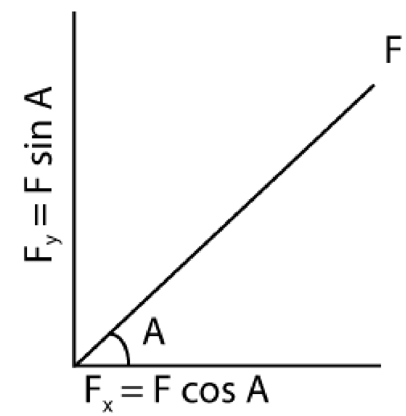
- Splitting a vector into two components is called **resolving** the vector. It is the reverse of using Pythagoras' theorem to add two perpendicular vectors, and so adding the two components will give you the original vector.

Resolution of vectors

- **Resolving vectors into two perpendicular components**

- Resolving a vector requires some simple trigonometry. In the diagram, the vector to be resolved is the force, F for angle A;

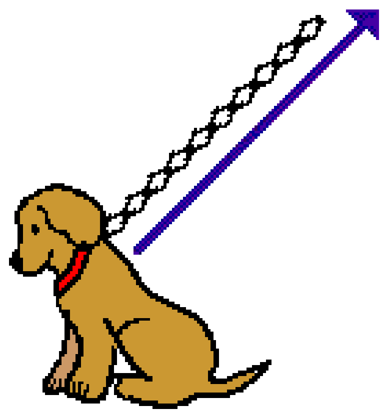
➢ the horizontal component of F : $F_x = F \cos A$
➢ the vertical component of F : $F_y = F \sin A$

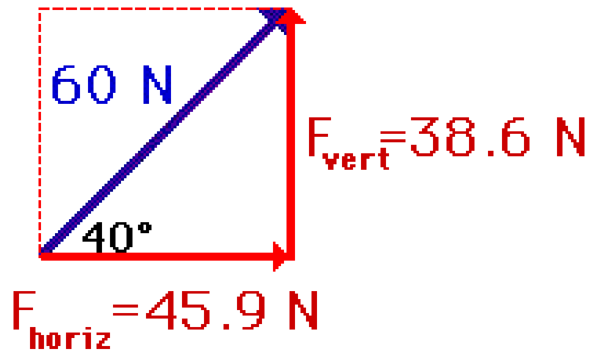


Note that the two components do not have to be horizontal and vertical. The angle can be changed to any required direction, and both components will still be perpendicular to each other

Resolution of vectors

- **Resolving vectors into two perpendicular components**





$$\sin 40^\circ = \frac{F_{vert}}{60\text{ N}} \qquad \cos 40^\circ = \frac{F_{horiz}}{60\text{ N}}$$

$$F_{vert} = 60\text{ N} \times \sin 40^\circ \qquad F_{horiz} = 60\text{ N} \times \cos 40^\circ$$

$$F_{vert} = 38.6\text{ N} \qquad F_{horiz} = 45.9\text{ N}$$

In short…

- Vectors addition and subtraction can be performed using diagram method or the resolve and recombine method

Reference links – Vector Resolution

- http://www.physicsclassroom.com/class/vectors/u3l1d.cfm
- http://www.physicsclassroom.com/class/vectors/U3l1e.cfm

K E Y C O N C E P T S

1. Scalar quantities are quantities that only have magnitudes
2. Vector quantities are quantities that have both magnitude and direction
3. Parallel vectors can be added arithmetically
4. Non-parallel vectors are added by graphical means using the parallelogram law.
5. Vectors addition and subtraction can be performed using diagram method or the resolve and recombine method

Youtube videos links with explanation on :
General Physics - Physical quantities

- http://www.youtube.com/watch?v=kuoQUv7bY2Y
- http://www.youtube.com/watch?v=Rmy85_EwLoY&feature=related


Questions and Answers

Newtonian Mechanics

Kinematics

Marline Kurishingal

Syllabus content

Section		AS	A2
II Newtonian mechanics	3. Kinematics	✓	
	4. Dynamics	✓	
	5. Forces	✓	
	6. Work, energy, power	✓	
	7. Motion in a circle		✓
	8. Gravitational field		✓

Section II: Newtonian mechanics

Recommended prior knowledge

Candidates should be able to describe the action of a force on a body.

They should be able to describe the motion of a body and recognise acceleration and constant speed. They should be able to use the relationship *average speed = distance / time*.

3. Kinematics

Content	Learning outcomes
3.1 Linear motion	Candidates should be able to:
3.2 Non-linear motion	*(a)* define displacement, speed, velocity and acceleration
	(b) use graphical methods to represent displacement, speed, velocity and acceleration
	(c) find displacement from the area under a velocity-time graph
	(d) use the slope of a displacement-time graph to find velocity
	(e) use the slope of a velocity-time graph to find acceleration
	(f) derive, from the definitions of velocity and acceleration, equations that represent uniformly accelerated motion in a straight line
	(g) solve problems using equations that represent uniformly accelerated motion in a straight line, including the motion of bodies falling in a uniform gravitational field without air resistance
	(h) recall that the weight of a body is equal to the product of its mass and the acceleration of free fall
	(i) describe an experiment to determine the acceleration of free fall using a falling body
	(j) describe qualitatively the motion of bodies falling in a uniform gravitational field with air resistance
	(k) describe and explain motion due to a uniform velocity in one direction and a uniform acceleration in a perpendicular direction.

Mechanics

The study of ***Physics*** begins with mechanics.

Mechanics is the branch of physics that focuses on the motion of objects and the forces that cause the motion to change.

There are two parts to mechanics: ***Kinematics*** and ***Dynamics***.

Kinematics deals with the concepts that are needed to describe motion, without any reference to forces.

Dynamics deals with the effect that forces have on motion.

Introduction

Kinematics is the **science of describing the motion of objects using words, diagrams, graphs, and equations**.

The goal of kinematics is to develop mental models to describe the motion of real-world objects.

We will learn to describe motion using:

1. Words
2. Diagrams
3. Graphs
4. Equations

Describing Motion with words

The motion of objects can be **described by words**.

Even a person without a background in physics has a collection of words, which can be used to describe moving objects. For example, going faster, stopped, slowing down, speeding up, and turning provide a sufficient vocabulary for describing the motion of objects.

In physics, we use these words as the language of kinematics.

1. Distance and Displacement

2. Speed and Velocity

3. Acceleration

These words which are used to describe the motion of objects can be divided into two categories.

The quantity is either a **vector** or **scalar**.

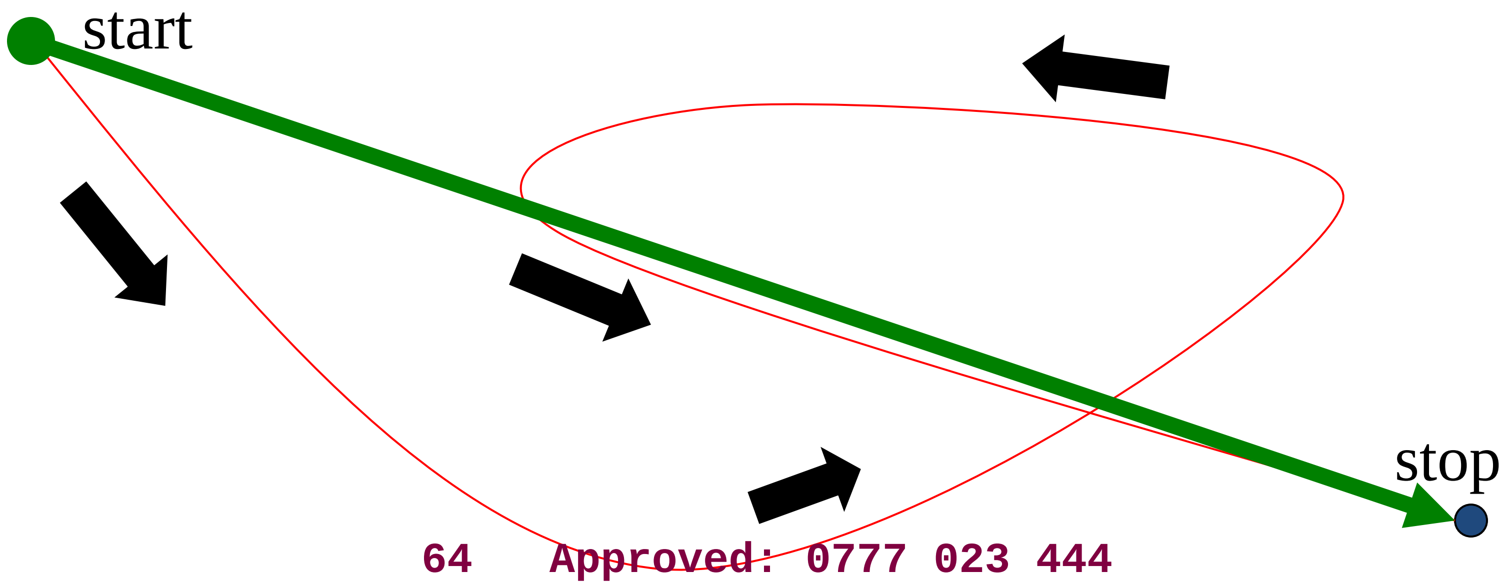
1. Scalars are quantities which are described by a magnitude only.

2. Vectors are quantities which are described by both a magnitude and a direction.

Distance	Displacement
Distance refers to **the total length of travel irrespective of the direction of the motion.** It is a **scalar quantity.** SI unit: metre (m) Other common units: kilometre (km), centimetre (cm)	Displacement refers to **the distance moved in a particular direction.** It is the object's overall change in position. It is a **vector quantity.** SI unit: metre (m) Other common units: kilometre (km), centimetre (cm)

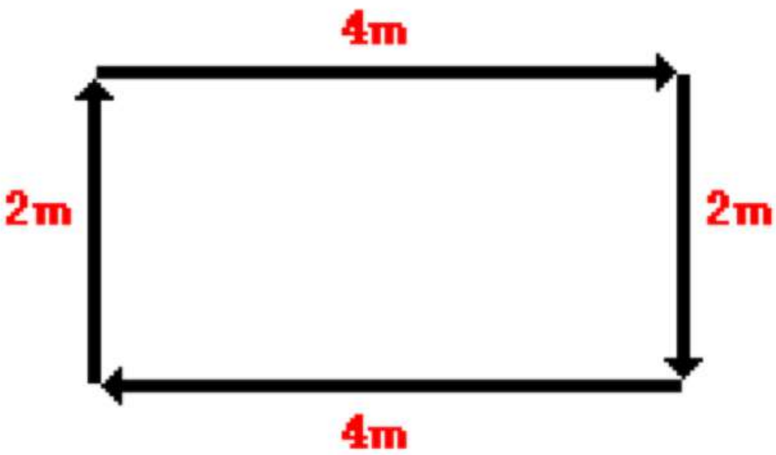
Distance vs. Displacement

- You drive the path, and your odometer goes up (your distance).
- Your displacement is the shorter <u>directed</u> distance from start to stop (green arrow).



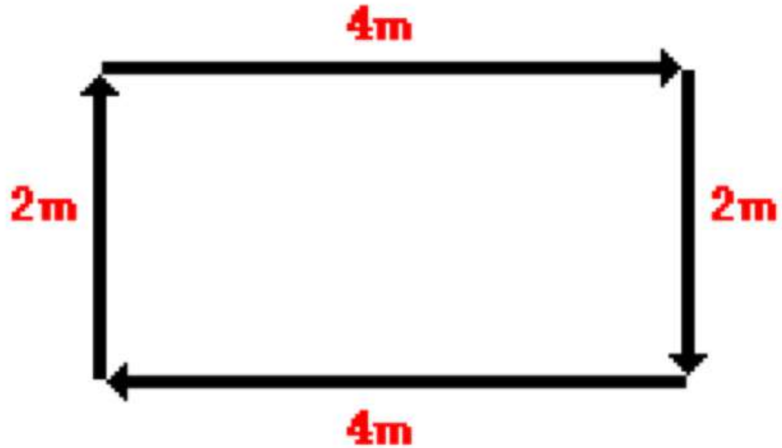
Example 1

A student walks 4 m East, 2 m South, 4 m West, and finally 2 m North.



Total distance = 12 m

During the course of his motion, the total length of travel is 12 m.



Total displacement = 0 m

When he is finished walking, **<u>there is no change in his position.</u>** The 4 m east is "canceled by" the 4 m west; and the 2 m south is "canceled by" the 2 m north.

Speed	Velocity
Speed is **the rate of change of distance.** It is a **scalar quantity.** $$\text{Speed} = \frac{\text{distance travelled}}{\text{time taken}}$$	Velocity is the **distance travelled in a specific direction.** It is also defined as **the rate of change of displacement.** It is a **vector quantity.** $$\text{Velocity} = \frac{\text{change in displacement}}{\text{time taken}}$$

When evaluating the velocity of an object, one must keep track of direction.

The direction of the velocity vector is the same as the direction which an object is moving. (It would not matter whether the object is speeding up or slowing down.)

For example:

If an object is moving rightwards, then its velocity is described as being rightwards.

Boeing 747 moving towards the west with a speed of 260m/s has a velocity of 260m/s, west.
Note that speed has no direction (it is a scalar) and velocity at any instant is simply the speed with a direction.

Instantaneous Speed and Average Speed

As an object moves, it often undergoes changes in speed.

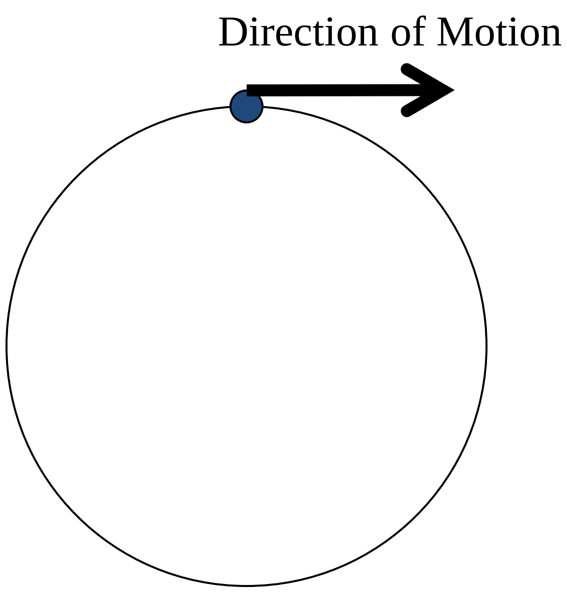
The speed at any instant is known as the **instantaneous speed**. (From the value of the speedometer)

The average speed of the entire journey can be calculated:

$$\text{Average Speed} = \frac{\text{Total distance travelled}}{\text{Total time taken}}$$

Speed Vs Velocity

An object is moving in a circle at a **constant speed** of 10 m s^{-1}.
We say that it has a constant speed but **its velocity is not constant.**
Why?



The direction of the object keeps changing.

Acceleration

- An object whose velocity is changing is said to accelerate.
- If the direction and / or speed of a moving object changes, the object is accelerating
- Acceleration is the rate of change of velocity

Time (s)	Velocity (m/s)
0	0
1	10
2	20
3	30
4	40
5	50

Acceleration

Acceleration is a vector quantity

SI unit: ms^{-2}

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

where a = acceleration, v =final velocity, u = initial velocity and t = time.

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

Describing Motion with Graphs

1.Plot and interpret a distance-time graph and a speed-time graph.

2. Deduce from the shape of a distance-time graph when a body is:

   (a) at rest
   (b) moving with uniform speed
   (c) moving with non-uniform speed

3. Deduce from the shape of a Velocity-time graph when a body is:

   (a) at rest
   (b) moving with uniform speed
   (c) moving with uniform acceleration
   (d) moving with non-uniform acceleration

4. Calculate the area under a speed-time graph to determine the distance travelled for motion with uniform speed or uniform acceleration.

Key Concepts

Distance-time Graph

Gradient of the Distance-time Graph is the speed of the moving object

Speed-time Graph

Gradient of the Speed-time Graph is the acceleration of the moving object.

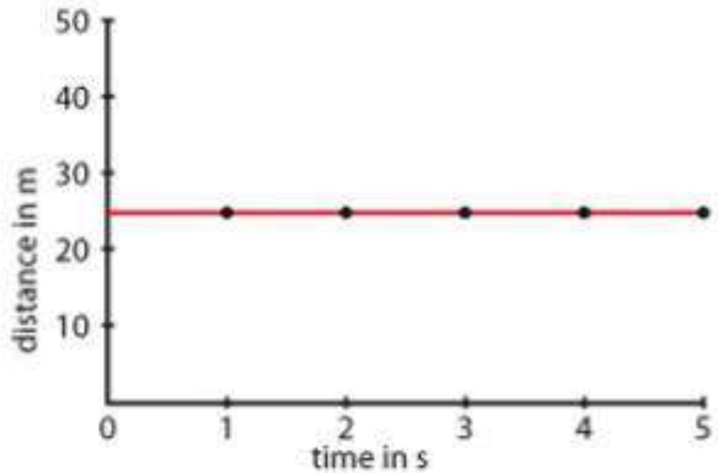
Area under the Speed-time Graph is the distance travelled.

Distance-time Graph

A car has travelled past a lamp post on the road and the distance of the car from the lamp post is measured every second. The distance and the time readings are recorded and a graph is plotted using the data. The following pages are the results for four possible journeys. The steeper the line, the greater the speed.

(a) Car at rest

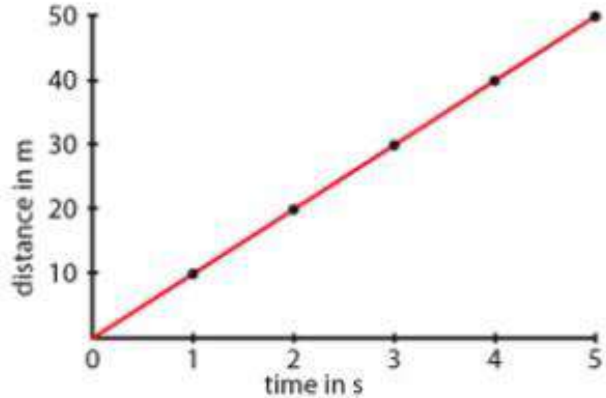
Time in s	0	1	2	3	4	5
Distance in m	25	25	25	25	25	25



The car is parked 25 m from the post, so the distance remains the same.

(b) Car moving with a uniform speed of 10 m s^{-1}

Time in s	0	1	2	3	4	5
Distance in m	0	10	20	30	40	50

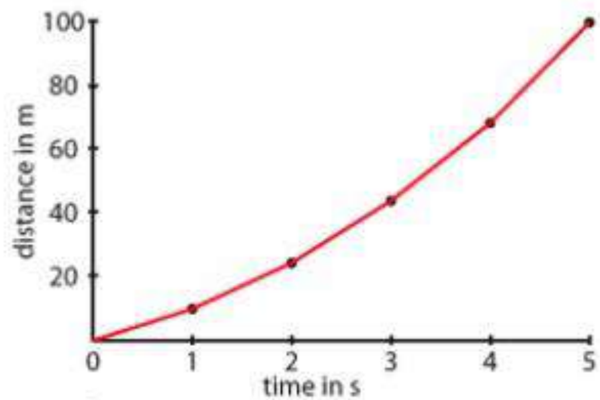


Distance increases 10 m for every 1 s.

(c) Car moving with non-uniform speed

(i) Car accelerating

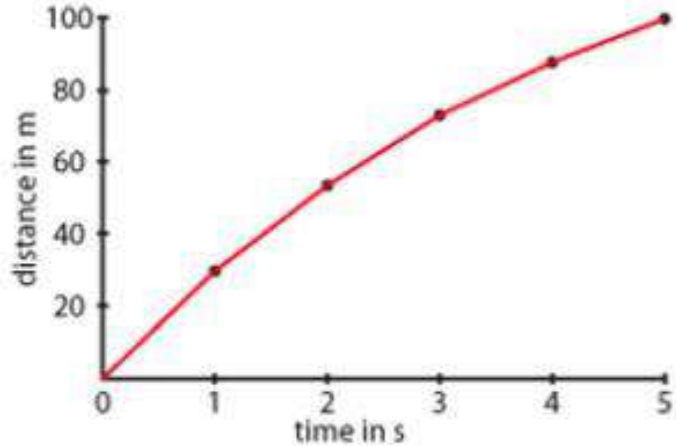
Time in s	0	1	2	3	4	5
Distance in m	0	10	25	45	70	100



Speed increases, so the car travels a longer distance as time increases.

(ii) Car decelerating

Time in s	0	1	2	3	4	5
Distance in m	0	30	55	75	90	100

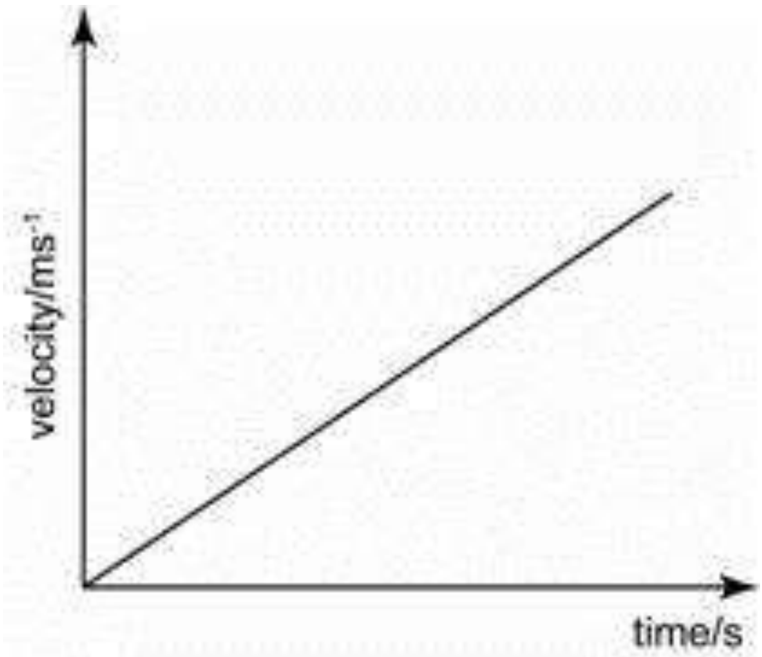


Speed decreases, so the car travels a shorter distance as time increases.

The gradient of the distance-time graph gives the speed of the moving object.

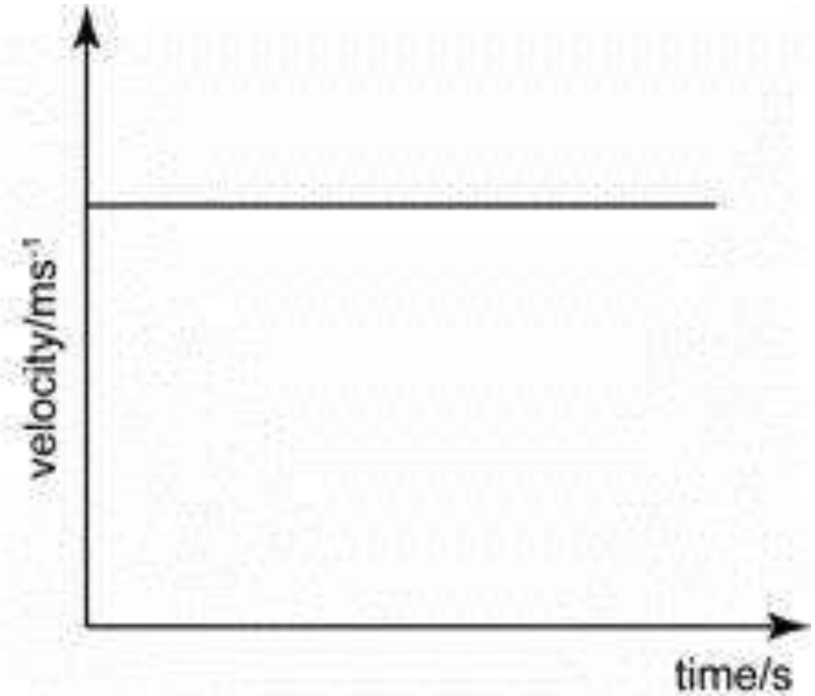
Velocity - Time Graph

- 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**.

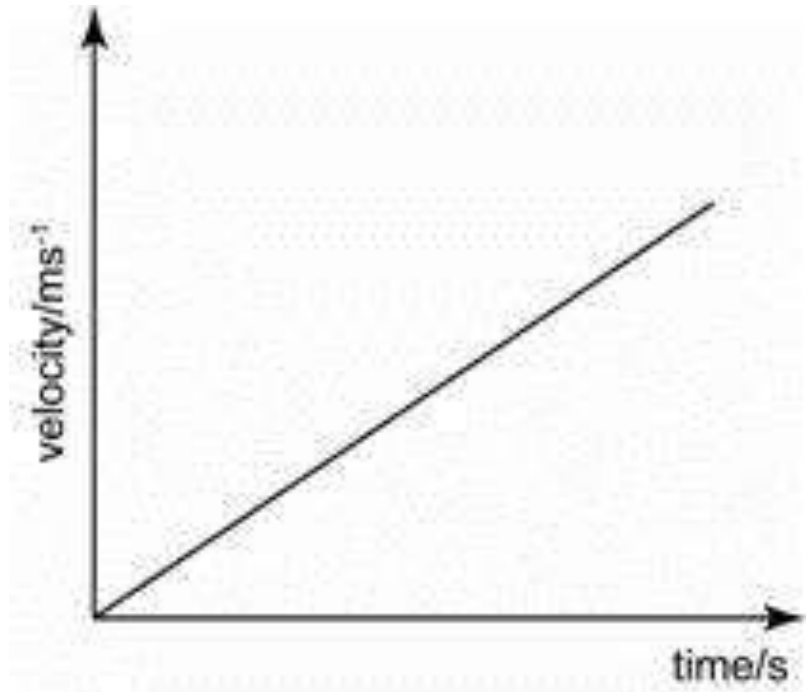


Analysing Velocity - Time Graph

- Uniform Velocity

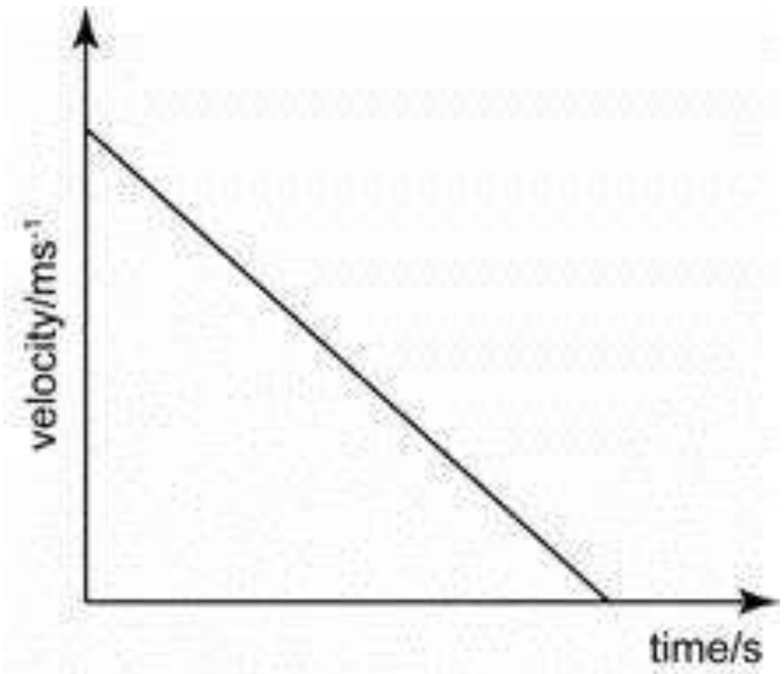


- Uniform Acceleration

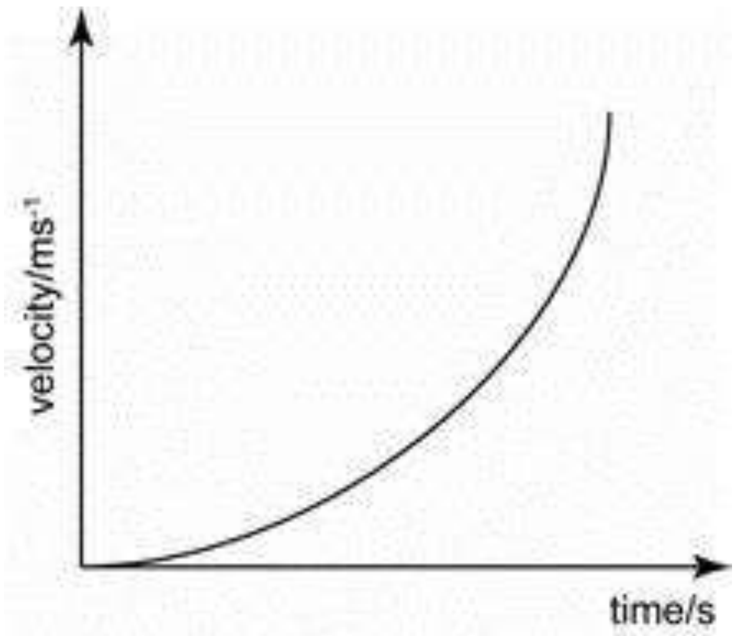


Analysing Velocity - Time Graph

- Uniform deceleration

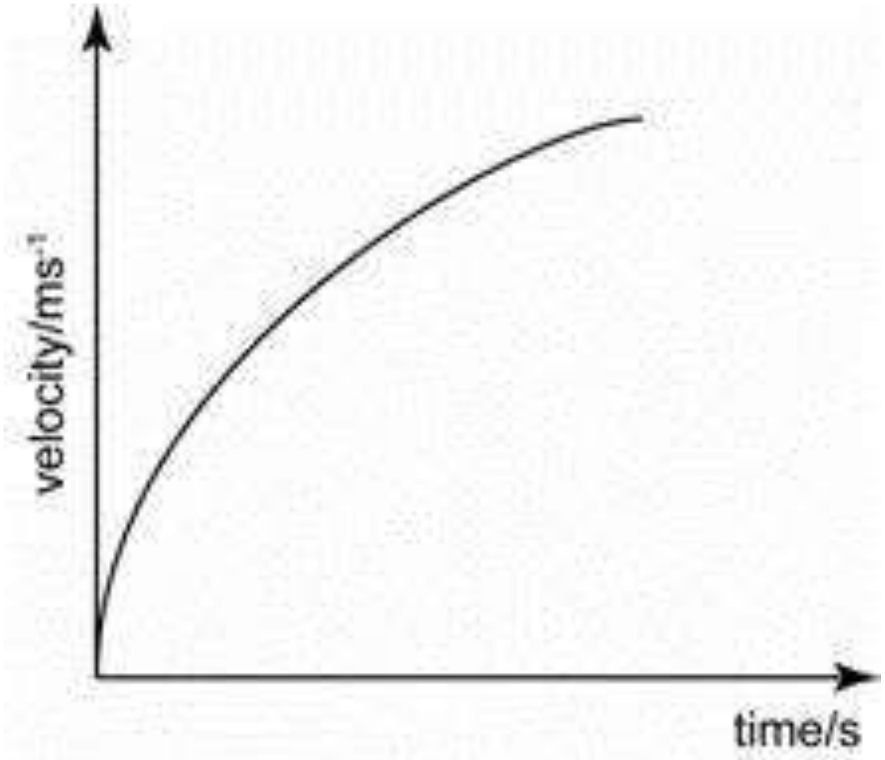


- Increasing acceleration



Analysing Velocity - Time Graph

Decreasing acceleration



How do you find the gradient of velocity-time graph?

- You need to select two points on the graph, for example (x_1,y_1) and (x_2,y_2).
- Once you have selected the points you put then into the equation $m=(y_2-y_1)/(x_2-x_1)$
- m = the gradient

- The gradient represents the acceleration.
- In other words, We take the vertical reading from the graph where the acceleration finishes and divide it by the horizontal reading where the acceleration finishes.

Example 1

Figure 2.14 shows the speed-time graph of a moving lift.

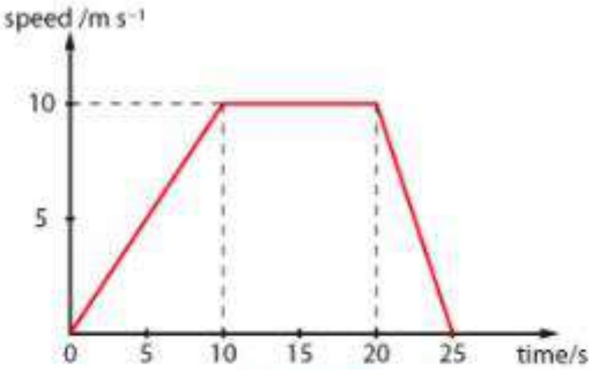


Figure 2.14

(a) What is the maximum speed of the lift?

(b) For how many seconds does the lift move?

(c) How much speed does the lift gain in the first 10 seconds? What is its acceleration?

(d) What is the deceleration of the lift in the last 5 seconds?

Solution

(a) The maximum speed of the lift is 10 m s^{-1}.

(b) The lift moves for 25 s.

(c) The lift gains 10 m s^{-1} in the first 10 s.

$$\text{Acceleration} = \frac{10-0}{10} = 1 \text{ m s}^{-2}$$

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

Therefore the deceleration is 2 m s^{-2}.

Example 2

Figure 2.15 shows the speed-time graph for a journey of ... his house to school. Look at the shape of the graph and describe the type of motion in each stage.

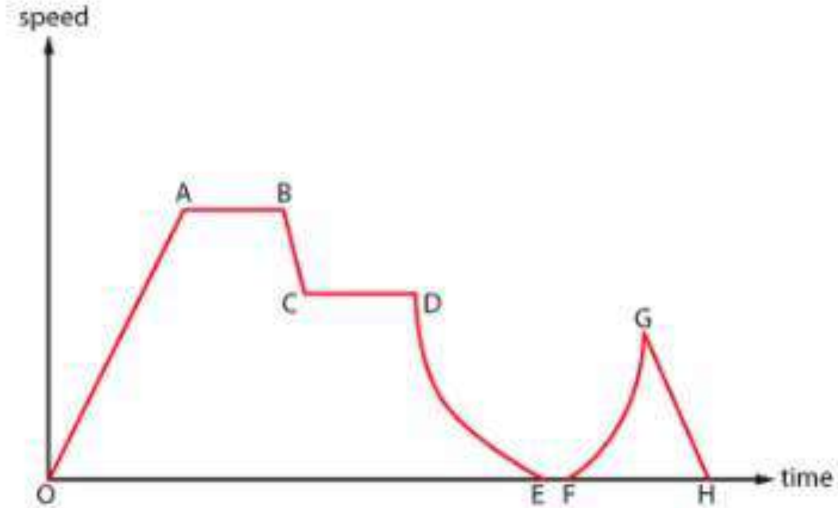


Figure 2.15

Solution

O	left home
O-A	moving with uniform acceleration
A-B	moving with uniform speed
B-C	moving with uniform deceleration
C-D	moving with uniform speed (speed lower than A-B)
D-E	moving with non-uniform deceleration (decreasing deceleration)
E-F	not moving
F-G	moving with non-uniform acceleration (increasing acceleration)
G-H	moving with uniform deceleration
H	reached school

Area under a speed-time graph

The figure below shows the speed-time graph of a car travelling with a uniform speed of 20 ms^{-1}. The distance travelled by the car is given by:

Distance = speed x time = 20 x 5

= 100 m

The same information of distance travelled can also be obtained by calculating the area under the speed-time graph.

The area under a speed-time graph gives the distance travelled.

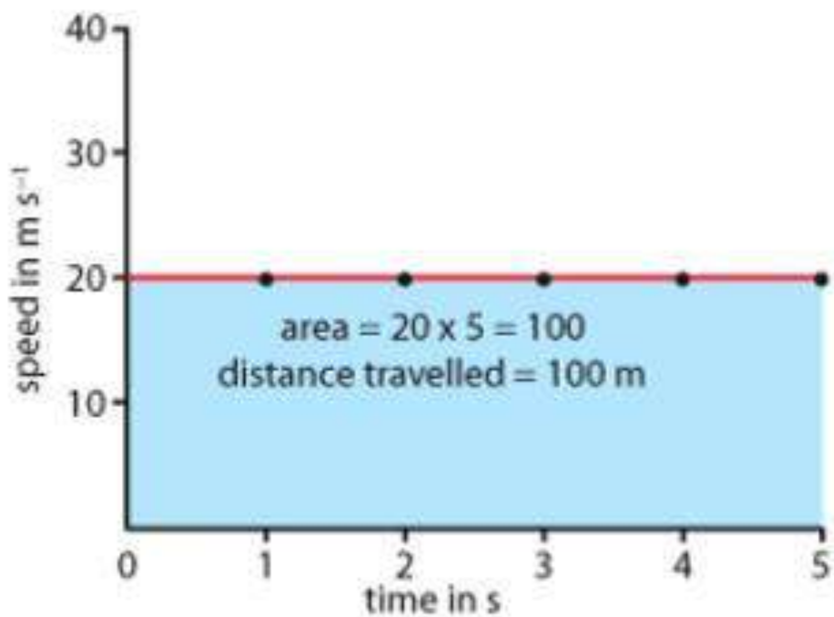


Figure 2.16

Example 3 - Question

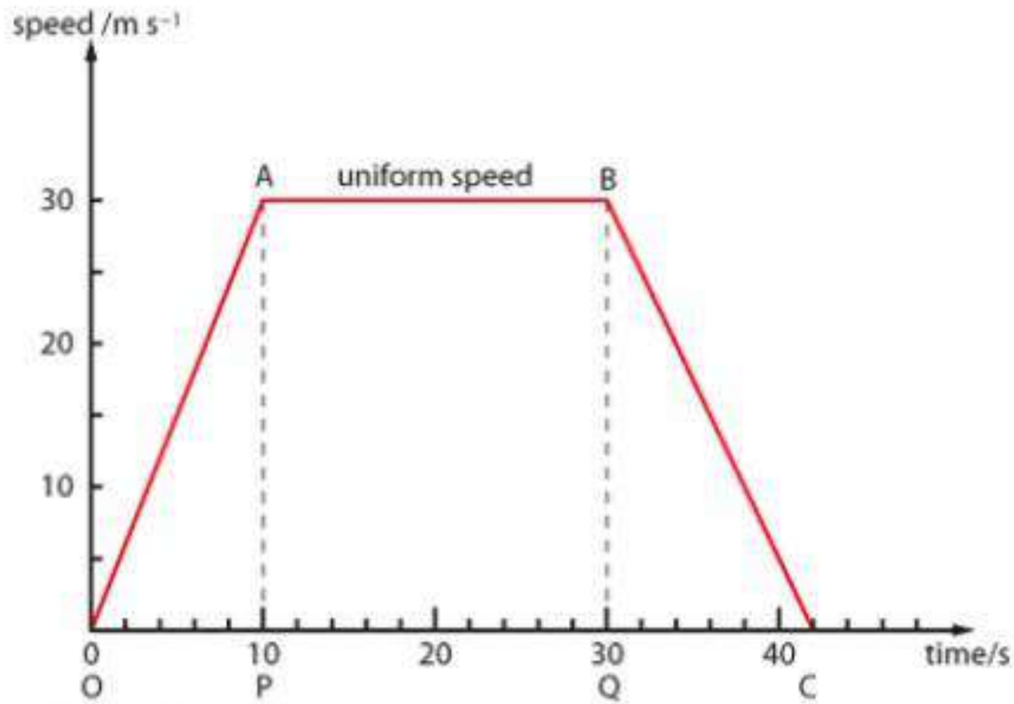


Figure 2.17 Speed-time graph of a car accelerating, moving with uniform speed and then decelerating

Figure 2.17 shows the speed-time graph of a car travelling along a straight road.

(a) What is the distance travelled during the first 10 s?

(b) What is the total distance travelled?

(c) What is the time taken for the whole journey?

(d) What is the average speed for the whole journey?

Example 3 - Solution

Solution

(a) During the first 10 s, distance travelled $= \text{area of triangle OAP}$

$$= \frac{1}{2} \times 10 \times 30$$

$$= 150 \text{ m}$$

(b) Total distance travelled $= \text{area of trapezium OABC}$

$$= \frac{1}{2} \times (20 + 42) \times 30$$

$$= 930 \text{ m}$$

(c) Time taken for the whole journey $= 42$ s

(d) Average speed for the whole journey $= \dfrac{\text{Total distance travelled}}{\text{Total time taken}}$

$$= \frac{930}{42}$$

$$= 22.1 \text{ m s}^{-1}$$

Fall freely…..

- http://www.youtube.com/watch?v=go9uekKOcKM
- http://www.youtube.com/watch?v=FHtvDA0W34I

Uniformly accelerated motion

- **Free fall** is motion with no acceleration other than that provided by gravity.

In other words………

- A free-falling object is an object which is falling under the sole influence of gravity.
- Any object which is being acted upon only be the force of gravity is said to be in a state of free fall.

Free Fall

Any object which is moving and being acted upon only be the force of gravity is said to be "in a state of free fall.“

- all objects fall freely at $g \approx 10$ m s^{-2} when near the earth and air resistance is negligible.
- speed of a free-falling body increases by 9.8 m s^{-1} every second or when a body is thrown up, its speed decreases by 9.8 m s^{-1} every second.

Although the acceleration due to gravity is considered constant, it tends to vary slightly over the earth since the earth is not a perfect sphere.

Examples

- Examples of objects in Free fall

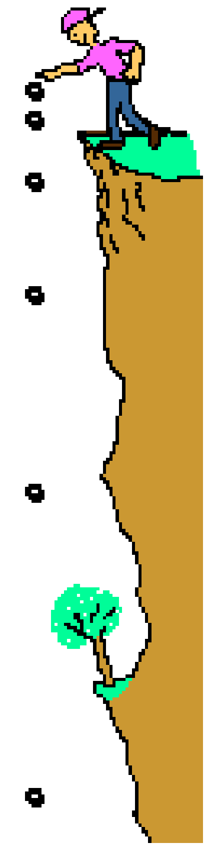
➢ A spacecraft (in space) with its rockets off (e.g. in a continuous orbit, or going up for some minutes, and then down)

➢ The Moon orbiting around the Earth.

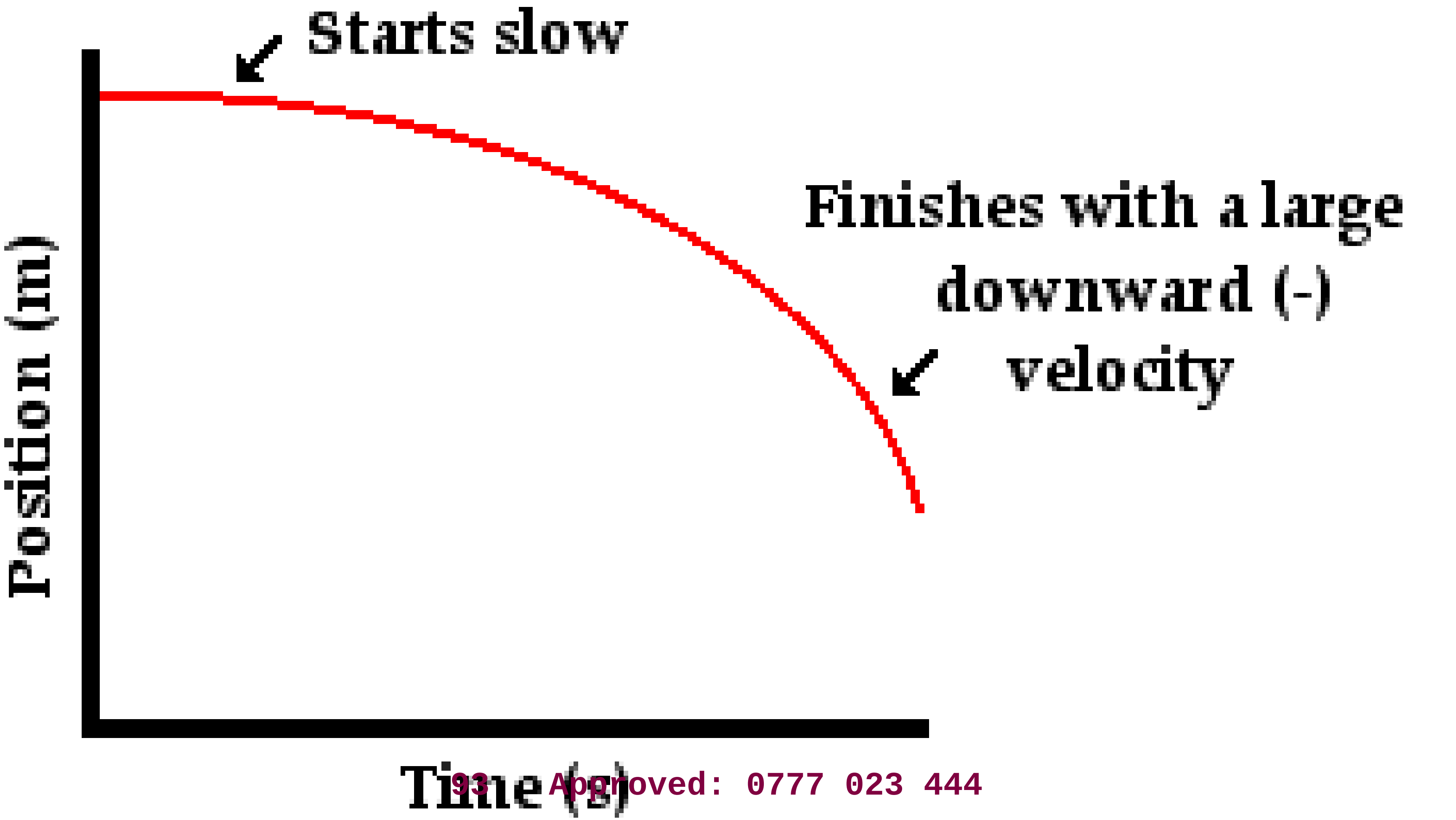
- Examples of objects not in Free fall

➢ Standing on the ground: the gravitational acceleration is counteracted by the normal force from the ground.

➢ Flying horizontally in an airplane: the wings' lift is also providing an acceleration.



Representing Free Fall by Graphs



Free fall graphs shows :

- **The line on the graph curves.**
- **A curved line on a position versus time graph signifies an accelerated motion.**
- **The position-time graph reveals that the object starts with a small velocity (slow) and finishes with a large velocity (fast).**

Check your Understanding !!

Questions to answer !

- “Doesn't a more massive object accelerate at a greater rate than a less massive object?" "Wouldn't an elephant free-fall faster than a mouse?"

- **The answer to the question (doesn't a more massive object accelerate at a greater rate than a less massive object?) is absolutely NOT!**

- ☐That is, absolutely not if we are considering the specific type of falling motion known as free-fall.
- ☐Free-fall is the motion of objects which move under the sole influence of gravity; free-falling objects do not encounter air resistance.
- ☐More massive objects will only fall faster if there is an appreciable amount of air resistance present.

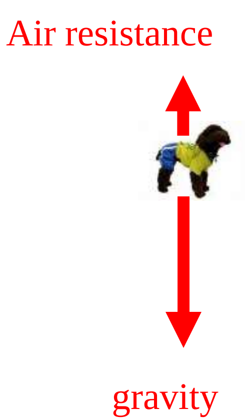
Force of gravity means the dog accelerates

To start, the dog is falling slowly (it has not had time to speed up).

There is really only one force acting on the dog, the force of gravity.

The dog falls faster (accelerates) due to this force.

Gravity is still bigger than air resistance



As the dog falls faster, another force becomes bigger – air resistance.

The force of gravity on the dog of course stays the same

The force of gravity is still bigger than the air resistance, so the dog continues to accelerate (get faster)

Gravity = air resistance

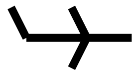
Terminal Velocity

As the dog falls faster and air resistance increases, eventually the air resistance becomes as big as (equal to) the force of gravity.

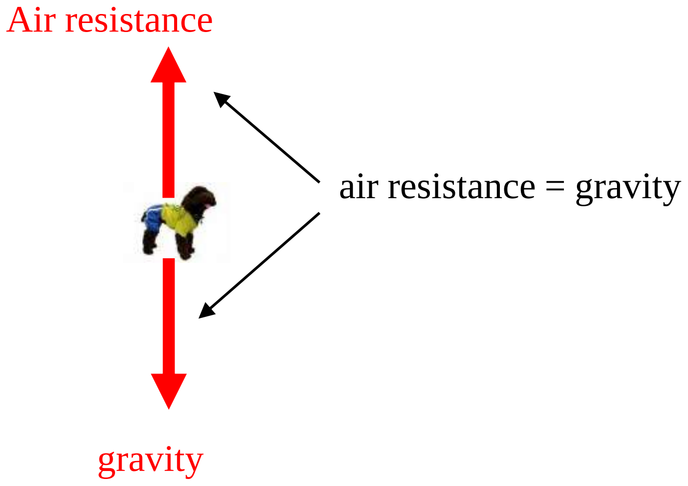
The dog stops getting faster (accelerating) and falls at constant speed.

This velocity is called the terminal Velocity

Terminal Speed



The dog will continue to fall at constant speed (called the terminal speed) until…………



Uniformly Accelerated Motion

- Acceleration is defined as the rate of change of velocity with respect to time, in a given direction. The SI units of acceleration are ms^{-2}.

- This would mean that if an object has an acceleration of 1 ms^{-2} it will increase its velocity (in a given direction) 1 ms^{-1} every second that it accelerates.

It means that acceleration is constant.

This meaning that velocity is varying with respect to time, we see this by this formula (v - u) / t (Time).

It means….

- If an object is held stationary in a uniform gravitational field and when it is released, it will fall. It will do so with uniform acceleration.
- Near the surface of the earth the acceleration is approximately 9.8 ms^{-2}.
- This means that every second that the object falls its velocity will increase by 9.8 ms^{-1} .

Check your understanding !

- What happens if an object is thrown up?

What happens if an object is thrown up?

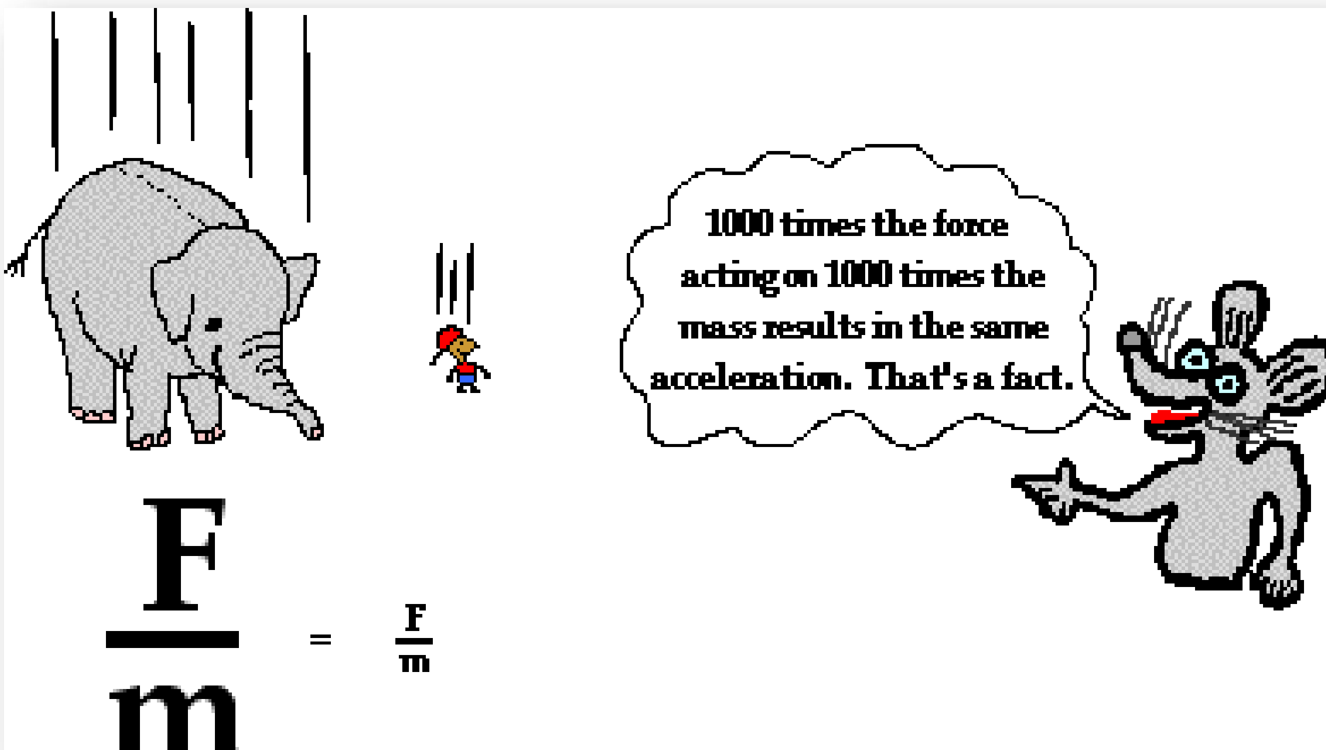
- The acceleration is still downward. If an object is thrown up with an initial velocity of 30 ms^{-1}, after one second it will only be going 20 ms^{-1} up, after 2 seconds it will only be going 10 ms^{-1}, after 3 seconds the object will have zero velocity!
- Even if the objects velocity is zero the acceleration is not zero.

An experiment with ‘g’.

- College building
- Stop watch
- A group of students on top floor
- A group of students on ground floor
- Need to check the distance between top floor and ground, time to calculate velocity.
- (This experiment will be carried out during next lesson)
- Upon investigation, g constant is found with one of the equations we have derived and it is as follows :

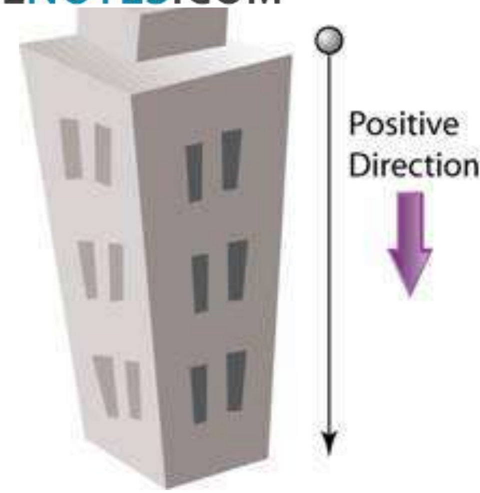
Remember (will study in Ch.4 Dynamics)

- **The actual explanation of why all objects accelerate at the same rate involves the concepts of force and mass.**

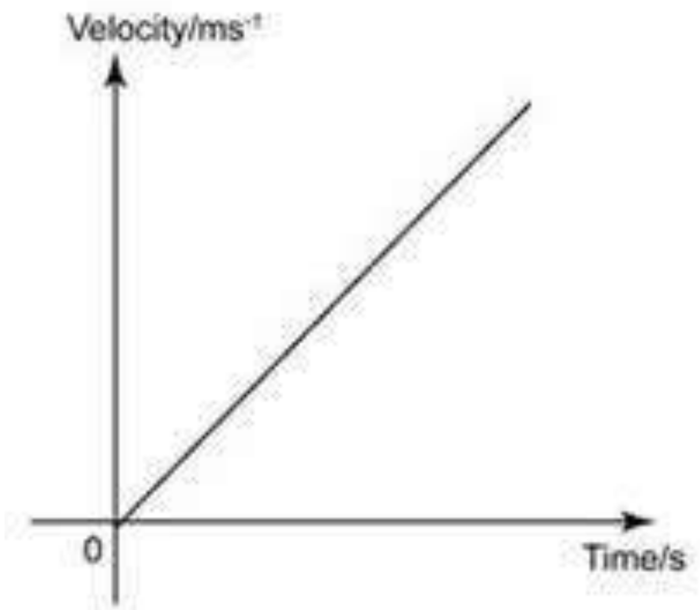


Graph of free falling :

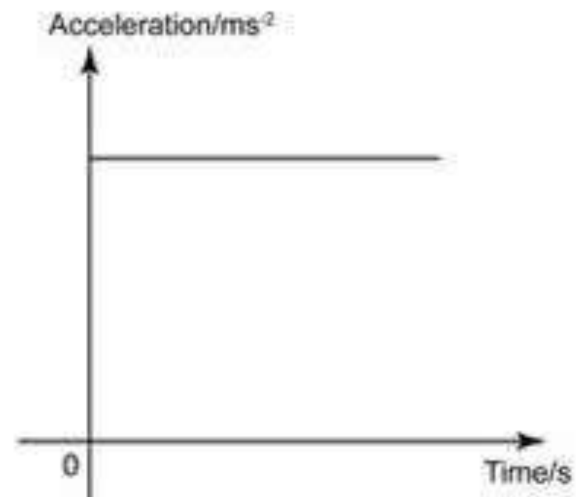
1. Dropping an object from high place



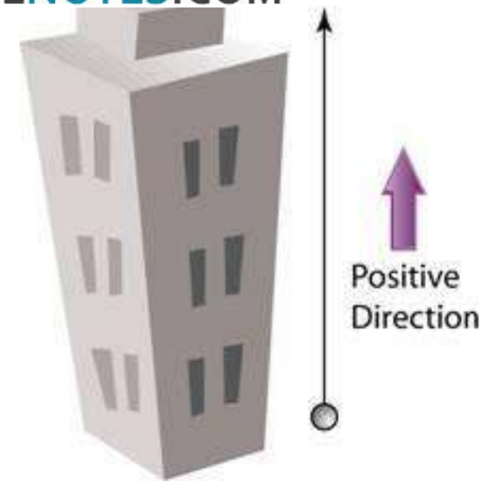
- Velocity - Time Graph



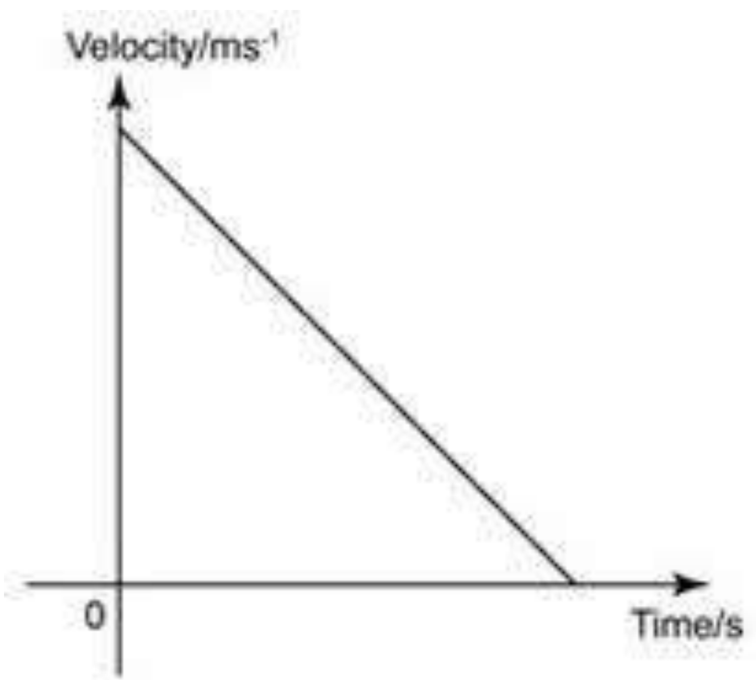
- Acceleration - Time Graph



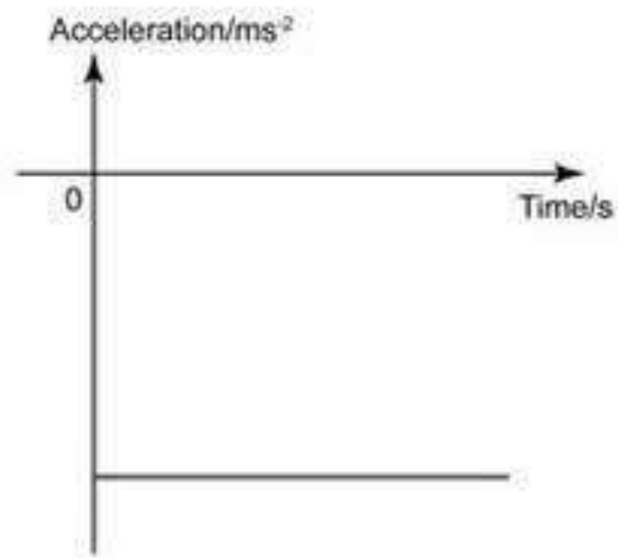
Graph of free falling :
2. **Launching Object Upward**



- Velocity - Time Graph

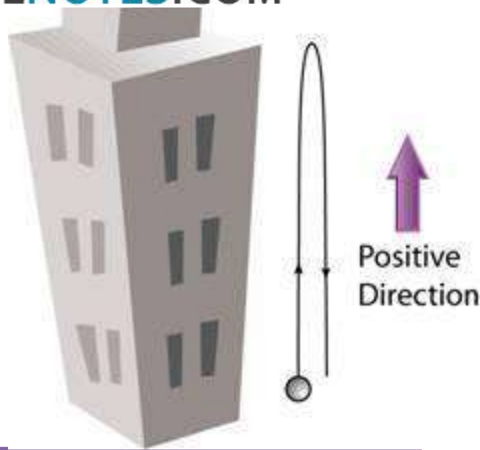


- Acceleration - Time Graph

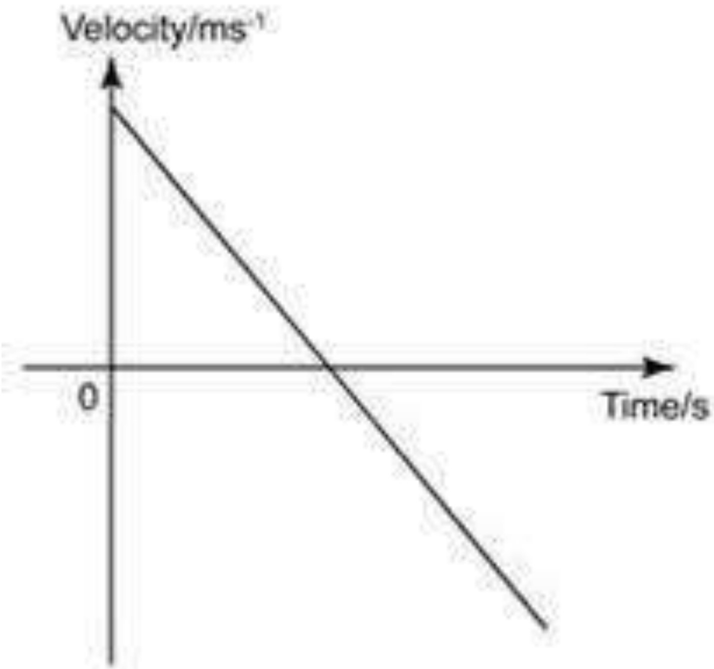


Graph of free falling :

3 . Object moving upward and fall back to the ground

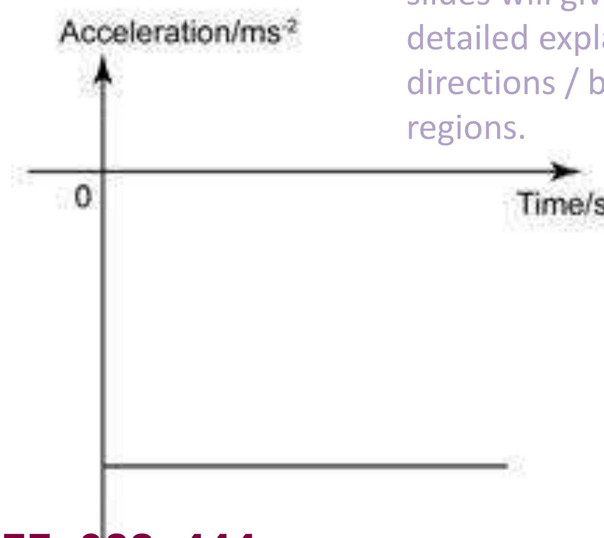


- **Velocity - Time Graph**

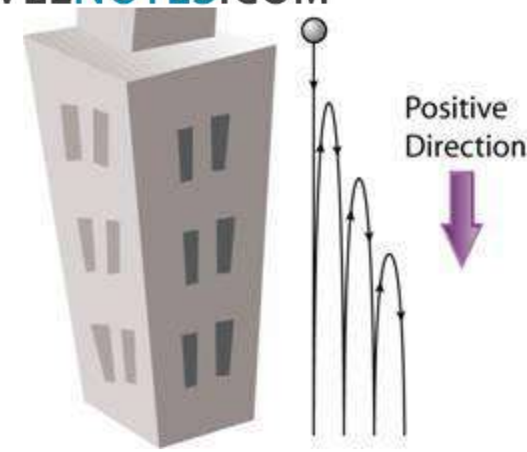


- **Acceleration - Time Graph**

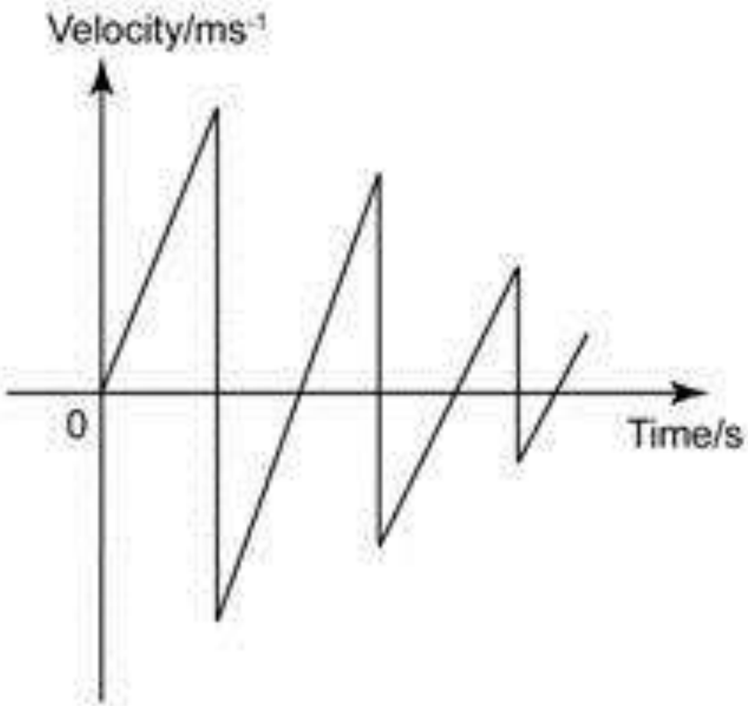
Note : The graph here is to show that the acceleration remains same. The following slides will give a detailed explanation on directions / both regions.



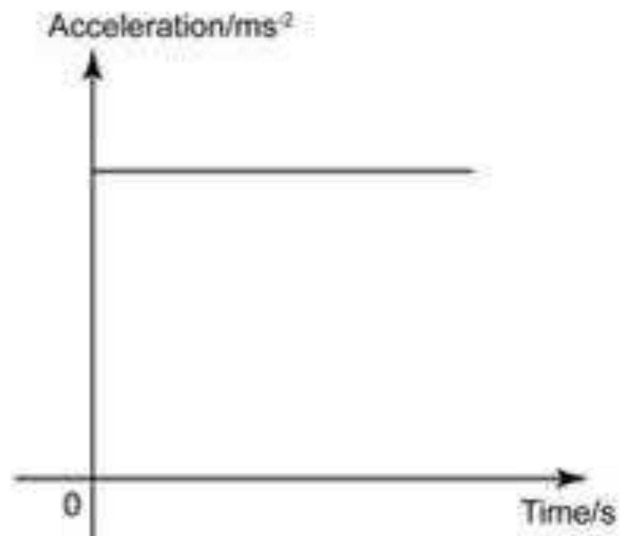
Graph of free falling :
4. Object falling and bounces back

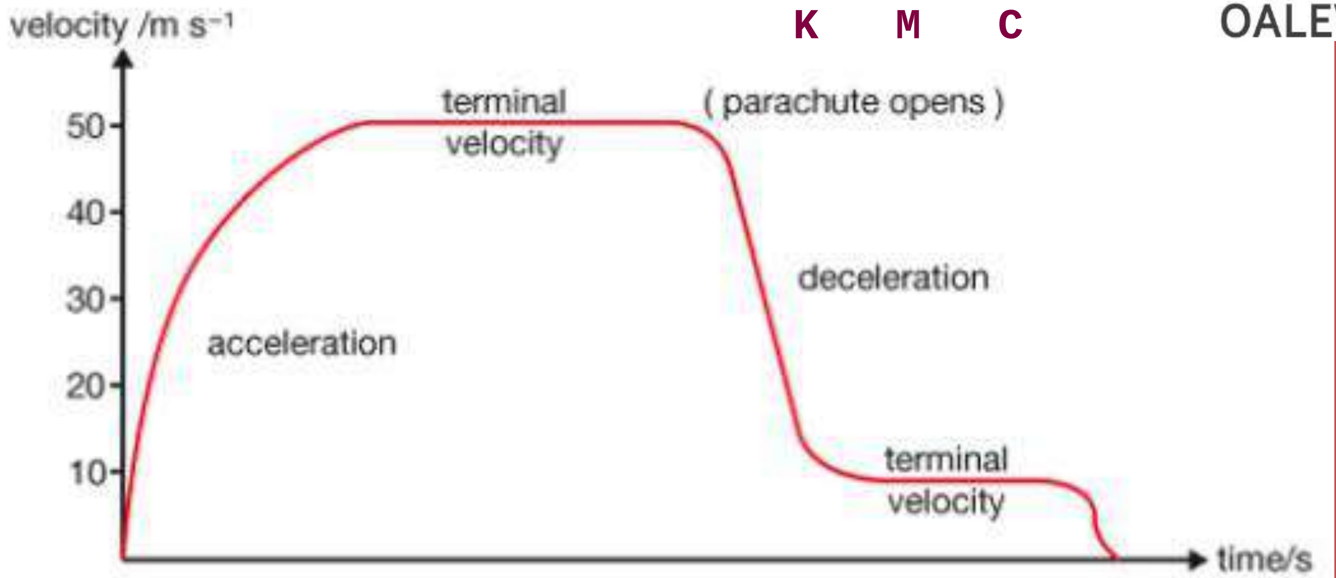


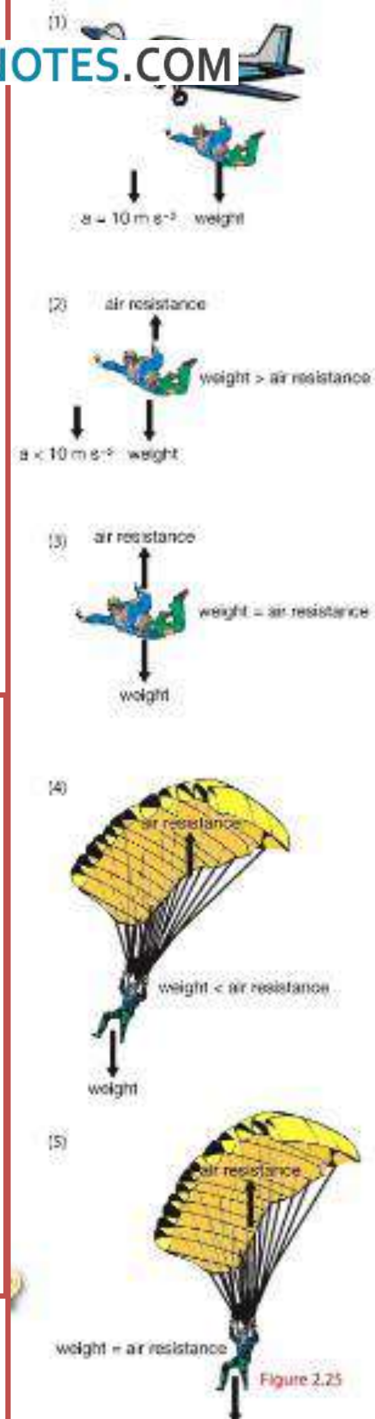
- Velocity - Time Graph



- Acceleration - Time Graph







At the point when the air resistance equals to the weight, there is no acceleration and the object will fall with "terminal velocity".

A small dense object, like a steel ball bearing, has a high terminal velocity. A light object, like a raindrop, or an object with large surface area like a piece of paper, has a low terminal velocity.

Positive Velocity & Negative Velocity

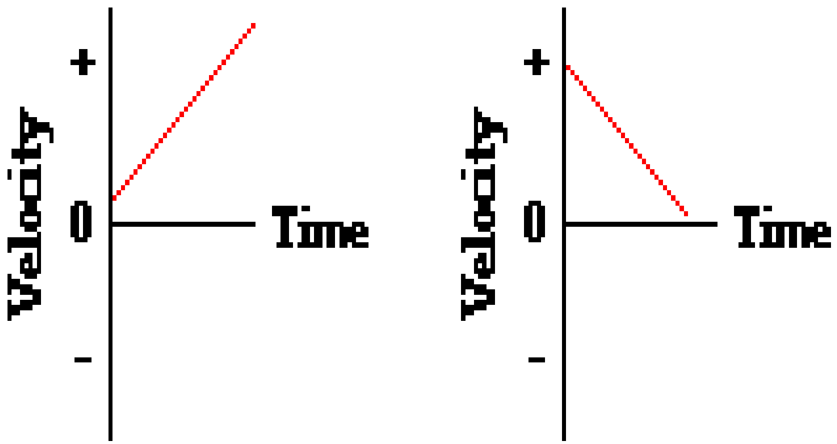
- How can one tell whether the object is moving in the positive direction (i.e., positive velocity) or in the negative direction (i.e., negative velocity)?
- And how can one tell if the object is speeding up or slowing down?

Positive Velocity & Negative Velocity

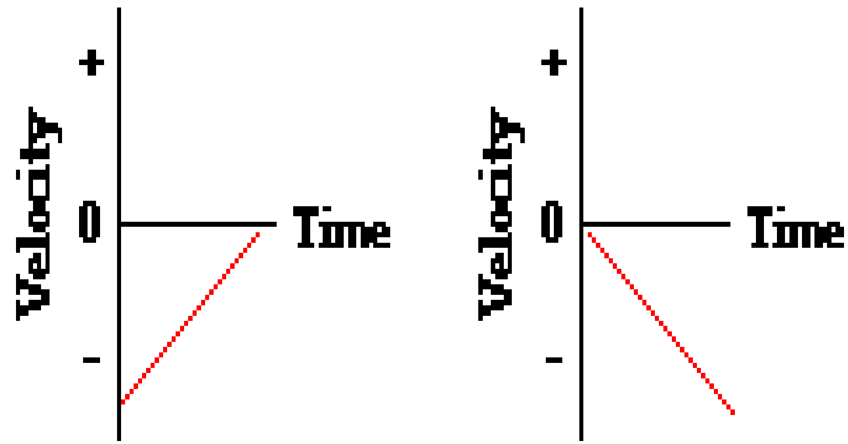
- Since the graph is a velocity-time graph, the velocity would be positive whenever the line lies in the positive region (above the x-axis) of the graph.
- Similarly, the velocity would be negative whenever the line lies in the negative region (below the x-axis) of the graph.
- A **positive velocity** means the object is moving in the positive direction; and a **negative velocity** means the object is moving in the negative direction.
- So one knows an object is moving in the positive direction if the line is located in the positive region of the graph (whether it is sloping up or sloping down). And one knows that an object is moving in the negative direction if the line is located in the negative region of the graph (whether it is sloping up or sloping down).
- And finally, if a line crosses over the x-axis from the positive region to the negative region of the graph (or vice versa), then the object has changed directions.

Positive Velocity & Negative Velocity

These objects are moving with a positive velocity.



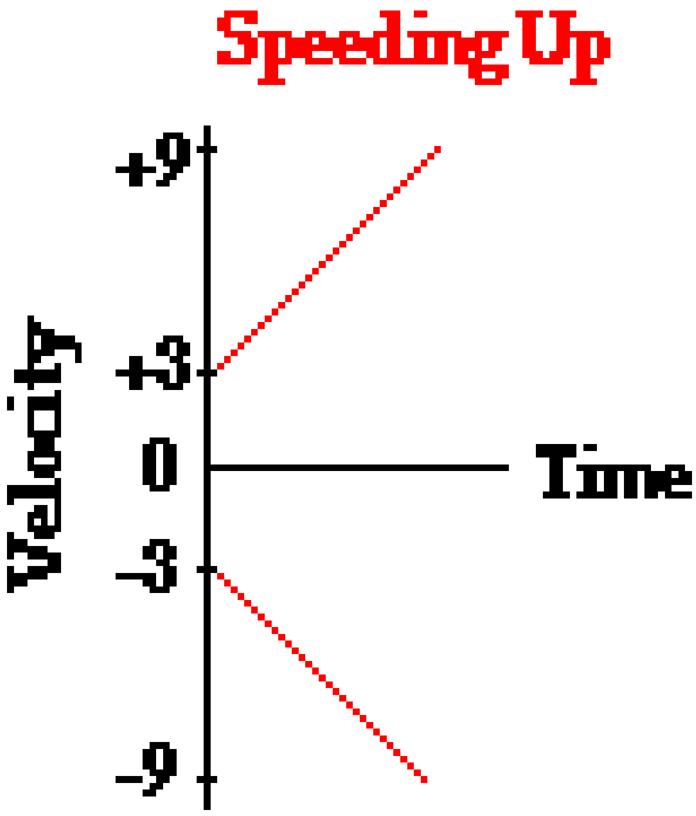
These objects are moving with a negative velocity.

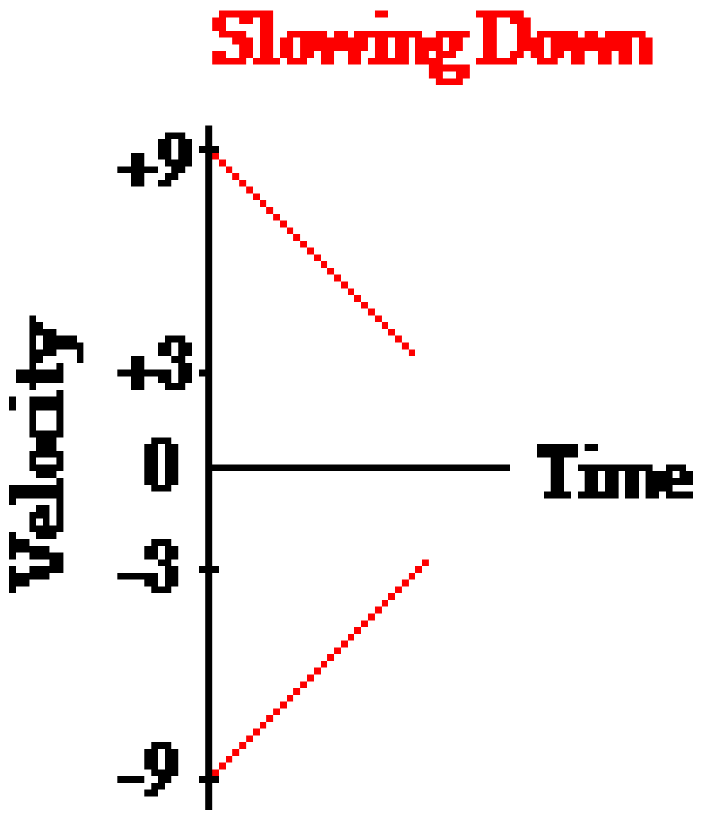


Positive Velocity & Negative Velocity

- Now how can one tell if the object is speeding up or slowing down?
- Speeding up means that the magnitude of the velocity is getting large. For instance, an object with a velocity changing from +3 m/s to + 9 m/s is speeding up. Similarly, an object with a velocity changing from -3 m/s to -9 m/s is also speeding up.
- In each case, the magnitude of the velocity is increasing; the speed is getting bigger.
- Given this fact, one would believe that an object is speeding up if the line on a velocity-time graph is changing from near the 0-velocity point to a location further away from the 0-velocity point. That is, if the line is getting further away from the x-axis (the 0-velocity point), then the object is speeding up. And conversely, if the line is approaching the x-axis, then the object is slowing down.

Positive Velocity & Negative Velocity





Equations of Motion

There are 4 equations that you can use whenever an object moves with ***constant, uniform acceleration in a straight line***. The equations are written in terms of the 5 symbols in the box:

s = displacement (m)

u = initial velocity (ms^{-1})

v = final velocity (ms^{-1})

a = constant acceleration (ms^{-2})

t = time interval (s)

Since a = (v - u) / t

$v = u + at$ … (1)

If acceleration is constant, the average velocity during the motion will be half way between v and u. This is equal to ½(u + v).

$\frac{1}{2}(u + v) = s/t$

$s = \frac{1}{2}(u + v)t$ … (2)

Using equation (1) to replace v in equation (2):

$s = \frac{1}{2}(u + u + at)t$

$s = \frac{1}{2}(2u + at)t$

$s = ut + \frac{1}{2}at^2$ … (3)

From equation (1), $t = (v - u)/a$

Using this to replace t in equation (2):

$$s = \tfrac{1}{2}(u + v)[(v - u)/a]$$

$$2as = (u + v)(v - u)$$

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

$$\underline{\boldsymbol{v^2 = u^2 + 2as}} \quad \ldots (4)$$

Note:

- You can only use these equations only if the acceleration is constant.
- Notice that each equation contains only 4 of our 5 "s, u, v, a, t" variables. So if know any 3 of the variables, we can use these equations to find the other 2.

Example 4

A cheetah starts from rest and accelerates at 2.0 ms^{-2} due east for 10 s. Calculate (a) the cheetah's final velocity, (b) the distance the cheetah covers in this 10 s.

Solution:

(a) Using equation (1): $v = u + at$

$$v = 0 + (2.0\ ms^{-2} \times 10\ s) = 20\ ms^{-1} \text{ due east}$$

(b) Using equation (2): $s = ½(u + v)t$

$$s = ½(0 + 20\ ms^{-1}) \times 10\ s = 100\ m \text{ due east}$$

You could also find the displacement by plotting a velocity-time graph for this motion. The magnitude of the displacement is equal to the area under the graph.

Example 5

An athlete accelerates out of her blocks at 5.0 ms^{-2}. (a) How long does it take her to run the first 10 m? (b) What is her velocity at this point?

Solution:

(a) Using equation (3): $s = ut + ½at^2$

$$10\ m = 0 + (1/2 \times 5.0\ ms^{-2} \times t^2)$$

$$t^2 = 4.0\ s^2$$

$$t = 2.0\ s$$

(b) Using equation (1): $v = u + at$

$$v = 0 + (5.0\ ms^{-2} \times 2.0\ s)$$

$$v = 10\ ms^{-1}$$

Example 6

A bicycle's brakes can produce a deceleration of 2.5 ms^{-2}. How far will the bicycle travel before stopping, if it is moving at 10 ms^{-1} when the brakes are applied?

Solution:

Using equation (4): $v^2 = u^2 + 2as$

$$0 = (10\ ms^{-1})^2 + (2 \times (-2.5\ ms^{-2}) \times s)$$

$$0 = 100\ m^2s^{-2} - (5.0\ ms^{-2} \times s)$$

$$s = 20\ m$$

Example 7

A student flips a coin into the air. Its initial velocity is 8.0 ms^{-1}. Taking g = 10 ms^{-2} and ignoring air resistance, calculate: (a) the maximum height, h, the coin reaches, (b) the velocity of the coin on returning to his hand, (c) the time that the coin is in the air.

Solution: (upward motion to be negative)

(a) $v^2 = u^2 + 2as$

$0 = (8.0\ ms^{-1})^2 + (2 \times (-10ms^{-2}) \times h)$

$h = 3.2$ m

(b) The acceleration is the same going up and coming down. If the coin decelerates from 8.0 ms^{-1} to 0 ms^{-1} on the way up, it will accelerate from 0 ms^{-1} to 8 ms^{-1} on the way down. The motion is symmetrical. So the velocity on returning to his hand is 8.0 ms^{-1} downwards.

(c) $v = u + at$

$0 = 8.0\ ms^{-1} + (-10\ ms^{-2} \times t)$

$t = 0.8$ s

The coin will take the same time between moving up and coming down. So total time in the air = 1.6 s.

You-tube videos links with explanation on : Newtonian Mechanism - Kinematics

- http://www.youtube.com/watch?v=go9uekKOcKM
- http://www.youtube.com/watch?v=xE71aKXjss0&feature=related

Any Questions?

Newtonian Mechanics

Dynamics

Marline Kurishingal

Syllabus content

Section		AS	A2
II Newtonian mechanics	3. Kinematics	✓	
	4. Dynamics	✓	
	5. Forces	✓	
	6. Work, energy, power	✓	
	7. Motion in a circle		✓
	8. Gravitational field		✓

Section II: Newtonian mechanics

Recommended prior knowledge

Candidates should be able to describe the action of a force on a body.

They should be able to describe the motion of a body and recognise acceleration and constant speed. They should be able to use the relationship *average speed = distance / time*.

4. Dynamics

Content	Learning outcomes
4.1 Newton's laws of motion 4.2 Linear momentum and its conservation	Candidates should be able to: *(a)* state each of Newton's laws of motion *(b)* show an understanding that mass is the property of a body that resists change in motion *(c)* describe and use the concept of weight as the effect of a gravitational field on a mass *(d)* define linear momentum as the product of mass and velocity *(e)* define force as rate of change of momentum *(f)* recall and solve problems using the relationship $F = ma$, appreciating that acceleration and force are always in the same direction *(g)* state the principle of conservation of momentum *(h)* apply the principle of conservation of momentum to solve simple problems including elastic and inelastic interactions between two bodies in one dimension (knowledge of the concept of coefficient of restitution is not required) *(i)* recognise that, for a perfectly elastic collision, the relative speed of approach is equal to the relative speed of separation *(j)* show an understanding that, while momentum of a system is always conserved in interactions between bodies, some change in kinetic energy usually takes place.

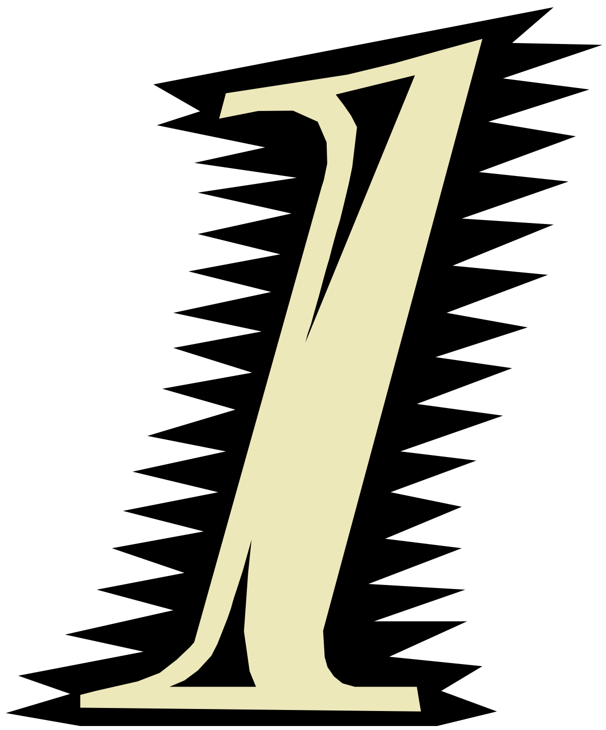
Newton’s laws of Motion

- ***Newton's laws of motion*** are three physical laws which provide relationships between the *forces* acting on a body and the *motion* of the body.

Newton’s Laws: Force and Motion

- The First Law: Force and Inertia
- The Second Law: Force, Mass and Acceleration
- The Third Law: Action and Reaction

Newton’s first law



Newton's first law of motion…..

An object at rest tends to stay at rest and object in motion tends to stay in motion unless acted upon by an external force.

What does this mean ?

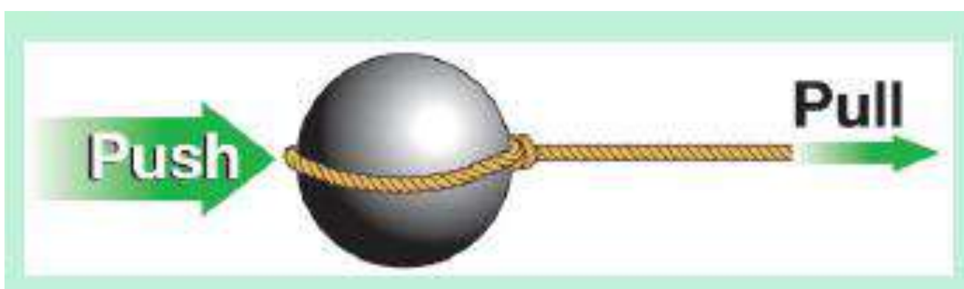
Basically, an object will keep doing what it was doing, unless acted on by an external force.

If the object was sitting still, it will remain stationary. If it was moving at a constant velocity, it will keep moving at a constant velocity.

It takes force to change the motion of an object.

The definition of force

- The simplest concept of force is a push or a pull.
- In other words, force is the *action* that has the ability to create or change motion.

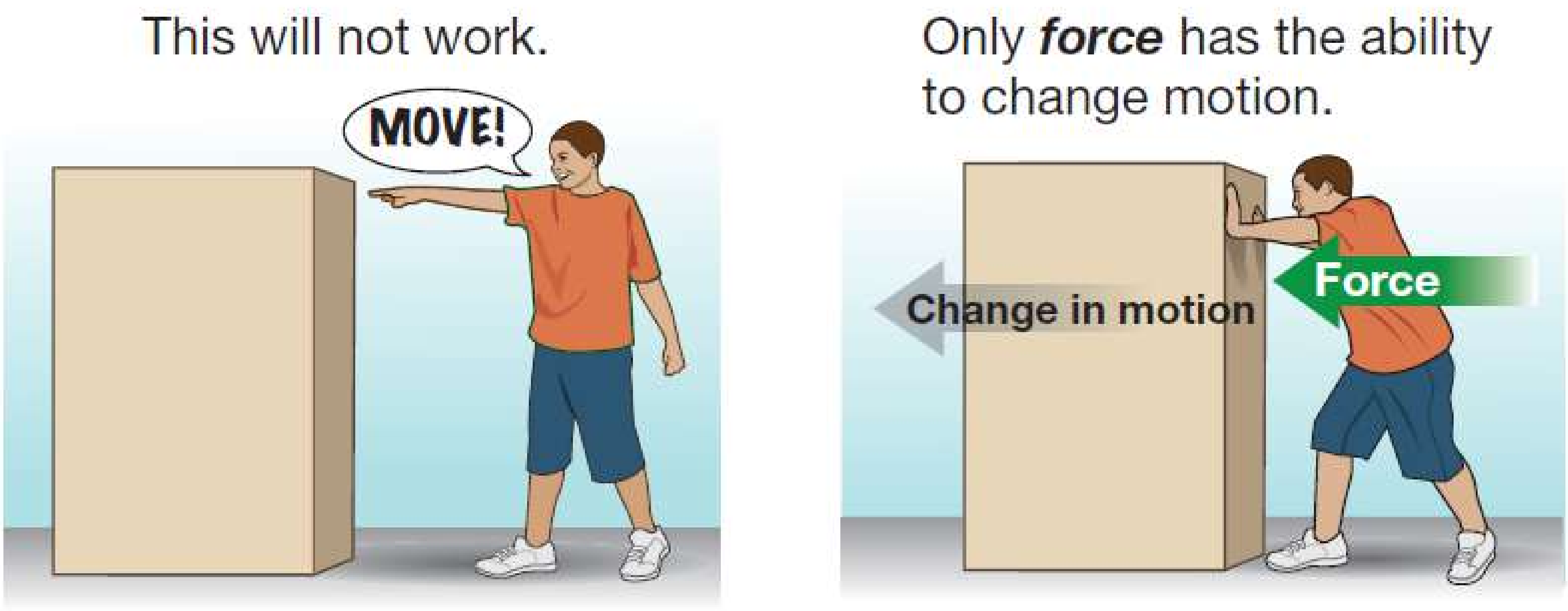


Force

- Force is an action that can change motion.
  - A force is what we call a push or a pull, or any action that has the ability to change an object's motion.
  - Forces can be used to increase the speed of an object, decrease the speed of an object, or change the direction in which an object is moving.

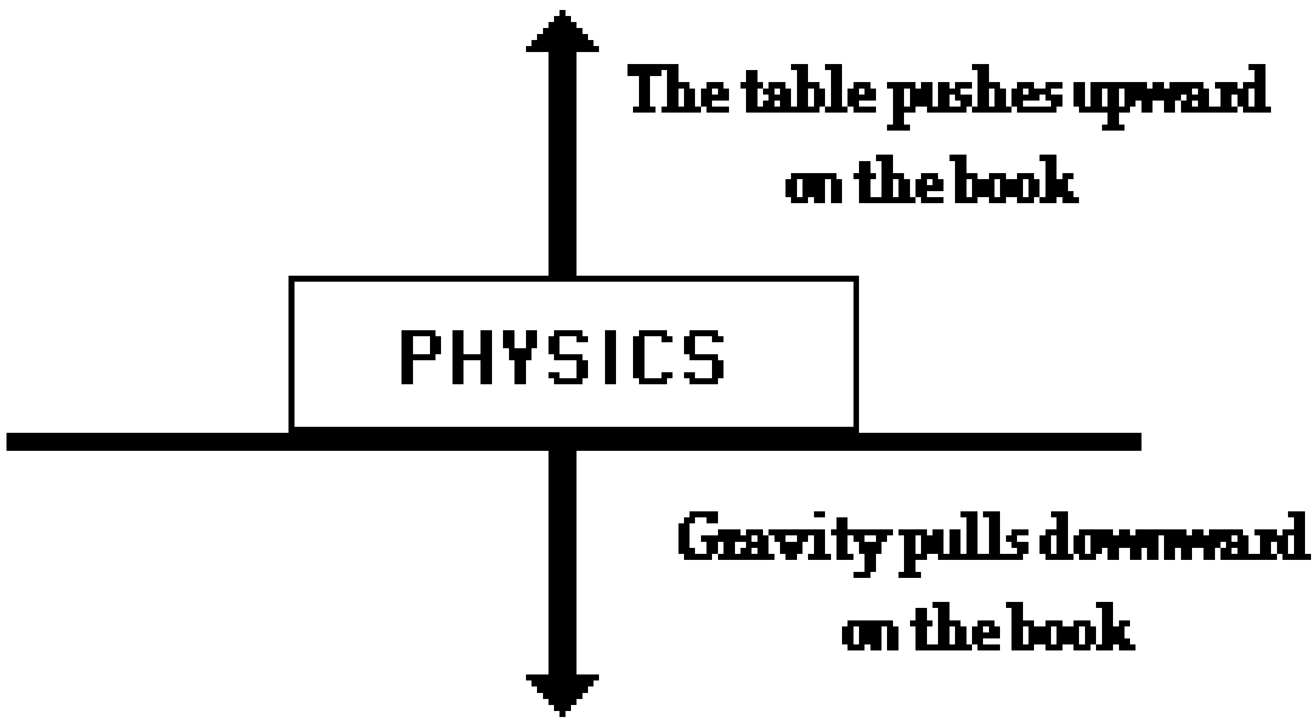
  - ***Inertia*** *is the resistance of any physical object to a change in its state of motion or rest, or the tendency of an object to resist any change in its motion.*

Force


This will not work.
MOVE!
Only *force* has the ability to change motion.
Change in motion
Force

Balanced force

The forces on the book are balanced.

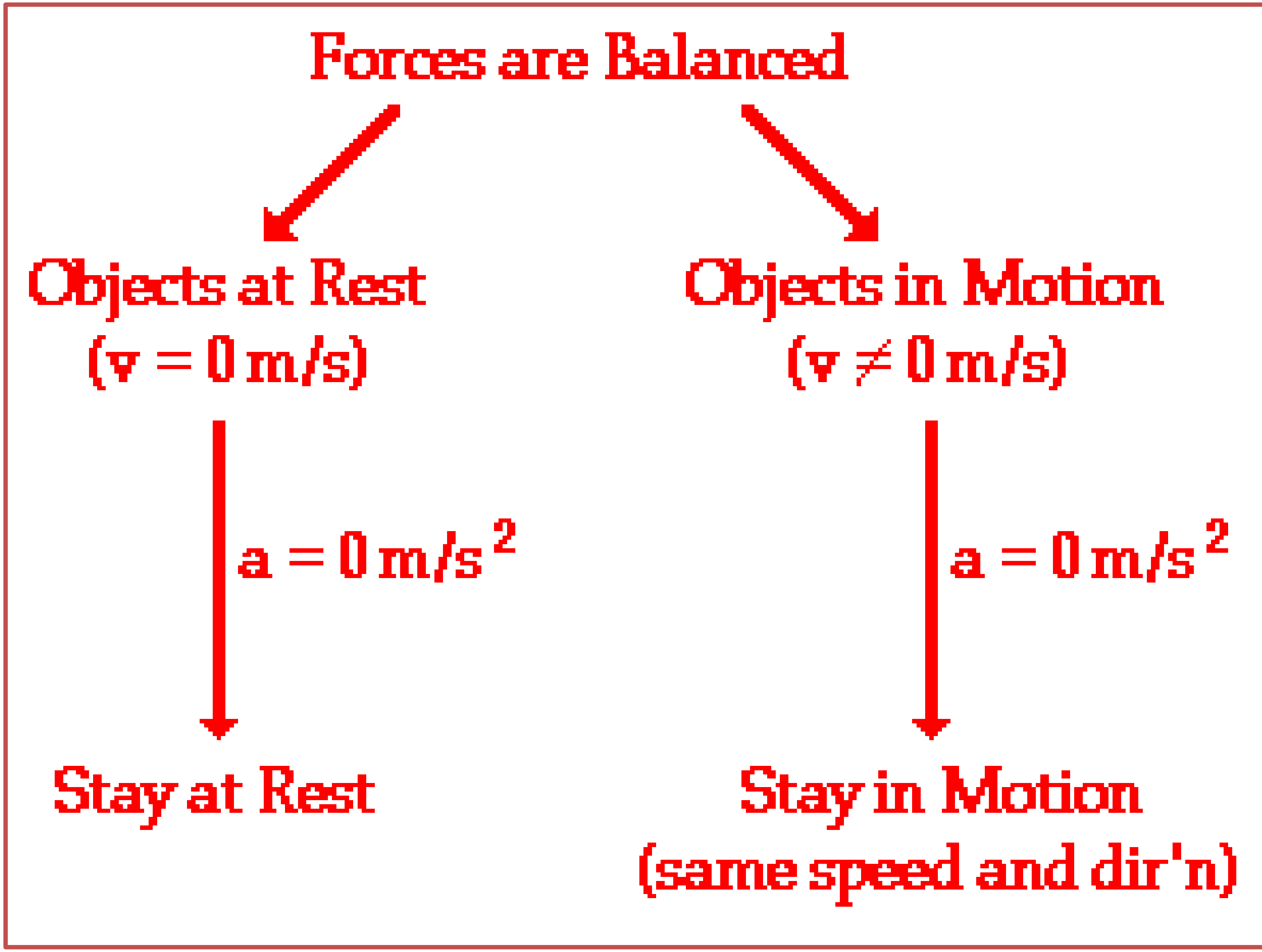


Balanced & Unbalanced

- If the forces on an object are equal and opposite or if the total force is zero they are said to be balanced, and the object experiences no change in motion.
- If they are not equal and opposite or if the total forces is not zero, then the forces are unbalanced and the motion of the object changes.

These are some examples from real life

A soccer ball is sitting at rest. It takes an unbalanced force of a kick to change its motion.


Forces are Balanced
Objects at Rest
(v = 0 m/s)
Objects in Motion
(v ≠ 0 m/s)
a = 0 m/s 2
a = 0 m/s 2
Stay at Rest
Stay in Motion
(same speed and dir'n)

Newton's First Law

Applied to Rocket Liftoff

"Every object persists in its state of rest or uniform motion in a straight line unless it is compelled to change that state by forces impressed on it."

Before firing:

Object in state of rest, airspeed zero.

Engine fired:

Thrust increases from zero.

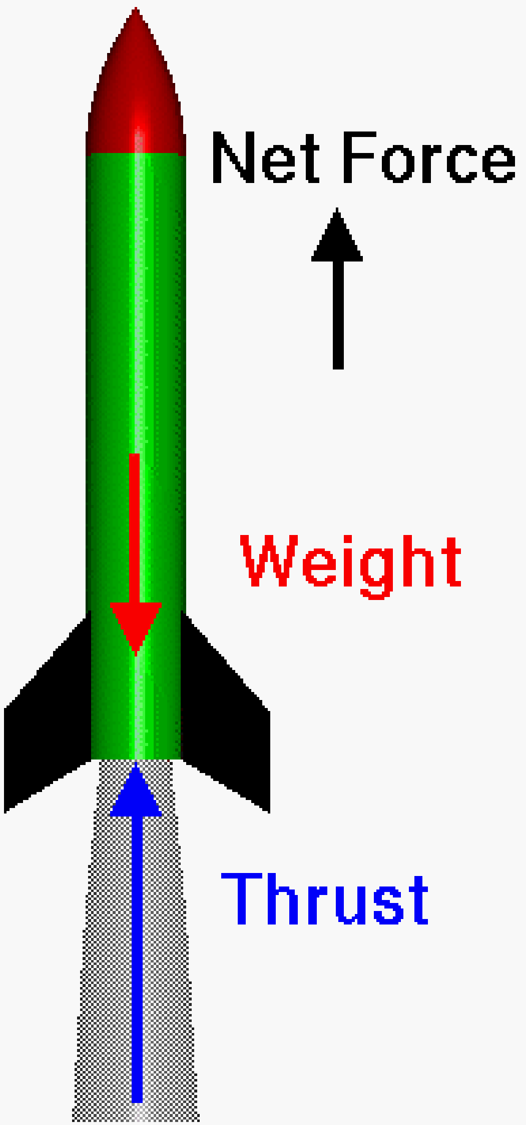
Weight decreases slightly as fuel burns.

When Thrust is greater than Weight:

Net force (Thrust – Weight) is positive upward.

Rocket accelerates upward

Velocity increases



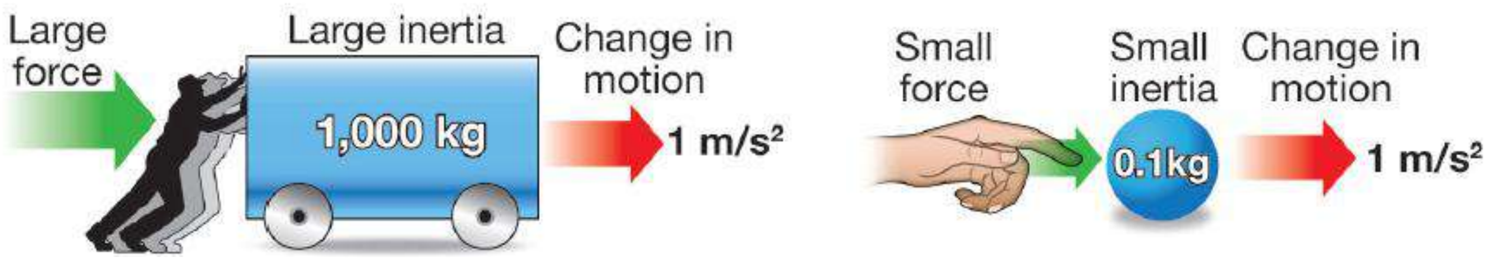
Newton's First Law is also called the *Law of Inertia*

Inertia: the tendency of an object to resist changes in its state of motion

The First Law states that *all objects have inertia*. The more mass an object has, the more inertia it has (and the harder it is to change its motion).

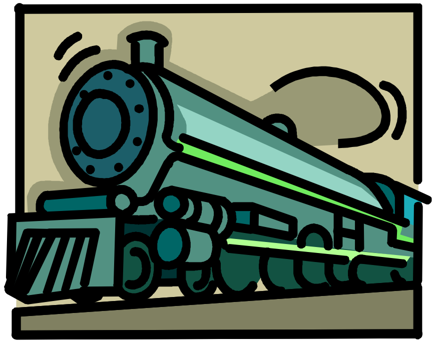
Inertia

- Inertia is a term used to measure the ability of an object to resist a change in its state of motion.
- An object with a lot of inertia takes a lot of force to start or stop; an object with a small amount of inertia requires a small amount of force to start or stop.
- The word "inertia" comes from the Latin word *inertus*, which can be translated to mean "lazy."



Examples from Real Life

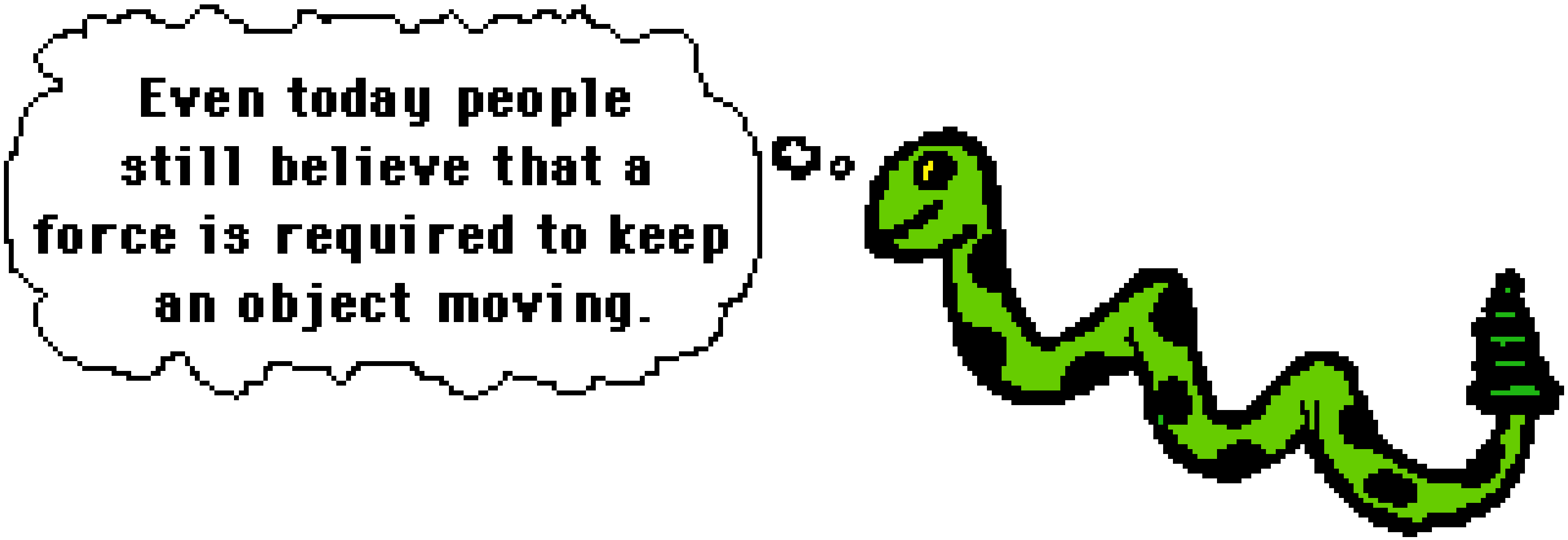
A powerful locomotive begins to pull a long line of boxcars that were sitting at rest. Since the boxcars are so massive, they have a great deal of inertia and it takes a large force to change their motion. Once they are moving, it takes a large force to stop them.



If objects in motion tend to stay in motion, why don't moving objects keep moving forever?

Things don't keep moving forever because there's almost always an unbalanced force acting upon it.

Example : A book sliding across a table slows down and stops because of the force of *friction*.


Even today people still believe that a force is required to keep an object moving.

Forces Don't Keep Objects Moving

- Newton's first law of motion declares that a force is <u>not</u> needed to keep an object in Motion.

- For example : Slide a book across a table and watch it slide to a rest position. The book in motion on the table top does not come to a rest position because of the *absence* of a force; rather it is the *presence* of a force - that force being the force of friction - that brings the book to a rest position.
- In the absence of a force of friction, the book would continue in motion with the same speed and direction - forever! (Or at least to the end of the table top.

If you throw a ball upwards it will eventually slow down and fall because of the force of *gravity*.

How do these systems in a car overcome the law of inertia?

- The engine
  - supplies force that allows you to change motion by pressing the pedal.
- The brake system
  - is designed to help you change your motion by slowing down.
- The steering wheel and steering system
  - is designed to help you change your motion by changing your direction.

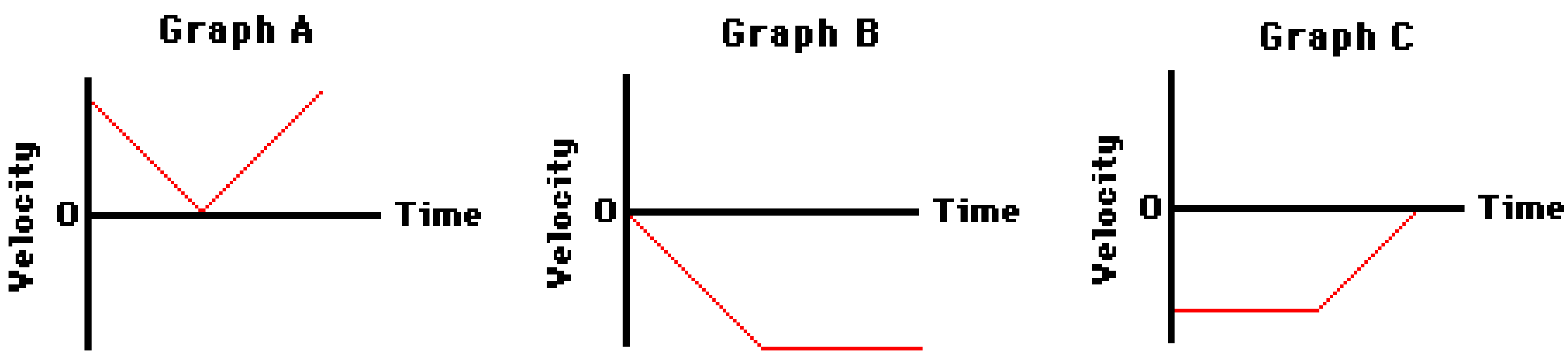
There are many more applications of Newton's first law of motion. Several applications are listed below. *Perhaps you could think about the law of inertia and provide explanations for each application*.

- Blood rushes from your head to your feet while quickly stopping when riding on a descending elevator.
- The head of a hammer can be tightened onto the wooden handle by banging the bottom of the handle against a hard surface.
- To dislodge ketchup from the bottom of a ketchup bottle, it is often turned upside down and thrusted downward at high speeds and then abruptly halted.
- While riding a skateboard (or wagon or bicycle), you fly forward off the board when hitting a curb or rock or other object that abruptly halts the motion of the skateboard.

Check your understanding !

- Luke drops an approximately 5.0 kg fat cat (weight = 50.0 N) off the roof of his house into the swimming pool below. Upon encountering the pool, the cat encounters a 50.0 N upward resistance force (assumed to be constant).

a) Which one of the velocity-time graphs best describes the motion of the cat? Support your answer with sound reasoning.



Answer

- **Graph B is correct.** The cat first accelerates with a negative (downward) acceleration until it hits the water. Upon hitting the water, the cat experiences a balance of forces (50 N downwards due to gravity and 50 N upwards due to the water).
- Thus, the cat will finish its motion moving with a constant velocity. Graph B depicts both the initial negative acceleration and the final constant velocity.

Newton's Second Law

Newton's second law of motion…..

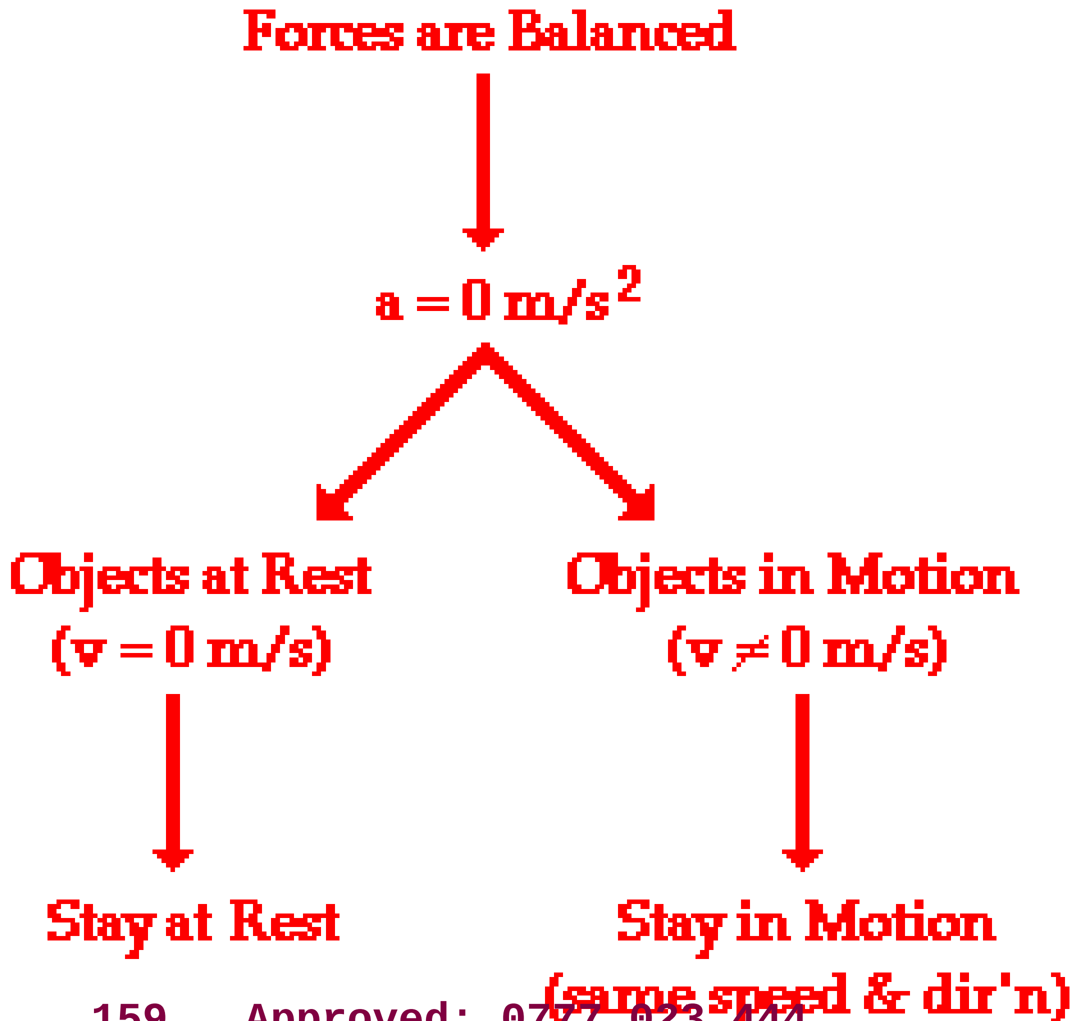
Force equals

mass times acceleration

F = ma

Acceleration: a measurement of how quickly an object is changing speed.

From 1st law... when forces are balanced.....



When forces are unbalanced...

Forces are Unbalanced

There is an acceleration

The acceleration depends directly upon the "net force"

The acceleration depends inversely upon the object's mass.

What does *F* = *ma* mean?

Force is *directly proportional* to mass and acceleration.

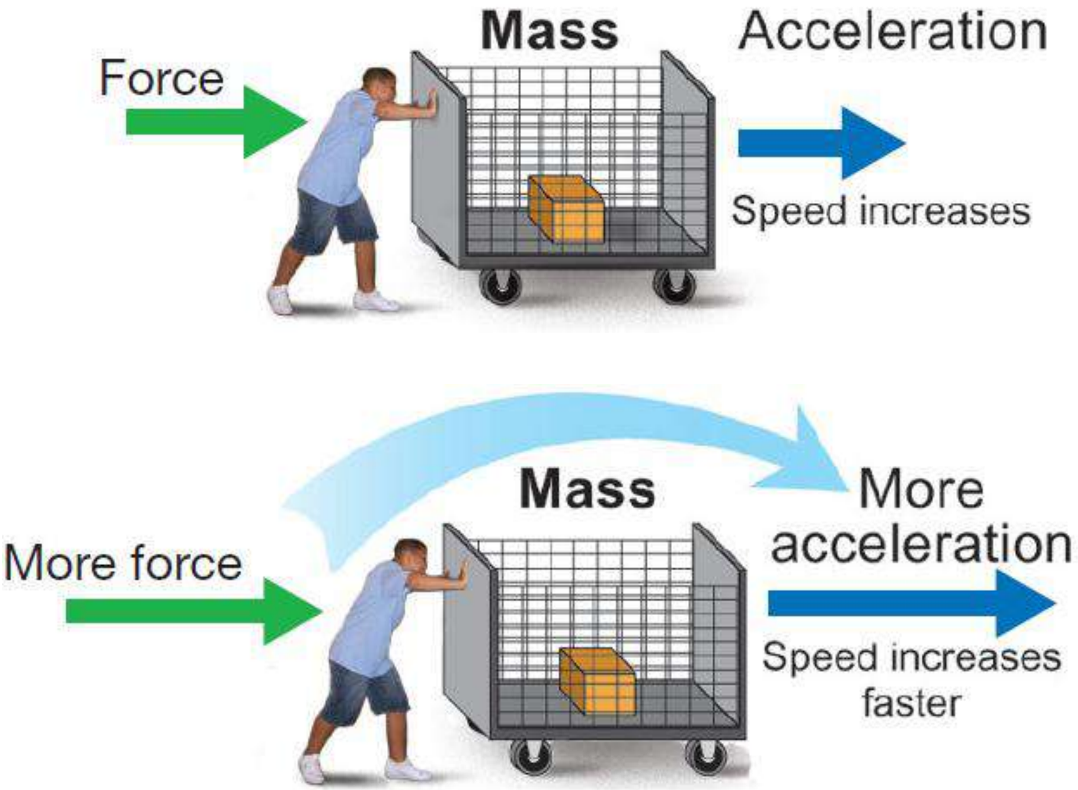
Imagine a ball of a certain mass moving at a certain acceleration. This ball has a certain force.

- Now imagine we make the ball twice as big (double the mass) but keep the acceleration constant. F = ma says that this new ball has *twice the force* of the old ball.

- Now imagine the original ball moving at twice the original acceleration. F = ma says that the ball will again have *twice the force* of the ball at the original acceleration.

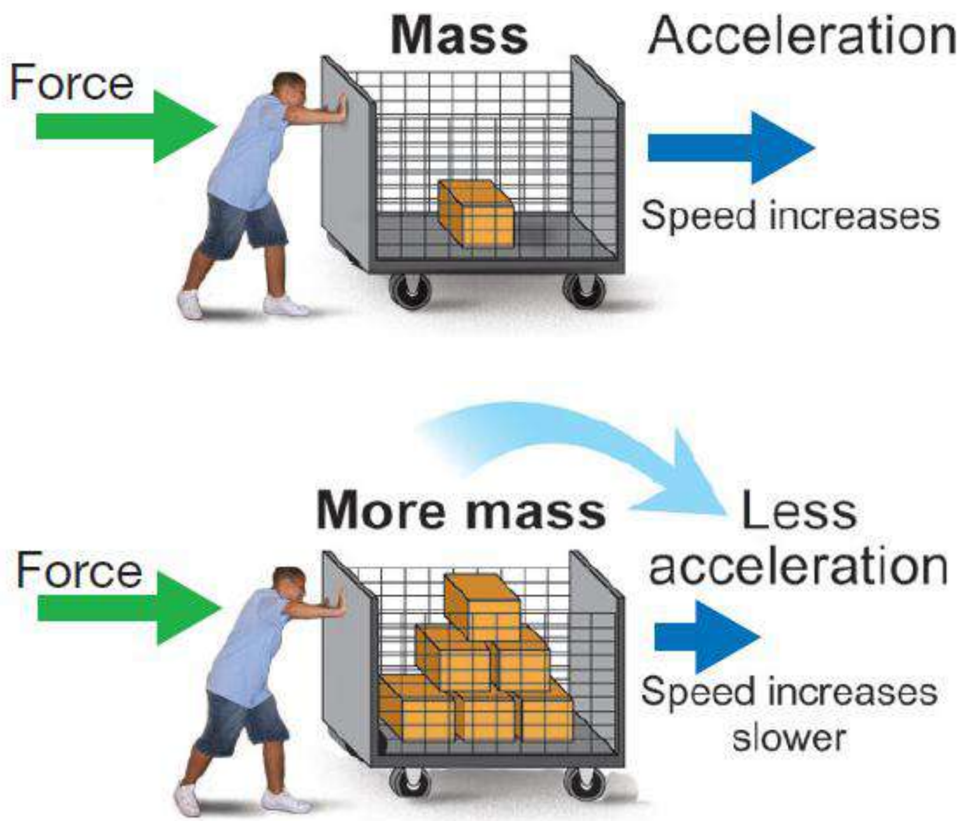
Newton's Second Law

- If you apply <u>more</u> force to an object, it accelerates at a higher rate.



Newton's Second Law

- If the same force is applied to an object with greater mass, the object accelerates at a slower rate because mass adds inertia.



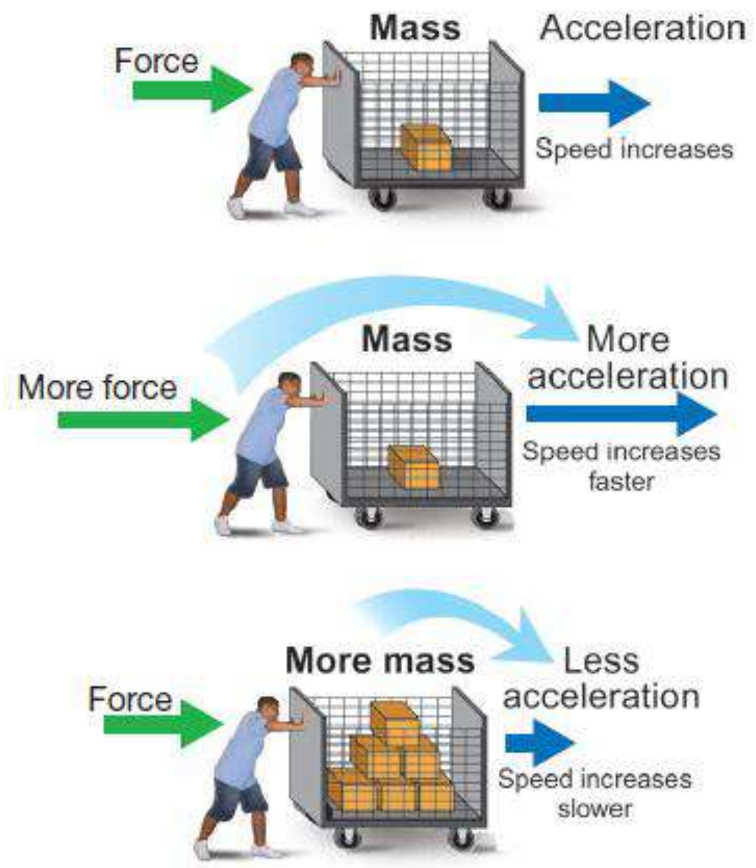
Newtons Second Law

Acceleration (m/s²)

Force (N)

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

Mass (kg)



Mass will resist changes in motion

- When you are standing on a bus, and the bus starts very quickly, your body seems to be pushed backward, and if the bus stops suddenly, then your body seems to be pushed forwards. Notice that when the bus turns left, you will seem to be pushed to the right, and when the bus turns right, you will seem to be pushed to the left.
- Also consider a full shopping cart. If you try to push it from a stationary position, it will take some effort to get it moving. The same is true if you try to stop it when it is moving at a high speed, or try to turn it left or right.

Mass will resist changes in motion (continued)

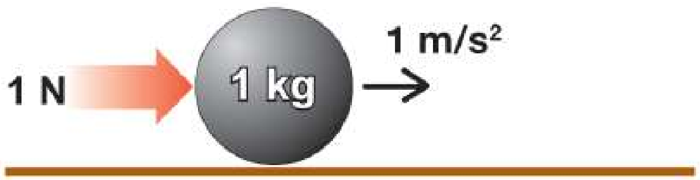
- In both cases, an object with **mass** is opposing a change in motion. In the first case, it is your body that tries to stay moving as it was before the change. Your body also tries to stay in a straight line when the bus turns, although it appears to be moving to the side.
- What is really happening is that your body is still moving straight and the bus turns in the opposite direction. The shopping cart exhibits the same behavior. When it is stationary, it tries to stay stationary, and when you try to stop it moving, it will try to continue. Your body and the cart both have mass.

Mass will resist changes in motion (continued)

- From this, we can define a property of mass: Mass will resist changes in motion.
- This says that any object with mass will resist any change in motion.
- Objects with greater mass will resist change in motion more than objects with less mass.
- In the SI system, the unit of mass is the kilogram (kg).

Unit of Force

- A force of one Newton is exactly the amount of force needed to cause a mass of one kilogram to accelerate at one m/s^2.
- We call the unit of force the Newton (N).



Units

Acceleration (m/s^2) → $a = \frac{F}{m}$ ← Force (newtons, N)

← Mass (kg)

More about $F = ma$

If you *double* the mass, you *double* the force. If you *double* the acceleration, you *double* the force.

What if you double the mass *and* the acceleration?

$$(2m)(2a) = 4F$$

Doubling the mass *and* the acceleration *quadruples* the force.

What does $F = ma$ say?

$$F = ma$$

basically means that the force of an object comes from its mass and its acceleration.

Weight as the effect of a gravitational field on a mass

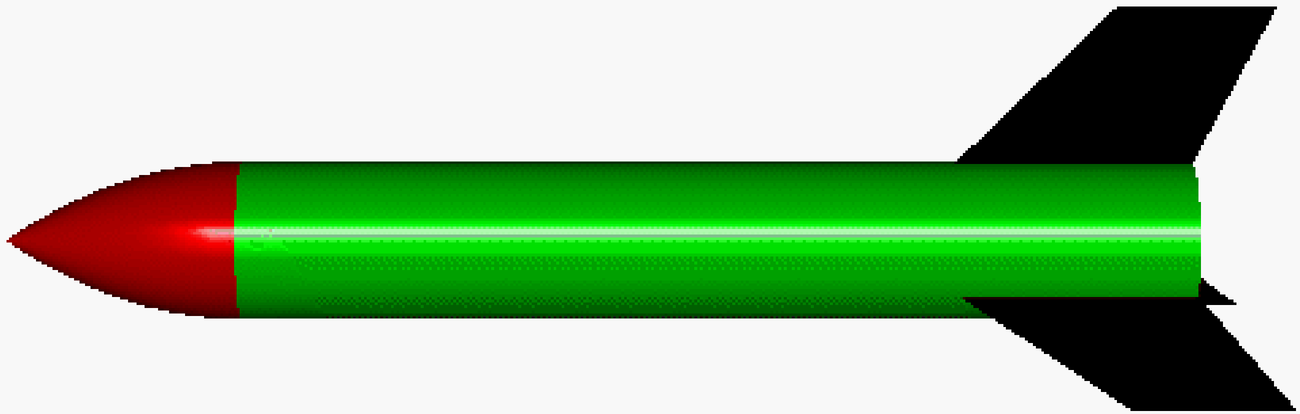
- In everyday usage the term "weight" is commonly used to mean mass, which scientifically is an entirely different concept.
- On the surface of the Earth, the acceleration due to gravity (the "strength of gravity") is approximately constant; this means that the ratio of the weight force of a motionless object on the surface of the Earth to its mass is almost independent of its location, so that an object's weight force can stand as a proxy for its mass, and vice versa.

Definition of Weight

- The word *weight* denotes a quantity of the same nature as a *force*.
- The weight of a body is the product of its mass and the acceleration due to gravity.

Newton's Second Law

Definitions



Differential Form: Force = change of momentum with change of time

$$F = \frac{d(mv)}{dt}$$

or:

Force = change in mass X velocity with time

$$F = \frac{(m_1 V_1 - m_0 V_0)}{(t_1 - t_0)}$$

With mass constant: Force = mass X acceleration

$$F = m\,a$$

Force, acceleration, momentum and velocity are all vector quantities.

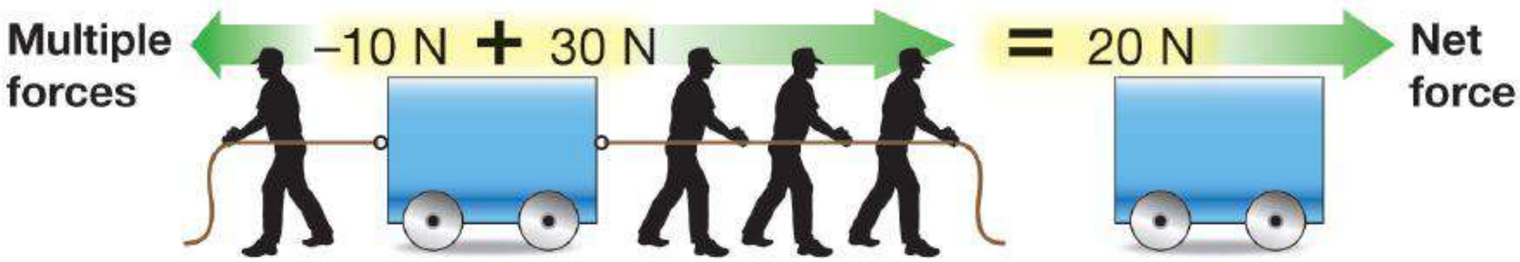
Each has both a magnitude and a direction.

Using the second law of motion

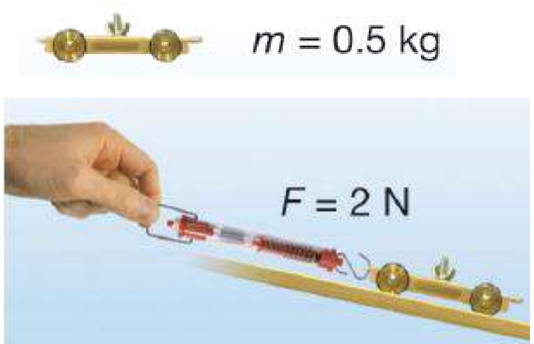
- The force *F* that appears in the second law is the net force.
- There are often many forces acting on the same object.
- Acceleration results from the <u>combined action</u> of all the forces that act on an object.
- When used this way, the word *net* means "total."

Using the second law of motion

- To solve problems with multiple forces, you have to add up all the forces to get a single net force before you can calculate any resulting acceleration.



Calculating acceleration



A cart rolls down a ramp. Using a spring scale, you measure a net force of 2 newtons pulling the car down. The cart has a mass of 500 grams (0.5 kg). Calculate the acceleration of the cart.

1. You are asked for the acceleration (*a*).
2. You are given mass (*m*) and force (*F*).
3. Newton's second law applies: $a = F \div m$
4. Plug in numbers. (Remember: 1 N = 1 kg·m/s^2)

Three forms of the second law

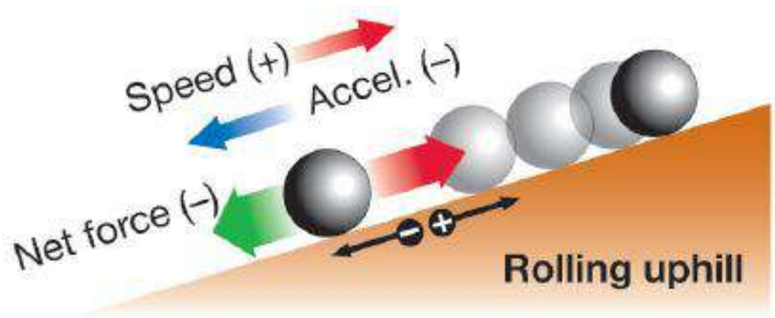
Use...	if you want to find...	and you know...
$a = \frac{F}{M}$	The acceleration (a)	The net force (F) and the mass (m)
$F = ma$	The net force (F)	The acceleration (a) and the mass (m)
$M = \frac{F}{a}$	The mass (m)	The acceleration (a) and the net force (F)

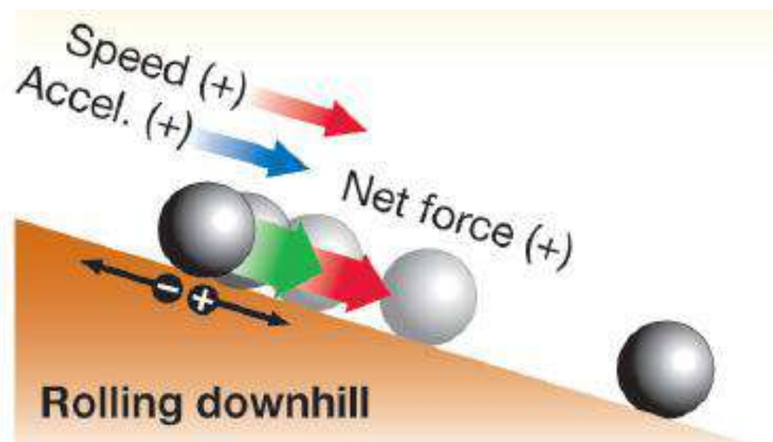
Finding the acceleration of moving objects

- The word dynamics refers to problems involving motion.
- In dynamics problems, the second law is often used to calculate the acceleration of an object when you know the force and mass.

Direction of acceleration

- Speed *increases* when the net force is in the same direction as the motion.
- Speed *decreases* when the net force is in the opposite direction as the motion.



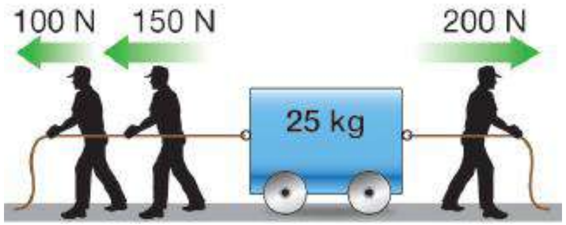


Positive and negative acceleration

- We often use positive and negative numbers to show the direction of force and acceleration.
- A common choice is to make velocity, force, and acceleration positive when they point to the right.

Acceleration from multiple forces

Three people are pulling on a wagon applying forces of 100 N, 150 N, and 200 N. Determine the acceleration and the direction the wagon moves. The wagon has a mass of 25 kilograms.



1. You are asked for the acceleration (*a*) and direction
2. You are given the forces (*F*) and mass (*m*).
3. The second law relates acceleration to force and mass: $a = F \div m$
4. Assign positive and negative directions. Calculate the net force then use the second law to determine the acceleration from the net force and the mass.

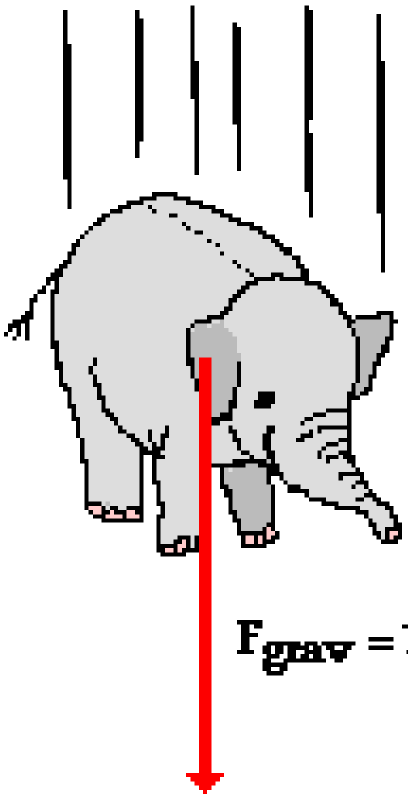
Finding force from acceleration

- Wherever there is acceleration there must also be force.
- Any change in the motion of an object results from acceleration.
- Therefore, any change in motion must be caused by force.

Coming back to…Free Fall Motion

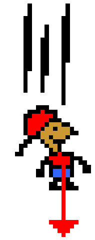
- As learned in an earlier chapter, free fall is a special type of motion in which the only force acting upon an object is gravity. Objects that are said to be undergoing *free fall*, are not encountering a significant force of air resistance; they are falling under the sole influence of gravity.
- Under such conditions, all objects will fall with the same rate of acceleration, regardless of their mass. But why?
- Consider the free-falling motion of a 1000-kg baby elephant and a 1-kg overgrown mouse.

$m = 1000\ kg$



$F_{grav} = 10\,000\ N$

$m = 1\ kg$



$F_{grav} = 10\ N$

$$a = \frac{F_{net}}{m} = \frac{10\,000\ N}{1000\ kg}$$

$a = 10\ m/s/s$

$$a = \frac{F_{net}}{m} = \frac{10\ N}{1\ kg}$$

$a = 10\ m/s/s$

Explanation on free fall....based on previous diagram

- If Newton's second law were applied to their falling motion, and if a free-body diagram were constructed, then it would be seen that the 1000-kg baby elephant would experiences a greater force of gravity. This greater force of gravity would have a direct affect upon the elephant's acceleration; thus, based on force alone, it *might be thought* that the 1000-kg baby elephant would accelerate faster. But acceleration depends upon two factors: force and mass. The 1000-kg baby elephant obviously has more mass (or inertia). This increased mass has an inverse affect upon the elephant's acceleration. And thus, the direct affect of greater force on the 1000-kg elephant is *offset* by the inverse affect of the greater mass of the 1000-kg elephant; and so each object accelerates at the same rate - approximately 10 m/s/s. The ratio of force to mass (F_{net}/m) is the same for the elephant and the mouse under situations involving free fall.
- This ratio (F_{net}/m) is sometimes called the **gravitational field strength** and is expressed as 9.8 N/kg (for a location upon Earth's surface). The gravitational field strength is a property of the location within Earth's gravitational field and not a property of the baby elephant nor the mouse. All objects placed upon Earth's surface will experience this amount of force (9.8 N) upon every 1 kilogram of mass within the object. Being a property of the location within Earth's gravitational field and not a property of the free falling object itself, all objects on Earth's surface will experience this amount of force per mass. As such, all objects free fall at the same rate regardless of their mass. Because the 9.8 N/kg gravitational field at Earth's surface causes a 9.8 m/s^2 acceleration of any object placed there, we often call this ratio the acceleration of gravity

Check your understanding!

Question 1

- Determine the accelerations that result when a 12-N net force is applied to a 3-kg object and then to a 6-kg object.

Answer 1

- Determine the accelerations that result when a 12-N net force is applied to a 3-kg object and then to a 6-kg object.
- Answer : A 3-kg object experiences an acceleration of**4 m/s^2**. A 6-kg object experiences an acceleration of **2 m/s^2**

Question 2

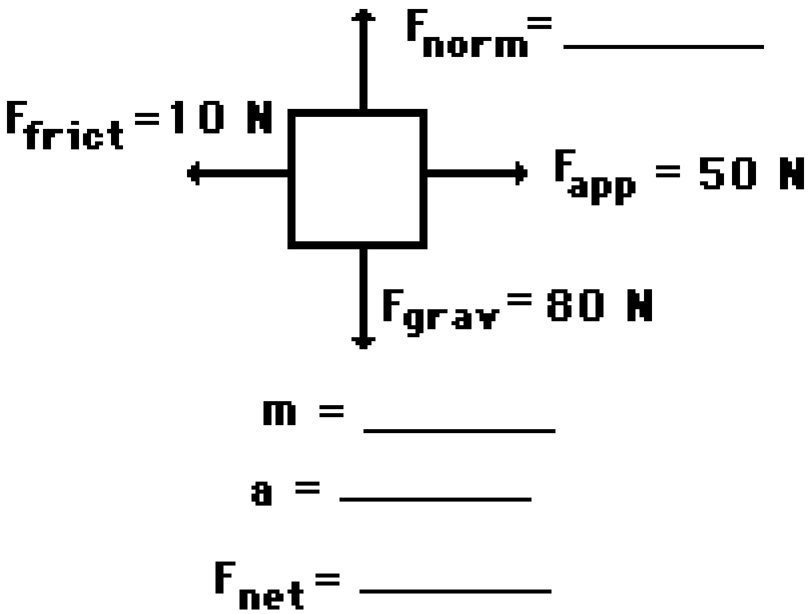
- Suppose that a sled is accelerating at a rate of 2 m/s^2. If the net force is tripled and the mass is doubled, then what is the new acceleration of the sled?

Answer 2

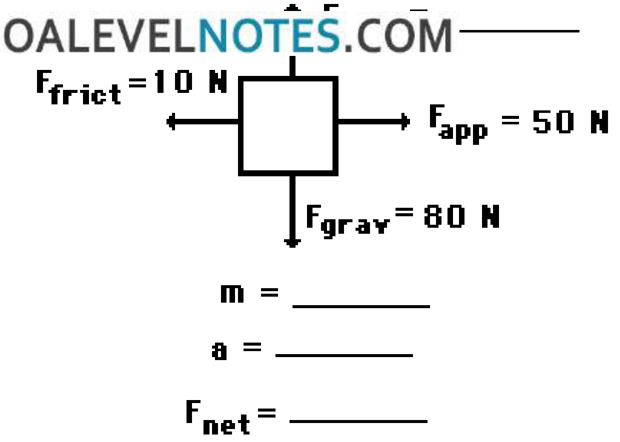
- Suppose that a sled is accelerating at a rate of 2 m/s^2. If the net force is tripled and the mass is doubled, then what is the new acceleration of the sled?
- Answer: **3 m/s^2**
- The original value of 2 m/s^2 must be multiplied by 3 (since a and F are directly proportional) and divided by 2 (since a and m are inversely proportional)

Question 3

- An applied force of 50 N is used to accelerate an object to the right across a frictional surface. The object encounters 10 N of friction. Use the diagram to determine the normal force, the net force, the mass, and the acceleration of the object. (Neglect air resistance.)



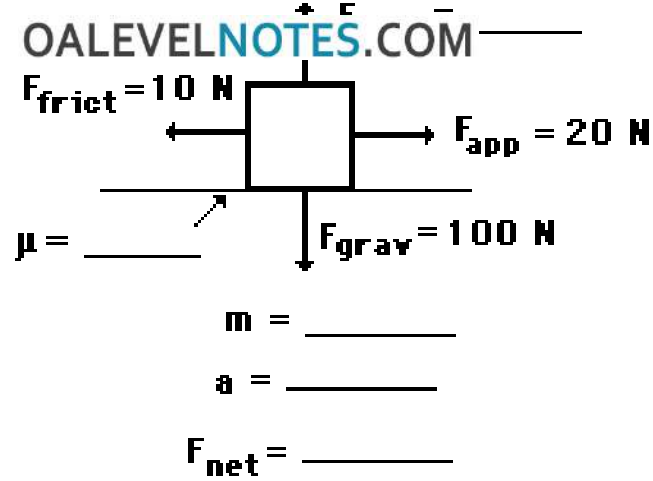
Answer 3



- Note: To simplify calculations, an approximated value of g is often used as 10 m/s²
- **F_{norm} = 80 N; m = 8.16 kg; F_{net} = 40 N, right; a = 4.9 m/s², right**
- (If you are using g = 10, F_{norm} = 80 N; m = 8 kg; F_{net} = 40 N, right; a = 5 m/s², right)
- Since there is no vertical acceleration, normal force = gravity force. The mass can be found using the equation F_{grav} = m g
- The F_{net} is the vector sum of all the forces: 80 N, up plus 80 N, down equals 0 N. And 50 N, right plus 10 N, left = 40 N, right.
- Finally, a = F_{net} / m = (40 N) / (8.16 kg) = 4.9 m/s².

K M C

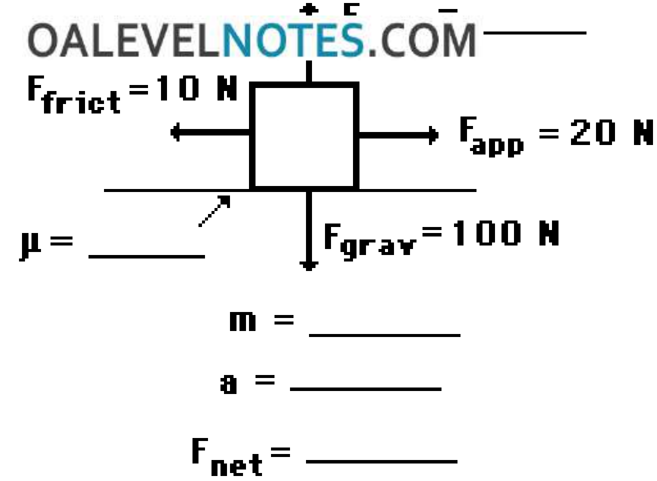
Question 4



- An applied force of 20 N is used to accelerate an object to the right across a frictional surface. The object encounters 10 N of friction. Use the diagram to determine the normal force, the net force, the coefficient of friction (µ) between the object and the surface, the mass, and the acceleration of the object. (Neglect air resistance.)
- *The* ***coefficient of friction*** *(COF), often symbolized by the Greek letter µ, is a dimensionless scalar value which describes the ratio of the force of friction between two bodies and the force pressing them together. The coefficient of friction depends on the materials used; for example, ice on steel has a low coefficient of friction, while rubber on pavement has a high coefficient of friction*.

K M C

Answer 4



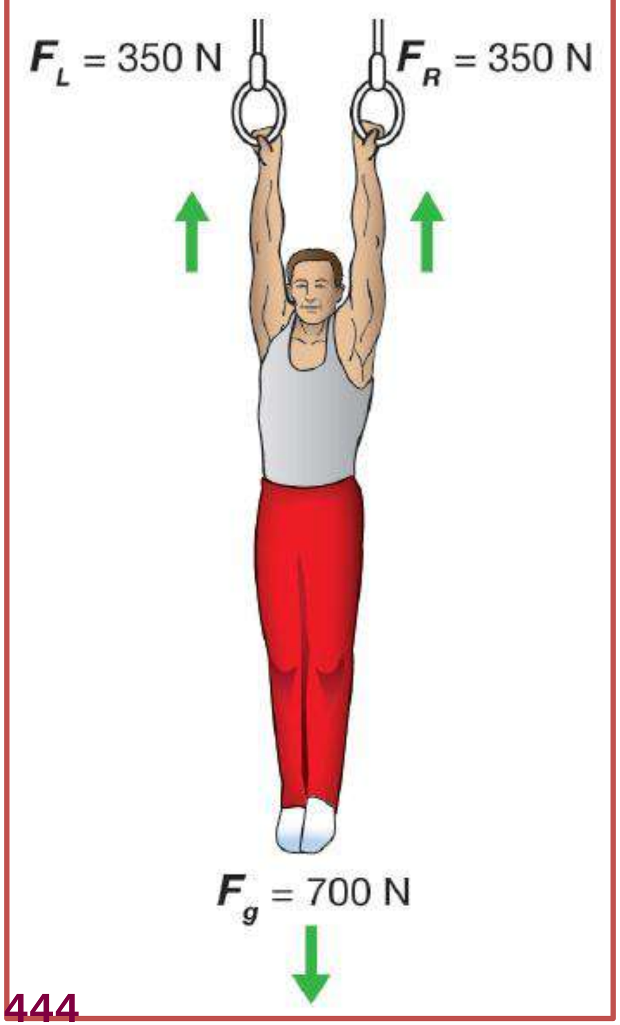
- **F_{norm} = 100 N; m = 10.2 kg; F_{net} = 10 N, right; "mu" = 0.1; a =0.980 m/s^2, right**
- (If you are using g=10, F_{norm} = 100 N; m = 10 kg; F_{net} = 10 N, right; "mu" = 0.1; a =1 m/s^2, right)
- Since there is no vertical acceleration, the normal force is equal to the gravity force. The mass can be found using the equation F_{grav} = m g.
- Using "mu" = F_{frict} / F_{norm}, "mu" = (10 N) / (100 N) = 0.1.
- The F_{net} is the vector sum of all the forces: 100 N, up plus 100 N, down equals 0 N. And 20 N, right plus 10 N, left = 10 N, right.
- Finally, a = F_{net} / m = (10 N) / (10.2 kg) = 0.980 m/s^2.

Equilibrium

- The condition of zero acceleration is called equilibrium.
- In equilibrium, all forces cancel out leaving zero net force.
- Objects that are standing still are in equilibrium because their acceleration is zero.

Equilibrium

- Objects that are moving at constant speed and direction are also in equilibrium.
- A static problem usually means there is no motion.



Calculating force

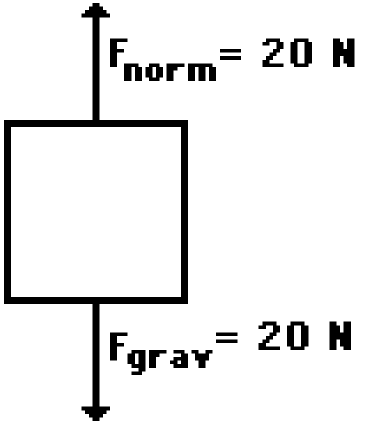
A woman is holding two dogs on a leash. If each dog pulls with a force of 80 Newtons, how much force does the woman have to exert to keep the dogs from moving?

1. You are asked for force (*F*).
2. You are given two 80 N forces and the fact that the dogs are not moving (a = 0).
3. Newton’s second law says the net force must be zero if the acceleration is zero.
4. The woman must exert a force equal and opposite to the sum of the forces from the two dogs.

Check your understanding on balanced forces!!

Who is wrong here? Anna or Noah?

- Two students are discussing on an object that is being acted upon by two individual forces (both in a vertical direction). During the discussion, Anna suggests to Noah that the object under discussion could be moving. In fact, Anna suggests that if friction and air resistance could be ignored (because of their negligible size), the object could be moving in a horizontal direction. According to Anna, an object experiencing forces as described at the right could be experiencing a horizontal motion.
- Noah objects, arguing that the object could not have any horizontal motion if there are only vertical forces acting upon it. Noah claims that the object must be at rest, perhaps on a table or floor. After all, says Noah, an object experiencing a balance of forces will be at rest. Who do you agree with?

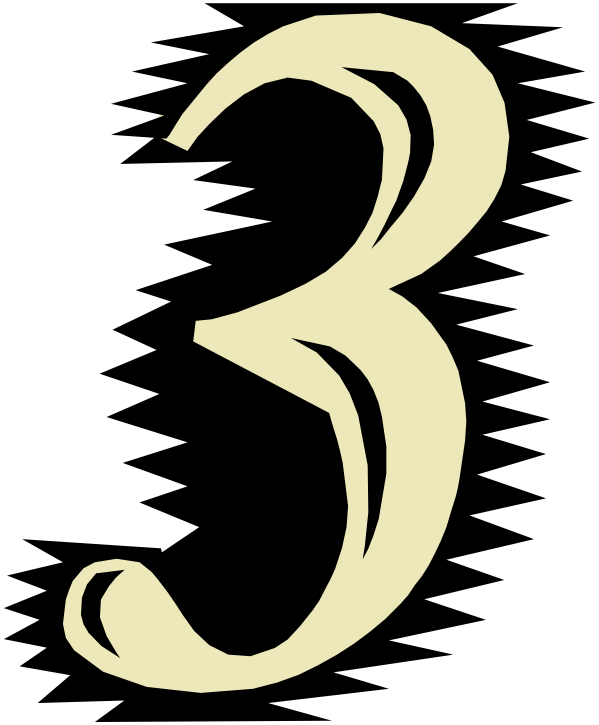


Answer

- **Anna** is correct.
- Noah may know the formulas but he does not know (or does not believe) Newton's laws. If the forces acting on an object are balanced and the object is in motion, then it will continue in motion with the same velocity.

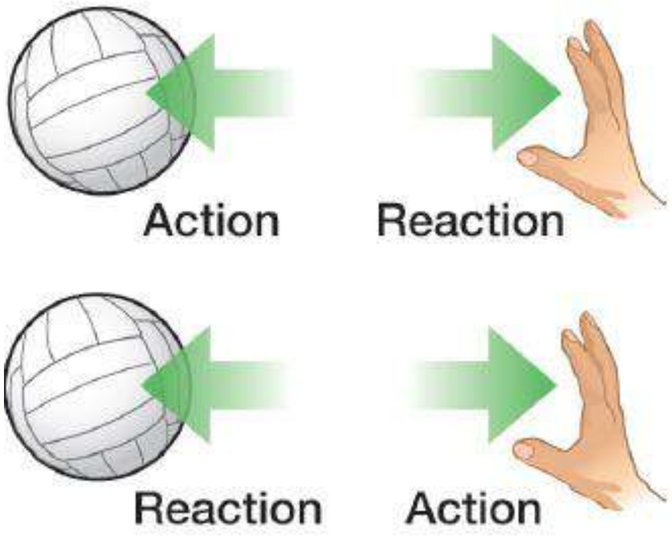
- *Remember: forces do not cause motion. Forces cause accelerations.*

Newton's Third Law



Newton's third law of motion.....

- *For every action there is an equal and opposite reaction.*



What does this mean?

For every force acting on an object, there is an equal force acting in the opposite direction.

Right now, gravity is pulling you *down* in your seat, but Newton's Third Law says your seat is pushing *up* against you with *equal force*. This is why you are not moving. There is a *balanced force* acting on you– gravity pulling down, your seat pushing up.

What happens if....

What happens if you are standing on a skateboard or a slippery floor and push against a wall?

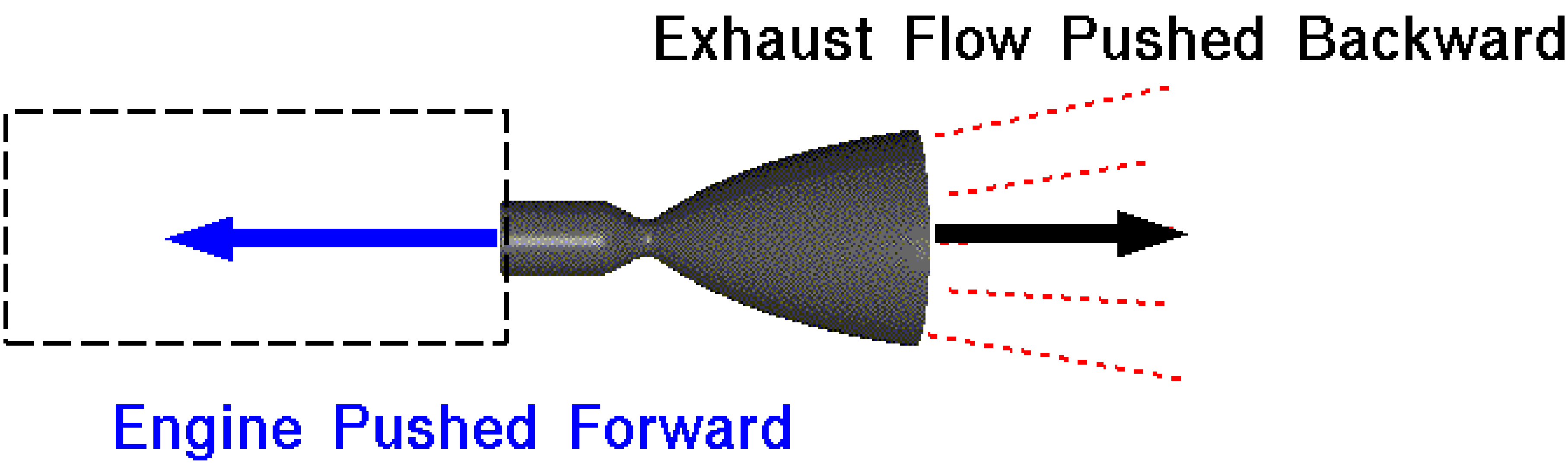
You slide in the opposite direction (away from the wall), because you pushed on the wall but the wall pushed back on you with equal and opposite force.

Newton's 3rd Law Demo

- http://www.youtube.com/watch?v=xQh8ji_4fZs

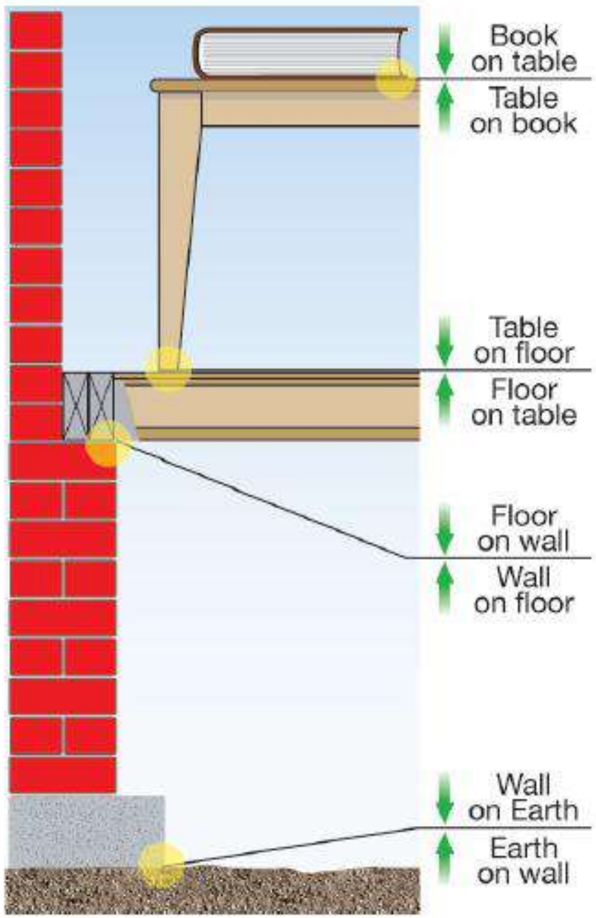
Newton's Third Law

Rocket Engine Thrust



For every action, there is an equal and opposite re-action.

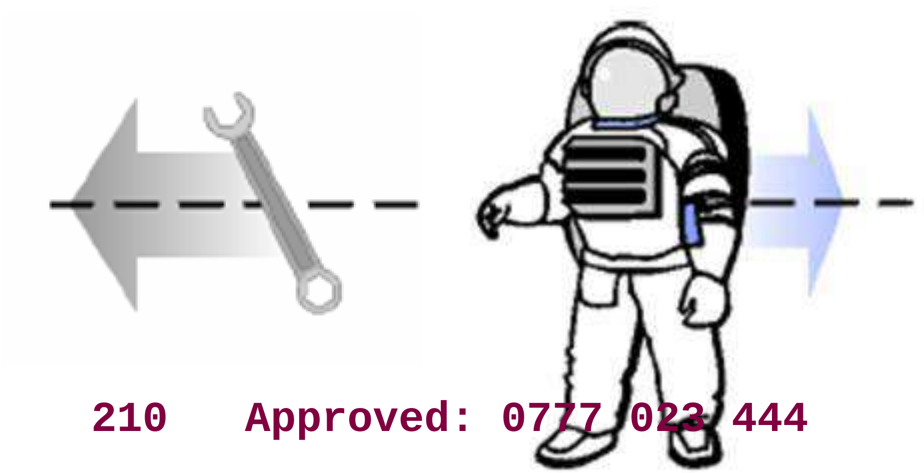
The Third Law: Action and Reaction



- "For every action there is an equal and opposite reaction."
- This statement is known as Newton's third law of motion.
- Newton's third law discusses pairs of objects and the interactions between them.

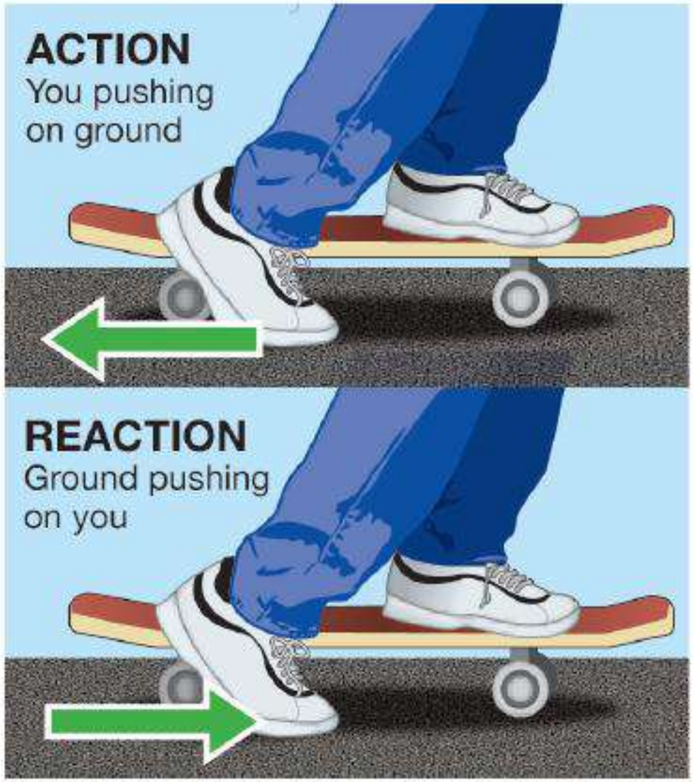
Forces occur in pairs

- The astronauts working on the space station have a serious problem when they need to move around in space: There is nothing to push on.
- One solution is to throw something opposite the direction you want to move.



Forces occur in pairs

- The two forces in a pair are called *action* and *reaction*.
- Anytime you have one, you also have the other.
- If you know the strength of one you also know the strength of the other since both forces are always equal.



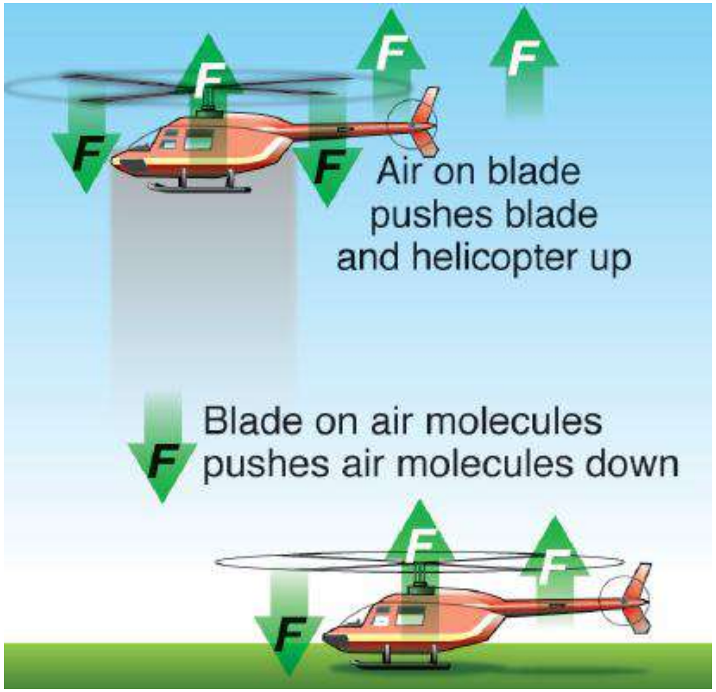
Third Law…

- Action and reaction forces act on different objects, *not* on the same object.
- The forces cannot cancel because they act on different objects.

Action & Reaction

- The act of moving or the ability to move from one place to another is called *locomotion*.
- Any animal or machine that moves depends on Newton's third law to get around.
- When we walk, we push off the ground and move forward because of the ground pushing back on us in the opposite direction.

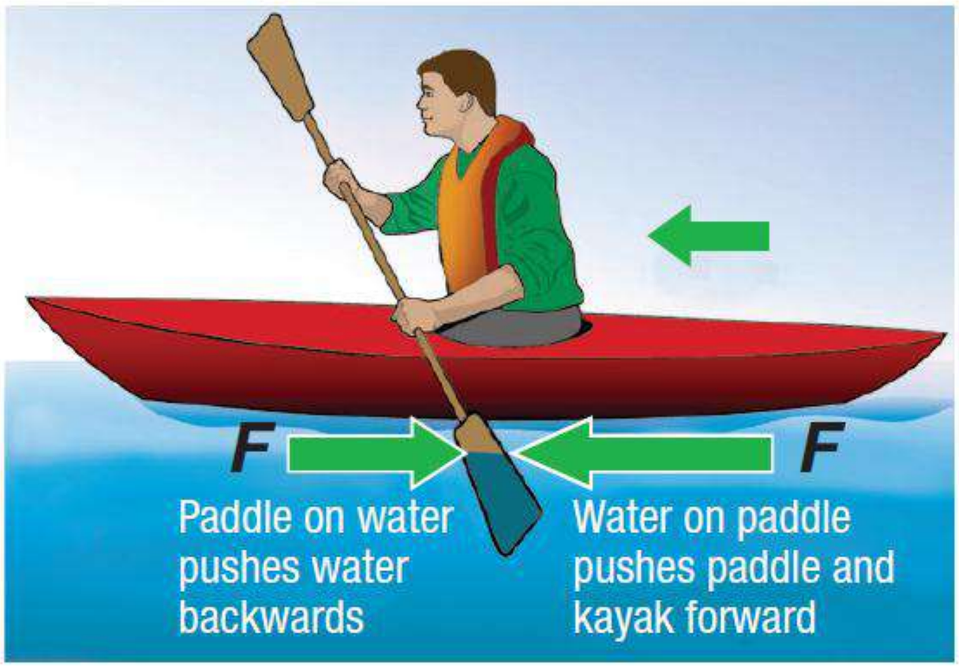
Action & Reaction

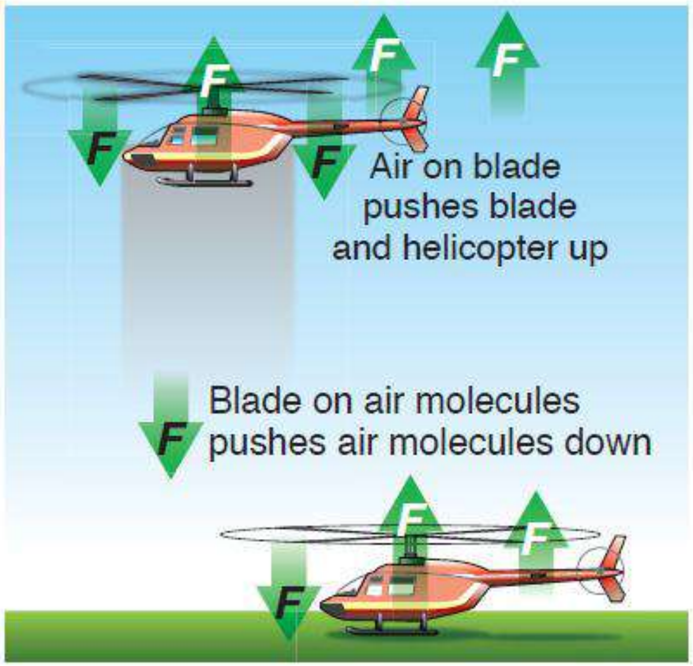


- Jets, planes, and helicopters push air.
- In a helicopter, the blades of the propeller are angled such that when they spin, they push the air molecules down.

The rotor blades of an helicopter are just like the wings of an airplane or a bird. As they move through the air, they pull the air above them downwards. That's the "**action**" part of the action-reaction. When the blades push the air downward, the helicopter is lifted. The air has considerable mass and inertia, and resists being pulled down—it tries to push the wings up instead. That's the "**reaction**" part, and that's also aerodynamic lift. The blades pull air downwards, and the reaction to this pushes the helicopter upwards.

Action Reaction Forces





Momentum as the product of mass and velocity

Momentum or Linear momentum or translational momentum is the product of the mass and velocity of an object.

Momentum = mass x velocity

For example, a heavy truck moving fast has a large momentum—it takes a large and prolonged force to get the truck up to this speed, and it takes a large and prolonged force to bring it to a stop afterwards. If the truck were lighter, or moving slower, then it would have less momentum.

- Like velocity, linear momentum is a vector quantity, possessing a direction as well as a magnitude:
- **Units**: $kgms^{-1}$ or Ns

Force as a rate of change of Momentum

- Consider a body of mass m, initially moving with a velocity of magnitude u. A force F acts on the body and causes it to accelerate to a final velocity of magnitude v.
- We can write Newton's second law in the form $\boxed{F = m\left(\frac{v - u}{t}\right)}$
- and a simple rearrangement shows the relation between force and momentum $\boxed{F = \frac{mv - mu}{t}}$ Remember, momentum = mass x velocity.
- Now, mv is the final momentum of the body and mu is the initial **momentum** of the body. Therefore, we have

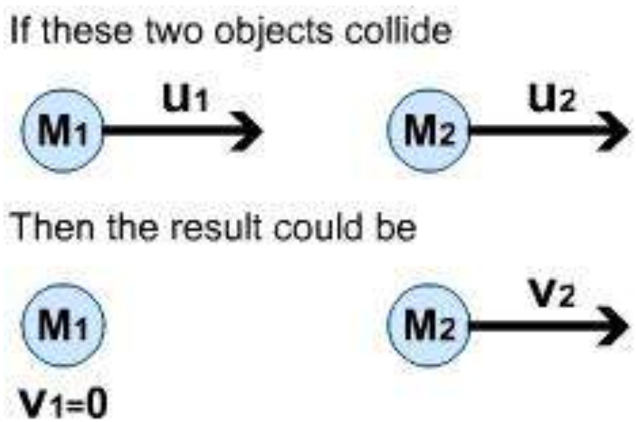
Force = rate of change of momentum $\boxed{F = \frac{\Delta p}{\Delta t}}$

Principle of Conservation of Momentum

- **The Principle of the Conservation of Momentum states that**: if objects collide, the total momentum before the collision is the same as the total momentum after the collision (provided that no external forces - for example, friction - act on the system).
- Of course, energy is also conserved in any collision, but it isn't always conserved in the form of kinetic energy.

Case 1

- To do any calculations for momentum, there are some simple rules to follow to make it easy:
- Always decide which direction is positive and which is negative, then stick to it.
- Always remember that the total momentum before the collision will be the same as the total momentum after the collision.
- **So,**

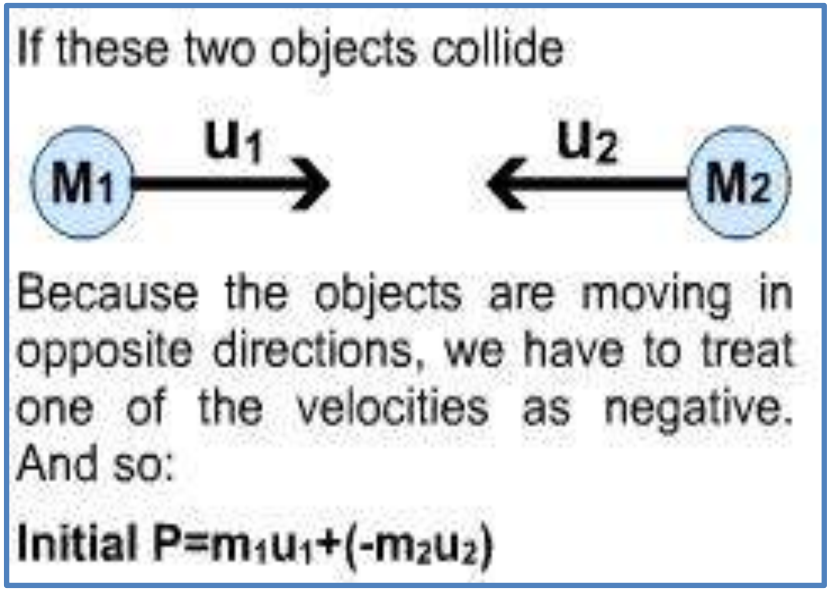


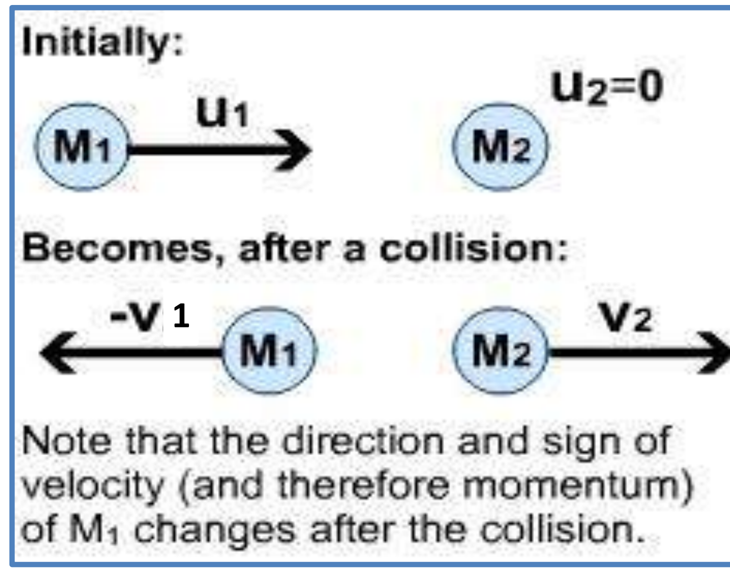
- **The conservation of momentum states:**
- $Momentum_{before} = Momentum_{after}$
- So, $(P_1 + P_2)$ before= $(P_1 + P_2)$ after
- Or, $m_1u_1 + m_2u_2 = m_1v_1 + m_2v_2$
- But notice that in this example, $\mathbf{v_1 = 0}$. So that term cancels and makes finding an answer much easier.

Case 2

- If the objects change direction in the collision or are going in different directions before the collision, make sure that you have got the signs for the velocities and therefore the momentums correct.

- ***Example 1*** ***Example 2***

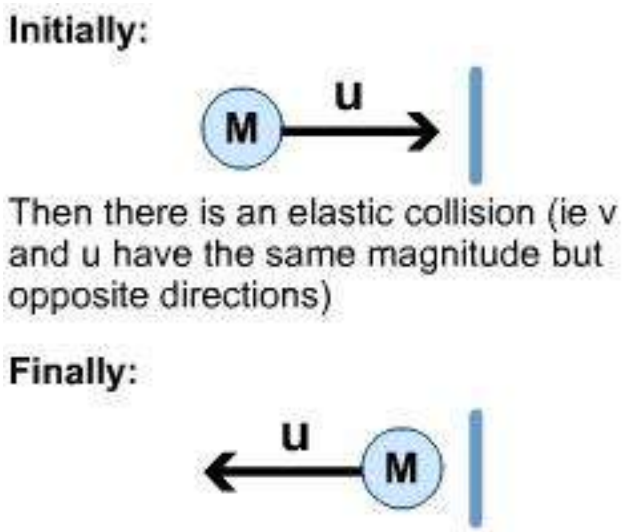




Case 3

- When objects **bounce back** after a collision, be careful about the change in momentum.

Example



So change in momentum = final P - initial P

= -mu - (+ mu)

= - 2mu

Explosions

- Explosions are a special type of collision. Momentum is conserved in an explosion. This is made easier by the fact that usually, the momentum **before** an explosion is **zero**. The Principle of the Conservation of Momentum states that the momentum **after** the explosion must therefore be **zero** as well.

- **What's the momentum of the universe?**

What is the momentum of the Universe?

- If the universe began with a Big Bang (for instance - an explosion), the momentum of the universe before the explosion was **zero**.

So what is its momentum ?

Force can be defined as the rate of change of momentum as:

$$F = ma$$

$$\text{But, } a = \frac{v - u}{t}$$

$$\text{So, } F = m\left(\frac{v - u}{t}\right) = \frac{mv - mu}{t} = \frac{\text{change in momentum}}{\text{time}}$$

Principle of Conservation of Momentum
Elastic and Inelastic collisions

- **Perfectly Elastic collisions**
- All momentum is conserved
- Kinetic energy **is** conserved as well.
- Relative speed of approach = relative speed of separation.
- (So if one is catching the other at 10m/s before the collision, it will be moving apart from it at 10m/s after the collision)
- **Perfectly Elastic** collisions are surprisingly common. All collisions between atoms are Perfectly Elastic according to the Kinetic Theory of Gases.

Principle of Conservation of Momentum
Elastic and Inelastic collisions

- **Perfectly Inelastic collisions**
- All momentum is conserved (as always).
- Kinetic energy is **not** conserved.
- The relative speed of separation is zero.
- (In other words, that means the objects stick together after the collision, they will move together, so just consider them as one object whose mass is the same as that of the two original masses combined).

Why is kinetic energy not conserved while momentum is conserved in a perfectly inelastic collision?

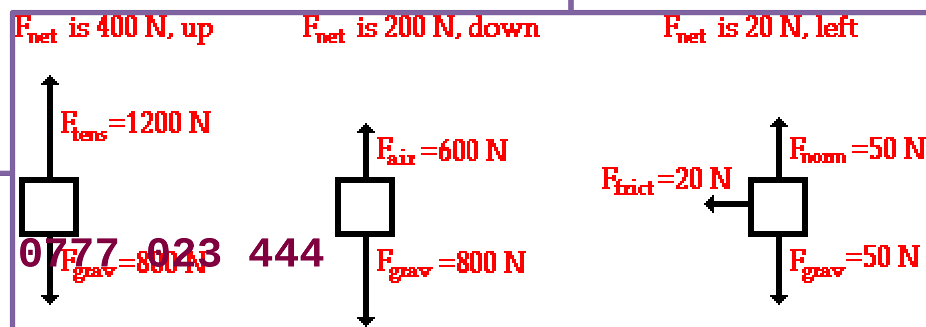
- It goes into heat, sound, work done to deform the colliding bodies etc. Other forms of energy, in other words.
- Momentum is not a type of energy. Momentum and energy are totally different physical quantities with different physical dimensions. (Energy is the capacity to do work)

  Conservation of momentum in a system occurs provided that there are no *external* forces acting on a system. This is a consequence of Newton's 2nd law and Newton's 3rd law.

  Newton's 2nd law says that the net force acting on a body is equal to the rate of change of its momentum.

  This is the full, general statement of the 2nd law. F = Δp/Δt.

  If the mass of the body is constant, this reduces to F = m(Δv/Δt) = ma. Therefore, if a net force acts on an object, its momentum will change with time. If there is no net force, then its momentum will not change.



How and when momentum is co

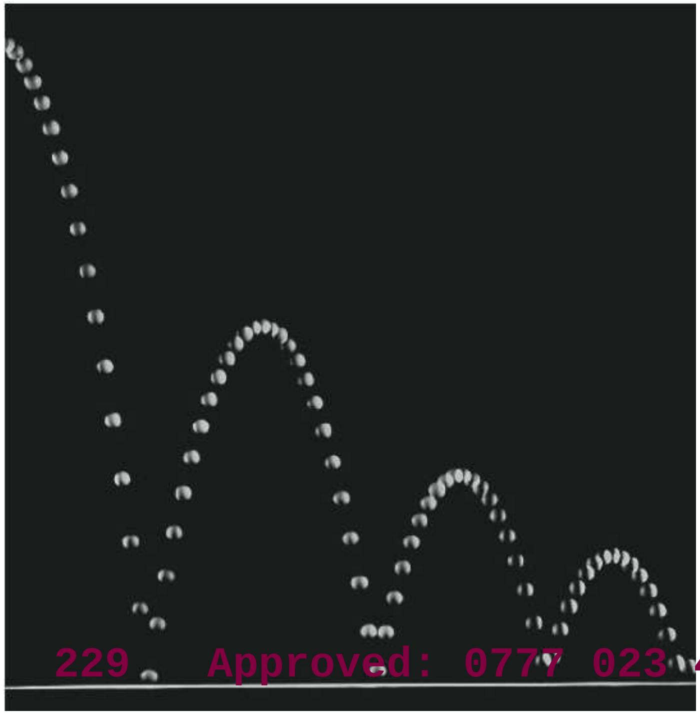
- Now, consider a system of interacting particles. The particles are moving around randomly. Every once in a while, two particles (1 and 2) may collide. While this is happening, particle 1 exerts a force on particle 2. However, Newton's 3rd law says that particle 2 must therefore, at the same time, exert a force on particle 1 of equal strength and opposite direction. These forces are also exerted over the same time interval (while the particles are in contact). Therefore, the change in momentum of particle 1 will be equal in magnitude and opposite in direction to the change in momentum of particle 2.
- These two momentum changes therefore cancel each other out. Each particle may individually change its momentum, but there will be no change to the *total* momentum of the system. In other words, since Newton's 3rd says that these *internal* forces always occur in matched "action-reaction" pairs, they cannot ever cause a change to the overall momentum of the system. Only an *external* force (a force from something that is not part of the system of particles) can cause a change in the total momentum of the system. In the absence of a net external force, $F_{tot} = 0$ and hence $\Delta p_{tot} = 0$. In the absence of external forces, momentum is *conserved*.

Last sub topic of Chapter 3

The projectile Motion

3. Kinematics

(k) describe and explain motion due to a uniform velocity in one direction and a uniform acceleration in a perpendicular direction.



PROJECTILE is a body which is thrown horizontally or at an angle relative to the horizontal which follows a curved path called trajectory.

A projectile is an object moving in two dimensions under the influence of Earth's gravity; its path is a parabola

Examples:
Ball being thrown, water coming out of the hose, a bullet fired from a gun, arrow shot from a bow, fountains.

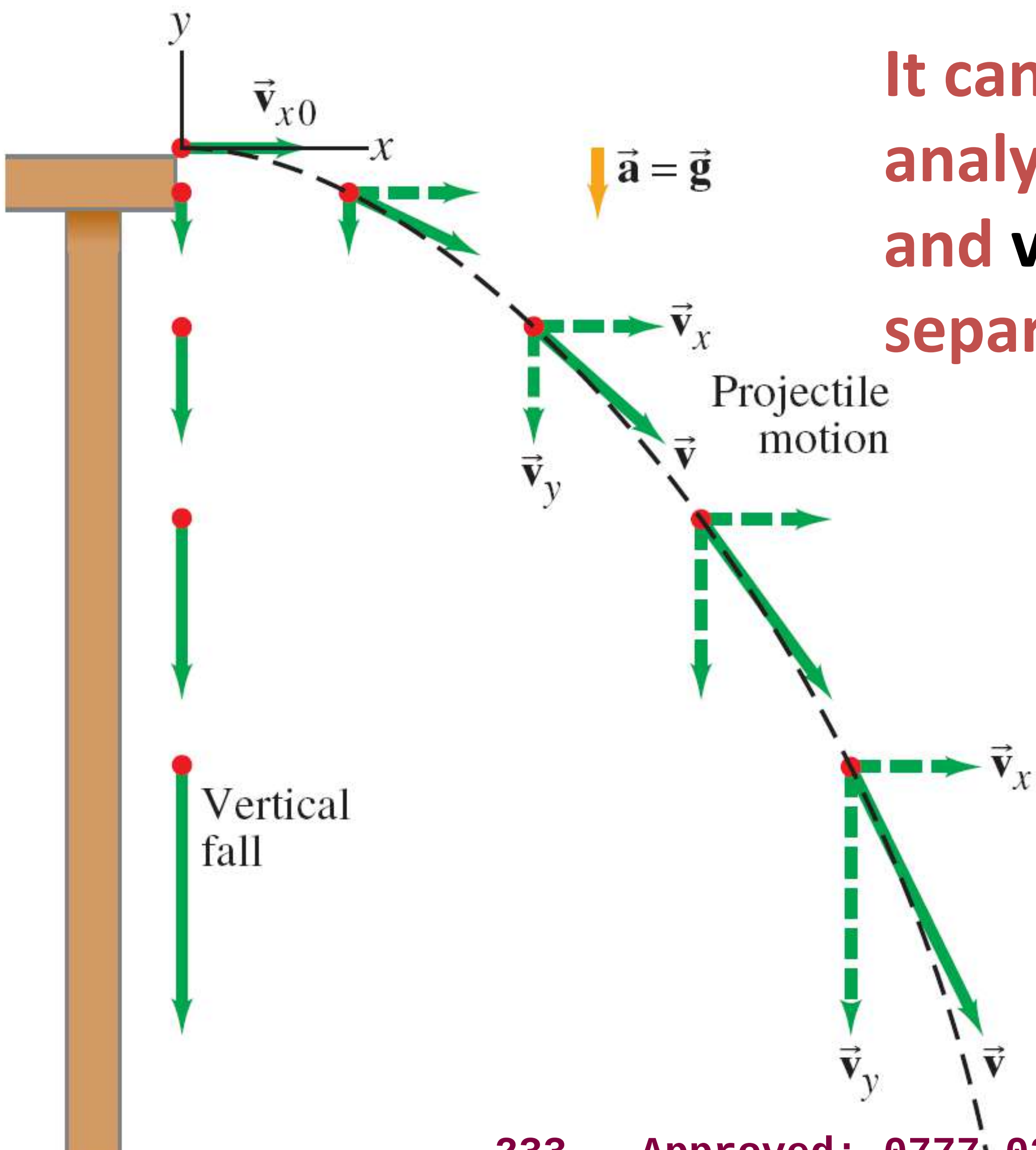
What is projectile motion?

*Made up of **horizontal** and **vertical** components

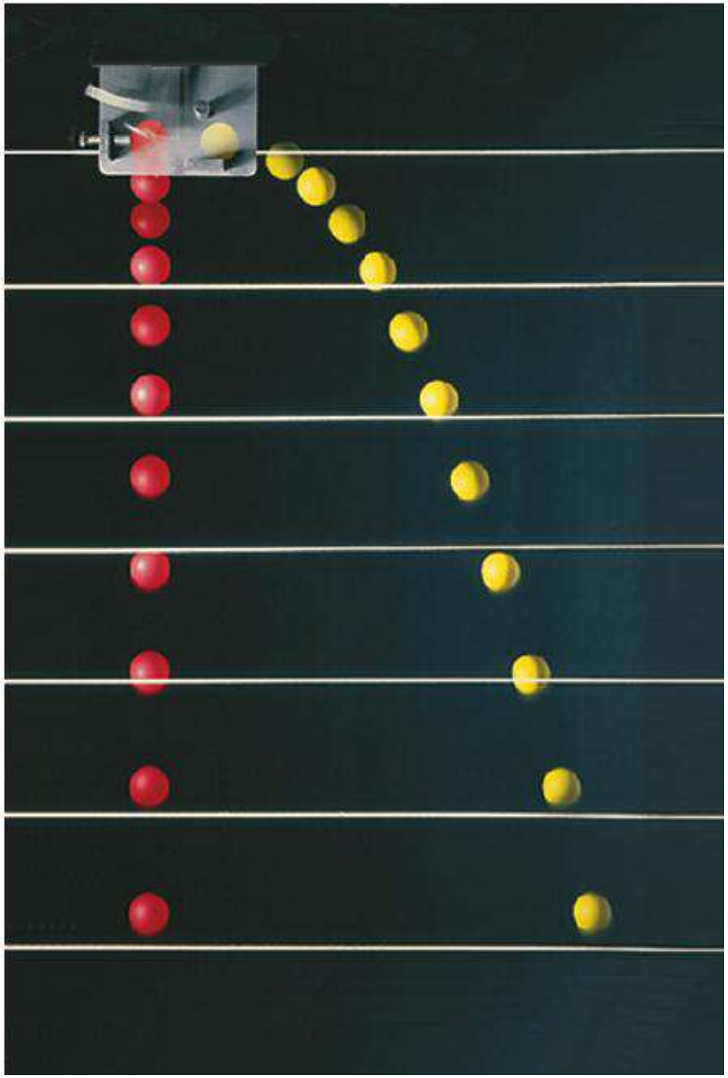
*Movement wherein an object is acted upon by gravity and air resistance

*Motion of a body following a curved path

PARABOLIC MOTION OF PROJECTILE



It can be understood by analyzing the **horizontal** and **vertical** motions separately.



The speed in the *x*-direction is constant; in the *y*-direction the object moves with constant acceleration *g*.

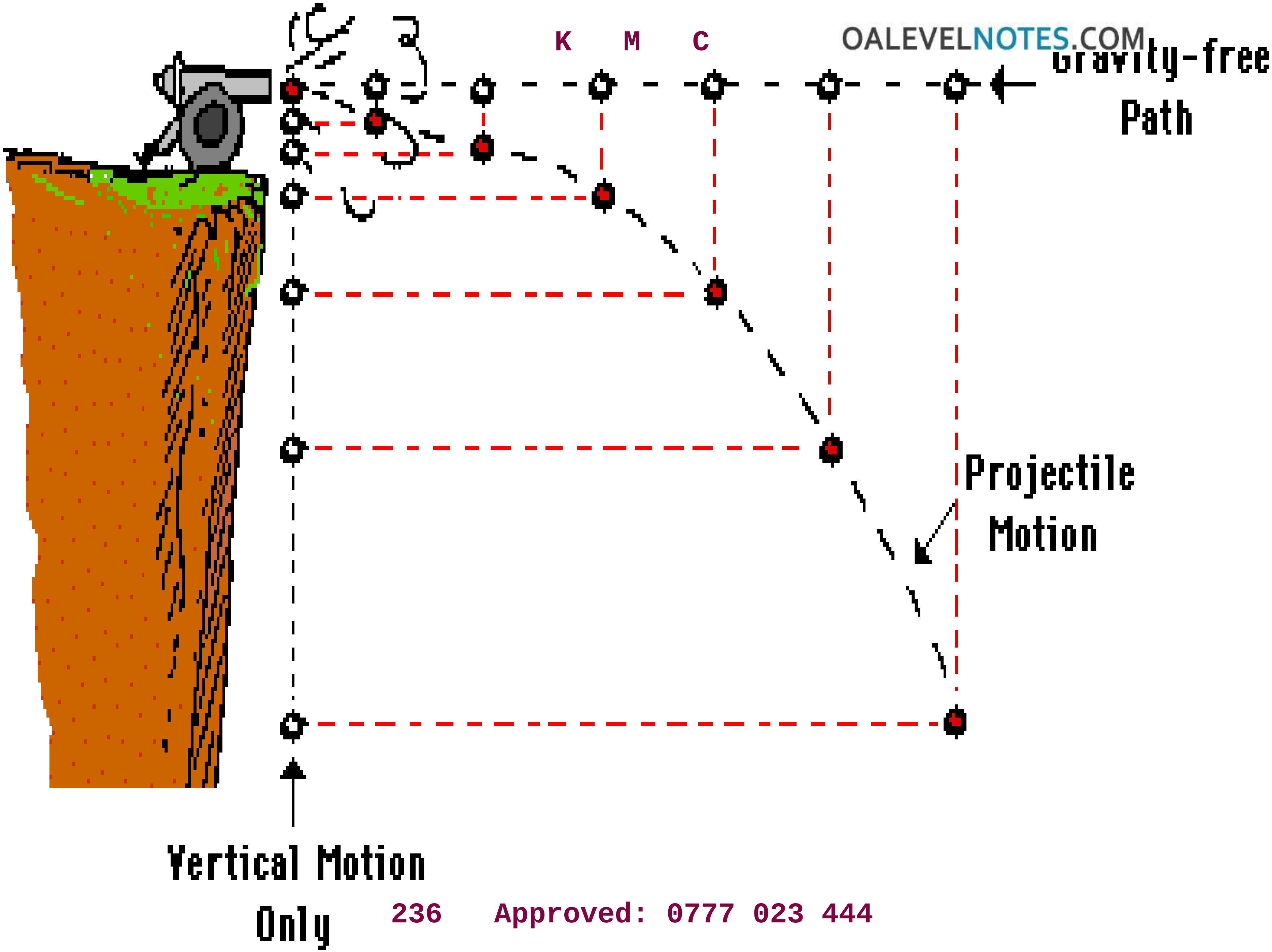
This photograph shows two balls that start to fall at the same time. The one on the right has an initial speed in the *x*-direction. It can be seen that vertical positions of the two balls are identical at identical times, while the horizontal position of the yellow ball increases linearly.

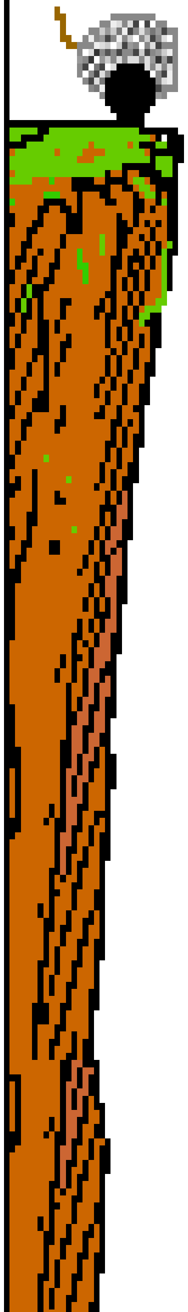
REMEMBER:

1. The horizontal velocity of a projectile is *constant* (never changing in value),

2. There is uniform vertical acceleration *caused by gravity*; its value is 9.8 m/s^2

3. The vertical velocity of a projectile changes by ~10 m/s each second,
the horizontal motion of a projectile is *independent* of its vertical motion.


Gravity-free
Path
Projectile
Motion
Vertical Motion
Only



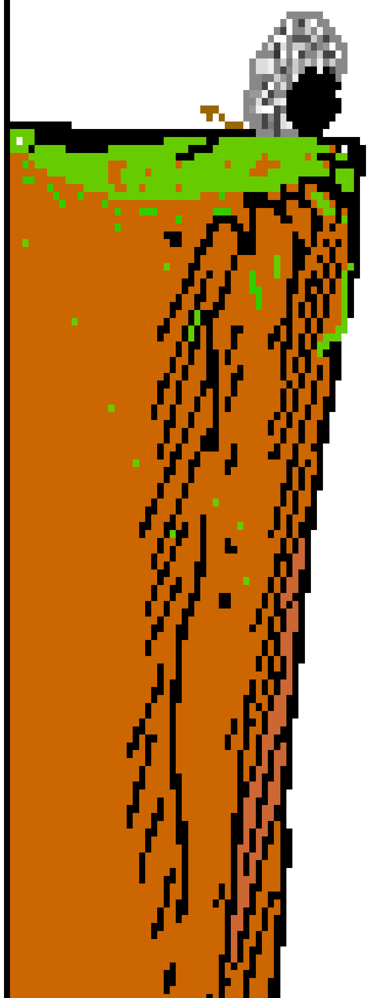
PROJECTILE I

(SIMPLE PROJECTILE)

$t = \text{--}\ s$

$v_x = \text{--}\ m/s \quad v_y = \text{--}\ m/s$

PROJECTILE II (WITH ANGLE)



$t = --\ s$

$v_x = --\ m/s \quad v_y = --\ m/s$

***All vertical components have y subscripts :**

v_y, d_y, t_y,

***All horizontal components have x subscripts:**

v_x, d_x

RANGE is the horizontal displacement of the projectile (d_x)

MAXIMUM HEIGHT is the vertical displacement of the projectile (d_y)

How to calculate – Projectile Motion

(From your reference book)

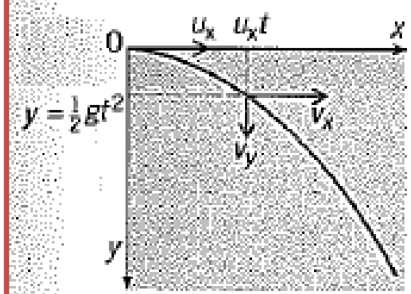
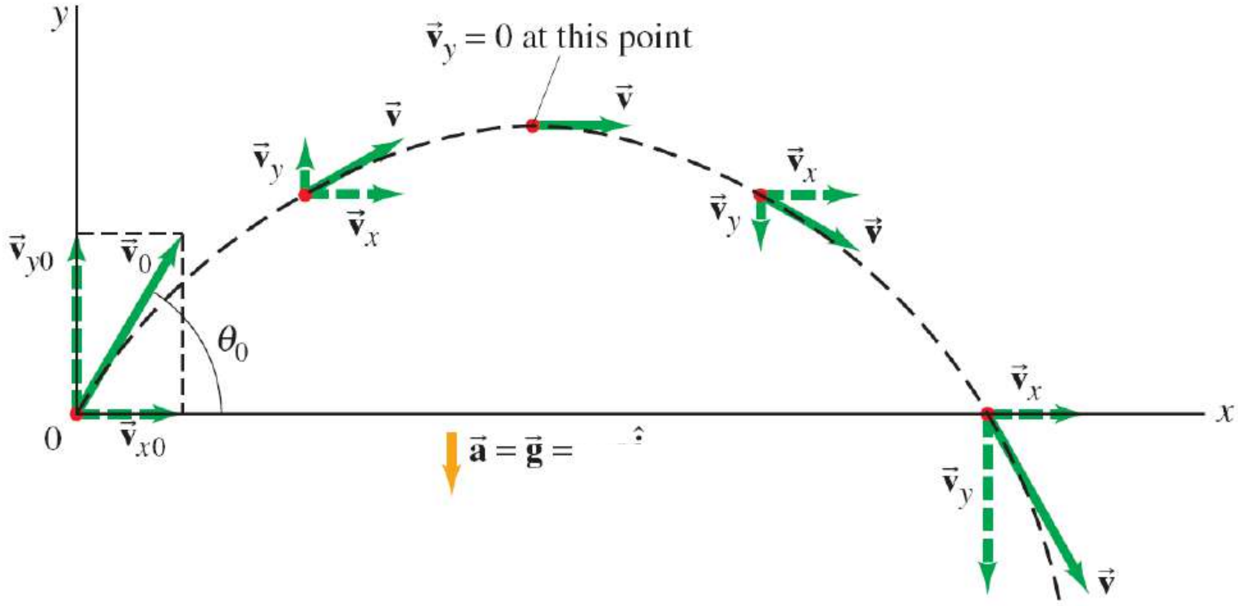


Figure 3.18

This topic is often called **projectile motion.** Galileo first gave an accurate analysis of this motion. He did so by splitting the motion up into its vertical and horizontal components, and considering these separately. The key is that the two components can be considered independently.

As an example, think about a particle sent off in a horizontal direction and subject to a vertical gravitational force (its weight). As before, air resistance will be neglected. We will analyse the motion in terms of the horizontal and vertical components of velocity. The particle is projected at time $t = 0$ at the origin of a system of x, y co-ordinates (Figure 3.18) with velocity u_x in the x-direction. Think first about the particle's vertical motion (in the y-direction). Throughout the motion, it has an acceleration of g (the acceleration of free fall) in the y-direction. The initial value of the vertical component of velocity is $u_y = 0$. The vertical component increases continuously under the uniform acceleration g. Using $v = u + at$, its value v_y at time t is given by $v_y = gt$. Also at time t, the vertical displacement y downwards is given by $y = \frac{1}{2}gt^2$. Now for the horizontal motion (in the x-direction): here the acceleration is zero, so the horizontal component of velocity remains constant at u_x. At time t the horizontal displacement x is given by $x = u_x t$. To find the velocity of the particle at any time t, the two components v_x and v_y must be added vectorially. The direction of the resultant vector is the direction of motion of the particle. The curve traced out by a particle subject to a constant force in one direction is a **parabola**.

If an object is **launched** at an initial angle of ϑ_0 with the horizontal, the analysis is similar except that the initial velocity has a **vertical** component.



Path of a projectile fired with initial velocity v_0 at angle θ_0 to the horizontal. Path is shown dashed in black, the velocity vectors are green arrows, and velocity components are dashed. The acceleration a = dv/dt is downward. That is, a = g.

(Not in syllabus, only for your info)

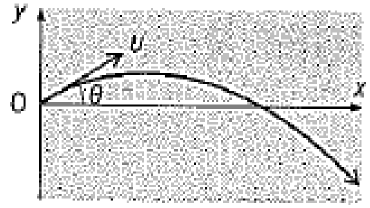


Figure 3.20

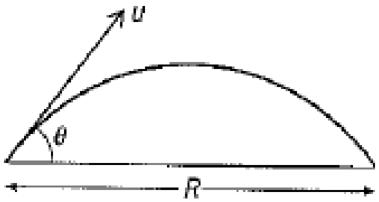


Figure 3.21

If the particle had been sent off with velocity u at an angle θ to the horizontal, as in Figure 3.20, the only difference to the analysis of the motion is that the initial y-component of velocity is $u \sin \theta$. In the example illustrated in Figure 3.20 this is upwards. Because of the downwards acceleration g, the y-component of velocity decreases to zero, at which time the particle is at the crest of its path, and then increases in magnitude again but this time in the opposite direction. The path is again a parabola.

For the particular case of a particle projected with velocity u at an angle θ to the horizontal from a point on level ground (Figure 3.21), the range R is defined as the distance from the point of projection to the point at which the particle reaches the ground again. We can show that R is given by

$$R = \frac{(u^2 \sin 2\theta)}{g}$$

Sample Problem – Projectile Motion

A stone is thrown from the top of a vertical cliff, 45 m high above level ground, with an initial velocity of 15 m s^{-1} in a horizontal direction (Figure 3.22). How long does it take to reach the ground? How far from the base of the cliff is it when it reaches the ground?

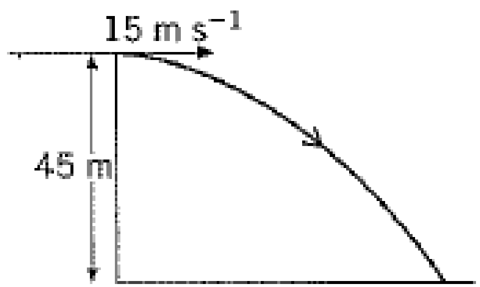


Figure 3.22

To find the time t for which the stone is in the air, work with the vertical component of the motion, for which we know that the initial component of velocity is zero, the displacement $y = 45$ m, and the acceleration a is 9.81 m s^{-2}. The equation linking these is $y = \frac{1}{2}gt^2$. Substituting the values, we have $45 = \frac{1}{2} \times 9.81t^2$. This gives $t = \sqrt{(2 \times 45/9.81)} =$ **3.0 s**.

For the second part of the question, we need to find the horizontal distance x travelled in the time t. Because the horizontal component of the motion is not accelerating, x is given simply by $x = u_x t$. Substituting the values, we have $x = 15 \times 3.0 =$ **45 m**.

Any Questions?

Matter

Deformation of Solids

Marline Kurishingal

Syllabus content

Section		AS	A2
III Matter	9. Phases of matter	✓	
	10. Deformation of solids	✓	
	11. Ideal gases		✓
	12. Temperature		✓
	13. Thermal properties of materials		✓

Section III: Matter

Recommended prior knowledge

Candidates should be able to describe matter in terms of particles, with a qualitative understanding of their behaviour.

Syllabus content

10. Deformation of solids

Content	Learning outcomes
10.1 Stress, strain	Candidates should be able to:
10.2 Elastic and plastic behaviour	*(a)* appreciate that deformation is caused by a force and that, in one dimension, the deformation can be tensile or compressive
	(b) describe the behaviour of springs in terms of load, extension, elastic limit, Hooke's law and the spring constant (i.e. force per unit extension)
	(c) define and use the terms stress, strain and the Young modulus
	(d) describe an experiment to determine the Young modulus of a metal in the form of a wire
	(e) distinguish between elastic and plastic deformation of a material
	(f) deduce the strain energy in a deformed material from the area under the force-extension graph
	(g) demonstrate knowledge of the force-extension graphs for typical ductile, brittle and polymeric materials, including an understanding of ultimate tensile stress.

Deformation of Solids

Definitions:

- **Stress**: is a measure of the force required to cause a particular deformation.
- **Strain**: is a measure of the degree of deformation.
- **Elastic Modulus**: the ratio of stress to strain

$$\text{Elastic Modulus} = \frac{\text{stress}}{\text{strain}}$$

The elastic modulus determines the amount of force required per unit deformation. A material with large elastic modulus is difficult to deform, while one with small elastic modulus is easier to deform.

Deformation of Solids : Changes in Length

Changes in Length

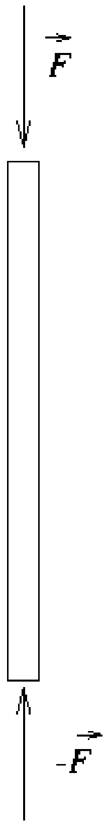
To stretch or compress something you must exert a force on it at either end.

Tensile Stress is the force per unit cross-sectional area exerted on the ends.

(Note the surface whose area we wish to measure is perpendicular to the force.)

Changes in Length (continued)

Tensile Stress



- **Tensile Strain** is the fractional change in original length.
- **Young's Modulus** (*Y*) is the ratio of tensile stress to tensile strain:

$$Y = \frac{\text{tensile stress}}{\text{tensile strain}} = \frac{F/A}{\Delta L/L_O} = \frac{F L_O}{A \Delta L}$$

where *F* is the applied force, L_O is the original length of the object, *A* is the cross-sectional area of the object, and ΔL is the change in the length of the object. Notice that *Y* has S.I. units of N/m^2.

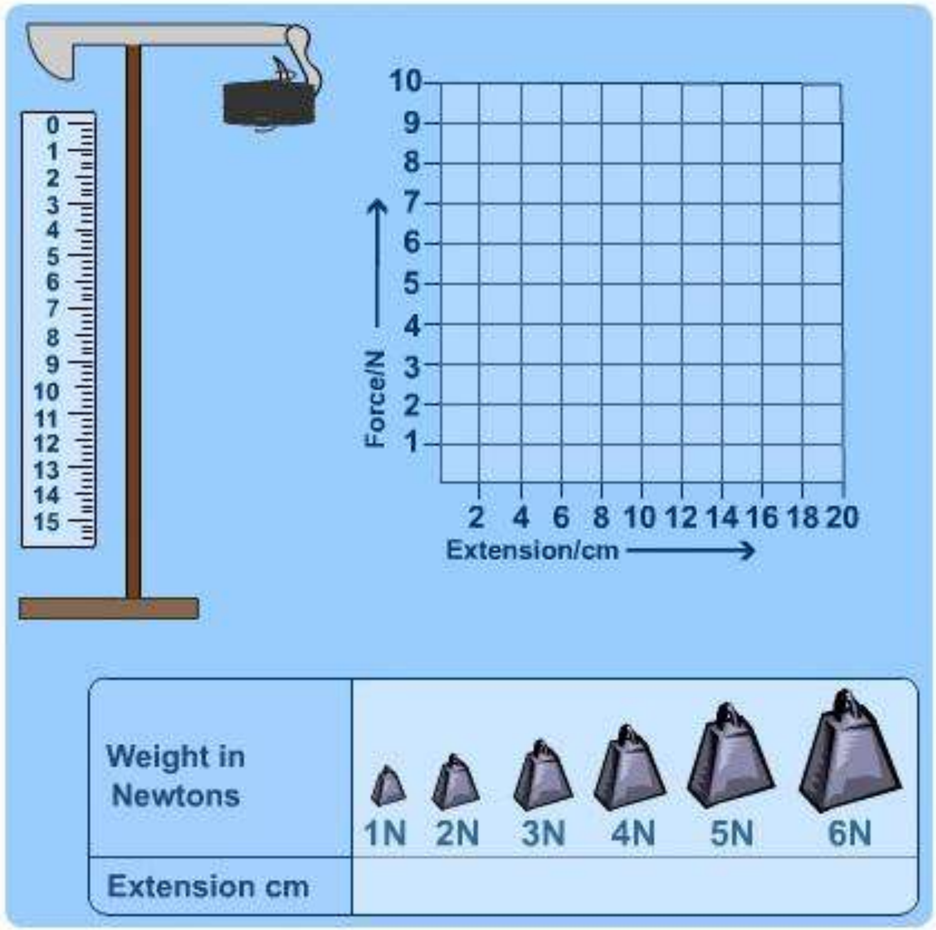
Hooke's Law

- Hooke's Law states that, for relatively small deformations of an object, the displacement of the deformation is directly proportional to the deforming force or load.

- Forces can cause objects to **deform**.

- The way in which an object deforms depends on its dimensions, the material it is made of, the size of the force and direction of the force.

If you measure how a spring stretches (extends its length) as you apply increasing force and plot extension (e) against force (F);



the graph will be a straight line.

Note: Because the force acting on the spring (or any object), causes stretching; it is sometimes called tension or tensile force.

This shows that **Force** is proportional to **extension. This is Hooke's law. It can be written as:**

F = ke

Where:.

F = tension acting on the spring.

e is extension = (l-l_o); l is the stretched length and l_o is original length, and.

k is the gradient of the graph above. It is known as the spring constant.

The above equation can be rearranged as

$$k = \frac{F}{e}$$

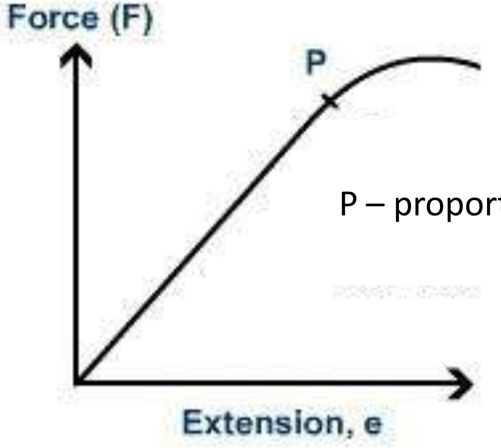
Spring constant = Applied force/extension

The **spring constant** k is measured in **Nm^{-1}** because it is the **force per unit extension.**

The value of *k* does not change unless you change the shape of the spring or the material that the spring is made of.

A stiffer spring has a greater value for the spring constant

In fact, a vast majority of materials obey Hooke's law for at least a part of the range of their deformation behaviour. (e.g. glass rods, metal wires).



P – proportionality limit

In the diagram above, if you extend the spring beyond point P, and then unload it completely; it won't return to its original shape. It has been permanently deformed. We call this point the **elastic limit** - the limit of **elastic behaviour.**

If a material returns to its original size and shape when you remove the forces stretching or deforming it (reversible deformation), we say that the material is demonstrating **elastic behaviour.**

If deformation remains (irreversible deformation) after the forces are removed then it is a sign of **plastic behaviour.**

Calculating stress

- **Stress**

➢ Stress is a measure of how strong a material is. This is defined as how much force the material can stand without undergoing some sort of physical change.

➢ Hence, the formula for calculating stress is the same as the formula for calculating pressure: $\sigma = \frac{F}{A}$

➢ where σ is stress (in Newtons per square metre but usually Pascals, commonly abbreviated Pa).

Calculating strain

Stress causes strain.

- Applying force on an object causes it to stretch. Strain is a measure of how much an object is being stretched. Strain is the ratio of extension to the original length.
- The formula for strain is: $\epsilon = \frac{\Delta l}{l_0} = \frac{l - l_0}{l_0} = \frac{l}{l_0} - 1$
- Where l_0 is the original length of some bar being stretched, and l is its length after it has been stretched. Δl is the extension of the bar, the difference between these two lengths.

Calculating Young's Modulus

- Young's Modulus is a measure of the stiffness of a material. It is defined as the ratio of stress to strain. It states how much a material will stretch (i.e., how much strain it will undergo) as a result of a given amount of stress.
- The formula for calculating it is: $E = \frac{\sigma}{\epsilon}$
- Strain is unit less so Young's Modulus has the same units as stress, i.e. N/m^2 or Pa.

Quantity	Equation	Symbol	Units
Stress	tension/cross sectional area $= F / A$	(sigma) σ	$N\ m^{-2} = Pa$
Strain	extension per **original** length $= \Delta L/L$	(epsilon) ε	no units (because it's a ratio of two lengths)
Young Modulus	stress/strain	E	$N\ m^{-2} = Pa$

Tensile strength & Yield strength

➢Tensile Strength

Tensile strength which is also known as **Ultimate tensile strength** or **ultimate strength** is the maximum stress that a material can withstand while being stretched or pulled before failing or breaking. Tensile strength is the opposite of compressive strength and the values can be quite different.

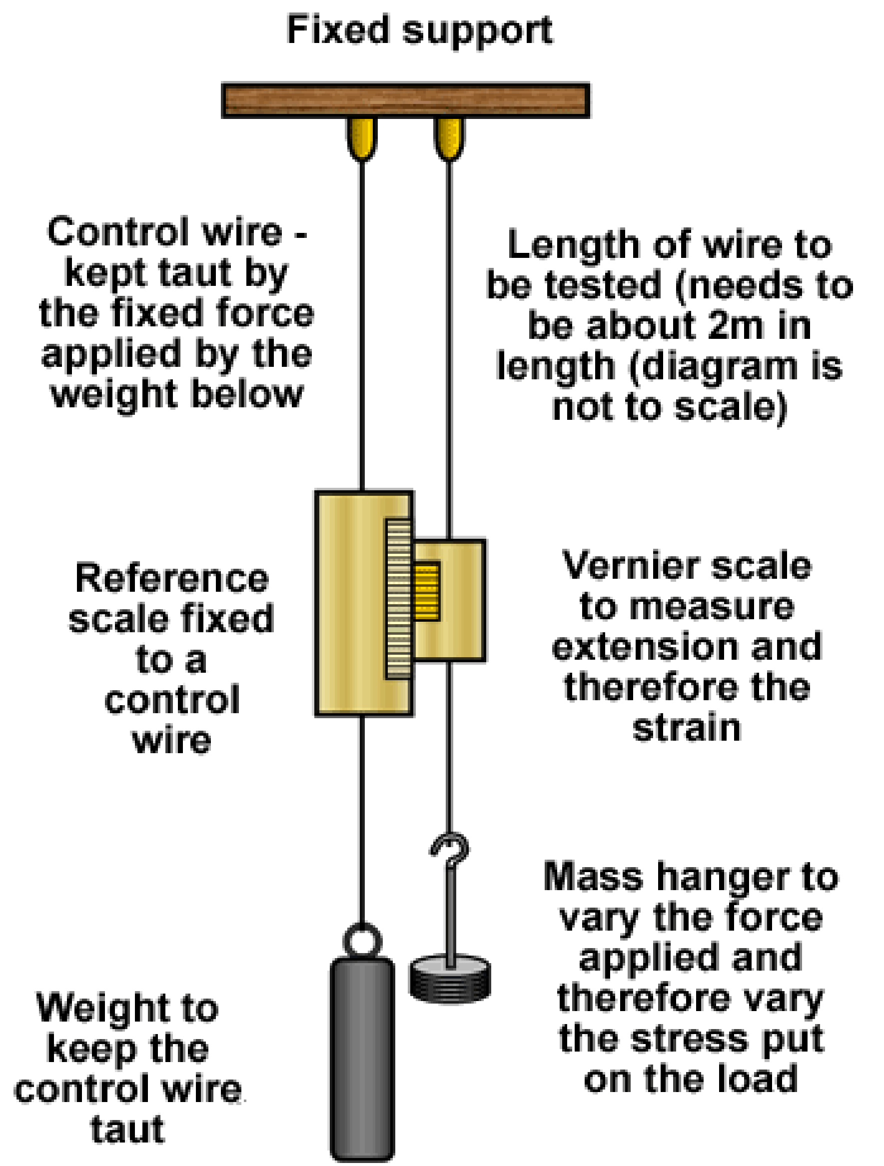
➢Yield Stress or Yield strength or Yield point

The yield stress is the level of stress at which a material will deform permanently. This is also known as Yield strength or Yield point. Prior to the yield point the material will deform elastically and will return to its original shape when the applied stress is removed.

It can be experimentally determined from the slope of a stress-strain curve created during tensile tests conducted on a sample of the material.

- The value of the Young's Modulus is quoted for various materials but the value is only approximate.
- This is because Young's Modulus can vary considerably depending on the exact composition of the material.
- For example, the value for most metals can vary by 5% or more, depending on the precise composition of the alloy and any heat treatment applied during manufacture.
- If a big force only produces a small extension then the material is 'stiff' and E is a big value. If a force produces a big extension then the material is not very stiff - it is easier to stretch and the value of E will be smaller.

An experiment to measure the Young's Modulus



An experiment to measure the Young's Modulus (continued)

- To minimize errors the control wire is the same length, diameter and material as the test wire. This means that **errors due to expansion (from the surroundings)** during the experiment are avoided as the test wire and control wire would both expand by the same amount and the scale would adjust position and eliminate the error.
- The wire must have **no kinks** in it otherwise there will be big extensions due to the wire straightening out rather than just stretching.
- Care must be taken that the **limit of proportionality** is **not exceeded**. This can be checked by removing the load after each addition of the weight. If the limit has not been exceeded the wire should return to the length it was before the weight was added.
- The wire is as **long** as possible (usually about 2m long) and it is as **thin** as possible so that **as big an extension as possible** can be recorded. (A typical extension for a 5N loading will be 1mm).

An experiment to measure the Young's Modulus (continued)

- The test wire is loaded with the weight hanger so that it is taut before readings are taken.
- The vernier scale is read and the result recorded as addition of 0N.
- Weights - usually starting at 0N and increasing in 5N increments to 100N - are then added and a reading of the vernier scale is taken at each addition.
- The experiment should be repeated twice and any anomalous results repeated and checked.

An experiment to measure the Young's Modulus (continued)

- A graph of load against extension is plotted. It should be a straight line through the origin (provided measurements are accurate).
- The gradient of that graph will be F/e. Using that value we can find the value of Young's Modulus for the wire.

$$E = \frac{\text{stress}}{\text{strain}}$$

$$= \frac{\frac{F}{A}}{\frac{e}{\ell}} = \frac{F\ell}{A\,e}$$

$$= \ell/A \times \text{Gradient}$$

Proportionality limit and Yield strength

- **Proportionality limit and Elastic limit**

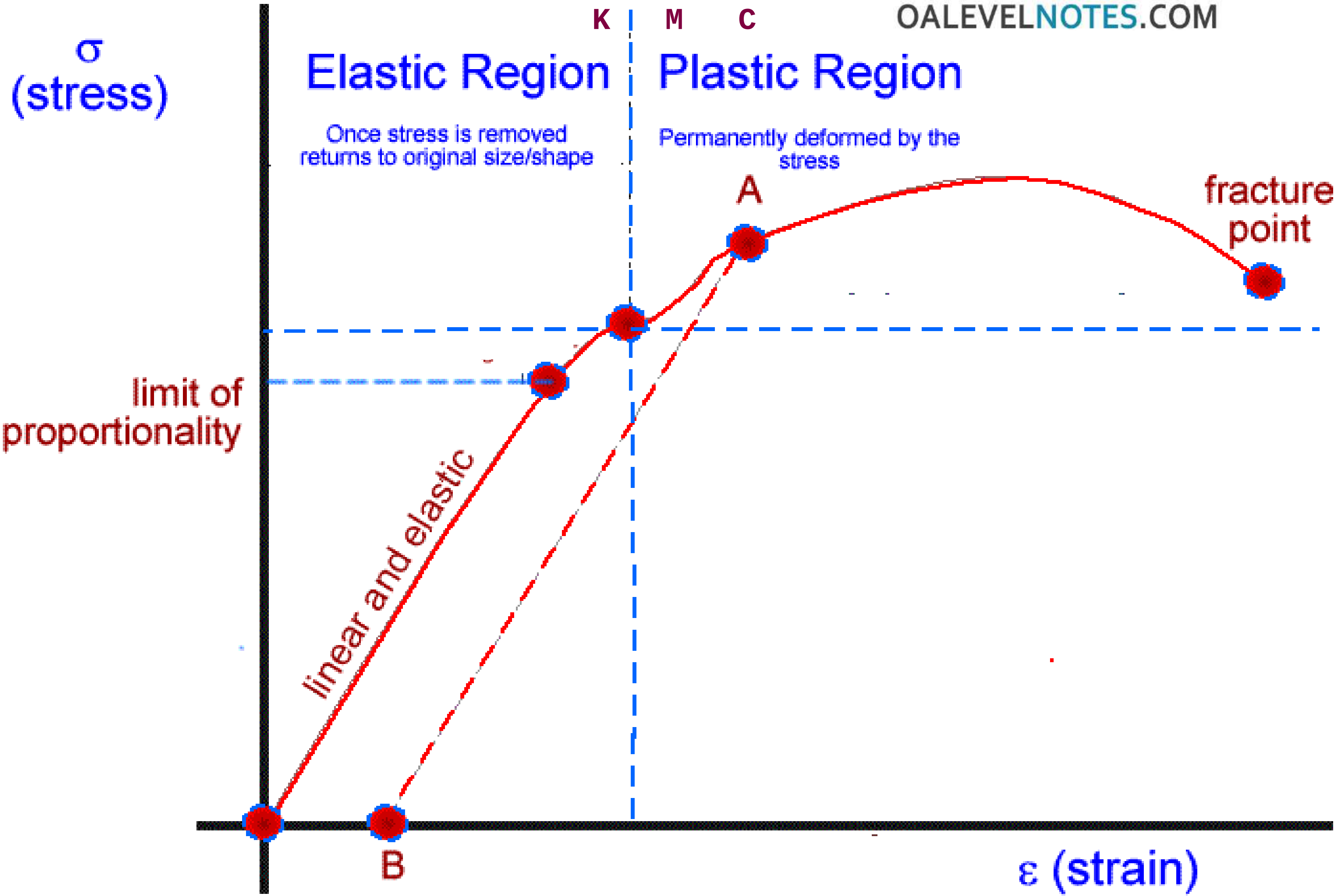
  Maximum amount a material can be stretched by a force and still (or may) return to its original shape depends on the material.

- **Yield point or Yield strength**

  The point where there is a large permanent change in length with no extra load force.

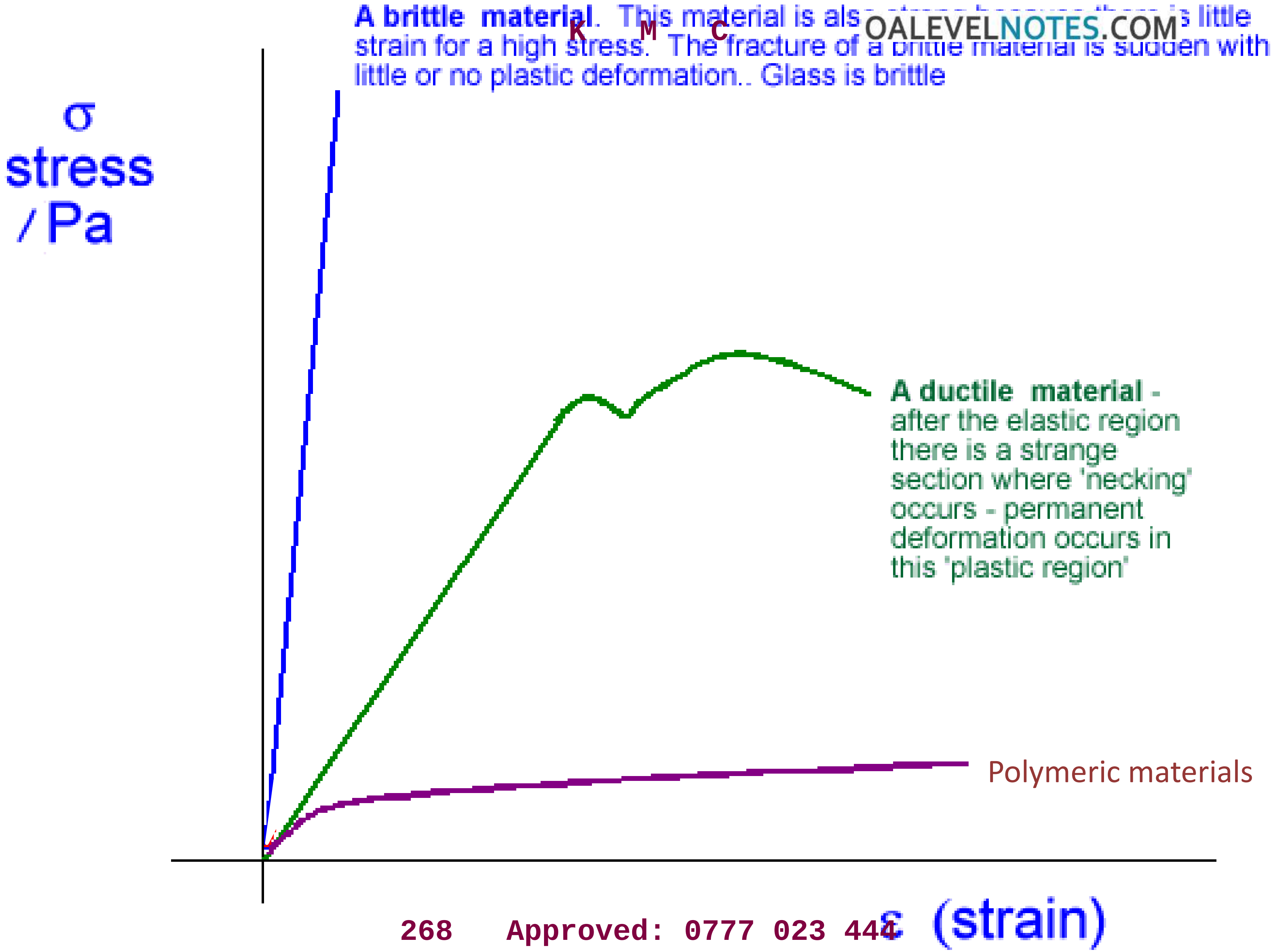
  yield point :- interface between elasticity and plasticity

- Elastic limit - up to which material can sustain the load and return back to its original position.
- Although these two points are so close to each other it can be treated as one, on a case to case basis.
- It depends upon material whether it's brittle or ductile.

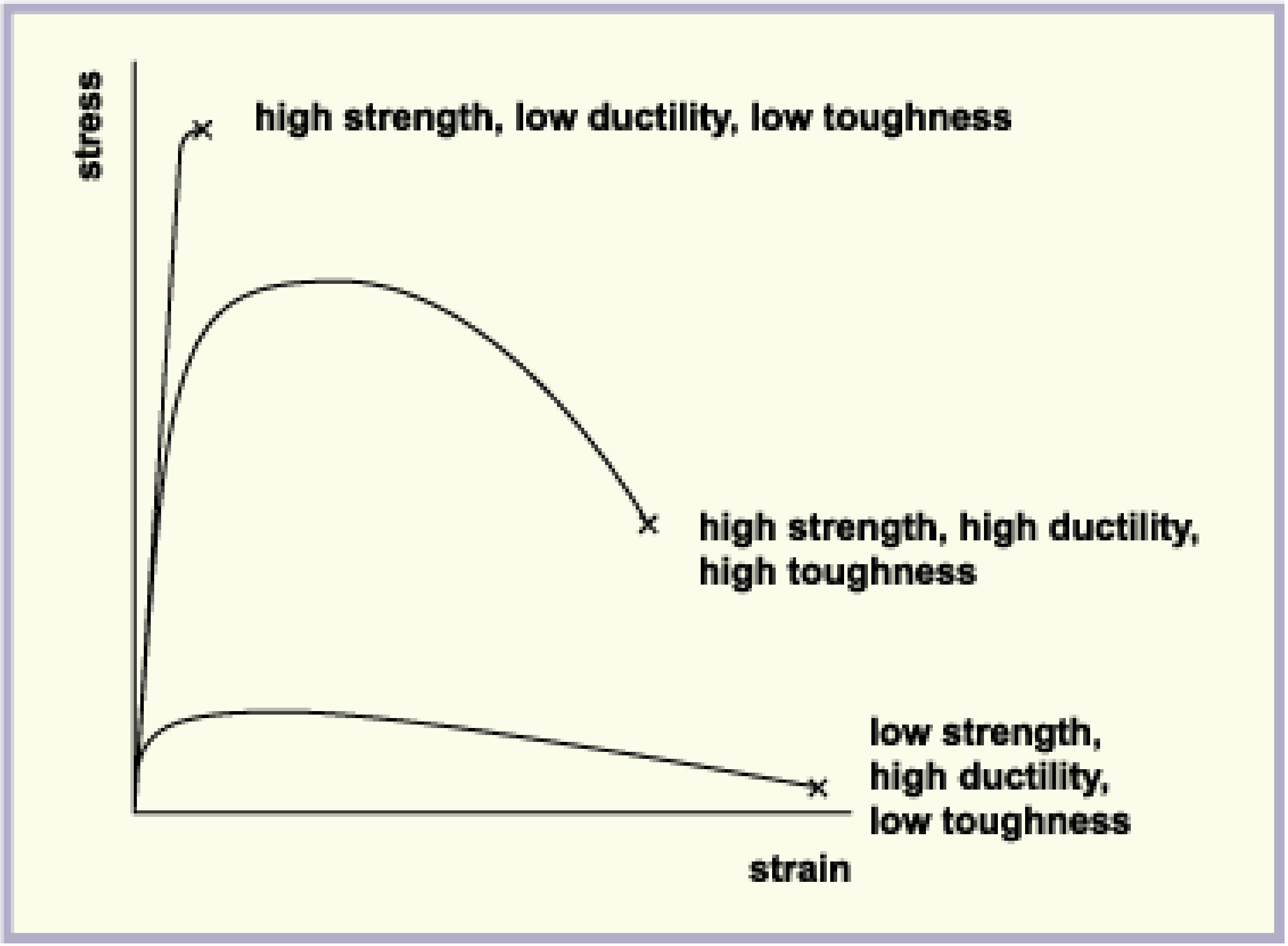


K
M
C
OALEVELNOTES.COM
σ (stress)
Elastic Region
Once stress is removed returns to original size/shape
Plastic Region
Permanently deformed by the stress
A
fracture point
limit of proportionality
linear and elastic
B
ε (strain)

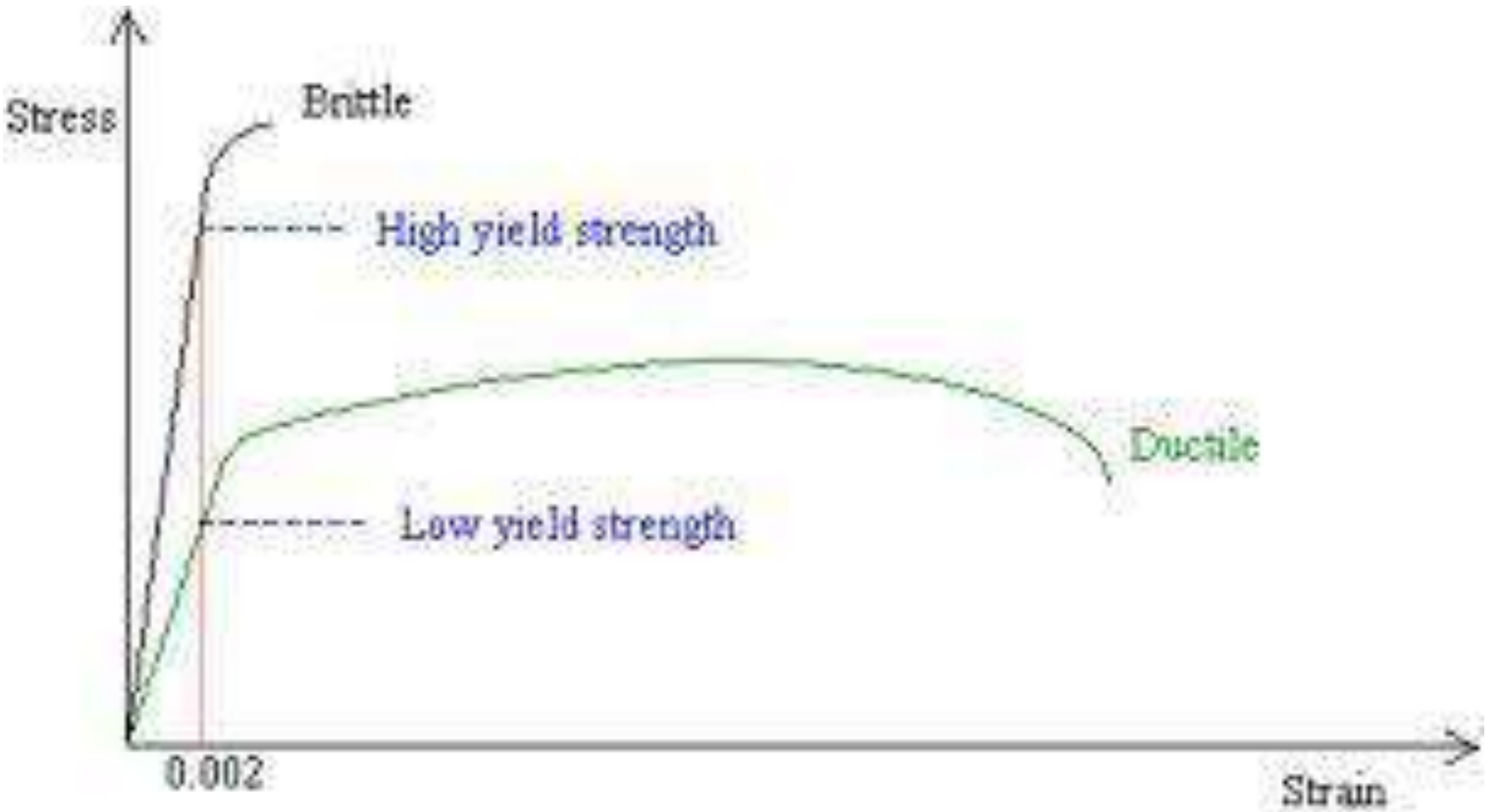
- The stretching behavior is summarized in a stress-strain graph in the previous slide. As the stress is increased initially Hooke's Law is obeyed - the stress-strain relationship for the wire is linear & elastic.
- Just before the plastic region is reached we get the limit of proportionality - beyond this for a small section we see non-linear behaviour but the stretching is still elastic.
- After the *yield strength*, the material enters the plastic deformation region, which means that the stretch of the wire is permanent. (For example, if the wire is stressed to point A on the graph and the stress is slowly decreased, the stress-strain curve follows the dotted line instead of the original curve to point **B** and there is a permanent extention when all stress is removed.) At the facture point the wire snaps.
- Differences in the shape and limits of the stress-strain diagram determines whether a material is considered ductile or brittle, elastic or plastic.


A brittle material. This material is als
s little
strain for a high stress. The fracture of a brittle material is sudden with
little or no plastic deformation.. Glass is brittle
σ stress / Pa
A ductile material - after the elastic region there is a strange section where 'necking' occurs - permanent deformation occurs in this 'plastic region'
Polymeric materials
ε (strain)

Strength, Ductility & Toughness



High Yield strength & Low yield strength



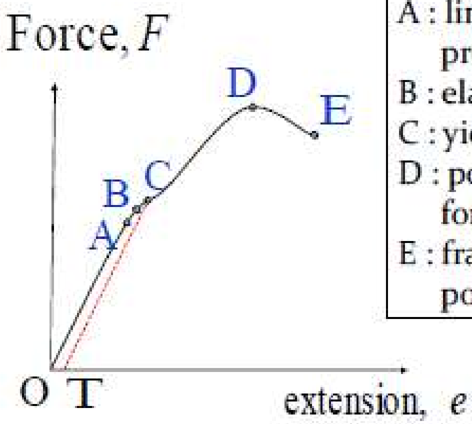
Energy in deformations

- Whenever we apply force to an object, it will cause deformation. If the deformation caused is within the elastic limit, the work done in deforming the object is stored within it as potential energy. We call this (elastic) **'strain energy'**. It can be released from the object by removing the applied force.

- The strain energy then performs work in **un-deforming** the object and returns to its original state.

Force-extension graphs for typical ductile, brittle and polymeric materials, including an understanding of ultimate tensile stress.

Force-Extension Graphs and Stress-Strain Graph



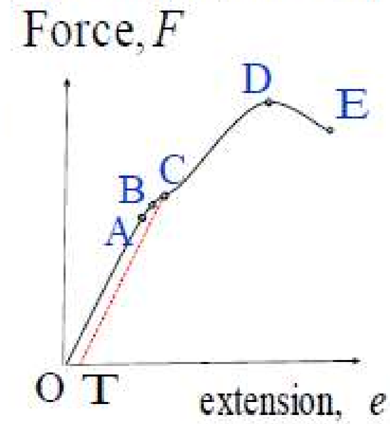
A : limit of proportionality
B : elastic limit
C : yield point
D : point of maximum force (stress)
E : fracture (breaking) point

Force-Extension Graphs

OA

- The force (stress) increases linearly with the elongation (strain) until point A. Point A is the limit of proportionality.

A : limit of proportionality



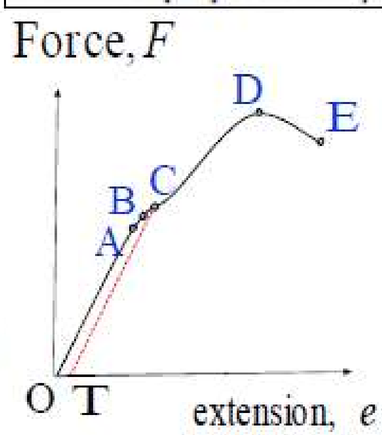
k : force(Hooke) constant

Force-Extension Graphs

OA

- The straight line graph (OA) obeys Hooke's law which states that "*Below the limit of proportionality, the restoring force, F_s is directly proportional to the elongation, e.*"

A : limit of proportionality



k : force(Hooke) constant

Force-Extension Graphs

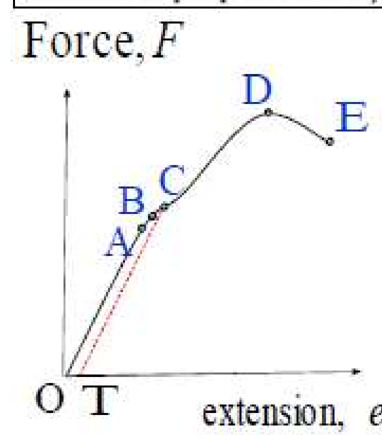
OA

$F_s = -ke$

Where

k = force (Hooke) constant

A : limit of proportionality



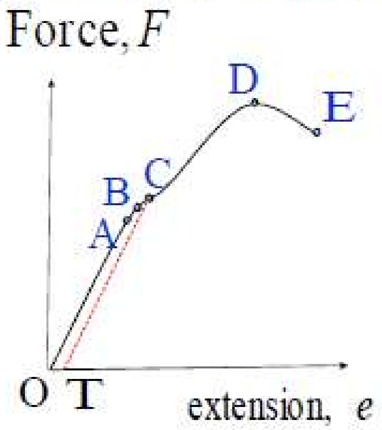
Force-Extension Graphs

k : force(Hooke) constant

OA

- $F_s = -ke$
  Where
  k = force (Hooke) constant
- The negative sign indicates that the restoring force is the opposite direction to increasing elongation.

A : limit of proportionality



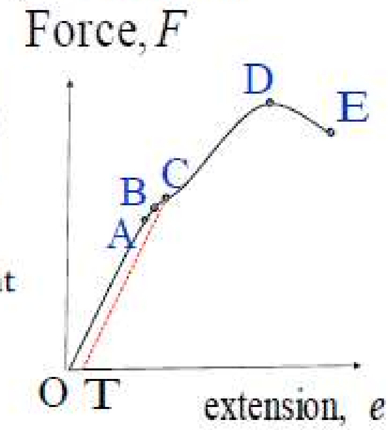
Force-Extension Graphs

k : force(Hooke) constant

B: This is the elastic limit of the material.

- Beyond this point, the material is permanently stretched and will never regain its original shape and length. If the force (stress) is removed, the material has a permanent elongation of OT.

B : elastic limit



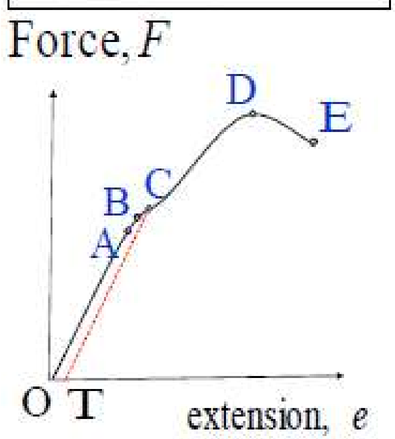
Force-Extension Graphs

k : force(Hooke) constant

OB

- The area between the two parallel line (AO and CT) represents the work done to produce the permanent elongation OT.
- OB region is known as elastic deformation.

B : elastic limit



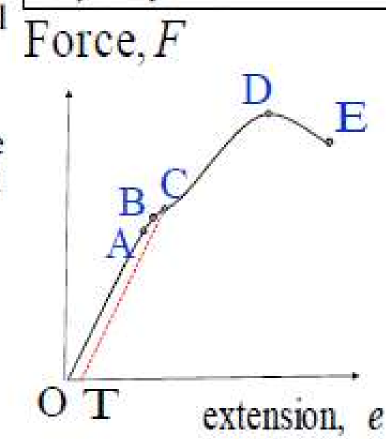
Force-Extension Graphs

k : force(Hooke) constant

C -The yield point marked a change in the internal structure of the material.

- The plane (layer) of the atoms slide across each other resulting in a sudden increase in elongation and the material thins uniformly.

C : yield point



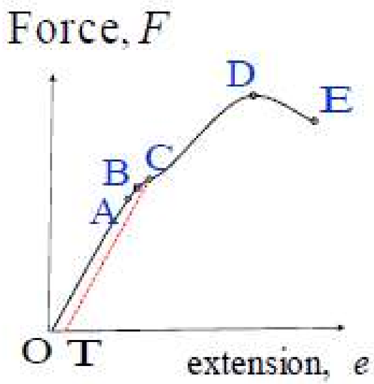
k : force(Hooke) constant

Force-Extension Graphs

D

- The force (stress) on the material is maximum and is known as the breaking force (stress). This is sometimes called the Ultimate Tensile Strength (UTS).

D : point of maximum force (stress)

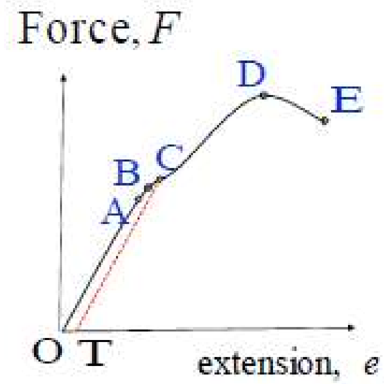


Force-Extension Graphs

E

- This is the point where the material breaks or fractures.

E : fracture (breaking) point



k : force(Hooke) constant

Force-Extension Graphs

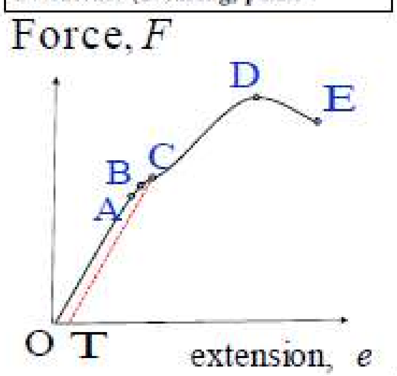
CDE

- This region is known as plastic deformation.
- - When the force (stress) increases, the elongation (strain) increases rapidly.

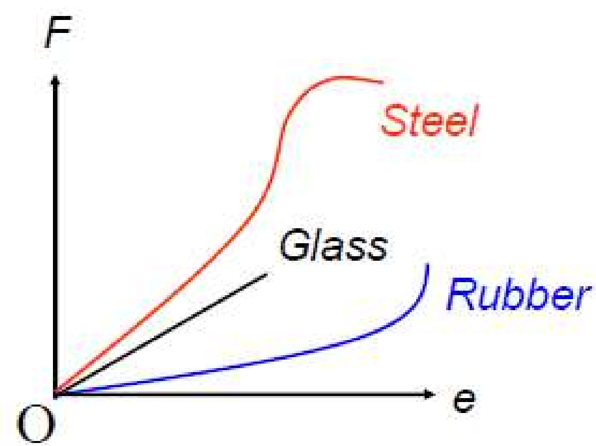
C : yield point

D : point of maximum force (stress)

E : fracture (breaking) point



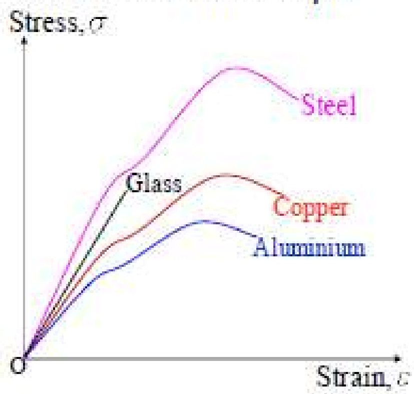
Extension-Force Graphs



Types of materials

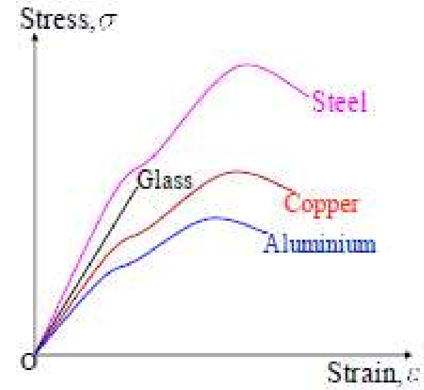
- Ductile materials - undergo plastic deformation before breaking.
- such as steel, copper, aluminium.

Stress-Strain Graph



Types of materials

- Brittle materials - do not show plastic behaviour (deformation).
- such as glass.



Young's Modulus (Y @ E)

- Definition – is defined as *the ratio of the tensile stress to the tensile strain if the limit of proportionality has not been exceeded.*

$$\boxed{Y = \frac{\text{Tensile stress}}{\text{Tensile strain}}} \qquad Y = \frac{\left(\frac{F_\perp}{A}\right)}{\left(\frac{e}{l_0}\right)} \implies \boxed{Y = \frac{F_\perp l_0}{Ae}}$$

Young's Modulus (Y @ E)

- Its dimension is given by

$$[Y] = \frac{[F_\perp][l_0]}{[A][e]} = ML^{-1}T^{-2}$$

- The unit of Young's modulus is kg m^{-1} s^{-2} @ N m^{-2} @ Pa.

Oscillations & Waves

Waves

Marline Kurishingal

Syllabus content

Section		AS	A2
IV Oscillations and waves	14. Oscillations		✓
	15. Waves	✓	
	16. Superposition	✓	

Section III: Matter

Recommended prior knowledge
Candidates should be able to describe matter in terms of particles, with a qualitative understanding of their behaviour.

15. Waves

Content	Learning outcomes
15.1 Progressive waves	Candidates should be able to:
15.2 Transverse and longitudinal waves	*(a)* describe what is meant by wave motion as illustrated by vibration in ropes, springs and ripple tanks
15.3 Polarisation	*(b)* show an understanding of and use the terms displacement, amplitude, phase difference, period, frequency, wavelength and speed
15.4 Determination of speed, frequency and wavelength	*(c)* deduce, from the definitions of speed, frequency and wavelength, the equation $v = f\lambda$
15.5 Electromagnetic spectrum	*(d)* recall and use the equation $v = f\lambda$
	(e) show an understanding that energy is transferred by a progressive wave
	(f) recall and use the relationship $intensity \propto (amplitude)^2$
	(g) compare transverse and longitudinal waves
	(h) analyse and interpret graphical representations of transverse and longitudinal waves
	(i) show an understanding that polarisation is a phenomenon associated with transverse waves
	(j) determine the frequency of sound using a calibrated c.r.o.
	(k) determine the wavelength of sound using stationary waves
	(l) state that all electromagnetic waves travel with the same speed in free space and recall the orders of magnitude of the wavelengths of the principal radiations from radio waves to γ-rays.

Introducing Waves

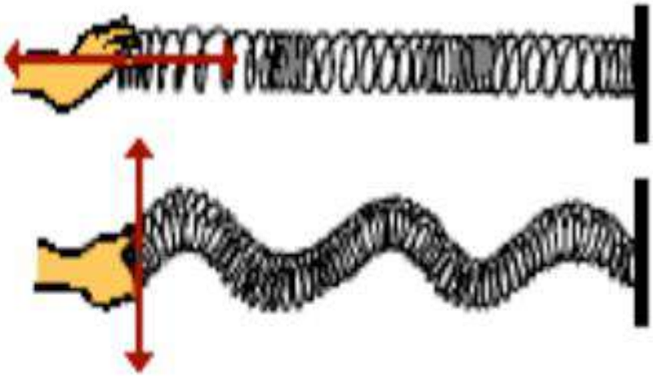
- Waves carry energy.
- For Example, during an earthquake, the seismic waves produced can cause great damage to buildings and the surroundings.
- What is a wave?
- Wave is a method of propagation of energy.

For example, when we drop a pebble into a pond of still water, a few circular ripples move outwards, on the surface of the water. As these circular ripples spread out, energy is being carried with them.

Sources of Waves

- The source of any wave is a ***vibration*** or ***oscillation***.
- For example, the forming of the slinky waves as shown.

➢ Wave motion provides a mechanism for the **transfer of energy** from one point to another ***without*** the physical transfer of the medium between the two points.



Slinky waves can be made by vibrating the first coil back and forth in either a horizontal or a vertical direction.

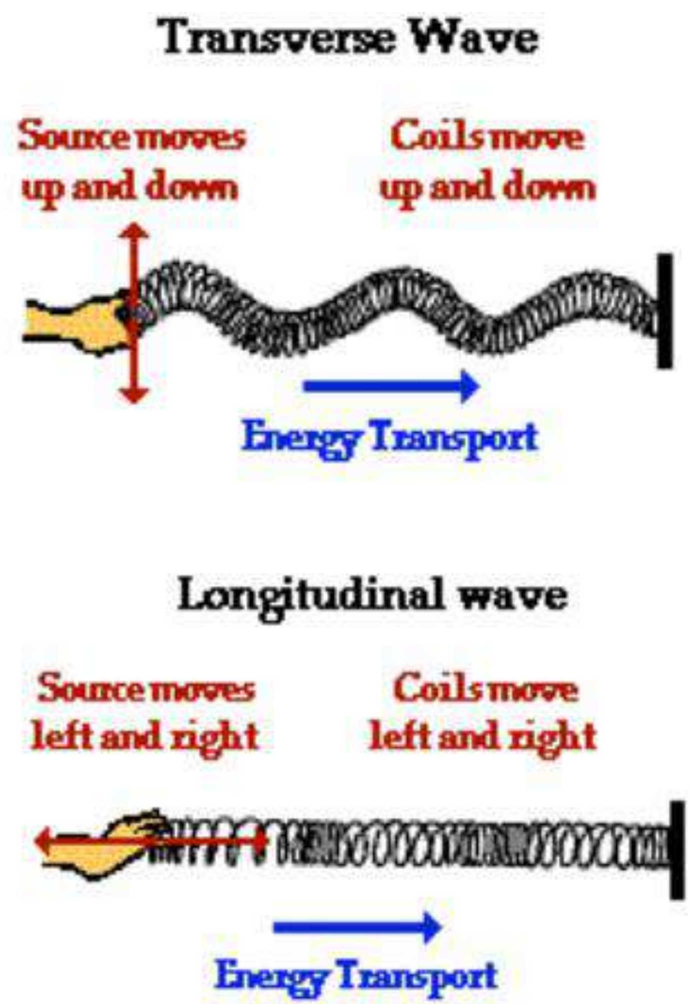
Two Types of Waves

- Transverse Wave

Rope waves, Water waves, Light waves, Radio waves, Electromagnetic waves.

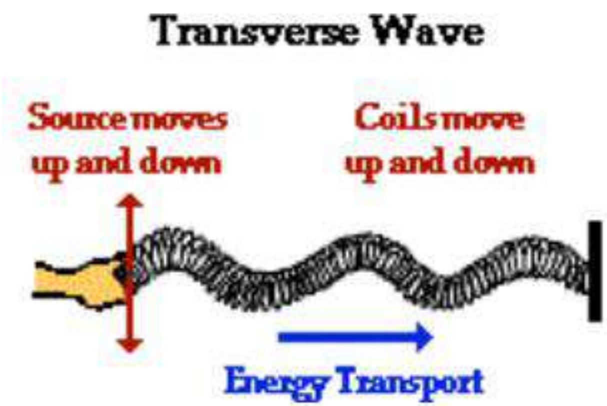
- Longitudinal Wave

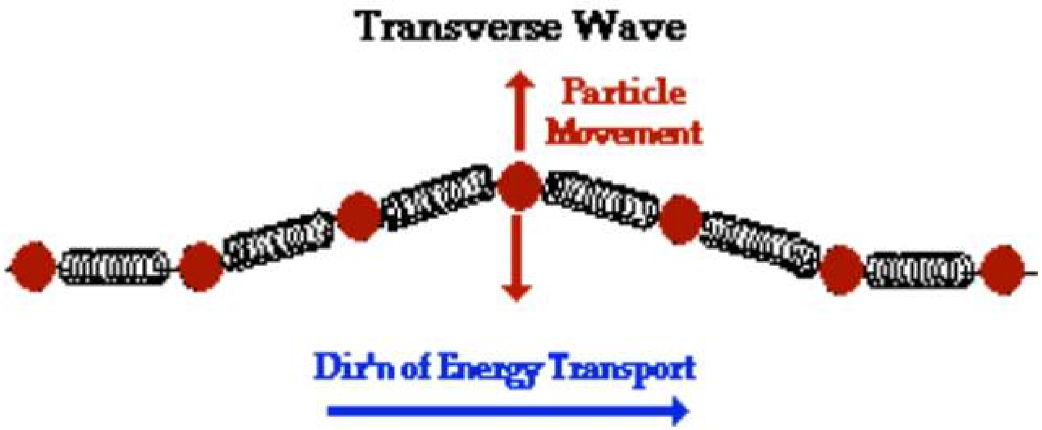
Sound waves and waves produced in a vertical oscillating spring under tension.



Transverse Waves

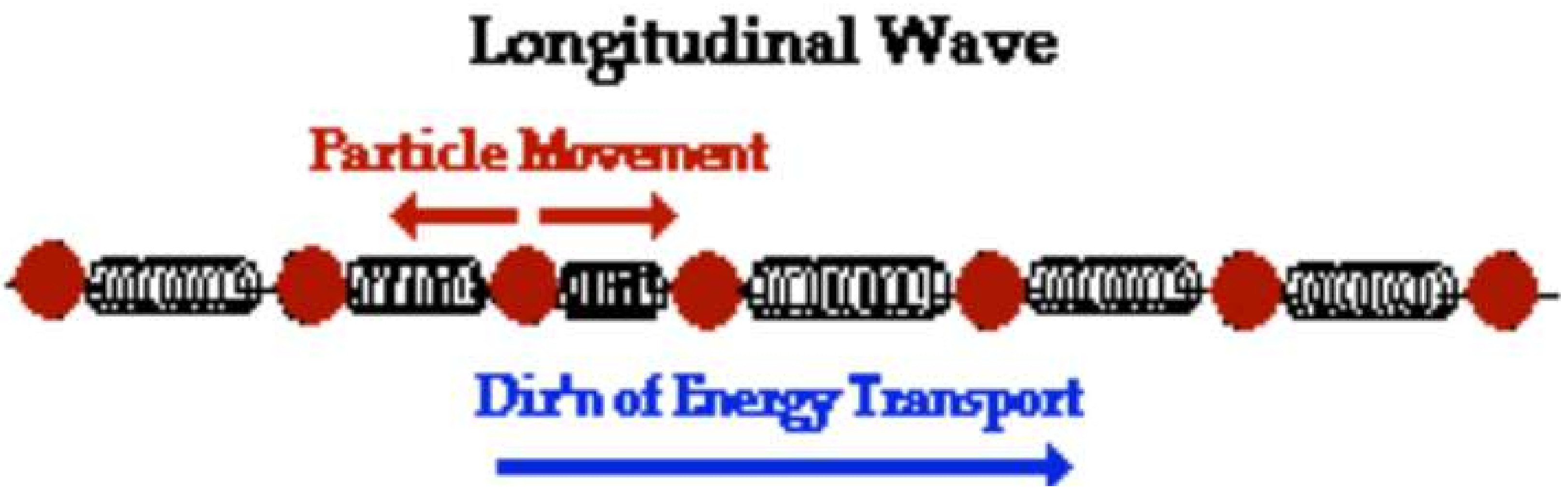
- *Transverse waves* propagate in a direction ***perpendicular*** to the direction of vibration.





Longitudinal Waves

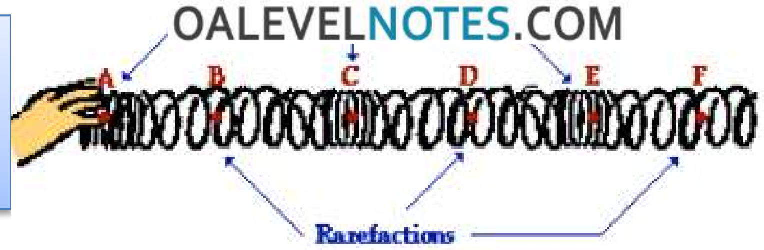
- *Longitudinal waves* propagate in a direction ***parallel*** to the direction of vibration.



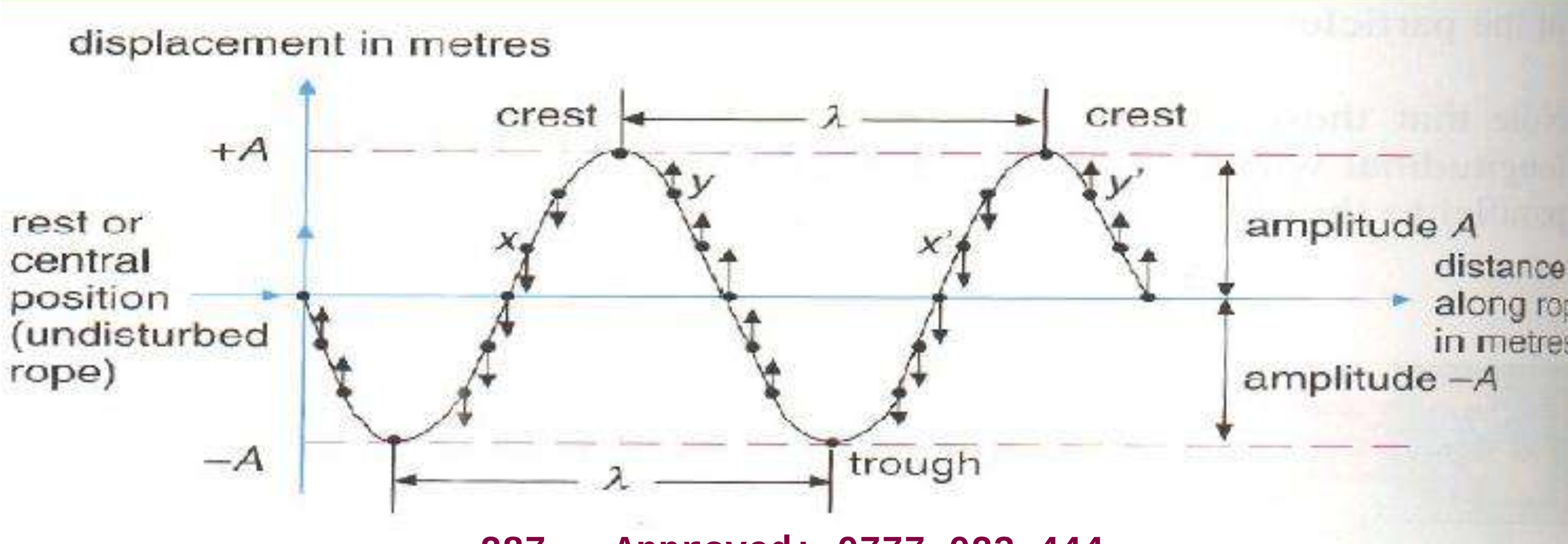
Reference link for Demonstration of waves

http://www.acs.psu.edu/drussell/demos/waves/wavemotion.html

Describing Waves



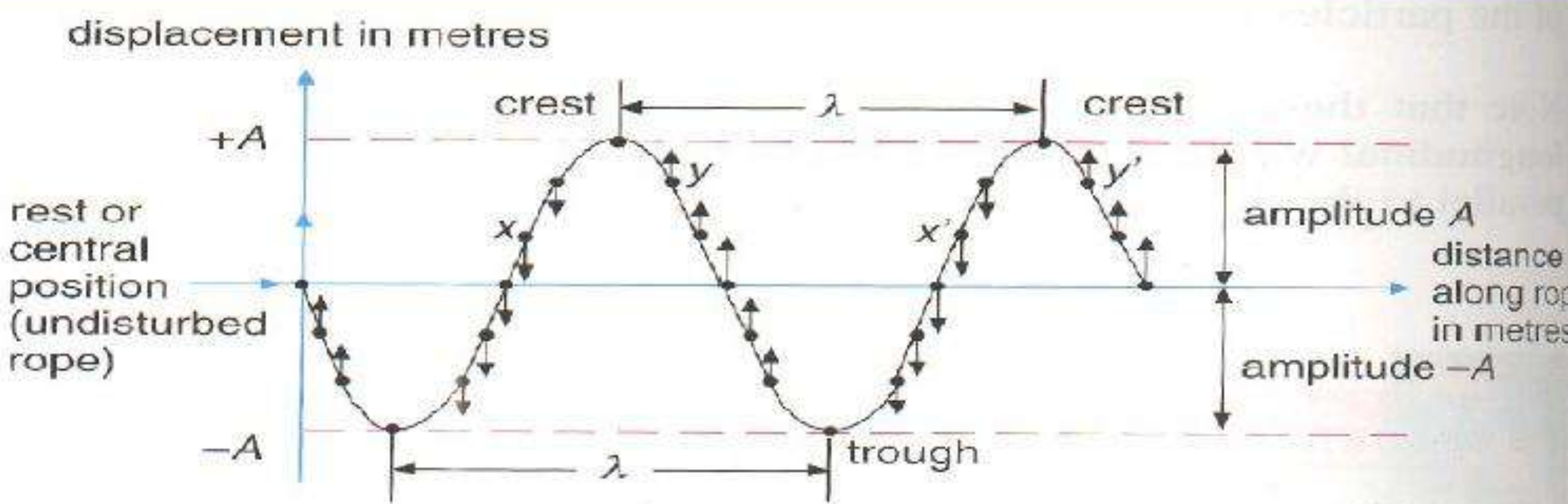
- **Crests and troughs**
  - High points and low points that characterise transverse waves only. For longitudinal waves, compressions and rarefactions are used.
- **Amplitude, A, SI Unit: metre (m)**
  - The value of the maximum displacement from the rest of central position in either direction.



A transverse rope wave

Describing Waves

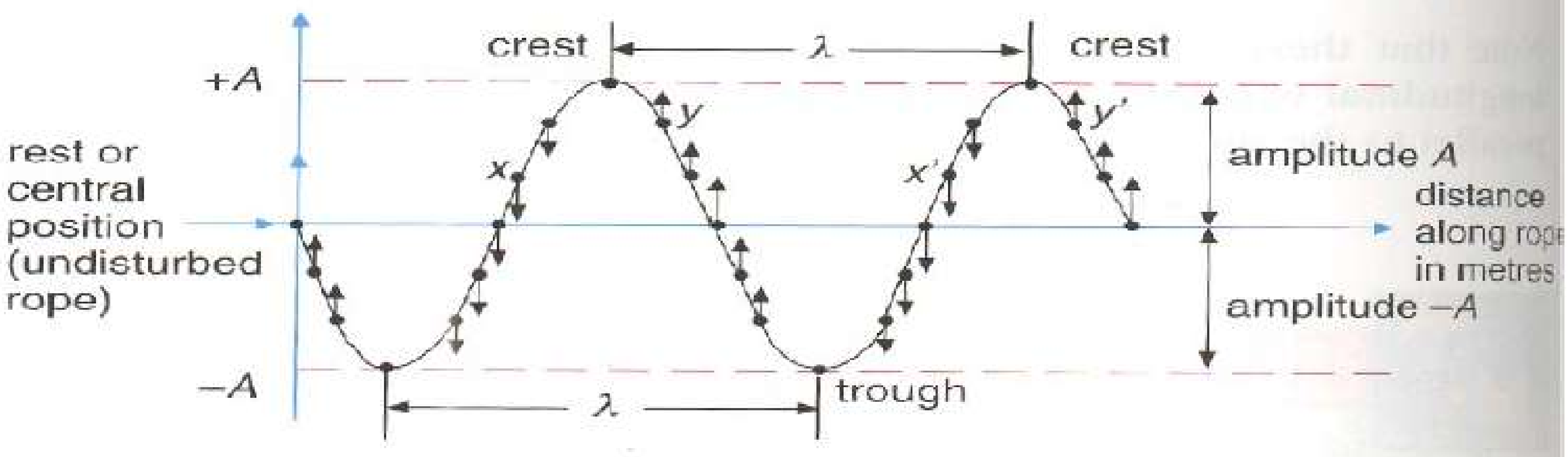
- **Wavelength, λ, SI Unit : metre (m)**
  - The shortest distance between any two points on a wave that are in phase. The two easiest points to choose for a distance of one wavelength are two successive crests or troughs.



A transverse rope wave

Describing Waves

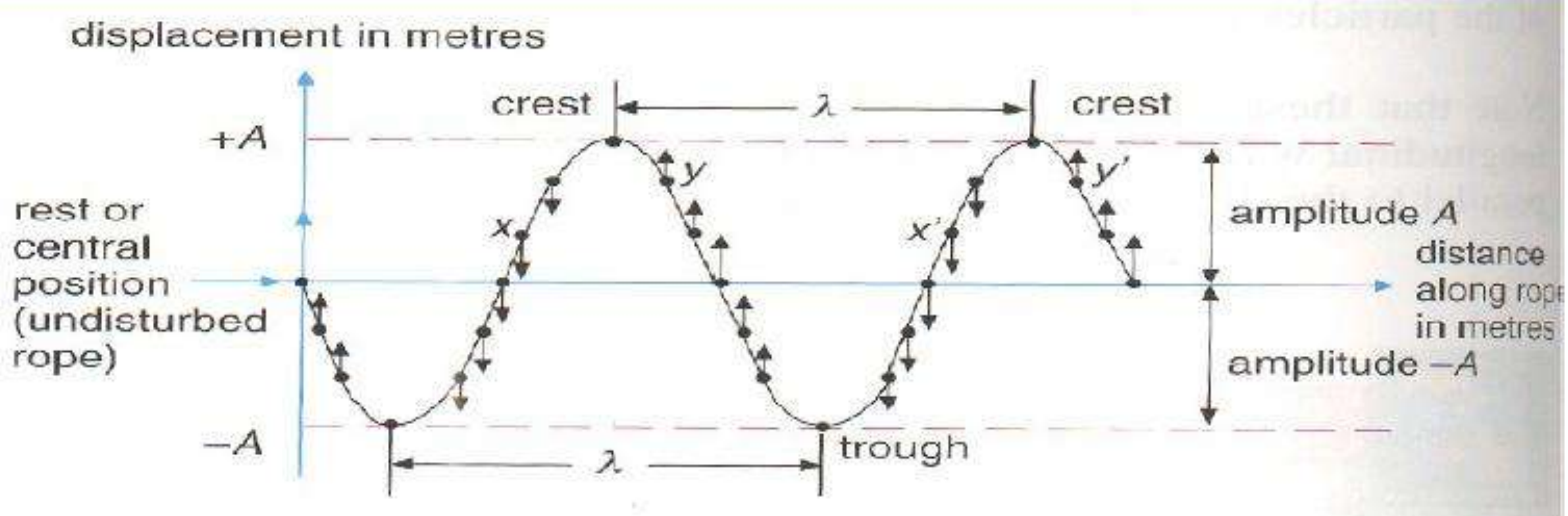
- **Frequency, *f*, SI Unit: hertz (Hz)**
  - The number of complete waves produced per second. The figure shows two complete waves and if they are produced in one second, then the frequency of this wave is two waves per second or 2 hertz.
- **Period, *T*, SI Unit: second (s)**
  - The time taken to produce one complete wave. $T = 1/f$



A transverse rope wave

Describing Waves

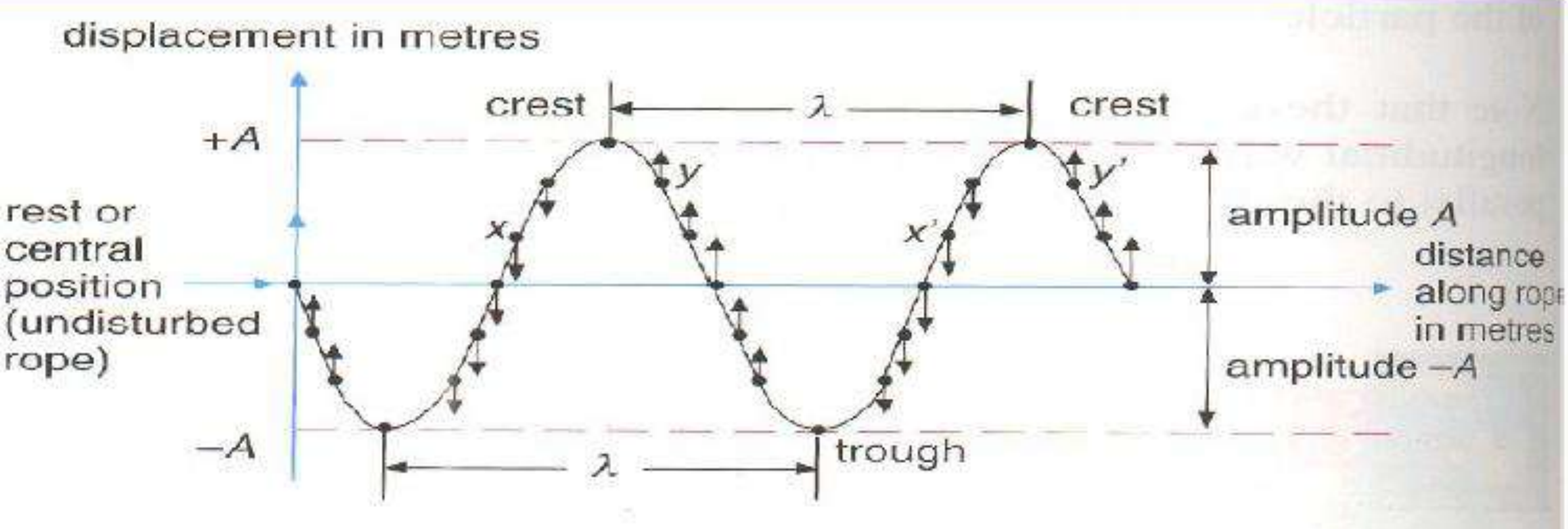
- **Wave Speed, *v*, SI Unit : metre per s (m/s)**
  - The distance travelled by a wave in one second.
- **Wave Front**
  - An imaginergy line on a wave that join all points which are in phase of vibration.



A transverse rope wave

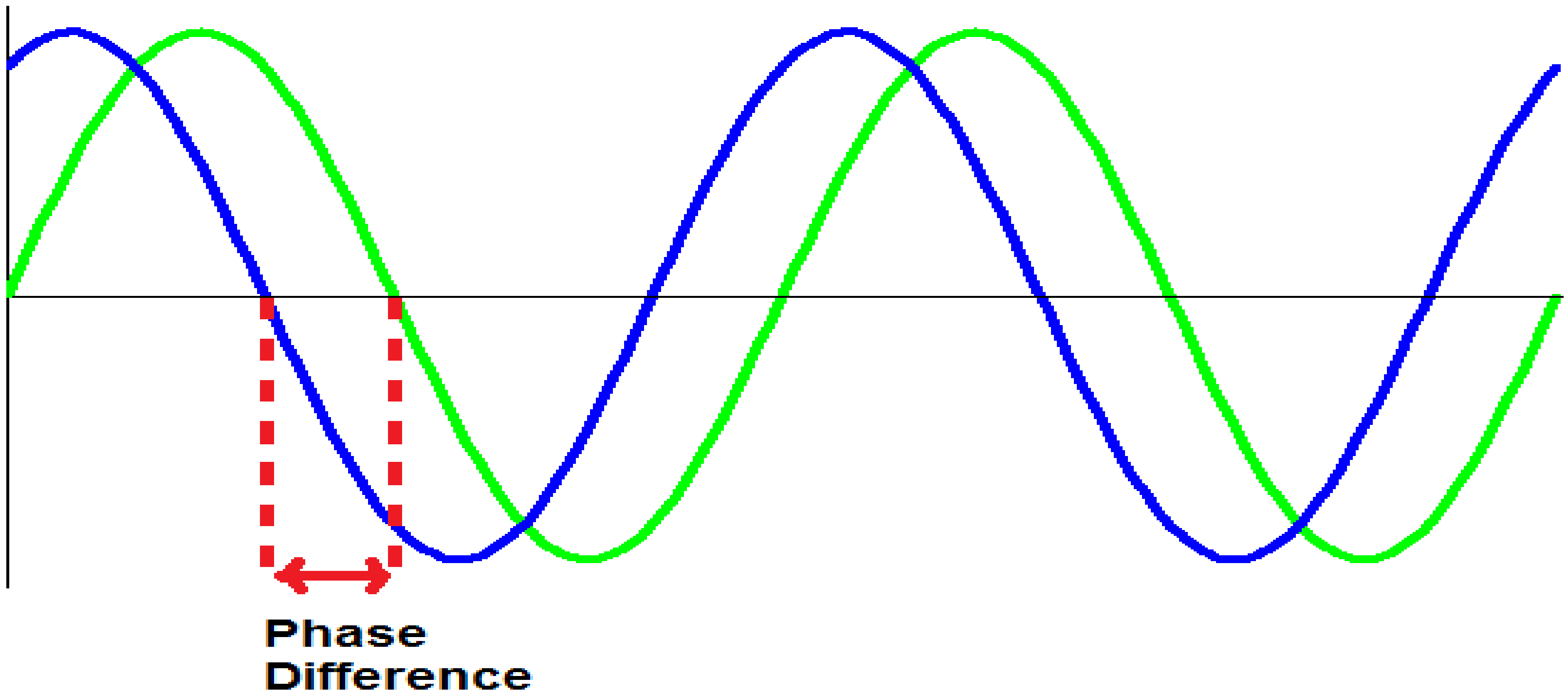
Describing Waves

- **Phase**
  - Two points (such as x &x', and y & y') are said to be in phase because that are moving in the same direction with the same speed and having the same displacement from the rest position. Any two crests or trough are in phases.



A transverse rope wave

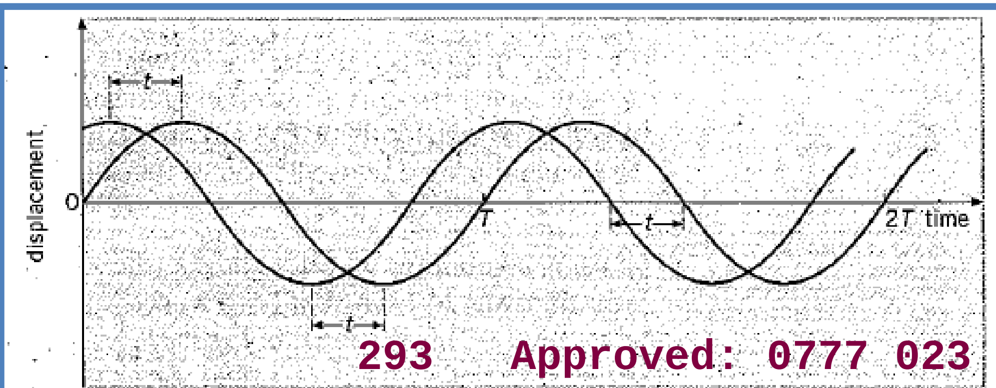
Describing Waves – Phase difference



Describing Waves – Phase difference

A term used to describe the relative positions of the crests or troughs of two waves of the same frequency is **phase**. When the crests and troughs of the two waves are aligned, the waves are said to be **in phase**. When a crest is aligned with a trough, the waves are **out of phase**. When used as a quantitative measure, phase has the unit of angle (radians or degrees). Thus, when waves are out of phase, one wave is half a cycle behind the other. Since one cycle is equivalent to 2π radians or 360°, the **phase difference** between waves that are exactly out of phase is π radians or 180°.

Consider Figure in which there are two waves of the same frequency, but with a phase difference between them. The period T corresponds to a phase angle of 2π rad or 360°. The two waves are out of step by a time t. Thus, phase difference is equal to $2\pi(t/T)$ rad $= 360(t/T)°$. A similar argument may be used for waves of wavelength λ which are out of step by a distance x. In this case the phase difference is $2\pi(x/\lambda)$ rad $= 360(x/\lambda)°$.



$\Phi = 2\Pi\frac{x}{\lambda}$ OR $\Phi = 360°\frac{x}{\lambda}$

Where ϕ is phase difference, x is distance, λ is the wavelength.

The wave equation and principle

- Speed = distance/time
- Wavelength is the distance moved by the wave in one cycle i.e distance
- Time = period = 1/frequency
- So speed = wavelength/period

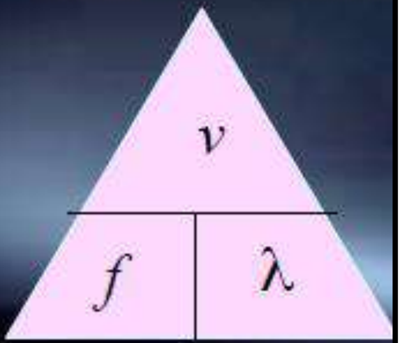
Speed = wavelength x frequency, i.e $v = \lambda f$

The Wave Equation

The relationship of v, λ & f

$$v = f\lambda$$

$v = f\lambda$
$f = v/\lambda$
$\lambda = v/f$

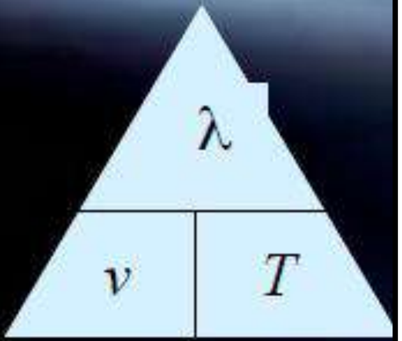


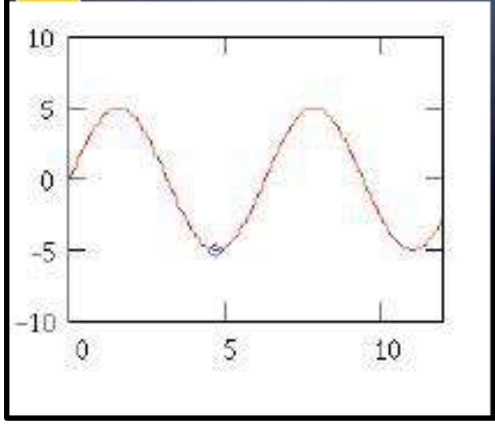
The relationship of v, λ & T

Since $T = 1/f$

$$v = \frac{\lambda}{T}$$

$f = 1/T$
$v = \lambda/T$
$\lambda = vT$
$T = 1/f$
$T = \lambda/v$





Example 1

Visible light has wavelengths between 400 nm and 700 nm, and its speed in a vacuum is 3.0×10^8 m s^{-1}.

What is the maximum frequency of visible light?

Solution:

From $v = f\lambda$, the frequency $f = \dfrac{v}{\lambda}$, i.e. f is inversely proportional to λ.

For maximum frequency, minimum wavelength should be used.

Hence, $$f_{max} = \frac{v}{\lambda_{min}} = \frac{3 \times 10^8 \text{ m s}^{-1}}{400 \times 10^{-9} \text{ m}} = \mathbf{7.5 \times 10^{14}\ Hz}.$$

Example 2

A sound wave of frequency 400 Hz is travelling in a gas at a speed of 320 m s^{-1}.

What is the phase difference between two points 0.2 m apart in the direction of travel?

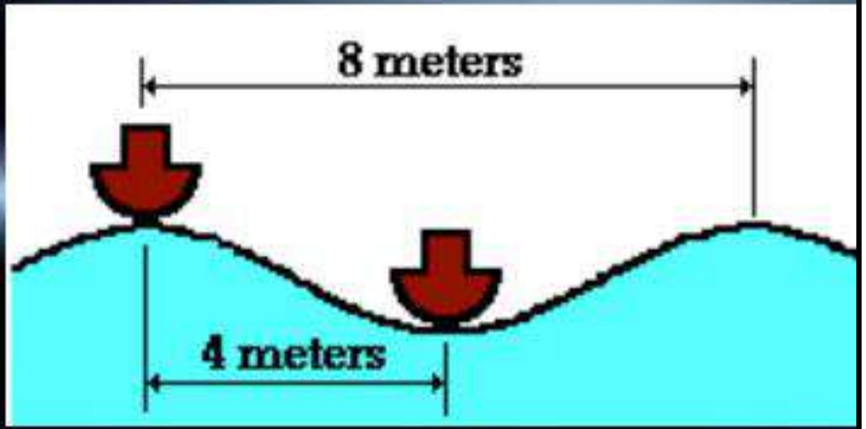
Solution:

Wavelength, $\lambda = \dfrac{v}{f} = \dfrac{320 \text{ m s}^{-1}}{400 \text{ Hz}} = 0.80$ m

$$\frac{\phi}{2\pi} = \frac{x}{\lambda} = \frac{0.2 \text{ m}}{0.8 \text{ m}} = \frac{1}{4} \quad \rightarrow \quad \boldsymbol{\phi = \frac{\pi}{2}}\ \textbf{rad}$$

Example 4

Two boats are anchored 4 metres apart. They bob up and down every 3 seconds, but when one is up the other is down. There are never any wave crests between the boats. Calculate the speed of the waves.



Solution:

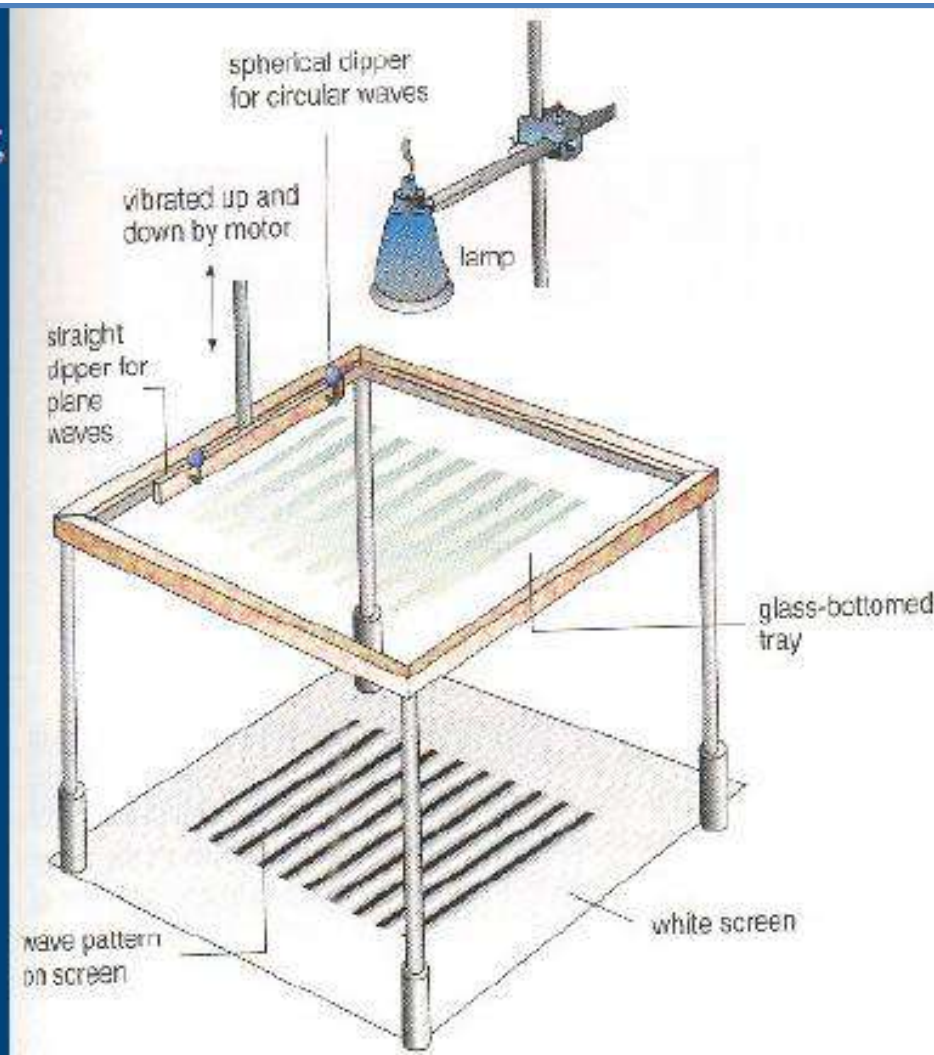
Period, $T = (3 \times 2)\ \text{s} = 6\ \text{s}$

Wavelength, $\lambda = 8\ \text{m}$

Speed, $v = \lambda/T = (8/6)\ \text{m/s} = 1.33\ \text{m/s}$

Ripple Tank (Wave production)

- The Structure
  - A shallow glass-bottomed tray;
  - A light source directly above the tray; and
  - A white screen beneath the tray used to capture the shadows formed when water waves traverse the tray.
- Production of waves
  - Plane waves by using the straight dipper
  - Circular waves by spherical dipper



Energy is transferred by a progressive wave

Wave Motion

- There are also two other ways to classify waves - by their motion. A wave in which energy is transferred from one place to another as a result of its motion is called a **progressive** wave.

- For example : An ultraviolet light wave, which transfers energy from the sun to the skin of people lying on the beach, for instance, is a progressive wave. In general, waves that move from one point to another transfer some kind of energy.
- In a progressive wave, the shape of the wave itself, is what is transferred, not the actual components of the medium.

Look at this animated example

- http://library.thinkquest.org/15433/unit5/5-3.htm

- This animation of a dog on a leash shows a progressive wave transferring energy from the boy to the dog, which end up getting flipped through the air.

Show an understanding that energy is transferred due to a progressive wave.

- **Oscillation** (or oscillatory motion) refers to the to-and-fro motion of **a particle** about an equilibrium position.

  The oscillatory motion of the particle is a continuous exchange of potential and kinetic energy of the particle.

- **Wave** refers to the combined motion of **a series of linked-particles**, each of which is originally at rest at its respective equilibrium position.
  Starting from the *oscillation* of the *first particle* about its equilibrium position, the **energy** of the oscillation is passed to the *second particle*, which in turn is passed to the *third particle* and subsequent particles in the series of linked-particles.

So ***wave motion* is the motion of *energy*** passed from one particle to the next in a series, through oscillatory motion of these particles, in sequence.

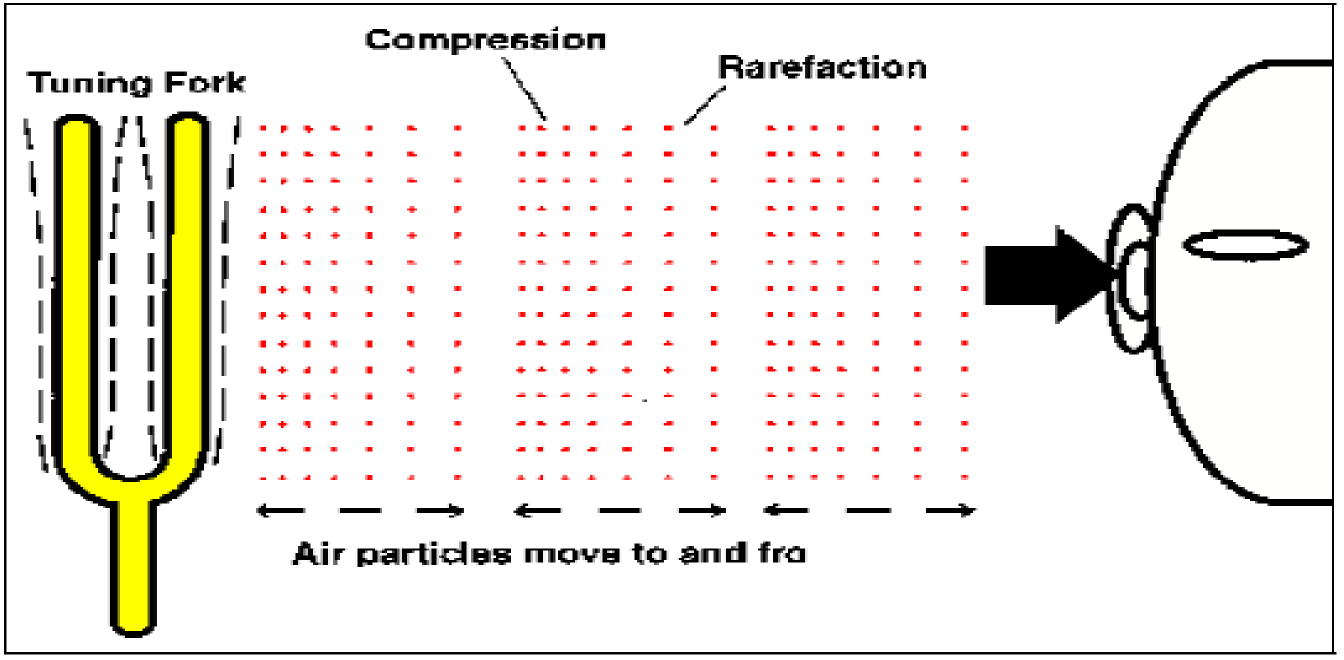
Examples:

(1) Sound wave:

When a sound wave is propagated from a tuning fork to an ear of a person some distance away, the vibration of the fork sets the air layer next to it into vibration.

The second layer of air is then set into vibration by the transfer of energy from the first layer.

This transfer of energy continues for subsequent layers until the layer of air next to the ear is also set into vibration, which in turn vibrates the ear-drum of the ear, enabling the person to hear the sound originated from the tuning fork.



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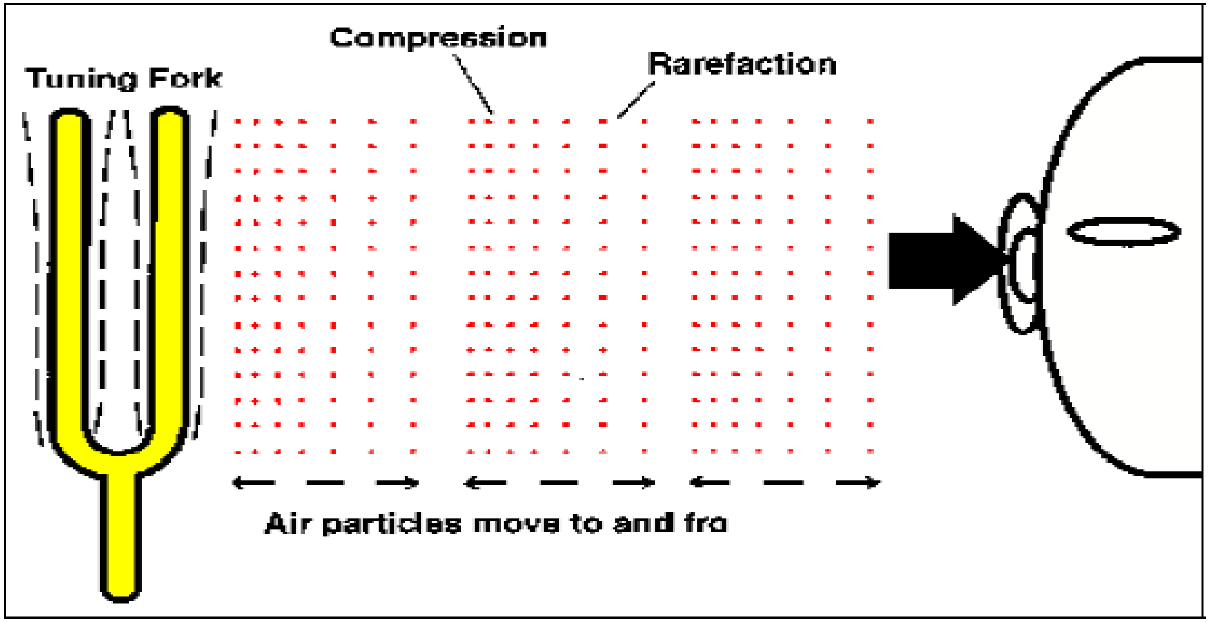


There is no net transfer of air particles from the tuning fork to the ear. The ear-drum in the ear can vibrate because energy has been transferred to it from the tuning fork, through the sequential vibration of the layers of air between the tuning fork and the ear. (Diagram above)

This sequential vibration of the layers of air forms regions of **compression** (where air layers are closer to each other) and regions of **rarefaction** (where air layers are further apart). The one-way movement of such regions from the tuning fork to the ear signifies the propagation of sound wave energy.

(2) Wave in a rope:

The wave travelling in a rope may originate from the vibration of the first particle at one end of the rope.
The energy of the vibrating first particle is transferred to the second particle, setting it into vibration.
This transfer of energy continues to subsequent particles in the rope until it reaches the other end of the rope.

(3) Water wave:

The energy of the vibrating water molecules is transferred to subsequent molecules along the surface of water, causing these molecules further from the vibrating source to be set into up-down motion.

The examples (1), (2) and (3) are examples of **progressive waves**, where energy is transferred from one region to another region through sequential vibration of a series of linked-particles.

The energy of a first vibrating particle is propagated along a series of linked-particles to another region. Sound energy is propagated from the tuning fork to the ear, energy from one end of a rope is propagated to the other end, and energy from one region of water surface next to a vibrating source is propagated to another region in the ripple tank.

Intensity of the Wave

One of the characteristics of a progressive wave is that it carries energy. The amount of energy passing through unit area per unit time is called the **intensity** of the wave. The intensity is proportional to the square of the amplitude of a wave. Thus, doubling the amplitude of a wave increases the intensity of the wave by a factor of four. The intensity also depends on the frequency: intensity is proportional to the square of the frequency.

For a wave of amplitude A and frequency f, the intensity I is proportional to A^2f^2.

If the waves from a point source spread out equally in all directions, we have what is called a **spherical wave**. As the wave travels further from the source, the energy it carries passes through an increasingly large area. Since the surface area of a sphere is $4\pi r^2$, the intensity is $W/4\pi r^2$, where W is the power of the source. The intensity of the wave thus decreases with increasing distance from the source. The intensity I is proportional to $1/r^2$, where r is the distance from the source.

This relationship assumes that there is no absorption of wave energy.

Recall and use the relationship, intensity $\propto$ (amplitude)^2.

Intensity, ***I***, is the **rate of incidence of energy per unit area normal to the direction of incidence.**

The rate of incidence of energy can be regarded as power.

The plane of the area, which the wave energy is incident onto, has to be normal (perpendicular) to the direction of the incidence of the wave energy.

The **unit** of intensity is **W m^{-2}**.

Intensity on an area A can be expressed as

$$I = \frac{P}{A}$$

where P is the power incident on the area normally.

$$\boxed{\textbf{Intensity} \propto \textbf{(amplitude)}^2}$$

A sound wave of amplitude 0.20 mm has an intensity of 3.0 W m^{-2}.

What will be the intensity of a sound wave of the same frequency which has an amplitude of 0.40 mm?

Solution:

The relation $I \propto (\text{amplitude})^2$

can be expressed as $I = k(\text{amplitude})^2$

where k is the constant of proportionality.

Substituting,

$$3.0 \text{ W m}^{-2} = k(0.20 \text{ mm})^2 \quad \text{- - - - - (1)}$$

New intensity, $I = k(0.40 \text{ mm})^2 \quad$ - - - - - (2)

$\dfrac{(2)}{(1)}$: $\dfrac{I}{3.0 \text{ W m}^{-2}} = 4 \quad \rightarrow \quad I = 12.0 \text{ W m}^{-2}$.

- For sound waves, **intensity** is a measure of **loudness**.
- For light waves, **intensity** is a measure of **brightness**.

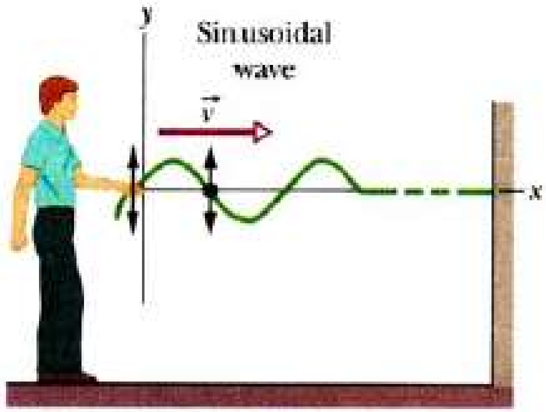
Analyse and interpret graphical representations of transverse and longitudinal waves.

- In a wave, there are ***two directions of motions:***

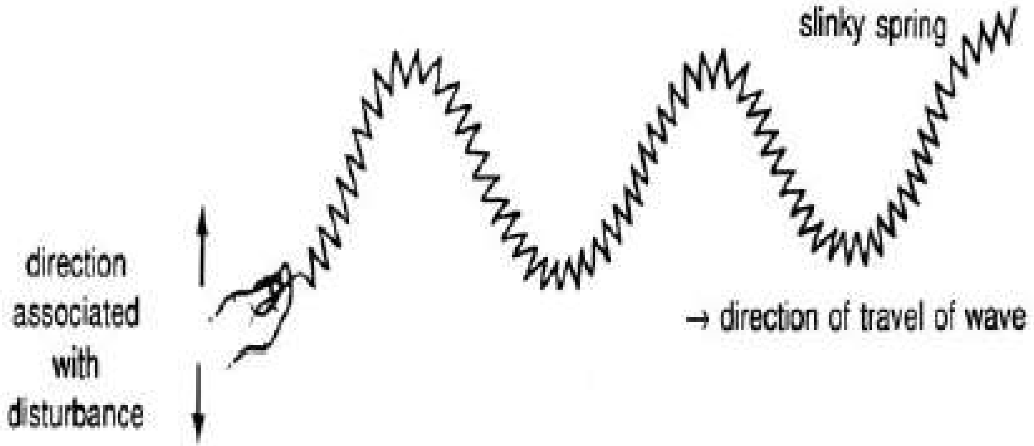
➢ direction of propagation of energy (which is the direction of *motion of the wave)*

➢ direction of oscillation of the particles in the wave.

A **<u>transverse wave</u>** is one in which the direction of propagation of energy is **perpendicular** to the direction of oscillation of the particles in the wave.

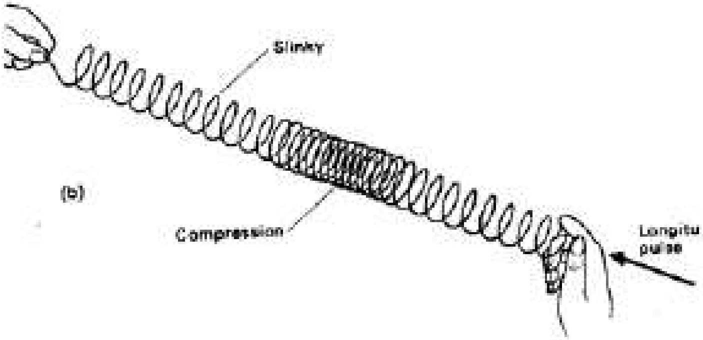


The string element's motion is ***perpendicular*** *to the wave's direction of travel. This is a transverse wave.*



In the example of a wave travelling along a string (or a wave travelling along a slinky diagrams above, the direction of propagation of the wave is along the string. If the wave is started from one end of the string by the oscillation of the first element in the direction *perpendicular* to the string, then this wave travelling along the string is an example of a *transverse wave*.

A **longitudinal wave** is one in which the direction of propagation of energy is **parallel** to the direction of oscillation of the particles in the wave.



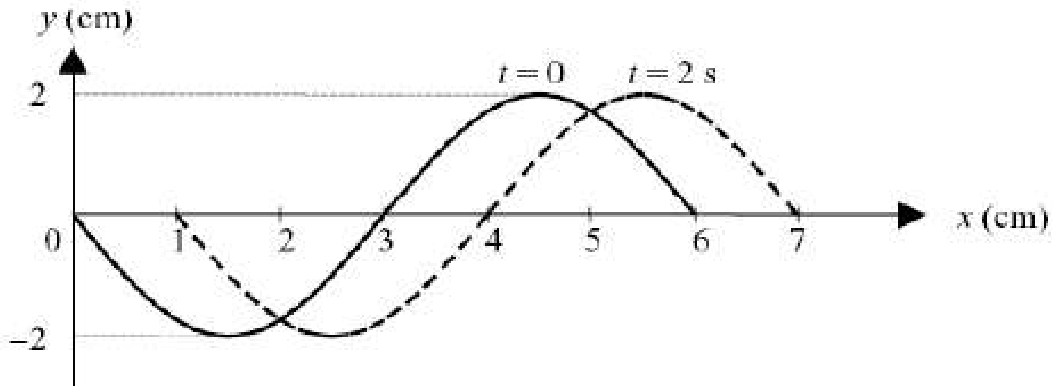
A visual demonstration of a longitudinal wave.

When a sound wave set up by the vibrating piston propagates along the pipe of air, the direction of propagation of sound energy is along the pipe to the right. The direction of oscillation of the air layers is back and forth, *parallel* to this direction. Hence sound wave is an example of a *longitudinal wave*.

Graphs representing waves

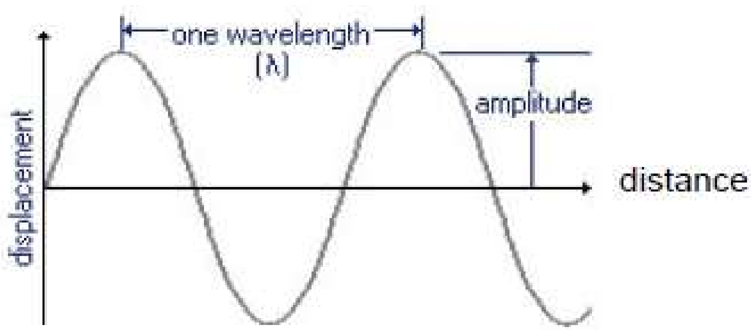
Graph 1 : Displacement vs. Position graphs

These are plotted with displacement, *y*, **against distance or position, *x***.



For a **transverse** wave moving from left to right along the *x*-axis, displacement of the particles in the wave, *y*, may be given a **+ve** sign for displacement **upwards**, and a **–ve** sign for displacement **downwards**.

For a **longitudinal** wave moving from left to right along the *x*-axis, displacement of the particles in the wave, *y*, may be given a **+ve** sign for displacement **to the right**, and a **–ve** sign for displacement **to the left**.

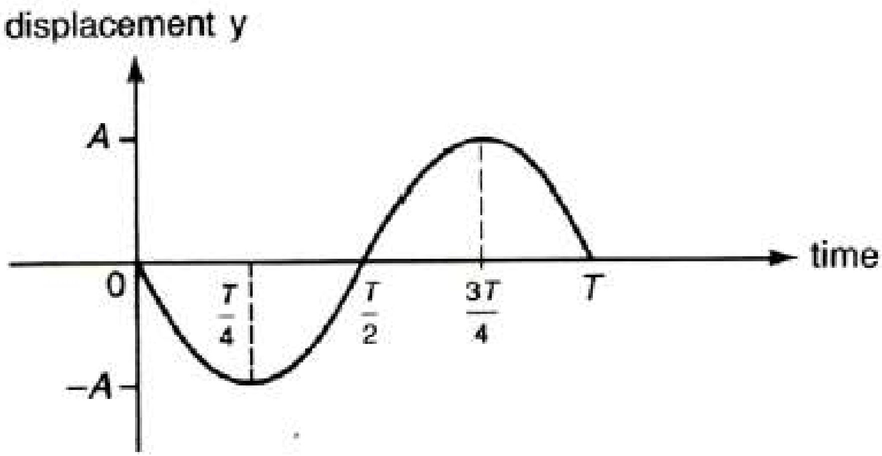


In Displacement vs. Position graphs,

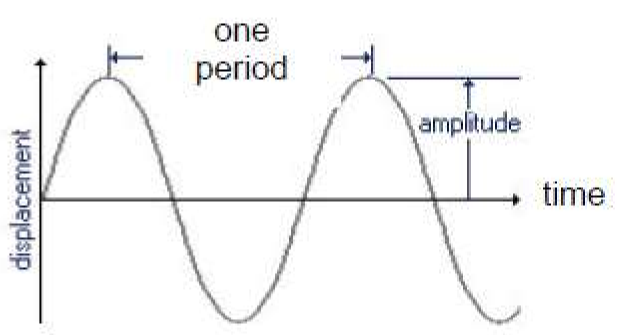
- the graph represents the actual wave at an instant in time
- the distance between consecutive crests or consecutive troughs is **one wavelength**
- The maximum height of the vertical axis = amplitude of **wave**

Graph 2 : Displacement vs. Time graphs

In contrast, graphs used to represent an **oscillation of a particle** are plotted with displacement, y, **against time, t**.



In the graph above, we are tracking the displacement of **one particle only** as time goes by. This does NOT represent the wave.



In Displacement vs. Time graphs,

- The graph represents the oscillation of one particle on the wave with time.
- the "distance" between consecutive crests or consecutive troughs is **one period**
- The maximum height of the vertical axis = amplitude of **oscillation**

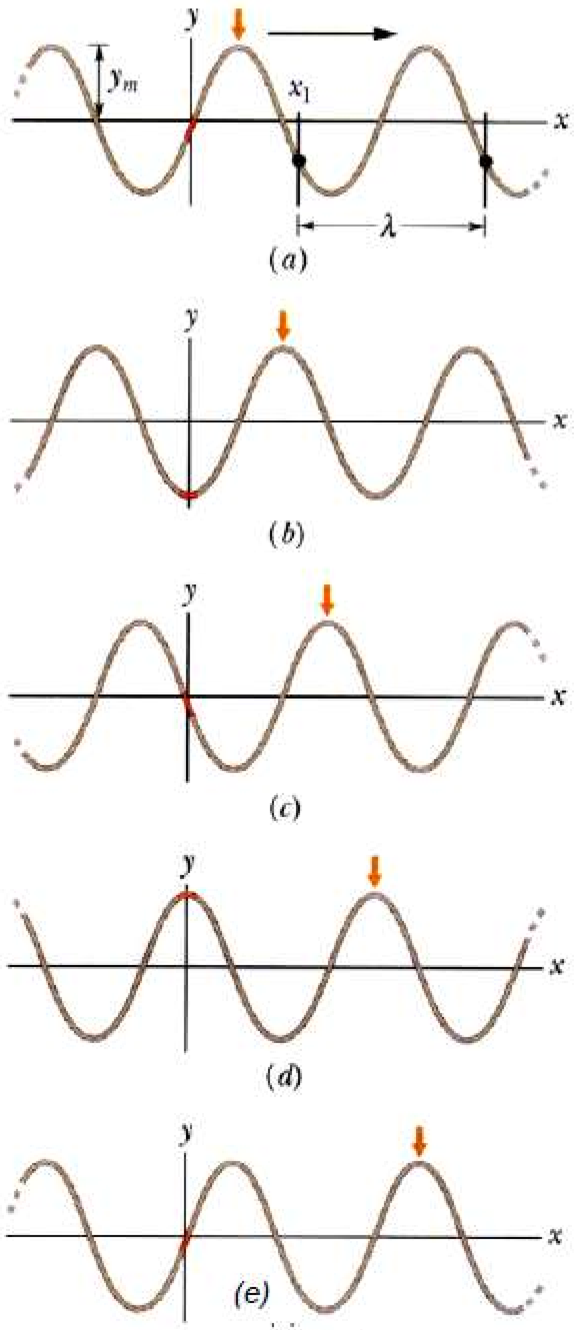


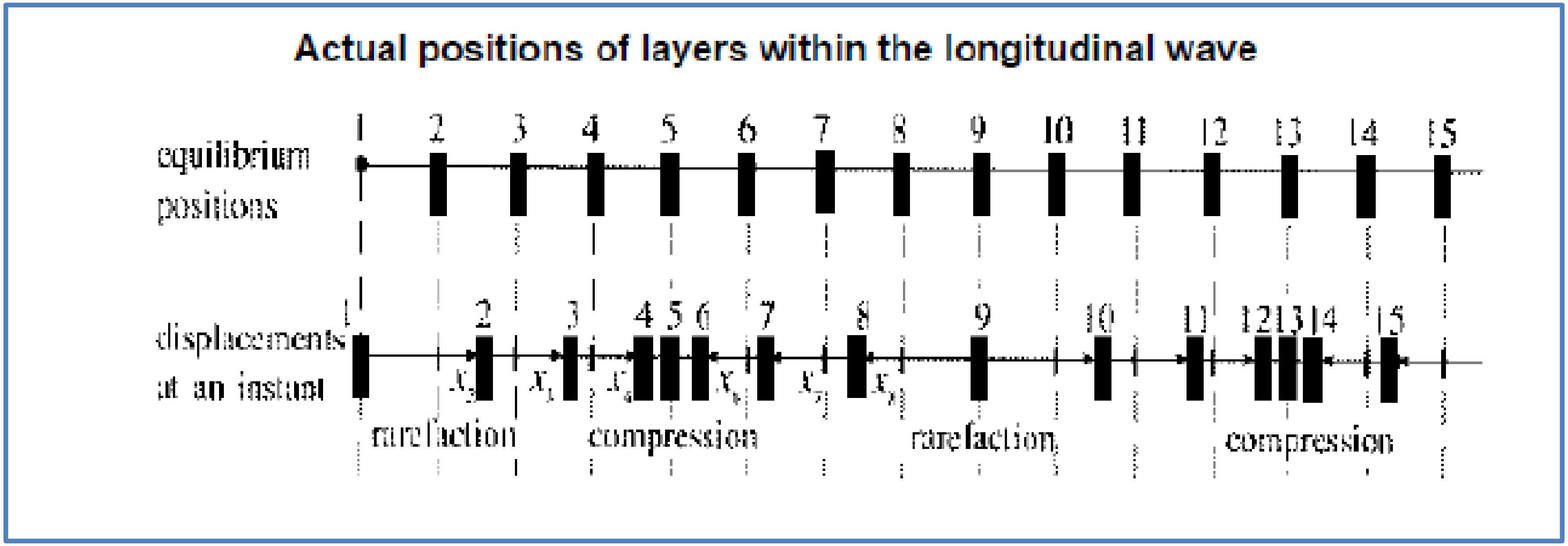
Fig.2

- Fig.2 shows 5 'sna transverse wave in a string, travelling in the +ve direction of an *x*-axis (left to right).

- The movement of the wave is indicated by the right-ward progress of the short down-pointing arrow, pointing at the middle 'crest' of the wave in snapshot (a).

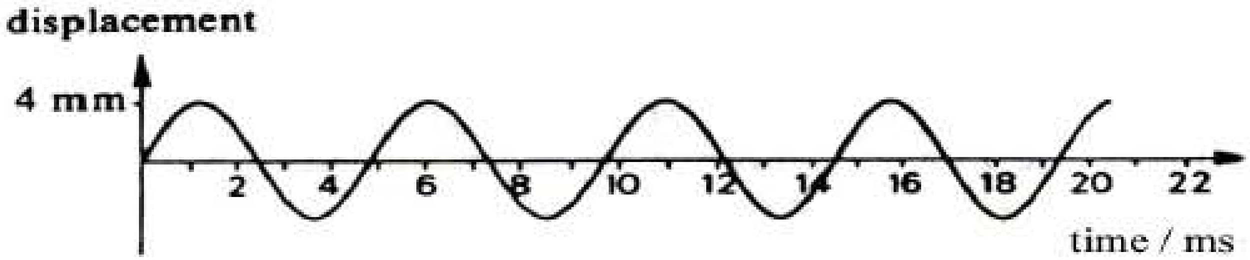
- From snapshots (a) to (e), the short arrow moves to the right with the wave, but each particle in the string moves parallel to the *y*-axis (up and down). An example of such a particle is along the *y*-axis (shown darkened).

- Each snapshot is taken at an interval of ¼ period. One full oscillation takes place from (a) to (e).


Actual positions of layers within the longitudinal wave
equilibrium positions
displacements at an instant
rarefaction
compression
rarefaction
compression

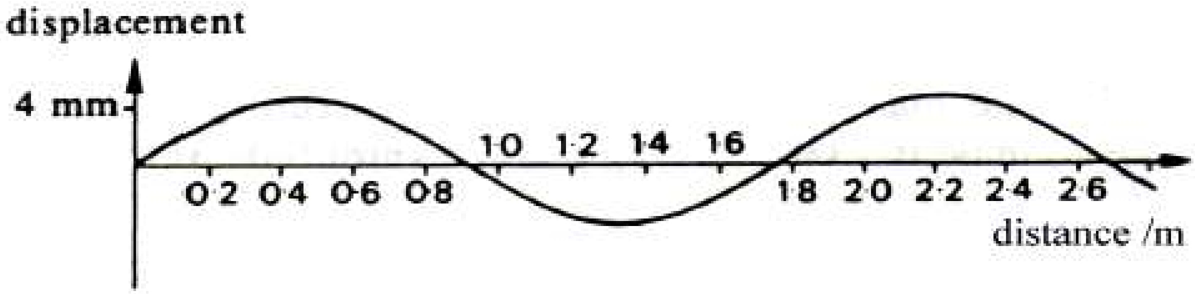
Summary For Part (f):

(1) **Displacement-time graph** is for the **oscillation of a particle** in the wave.



The graph above shows an element oscillating with an amplitude of 4 mm.
Its **period** of oscillation is about 5 ms.

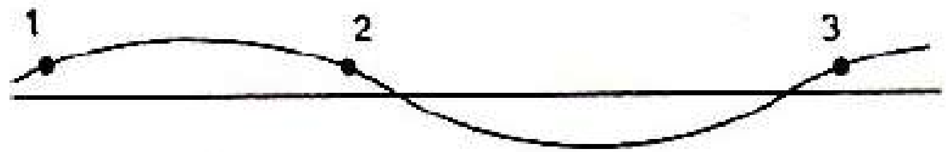
(2) **Displacement-distance graph** is for a **snapshot of a wave motion at an instant**.



The graph above shows an instant of a wave with an amplitude of 4 mm.
Its **wavelength** is about 1.8 m.

Example 7

The diagram below shows an instantaneous position of a string as a transverse progressive wave travels along it from left to right.

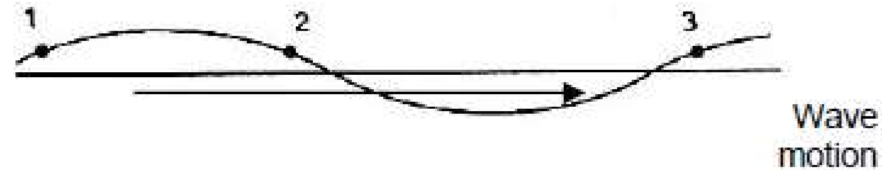


Which one of the following correctly shows the directions of the velocities of the points 1, 2 and 3 on the string?

	1	2	3
A	→	→	→
B	→	←	→
C	↓	↓	↓
D	↓	↑	↓
E	↑	↓	↑

Solution

Knowing that the wave is traveling from LEFT to RIGHT, sketch how the wave would look like just an instant after:

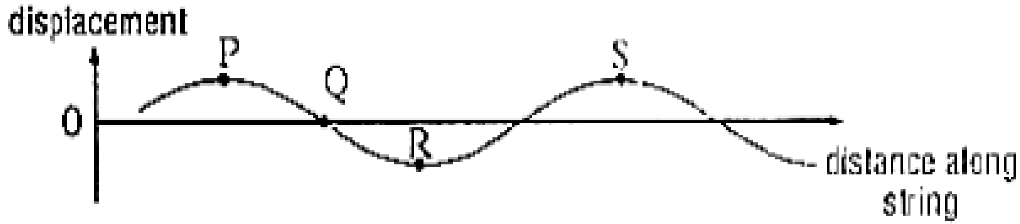


Then look at the points concerned.
Since it is a TRANSVERSE wave, the particles only oscillates perpendicular to the wave direction.
This eliminates Answers A & B.

Ans D

Example 8

The graph shows the shape **at a particular instant** of part of a transverse wave travelling along a string.



Which statement about the motion of elements of the string is correct?

A The speed of the element at P is a maximum
B The displacement of the element at Q is always zero
C The energy of the element at R is entirely kinetic
D The acceleration of the element at S is a maximum

Solution:
Although the graph represents the whole wave at an instant in time, the question requires you to **analyse the motion of the individual particles** within the wave at this instant.

Element P: At extreme end of oscillation → stationary
Element Q: At equilibrium position → moving fastest
Element R: At extreme end of oscillation → stationary, no kinetic energy
Element S: At extreme end of oscillation → max displacement, max acceleration

Ans: D

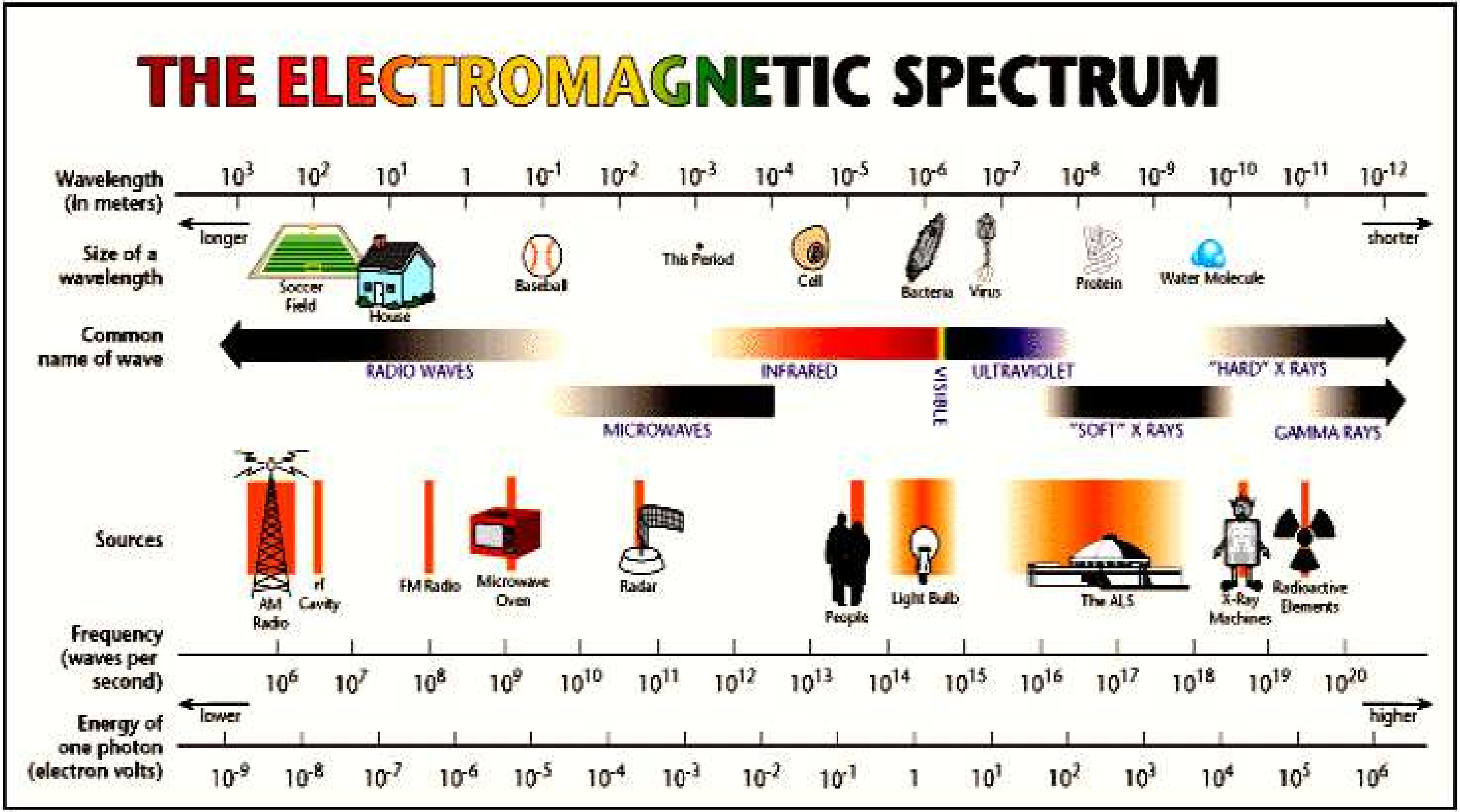
Electromagnetic Waves

James Clerk Maxwell's (1831 – 1879) crowning achievement was to show that a beam of light is a travelling wave of electric and magnetic field, an *electro-magnetic* wave.

In Maxwell's time, the *visible*, *infrared* and *ultraviolet* form of light were the only electromagnetic waves known. *Heinrich Hertz* then discovered what we now call *radio waves* and verified that they move through the laboratory at the same speed as visible light.

We now know a wide spectrum of electromagnetic waves. The Sun, being the dominant source of these waves, continually bathes us with electromagnetic waves throughout this spectrum.

Reference : * This is a very useful video
http://www.youtube.com/watch?v=pYE8UHcL_gU


THE ELECTROMAGNETIC SPECTRUM
Wavelength (in meters)
10^3 10^2 10^1 1 10^{-1} 10^{-2} 10^{-3} 10^{-4} 10^{-5} 10^{-6} 10^{-7} 10^{-8} 10^{-9} 10^{-10} 10^{-11} 10^{-12}
longer
shorter
Size of a wavelength
Soccer Field
House
Baseball
This Period
Cell
Bacteria
Virus
Protein
Water Molecule
Common name of wave
RADIO WAVES
INFRARED
VISIBLE
ULTRAVIOLET
"HARD" X RAYS
MICROWAVES
"SOFT" X RAYS
GAMMA RAYS
Sources
AM Radio
rf Cavity
FM Radio
Microwave Oven
Radar
People
Light Bulb
The ALS
X-Ray Machines
Radioactive Elements
Frequency (waves per second)
10^6 10^7 10^8 10^9 10^{10} 10^{11} 10^{12} 10^{13} 10^{14} 10^{15} 10^{16} 10^{17} 10^{18} 10^{19} 10^{20}
lower
higher
Energy of one photon (electron volts)
10^{-9} 10^{-8} 10^{-7} 10^{-6} 10^{-5} 10^{-4} 10^{-3} 10^{-2} 10^{-1} 1 10^1 10^2 10^3 10^4 10^5 10^6

Type of EM wave	Typical Wavelengths λ and its corresponding frequency, f.	Orders of magnitude for wavelength, λ / m
Gamma (γ) rays	λ = 1 pm = 10^{-12} m f = 3×10^{20} Hz	10^{-12}
x-rays	λ = 100 pm = 10^{-10} m f = 3×10^{18} Hz	10^{-10}
UV ultraviolet	λ = 10 nm = 10^{-8} m f = 3×10^{16} Hz	10^{-8}
Visible light	λ_{red} **= 700 nm** λ_{green} = 600 nm = 0.6 μm λ_{violet} **= 400 nm** f_{green} = 5×10^{14} Hz	10^{-6}
IR (infra-red)	λ = 100 μm = 10^{-4} m f = 3×10^{12} Hz	10^{-4}
Radio wave (*includes microwaves, UHF, VHF etc*)	λ = 3 m f = 10^{8} Hz	$10^{0} \sim 10^{-2}$

Properties of Electromagnetic Waves

1) EM waves have the same **speed, *c*, in vacuum** ($c \approx 3 \times 10^{8}$ m s^{-1}).
2) EM waves consist of oscillating **electric and magnetic fields** that are perpendicular to each other.
3) EM waves are all **transverse waves**.

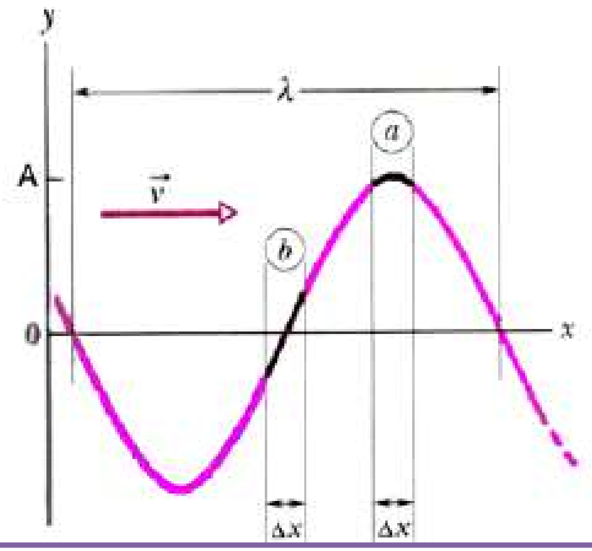
Energy (E) and Intensity (I) of a Progressive Wave

When we set up a wave on a stretched string, we provide energy for the motion of the string. As the wave moves away from us, it transports that energy as both kinetic energy and elastic potential energy.

Kinetic Energy

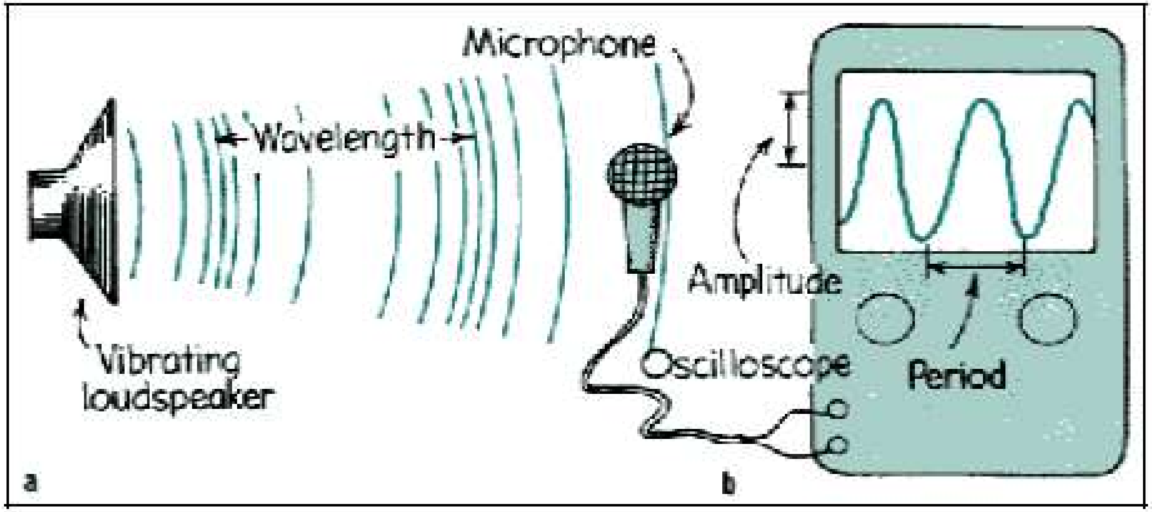
An element of the string of mass Δm, oscillating transversely in simple harmonic motion as the wave passes through it, has KE associated with its transverse velocity $\vec{u}$.

- When the element is rushing through its $y = 0$ position (element b in the diagram), its transverse velocity – and thus its KE - is a maximum.
- When the element is at its extreme position $y = A$ (element a), its transverse velocity – and thus its KE – is zero.



The frequency of sound using a calibrated CRO

(This topic was done in Second chapter : Measurement & Techniques)



A calibrated c.r.o. (cathode-ray oscilloscope) implies that the time-base is set such that the period, T, of oscillations of the air layers detected by the microphone may be read.

Using the relation

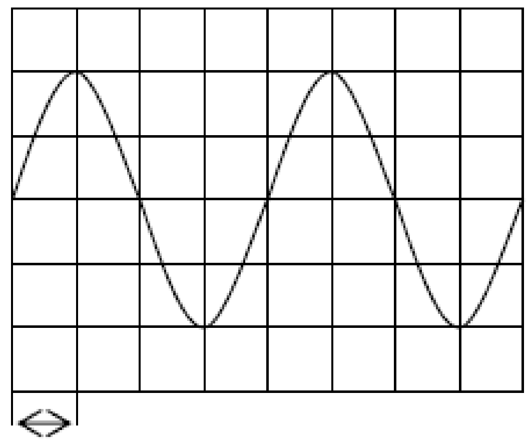
$$f = \frac{1}{T}$$

the frequency, f, of sound produced by the vibrating loudspeaker may be determined.

Sample problem

(This topic was done in Second chapter : Measurement & Techniques)

The trace shown appeared on an oscilloscope screen with the time-base set to 2.0 ms cm^{-1}.



What is the frequency of the signal?

A 40 Hz **B** 125 Hz **C** 250 Hz **D** 500 Hz

Solution

Period, $T = 2.0 \text{ ms cm}^{-1} \times 4 \text{ cm} = 8.0 \text{ ms}$

Frequency, $f = \frac{1}{T} = \frac{1}{8 \times 10^{-3}} = 125 \text{ Hz}$ **Ans: B**

The wavelength of sound using stationary waves

- This topic would be studied in detail in next chapter ‘Superposition’.
- Please refer to notes on Stationary Waves in the topic Superposition.

POLARISATION

Electromagnetic Wave : Electric Field & Magnetic Field

- A light wave is an electromagnetic wave that travels through the vacuum of outer space.
- Electromagnetic wave is a transverse wave that has both an electric and a magnetic component.

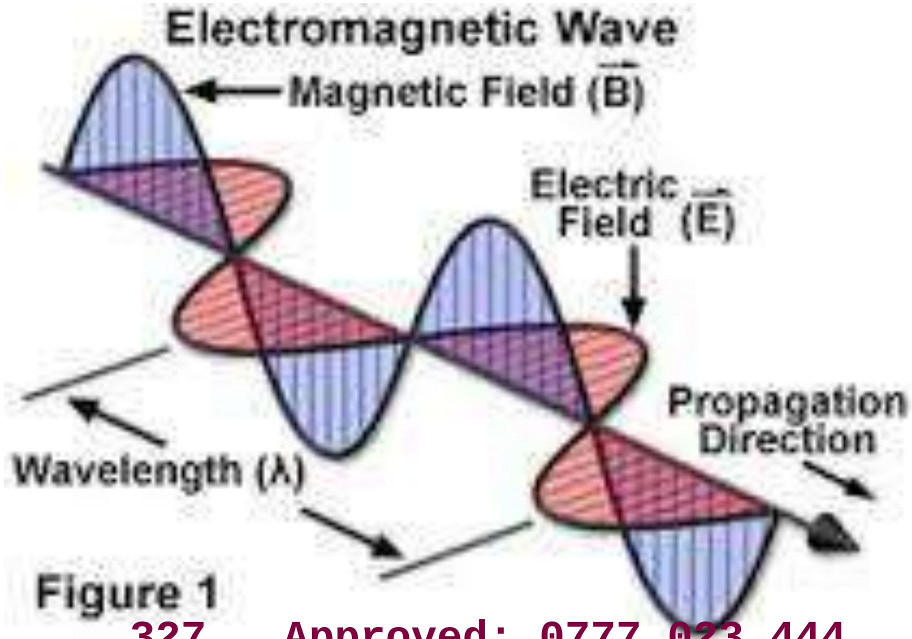
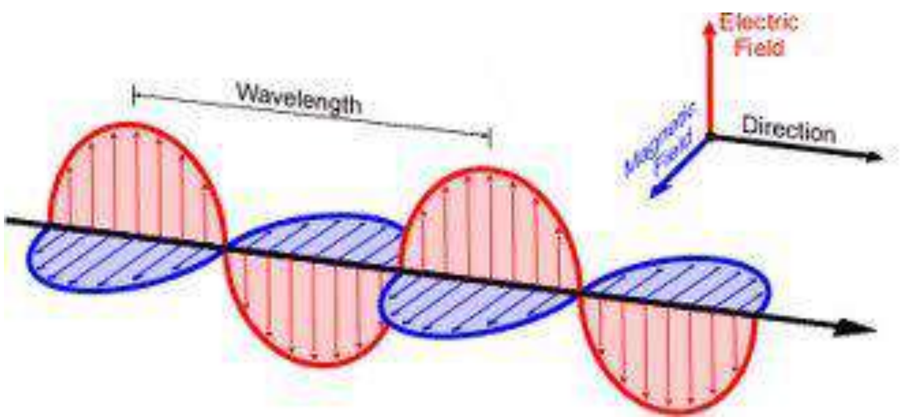


Figure 1

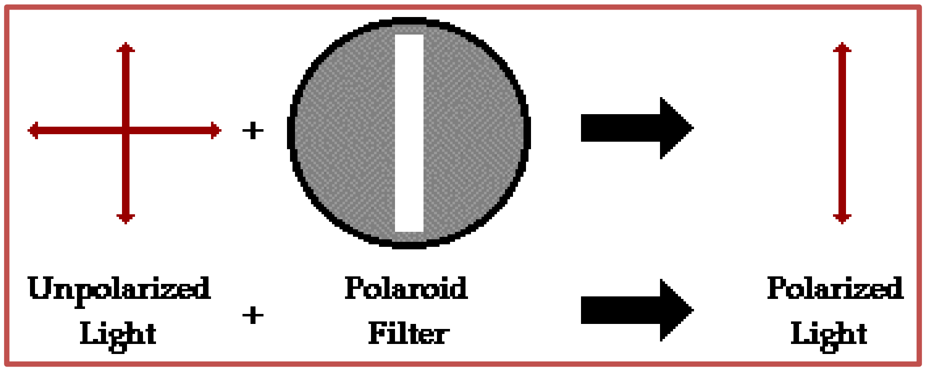
Electromagnetic Wave : Electric Field & Magnetic Field

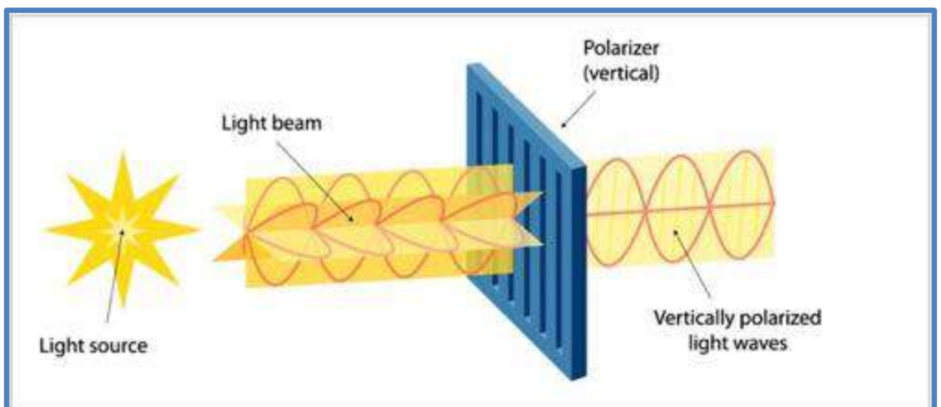
- A light wave that is vibrating in more than one plane is referred to as **unpolarized light**.
- Light emitted by the sun, by a lamp in the classroom or by a candle flame are examples of unpolarized light.
- Such light waves are created by electric charges and vibrate in a variety of directions.



Polarization is a phenomenon associated with transverse waves

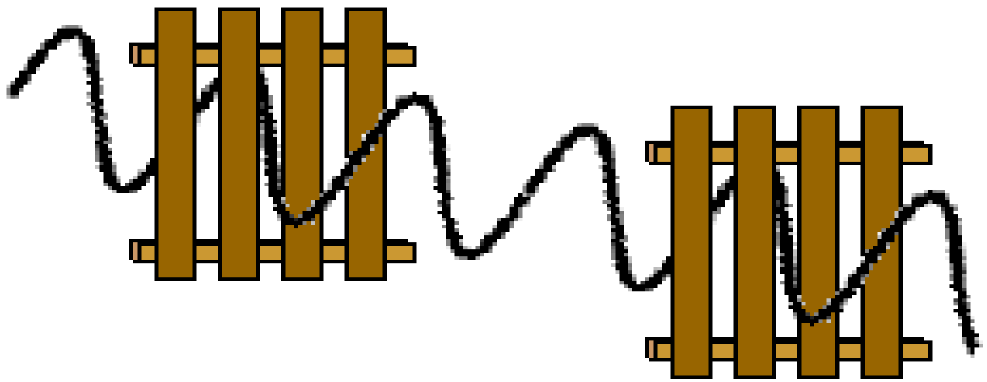
- Process by which a wave's oscillations are made to occur in ***one plane*** only.
- Associated with ***transverse waves*** only.



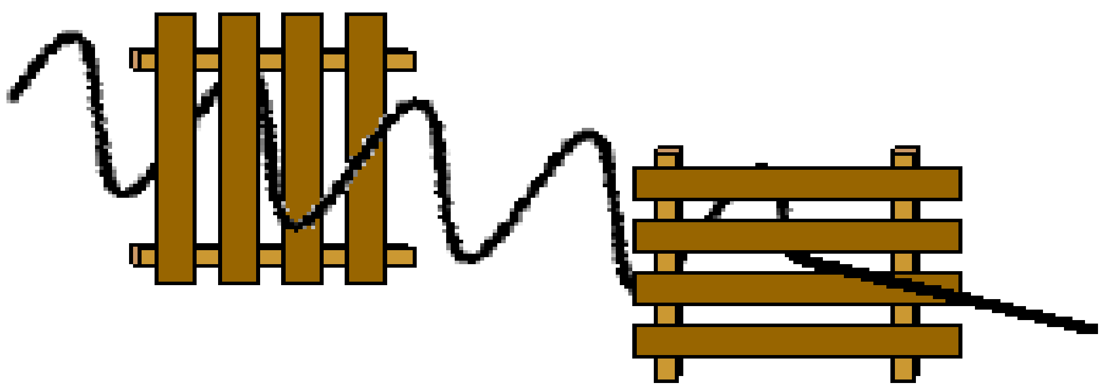


Note : Here, Polarization of light is analogous to that shown in the diagrams.

The Picket Fence Analogy



When the pickets of both fences are aligned in the vertical direction, a vertical vibration can make it through both fences.



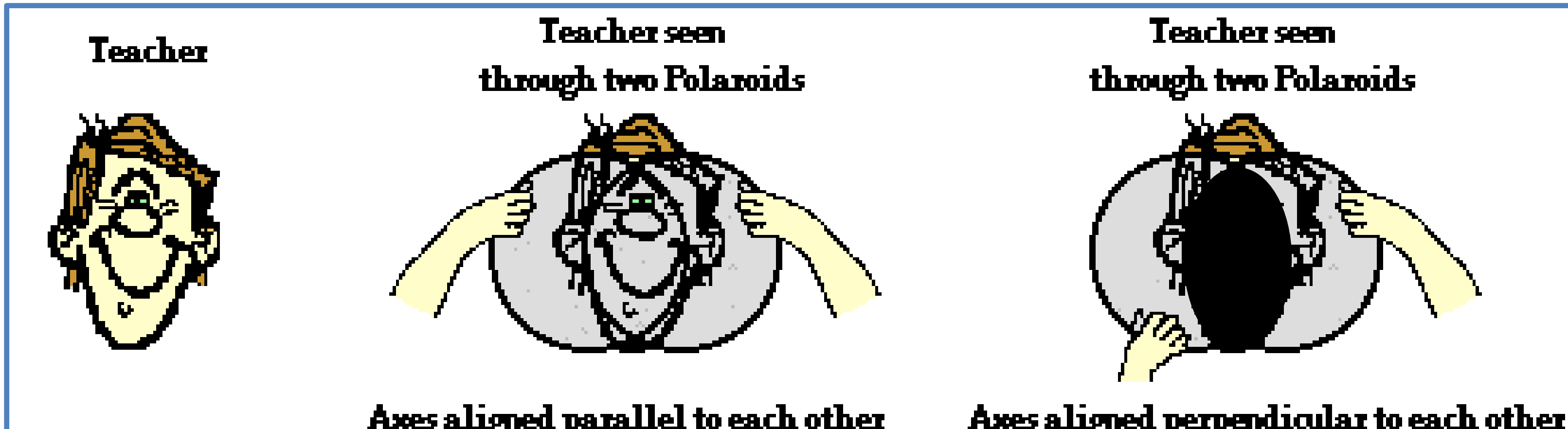
When the pickets of the second fence are horizontal, vertical vibrations which make it through the first fence will be blocked.

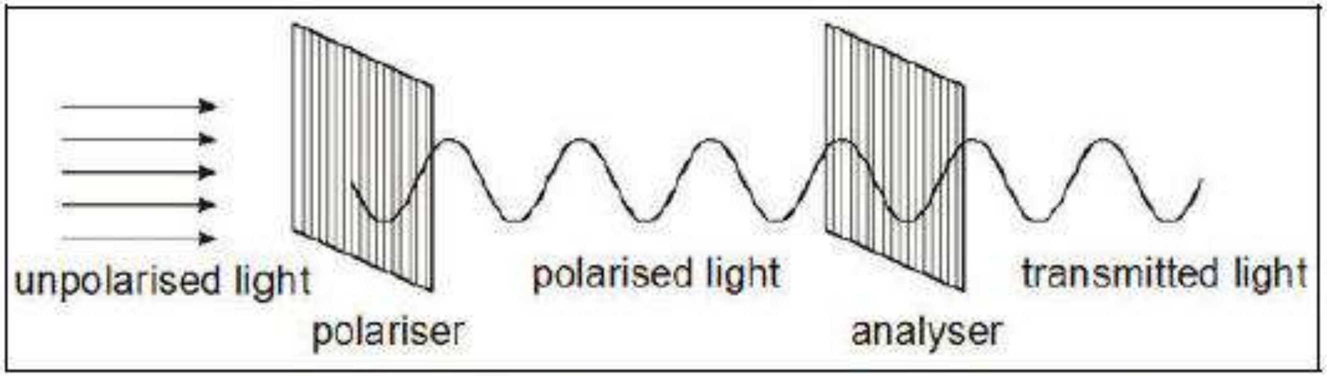
Show an understanding that **Polarisation** is a phenomenon associated with transverse waves

Reference link : http://www.youtube.com/watch?v=e8aYoLj2rO8

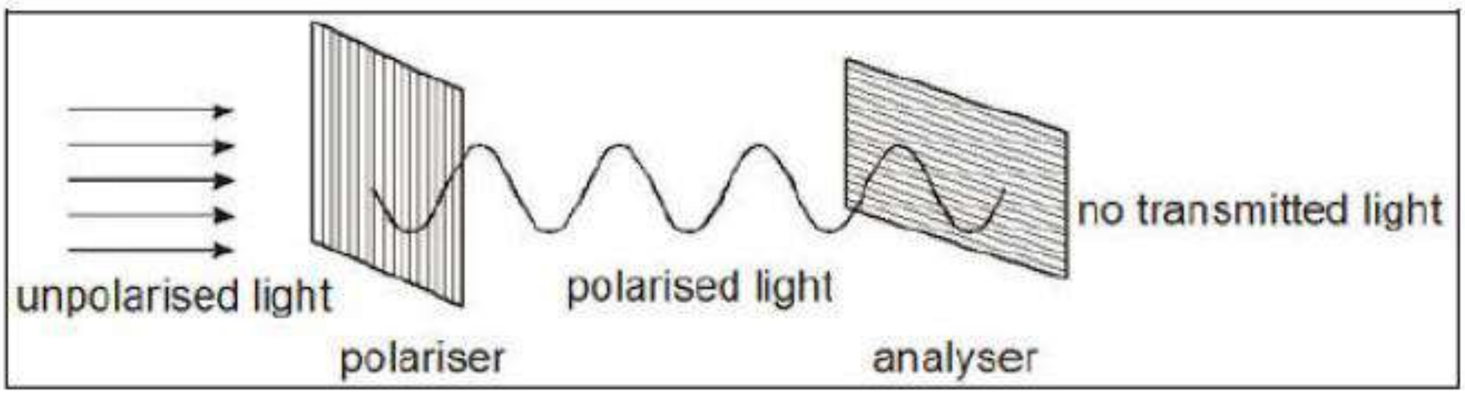
Polarization by Use of a Polaroid Filter

- The most common method of polarization involves the use of a **Polaroid filter**.
- Polaroid filters are made of a special material that is capable of blocking one of the two planes of vibration of an electromagnetic wave.
- In this sense, a Polaroid serves as a device that filters out one-half of the vibrations upon transmission of the light through the filter. When unpolarized light is transmitted through a Polaroid filter, it emerges with one-half the intensity and with vibrations in a single plane; it emerges as polarized light.





Light travelling *parallel* to polariser → the transmitted light has (almost) the same intensity as the polarised light (i.e. the amplitude of the light wave is identical).



When the 2nd polariser, or the Analyser is *perpendicular* to polariser, no transmitted light is observed. Hence, intensity is zero. (i.e. the amplitude of the light wave is zero).

A longitudinal waves cannot be Polarised. Why?

A longitudinal waves cannot be polarised because the particles in the wave oscillate parallel to the wave direction and cannot be restricted to vibrate in any plane.

Applications of Polarizations

1) Polaroid sunglasses

- The glare from reflecting surfaces can be diminished with the use of Polaroid sunglasses.
- The polarization axes of the lens are vertical, as most glare reflects from horizontal surfaces.

Applications of Polarizations

2) Polarization is also used in the entertainment industry to produce and show 3-D movies.

Reference link : http://www.youtube.com/watch?v=qIKzPgo2rNw

HOW 3D WORKS (not in syllabus, just for your information only)

- Three-dimensional movies are actually two movies being shown at the same time through two projectors.
- The two movies are filmed from two slightly different camera locations. Each individual movie is then projected from different sides of the audience onto a metal screen.
- The movies are projected through a polarizing filter. The polarizing filter used for the projector on the left may have its polarization axis aligned horizontally while the polarizing filter used for the projector on the right would have its polarization axis aligned vertically.
- Consequently, there are two slightly different movies being projected onto a screen. Each movie is cast by light that is polarized with an orientation perpendicular to the other movie. The audience then wears glasses that have two Polaroid filters. Each filter has a different polarization axis - one is horizontal and the other is vertical. The result of this arrangement of projectors and filters is that the left eye sees the movie that is projected from the right projector while the right eye sees the movie that is projected from the left projector. This gives the viewer a perception of depth.

QUESTION TIME !

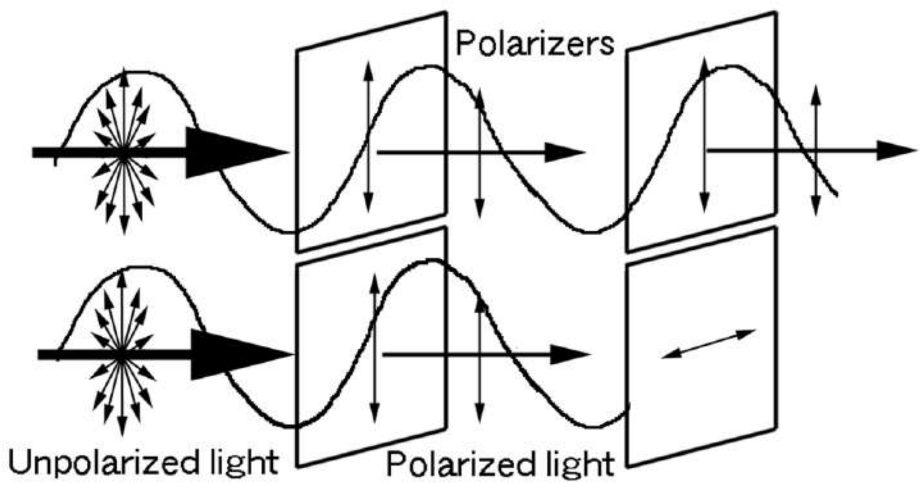
Check your understanding on Polarization

Question No.1

1. Suppose that light passes through two Polaroid filters whose polarization axes are parallel to each other. What would be the result?

Answer - Question No.1

The first filter will polarize the light, blocking one-half of its vibrations. The second filter will have no affect on the light. Being aligned parallel to the first filter, the second filter will let the same light waves through.



Question No.2

2. Which of the following **cannot** be polarised?

A-infrared waves

B-microwaves

C-sound waves

D- ultraviolet waves

Answer - Question No.2

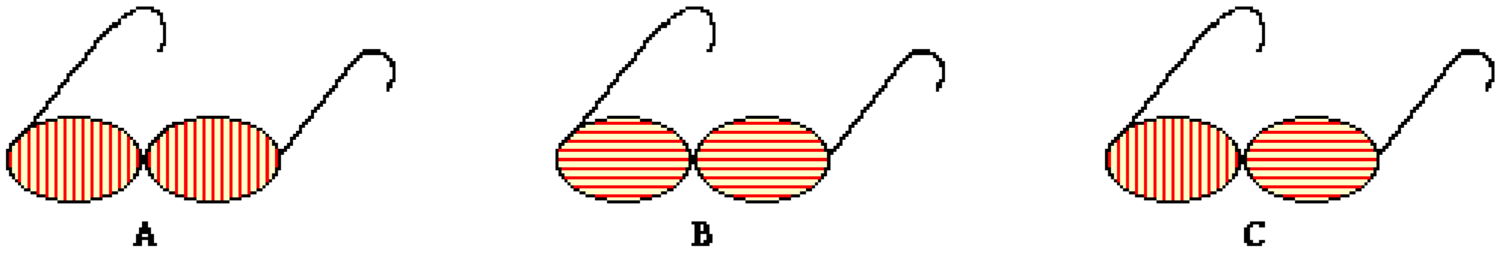
- Answer: **C – Sound waves**

A longitudinal waves cannot be polarised because the particles in the wave oscillate parallel to the wave direction and cannot be restricted to vibrate in any plane.

Question No.3

3. Consider the three pairs of sunglasses below. Identify the pair of glasses which is capable of eliminating the glare resulting from sunlight reflecting off the calm waters of a lake? ___________ Explain.

(The polarization axes are shown by the lines.)



Answer - Question No.3

- Answer: **A**
- The glare is the result of a large concentration of light aligned parallel to the water surface. To block such plane-polarized light, a filter with a vertically aligned polarization axis must be used.


Q&A

Electricity & Magnetism

Current of Electricity

Marline Kurishingal

Syllabus content

Section		AS	A2
V Electricity and magnetism	17. Electric fields	✓	✓
	18. Capacitance		✓
	19. Current of electricity	✓	
	20. D.C. circuits	✓	
	21. Magnetic fields		✓
	22. Electromagnetism		✓
	23. Electromagnetic induction		✓
	24. Alternating currents		✓

Section V: Electricity and magnetism

Recommended prior knowledge

Candidates should be aware of the two types of charge, charging by friction and by induction. They should be able to distinguish between conductors and insulators using a simple electron model.

19. Current of electricity

Content

19.1 Electric current

19.2 Potential difference

19.3 Resistance and resistivity

19.4 Sources of electromotive force

Learning outcomes

Candidates should be able to:

(a) show an understanding that electric current is the flow of charged particles

(b) define charge and the coulomb

(c) recall and solve problems using the equation $Q = It$

(d) define potential difference and the volt

(e) recall and solve problems using $V = \frac{W}{Q}$

(f) recall and solve problems using $P = VI$, $P = I^2R$

(g) define resistance and the ohm

(h) recall and solve problems using $V = IR$

(i) sketch and explain the I-V characteristics of a metallic conductor at constant temperature, a semiconductor diode and a filament lamp

(j) sketch the temperature characteristic of a thermistor (thermistors will be assumed to be of the negative temperature coefficient type)

(k) state Ohm's law

(l) recall and solve problems using $R = \frac{\rho L}{A}$

(m) define e.m.f. in terms of the energy transferred by a source in driving unit charge round a complete circuit

(n) distinguish between e.m.f. and p.d. in terms of energy considerations

(o) show an understanding of the effects of the internal resistance of a source of e.m.f. on the terminal potential difference and output power

Recap……

- Types of electricity
- **Current Electricity**: Net flow of charges in a certain direction
- **Static Electricity**: No net flow of charges in a certain direction

- Matter can be classified into 3 types according to their electrical properties:

- **Conductors** – Materials which have mobile charge carriers, mainly electrons and ions which will drift to constitute an electric current under the effect of an applied electric field. Hence they can conduct electricity. Examples include metals and electrolyte solutions.
- **Insulators** – Materials which have no mobile charge carriers that can drift under the effect of an applied electric field. Hence they cannot conduct electricity. Examples include rubber, wood and plastic.
- **Semiconductors** – Materials which have intermediate electrical conductivity which vary substantially with temperature. Examples include Germanium, Silicon.

Show an understanding that electric current is the rate of flow of charged particles.

- All matter is made up of tiny particles called atoms, each consisting of a positively charged nucleus with negatively charged electrons moving around it.
- Charge is measured in units called coulombs (C). The charge on an electron is -1.6×10^{-19} C.
- Normally atoms have equal number of positive and negative charges, so that their overall charge is zero.
- For some atoms, it is relatively easy to remove an electron, leaving an atom with an unbalanced number of positive charges. This is called positive ion.

Show an understanding that electric current is the rate of flow of charged particles. (continued from previous slide)

- Atoms in metals have one or more electrons which are not held tightly to the nucleus.
- These free (or mobile) electrons wander at random throughout the metal.
- But when a battery (or source) is connected across the ends of the metal, the free electrons drift towards the positive terminal of the battery (or source) producing an electric current.

Show an understanding that electric current is the rate of flow of charged particles. (continued from previous slide)

- The size of the electric current is given by the rate of flow of charge and is measured in units called amperes with symbol A.
- A current of 3 amperes means that 3 coulombs pass a point in the circuit every second. In 5 seconds, a total charge of 15 coulombs will have passed the point.

Electric current

- **Electric current** is the rate of flow of electric charge.
- Mathematically, $I = \frac{Q}{t}$ *where*

I is the electric current (unit: ampere, symbol: A);

Q is the electric charge (unit: coulomb, symbol: C);

t is the time taken (unit: second, symbol: s)

Charge & Coulomb

- From the definition of electric current $I = \frac{Q}{t}$ we obtain, $Q = It$.
- **Electric charge** flowing through a section of a circuit is the product of the electric current and the time that it flows.

- $Q = It$, substituting in units we obtain the following :
- 1 C = (1 A) (1 s) = 1 A s
- **One coulomb** is the quantity of electric charge that passes through a section of a circuit when a steady current of one ampere flows for one second.

Solve problems using the equation $Q = It$

Example 1

Given that the electric current flowing through a circuit is 0.76 mA, calculate the electric charge which passes each section of the circuit over a time of 60 s.

Solution:

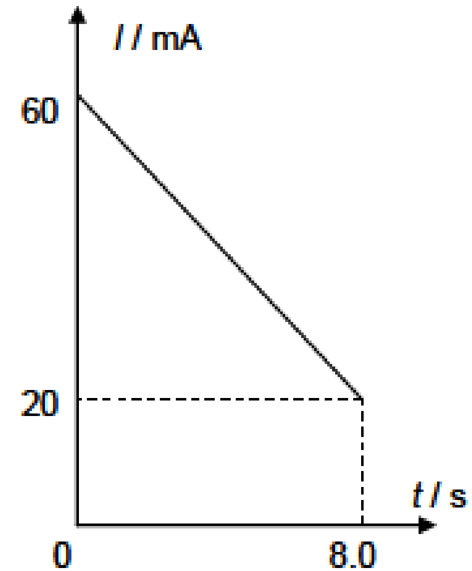
$$[Q = It]$$

$$Q = (0.76 \times 10^{-3})(60) = 0.0456 = 4.56 \times 10^{-2}\,\text{C}$$

Solve problems using the equation $Q = It$

Example 2

Over a time of 8.0 s, the electric current flowing through a circuit component is reduced uniformly from 60 mA to 20 mA. Calculate the charge that flows during this time.



Solution:

Charge = area under current-time graph

$$= \tfrac{1}{2}(8.0)(60 + 20)(10^{-3}) = 0.32\ \text{C}$$

Resistance and Ohm

Ohm's Law states that the current through the conductor is directly proportional to the potential difference between its ends provided its temperature and other physical conditions remain constant.

Mathematically

$$I \propto V \quad \Rightarrow \quad V = RI \quad \Rightarrow \quad R = \frac{V}{I}$$

The proportionality constant R in the equation is the electrical resistance of the device. It is constant for a metallic conductor under steady physical conditions. Materials which obey Ohm's law are called ohmic conductors.

Resistance of a conductor is defined as the ratio of the potential difference across it to the current flowing through it.

From $R = \frac{V}{I}$, $1\ \Omega = 1\ \text{V A}^{-1}$ defines the ohm.

The **ohm** is the resistance of a conductor if a current of one ampere flows through when there is a potential difference of one volt across it.

Example 5

A 12 V 24 W bulb is connected in series with a variable resistor and a 18 V battery of negligible internal resistance. The variable resistor is adjusted until the bulb operates at its normal rating.

Determine

(i) the current in the bulb
(ii) the resistance of the bulb
(iii) the p.d. across the variable resistor;
(iv) the power dissipation in the variable resistor.

Solution:

(i) $P = VI$
$24 = (12)I$
$I = 2.0$ A

(ii) $V = IR$
$12 = (2.0)R$
$R = 6.0\ \Omega$

(iii) p.d. across variable resistor = 18 – 12 = 6.0 V

(iv) $P = VI = (6.0)(2.0) = 12$ W

Resistance & Resistivity

The resistance R of a sample is <u>directly proportional to its length l</u> and <u>inversely proportional to its cross-sectional area A</u>.

$$R \propto \frac{l}{A}$$

The relationship could be expressed as an algebraic equation by introducing a constant of proportionality as follows:

$$R = \frac{\rho l}{A}$$

The constant ρ is now recognised as a property of the material and is called its **resistivity**. Hence

$$\rho = \frac{RA}{l}$$

where ρ is the resistivity of the material, in Ω m
R is the resistance of the sample, in ohms (Ω)
A is the cross-section area of the sample, in m^2
l is the length of the sample, in metres (m)

Resistivity is useful when comparing various materials on their ability to conduct electricity. A high resistivity means a sample of the material is a poor conductor. A low resistivity means a sample of the material is a good conductor.

Resistivity

- Resistivity is defined as the electrical property of a material that determines the resistance of a piece of given dimensions.

- It is equal to $\rho = \frac{RA}{l}$ where R is the resistance, A the cross-sectional area, and l the length, and is the reciprocal of conductivity. It is measured in ohm metres. It is denoted by the symbol **ρ.**

Solve problems using $R = \frac{\rho L}{A}$

Example 6

The resistivity of a material is 3.1×10^{-5} Ω m. Determine the resistance of a sample of the material given that its length is 20 cm and its cross-section area is 2.0 mm^2.

Solution:

$$R = \frac{\rho l}{A} = \frac{(3.1 \times 10^{-5})(0.20)}{(2.0)(0.001)^2} = 3.1\Omega$$

Potential difference and Volt

- Defining p.d in terms of energy:
  - The potential difference between two points in a circuit is defined as the electrical energy converted to other forms of energy per unit charge passing between the two points.
- Alternatively, defining p.d in terms of power:
  - The p.d. between two points in a circuit is defined as the rate of conversion of electrical energy to other forms of energy per unit current flowing between the two points.

Potential difference and Volt (continued)

In terms of energy:

$$\text{potential difference (p.d.)} = \frac{\text{energy converted}}{\text{charge}}$$

$$\text{hence } \boldsymbol{V} = \frac{\boldsymbol{W}}{\boldsymbol{Q}} \text{ or } W = QV\text{ .}$$

In terms of power:

$$\text{potential difference (p.d.)} = \frac{\text{power converted}}{\text{current}}$$

$$\text{hence } V = \frac{P}{I} \text{ or } \boldsymbol{P} = \boldsymbol{VI}\text{ .}$$

where V is the p.d., in volts (V)
W is the energy converted, in joules (J)
Q is the electric charge moved, in coulombs (C)
P is the power converted, in watts (W)
I is the electric current flowing, in amperes (A)

Since $V = IR$ from learning outcome (h), $\boldsymbol{P} = \boldsymbol{I}^2\boldsymbol{R}$.

From $V = \dfrac{W}{Q}$, 1 V = 1 J C^{-1} defines the volt (in terms of energy).

Potential difference and Volt (continued)

The **volt** is the potential difference between two points in a circuit if one joule of electrical energy is converted to other forms of energy when one coulomb of charge passes between the two points.

Alternatively, from $P = VI$, $1\ \text{V} = 1\ \text{W A}^{-1}$ defines the volt (in terms of power).

The **volt** is the potential difference between two points in a circuit if one watt of electrical power is converted to other forms of power when one ampere of current passes between the two points.

Potential difference and Volt (continued)

Note:

- Since the unit for p.d. is volt, p.d. is frequently called voltage.
- The p.d. can only be used if the two points are stated clearly. For a single circuit component, the two points are usually the two ends of the component hence the p.d. across the component.
- Sometimes the term "potential at a point" in a circuit is used. This has meaning only if there is a defined reference point for zero potential e.g. the electrical **earth** has zero potential.

Just for your info : The real Earth is electrically neutral. This means that it has the same number of electrons and protons, so their charges cancel out overall. Scientifically, we describe this by saying that the Earth has an Electric Potential of zero.

Solve problems using $V = \frac{W}{Q}$

Example 4

An immersion heater is rated at 3000 W and is switched on for 2000 s. During this time a charge of 25 kC is supplied to the heater. Determine the potential difference across the heater.

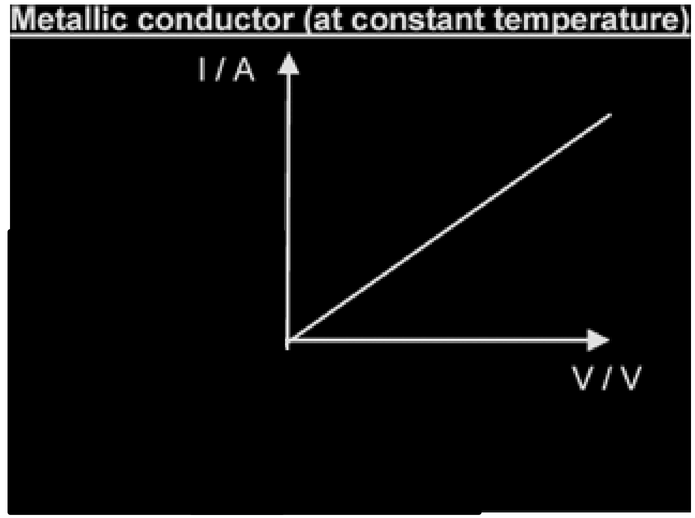
Solution:

$$V = \frac{W}{Q} = \frac{(3000)(2000)}{25000} = 240\ \text{V}$$

Sketch and explain
the *I-V characteristics*
of
***a metallic conductor at* constant temperature,**
a semiconductor diode
and
a filament lamp.

Sketch and explain the *I-V characteristics of a metallic conductor at* constant temperature

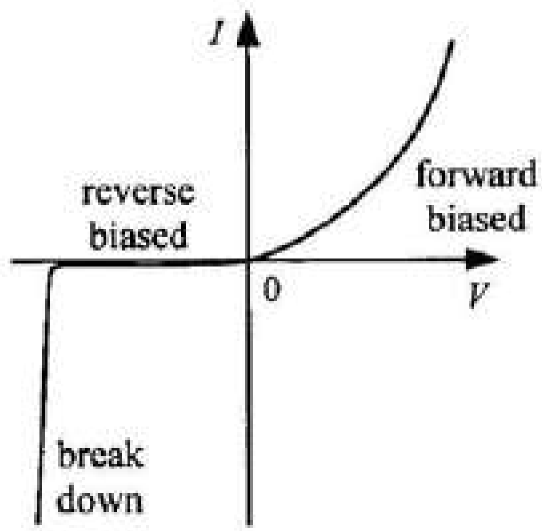
1) Metallic conductor at constant temperature



- The *I-V* characteristic of a metallic conductor at constant temperature is a straight line through the origin. This implies constant *I-V* ratio, i.e. constant resistance. Therefore a metallic conductor at constant temperature is an ohmic conductor.
- In terms of the movement of charge carriers, resistance in metallic conductors arises from the reduction in the drift velocity of free electrons due to collision with lattice ions. If the temperature of the conductor is kept constant, the lattice ion vibrations will remain the same hence its resistance will remain the constant.
- In short, the resistance of a metallic conductor is constant at constant temperature (ohmic conductor).

Sketch and explain the *I-V characteristics of* a semiconductor diode

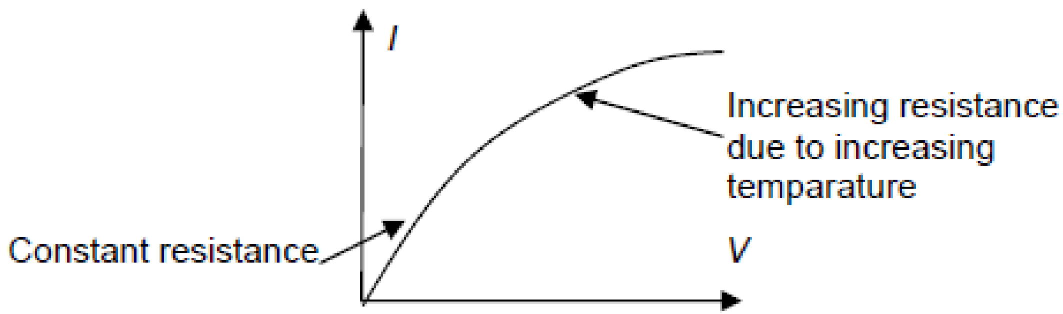
2) Semiconductor diode



- A diode is a device that has a low resistance in one direction (forward-biased direction) and a very high resistance in the other direction (reverse-biased direction).
- The *I-V* characteristic of a forward-biased semiconductor diode is similar to that of a thermistor, i.e. resistance decreases as p.d. increases.
- The *I-V* characteristic of a reverse-biased semiconductor diode is nearly zero. If reverse-biased p.d. is too high, the diode will break down and conduct electricity.

Sketch and explain the *I-V characteristics of a* filament lamp.

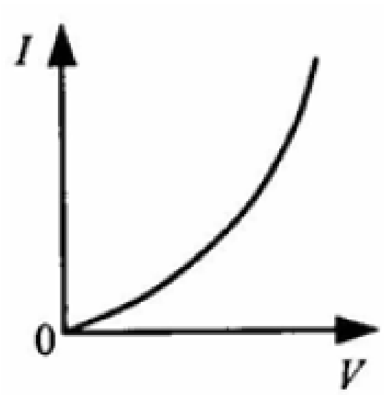
3) Filament lamp

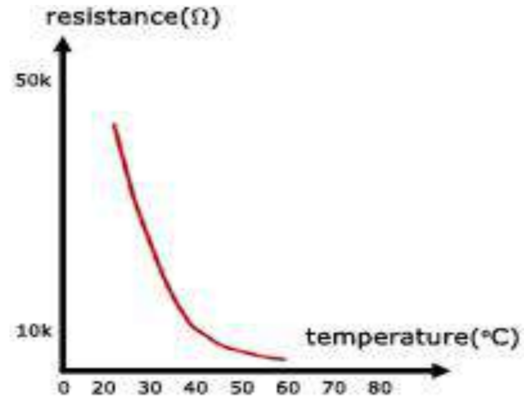


- A filament lamp contains a long thin wire made of metal with high melting point (e.g. tungsten).
- With low p.d. across the filament lamp, low current flowing through it and the heating effect is insignificant hence the resistance is fairly constant.
- As the p.d. across a filament lamp increases, current increases. Heating effect is significant resulting in temperature increase.
- The resistance of metals increases with temperature. Hence, decreasing *I-V* gradient.
- In terms of the movement of charge carriers, the lattice ion vibrations will be more at higher temperature. There will be more reduction in the drift velocity of electrons due to collision with lattice ions hence current will be lower and resistance will be higher.
- In short, the resistance of a filament lamp increases as the p.d. applied across it increases.

The temperature characteristic of a thermistor

Thermistor *I-V* characteristic and temperature characteristic





- A thermistor is a resistor made of semiconductors.
- With low p.d. across the thermistor, low current flowing through it and the heating effect is insignificant hence the resistance is fairly constant.
- As the p.d. across a thermistor increases, current increases. Heating effect is significant resulting in temperature increase.
- The resistance of semiconductors decreases with temperature. Hence, increasing *I-V* gradient.
- In terms of the movement of charge carriers, the lattice ion vibrations will be more at higher temperature. There will be more reduction in the drift velocity of charge carriers due to collision with lattice ions. However the concentration of charge carriers in semiconductors increases significantly with temperature. Hence the overall effect is a reduction in resistance.
- In short, the resistance of a thermistor decreases as its temperature increases.

E.M.F in terms of the energy transferred by a source in driving unit charge round a complete circuit

Movement of charge carriers is possible only if they possess energy and are allowed to dissipate their energy. Sources like batteries and generators provide the energy to the charge carriers. Available path(s) for charge carriers to dissipate their energy cause their movement.

Defining in terms of energy:

The **electromotive force (e.m.f.)** of a source is defined as the non-electrical energy converted to electrical energy per unit charge driven through the source.

Defining in terms of power:

The **electromotive force (e.m.f.)** of a source is defined as the non-electrical power converted to electrical power per unit current delivered by the source.

The SI unit of e.m.f. is same as that of potential difference, i.e. the volt. (Recall that $1\ V = 1\ J\ C^{-1}$ or $1\ W\ A^{-1}$)

E.M.F in terms of the energy transferred by a source in driving unit charge round a complete circuit (continued from previous slide)

Mathematically, $E = \dfrac{W}{Q}$ or $E = \dfrac{P}{I}$

where E is the e.m.f. of the source, in volts (V)
W is the energy converted, in joules (J)
Q is the electric charge moved, in coulombs (C)
P is the power converted, in watts (W)
I is the electric current delivered, in amperes (A)

Examples include:

- In a battery, chemical energy converted to electrical energy through chemical reactions.
- In a generator, mechanical energy (in the form of rotational kinetic energy) is converted to electrical energy.

Distinguish between e.m.f. and p.d. in terms of energy considerations

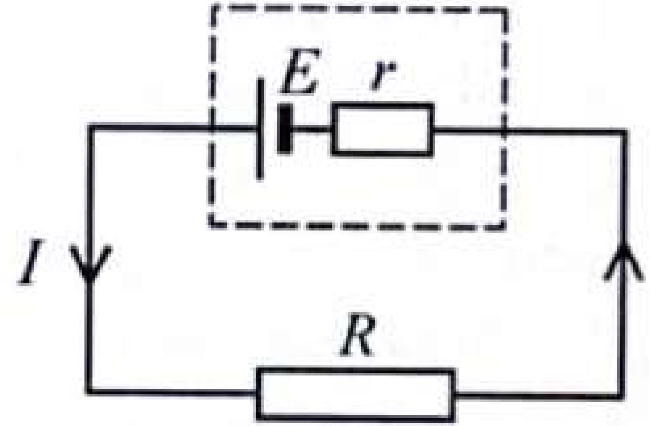
- The electromotive force (e.m.f.) of a source is defined using the non-electrical energy converted to electrical energy while the potential difference (p.d.) between two points is defined using electrical energy converted to non-electrical energy.

The effects of the internal resistance of a source of e.m.f. on the terminal potential difference and output power.

- In practice, no energy source (battery or generator) is perfect.
- Some of the electrical energy delivered by a source is always dissipated within itself.
- The source is said to have internal resistance. When the external load is large, the internal resistance has negligible effect.
- When the external load is not large, the internal resistance can be depicted as a series resistor within the source as shown in the diagram in next slide.

The effects of the internal resistance of a source of e.m.f. on the terminal potential difference and output power.

(continued from previous slide)



The energy delivered by the source is then shared between its internal resistance and external load,

i.e. energy supplied = energy dissipated (external + internal).

$$EIt = I^2Rt + I^2rt$$

$$\Rightarrow \quad E = IR + Ir$$

$$\Rightarrow \quad E = I(R+r)$$

E = V

V x I = P

The **terminal p.d.** is the potential difference across the source. It is equivalent to the potential difference across the external circuit.

Hence terminal p.d. is $V = IR = E - Ir$

where V is the terminal p.d., in volts (V)

E is the e.m.f. of the source, in volts (V)

I is the electric current delivered, in amperes (A)

R is the resistance of the external circuit, in ohms (Ω)

r is the internal resistance of the source, in ohms (Ω)

The effects of the internal resistance of a source of e.m.f. on the terminal potential difference and output power.

(continued from previous slide)

It can be deduced that when the source is connected to an external circuit, the terminal p.d. of the source is reduced by the amount Ir.

$$V = E - Ir$$

When the current I through the source is zero (such as when the external circuit is open) then terminal p.d. V will be equal to the e.m.f. E.

I in the above equation becomes Zero

When the internal resistance is negligible, the terminal p.d. will be approximately equal to the e.m.f. E.

Alternatively, viewing in terms of power, the power delivered by the source is shared between its internal resistance and external load,

i.e. power supplied = power dissipated (external + internal).

$$P_E = P_R + P_r$$

$$EI = I^2R + I^2r$$

The power dissipated internally ($P_r = I^2r$) is wasted in heating up the energy source. Only the power that is dissipated externally ($P_R = I^2R$) is available to the external circuit so the efficiency of the source is always below 100%.

$$\text{Efficiency } \eta = \frac{\text{useful power}}{\text{total power}} = \frac{VI}{EI} = \frac{I^2R}{I^2(R+r)} = \frac{R}{R+r}$$

Show an understanding of the effects of the internal resistance of a source of e.m.f. on the terminal potential difference and output power.

Example 7

A battery of e.m.f. 12 V and internal resistance 0.014 Ω delivers a 2.0 A current when first connected to a motor. Calculate the resistance of the motor.

Solution:

$$E = I(R+r) \Rightarrow 12 = 2.0(R + 0.014) \Rightarrow R = 5.99\ \Omega$$

Modern Physics

Nuclear Physics

Marline Kurishingal

Syllabus content

Section		AS	A2
VI Modern Physics	25. Charged particles		✓
	26. Quantum physics		✓
	27. Nuclear physics	✓	✓

Section VI: Modern Physics

Recommended prior knowledge

Candidates should be able to describe matter in terms of atoms, with electrons orbiting a positively charged nucleus. Candidates should have studied some of the material in Section IV.

27. Nuclear physics

Content	Learning outcomes
27.1 The nucleus 27.2 Isotopes 27.3 Nuclear processes	Candidates should be able to: *(a)* infer from the results of the α-particle scattering experiment the existence and small size of the nucleus *(b)* describe a simple model for the nuclear atom to include protons, neutrons and orbital electrons *(c)* distinguish between nucleon number and proton number *(d)* show an understanding that an element can exist in various isotopic forms, each with a different number of neutrons *(e)* use the usual notation for the representation of nuclides *(f)* appreciate that nucleon number, proton number, and mass-energy are all conserved in nuclear processes *(g)* represent simple nuclear reactions by nuclear equations of the form $^{14}_{7}N + ^{4}_{2}He \rightarrow ^{17}_{8}O + ^{1}_{1}H$ *(h)* show an appreciation of the spontaneous and random nature of nuclear decay *(i)* show an understanding of the nature and properties of α-, β- and γ-radiations (β^{+} is not included: β-radiation will be taken to refer to β^{-}) *(j)* infer the random nature of radioactive decay from the fluctuations in count rate

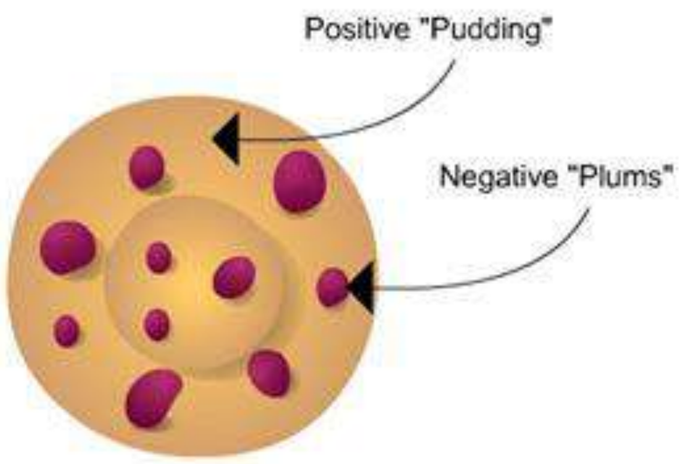
The results of the α-particle scattering experiment & the existence and small size of the nucleus

Rutherford Alpha Particle Scattering Experiment

Rutherford Alpha Particle Scattering Experiment

- **Rutherford's** alpha particle scattering experiment changed the way we think of atoms.

- Before the experiment the best model of the atom was known as the Thomson or **"plum pudding"** model. The atom was believed to consist of a positive material "pudding" with negative "plums" distributed throughout.



Rutherford Alpha Particle Scattering Experiment

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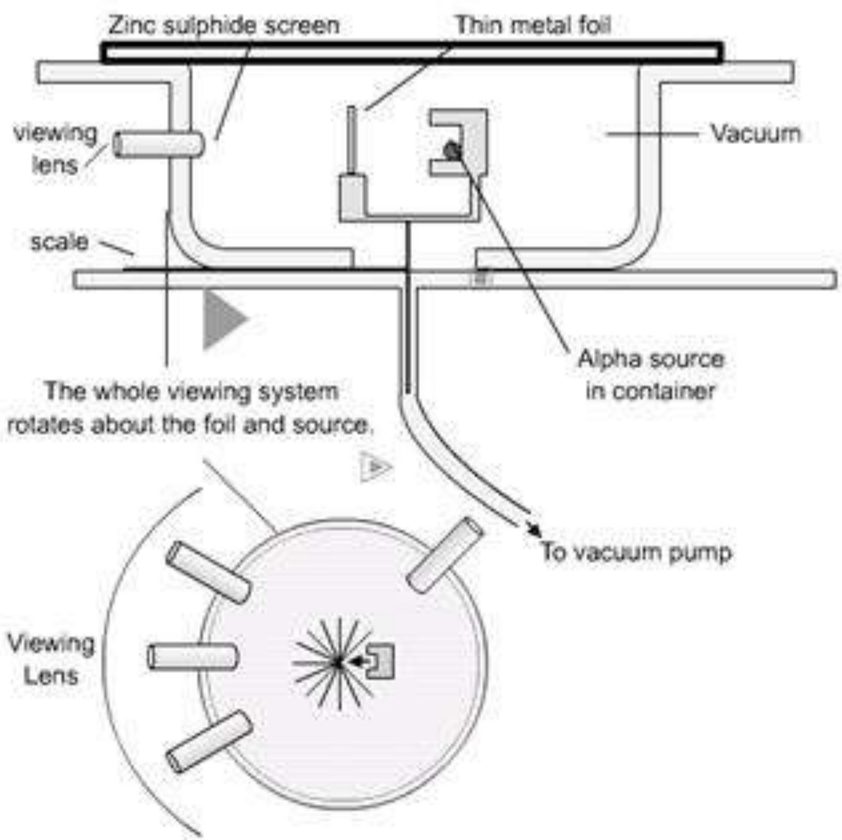


Note : Diagram is only for your reference, its not in syllabus

- Rutherford directed beams of alpha particles (which are the nuclei of helium atoms and hence positively charged) at thin gold foil to test this model and noted how the alpha particles scattered from the foil.

Rutherford Alpha Particle Scattering Experiment

(continued from previous slide)

- **Rutherford made 3 observations:**

➢ **Most** of the fast, highly charged alpha particles went whizzing straight through un-deflected. This was the expected result for **all** of the particles if the plum pudding model was correct.

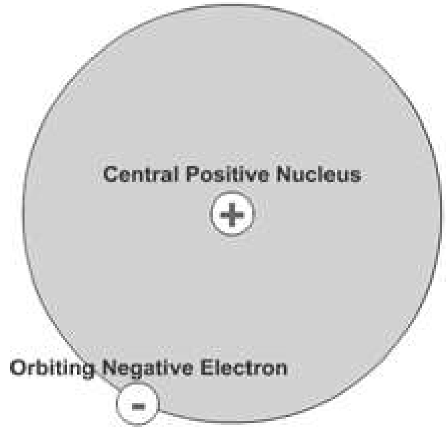
➢ **Some** of the alpha particles were deflected back through large angles. This was **not** expected.

➢ A **very small number** of alpha particles were deflected **backwards**! This was definitely not as expected.

Rutherford Alpha Particle Scattering Experiment

(continued from previous slide)

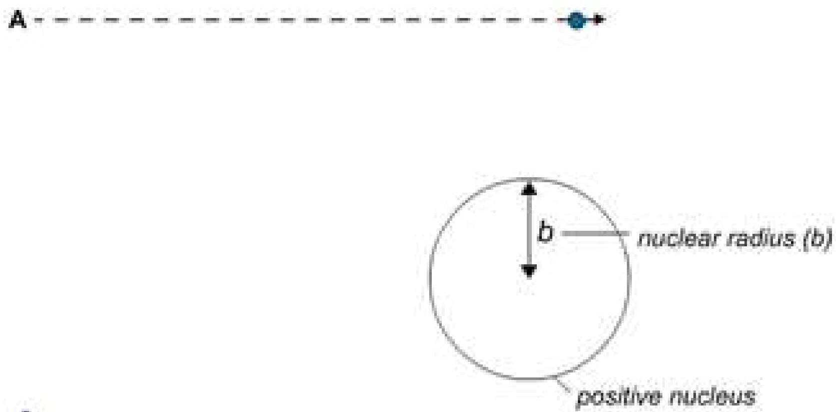
- **To explain these results a new model of the atom was needed.**



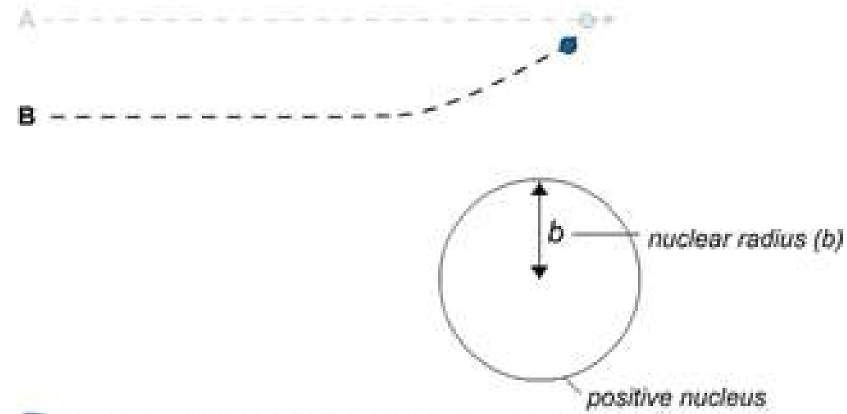
- In this model the positive material is concentrated in a small but massive (lot of mass - not size) region called the **nucleus.** The negative particles (electrons) must be around the outside preventing the atom from trespassing on its neighbours space to complete this model.
- The diagram in next slide will help you to understand the results of the experiment.

Rutherford Alpha Particle Scattering Experiment

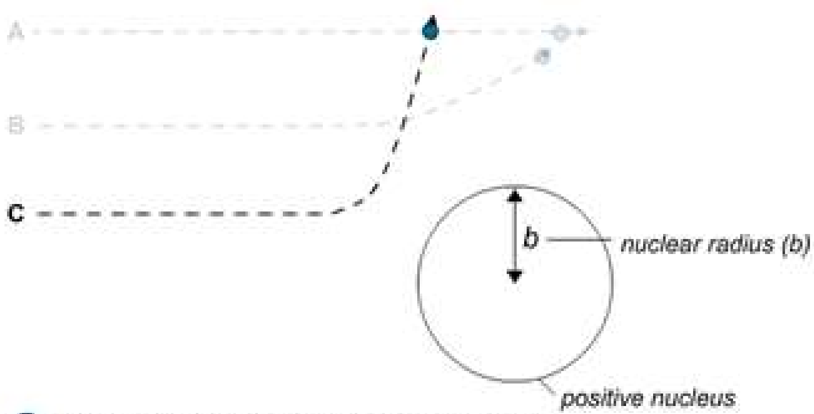
(continued from previous slide)



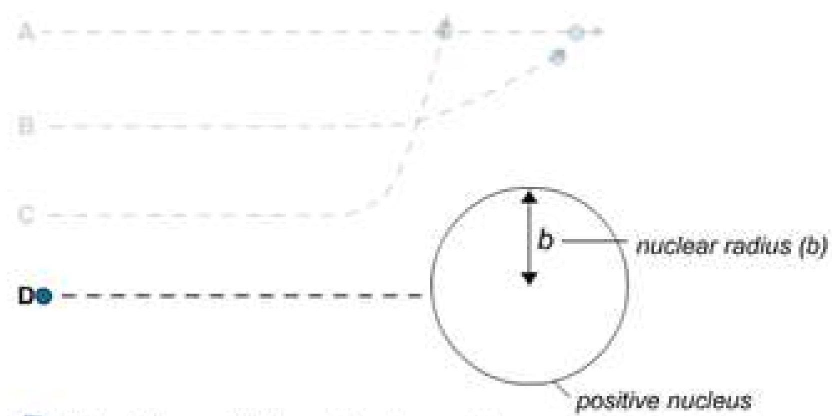
A Alpha particles this far from the nucleus experience little or no deflection as they are not close enough to the small positive nucleus.



B Here, alpha particles will be slightly deflected as they are closer to the nucleus, so you will see some scattering.

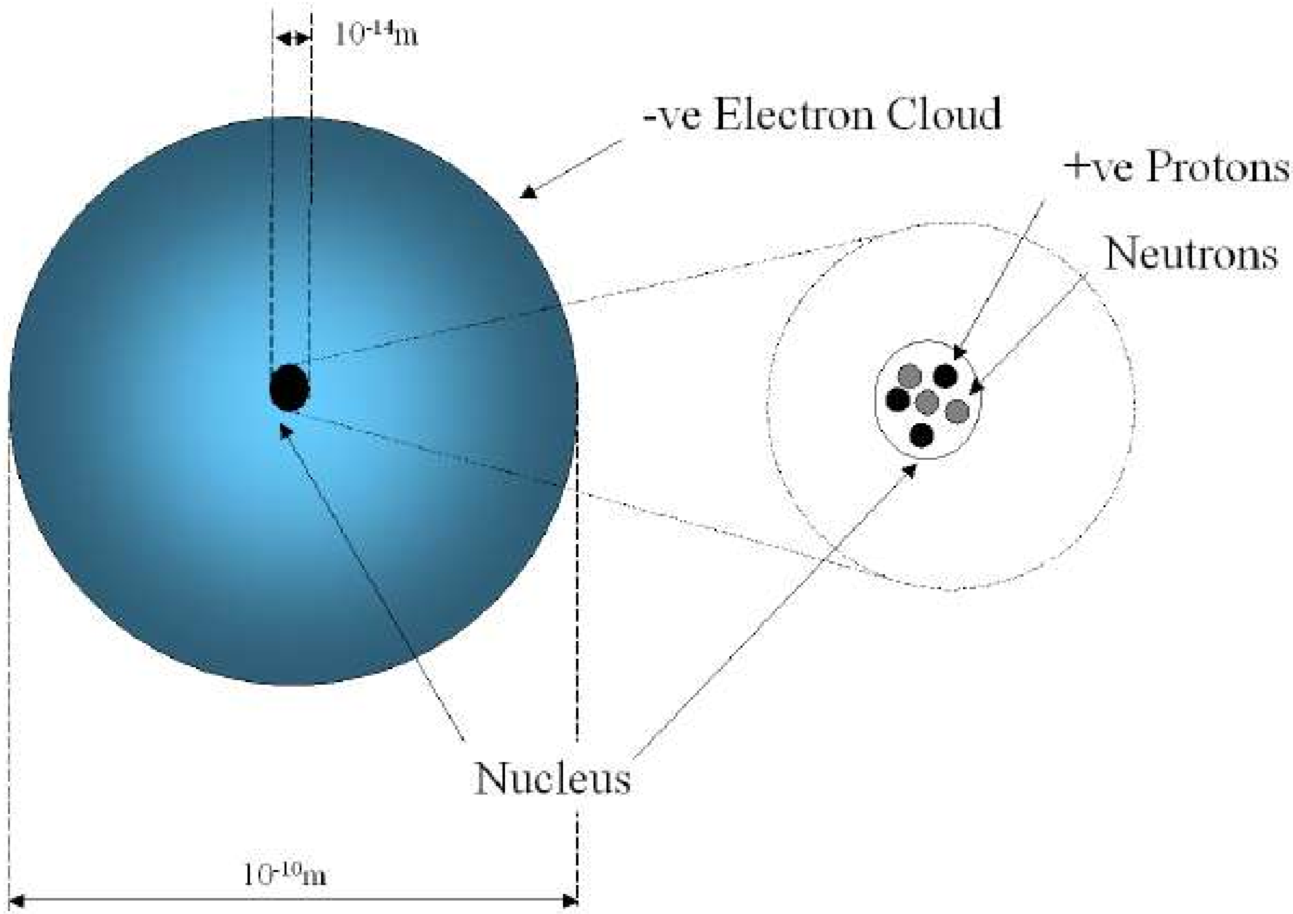


C This close to the nucleus, the alpha particles experience a large deflection, so they are scattered through large angles.



D The alpha particle has a head on collision with the nucleus so it bounces straight back

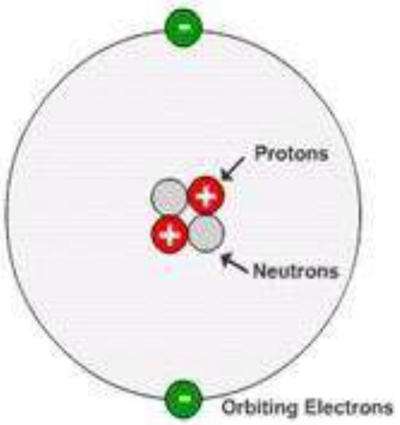
describe a simple model for the nuclear atom to inclu... and orbital electrons



	Protons	Neutrons	Electrons
Relative Mass	1	1	Negligible
Charge	[illegible]	Neutral	-1

Particles in the Atom

Atoms contain 3 types of particles: protons, neutrons and electrons.



It is important to understand that the picture above is a **model** of the atom. It conveys an impression of what the atom is like, but is not a completely true representation.

As an example of this consider the relative sizes of the nucleus and whole atom. It can be found that a typical nuclear diameter is 1 x 10^{-14}m while the typical atomic diameter is 1 x 10^{-10}m. Thus the nucleus is around 10,000 times smaller than the entire atom. You could build a model of an atom by placing a pea on the centre spot of a football stadium (to represent the nucleus) and then placing the electrons somewhere out in the stands. The picture above certainly does not reflect this fact accurately! Molecules are simply combinations of 1 or more atoms so are slightly larger than atoms themselves.

Each of these particles has a **mass** and a **charge.**

Table of masses and charges

	Mass/Kg	Charge/Coulombs
Proton	1.660×10^{-27}	1.602×10^{-19}
Neutron	1.660×10^{-27}	0
Electron	9.110×10^{-31}	1.602×10^{-19}

It is possible to simplify this information by looking for patterns in the numbers.

Firstly, notice that the electron and proton have **equal** and **opposite** charges. A new unit of charge called the **elementary charge** ($e = 1.602 \times 10^{-19}$ Coulombs) allows us to assign the values of +1e and **-**1e, to the charge of these particles.

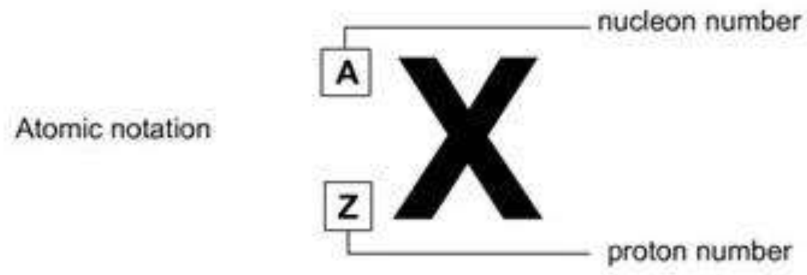
Secondly, as the mass of the proton, neutron and electron are very small a more convenient unit is the atomic mass unit ($u = 1.660 \times 10^{-27}$ kg). Using this new unit we can approximate the masses of the proton, neutron and electron to be 1u, 1u and 0 u respectively. The **relative atomic masses** of the three particles can therefore simply be stated as 1,1,0.

Table of relative masses and charges

	Relative Mass	Relative Charge
Proton	1	+1
Neutron	1	0
Electron	0	-1

Many different atoms can be built using the 3 particles described above. 91 different atoms occur naturally (the chemical elements) and many more can be found in situations where energy levels are high. It is useful to have a concise way of describing these atoms.

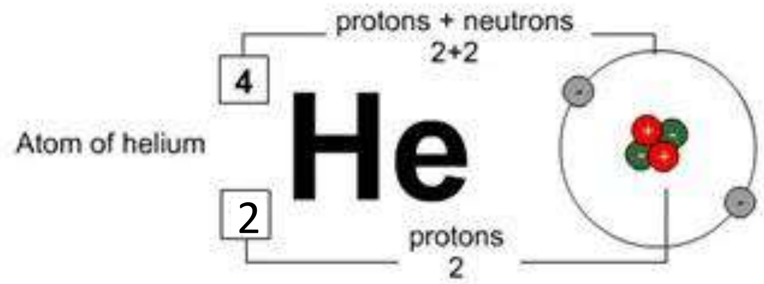
To describe the number of particles in a given atom, we use this notation:



The top number (A) is called the **nucleon number** (as it is the number of things in the nucleus of the atom) or the **mass number** (as it is the mass of the atom.)

The bottom number (Z) is called the **proton number** (as it is the number of protons) or the **atomic number** (as it is the number that tells you which element the atoms belongs to).

The letters give you a clue as to the name of the element. ***For example here is an atom of helium:***.



How do we know about the protons and neutrons in the nucleus?

It is an established scientific fact that the atom has a small, central nucleus containing protons and neutrons. **But how did physicists gather evidence to support this view?**

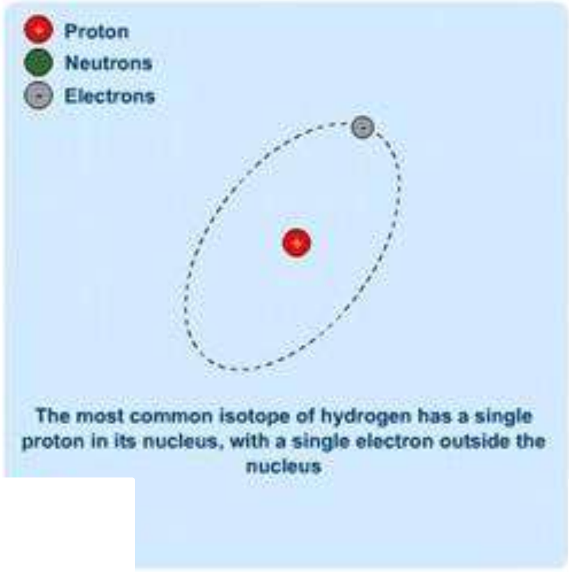
The Rutherford scattering experiment proved that the nucleus was small and positive but it took a different experiment to prove the existence of the protons and neutrons within. Very high-energy electrons have enough energy to actually penetrate into the nucleus itself.

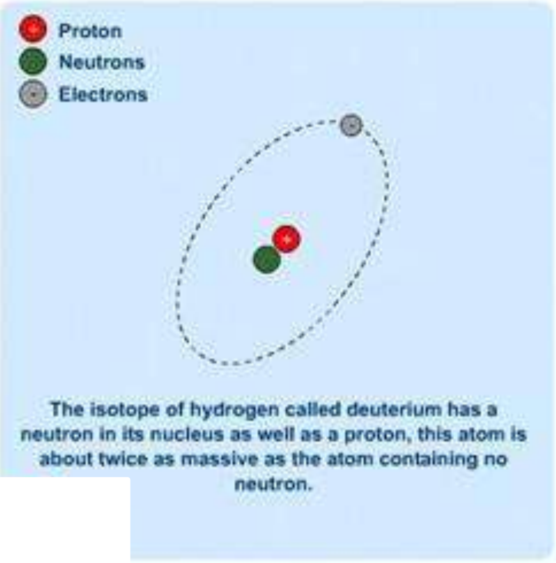
Isotopes

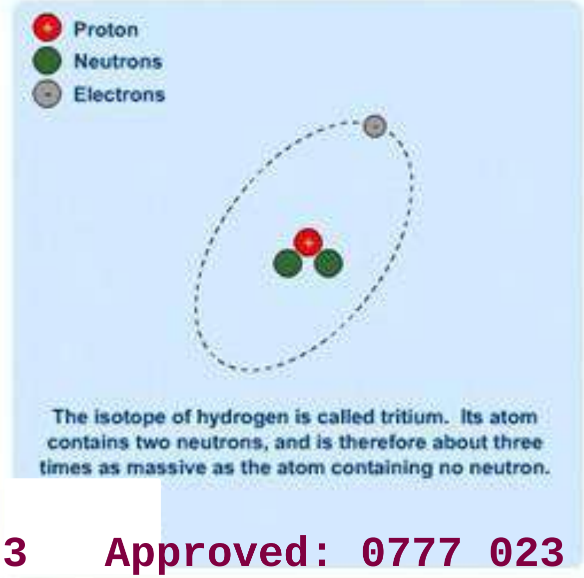
The **number of protons in an atom is crucial**. It gives you the charge of the nucleus and therefore it gives you the number of electrons needed for a neutral atom. And the number of electrons governs how an atom behaves and reacts chemically with other atoms. In other words, it gives you its properties. So the number of protons makes the atom belong to a particular element. **Change the number of protons and you change the element.**

The number of neutrons in the nucleus is less crucial. You can change the number of neutrons without changing the chemical properties of the atom. So it behaves in the same way. Atoms with the same proton number but different numbers of neutrons are called isotopes.

Here are the 3 isotopes of hydrogen.







Recap…

distinguish between nucleon number and proton number

Nucleon number A:	The number of nucleons (Protons and Neutrons)
Proton number Z:	The number of protons in the nucleus
Neutron number N:	The number of neutrons in the nucleus

show an understanding that an element can exist in various isotopic forms, each with a different number of neutrons

Nuclide:	An atom with a particular number of protons and neutrons
Isotope:	Isotopes are nuclides that contain the same number of protons, but different numbers of neutrons.
Nucleon:	Component of the nucleus = Protons and Neutrons

Decay equations

To show what happens before and after a nuclear reaction (reaction involving the nucleus of an atom) we use equations that show both the proton (Z) and nucleon number (A). To balance a nuclear equation (left side and right side) you have to make sure that the sum of the nucleon (top) numbers on the left hand side equals the sum of the nucleon numbers on the right hand side AND the sum of the proton numbers on both sides also balance.

For Example:.

$$^{14}_{7}N + {}^{4}_{2}He \rightarrow {}^{17}_{8}O + {}^{1}_{1}H$$

Note : This equation is an example for balanced equation. Do not consider it for alpha emission.

Top row = 18 on both the left and right sides.

Bottom row = 9 on both the left and right sides.

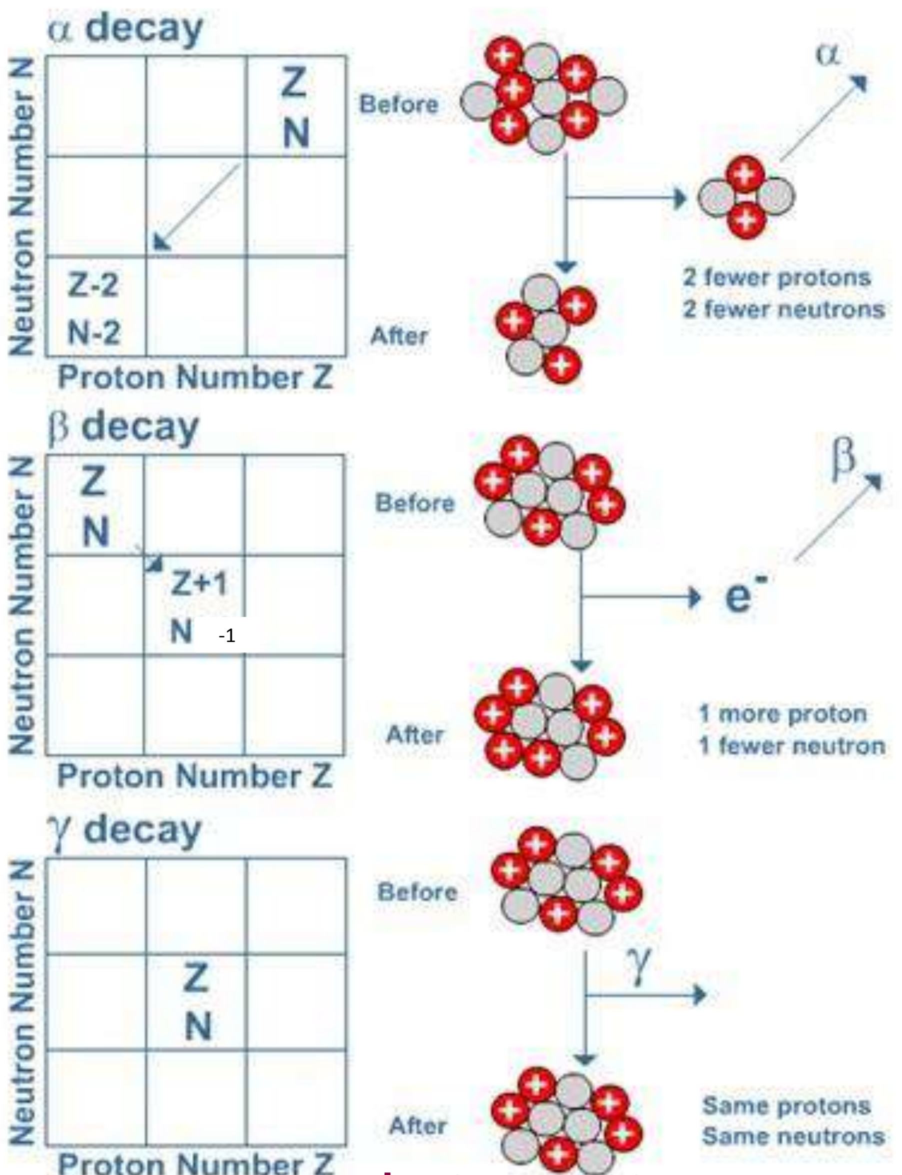
This is a balanced equation.

Nuclear equations such as these are useful for explaining what happens in radioactive decay processes.

Unstable nuclei emit **alpha, beta** or **gamma** radiation in order to become more stable.

As a result of emitting this radiation the character of the nucleus remaining is changed. This is **radioactive decay**.

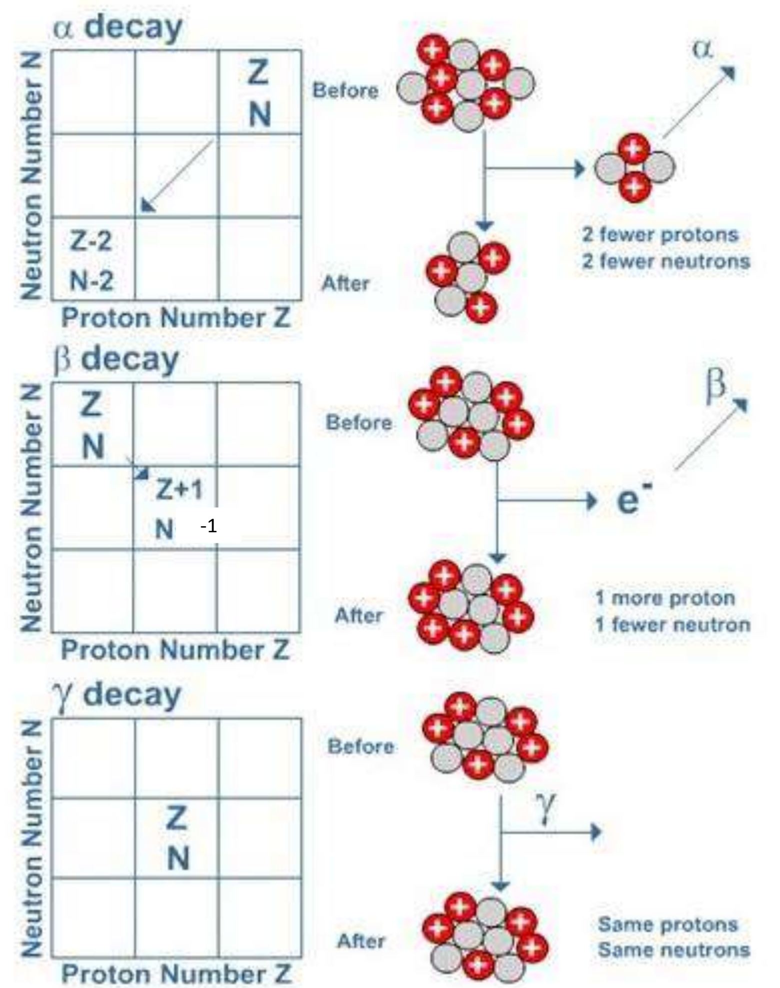
The diagrams below show what happens when a nucleus emits alpha, beta or gamma radiation.



- In alpha decay 2 protons and 2 neutrons are emitted. Notice that this reduces the nucleon number by 4 and the proton number by 2. A new element is thus formed.

- In beta decay a neutron changes into a proton (which remains in the nucleus) and an electron (which is emitted as beta radiation). The net effect is an increase in proton number by 1, while the nucleon number stays the same. Again a new element is formed.

- When a nucleus has undergone alpha or beta decay it is often left in a high-energy (**excited**) state. This energy can be lost in the form of an emitted a gamma ray. Because the composition of the nucleus is unchanged no new element is formed.



Recap…

represent simple nuclear reactions by nuclear equations of the form

$^{14}{}_{7}N + {}^{4}{}_{2}He \longrightarrow {}^{17}{}_{8}O + {}^{1}{}_{1}H$

Alpha decay….

$${}^{A}_{Z}X \rightarrow {}^{A-4}_{Z-2}Y + {}^{4}_{2}\alpha$$

Example….

$${}^{241}_{95}Am \rightarrow {}^{237}_{93}Np + {}^{4}_{2}\alpha$$

Beta decay

$${}^{A}_{Z}X \rightarrow {}^{A}_{Z+1}Y + {}^{0}_{-1}\beta + \overline{\nu}$$

$${}^{90}_{38}Sr \rightarrow {}^{90}_{39}Y + {}^{0}_{-1}\beta + \overline{\nu}$$

Gamma decay

$${}^{A}_{Z}X^{*} \rightarrow {}^{A}_{Z}X + {}^{0}_{0}\gamma$$

In any nuclear reaction the following must *always* be true:

- The total atomic number before the reaction must be the same as the total atomic number after the reaction.
- The total atomic mass before the reaction must be the same as the total atomic mass after the reaction.

The first requirement above is the statement of the conservation of charge in nuclear reactions.
The second requirement is the statement of the conservation of nucleon number.

Why are Some Atoms Radioactive?

Instability

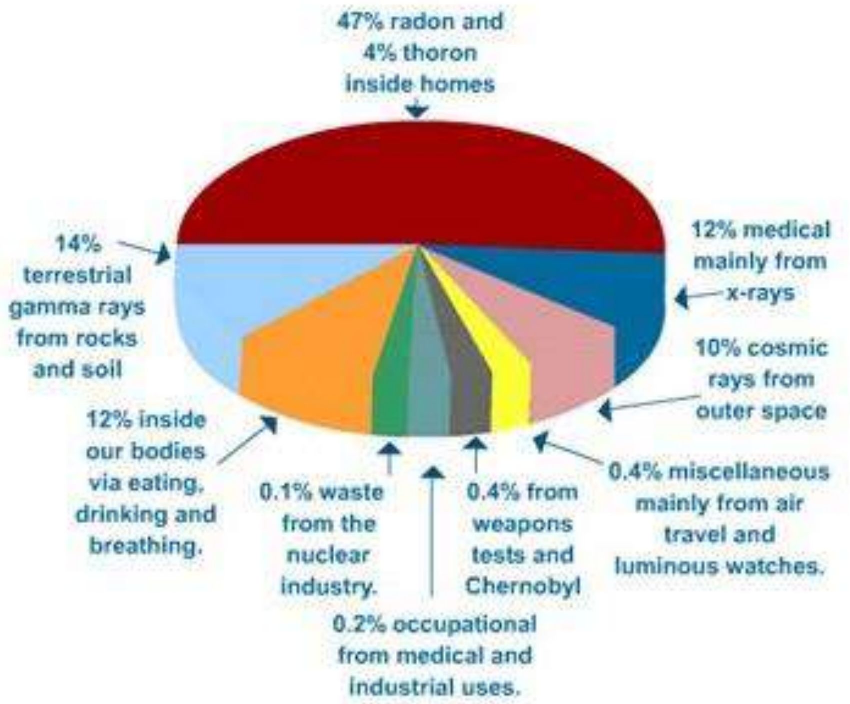
Some atoms are unstable. They have too much energy or the wrong mix of particles in the nucleus. So to make themselves more stable, they breakdown (or decay) and get rid of some matter and/or some energy. This is called radioactive decay and isotopes of atoms that do this are called **radioisotopes.**

The process is spontaneous and random. You can't do anything to speed it up or slow it down and you can't predict when it will happen. The only reason we can do any calculations on radioisotopes is because there are **huge** numbers of atoms in most samples so we can use statistics to accurately predict what's most likely to happen.

Background Radiation

A Geiger counter set up anywhere on Earth will always register a count. This is due to tiny fragments of radioactive elements present in all rocks and soil, the atmosphere and even living material. The Earth is also continuously bombarded by high-speed particles from outer space and the Sun called cosmic rays. In addition the nuclear and health industries produce small amounts of radiation each year. Collectively this radiation around us from natural and unnatural sources is called **background radiation.**

The chart shows the main sources of background radiation.



When carrying out practical work involving count-rates from radioactive sources, allowance should be made for this background radiation. This can usually be done effectively by measuring the background count in the laboratory for several minutes, and subtracting the appropriate amount from subsequent readings taken with the source.

What is ionising radiation?

Alpha, beta and gamma

Ionising radiation comes in three varieties:

α (alpha) particles

β (beta) particles

γ (gamma) rays.

All of these forms of radiation are energetic enough to pull electrons away from atoms. The atoms that have had electrons removed in this way are now charged particles, or **ions**, and hence the name **ionising radiation.**

The fact that these radiations are ionising allows them to be detected and discriminated from other forms of radiation (such as infra-red or radiowaves). Detectors such as ionisation chambers, Geiger-Muller tubes and cloud chambers all rely on the ionising properties of these radiations to produce measurable effects.

Properties of alpha, beta and gamma radiation

Alpha Particles.

Alpha particles are strongly ionising but can be stopped by paper or skin. They have a strong positive charge (+2) and a mass of 4 (i.e. 4 times the mass of a proton)

An alpha particle is in fact the same as a helium nucleus - 2 protons and 2 neutrons.

Beta particles.

Beta particles are electrons - but they are called beta particles to identify that they came from the nucleus of the atom.

How do you get an electron from the nucleus? A neutron splits up and becomes a proton and an electron. The proton remains behind in the nucleus, the electron is emitted.

Beta particles are also strongly ionising (perhaps 1 beta particle will cause 100 ionisations).

Gamma Rays.

Gamma rays are very poor at ionising (about 1 to 1) but they are very difficult to stop (they are very penetrating). As they are not good ionisers, they are less dangerous to life.

They are in fact pure energy (at the shortest wavelength end of the E-M spectrum) and gamma emission accompanies most emissions of beta or alpha particles.

Recap....

show an understanding of the nature and properties of α-, β- and γ- radiations (β+ is not included: β- radiation will be taken to refer to β–)

Property	Alpha	Beta	Gamma
Description	Helium nuclei	Electron from the nucleus	Electromagnetic radiation
~Ionising power	High	Medium	Low
Penetration (absorbed by)	Low (paper)	Medium (5mm Al)	High (Thick lead)
Charge	+ve	-ve	None