Motion
Unit 3 AoS#3

Monash University – Revision Lecture

Paul J Cuthbert

MOTION:

-Motion Basics

-Forces

-Energy

-Momentum & Collisions

-Projectile Motion

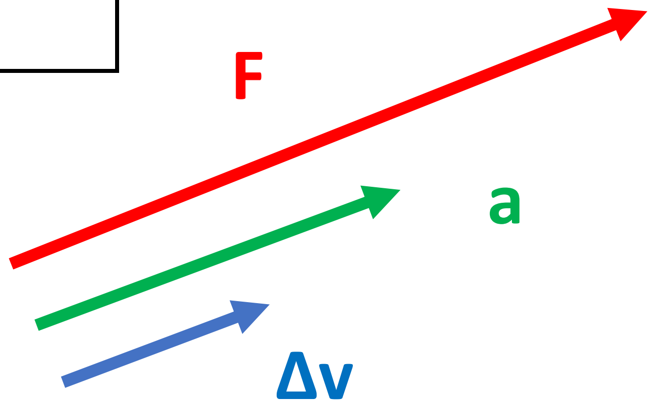
-Circular Motion

Motion Basics-
Forces on bodies & Newton's Laws

Newton's 2nd Law
N2

$$\Sigma \mathbf{F} = m \times \mathbf{a} = m \times \Delta \mathbf{V}/\Delta t$$

Total Force (N = kg m/s²)	Mass (kg)	Acceleration (m/s²)



This is a vector equation and can therefore be applied to just one particular direction if needed.

The equals signs also imply all the **vector** quantities have the **same direction**.

ΣF	a	Δv
↑	↑	↑
Net Force	Acceleration	*Change* in Velocity

All must have the **<u>same</u>** Direction

Forces that act ON the body – N1 & N2

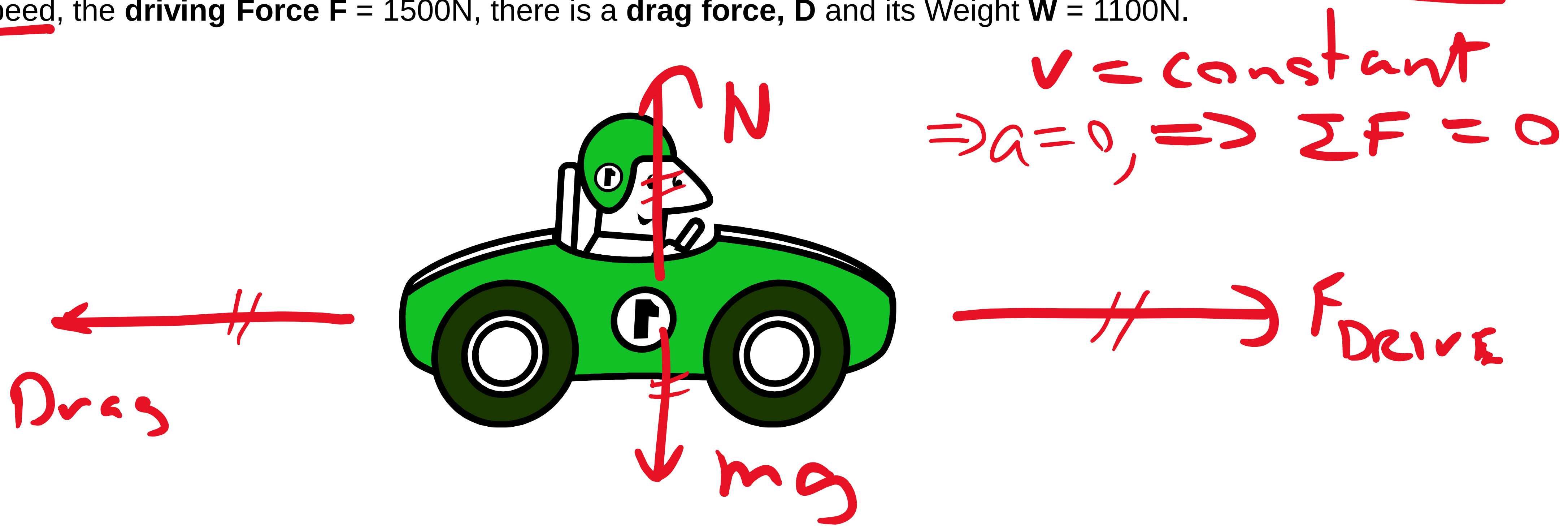
Problem:

1/ Draw all the forces that act *on* the car (treat the car as a point object) given that the it is travelling at constant speed, the **driving Force F** = 1500N, there is a **drag force, D** and its Weight **W** = 1100N.

Forces that act ON the body

SOLUTION:

1/ Draw all the forces that act *on* the car (treat the car as a point object) given that the it is travelling at constant speed, the **driving Force F** = 1500N, there is a **drag force, D** and its Weight **W** = 1100N.



Forces that act EXPLAIN the MOTION of the body – N3

Problem:

2/ Now draw the force(s) that are the action-reaction pair *in the sense of Newton's 3rd Law* that explain the forward motion of the car: [Label each force in the form of $F_{\text{by A on B}}$]

NOTE: this is a very different question to the previous question.

This is a Newton's 3rd Law question and we have to draw forces acting on 2 *different* bodies to answer it.

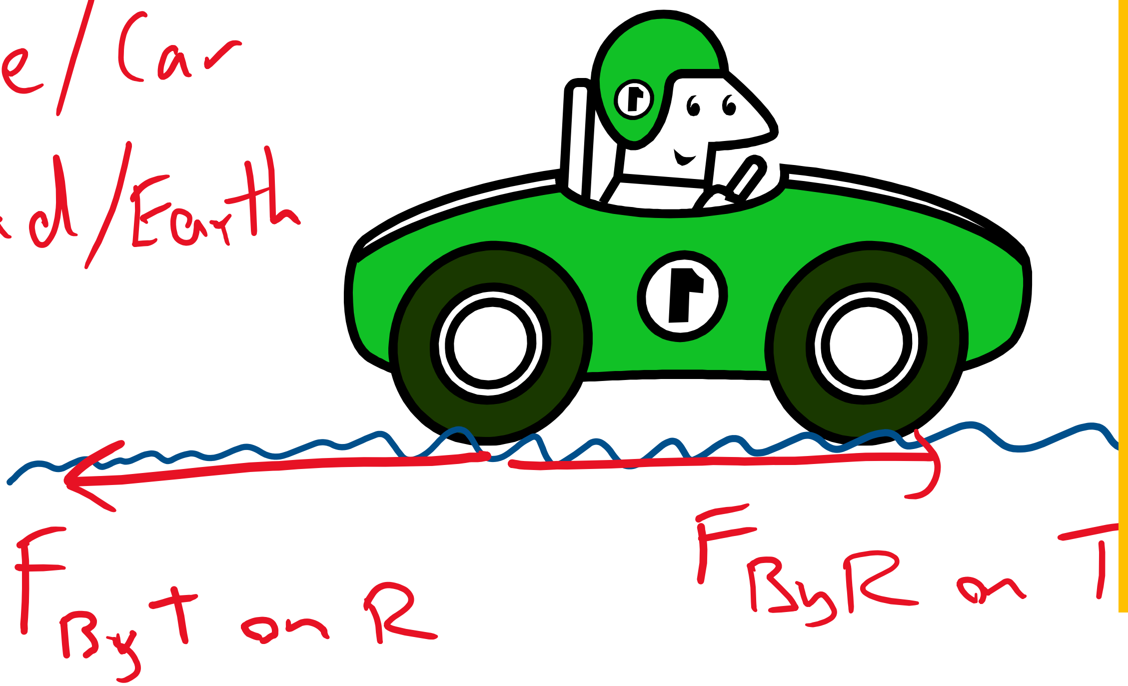
Forces that act EXPLAIN the MOTION of the body – N3

Solution:

2/ Now draw the force(s) that are the action-reaction pair *in the sense of Newton's 3rd Law* that explain the forward motion of the car: [Label each force in the form of $F_{by\ A\ on\ B}$]

T=Tyre/Car

R=Road/Earth



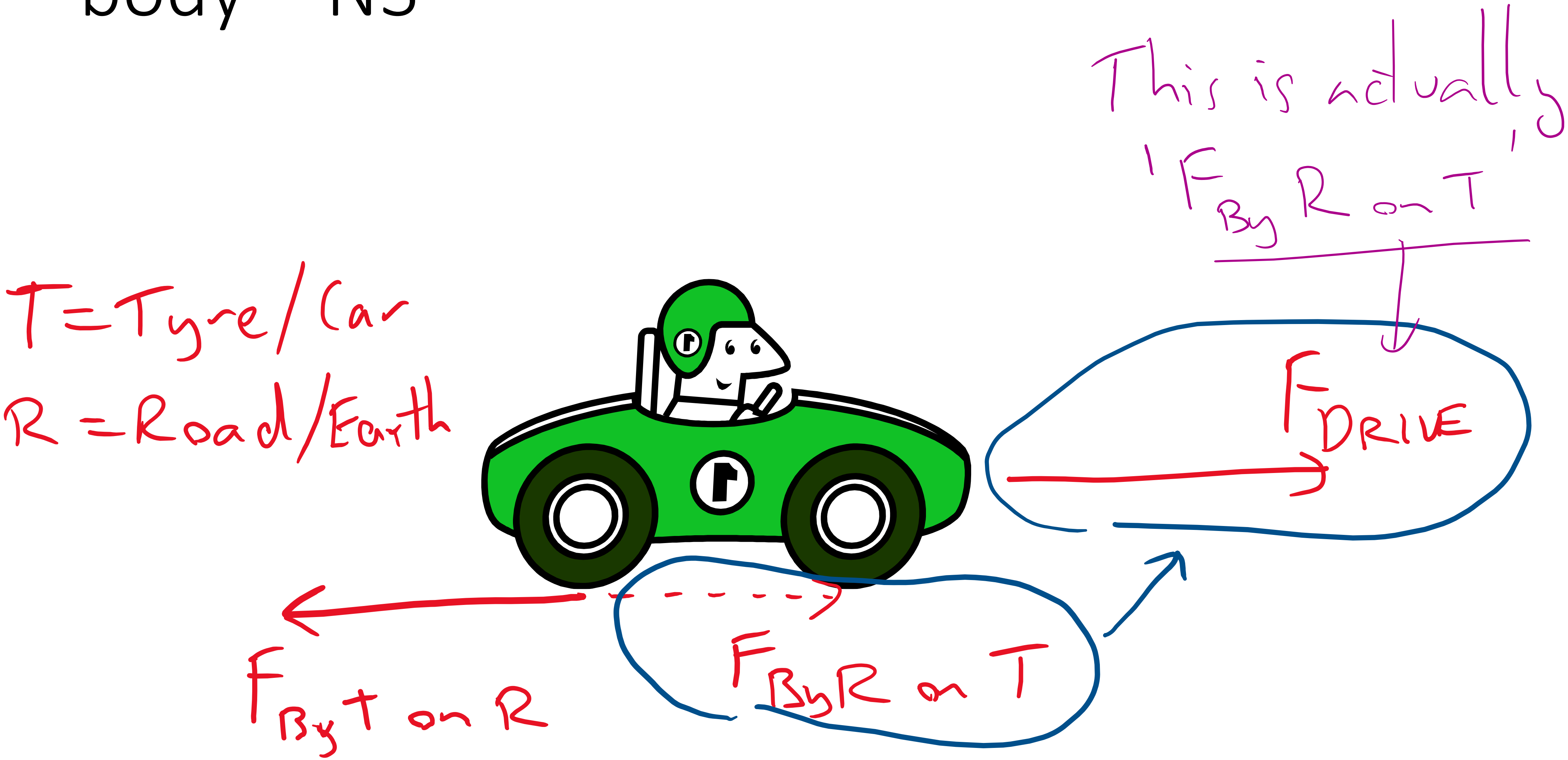
NEWTONS 3rd LAW

This involves ACTION-REACTION pairs of forces.

NOTE: Action-Reaction pairs

- Always act on **different** bodies.
- Are always **equal in magnitude** and opposite in direction.
- Never cancel.

Forces that act EXPLAIN the MOTION of the body – N3



Example:

Area of study 1 – Motion in one and two dimensions

A cyclist is towing a small trailer along a level bike track (Figure 1). The cyclist and bike have a mass of 90 kg, and the trailer has a mass of 40 kg. There are opposing constant forces of 190 N on the rider and bike, and 70 N on the trailer. These opposing forces do not depend on the speed of the bike.

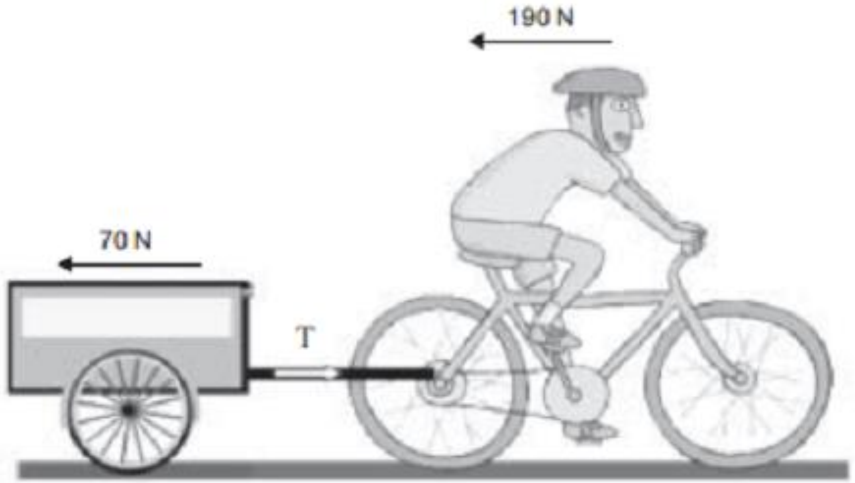


Figure 1

The bike and trailer are initially travelling at a constant speed of 6.0 m s^{-1}.

Question 1

What driving force is being exerted on the road by the rear tyre of the bicycle?

	N

2 marks

Solution:

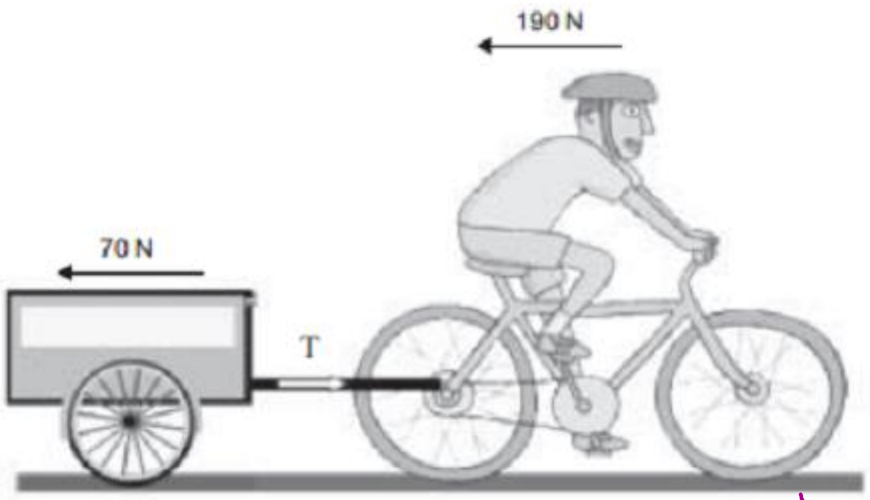


Figure 1

The bike and trailer are initially travelling at a constant speed of 6.0 m s^{-1}.

'Dummy' data

→ $a = 0$

$\Rightarrow \sum F = 0$

Question 1

What driving force is being exerted on the road by the rear tyre of the bicycle?

$= 70 + 190$

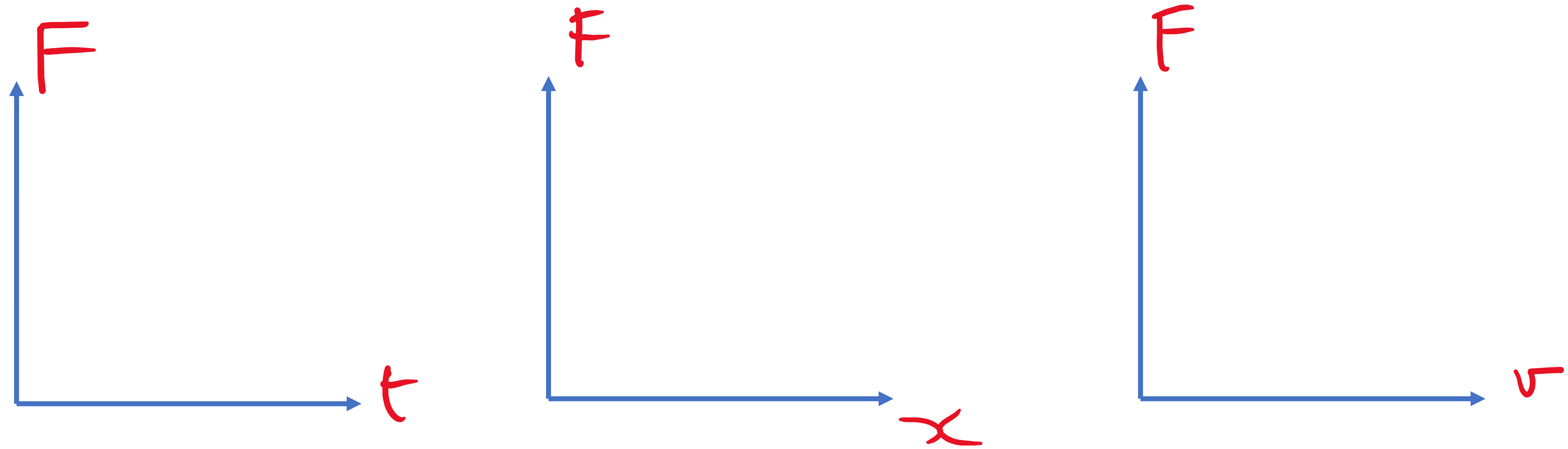
260 N

2 marks

Difficult N2 problems

Newton's Second Law (N2) problems are harder when the force acting on a body isn't constant, therefore when the force *varies* with something.

There are usually 3 possibilities:



Use the following information to answer Questions 1 and 2.

A tugboat is towing a ship with a tow rope as shown in Figure 1.

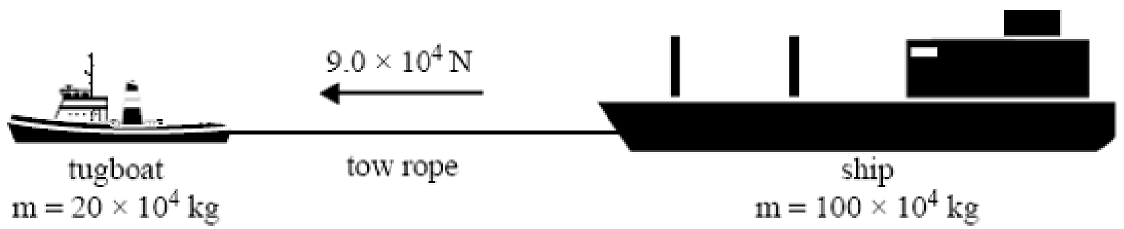


Figure 1

VCAA Problem: **2008 June Exam** – a Force that varies with SPEED

Mass of tugboat = 20×10^4 kg

Mass of ship = 100×10^4 kg

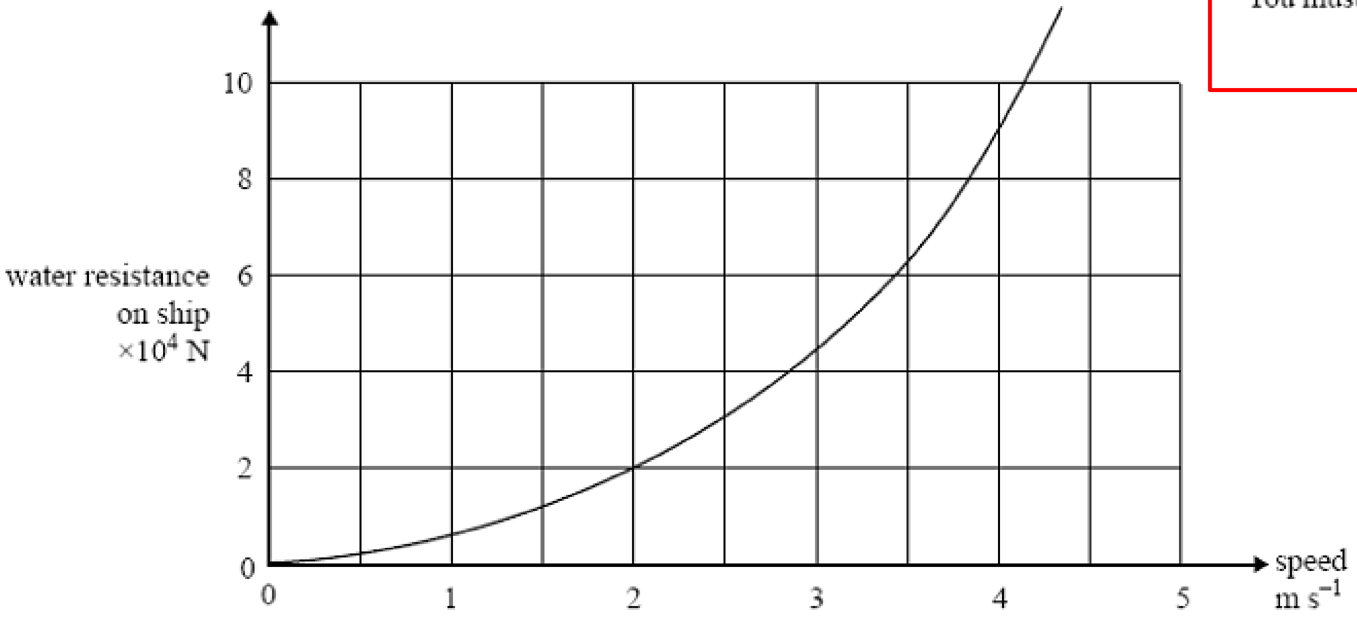
The tugboat exerts a constant force of 9.0×10^4 N on the tow rope.

The water resistance on the ship as a function of speed is shown in Figure 2.

Question 1

What is the acceleration of the ship when the tugboat and ship are travelling at 2.0 m s^{-1}?

You must show your working.



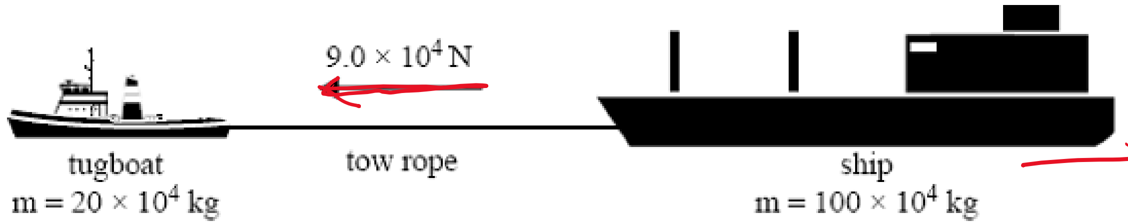
P J Cuthbert

Figure 2

Use the following information to answer Questions 1 and 2.

A tugboat is towing a ship with a tow rope as shown in Figure 1.

SOLUTION



2×10^4 N at 2 m/s

Figure 1

Question 1

What is the acceleration of the ship when the tugboat and ship are travelling at 2.0 m s^{-1}?

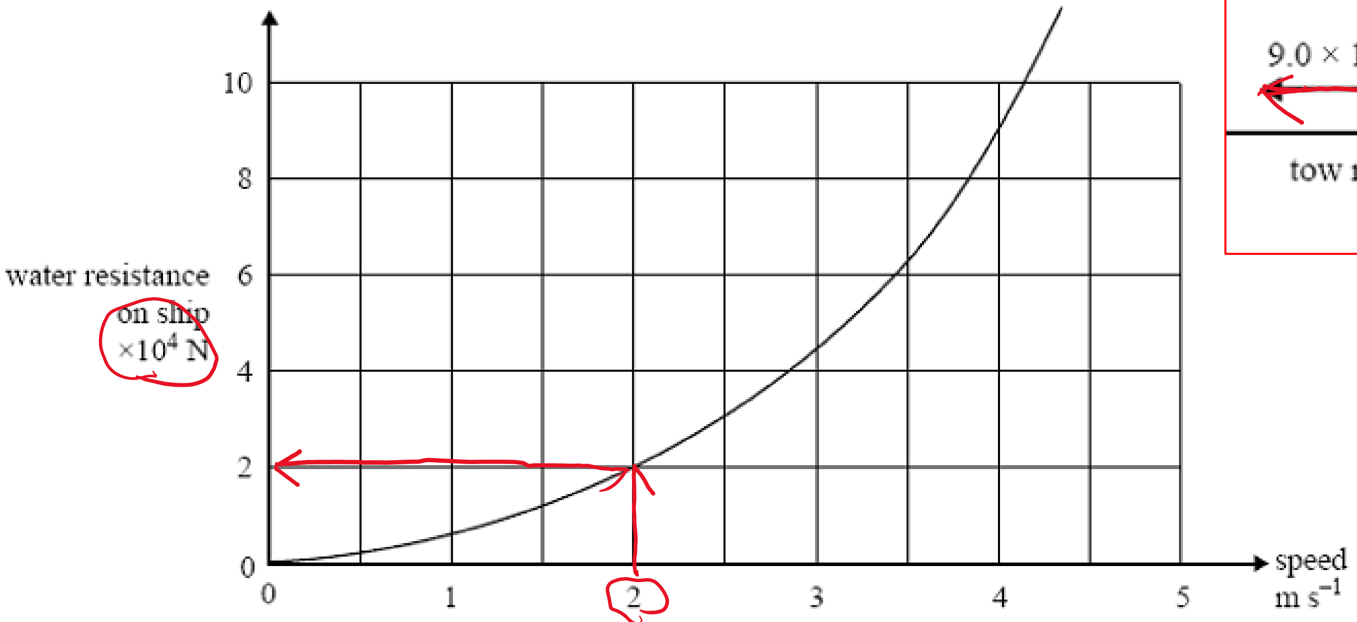
You must show your working.

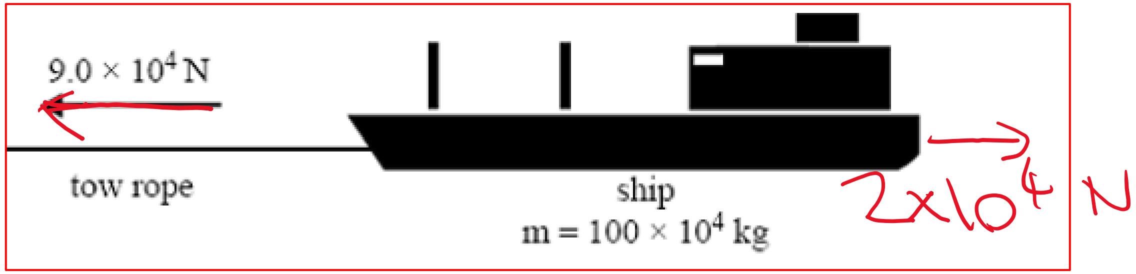
Mass of tugboat = 20×10^4 kg

Mass of ship = 100×10^4 kg

The tugboat exerts a constant force of 9.0×10^4 N on the tow rope.

The water resistance on the ship as a function of speed is shown in Figure 2.





$$a = \frac{\Sigma F}{m} = \frac{9E4 - 2E4}{100E4} = \frac{7E4}{100E4} = 0.07\ \text{m s}^{-2}$$

Figure 2

Use the following information to answer Questions 1 and 2.

A tugboat is towing a ship with a tow rope as shown in Figure 1.

VCAA Problem: **2008 June Exam** – a Force that varies with SPEED

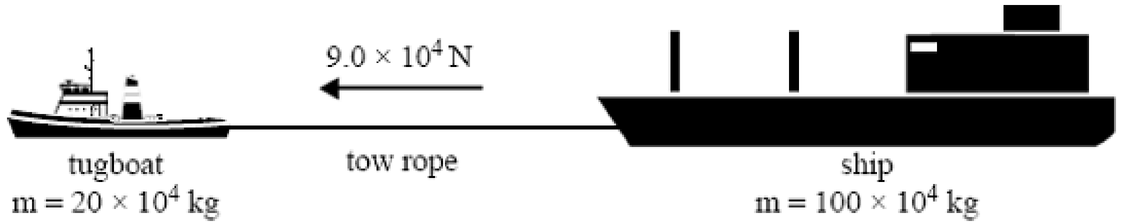
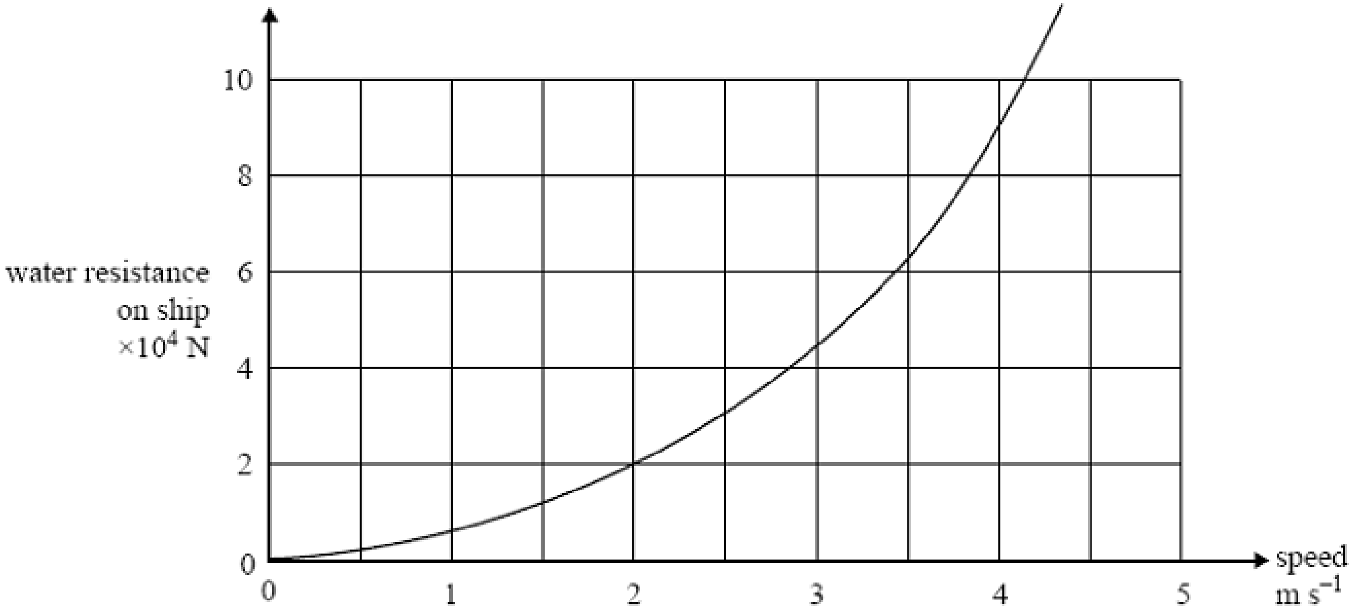


Figure 1

Mass of tugboat = 20×10^4 kg
Mass of ship = 100×10^4 kg

The tugboat exerts a constant force of 9.0×10^4 N on the tow rope.
The water resistance on the ship as a function of speed is shown in Figure 2.

Question 2
After a time, the tugboat and ship are travelling at a constant speed.
What is this constant speed?



P J Cuthbert

Figure 2

Use the following information to answer Questions 1 and 2.

A tugboat is towing a ship with a tow rope as shown in Figure 1.

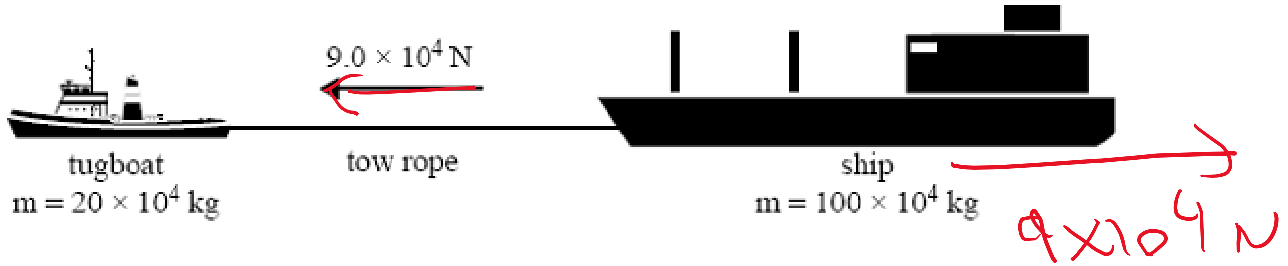


Figure 1

$\Sigma F = 0$

VCAA Problem: **2008 June Exam** – a Force that varies with SPEED

SOLUTION

Mass of tugboat = 20×10^4 kg

Mass of ship = 100×10^4 kg

The tugboat exerts a constant force of 9.0×10^4 N on the tow rope.

The water resistance on the ship as a function of speed is shown in Figure 2.

Question 2

After a time, the tugboat and ship are travelling at a constant speed.

What is this constant speed?

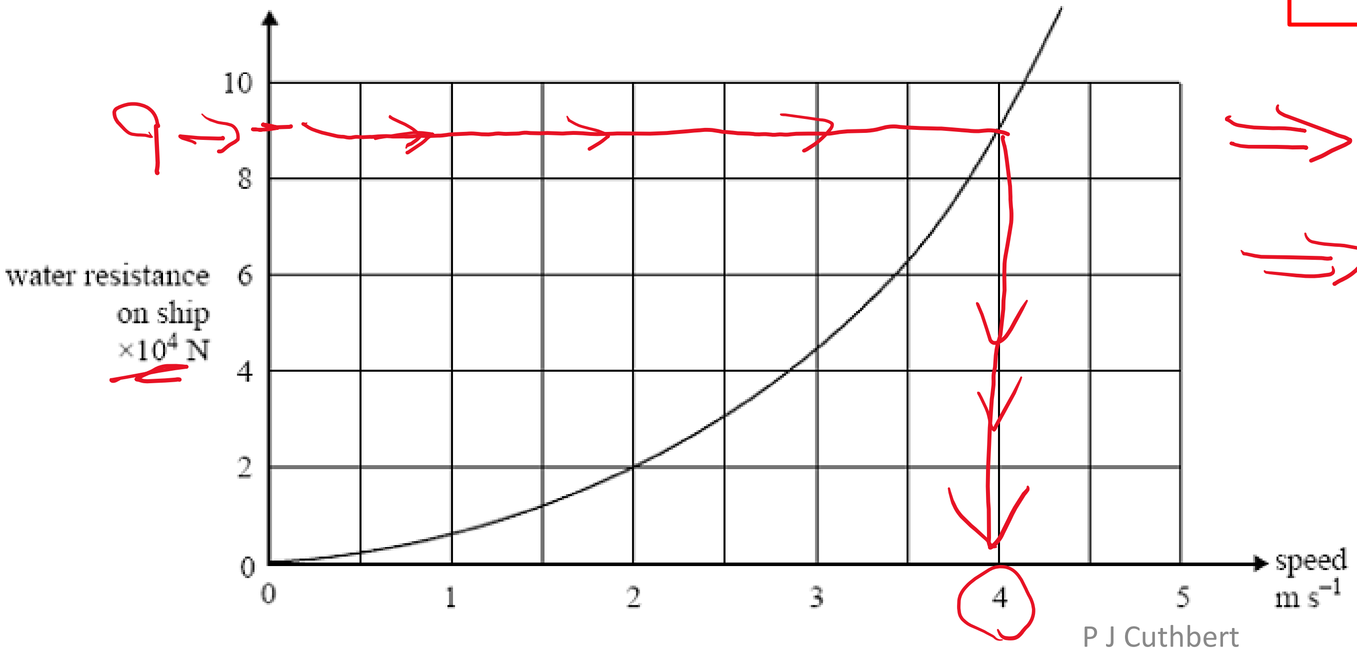


Figure 2

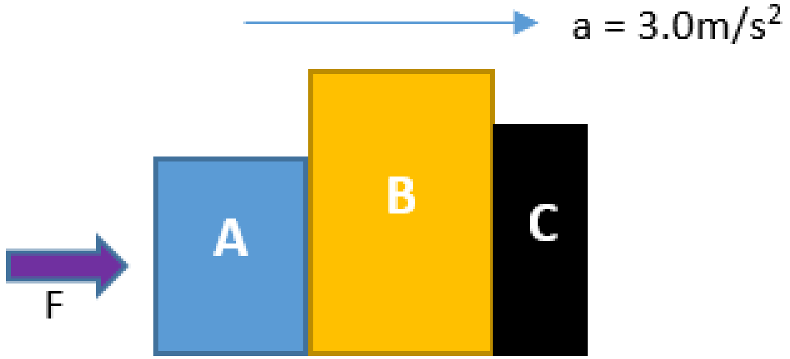
$\Rightarrow \Sigma F = 0$

$\Rightarrow$ Resistance $= 9 \times 10^4$ N

$\Rightarrow v = 4\ ms^{-1}$

Forces – Newton's 3rd Law

1. Three masses A, B and C are in constant contact and pushed together by a force F across a frictionless surface so that the system accelerates at a constant $3.0 m/s^2$.



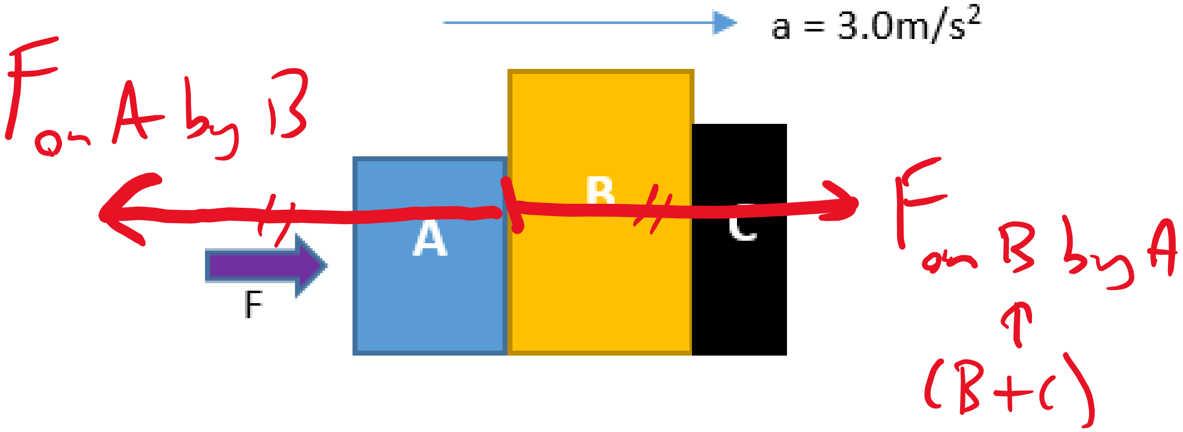
Body	Mass (kg)
A	3kg
B	5kg
C	2kg

Calculate the force that block B exerts on block A.

Forces – Newton's 3rd Law

SOLUTION

1. Three masses A, B and C are in constant contact and pushed together by a force F across a frictionless surface so that the system accelerates at a constant $3.0 m/s^2$.



Body	Mass (kg)
A	3kg
B	5kg
C	2kg

Calculate the force that block B exerts on block A.

$$\underline{N3}: \quad F_{on\ A\ by\ B} = F_{on\ B(+C)\ by\ A} = (m_B + m_C) \times a$$
$$= (5+2) \times 3 = \underline{21\ N}$$

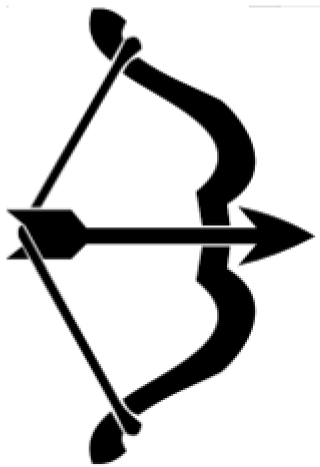
Force vs Distance graphs

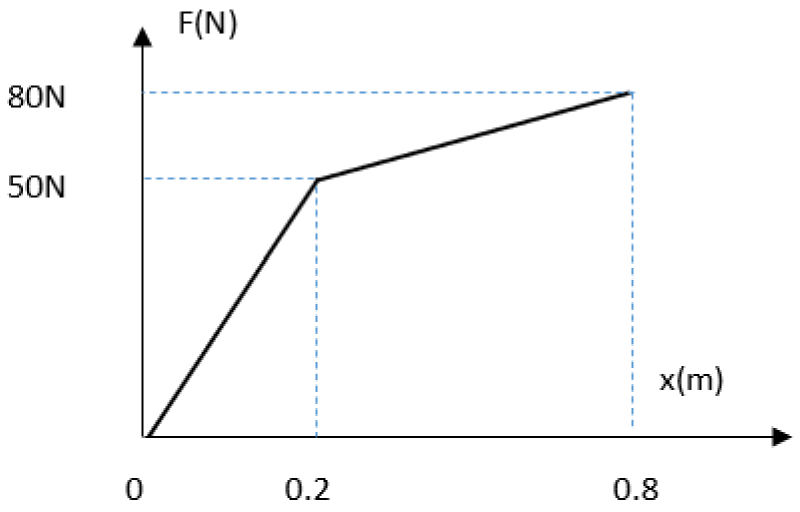
Work Done = Energy gained = F x D *only* when F is **constant**

= **Area under a Force – displacement graph (always true)**

= ½ kx^2 (only when k is constant, which it's not in this example)

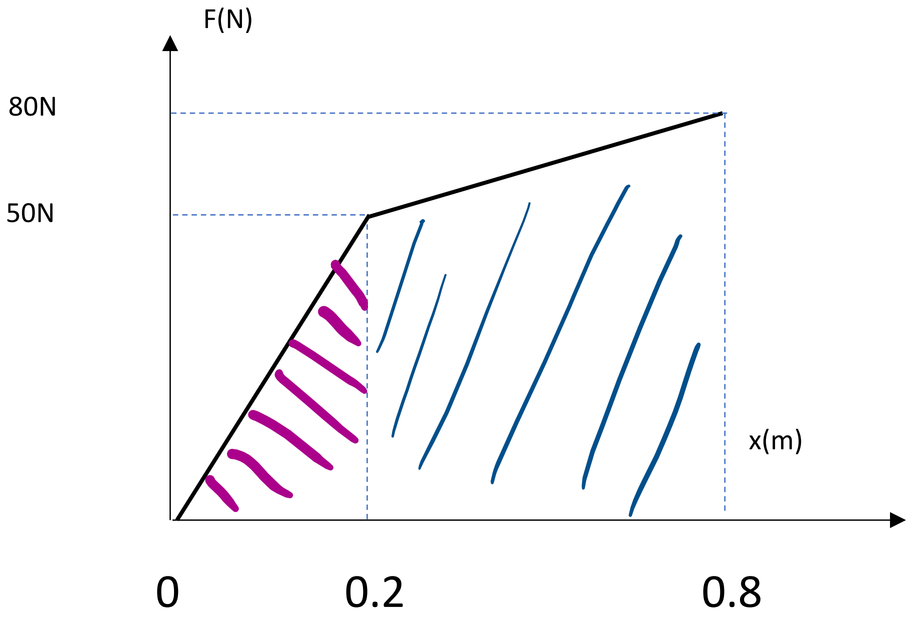
5. A bow has a force distance graph as shown. The distance, x, represents the distance that the string is drawn back from its resting position.





(a) How much work must be done to draw the string of the bow back to 0.8m?

(b) If the arrow loaded has a mass of 15g (0.015kg), how fast will it be released?



SOLUTION

(a) Work done = Area under Graph

= triangle + trapezium

= ½ x 0.2 x 50 + ½(0.8 – 0.2) x (50 + 80)

= 5 + 39 = 44 Joules

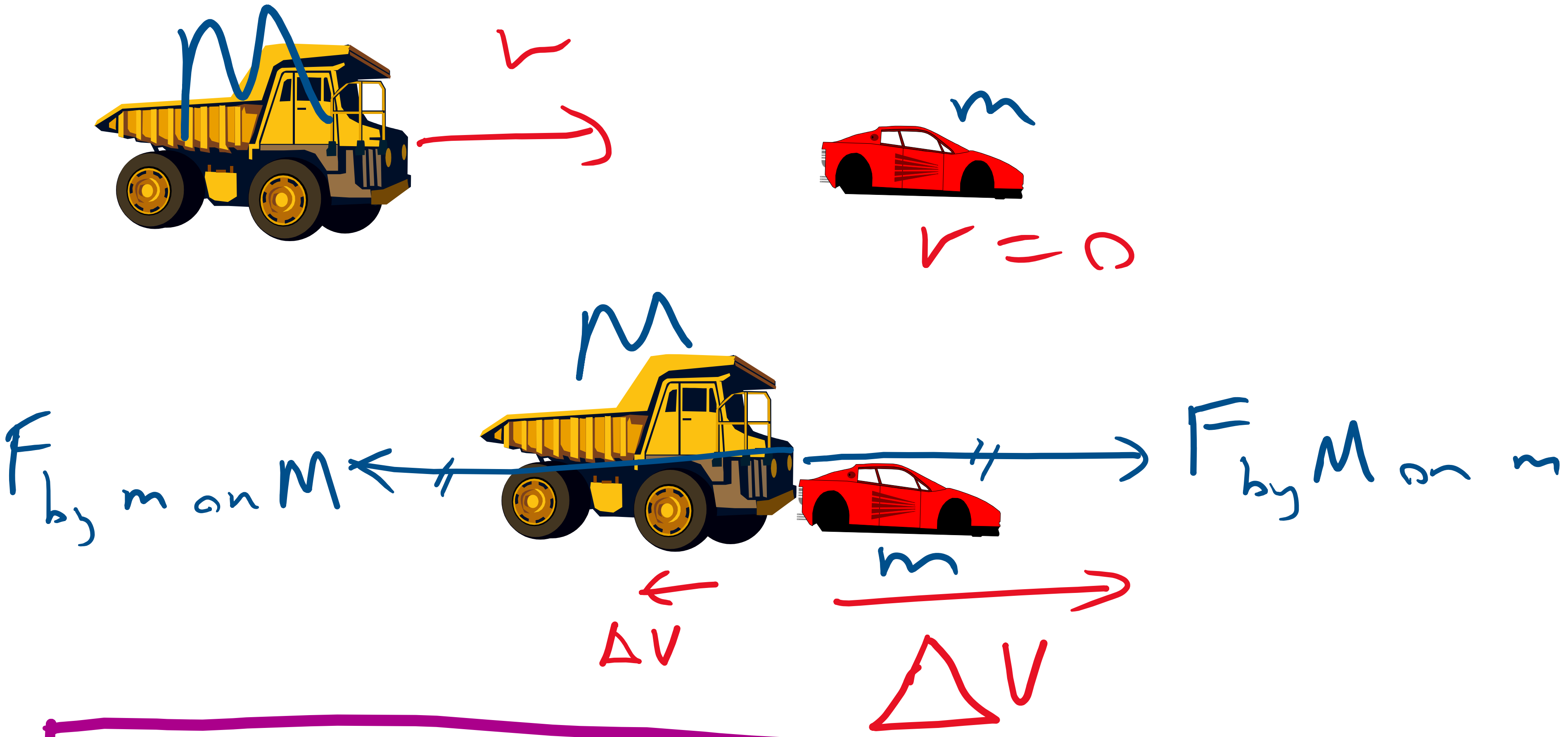
(b) Work Done = Gain in KE

$44 = \frac{1}{2} \times 0.015\, v^2$

$v = \sqrt{(88/0.015)} = 76.5$ m/s

Momentum & Impulse

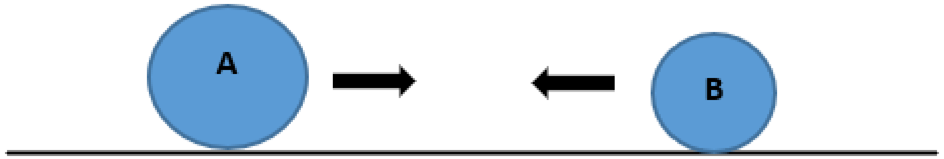
Analysing Collisions



$$M \Delta v = m \Delta v$$

CONSERVATION OF MOMENTUM & Analysing Collisions

3. Two masses A and B are shown below. Body A has mass 5kg and is moving to the right at 3m/s. Body B has mass 2.5kg is moving to the left at 8m/s. After the collision mass A is moving to the left at 2m/s.



(a) Calculate the speed of mass B after the collision. (b) Indicate body B's direction after the collision

m/s	

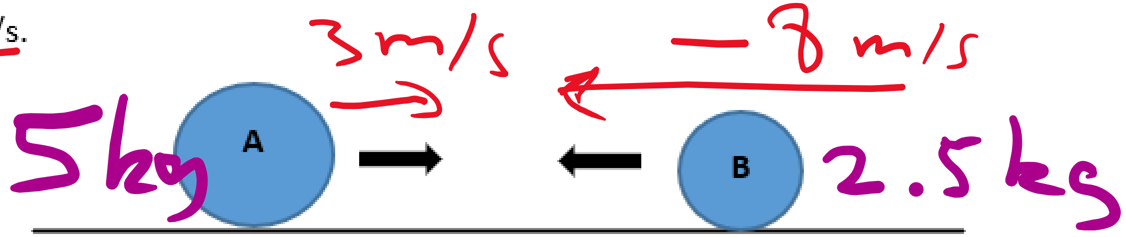
Direction: LEFT or RIGHT	

CONSERVATION OF MOMENTUM & Analysing Collisions

This is a REBOUND Problem – important to get the sign of the velocity correct

3. Two masses A and B are shown below. Body A has mass 5kg and is moving to the right at 3m/s. Body B has mass 2.5kg is moving to the left at 8m/s. After the collision mass A is moving to the left at 2m/s.

choose → positive



(a) Calculate the speed of mass B after the collision. (b) Indicate body B's direction after the collision

$p_i = 5 \times 3 + 2.5 \times {}^{-}8 = 15 - 20 = -5\ kgm/s$

$= p_f = 5 \times {}^{-}2 + 2.5\ v_B$

$\Rightarrow -10 + 2.5\ v_B = -5 \Rightarrow 2.5\ v_B = 5$

$v_B = +2\ m/s$

2.0 m/s		Direction: LEFT or RIGHT	RIGHT

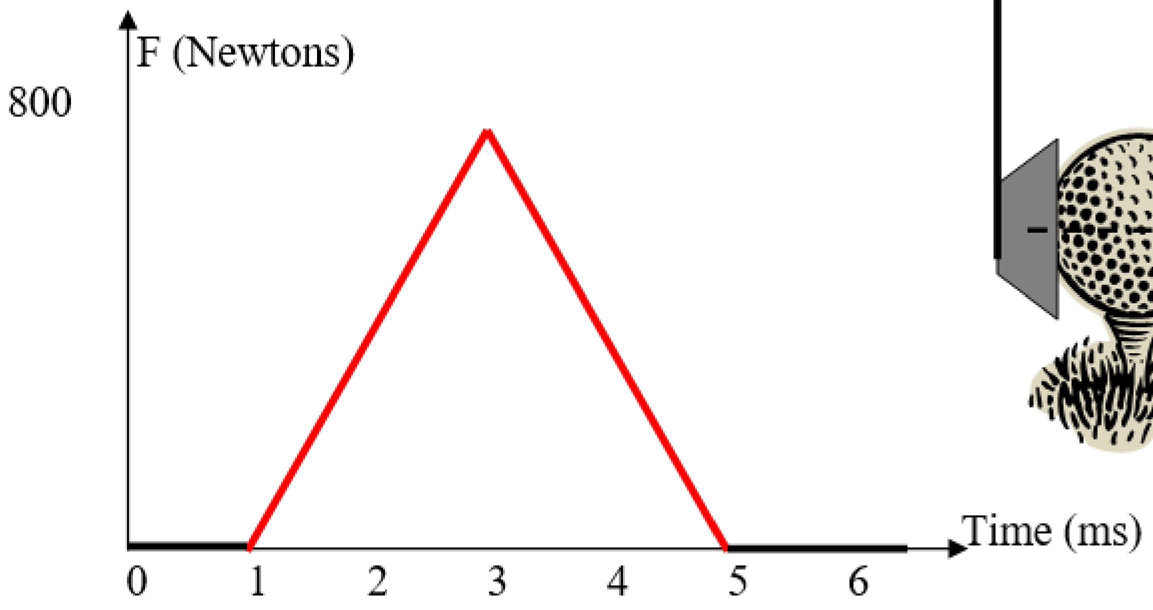
P J Cuthbert

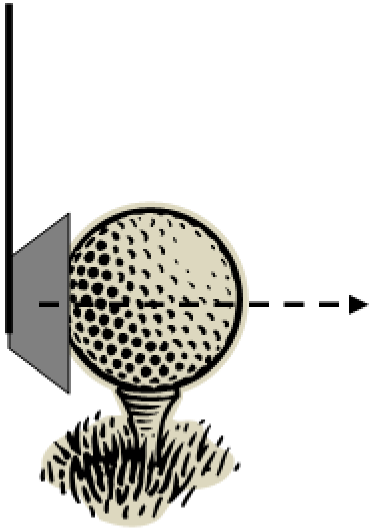
IMPULSE = F Δt (only if F is constant)

= Δp

= Area under a F vs t graph (always)

8. A force vs time (in ms = milliseconds = 10^{-3}s) graph is produced for a golf club hitting a golf ball of mass 0.046kg, initially at rest:

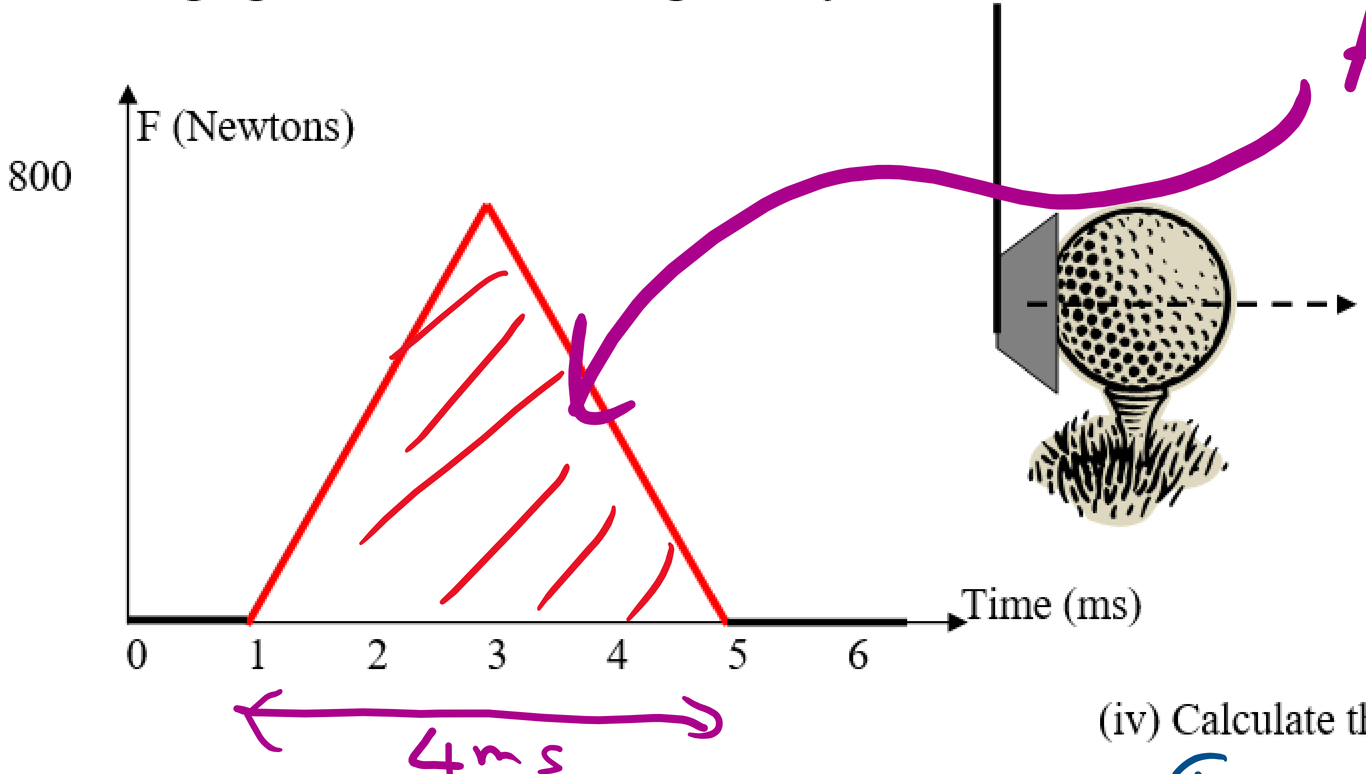




(i) What is the impulse of the club on the ball?

(iv) Calculate the speed that the golf ball leaves the tee at:

8. A force vs time (in ms = milliseconds = 10^{-3}s) graph is produced for a golf club hitting a golf ball of mass 0.046kg, initially at rest:



Area

$= \frac{1}{2} \times 4 \times 10^{-3} \times 800$

$= 1.6$ Ns

(i) What is the impulse of the club on the ball?

= Area = 1.6 Ns

(iv) Calculate the speed that the golf ball leaves the tee at:

$I = \Delta p = m \Delta v$

$1.6 = 0.046 (v - 0)$

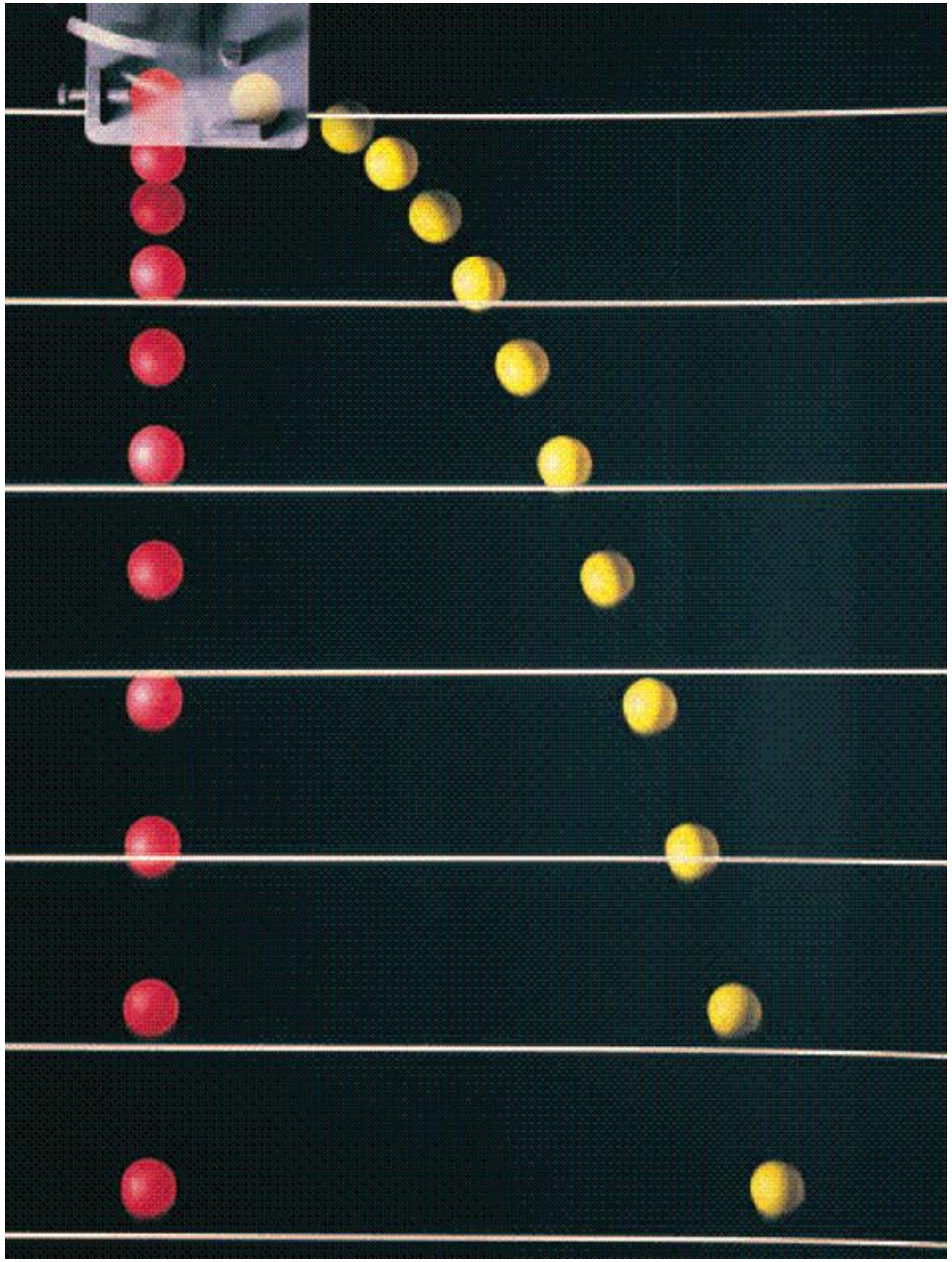
$v = 1.6 / 0.046 = 34.8$ m/s

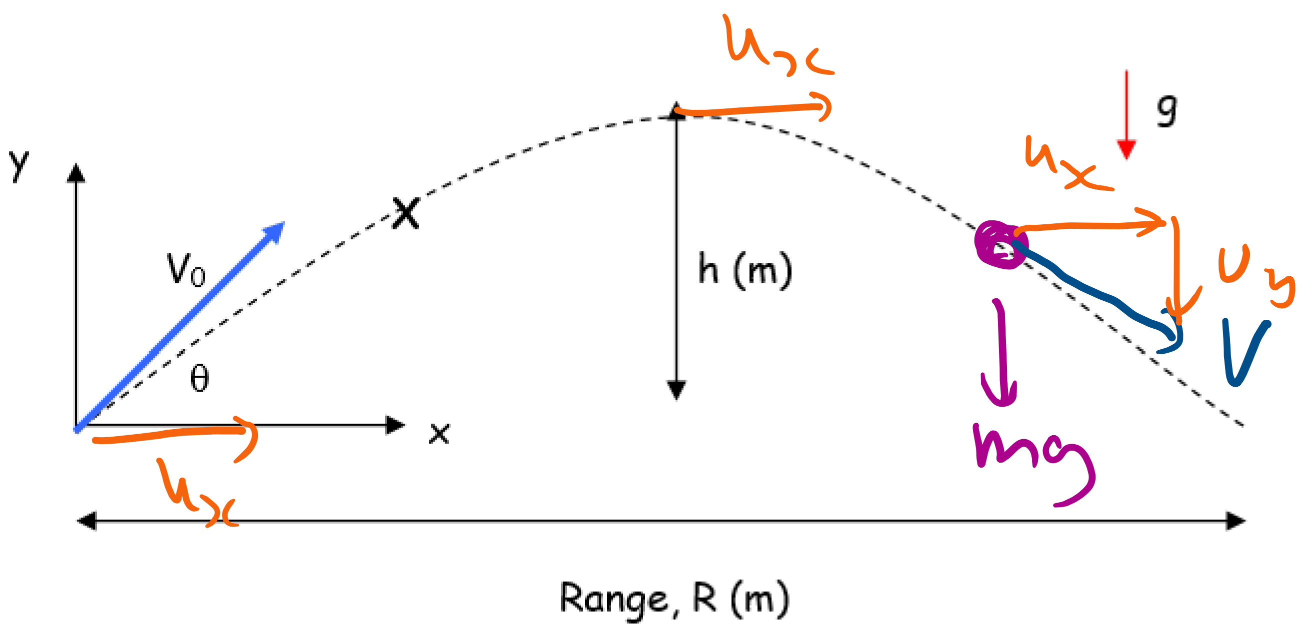
Projectile Motion

-Vertical

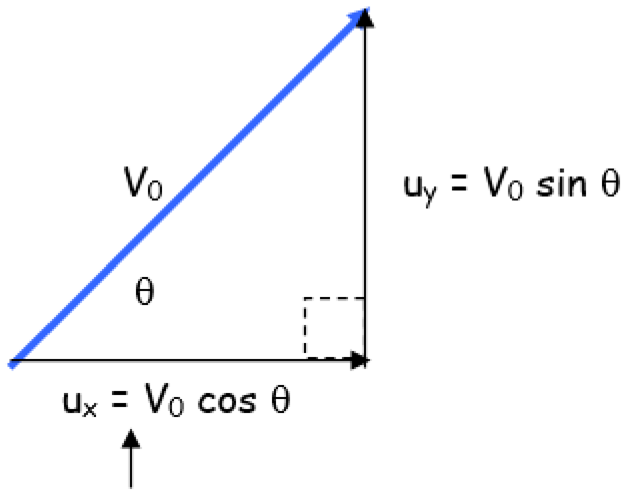
-Horizontal

-Oblique





Initial Velocity components:



This component is constant
(No horizontal force acting).

The acceleration is constant, so these apply:

$v = u + at$

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

$d = ut + \frac{1}{2}at^2$

$v^2 = u^2 + 2ad$

And apply in the x & y direction independently

Problem:

$a = -10 \downarrow$

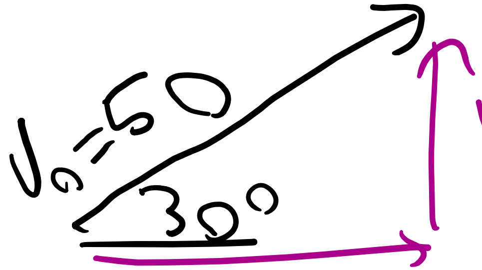
Consider a golf ball struck at 50 m/s at an angle of 30⁰ to the ground. It lands at the same level.

Determine:

(i) It's time of flight:

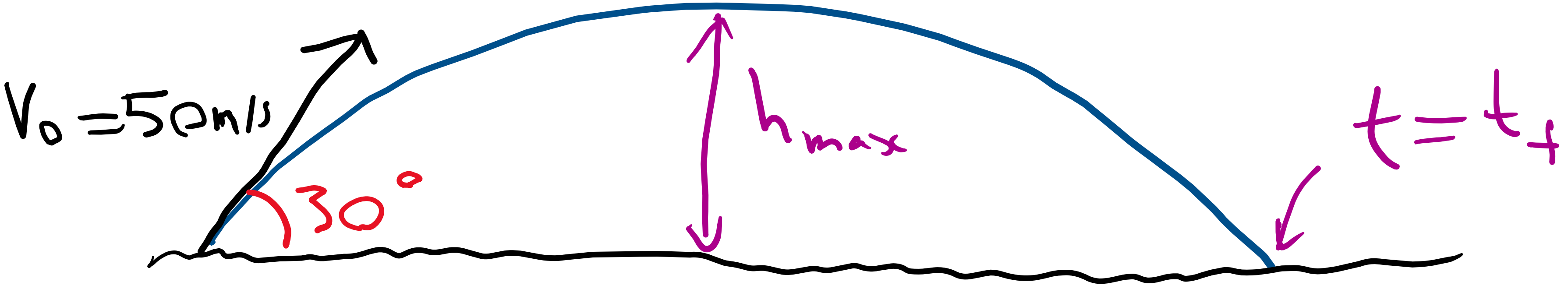
(ii) Maximum height

(iii) Range:



$u_y = 50 \sin 30° = 25$ m/s

$u_x = 50 \cos 30 = 43.3$ m/s (constant)



Solutions – method 1:

(i) t_{flight} : $u_y = 25\text{ m/s}$, $a = -10 \Rightarrow \frac{t_f}{2} = \frac{25}{g} = 2.5\text{ sec}$

$\Rightarrow t_f = 5\text{ sec}$.

(ii) h_{max} : At h_{max}, $v_y = 0$, $a = -10$, $u_y = 25$, $d = h = ?$

(a) $v^2 = u^2 + 2ad$ ← apply in y-dirn

$0^2 = 25^2 + 2(-10)h \Rightarrow h = -25^2/-20 = 31.25\text{m}$

OR (b) At top, $t = 2.5\text{sec}$: $d = ut + \frac{1}{2}at^2$

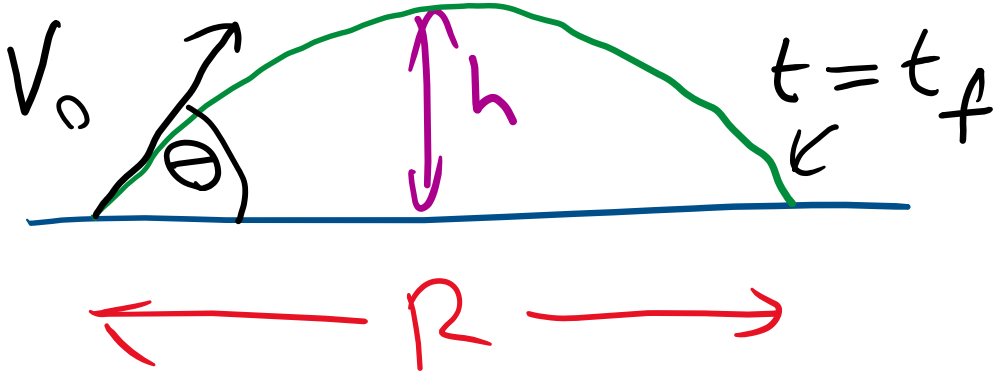
$\Rightarrow h = 25 \times 2.5 + \frac{1}{2}(-10)2.5^2 = 31.25\text{ m}$

(iii) Range $R = u_x \times t_f = 43.3 \times 5 = 216.5\text{m}$

↑ constant

Useful 'short-cuts' – projectile motion

- Time of flight: $t_f = \dfrac{2V_0 \sin\theta}{g}$
- Maximum height: $h = \dfrac{V_0^{\,2} \sin^2\theta}{2g}$
- Range: $R = u_x \times t_f = \dfrac{V_0^{\,2} \sin 2\theta}{g}$



Put on your A3 sheet.

Solutions – method 2: Use the short-cut formulae

$V_0 = 50\ m/s \qquad \theta = 30^\circ$

(i) $t_f = \dfrac{2V_0 \sin\theta}{g} = \dfrac{2 \times 50 \times \sin 30^\circ}{10} = 5\ sec$

(ii) $h_{max} = \dfrac{V_0^2 \sin^2\theta}{2g} = \dfrac{50^2 (\sin 30^\circ)^2}{2 \times 10} = 31.25\ m$

(iii) $R = \dfrac{V_0^2 \sin 2\theta}{g} = \dfrac{50^2 \sin 60^\circ}{10} = 216.5\ m$

NOTE: we can use the short-cuts because the projectile lands at the same level it is projected from.

Being careful about using the short-cut formulae

Use the following information to answer Questions 5–7.

A batsman hits a cricket ball (from ground level) at a speed of 30.0 m s^{-1} and at an angle of 36.9° to the horizontal as shown in Figure 4. Air resistance can be ignored.

Figure 4

It's ok here, ball passes h_{max}

Question 5

What is the maximum height that the ball reaches?

You must show your working.

m

2 marks

Being careful about using the short-cut formulae

Use the following information to answer Questions 5–7.

A batsman hits a cricket ball (from ground level) at a speed of 30.0 m s^{-1} and at an angle of 36.9° to the horizontal as shown in Figure 4. Air resistance can be ignored.

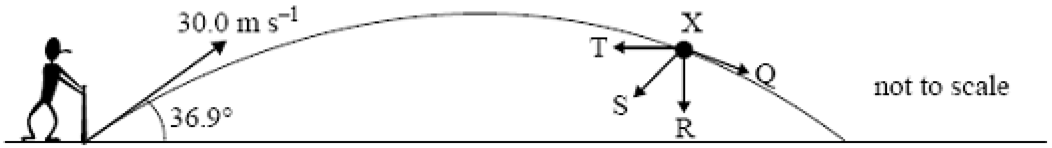


Figure 4

Question 5

What is the maximum height that the ball reaches?

You must show your working.

$$h_{max} = \frac{v^2 \sin^2\theta}{2g} = \frac{30^2(\sin 36.9)^2}{2\times10}$$ (1)

16.2 m (1)

2 marks

Can’t use a short-cut here, it’s not symmetrical

An advertising board is now placed on the boundary of the cricket ground at a distance 72.0 m from the batsman as shown in Figure 5.

Question 7

Assuming the ball is hit exactly the same way as in the previous question, at what height above the ground will the ball strike the advertising board?

You must show your working.

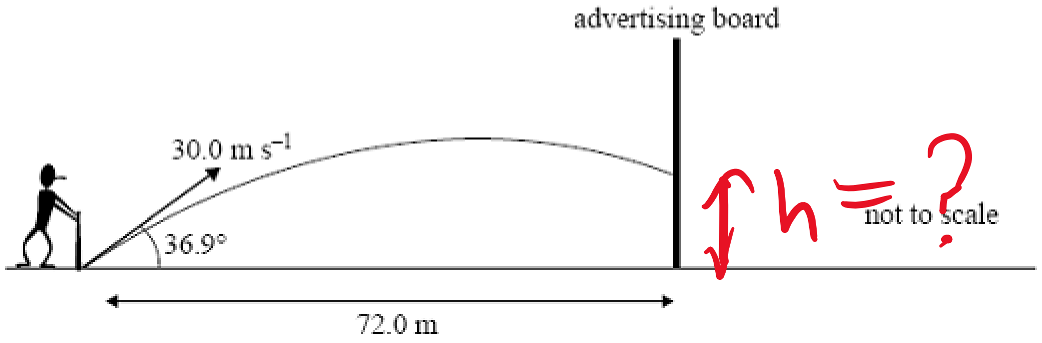
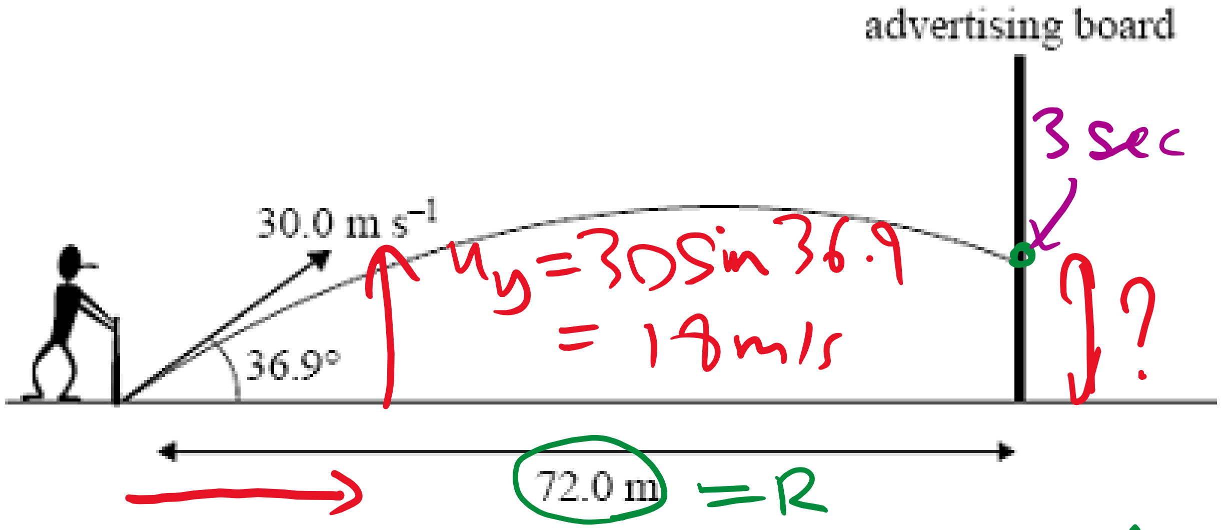


Figure 5

m

3 marks

SOLUTION:



$u_x = 30 \cos 36.9$

$= 24$ m/s

(constant)

(i) Find the time t_f

$R = u_x \times t_f$

$72 = 24 \times t_f$

$t_f = 3$ sec

(ii) height of ball at $t = 3$ sec?

$d_y = u_y t + \frac{1}{2} a_y t^2$ (↑ dirn)

$= 18 \times 3 + \frac{1}{2}(-10) \times 3^2$

$= 54 - 45 = 9$ m

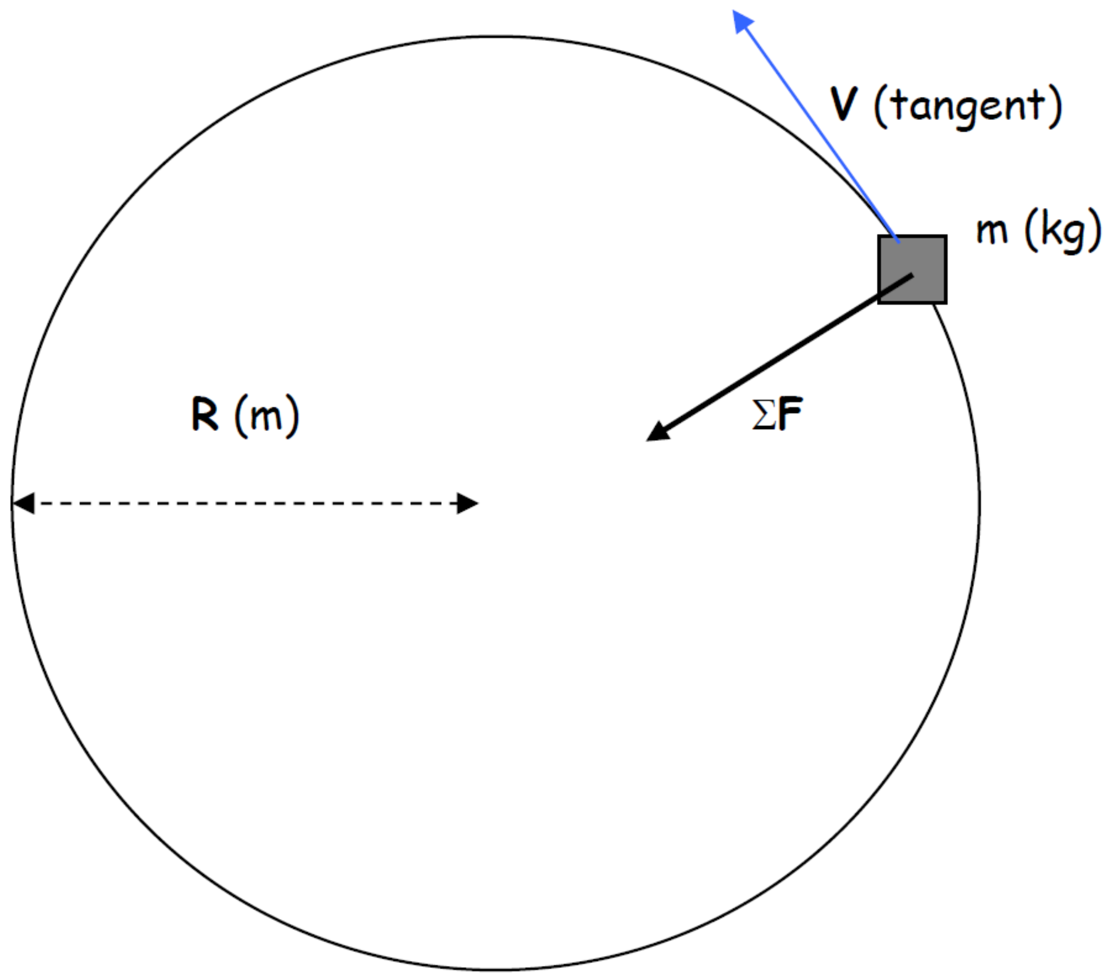
Circular (Centripetal) Motion

$$v = \frac{2\pi R}{T}$$

$$a = \frac{v^2}{R}$$

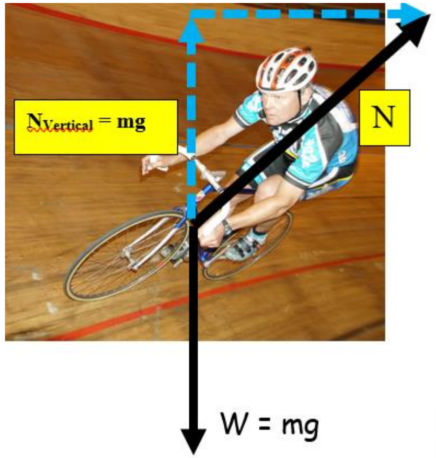
And by Newton's 2nd Law:

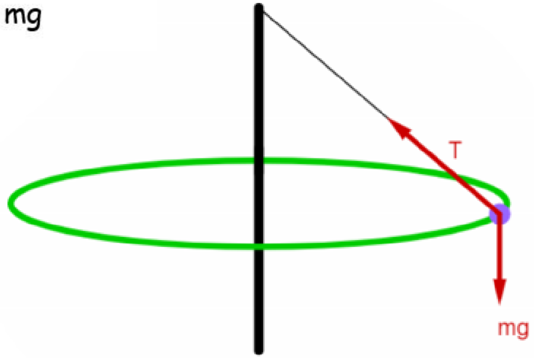
$$\Sigma F = ma = m\frac{v^2}{R} = \frac{4\pi^2 Rm}{T^2}$$



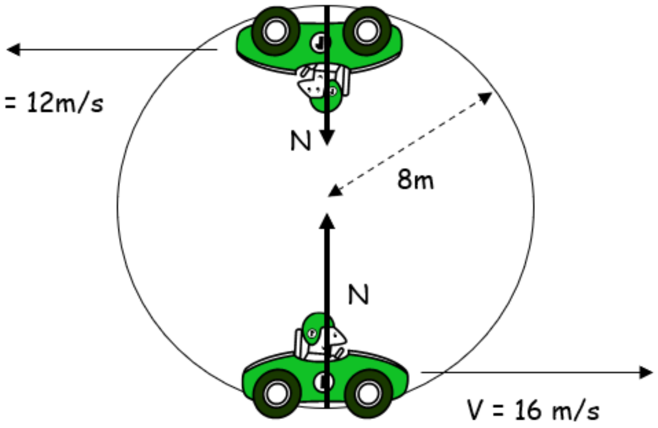
Different cases to cover:

1-Constant speed:
-horizontal planes
-banked tracks
-conical pendulum

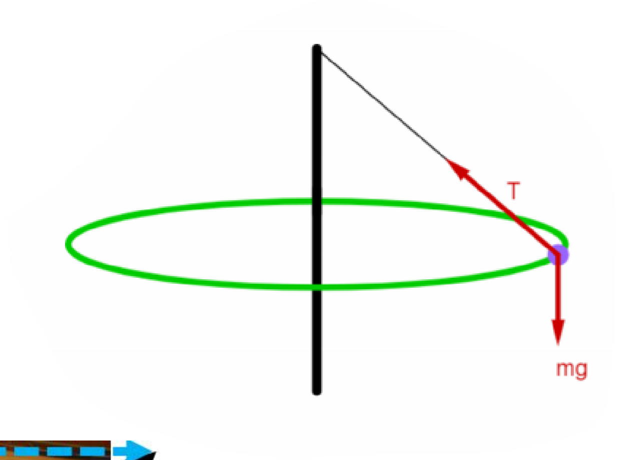


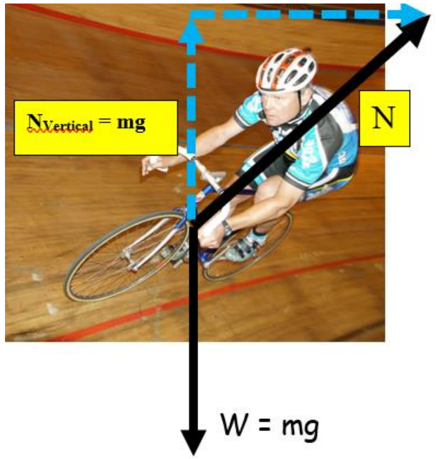


2-Vertical planes:
-calculations for highest point (top) and lowest point (bottom) only



Case 1: a horizontal plane

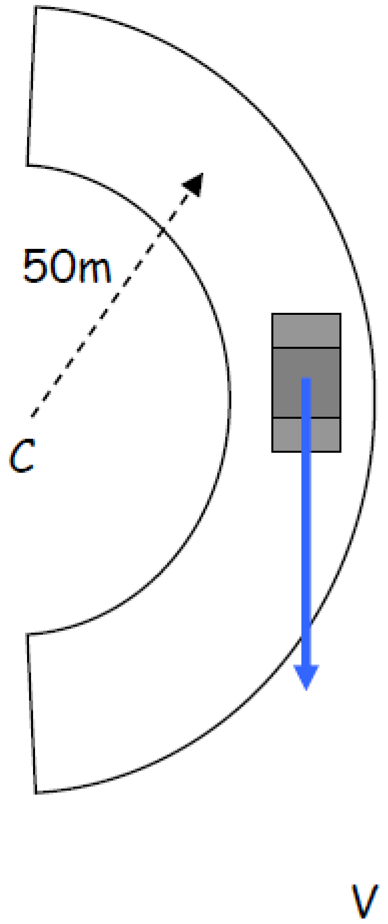




Problems:

1. Consider a 1500kg car turning around a circular corner of radius 50m at 36 km/h. (Shown in the diagram viewed from above)

(i) Calculate the size of the car's acceleration towards the centre of the curve:



(ii) What is the size of the centripetal force on the car?

(iii) What supplies this force?

(iv) If the car tried to take the corner at *twice* this speed (72 km/h), how much force would the road be required to produce?

Solutions:

1. Consider a 1500kg car turning around a circular corner of radius 50m at 36 km/h. (Shown in the diagram viewed from above)

$\frac{36}{3.6} = 10\ ms^{-1}$

(i) Calculate the size of the car's acceleration towards the centre of the curve:

$a = \frac{v^2}{r} = \frac{10^2}{50} = 2\ m/s^2$

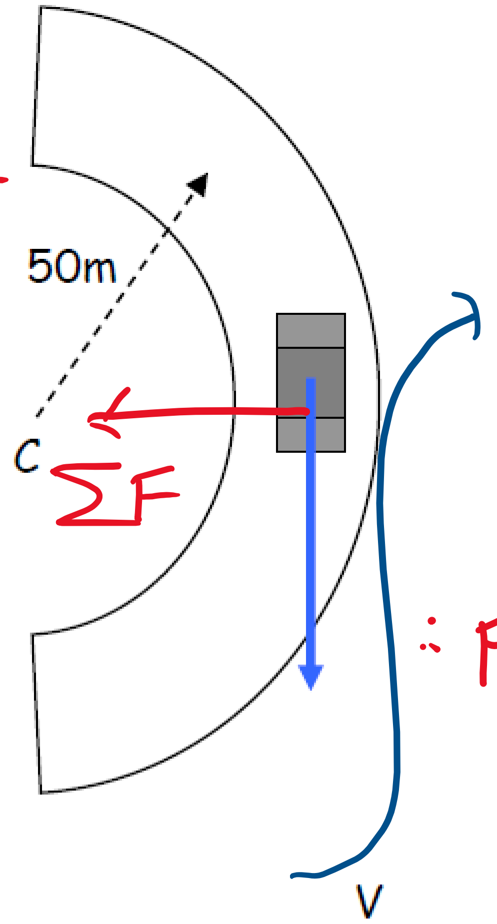
(ii) What is the size of the centripetal force on the car?

$F = ma = 1500 \times 2$

$= 3000\ N$

(iii) What supplies this force?

Friction - by Road on Tyres



$F \propto v^2$

$\therefore$ If $v \uparrow \times 2$

$\Rightarrow F \uparrow \times 2^2$

$\therefore F_{new} = 4 \times 3000$

$= 12{,}000\ N$

(iv) If the car tried to take the corner at *twice* this speed (72 km/h), how much force would the road be required to produce?

Question 2 (5 marks)

A steel ball of mass 2.0 kg is swinging in a circle of radius 0.50 m at a constant speed of 1.7 m s^{-1} at the end of a string of length 1.0 m, as shown in Figure 3a.

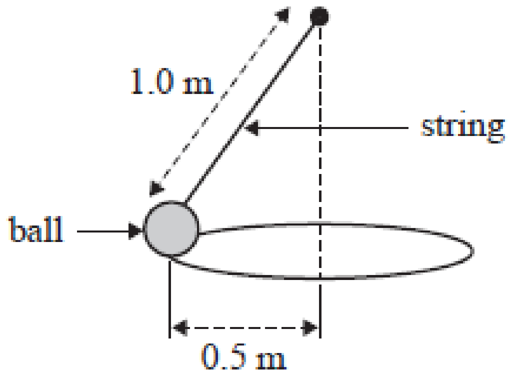


Figure 3a

Figure 3b

a. On Figure 3b above, draw all the forces **on the ball**. Label all forces. Draw the resultant force as a dotted line labelled F_R. 2 marks

VCAA 2016

SOLUTION

$g = 10$

Question 2 (5 marks)

A steel ball of mass 2.0 kg is swinging in a circle of radius 0.50 m at a constant speed of 1.7 m s^{-1} at the end of a string of length 1.0 m, as shown in Figure 3a.

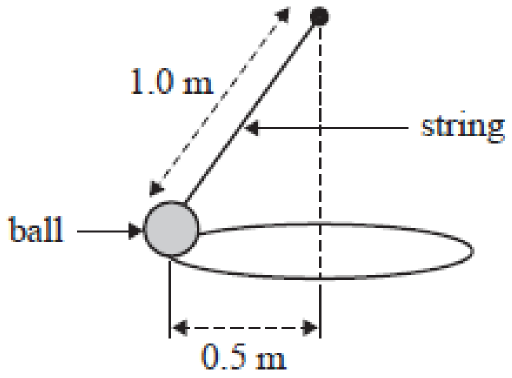


Figure 3a

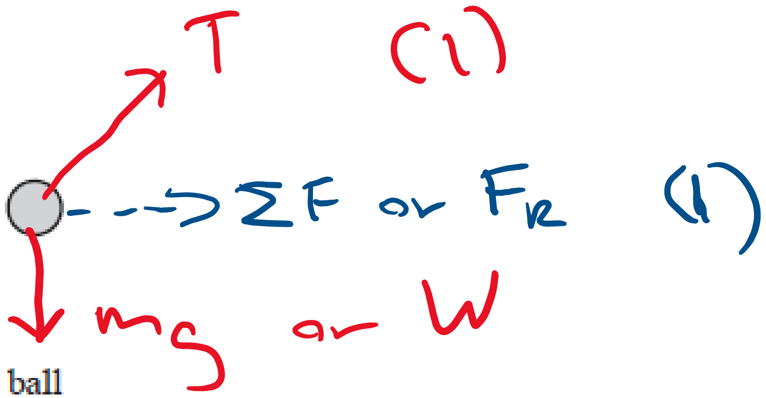


Figure 3b

(Don't say 'Gravity')

a. On Figure 3b above, draw all the forces on the ball. Label all forces. Draw the resultant force as a dotted line labelled F_R.

2 marks

VCAA 2016

Question 2 (5 marks)
A steel ball of mass 2.0 kg is swinging in a circle of radius 0.50 m at a constant speed of 1.7 m s^{-1} at the end of a string of length 1.0 m, as shown in Figure 3a.

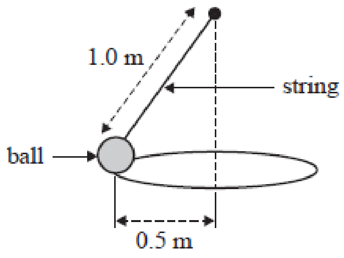


Figure 3a

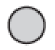


Figure 3b

b. Calculate the tension in the string shown in Figure 3a. Show your working. 3 marks

______ N

VCAA 2016 **SOLUTION**

Question 2 (5 marks)

A steel ball of mass 2.0 kg is swinging in a circle of radius 0.50 m at a constant speed of 1.7 m s^{-1} at the end of a string of length 1.0 m, as shown in Figure 3a.

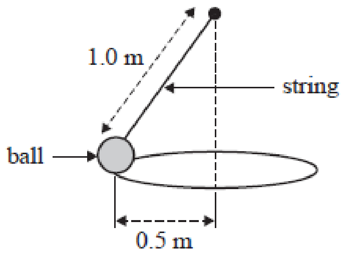


Figure 3a

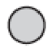


Figure 3b

$m = 2$ kg, $g = 10$

$v = 1.7$ m/s

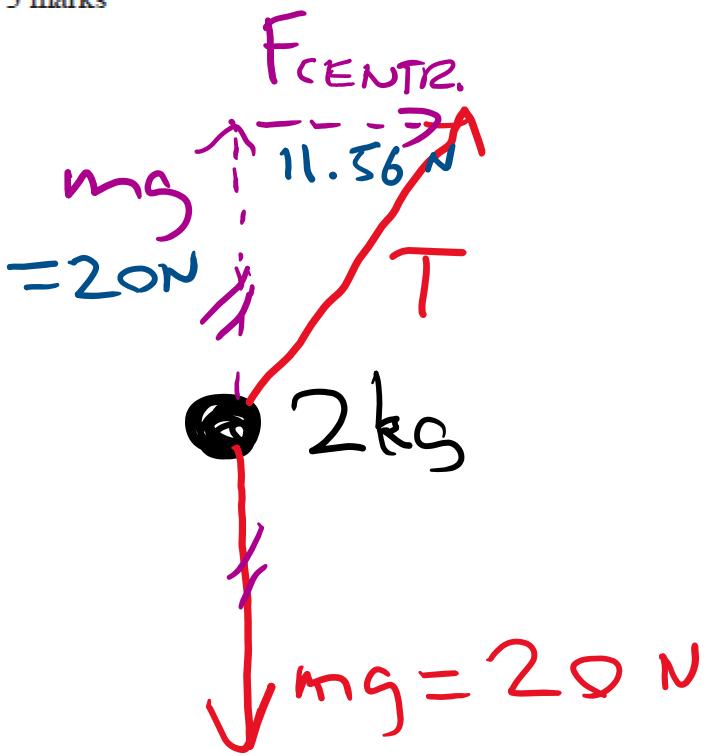
$F_c = \frac{mv^2}{R} = \frac{2 \times 1.7^2}{0.5} = 11.56$ N

b. Calculate the tension in the string shown in Figure 3a. Show your working. 3 marks

$T = \sqrt{(mg)^2 + F_{centr}^2}$

$= \sqrt{20^2 + 11.56^2}$

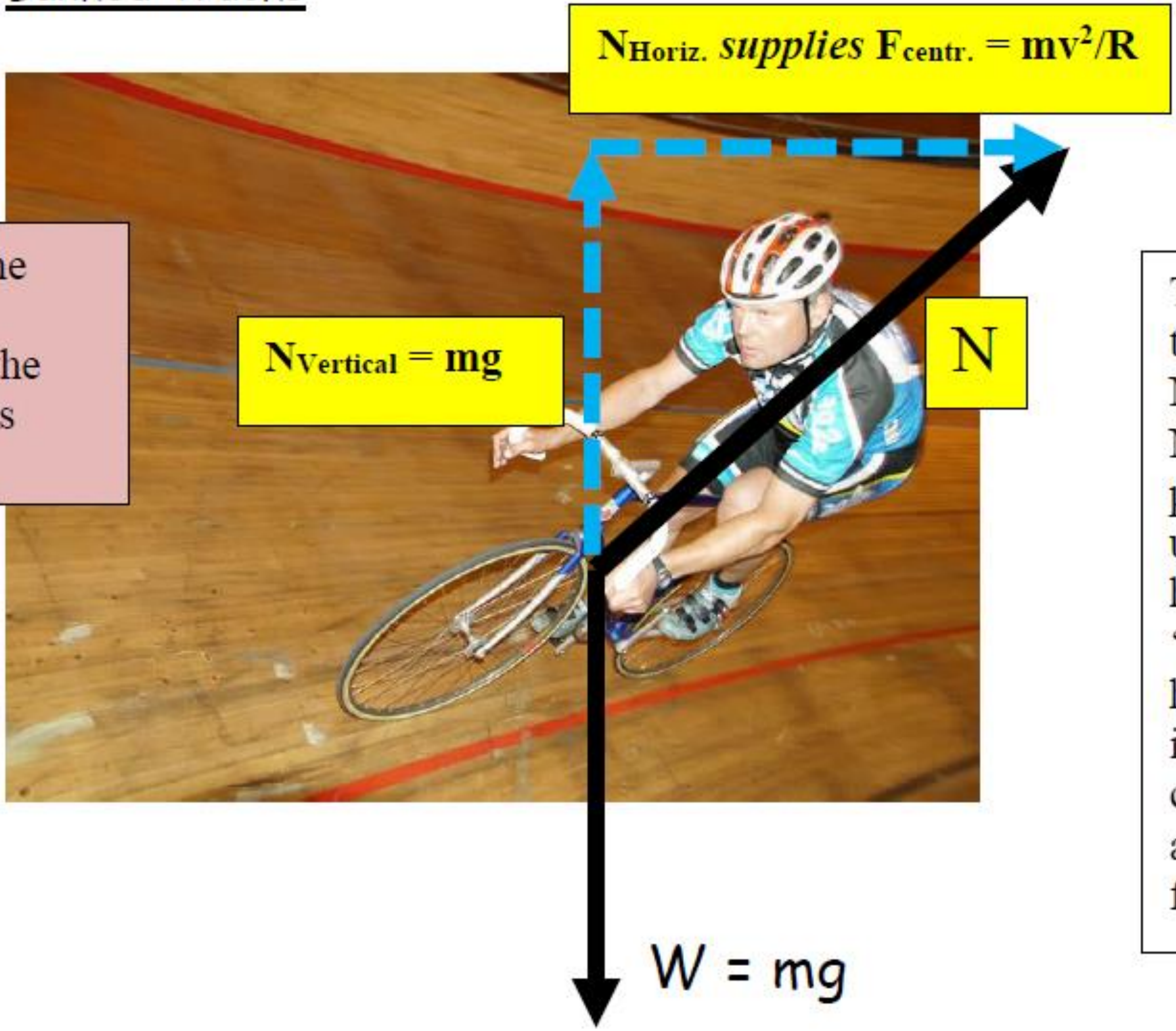
23.1 N



Banked Tracks

This is F_{NET}

Note, in the **vertical** direction the net force is ZERO



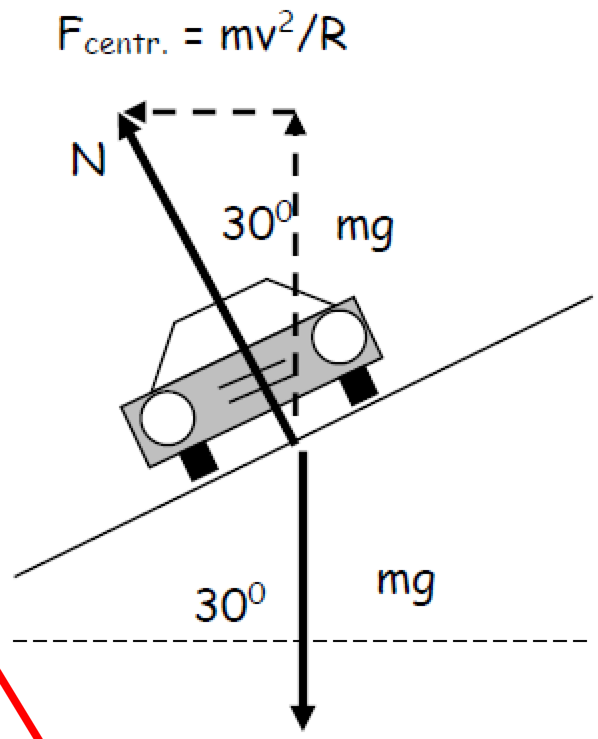
The banking (sloping) of the track means that the Normal Reaction Force, N, which would have pointed vertically straight up for a vehicle on a horizontal road, now 'leans' over and has a net, horizontal component that is able to supply a centripetal force and the absence of any sideways friction.

Problem 5.

Consider a 1500kg NASCAR racing on a banked section of the track on a corner of radius 25m.

Note: from this diagram, we find for a track banked at angle Θ (30^0 in this example)

$\tan\theta = \frac{mv^2}{R}/mg$ or: $\tan\theta = \frac{v^2}{gR}$



(i) Calculate the size of the Normal Reaction Force's contribution to the centripetal force. (Neglecting any friction between the tyres and Road - quite unrealistic!)

Useful for your A3 sheet of exam notes

SOLUTION

Problem 5.

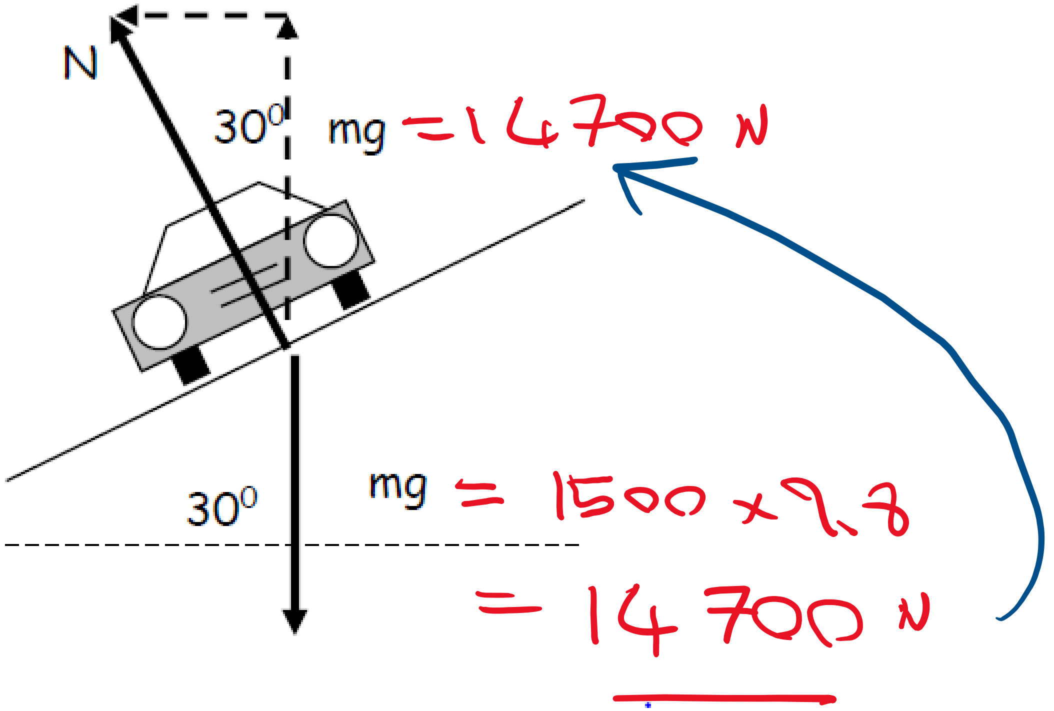
Consider a 1500kg NASCAR racing on a banked section of the track on a corner of radius 25m.

Note: from this diagram, we find for a track banked at angle Θ (30^0 in this example)

$\tan\theta = \frac{mv^2}{R}/mg$ or: $\boldsymbol{\tan\theta = \frac{v^2}{gR}}$

$F_{centr.} = mv^2/R$

$g = 9.8$



(i) Calculate the size of the Normal Reaction Force's contribution to the centripetal force. (Neglecting any friction between the tyres and Road - quite unrealistic!)

$\cos 30^0 = \frac{14700}{N}$

$N = \frac{14700}{\cos 30^0} = 16970\ N$

(ii) Calculate the highest cornering speed of the car.

(2 marks)

SOLUTION

(ii) Calculate the highest cornering speed of the car.

$$\tan\theta = \frac{v^2}{gR}$$

$g = 9.8$

$\theta = 30^\circ$

$R = 25\,m$

note: v & θ are independent of the mass

$$\Rightarrow \tan 30^\circ = \frac{v^2}{9.8 \times 25} \quad (1)$$

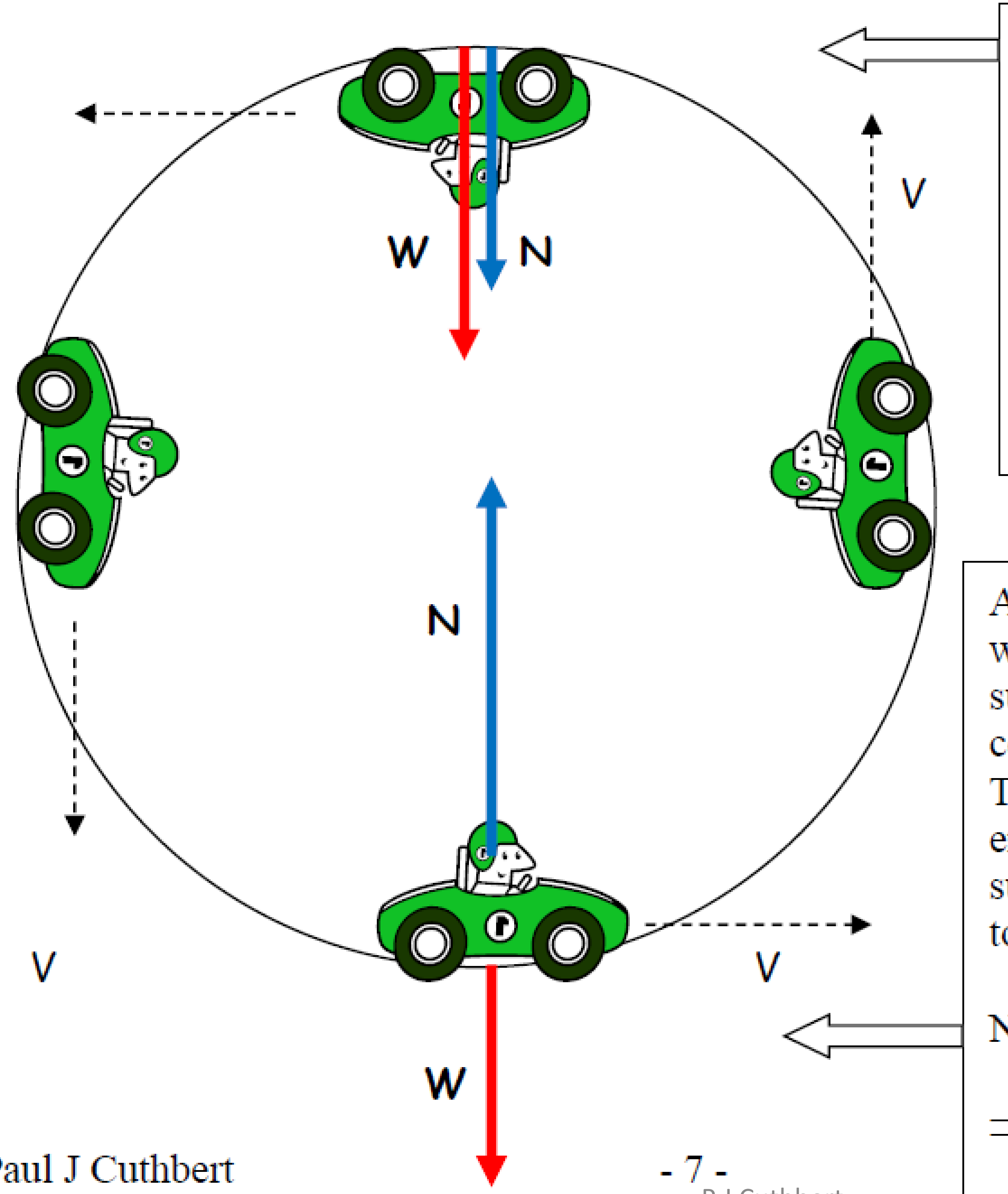
$$v = \sqrt{9.8 \times 25 \times \tan 30^\circ} = 11.9\,m/s \quad (1)$$

Motion in a VERTICAL CIRCLE: **Non Uniform Circular Motion**

In the previous examples all the motion was only the horizontal plane.

Now we need to consider the forces on a body that is moving in a vertical circle.

In this case the weight force, W = mg, needs to be considered and the normal reaction force, N, changes in size throughout the motion.



At the top **W** helps supply the centripetal force. So **N** (the normal reaction force) from the track is smaller than it is at the bottom.

$N + W = mv^2 / R$

$\Rightarrow N = mv^2 / R - W$

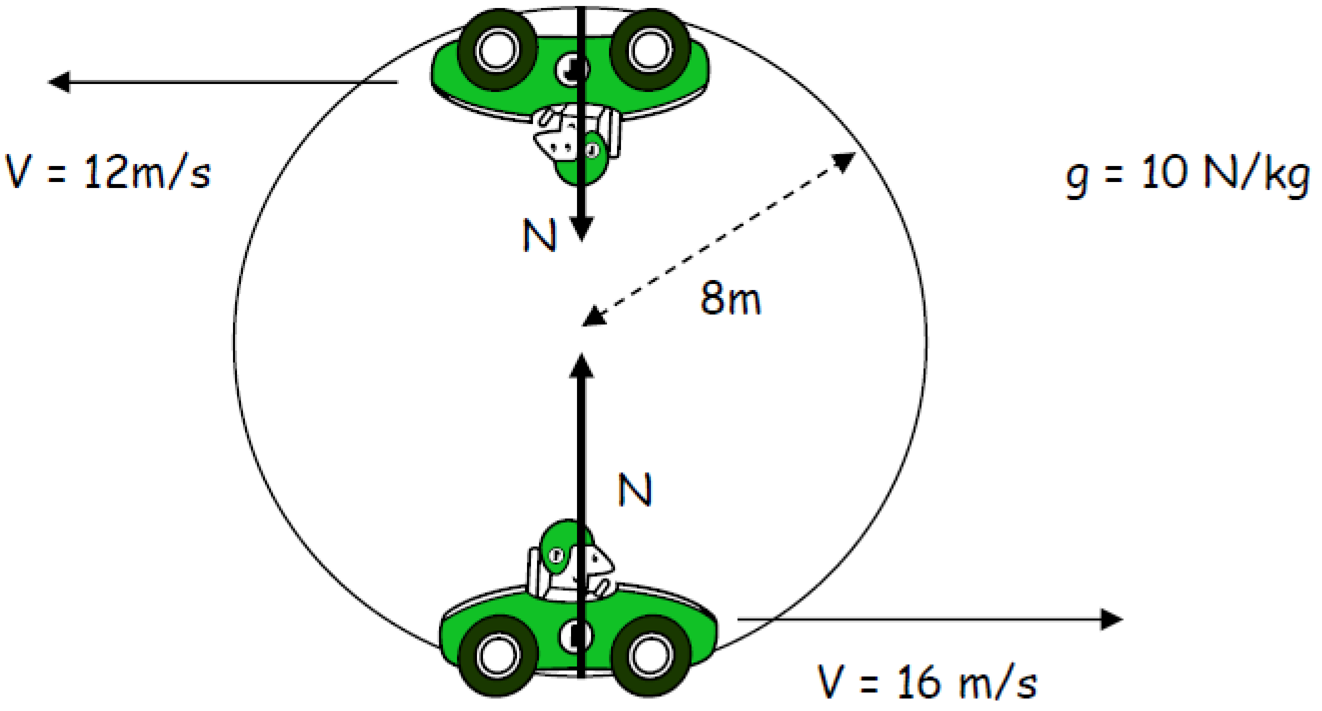
At the bottom **W** points in the wrong direction to be able to supply any part of the centripetal force.
Therefore **N** must be large enough to oppose **W** and supply a centripetal force up towards the centre of the circle.

$N - W = mv^2 / R$

$\Rightarrow N = mv^2 / R + W$

PROBLEM

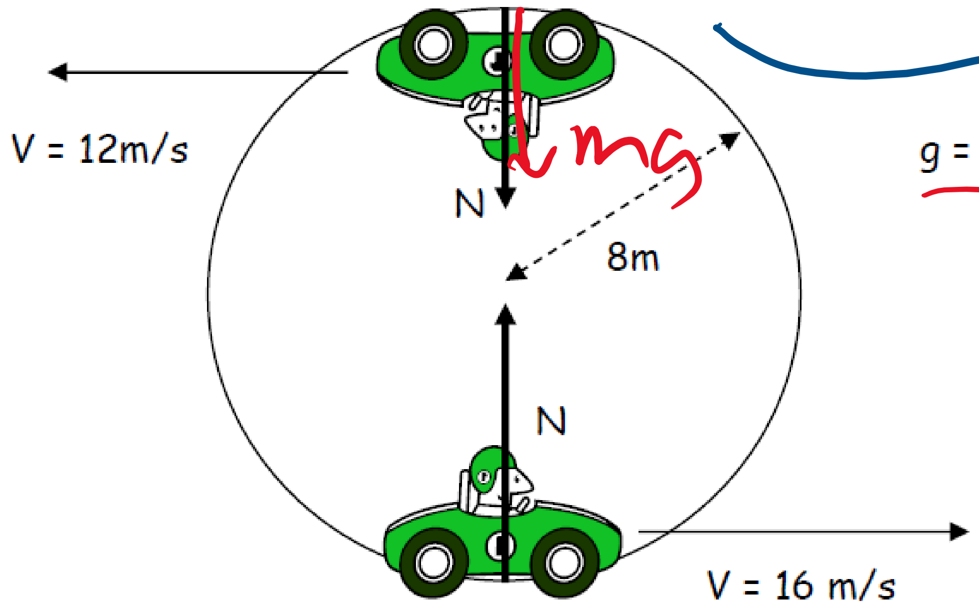
1. A car of mass 1500kg is doing a trick in a looped track of radius 8m.



Find the size of the track's normal reaction force, N, on the car at the:
(a) Top of the loop and (b) bottom of the loop.

SOLUTIONS

1. A car of mass 1500kg is doing a trick in a looped track of radius 8m.



g = 10 N/kg

(a) At the Top

$\Sigma F = ma$ (N2)

$N + mg = m\frac{v^2}{R}$

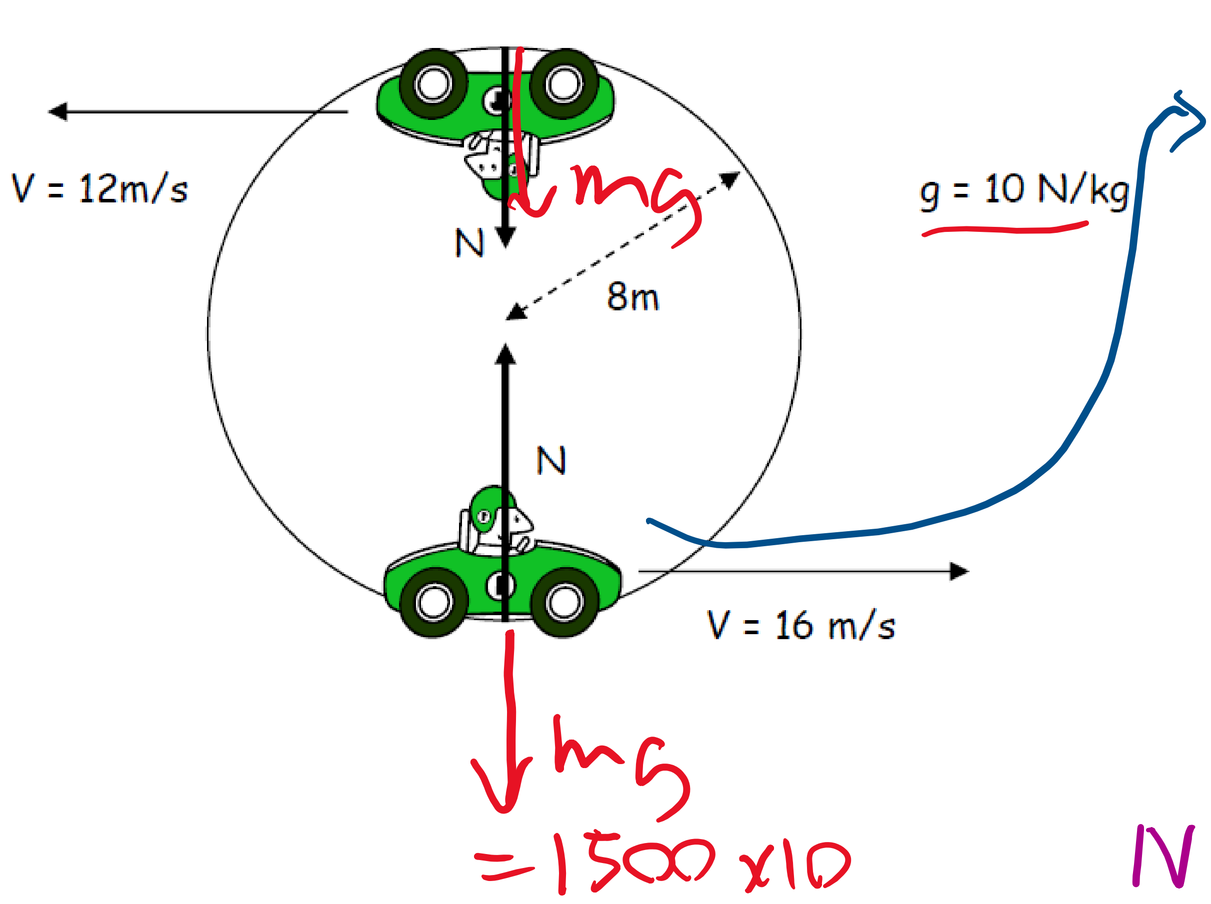
$N + 15000 \times 10 = 1500 \times \frac{12^2}{8}$

$\Rightarrow N = 27000 - 15000$

$= \underline{12,000}$ N

SOLUTIONS

1. A car of mass 1500kg is doing a trick in a looped track of radius 8m.



(b) At the bottom:

$$\Sigma F = ma$$

$$N - mg = \frac{mv^2}{R}$$

$$N - 1500 \times 10 = \frac{1500 \times 16^2}{8}$$

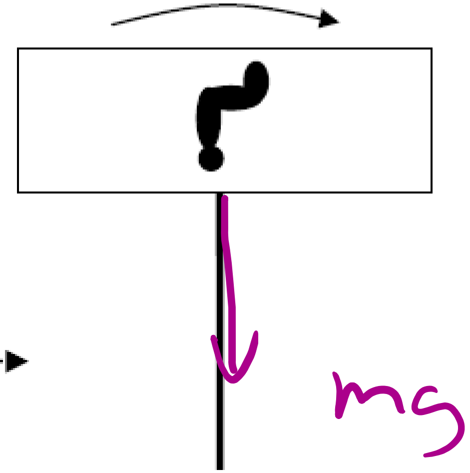
$$N = 15000 + 48000$$

$$= \underline{63{,}000\,N}$$

Vertical circular motion – when is N = 0?

Gondola
Mass = 2100kg

Radius = 9m

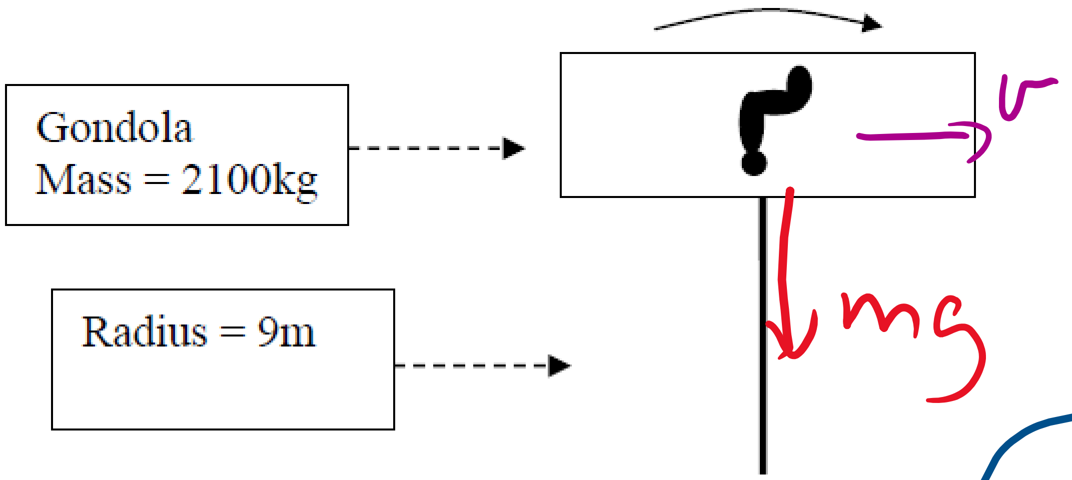


$g = 9.8$

$N = 0$

$\Rightarrow$ "Feel Weightless"

Vertical circular motion – when is N = 0?



$N = 0$

N2: $\sum F = ma$

$N + mg = m\frac{v^2}{R}$

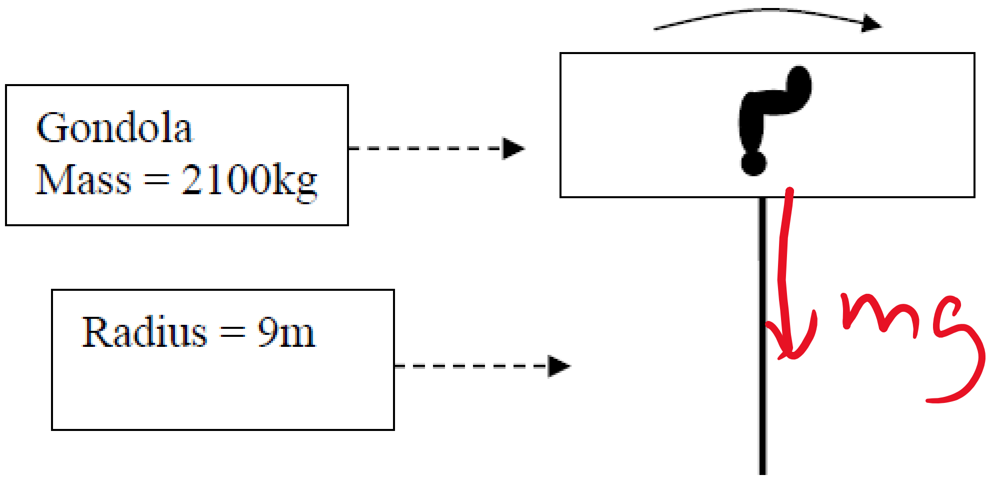
$\Rightarrow 0 + mg = m\frac{v^2}{R}$

$g = \frac{v^2}{R}$

$\Rightarrow v = \sqrt{gR}$ when $N = 0$

useful for your A3 notes

Vertical circular motion – when is N = 0?



$N = 0$

$V = \sqrt{gR}$

$= \sqrt{9.8 \times 9} = 9.4 \text{ m/s}$

Spring Questions-Hooke's Law & Elastic PE

Spring questions are often the most difficult questions on the VCAA Physics paper.

They are generally the only questions that involve three different energies in the same problem:
- Masses on the end of springs moving *vertically* have a total energy made up of changing KE, GPE and Elastic (Spring) PE.

Note: you **can't use the constant acceleration formulae for spring questions:**

$v = u + at$
$x = ut + \frac{1}{2}at^2$
$v^2 = u^2 + 2ax$

F = kx, therefore the force is not constant and so the **acceleration is not constant.**

Hooke's Law	$F = k\Delta x$
Elastic (strain/spring) potential energy	$EPE = E_S = \frac{1}{2}k(\Delta x)^2$
Gravitational potential energy	$GPE = E_g = mgh$
Kinetic Energy	$KE = E_K = \frac{1}{2}mv^2$
Total Energy	E(total) = KE + GPE + EPE

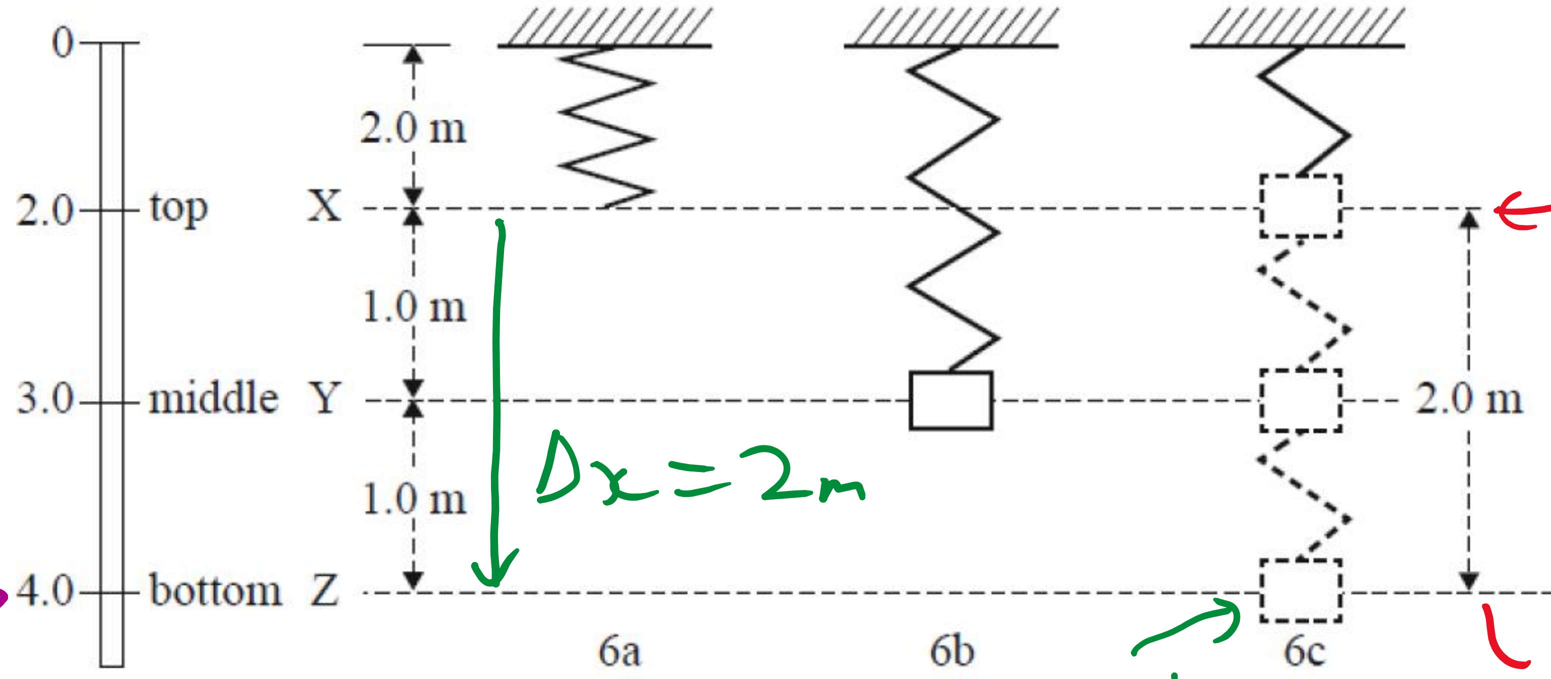
VCAA 2013

Worked Example

Question 6 (6 marks)

Students hang a mass of 1.0 kg from a spring that obeys Hooke's law with $k = 10\ \text{N m}^{-1}$. The spring has an unstretched length of 2.0 m. The mass then hangs stationary at a distance of 1.0 m below the unstretched position (X) of the spring, at Y, as shown at position 6b in Figure 6. The mass is then pulled a further 1.0 m below this position and released so that it oscillates, as shown in position 6c.

$E_{TOTAL} = KE + GPE + EPE = \text{constant}$



$\Delta x = 2\text{m}$

$\leftarrow KE = 0$

$U_G = 0 = GPE$, $KE = 0$

$E_T = KE + GPE + EPE$
$= 0 + 0 + 20\text{J} = 20\text{J}$

$EPE = \frac{1}{2} k \Delta x^2$
$= \frac{1}{2} \times 10 \times 2^2 = 20\text{J}$

The zero of gravitational potential energy is taken to be the bottom point (Z).

The spring potential energy and gravitational potential energy are plotted on a graph, as shown in Figure 7.

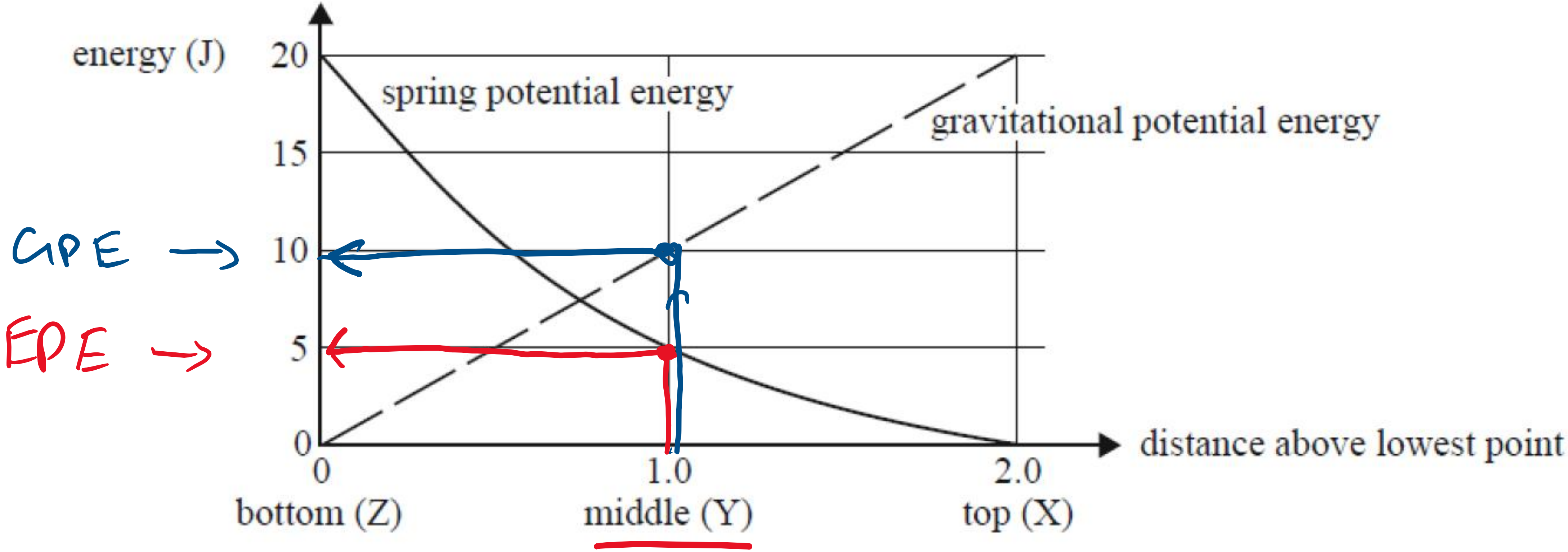


Figure 7

a. Calculate the total energy of the system when the mass is at its lowest point (Z). 1 mark

At: $E_T = KE + GPE + EPE$

$= 0 + 0 + \frac{1}{2} \times 10 \times 2^2$

20 J

b. From the data in the graph, calculate the speed of the mass at its midpoint (Y). 2 marks

$E_T = \text{constant} = 20\text{J}$, $m = 1\text{kg}$

$\Rightarrow E_T(Y) = KE_Y + GPE_Y + EPE_Y = 20\text{J}$

$\Rightarrow KE_Y + 10 + 5 = 20$ ← Graph

$\Rightarrow KE_Y = \frac{1}{2} \times 1 \times V_Y^2 = 20 - 5 - 10$

$= 5\text{J}$

$\Rightarrow \frac{1}{2} V_Y^2 = 5$, $V_Y = \sqrt{10}$ ← Don't answer as a SURD

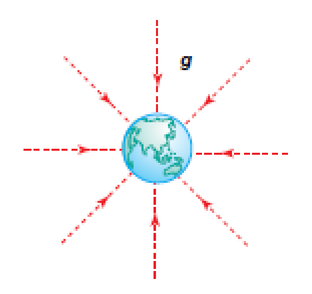
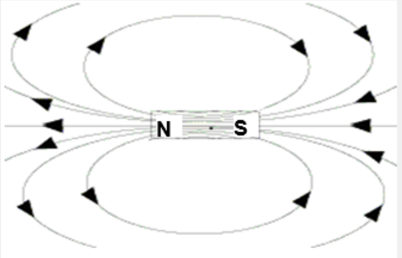
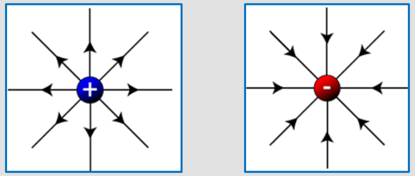
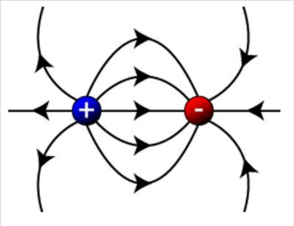
3.16 m s^{-1}

Fields
Unit 3 AoS#2

Monash University – Revision Lecture

- Gravitational Fields and Satellite Motion
- Magnetic Fields
- Electric Fields

Paul J Cuthbert

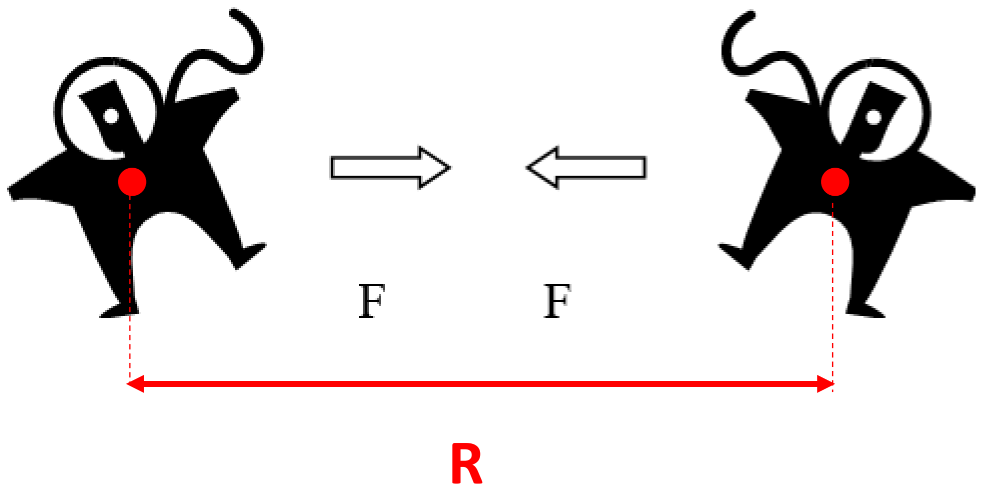
	Gravity	Magnetic Fields	Electric Fields
Monopole only			
Dipole only			
Monopole and Dipoles			 

1. Gravitational Fields & Satellite Motion

1-Newton's Law of Universal Gravitation

Gravitational attraction - Mass attracts mass.

$m_1 = M$



$m_2 = m$

R is measured between the *centre of mass* of the two bodies.

$$F = \frac{Gm_1m_2}{R^2} = \frac{GMm}{R^2}$$

Newtons → F

kilograms → m_1, m_2, M, m

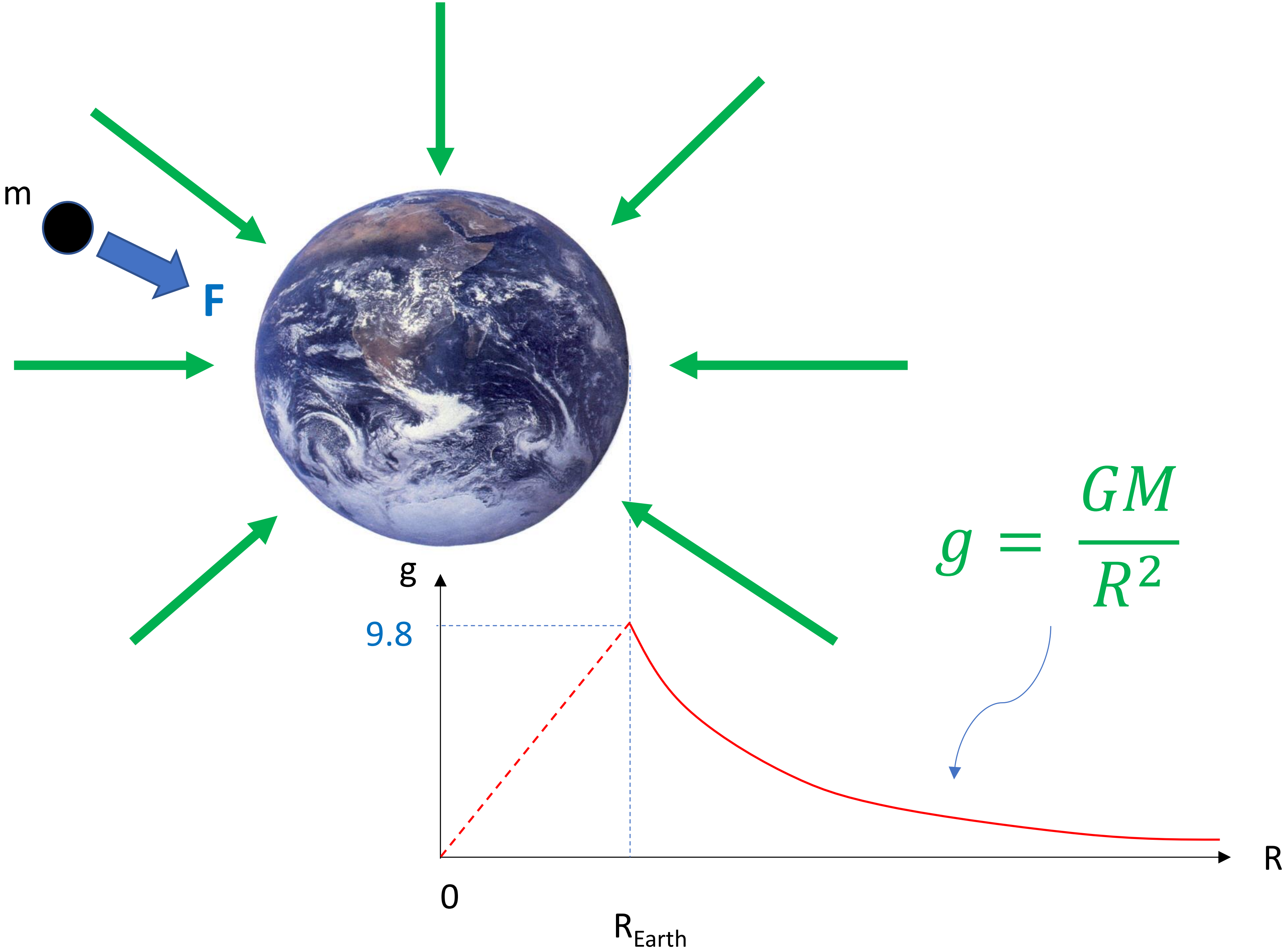
metres → R

$G = 6.67 \times 10^{-11}\ N\ m^2kg^{-2}$

Paul J Cuthbert

The GRAVITATIONAL FIELD

$$g = F/m$$
$$= GMm/R^2/m$$
$$= GM/R^2$$



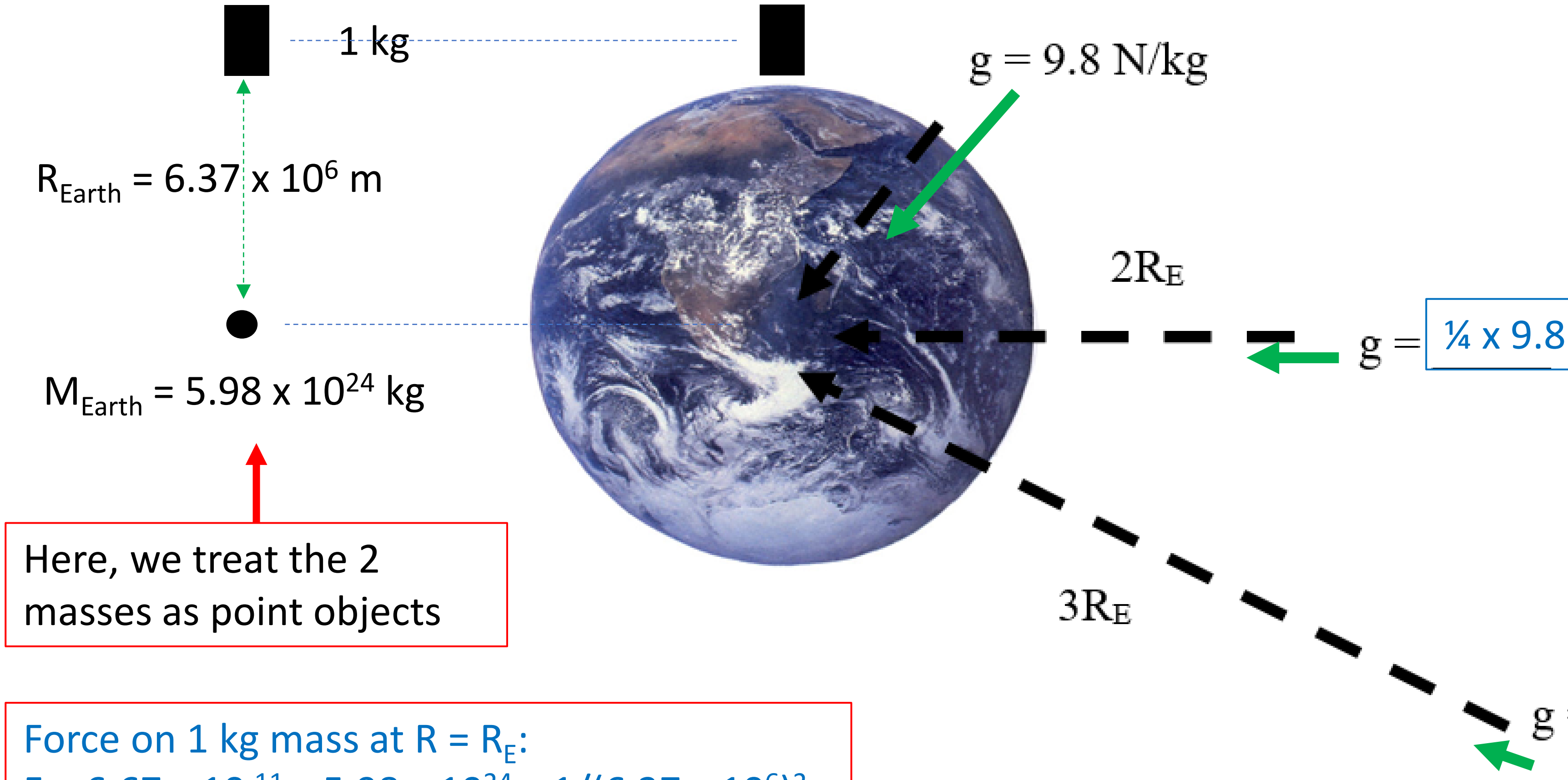
Gravity is a monopole

The force is only attractive

The direction of the field is given by the direction of the force on a 'test mass' m

The value of g (Newtons per kg) can be defined as the force experienced by 1 kg at a distance R from the planet or star's centre.

$$g = \frac{GM}{R^2}$$



Here, we treat the 2 masses as point objects

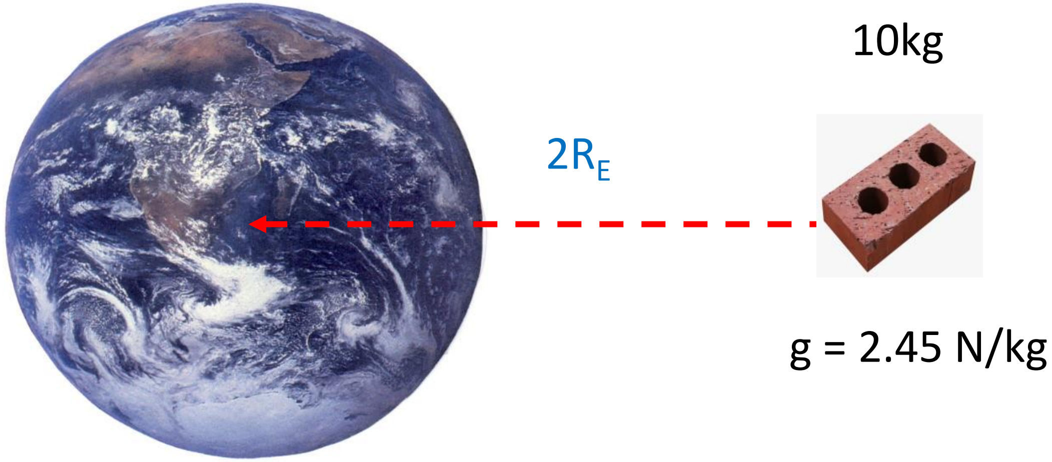
Force on 1 kg mass at R = R_E:
F = 6.67 x 10^{-11} x 5.98 x 10^{24} x 1/(6.37 x 10^6)^2
= 9.8 N
-which is of course, the *Weight* of a 1 kg mass

Problems:

If a 10 kg mass is placed at 2 x R_E (an *altitude* of 1 Earth radius) and let go:

(i) What will be its WEIGHT at that distance from Earth?

(ii) What will be its ACCELERATION towards the Earth?

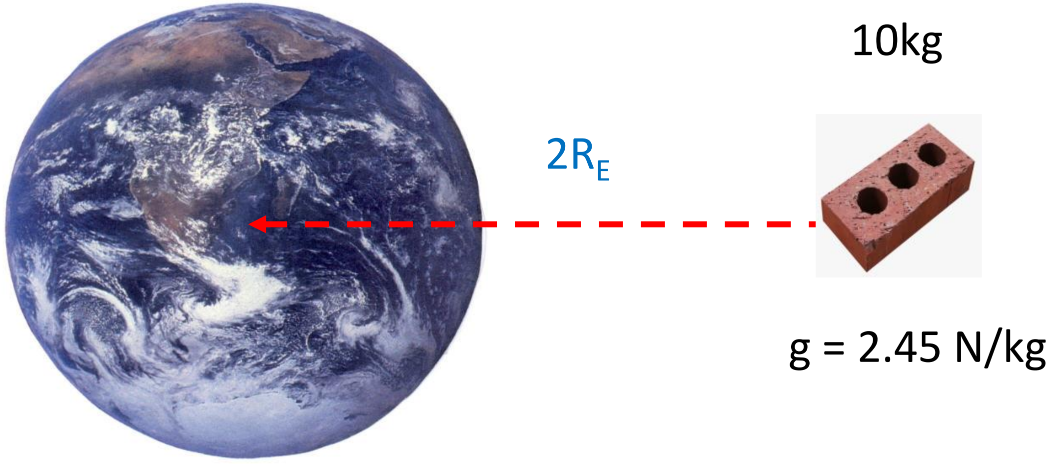


Problems:

If a 10 kg mass is placed at 2 x R_E (an *altitude* of 1 Earth radius) and let go:

(i) What will be its WEIGHT at that distance from Earth?

(ii) What will be its ACCELERATION towards the Earth?



Solutions:

(i) $W = mg = 10 \times 2.45 = 24.5$ N

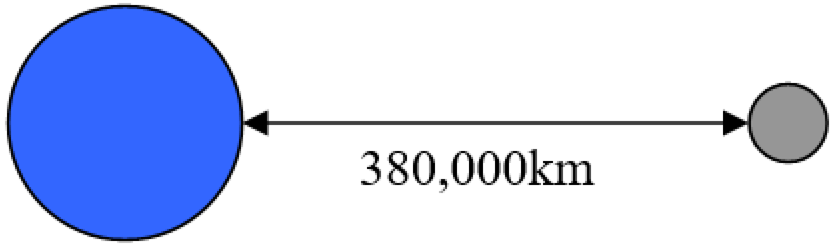
(ii) $a = g = 2.45\ ms^{-2}$ (all masses fall at the same rate)*

*The net force, F, on the brick = ma = its weight, W, mg: ma = mg => a = g

Problem:

There is a point between the Earth & Moon where a spaceship will be pulled just as strongly back towards earth as is it towards the moon. At this point the gravitational forces cancel and those aboard will be completely weightless. What is the distance from Earth?

Data: $M_{MOON} = 7.34 \times 10^{22}$ kg
$M_{EARTH} = 5.98 \times 10^{24}$ kg

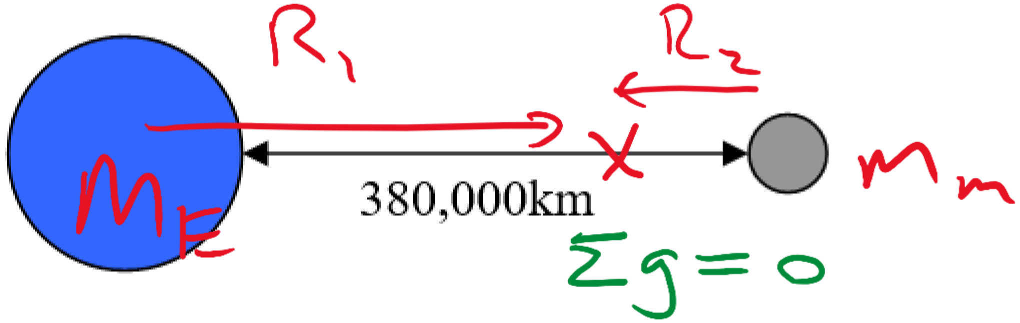


Solution:

There is a point between the Earth & Moon where a spaceship will be pulled just as strongly back towards earth as is it towards the moon. At this point the gravitational forces cancel and those aboard will be completely weightless. What is the distance from Earth?

$$\frac{M_E}{M_m} \simeq 81$$

Data: $M_{MOON} = 7.34 \times 10^{22}$ kg
$M_{EARTH} = 5.98 \times 10^{24}$ kg



$$g_E = \frac{GM_E}{R_1^2} \qquad g_m = \frac{Gm_m}{R_2^2}$$

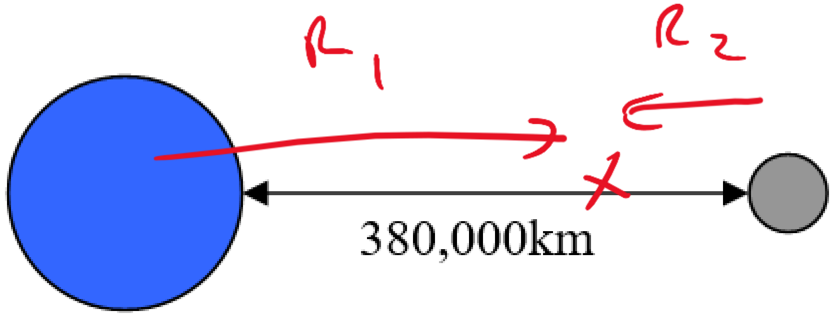
At x: $\overleftarrow{g_E} = \overrightarrow{g_m}$

$$\frac{GM_E}{R_1^2} = \frac{GM_m}{R_2^2} \Rightarrow \left(\frac{R_1}{R_2}\right)^2 = \frac{M_E}{M_m} = 81, \quad \frac{R_1}{R_2} = \sqrt{81} = 9$$

Solution:

There is a point between the Earth & Moon where a spaceship will be pulled just as strongly back towards earth as is it towards the moon. At this point the gravitational forces cancel and those aboard will be completely weightless. What is the distance from Earth?

Data: $M_{MOON} = 7.34 \times 10^{22}$ kg
$M_{EARTH} = 5.98 \times 10^{24}$ kg



$R_1 + R_2 = 3.8 \times 10^5$ km

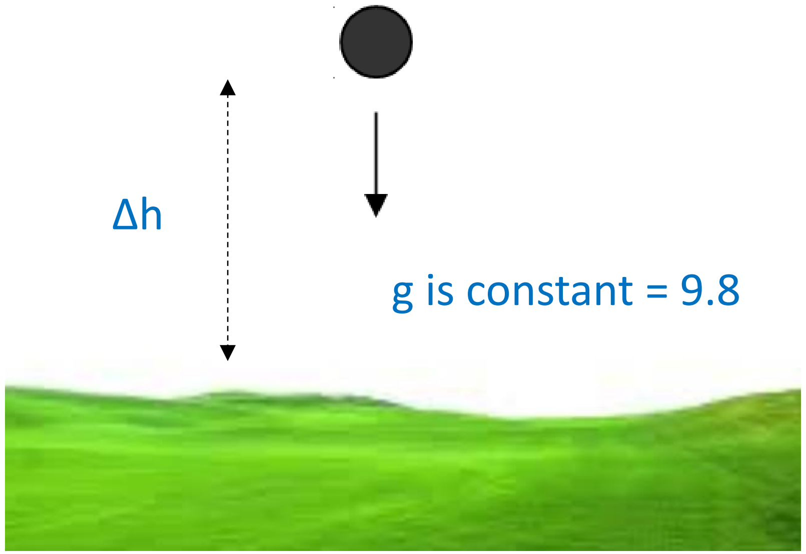
$R_1 = 9 R_2$
$= 9(3.8 \times 10^5 - R_1)$

$R_1 = \underline{342{,}000 \text{ km}}$

KE and PE in gravitational Fields – when R is very large

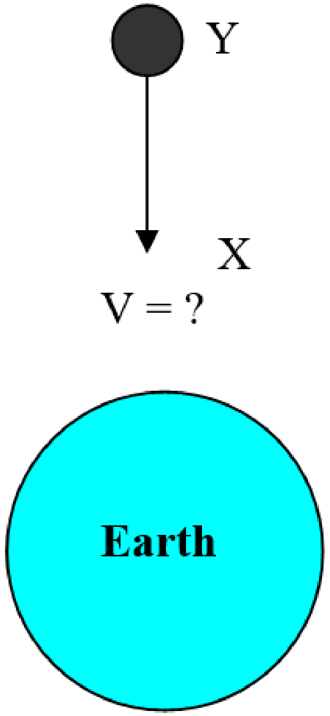
Consider 2 falling objects dropped from rest:

1.



$\Delta PE = mg\Delta h$

2.



$$g \propto \frac{1}{R^2}$$

g is not constant over very large distances.

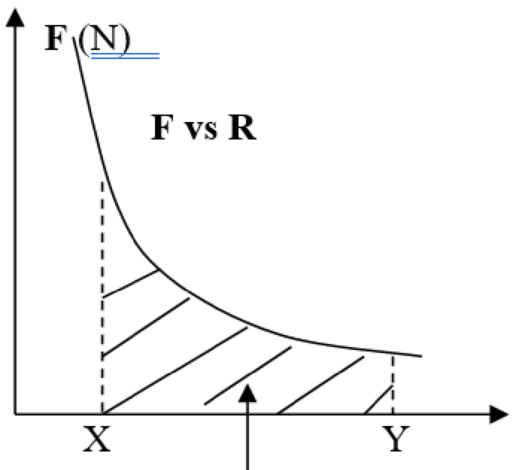
Therefore

$\Delta PE \neq mg\Delta h$

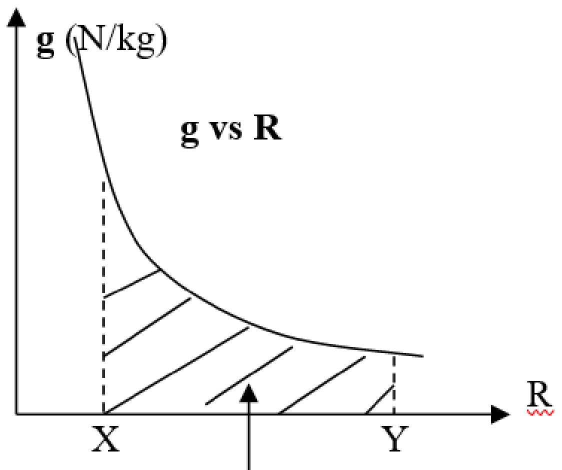
To calculate the change in PE(loss) = gain in KE as the mass, m, 'falls' in to a planet or star -we use the AREA under the graph:

There are *two* types of graphs:

The area under a Force vs displacement = Work Done



OR



Area = ΔP.E
= decrease in P.E. as mass falls from Y to X (Joules)

= increase in K.E. of mass

Area
= decrease in P.E. as mass falls from Y to X *for each kg of mass*, (since g = F/m)

For this graph:

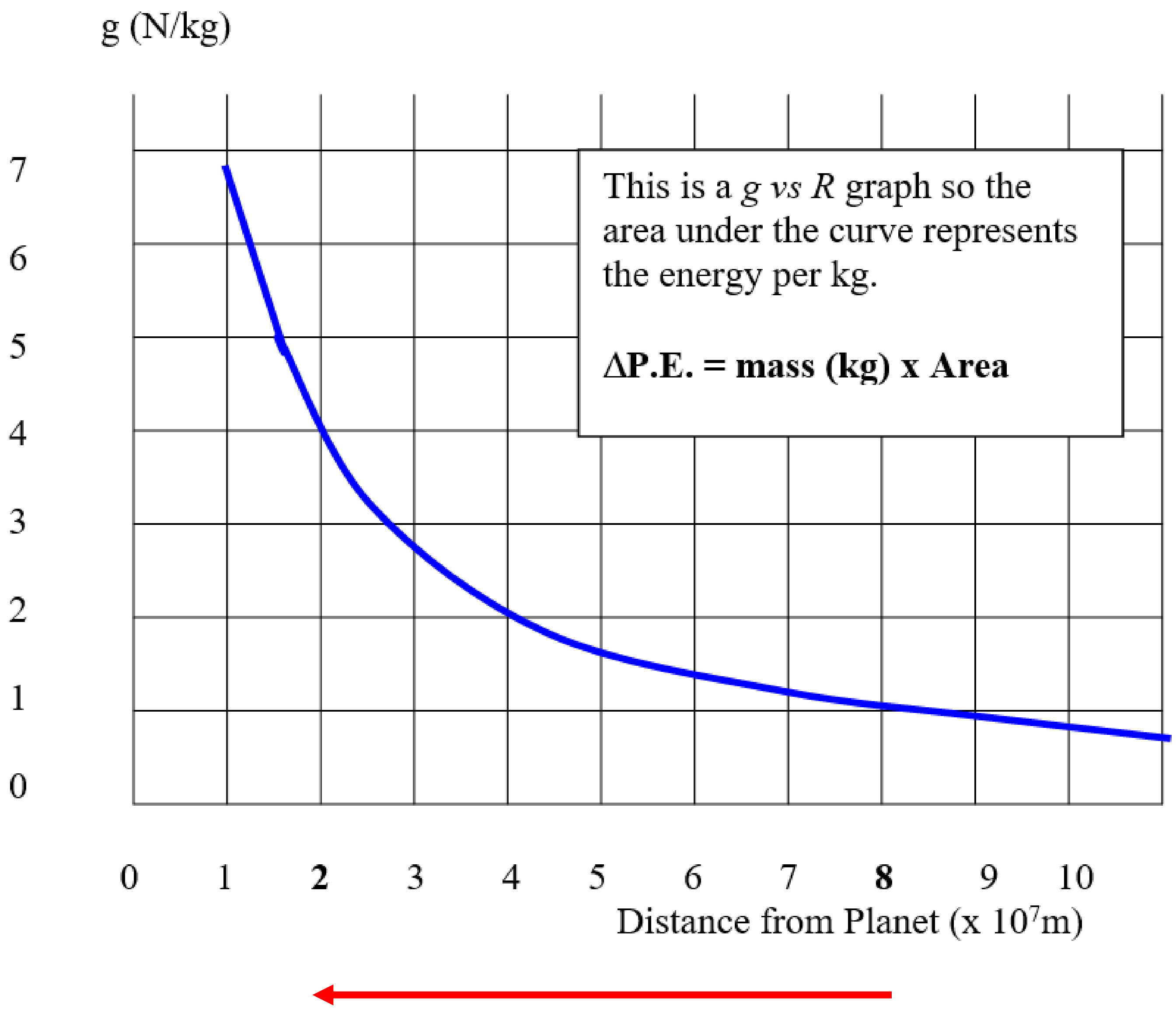
ΔP.E. = MASS (kg) x Area

Here, the mass refers to the **mass** of the falling body (meteor, comet, space probe), *not* the mass of the Planet or Star

Problem:

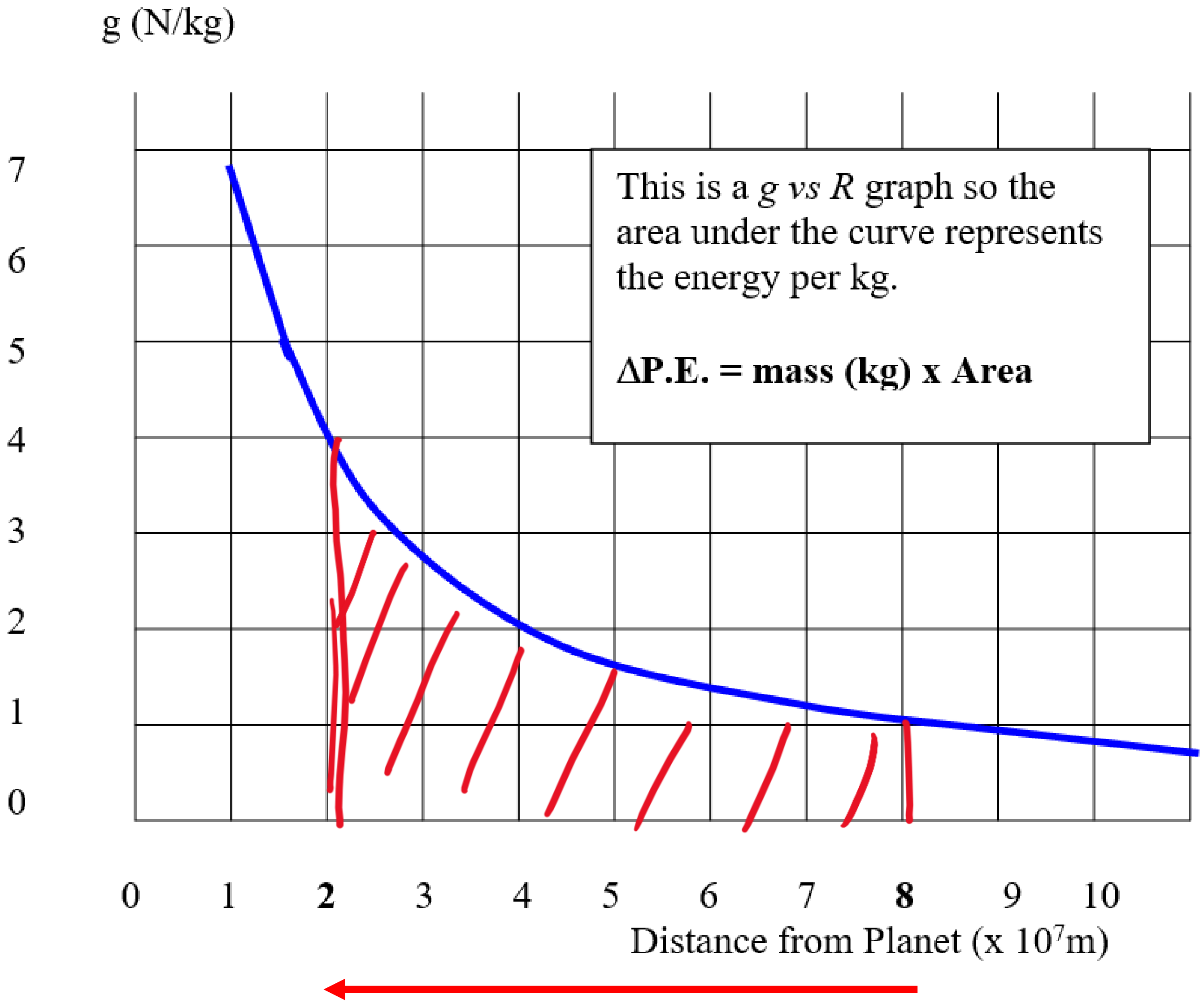
A space probe of mass 180kg, initially at rest, turns off its retro rockets and approaches a planet from a distance of 8.0×10^7 m (from its centre). Assuming gravity is the only force acting on the probe, when it reaches a distance of 2×10^7 m:

(i) What will be its decrease in P.E. and
(ii) Show its speed will be 1.55×10^4m/s (15.5 km/sec).


g (N/kg)
7
6
5
4
3
2
1
0
0 1 2 3 4 5 6 7 8 9 10
Distance from Planet (x 10^7m)
This is a g vs R graph so the area under the curve represents the energy per kg.
ΔP.E. = mass (kg) x Area

Solution

In these problems, there's no drag in outer space,
so KE(gain) = PE(loss) *exactly*.



No. of squares shaded ≈ 12

Each square = 1N/kg x 1 x 10^7 m
= 10^7 J/kg

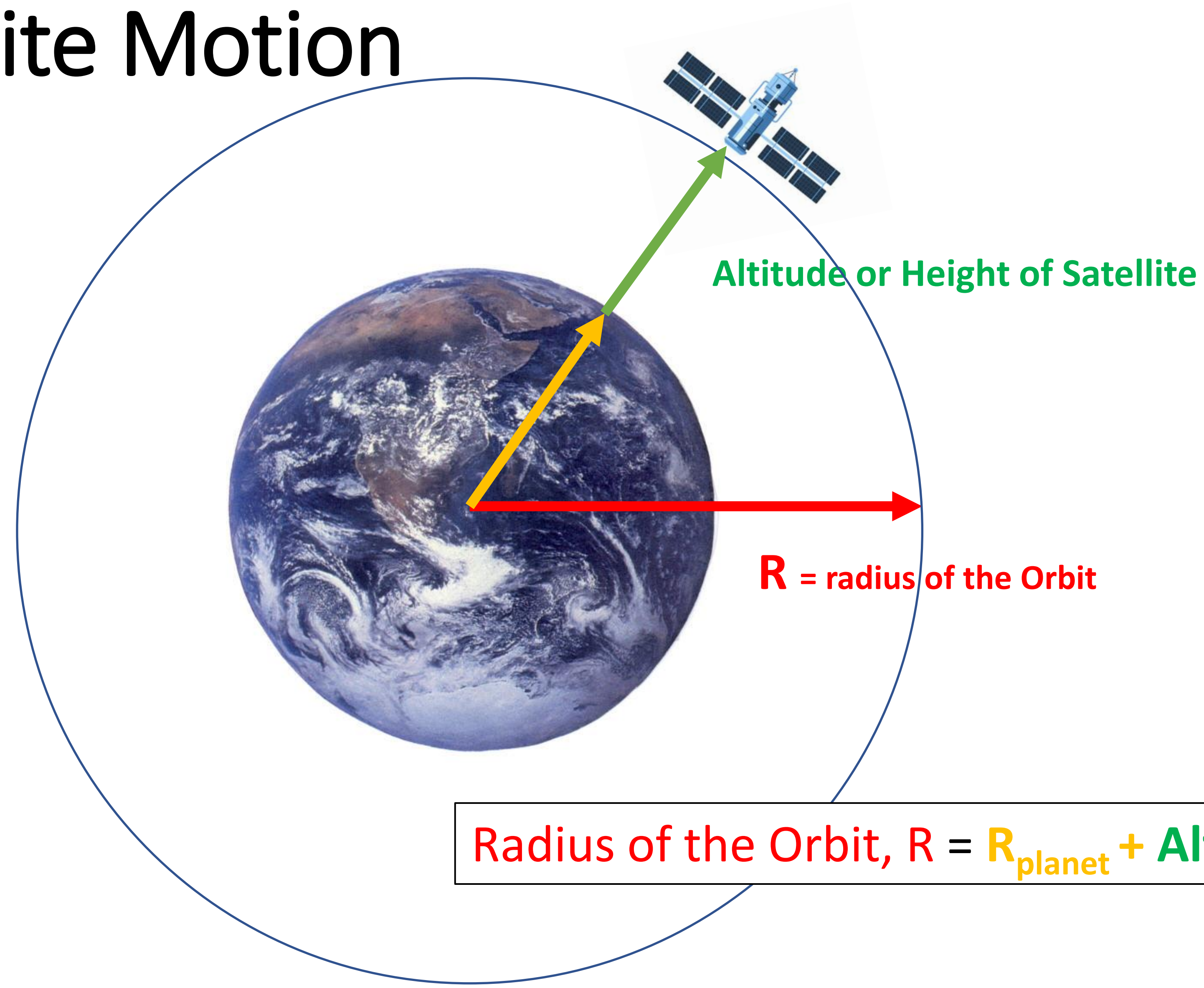
PE(loss) = 12 x 10^7 J/kg x 180 kg
= 2.16 x 10^{10} J

= KE(gain)* = ½ mv^2
= ½ x 180 x v^2

v = 15,490 m/s

*KE(initial) = 0

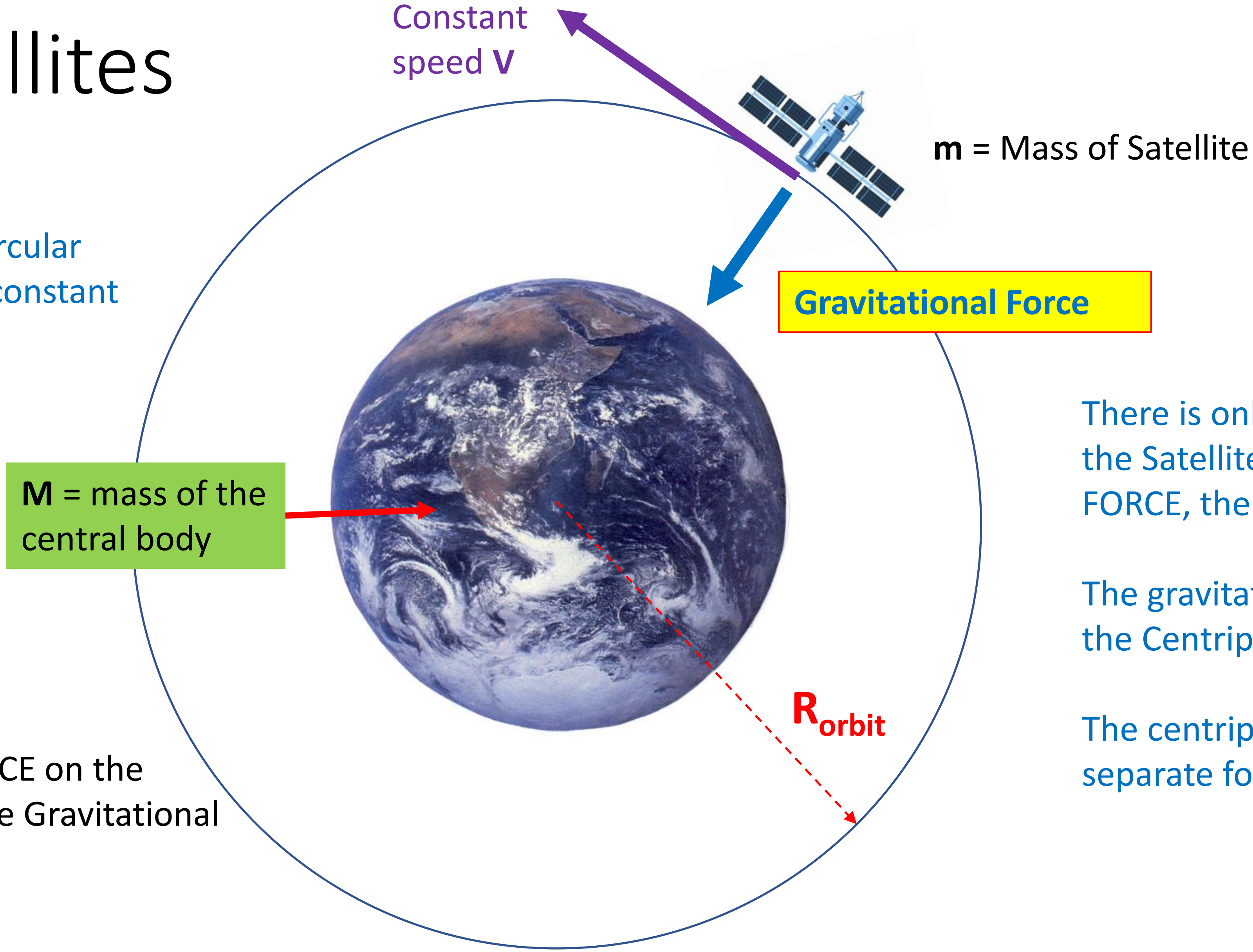
2-Satellite Motion



Radius of the Orbit, R = R_{planet} + Altitude

Satellites

Assumptions:
-the orbit is circular
-the speed is constant
-M >> m



There is only ONE Force acting on the Satellite: the GRAVITATIONAL FORCE, there are no others.

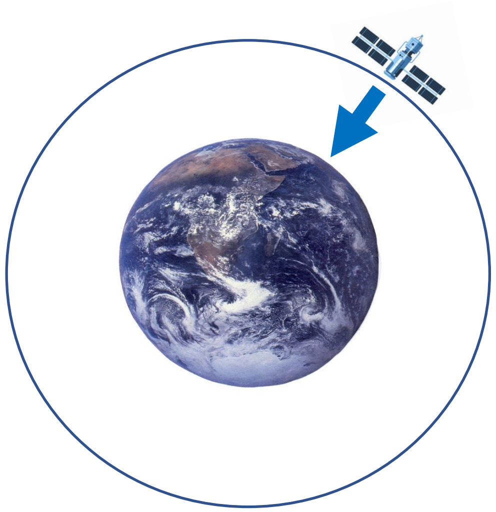
The gravitational force *supplies* the Centripetal Force.

The centripetal force is not a separate force acting.

The NET FORCE on the Satellite is the Gravitational Force.

What is the DIRECTION of the **force** acting on a Satellite in a circular orbit?

State: 'The FORCE is directed toward the centre of the Earth (or the Central Mass)'



Don't say 'the force is *DOWN*' -you're physics students, not 'flat Earthers'

Equations of Satellite Motion

F(gravitational force) = F(centripetal)

Orbital Speed:

$$\Rightarrow \quad \frac{GMm}{R^2} = \frac{mv^2}{R}$$

$$\Rightarrow \quad \frac{GM}{R^2} = \frac{v^2}{R}$$

$$\Rightarrow \quad v = \sqrt{\frac{GM}{R}}$$

$$\frac{GMm}{R^2} = \frac{4\pi^2 Rm}{T^2}$$

$$\frac{GM}{R^2} = \frac{4\pi^2 R}{T^2}$$

For all satellites of the *same* central mass M:

$T^2 \propto R^3$

$$T^2 = \left(\frac{4\pi^2}{GM}\right)R^3$$

*M is always the mass of the **central** body, **never** the orbiting body.*

Put these formulas on your A3 sheet

Problem: VCAA Exam 2019

Question 5 (5 marks)

Navigation in vehicles or on mobile phones uses a network of global positioning system (GPS) satellites. The GPS consists of 31 satellites that orbit Earth.

In December 2018, one satellite of mass 2270 kg, from the GPS Block IIIA series, was launched into a circular orbit at an altitude of 20 000 km above Earth's surface.

b. Calculate the period of the satellite to three significant figures. You may use data from the table below in your calculations. Show your working. 3 marks

Data

mass of satellite	2.27×10^{3} kg
mass of Earth	5.98×10^{24} kg
radius of Earth	6.37×10^{6} m
altitude of satellite above Earth's surface	2.00×10^{7} m
gravitational constant	6.67×10^{-11} N m^{2} kg^{-2}

Solution:

b. Calculate the period of the satellite to three significant figures. You may use data from the table below in your calculations. Show your working. 3 marks

Data

mass of satellite	2.27×10^3 kg
mass of Earth	5.98×10^{24} kg
radius of Earth	6.37×10^6 m
altitude of satellite above Earth's surface	2.00×10^7 m
gravitational constant	6.67×10^{-11} N m^2 kg^{-2}

Irrelevant – T does not depend on the mass of the satellite.

Central body, M

Add these for the radius, R, of the orbit:

$R = 6.37 \times 10^6 + 2.00 \times 10^7$ m

$= 2.637 \times 10^7$ m

From your A3 sheet, use:

$T^2 = (4\pi^2/GM)\, R^3$ **(1)**

$= 4\pi^2/(6.67 \times 10^{-11} \times 6.37 \times 10^{24}) \times (2.637 \times 10^7)^3$ **(1)**

T = 42,602 sec (this is 5 s.f.)

= 42,600 s (this is *still* 5 s.f.)

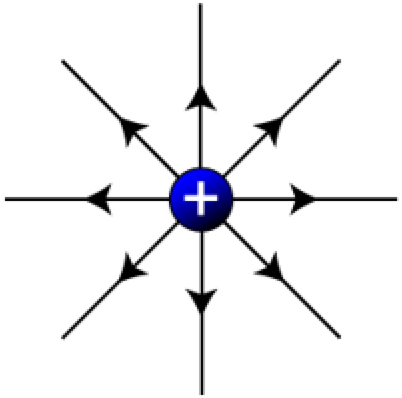
= 4.26×10^4 s (this is 3 s.f)* **(1)**

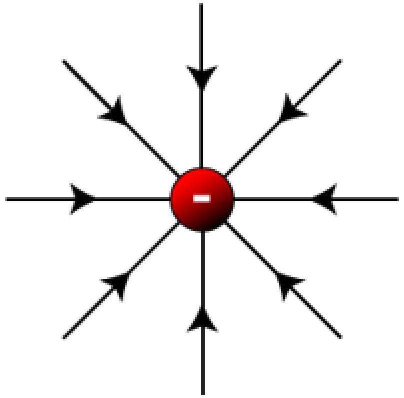
*If you always answer in Standard Form, you can't go wrong with getting the no. of s.f. correct.

2. Electric Fields

Charges & Electric Fields

Electric Field lines indicate the direction of force on a *positive* test charge in the region of an electric charge.





Field lines leave a positive charge and enter a negative charge.

Of course, this is a 2D representation of a 3D field pattern.

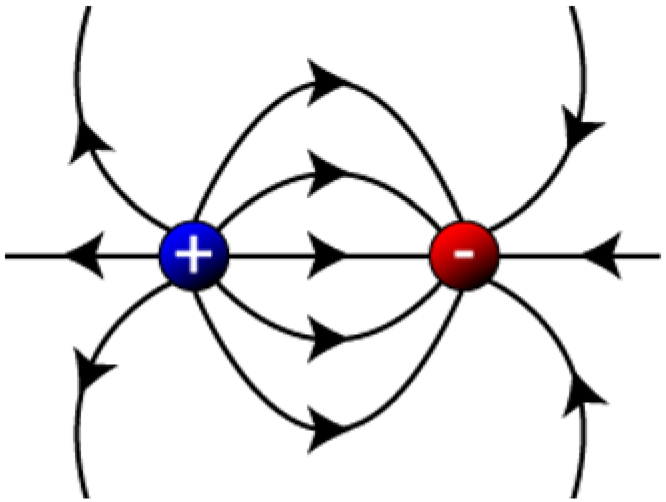
There would be lines pointing into and out of the page too.

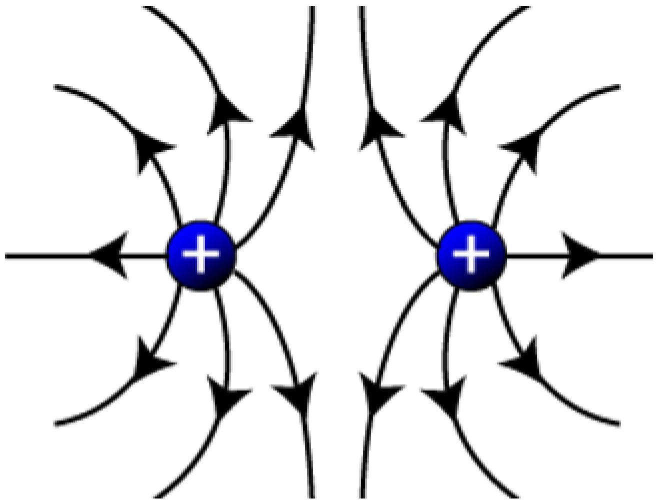
- Field lines *never* touch or cross each other.

- The density (or closeness) of the field lines indicates the field's strength.

- Unlike magnetic field lines which are continuous loops, with no beginning or end, electric field lines can have a beginning on a positive charge and can terminate on a negative charge.

Pairs of charges:



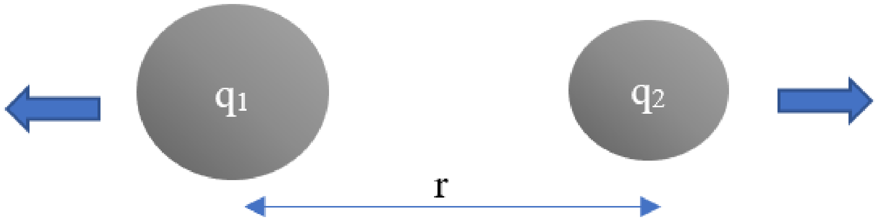


Suggest you have some examples of these field lines on your A3 sheet

Electric Force between charges -Coulomb's Law

Like charges repel, unlike charges attract.

Coulomb's Law is to calculate the strength (usually only the magnitude) of the force between 2-point charges.



F (assuming like charges, repulsion)

It is found experimentally that: $F \propto q_1, q_2, \frac{1}{r^2}$

Giving Coulomb's Law:

$$\boldsymbol{F = \frac{kq_1q_2}{r^2}}$$

Coulombs

N

m

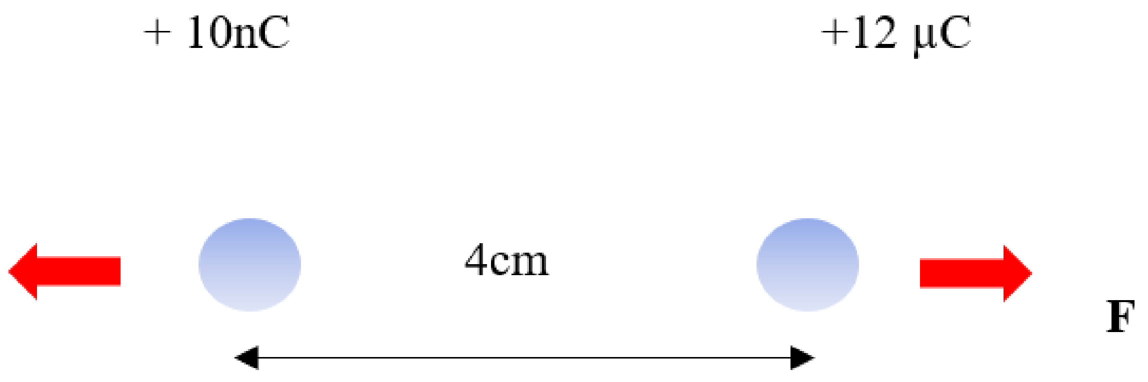
$k = 9 \times 10^9\ Nm^2C^{-2}$

Compare this to Newton's law of Universal Gravitation:

$$F = \frac{GM_1M_2}{r^2}$$

Problem

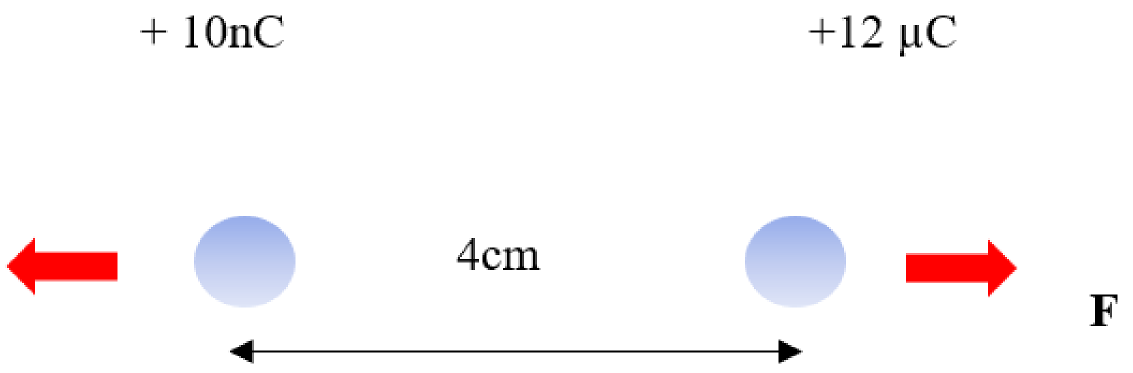
Calculate the magnitude of the force (Newtons) of repulsion between these charges:



N

Problem

Calculate the magnitude of the force (Newtons) of repulsion between these charges:



$q_1 = 10 \times 10^{-9}C$ $q_2 = 12 \times 10^{-6}C$

$$F = \frac{kq_1q_2}{r^2} = \frac{9 \times 10^9 \times 10 \times 10^{-9} \times 12 \times 10^{-6}}{0.04^2} = 0.675$$

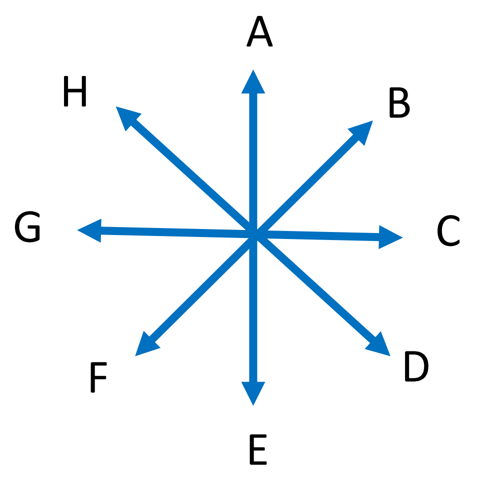
Note: Know your UNITS:

A question like this would probably be worth only 2 marks.
If you don't get the unit conversions correct for both the Coul. Unit and 4 cm to metres then you will lose the first mark and therefore cannot access the second mark.

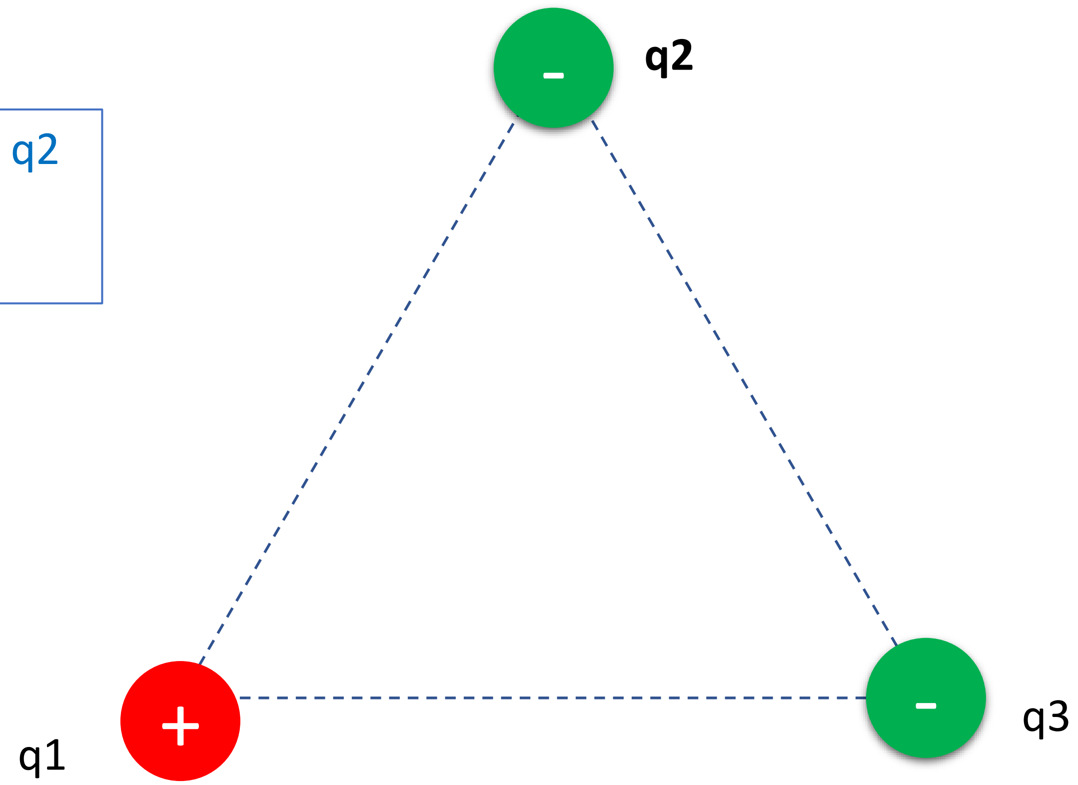
0.675	N

Problem:

Draw a vector to represent the net force acting on charge q2

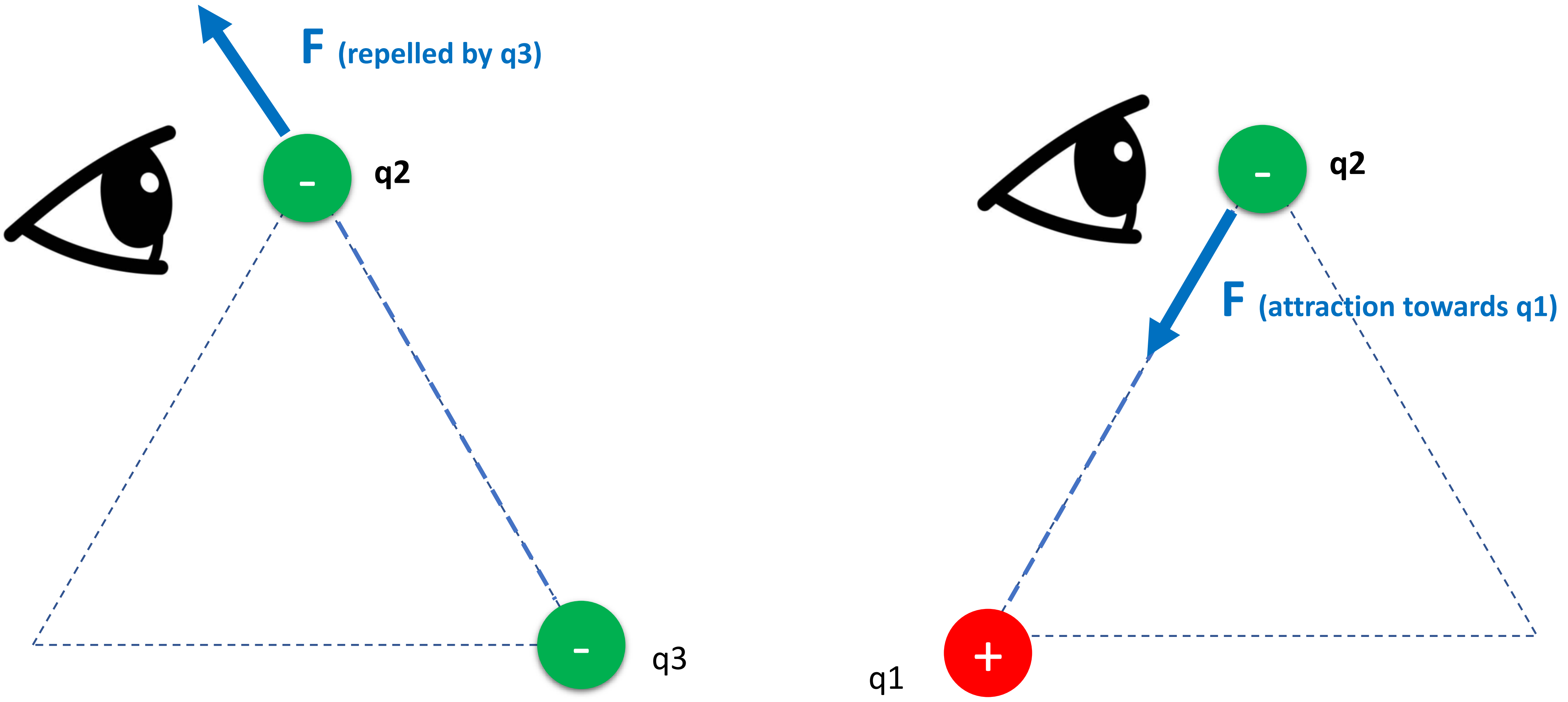


Note: The charges q1, q2 & q3 are **equal** in magnitude.



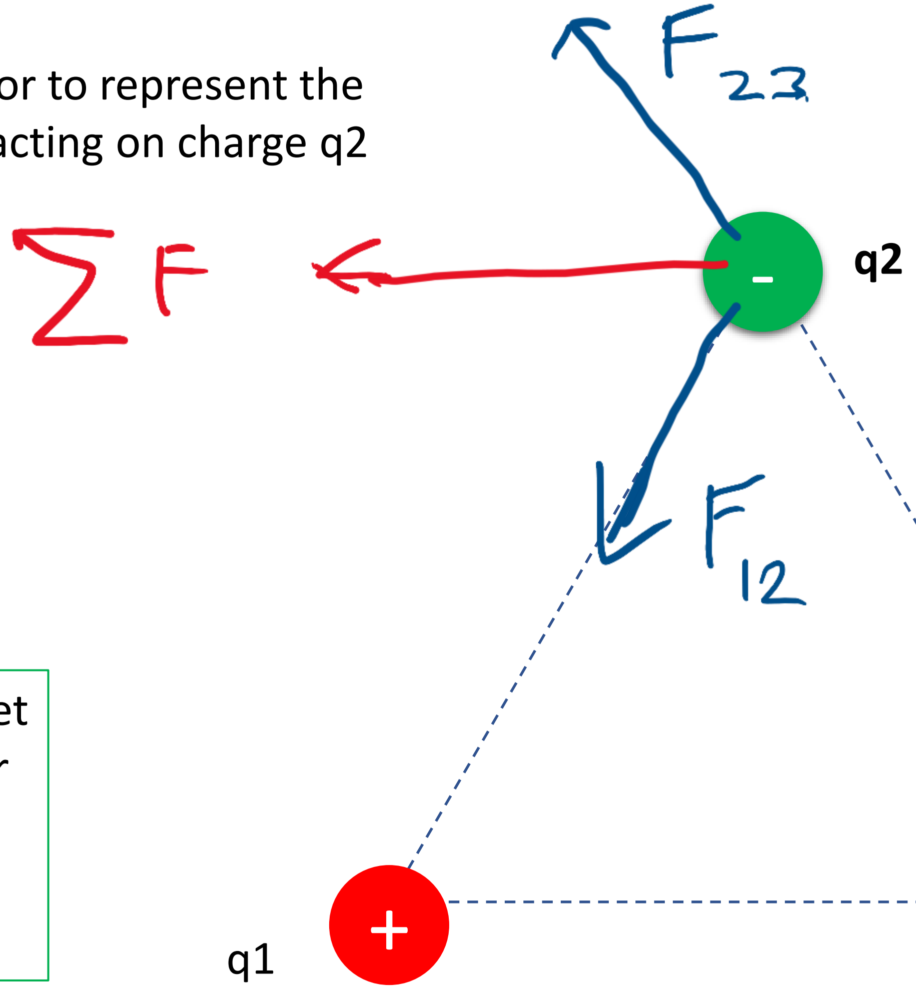
SOLUTION:

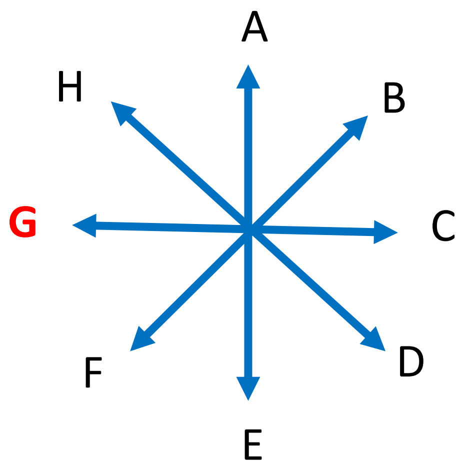
Consider the affect on q2 by each charge one at a time, then combine.



Solution:

Draw vector to represent the net force acting on charge q2



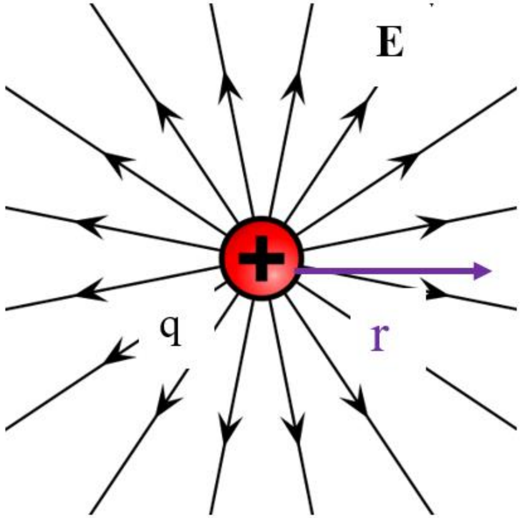


And we would get the same answer for the direction of the Electric Field

Calculating Electric Fields and the Force on an electric charge

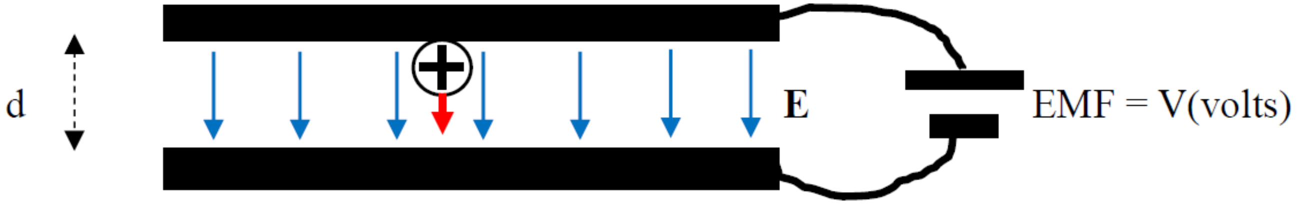
There are 2 different cases you need to know:

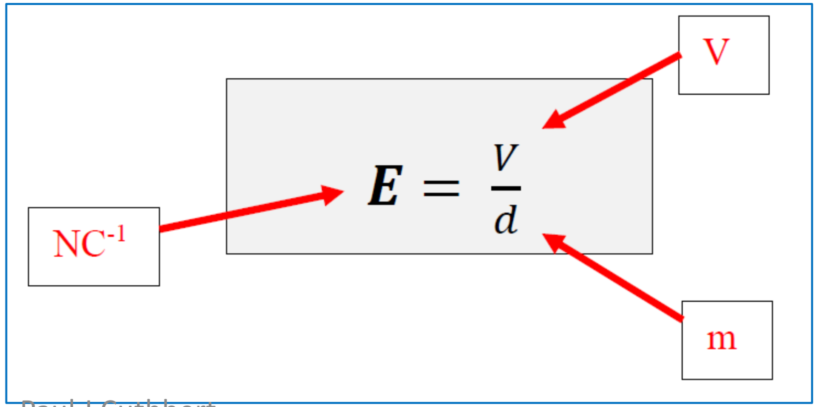
1. Point Charge



$$E = \frac{kq}{r^2}$$

2. Parallel Plates

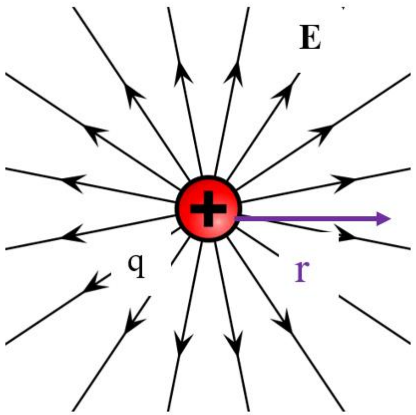


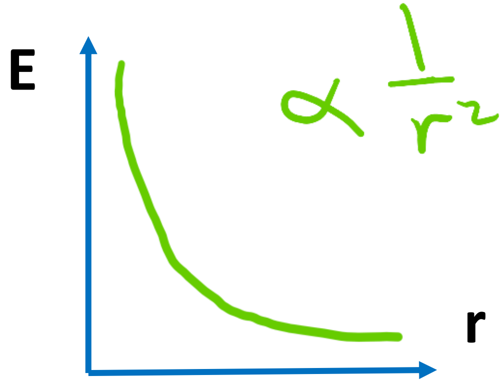


Calculating Electric Fields and the Force on an electric charge

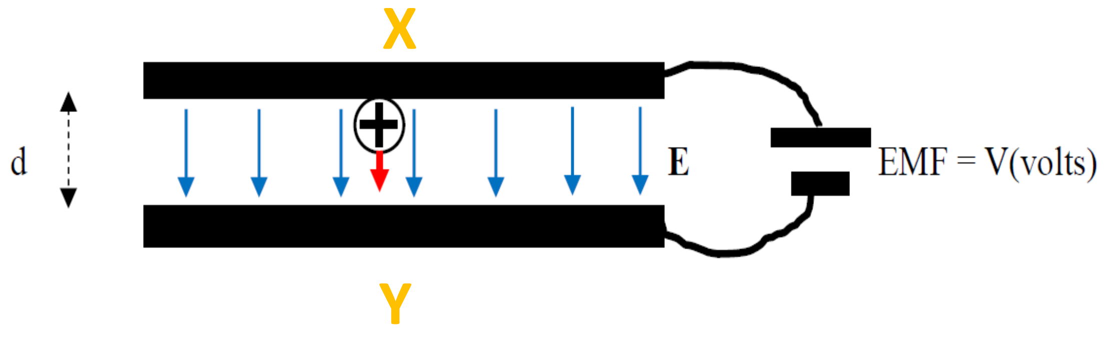
There are 2 different cases you need to know:

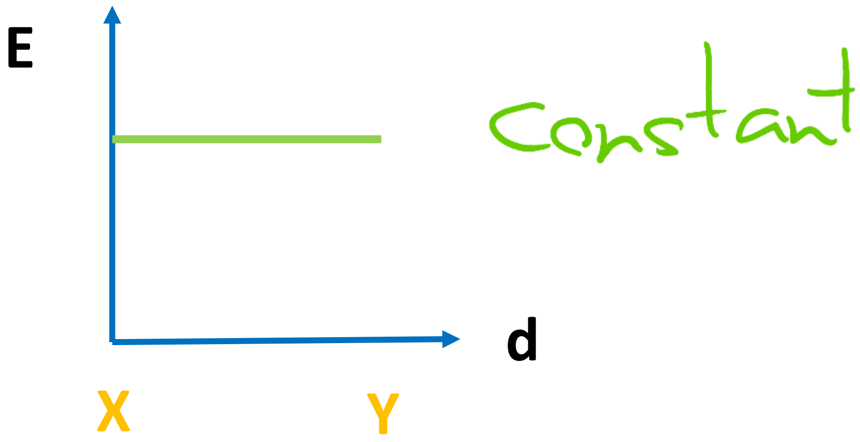
1. Point Charge





2. Parallel Plates





Calculating the Force from the Electric Field

Note: for both Point Charges & Parallel Plates,
The magnitude of the **FORCE (N)** on a charge, **q** (Coul.) in an Electric Field, **E** (N/C) is calculated from:

$$F = q \times E$$

Note also, this formula is very similar to the formula for calculating the gravitational force on a mass ('weight') in a field of strength g (N/kg)

$F_E = q \times E$

Source of the field

Strength of the Field

$F_g = m \times g$

1. Point Charge:

$$E = \frac{kq}{r^2}$$

Problems

1/ (a) Calculate the magnitude of the strength of the electric field 5cm from a charge of 6nC.

NC^{-1}

(b) What will be the strength of the field at a distance of 10cm from this charge?

NC^{-1}

(c) What will be the electric force on an electron placed at 5 cm from the charge?

N

Solutions:

1/ (a) Calculate the magnitude of the strength of the electric field 5cm from a charge of 6nC.

$$E = \frac{kq}{r^2} = \frac{9 \times 10^9 \times 6 \times 10^{-9}}{0.05^2} = \frac{54}{0.0025} = 21600$$

2.16×10^4 NC^{-1}

(b) What will be the strength of the field at a distance of 10cm from this charge?

This is double the previous distance and since $E \propto \frac{1}{r^2}$ the field will be ¼ of 2.16×10^4

5400 NC^{-1}

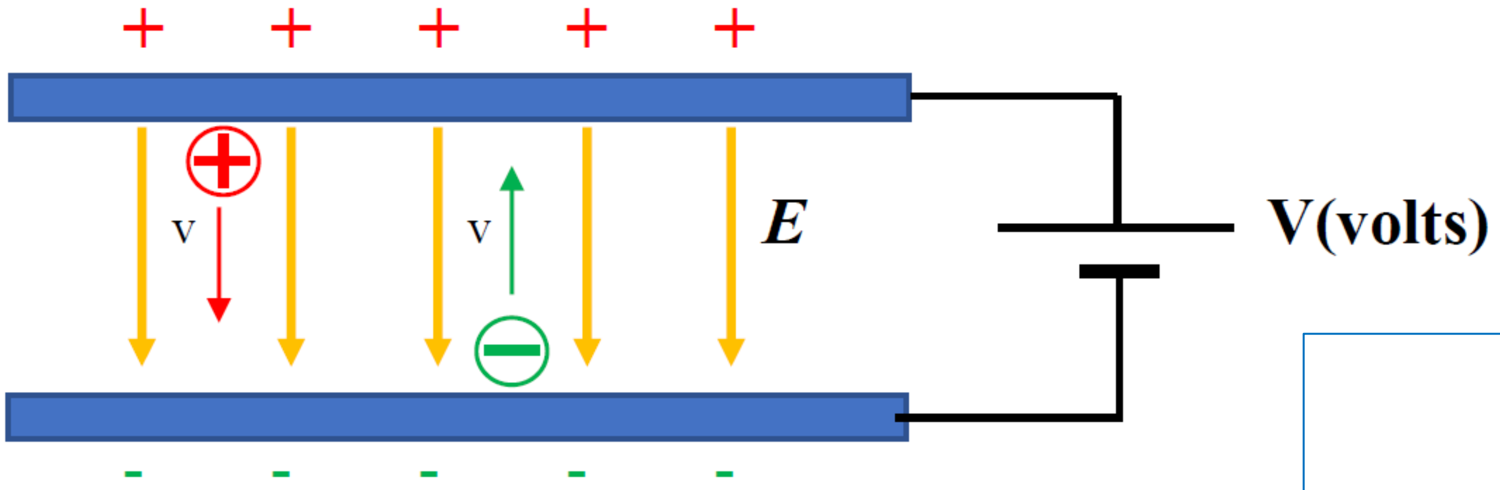
(c) What will be the electric force on an electron placed at 5 cm from the charge?

$F = qE = 1.6 \times 10^{-19} \times 2.16 \times 10^4 = 3.5 \times 10^{-15}$ N

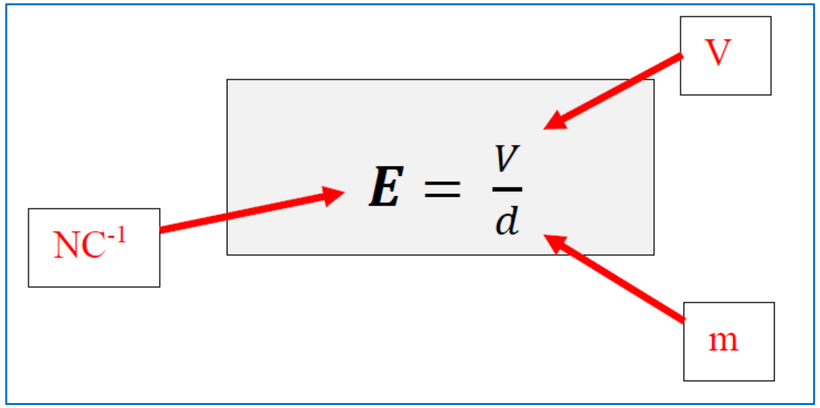
3.5×10^{-15} N

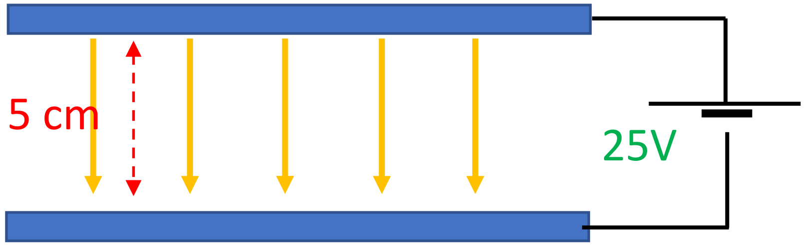
2. Parallel Plates:

<u>Note</u>: Positive charges move in the direction of the electric field and negative charges move against its direction (that is to say, these charges move in the direction that the electric forces act on them according to their sign).



Units: N/C = V/m





$$E = \frac{V}{d}$$

Problems

In the above example consider the EMF = 25V and the separation of the plates = 0.05m.

(a) What is the strength of the electric field at all points between the plates?

Vm^{-1}

(b) What would be the force on an electron placed in the electric field between the plates?

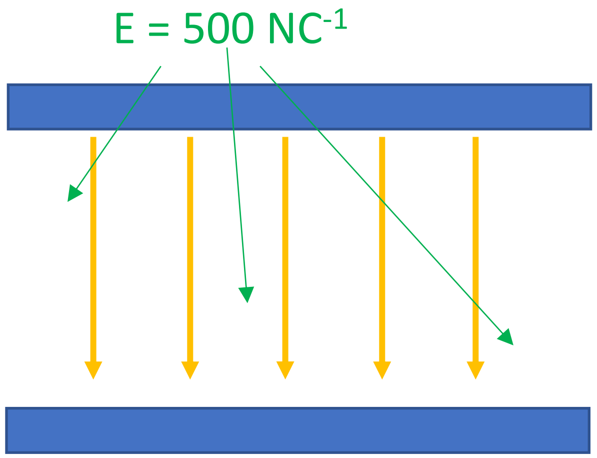
N

(c) At what rate will this electron accelerate towards the upper, positive plate?

ms^{-2}

Solutions:

Note: the field between parallel plates is constant.
So the value of E = 500 is the same at every point.



In the above example consider the EMF = 25V and the separation of the plates = 0.05m.

(a) What is the strength of the electric field at all points between the plates?

$$E = \frac{V}{d} = \frac{25}{0.05} = 500\ Vm^{-1}$$

500 Vm^{-1}

(b) What would be the force on an electron placed in the electric field between the plates?

$$F = qE = 1.6 \times 10^{-19} \times 500 = 8 \times 10^{-17}$$

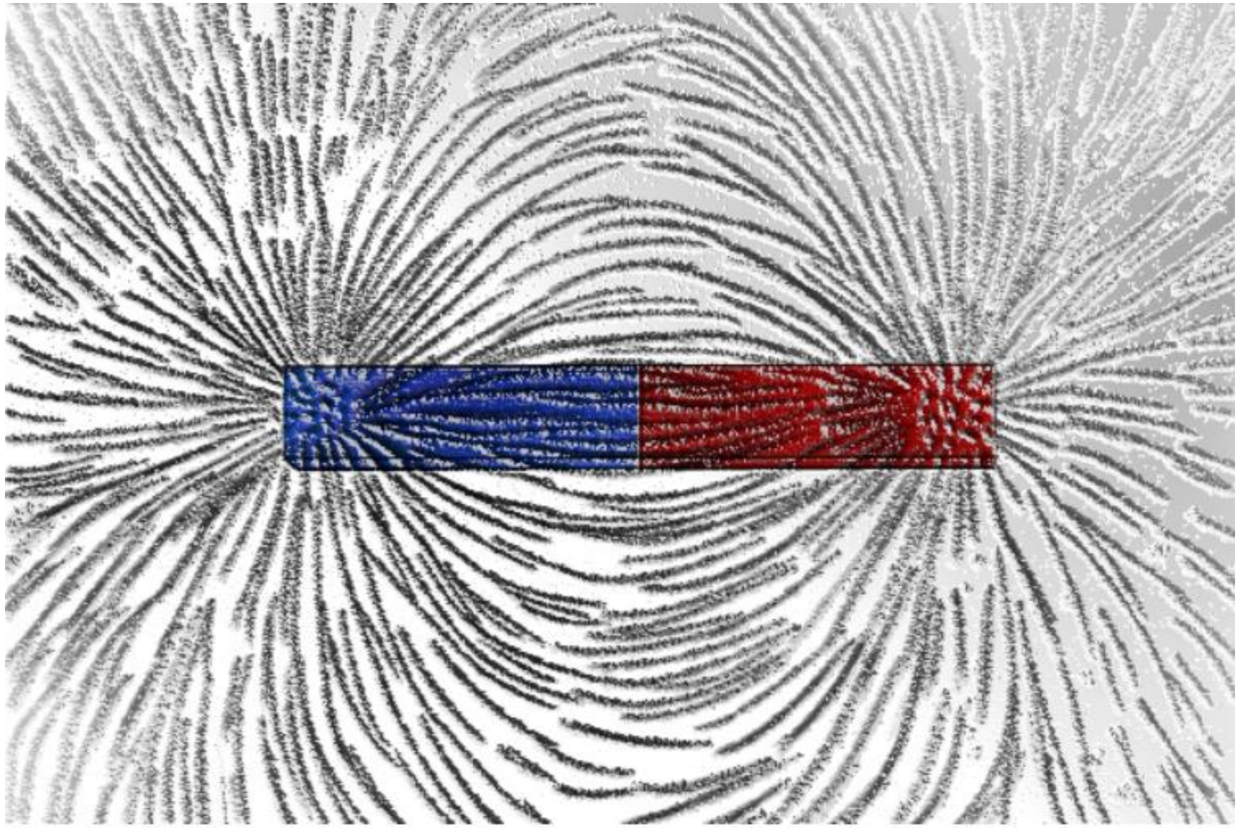
8×10^{-17} N

(c) At what rate will this electron accelerate towards the upper, positive plate?

$$F = ma, \quad \Rightarrow a = \frac{F}{m} = \frac{8 \times 10^{-17}}{9.1 \times 10^{-31}} = 8.79 \times 10^{13}$$

8.79×10^{13} ms^{-2}

3. Magnetic Fields



Know how to draw fields – it's a common exam question:

VCAA 2006

Area of study 1 – Electric power

Figure 1 below shows a solenoid powered by a battery.

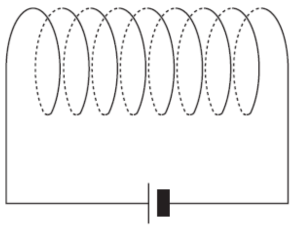


Figure 1

Question 1

Complete the diagram above by sketching **five** magnetic field lines created by the solenoid.

Make sure that you clearly show the direction of the field, including both inside and outside the solenoid.

3 marks

VCAA 2008

Area of study 1 – Electric power

Figure 1 shows a coil of wire connected to a battery. The plane of the coil is perpendicular to the page.

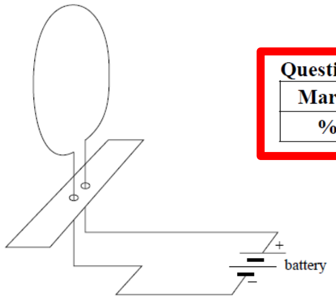


Figure 1

Question 1

Draw five magnetic field lines to show the magnetic field through the coil. You should include arrows to show direction.

2 marks

Question 1

Marks	0	1	2	Average
%	25	28	46	1.3

VCAA 2007

Question 1

Figure 1 shows a bar magnet.

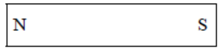


Figure 1

Complete the diagram by sketching five magnetic field lines around the magnet. You must include arrows which show the direction of the magnetic field of the magnet.

2 marks

Question 2

A second bar magnet is placed next to the original as shown in Figure 2.

VCAA 2007

Figure 2

Complete the diagram by sketching magnetic field lines to indicate the shape of the magnetic field around the magnets.

2 marks

VCAA 2009

VCAA 2010

Question 4

A coil of wire is placed around an iron bar. The coil is connected to a DC battery.

This is shown in Figure 2.

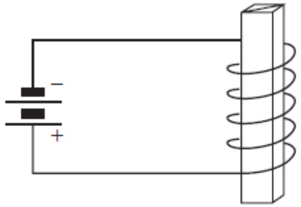


Figure 2

On the diagram in Figure 2, draw **four** lines, each with an arrow indicating direction, that show the magnetic field in the region around the iron bar.

2 marks

Question 4

Marks	0	1	2	Average
%	25	33	42	1.2

Area of study 1 – Electric power

The following information relates to Questions 1–5.

Figure 1 shows a solenoid and a battery.

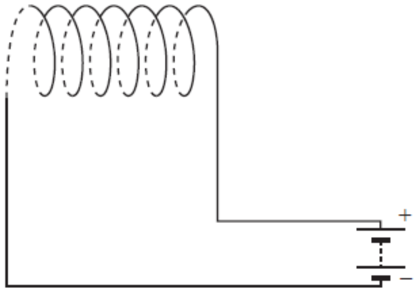


Figure 1

Question 1

Draw **three** magnetic field lines, with arrows to show direction, to indicate the magnetic field produced both inside and outside the solenoid.

2 marks

Question 1

Marks	0	1	2	Average
%	20	36	44	1.3

VCAA 2016

Area of study – Electric power

Question 12 (3 marks)
Two bar magnets are arranged in three different ways, as shown in Figures 17a, 17b and 17c.

Figure 17a

Figure 17b

Figure 17c

In the space between the magnets in each figure, draw **at least four** magnetic field lines for each arrangement. Attach arrowheads to each field line, showing the direction of the field along each line.

VCAA Solutions 2016

At least four field lines for each situation were required.

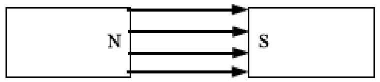


Figure 17a

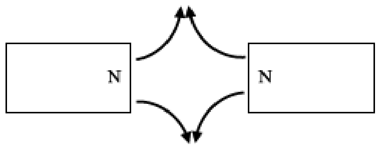


Figure 17b

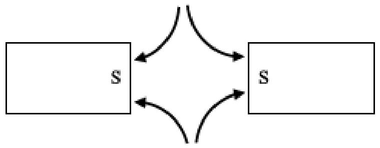


Figure 17c

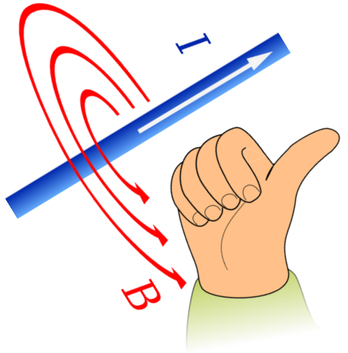
Question 12

Marks	0	1	2	3	Average
%	10	14	28	48	2.2

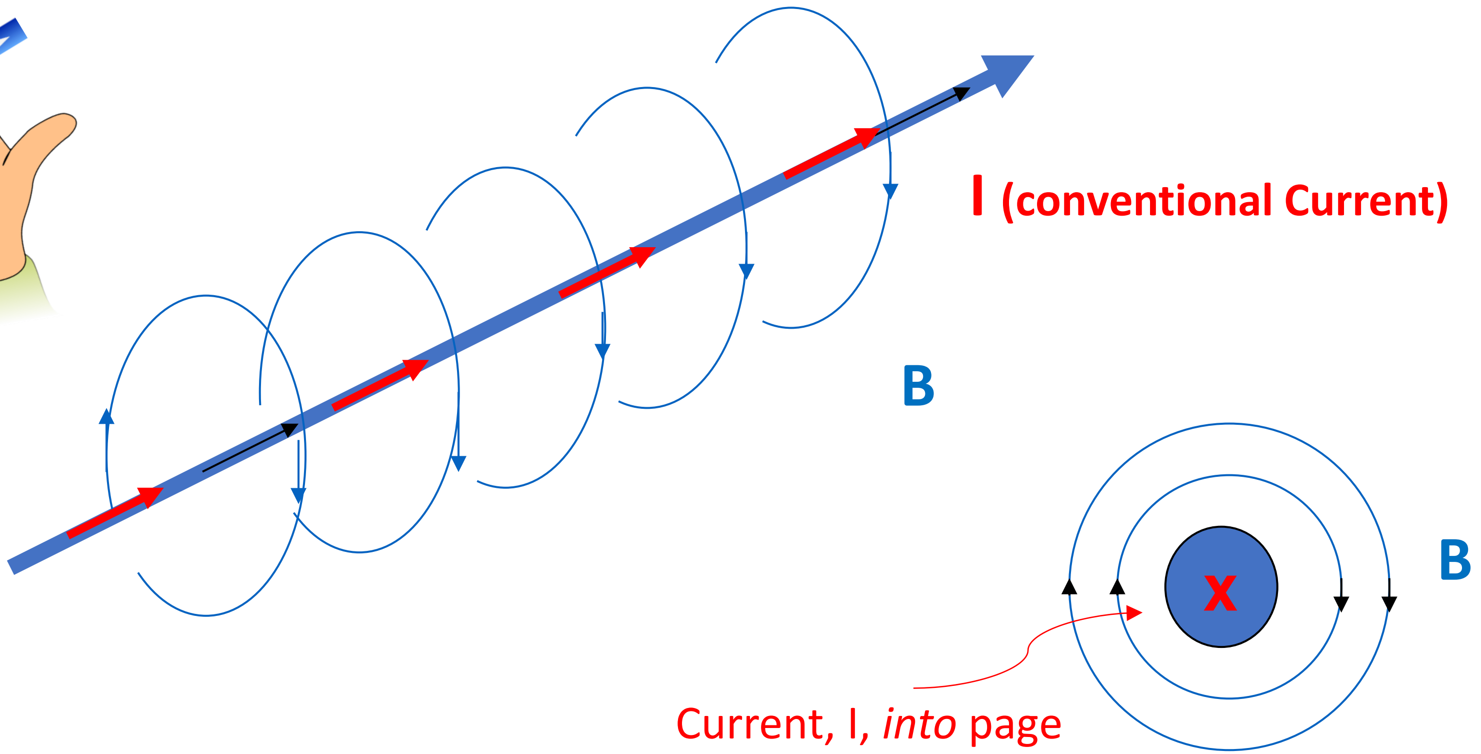
At least four field lines for each situation were required.

Magnetic Field of a Current, I(A)

[Walter Fendt-Field of a Straight Wire]



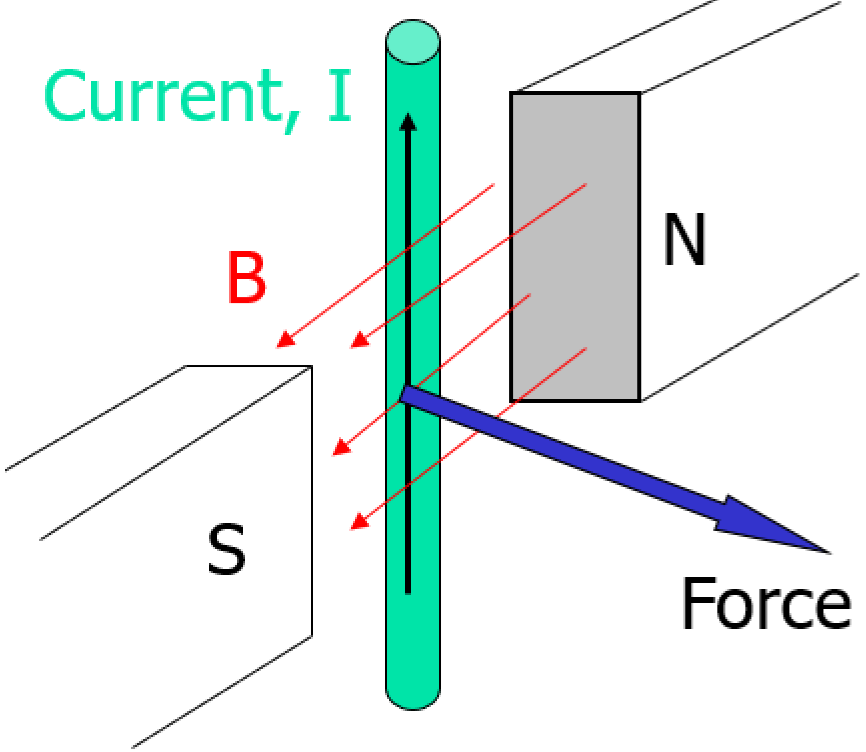
Right Hand
Curl/Screw/Grip Rule

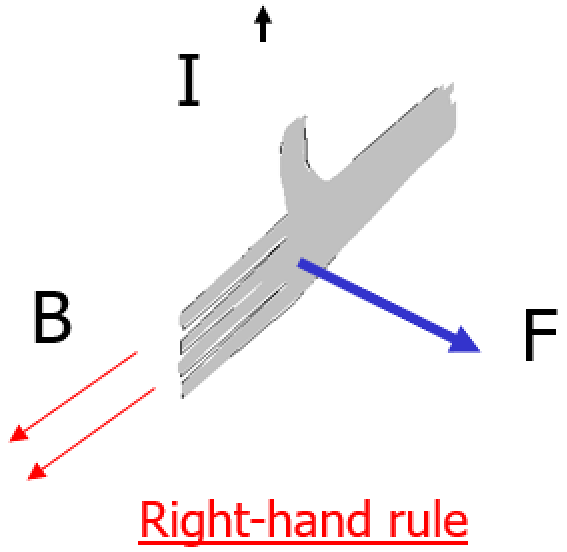


Magnetic Force on a Current

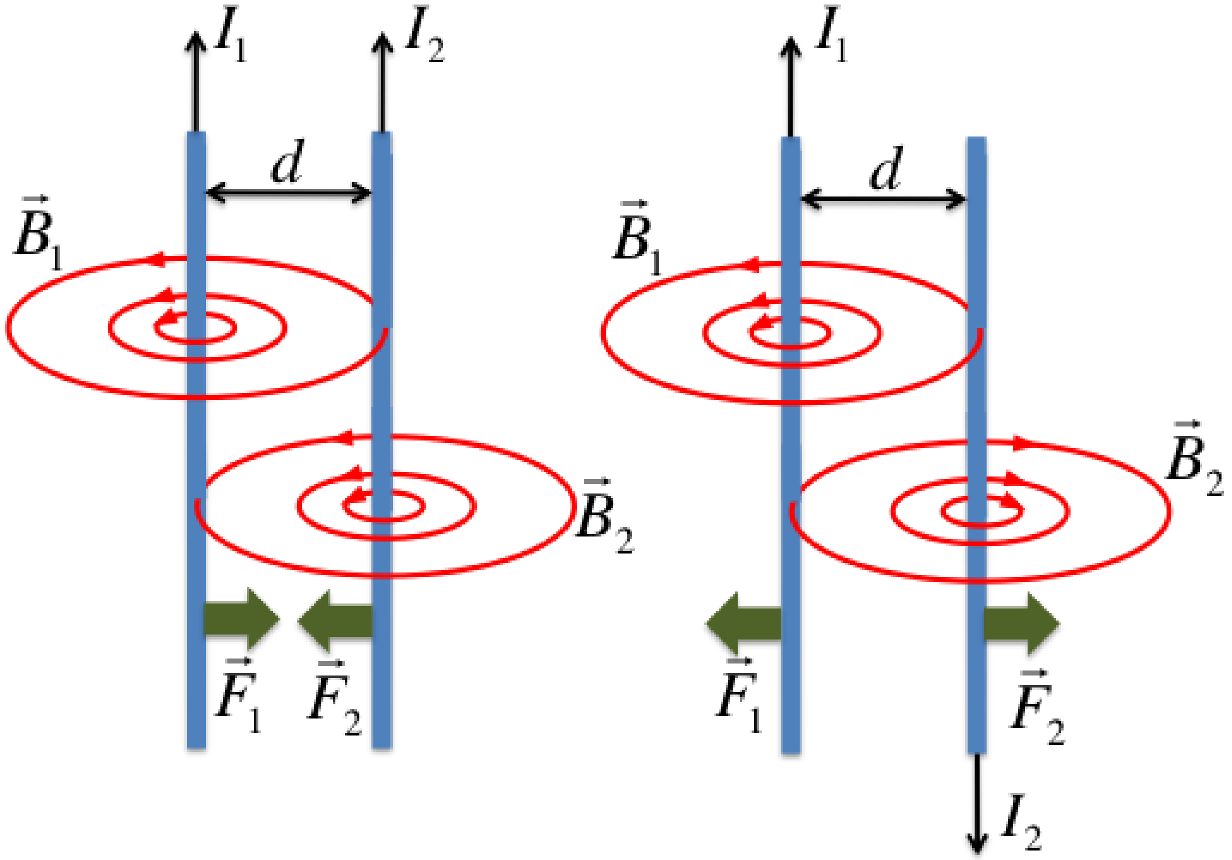
Walter Fendt-Force on a Current

$$F = nBIL$$





Parallel currents



2023 NHT Paper

Antiparallel Currents

Question 3 (3 marks)

Two thin, light aluminium tubes, A and B, are supported in a vertical wooden rack, as shown in Figure 3. Both of the aluminium tubes rest horizontally on wooden pegs.

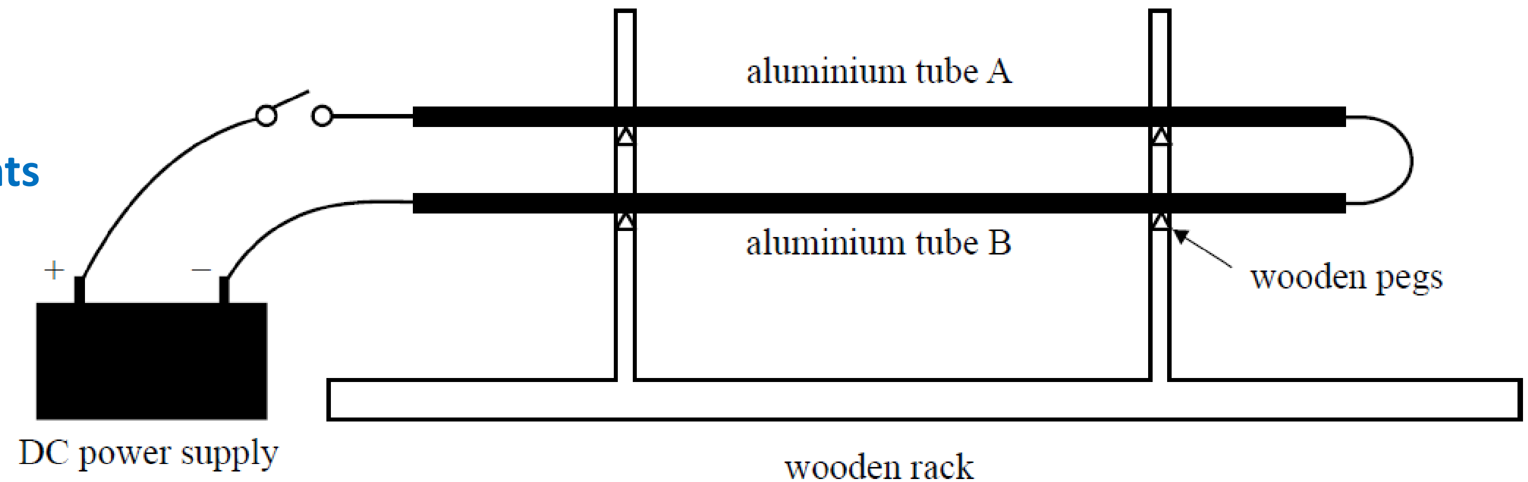


Figure 3

The two thin, light aluminium tubes form a series circuit with a DC power supply. It was observed that one of the tubes jumped upwards when the DC power supply was switched on.

Identify which tube jumped upwards and explain why this occurred.

Aluminium tube ☐

2023 NHT Paper

Solution

Question 3 (3 marks)

Two thin, light aluminium tubes, A and B, are supported in a vertical wooden rack, as shown in Figure 3. Both of the aluminium tubes rest horizontally on wooden pegs.

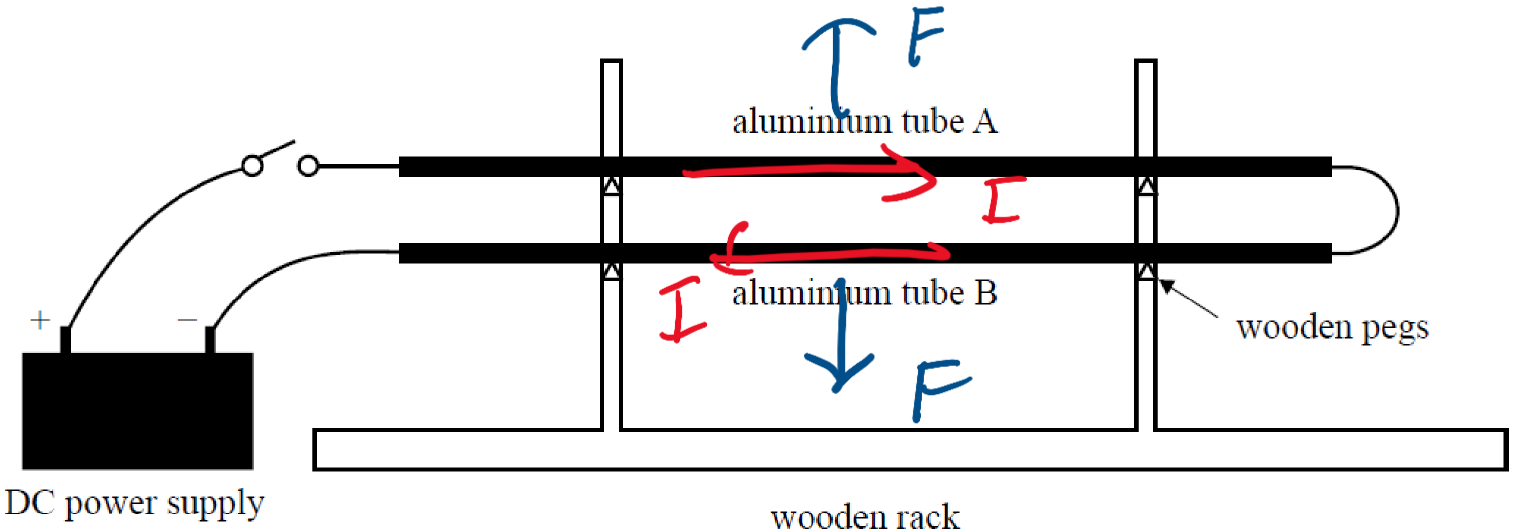


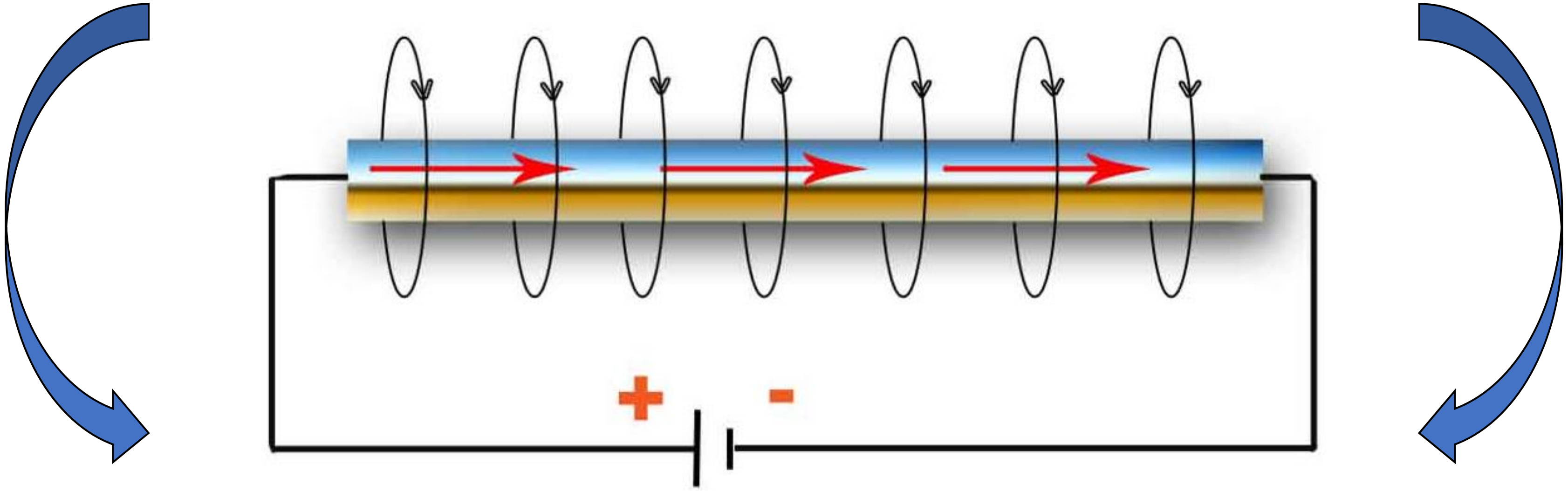
Figure 3

The two thin, light aluminium tubes form a series circuit with a DC power supply. It was observed that one of the tubes jumped upwards when the DC power supply was switched on.

Identify which tube jumped upwards and explain why this occurred.

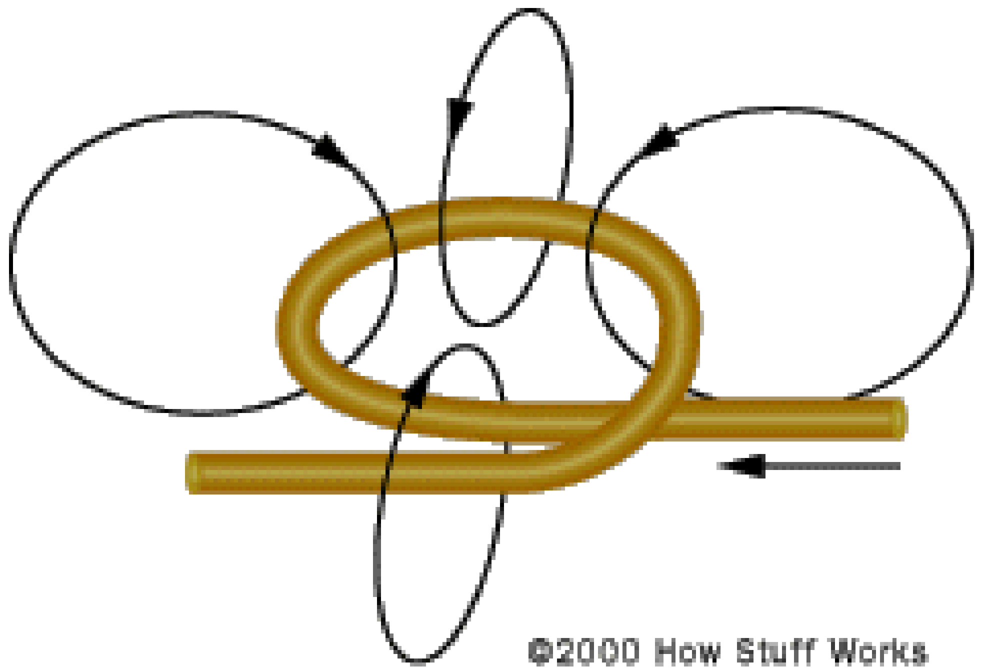
Aluminium tube | A |

Forming a solenoid

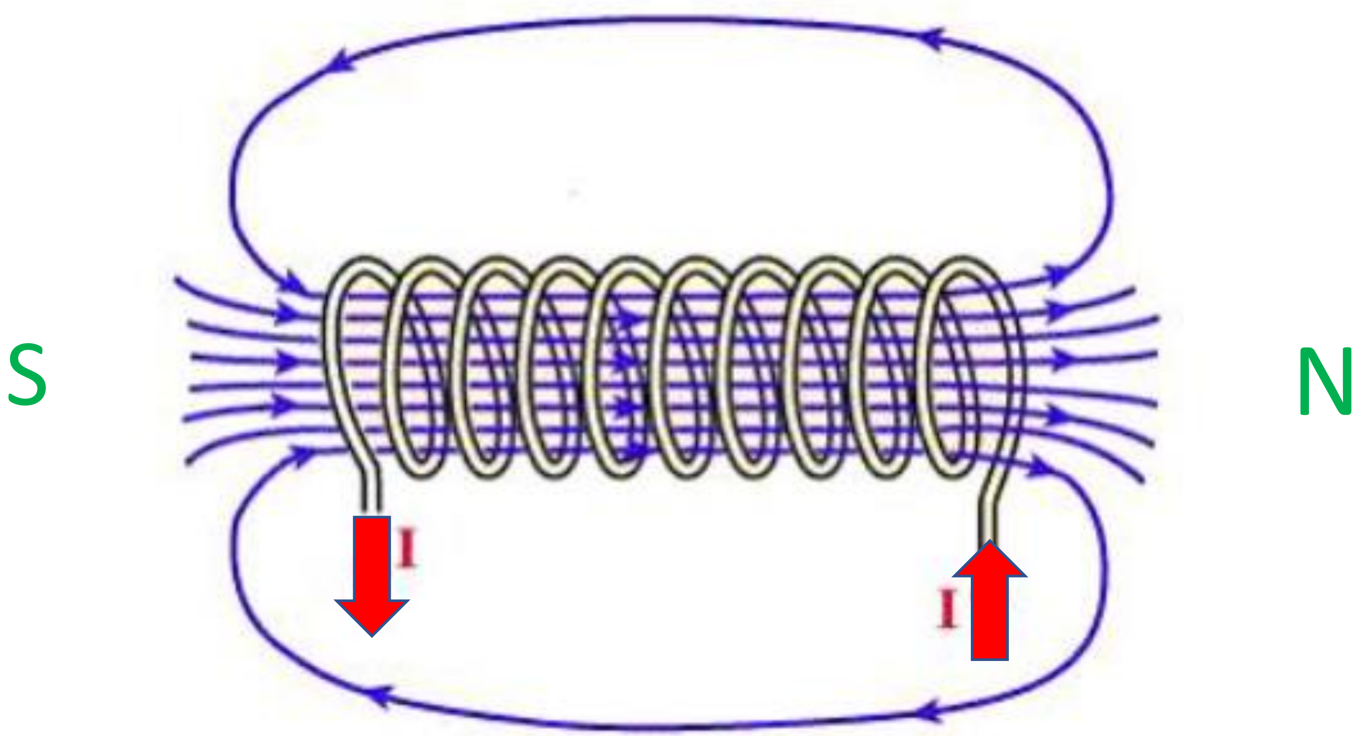


Bend this wire into a loop

Solenoids



Solenoids



Increasing the field strength inside a solenoid:

- Increase the number of loops.
- Increase the current.
- Insert an iron core.

Nov 2005

Area of study 1 – Electric power

A vertical wire carrying a current I is placed opposite the centre of a permanent bar magnet as shown in Figure 1.

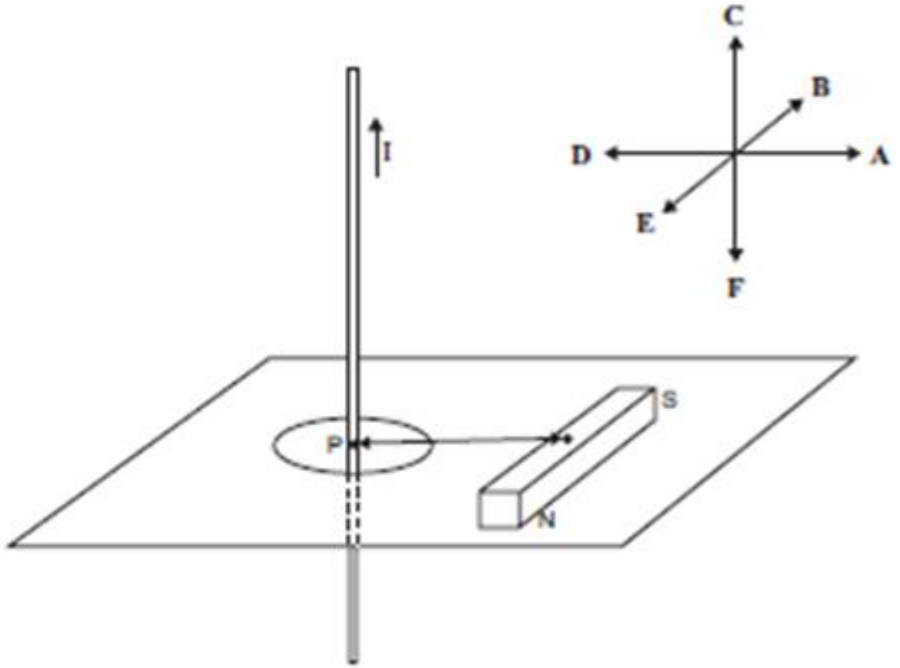


Figure 1

Question 1

Which of the arrows (**A–F**) best shows the direction of the magnetic force on the wire at the point P?

2 marks

Nov 2005

SOLUTION

Area of study 1 – Electric power

A vertical wire carrying a current I is placed opposite the centre of a permanent bar magnet as shown in Figure 1.

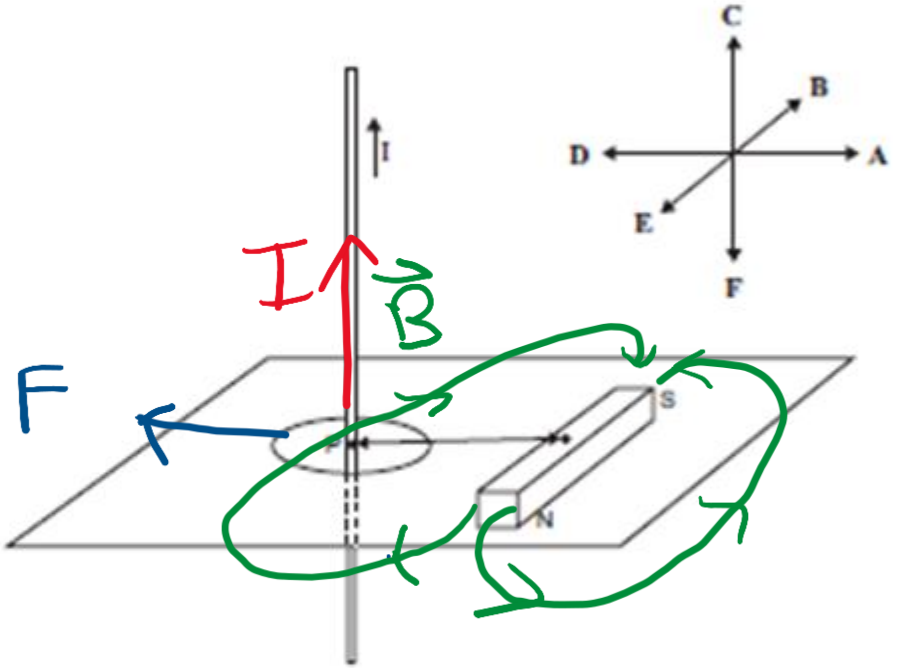


Figure 1

Question 1

Which of the arrows (A–F) best shows the direction of the magnetic force on the wire at the point P?

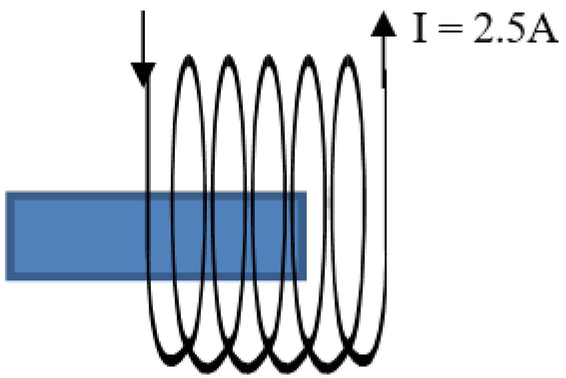
D

2 marks

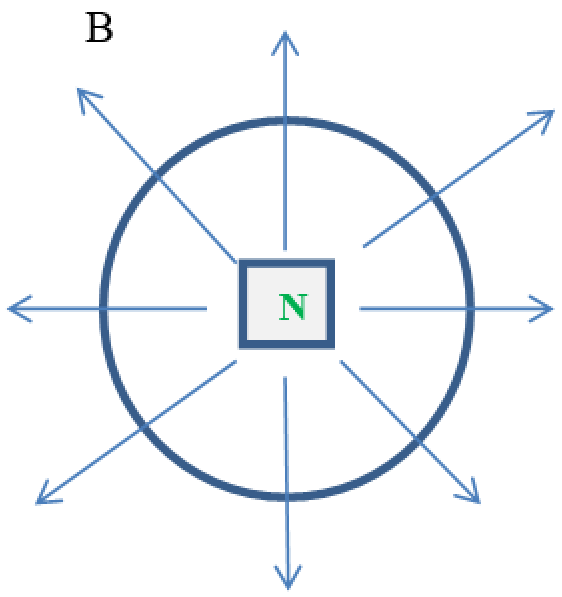
Problem

60 loops of wire of radius 5.0cm
in a speaker coil.
A current of 2.5A flows in the
Coils.

A magnet is inserted into the solenoid and magnetic field uniformly threads the whole area of the coils in a radial pattern from the centre outwards.



B = 0.030T



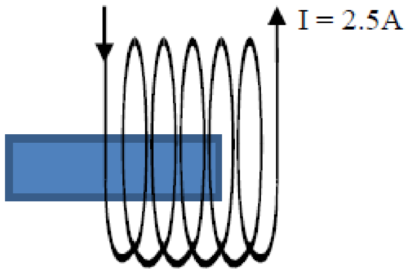
Calculate the magnitude of the magnetic **force** on the coils of wire:

Solution

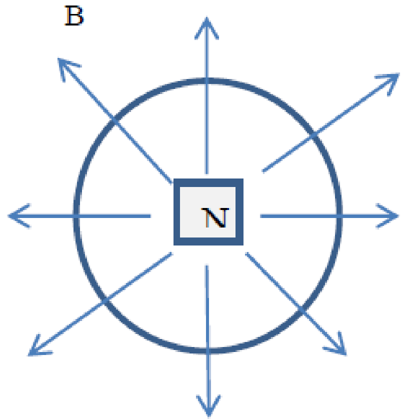
2. 60 loops of wire of radius 5.0cm in a speaker coil.
A current of 2.5A flows in the Coils.

$I = 2.5A$
$n = 60$
$r = 0.05m$

A magnet is inserted into the solenoid and magnetic field uniformly threads the whole area of the coils in a radial pattern from the centre outwards.



B = 0.030T



Calculate the magnitude of the magnetic **force** on the coils of wire:

$F = nBIL$ $\quad L = 2\pi r$

$= 60 \times 0.03 \times 2.5 \times 2\pi \times 0.05$

$= 1.41\ N$

It's essential you get the 'n' correct.

Notes:
- Typically the dimensions used in these types of problems are centimetres.

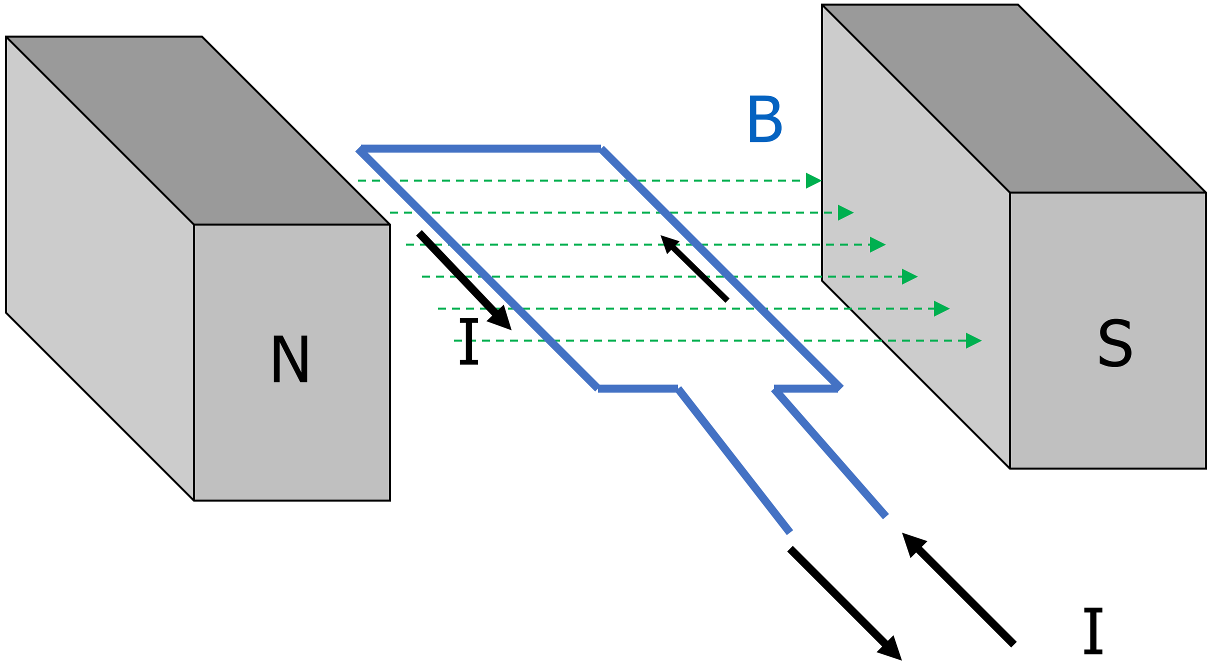
1 cm = 0.01 m = 10^{-2} m

Remember, it's critical you get unit conversions correct.

- The formulas for the circles:
$C = 2\pi R$ & $A = \pi R^2$ may be useful on your A3 sheet.

DC Motor

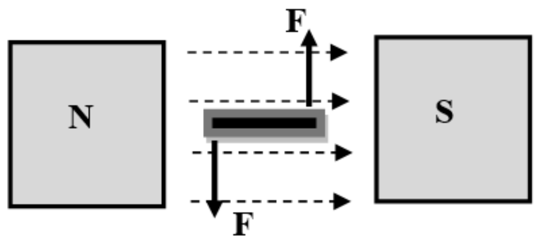
Direction of
Rotation?



Paul J Cuthbert

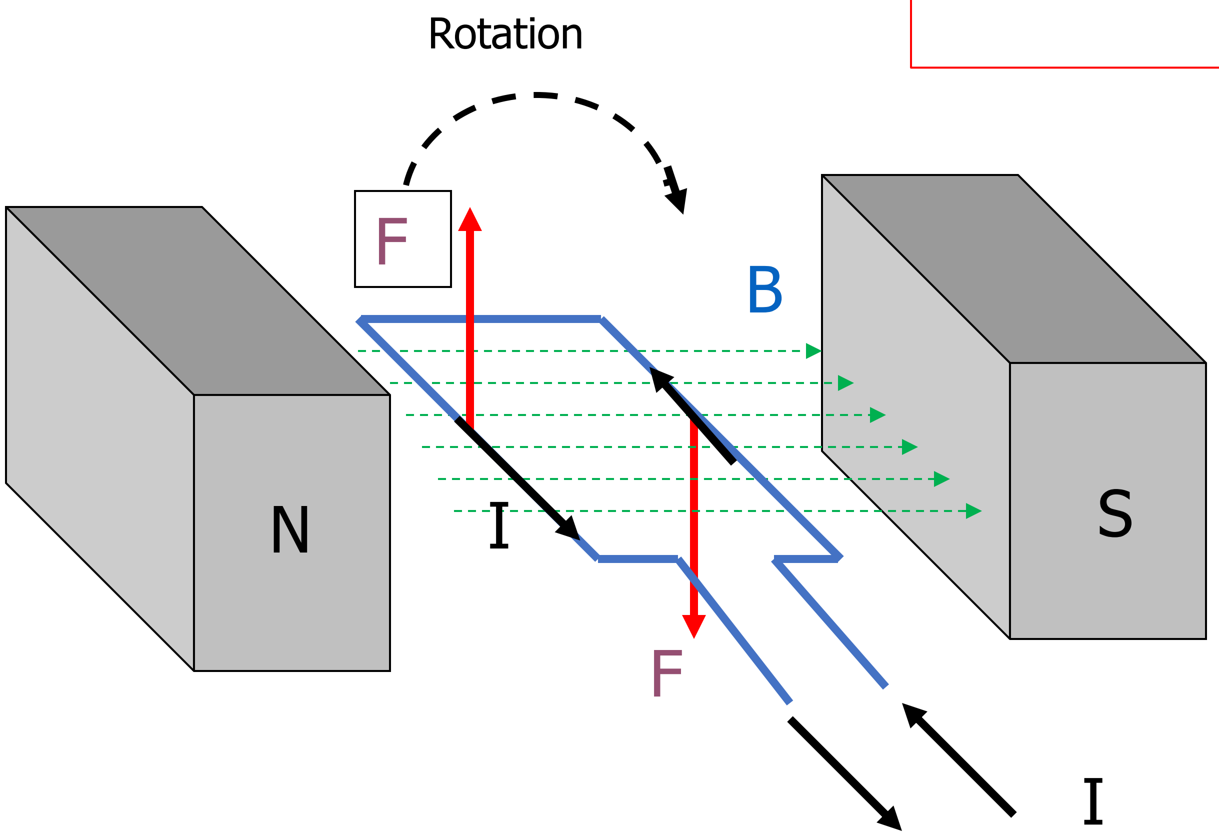
DC Motor

NOTE:



This is the position of *maximum* torque: the force and current (into and out of the page) are perpendicular.

This is the ideal position to start the motor in.



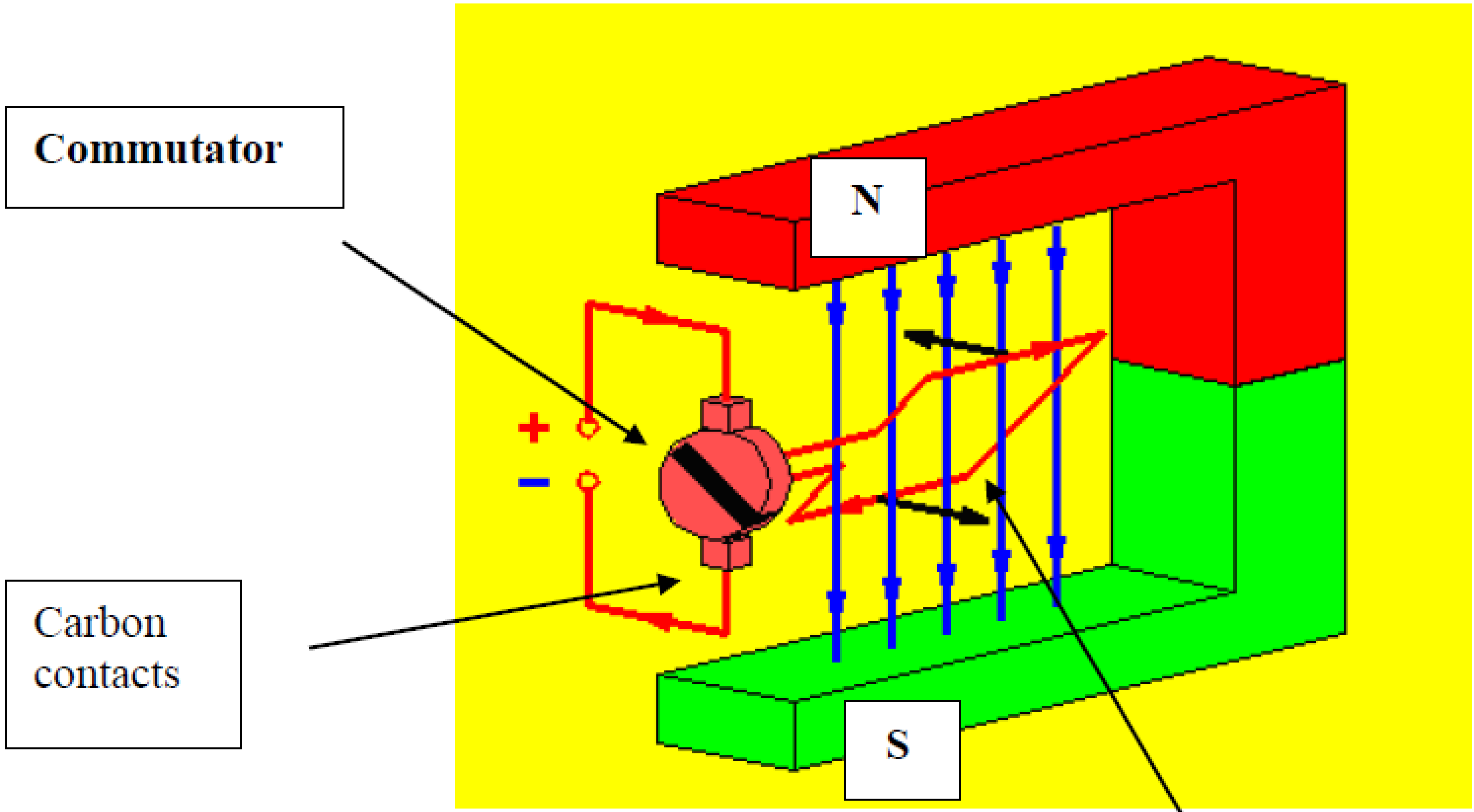
TORQUE τ = F x r

Note: the <u>qualitative</u> (no calculations) understanding of torque was added to the new Study Design.

Paul J Cuthbert

Walter Fendt: DC Electric Motor

DC Electric Motor (from *Walter Fendt applets*)



Armature. The part that rotates.
This will normally have many thousands of turns to increase the size of the force.

Know how a COMMUTATOR works:

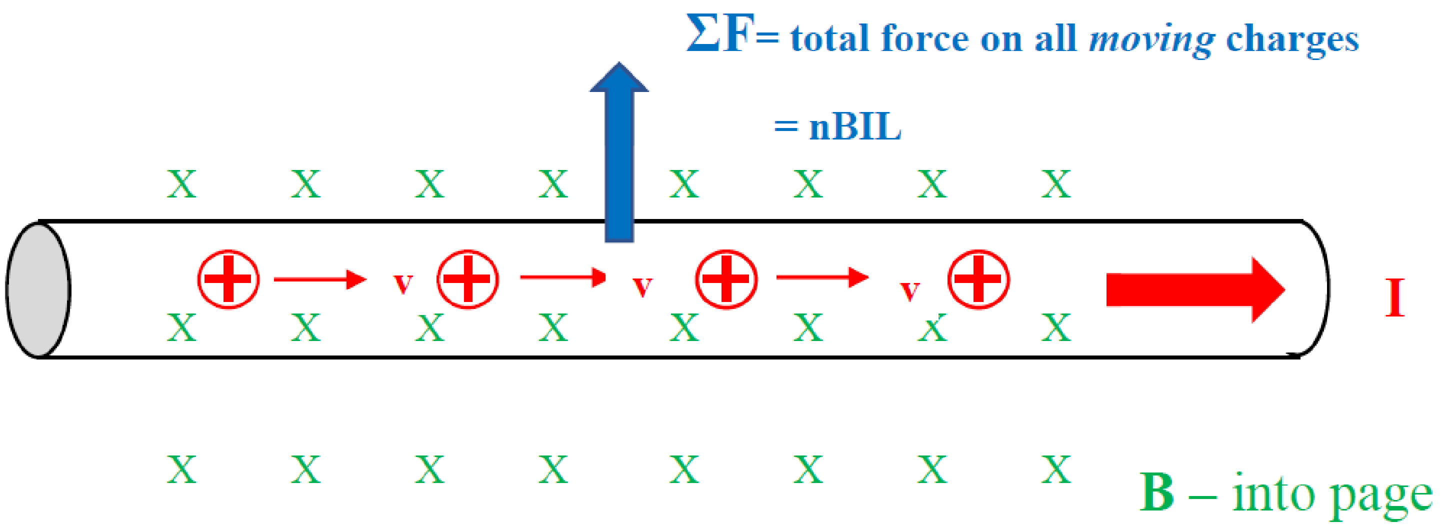
-it reverses the direction of the current and therefore the force on the wires every 180^0 to maintain a continuous direction of rotation.

Magnetic Force on a charge, q at speed v

Charges moving in Magnetic Fields

We already know a (conventional) current, I, experiences a magnetic force, F_B, when a magnetic field, B, is perpendicular to it.

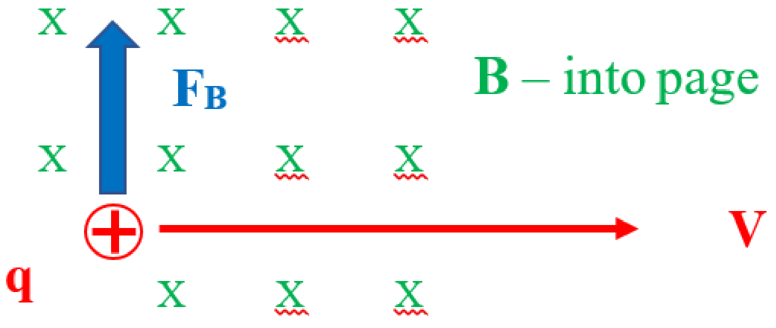
The direction of this force is given by the Right-Hand-Slap-Rule.

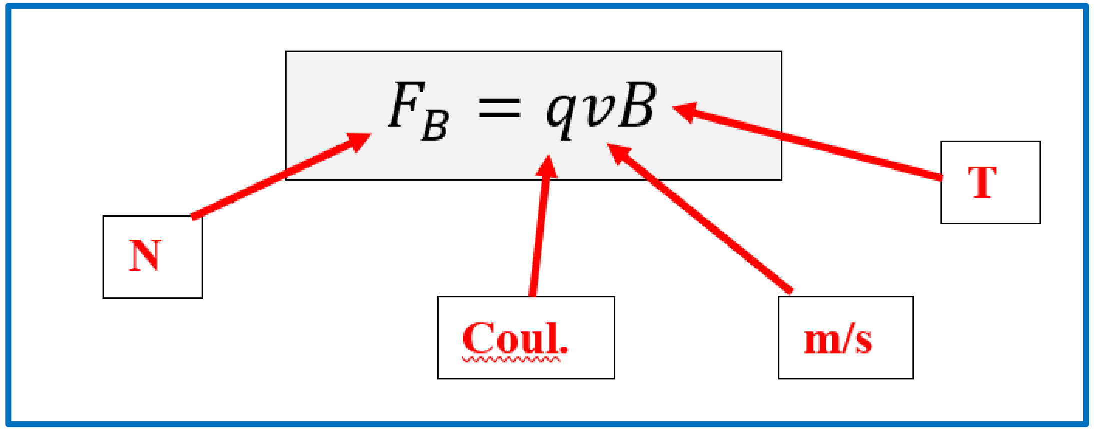


The magnetic force is not on the wire itself, but on all the moving charges that make up the wire. They are pushed and take the wire with them (if it is free to move).

Consider 1 of those charges:

Magnetic force on a single, positive charge, q.





The **right-hand-slap-rule** remains basically the same as it is for F = BIL:

Thumb – direction of **V** (which is also the direction of the single-charge current, I)

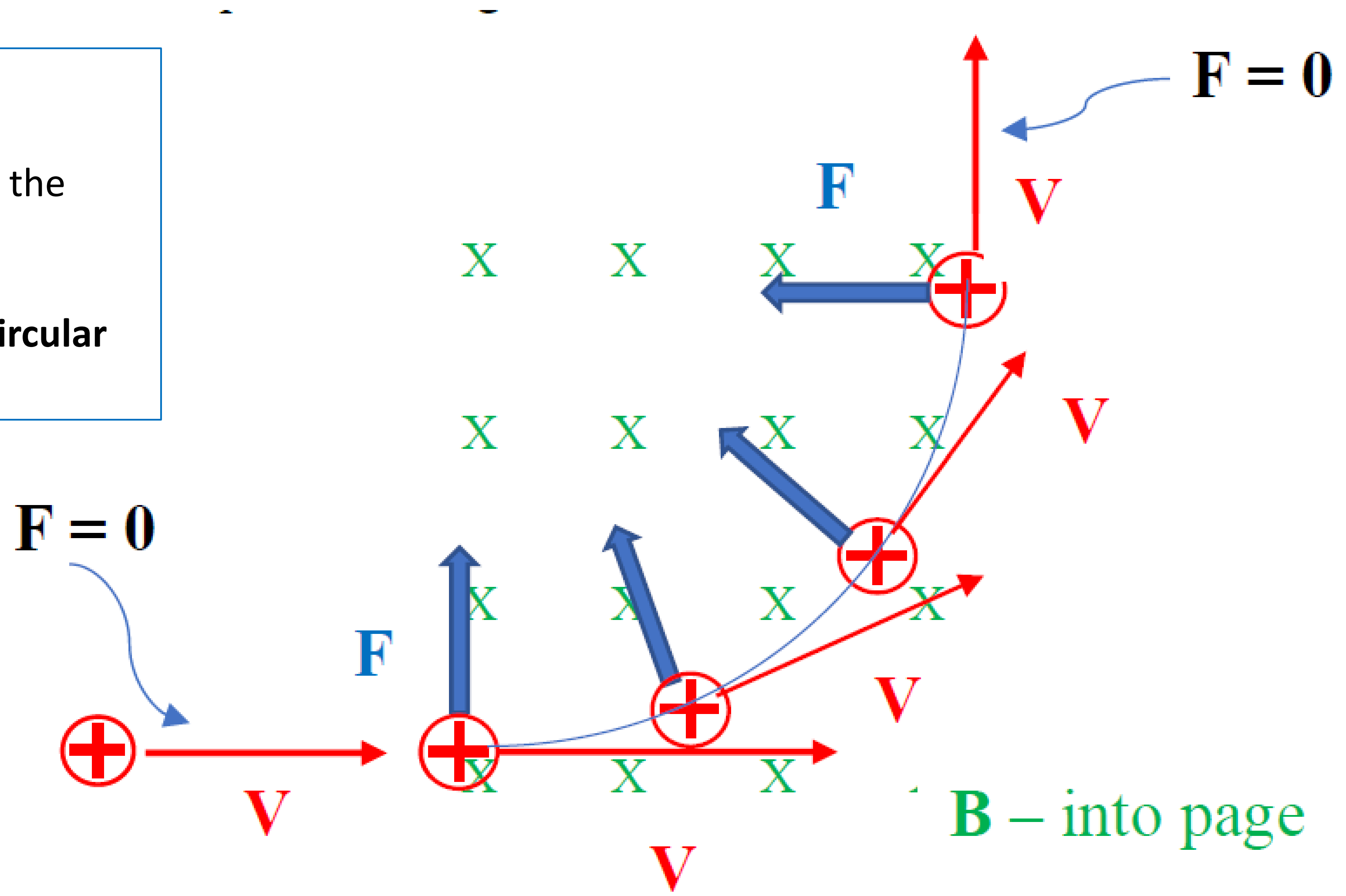
Fingers – direction of **B**

Palm - vector out of the palm gives the direction of the force **F** on a *positive* charge
(Force on a negative charge would be out the back of your right hand).

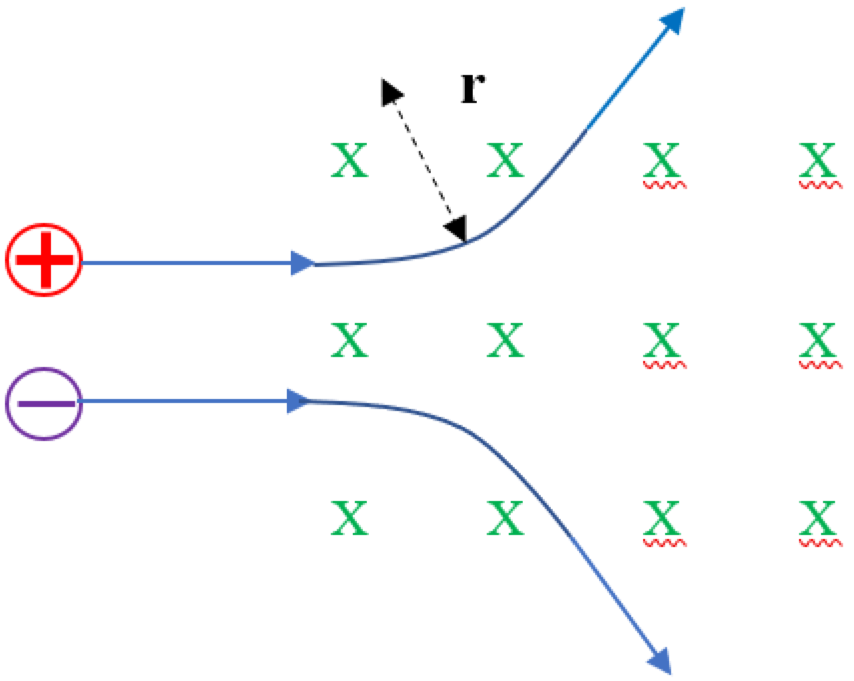
While in the B-Field: charges particles move in a circular arc.

The force is:
-constant
-always perpendicular to the velocity

This is the definition of **circular motion.**

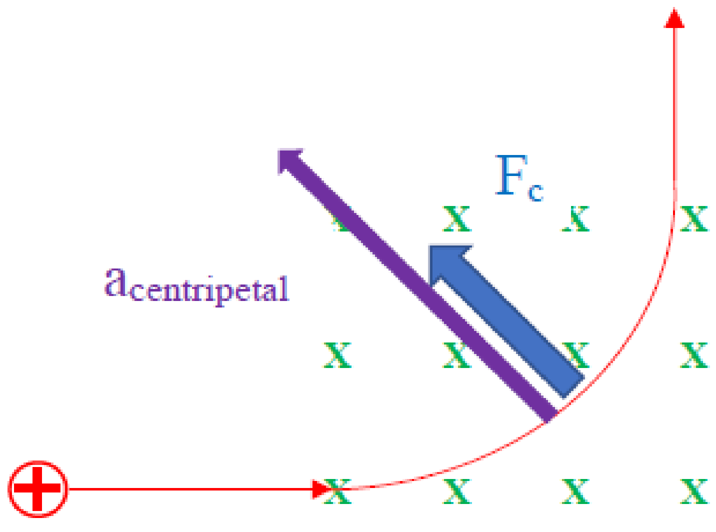


Negative charges will bend in the *opposite* direction:



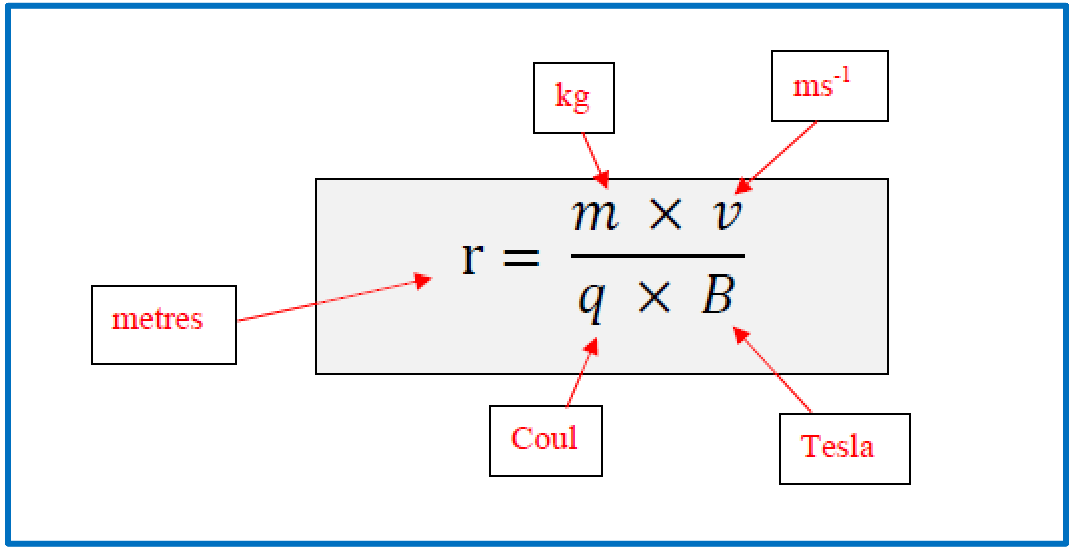
B-into the page

Note: as there is no magnetic force along the path of the moving charge, its speed (magnitude of velocity) and KE do not change. Its acceleration is purely centripetal – so only its direction changes.



$V_{final} = V_{initial}$
$KE_{final} = KE_{initial}$

$V_{initial}$
$KE_{initial}$



$$r = \frac{m \times v}{q \times B}$$

$$F_C = F_{centripetal} = \frac{mv^2}{r} = F_{Magnetic} = qvB$$

Problems:

A proton (charge = 1.6×10^{-19}C) of mass 1.67×10^{-27} kg is fired at a speed of 2.0×10^{7} ms^{-1} at right angles a magnetic field of magnitude 0.25T.

1/ What is the magnitude of the magnetic force on this charge?

N

2/ What is the magnitude of the proton's centripetal acceleration while it is in the magnetic field?

ms^{-2}

3/ Calculate the radius of curvature, r, of the proton's path while it is in the magnetic field.

m

Solutions:

A proton (charge = 1.6×10^{-19}C) of mass 1.67×10^{-27} kg is fired at a speed of 2.0×10^{7} ms^{-1} at right angles a magnetic field of magnitude 0.25T.

1/ What is the magnitude of the magnetic force on this charge?

$$F_B = qvB = 1.6 \times 10^{-19} \times 2.0 \times 10^{7} \times 0.25 = 8.0 \times 10^{-13}$$

8.0×10^{-13} N

2/ What is the magnitude of the proton's centripetal acceleration while it is in the magnetic field?

$$F = ma, \ therefore: F_{centripetal} = m \times a_{centripetal}$$

$$F_{magnetic} \ supplies \ F_{centripetal}$$

$$a_{centripetal} = \frac{F_B}{m} = \frac{8 \times 10^{-13}}{1.67 \times 10^{-27}} = 4.79 \times 10^{14}$$

4.8×10^{14} ms^{-2}

3/ Calculate the radius of curvature, r, of the proton's path while it is in the magnetic field.

$$a_{centr.} = \frac{v^2}{r}, \Rightarrow \ r = \frac{v^2}{a_{centr.}} = \frac{(2 \times 10^7)^2}{4.79 \times 10^{14}} = 0.835$$

OR, use:

$$r = \frac{mv}{qB} = \frac{1.67 \times 10^{-27} \times 2 \times 10^7}{1.6 \times 10^{-19} \times 0.25} = 0.835$$

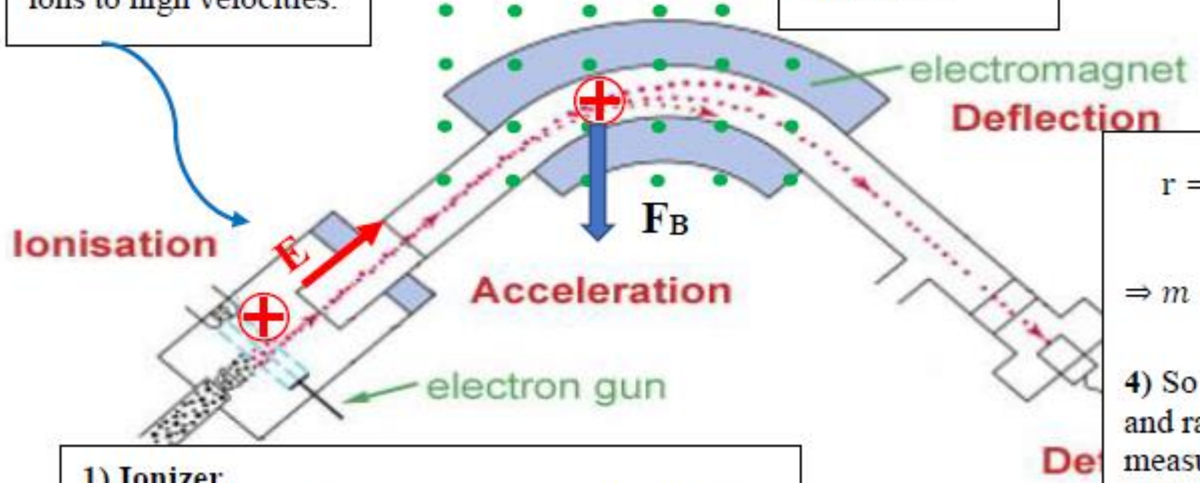
0.835 m

The Mass Spectrometer – an essential tool in chemistry

These can be used to measure masses far too small for scales: atoms & molecules.

2) High Voltage, V.
E-field: accelerates ions to high velocities.

3) B-*out of page*: bends ions.



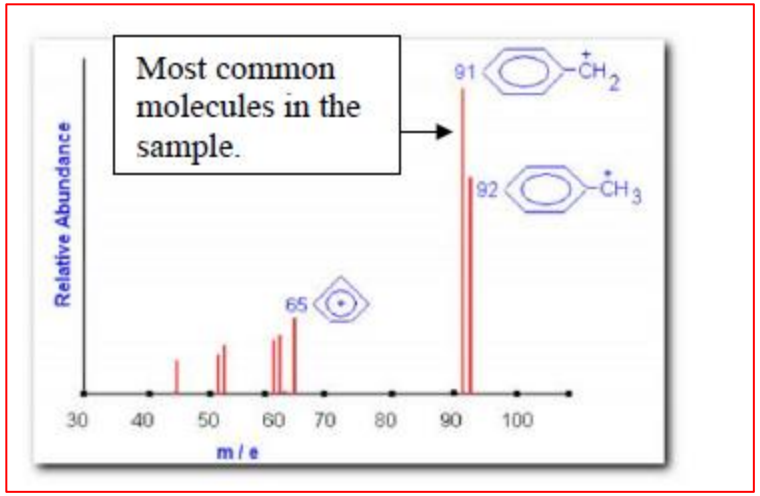
$$r = \frac{m \times v}{q \times B}$$

$$\Rightarrow m = \frac{r \times q \times B}{v}$$

4) So once v, B and radius r are measured, the ion's mass, m, can be determined.

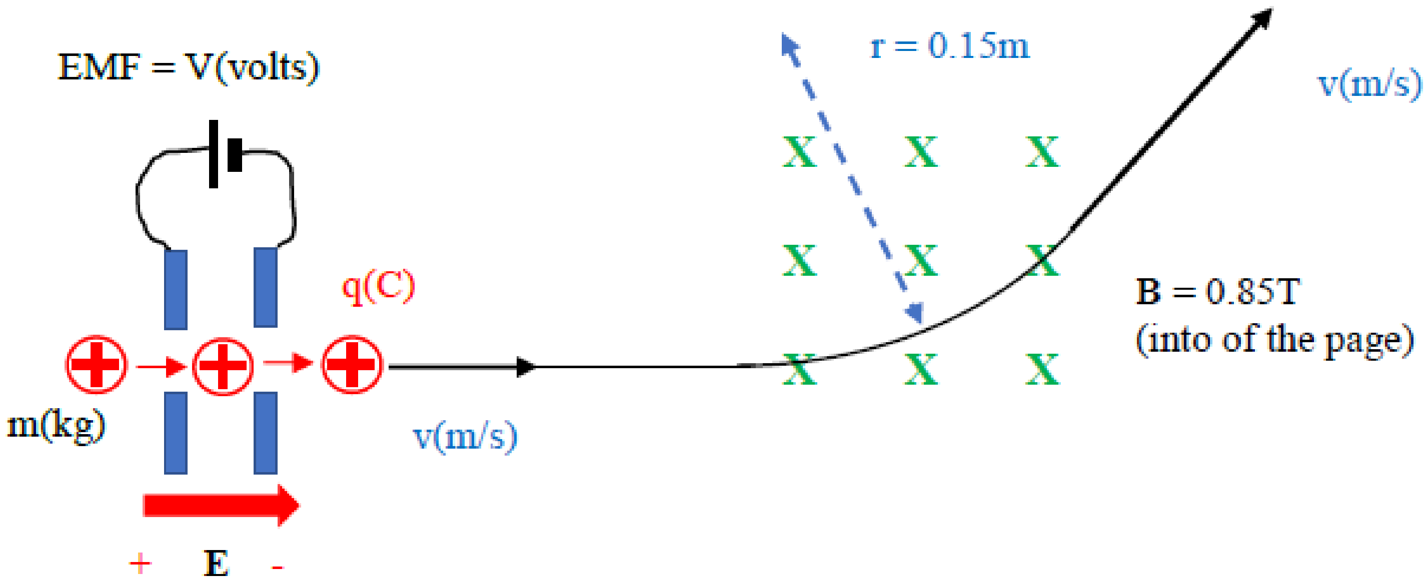
1) Ionizer.
This knocks electrons off atoms or molecules to create positive ions that the E-field can then accelerate towards the bending B-field.

Ion's charge will be:
$= N \times {}^{+}1.6 \times 10^{-19}$ Coul., where $N = 1, 2, 3, \ldots$



Problems:

A stream of identical ions, each of mass m(kg) are accelerated by a potential difference V(volts) to a velocity of v = 42000 m/s into a magnetic field, B, that bends them into a circular arc of radius r (metres).



Each molecule has been singly ionized ($q = +1.6 \times 10^{-19}$ Coul.) by an electron gun (not shown) prior to entering the accelerating electric field, **E**.

Use this data to determine the ion's mass, m:

Solutions:

Each molecule has been singly ionized ($q = +1.6 \times 10^{-19}$ Coul.) by an electron gun (not shown) prior to entering the accelerating electric field, **E**.

Use this data to determine the ion's mass, m:

$v = 42000$ m/s
$B = 0.85$T
$q = 1.6 \times 10^{-19}$ C
$r = 0.15$m

$$r = \frac{m \times v}{q \times B}$$

$$\Rightarrow \quad m = \frac{r \times q \times B}{v} = \frac{0.15 \times 1.6 \times 10^{-19} \times 0.85}{42000} = 4.857 \times 10^{-25}$$

4.86×10^{-25} kg

Charges between parallel plates

1. Gain in KE for charges crossing from one plate to another

   $$KE(gain) = qV = \frac{1}{2} mv^2$$

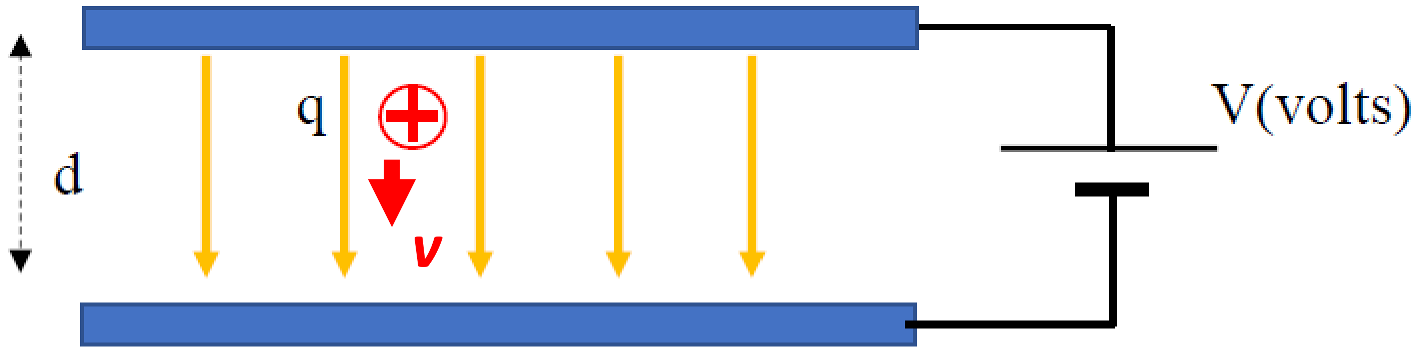
2. Balance of Electric Force = qE, with weight force = mg for charged droplets

   $$qE = mg, \text{ where } E = V/d$$

3. Charges moving between crosses E and B fields

   $$E = vB$$

1. A charge, q, with mass, m crossing a potential difference, V (volts)



Work done on charge.

Charge's gain in K.E.

$$qV = \frac{1}{2}mv^2$$

Charge (Coul)

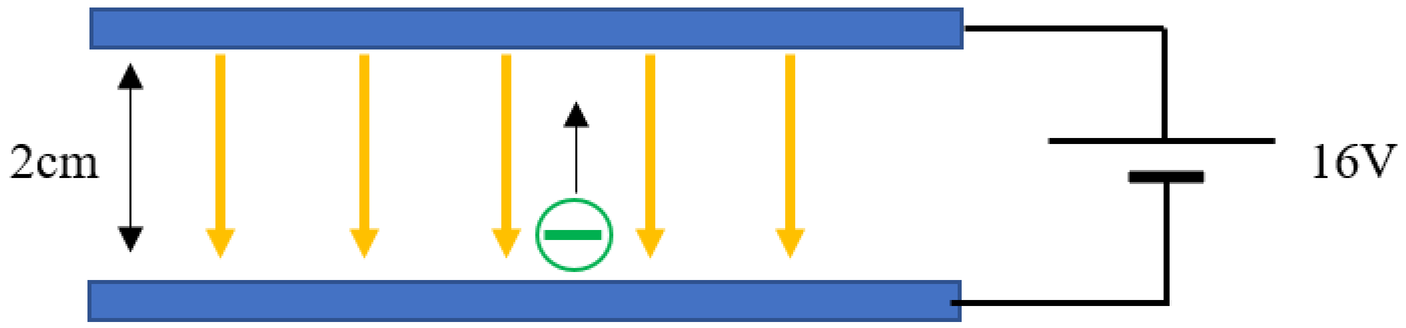
EMF (Volts)

Mass of charge (kg)

Velocity of charge (m/s)

Problems:

An electron is accelerated by an EMF = 16V across a 2cm gap as shown:



1. What is the electron's gain in KE when it crosses the gap between the plates?

2. What is the impact velocity of the electron with the positive plate?
(Note: this is independent of E or d)

Solutions:

1. What is the electron's gain in KE when it crosses the gap between the plates?

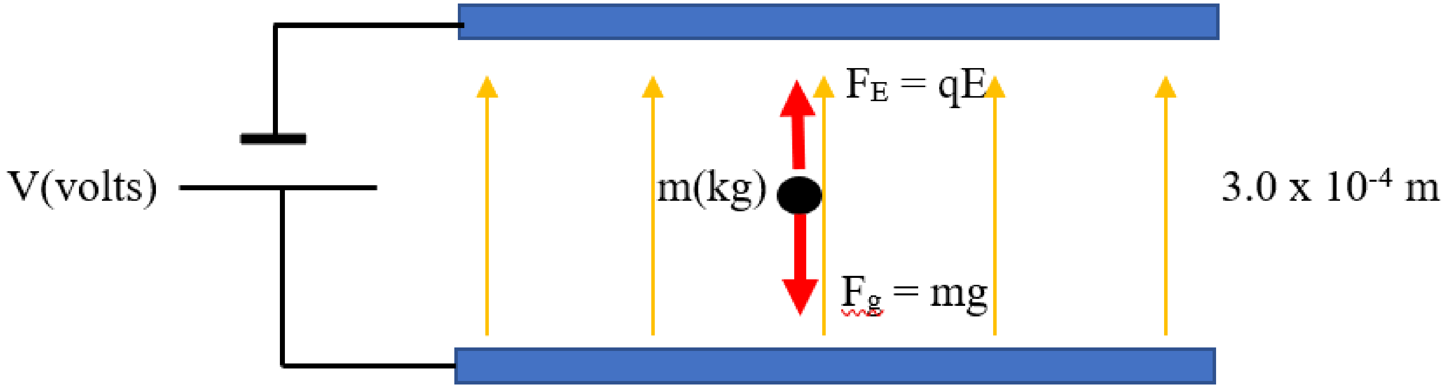
$$KE_{gain} = qV = 1.6 \times 10^{-19} \times 16 = 2.56 \times 10^{-18} J$$

2. What is the impact velocity of the electron with the positive plate?
(Note: this is independent of E or d)

$$KE_{gain} = qV = \frac{1}{2}mv^2, \quad v = \sqrt{\frac{2 \times KE_{gain}}{m}} =$$
$$\sqrt{\frac{2 \times 2.56 \times 10^{-18}}{9.1 \times 10^{-31}}} = 2.37 \times 10^{6} \text{ m/s}$$

2. Balance of Electric Force = qE, with weight force = mg, for charged droplets

A charged particle of mass m, where the electric force = the weight force

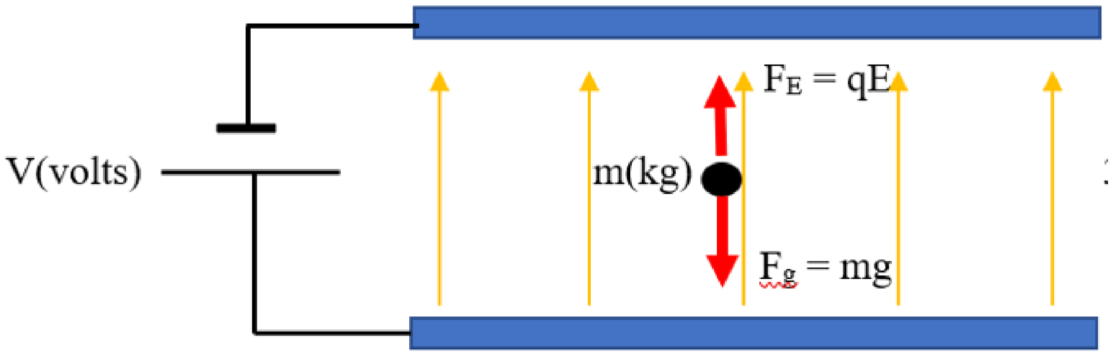


If the forces on the mass are in equilibrium then **ΣF = 0** and the mass will fall at a constant terminal velocity.

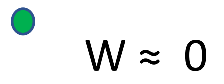
$$\mathbf{qE = mg}$$

NOTE:
In problems where there are charges between parallel charged plates – only consider the weight force: W = mg for objects like oil drops that consist of many millions of atoms and therefore have enough weight to counter an electric force in the opposite direction.

Neglect the weigh force W = mg for electron and protons. Their weight is just far too small to matter compared with the size of electric forces acting on them.



Electron or Proton



<u>Problem</u>:

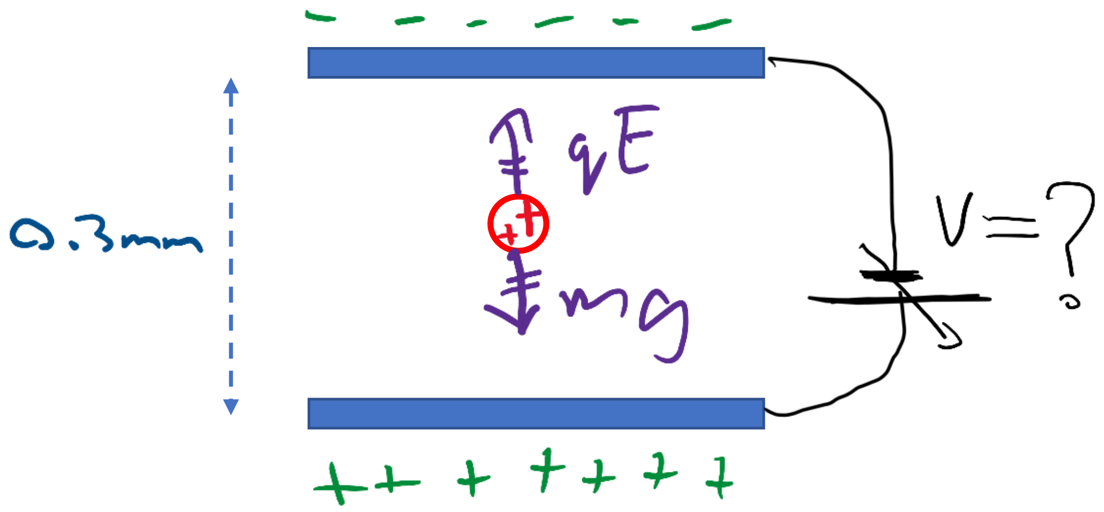
Consider a small drop of oil that has been exposed to x-rays and consequently has lost 2 of its electrons. The drop's mass is 6ng.

What voltage will be needed across the 0.3mm gap to ensure the drop falls at terminal velocity?

Data: g = 9.8N/kg, q = 2 x e^- = 2 x 1.6 x 10^{-19} = 3.2 x 10^{-19}C, m = 6 x 10^{-9} x 10^{-3} = 6 x 10^{-12} kg

Firstly calculate:

qE = mg => E = mg/q



Secondly:

$E = V/d \Rightarrow V = E \times d =$

Solution:

Data: g = 9.8N/kg, q = 2 x e^- = 2 x 1.6 x 10^{-19} = 3.2 x 10^{-19}C, m = 6 x 10^{-9} x 10^{-3} = 6 x 10^{-12} kg

Firstly calculate: qE = mg

=> E = mg/q =

$$E = \frac{F}{q} = \frac{mg}{q} = \frac{6 \times 10^{-12} \times 9.8}{3.2 \times 10^{-19}} = 1.8375 \times 10^{8}$$

Secondly:

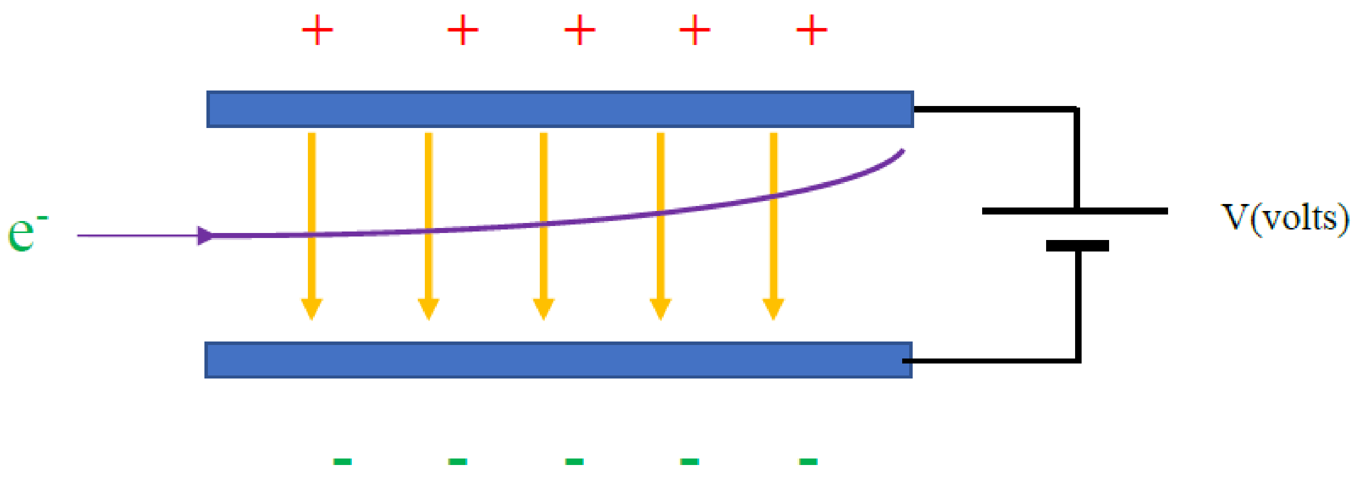
E = V/d ⇒ V = E × d =

$$V = E \times d = 1.8375 \times 10^{8} \times 3.0 \times 10^{-4} = 55{,}125$$

5.5×10^4 V

3. Charges moving between crosses E and B fields

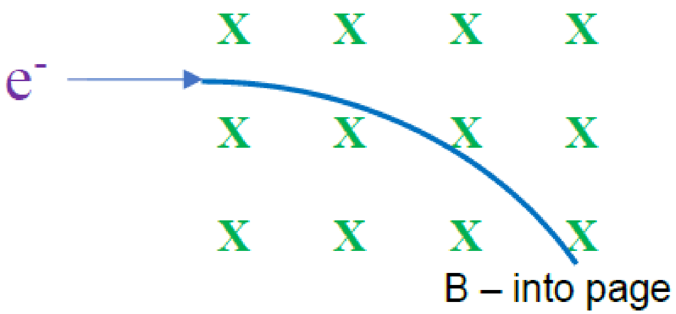
Firstly, consider an electron accelerated to a speed v (m/s) and then allowed to enter an electric field, E, as shown.



The path of the particle would be identical to a mass projected horizontally with a gravitational field that is in the vertical direction (except upside down). That path is a parabola as there in no force in the horizontal direction.

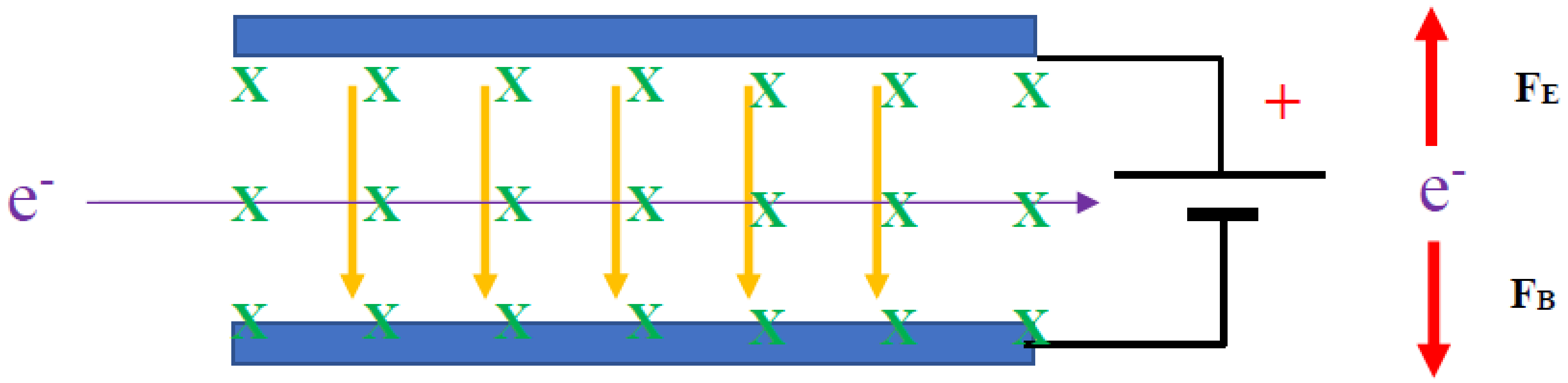
Note: for particles such as electrons and protons, neglect their weight force W = mg. It's far, far smaller than the electric force, F = qE, that is accelerating these charges between the plates.

Now consider that electron moving left to right in a magnetic field, B, that is into the page.



A positive charge (e.g. a proton) would bend upwards moving left to right so a negative charge will bend in a circular arc in the opposite direction.

Now, combine the 2 fields.

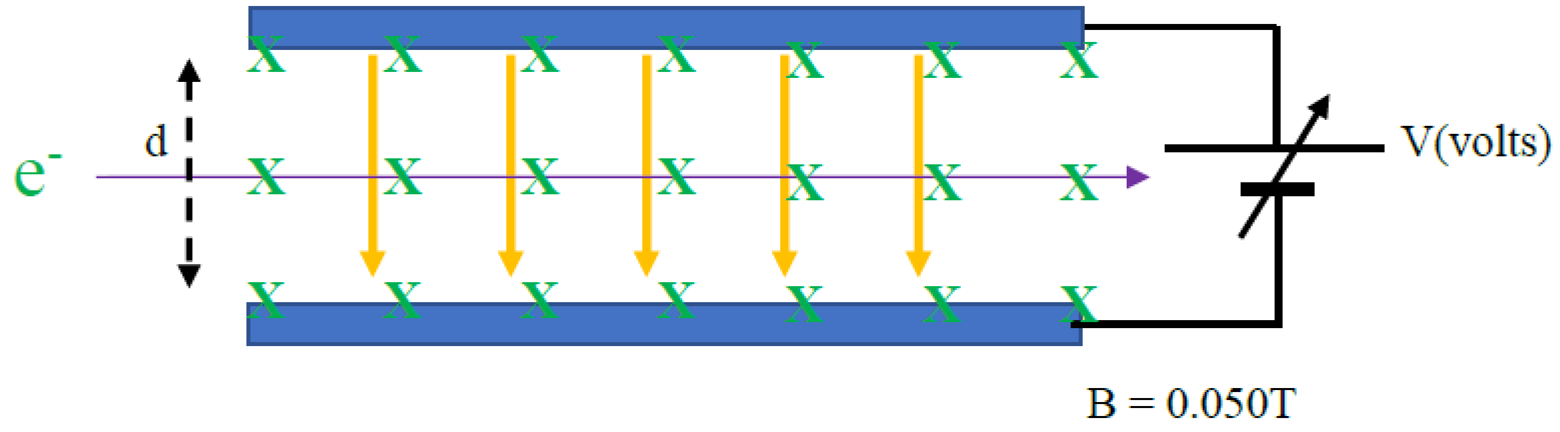


If the magnetic force, F_B, and electric force, F_E, on the electron exactly balance then $\Sigma F = 0$ (neglecting the negligible weight force) and it will follow a straight-line path according Newton's 1st law.

Here $F_B = F_E \quad \Rightarrow \quad qvB = qE \quad \Rightarrow \quad vB = E \quad \Rightarrow \quad v = \dfrac{E}{B}$

Problems:

A beam of electrons is moving at 3.0×10^6 m/s when they enter crossed electric and magnetic fields as shown. The voltage has been adjusted until the path of the electrons is perfectly straight.



d = 2.0cm

1/ Calculate the magnitude of the electric field, E from this data.

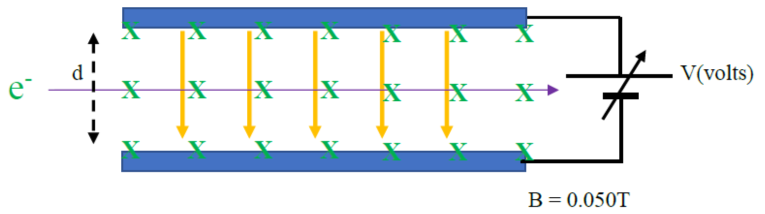
NC^{-1}

2/ Determine the voltage that the supply has to be set to:

V

Problems:

A beam of electrons is moving at 3.0×10^6 m/s when they enter crossed electric and magnetic fields as shown. The voltage has been adjusted until the path of the electrons is perfectly straight.



d = 2.0cm

Solutions:

When $F_E = F_B$:

$E = qB$

1/ Calculate the magnitude of the electric field, E from this data.

$E = \frac{V}{d} = \frac{F_E}{q}$, However, we don't know V or F_E

But, since we know $\Sigma F = 0$, $\Rightarrow F_E = F_B = qvB$

$\Rightarrow F_E = qE = qvB$ therefore,

$\Rightarrow E = vB = 3 \times 10^6 \times 0.05 = 150{,}000$

1.5×10^5 NC^{-1}

2/ Determine the voltage that the supply has to be set to:

$E = \frac{V}{d}$ $d = 2cm = 0.02m$

$V = E \times d = 1.5 \times 10^5 \times 0.02 = 3{,}000$ volts

3.0×10^3 V

Generators, Transformers & Transmission
Unit 3 AoS#3

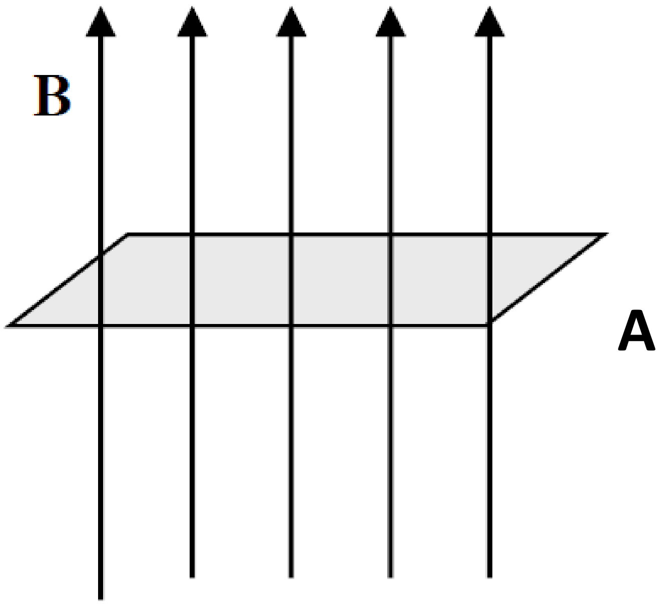
Monash University – Revision Lecture

Summary

- Magnetic Flux
- Induction and Flux Changes & Faraday's Law
- Generation – AC and DC,
- Lenz's Law
- Peak and RMS values
- Transformers
- Transmission Line Losses
- Photovoltaic Cells (Solar Cells) – added to the U3 Study Design in 2024

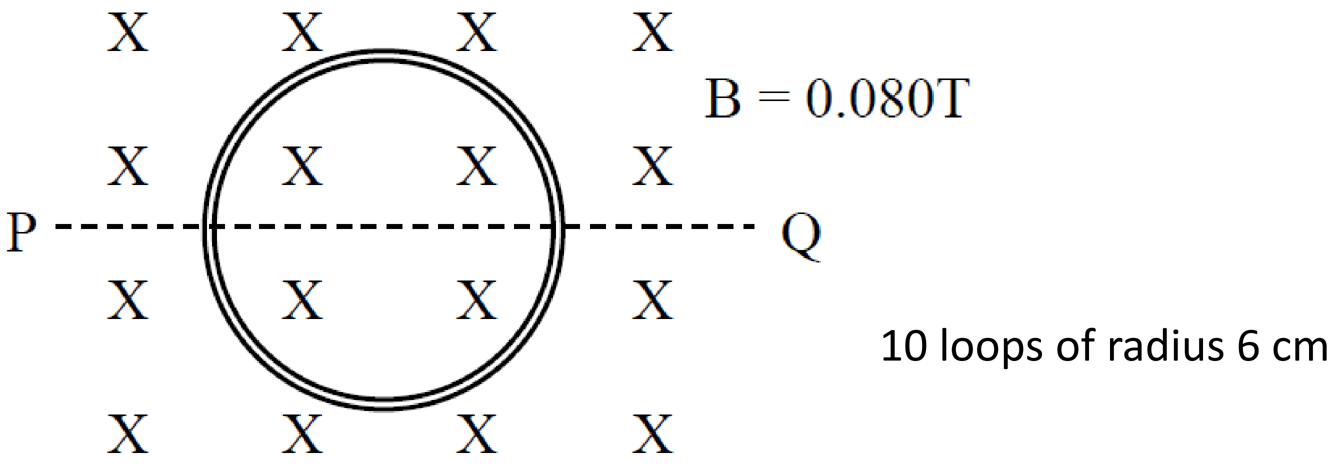
Magnetic Flux ϕ_B

- This is measure of the magnetic field lines enclosed
- It is defined as $\boldsymbol{\phi_B = B_\perp A} = BA_\perp$ where ⊥ represents the perpendicular component
- The unit of Flux is $Tm^2 = Wb$ (Tesla metre-squared or Weber)
- Flux alone, does not induce and EMF, flux *changes* induce EMFs
- A flux change in a loop will always induce an EMF, an only if that loop is a closed, complete circuit, it will also induce a current.
- This size of the Induced EMF is given by Faraday's Law
- The direction of the Induced EMF and current is given by Lenz's Law



$1\ cm^2 = 10^{-4}\ m^2$

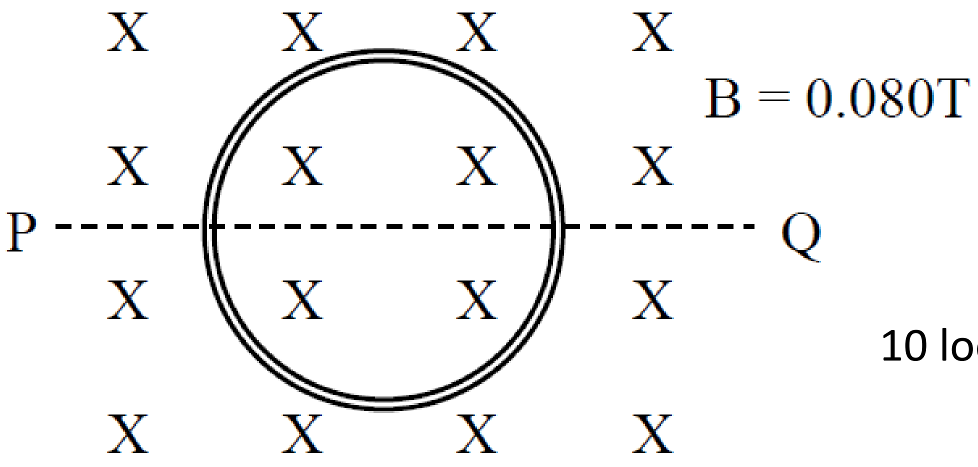
Problems:



1. Calculate the magnetic flux through the loops

2. Calculate the change in flux when this loop is rotated through 180^0 about the axis PQ

Problems:



10 loops of radius 6 cm

1. Calculate the magnetic flux through the loops

$\phi_B = BA = 0.08 \times \pi \times 0.06^2 = 9.05 \times 10^{-4}$ Wb

Note: Flux is only ever calculated for ONE LOOP

2. Calculate the change in flux when this loop is rotated through 180^0 about the axis PQ

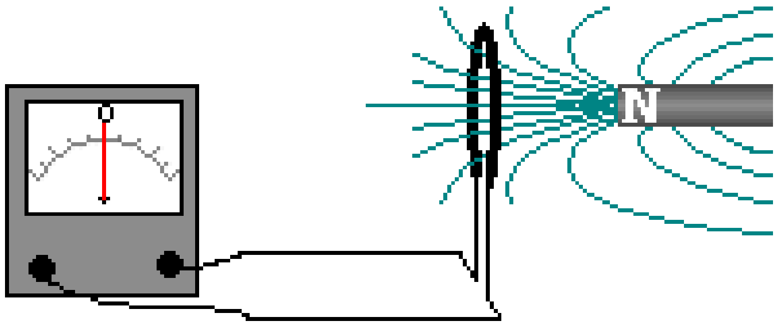
$\Delta\phi_B = \phi_B(\text{final}) - \phi_B(\text{initial}) = BA - -BA = 2 \times BA$

$= 2 \times 9.05 \times 10^{-4}$

$= 1.81 \times 10^{-3}$ Wb

Electromagnetic Induction & Faraday's Law

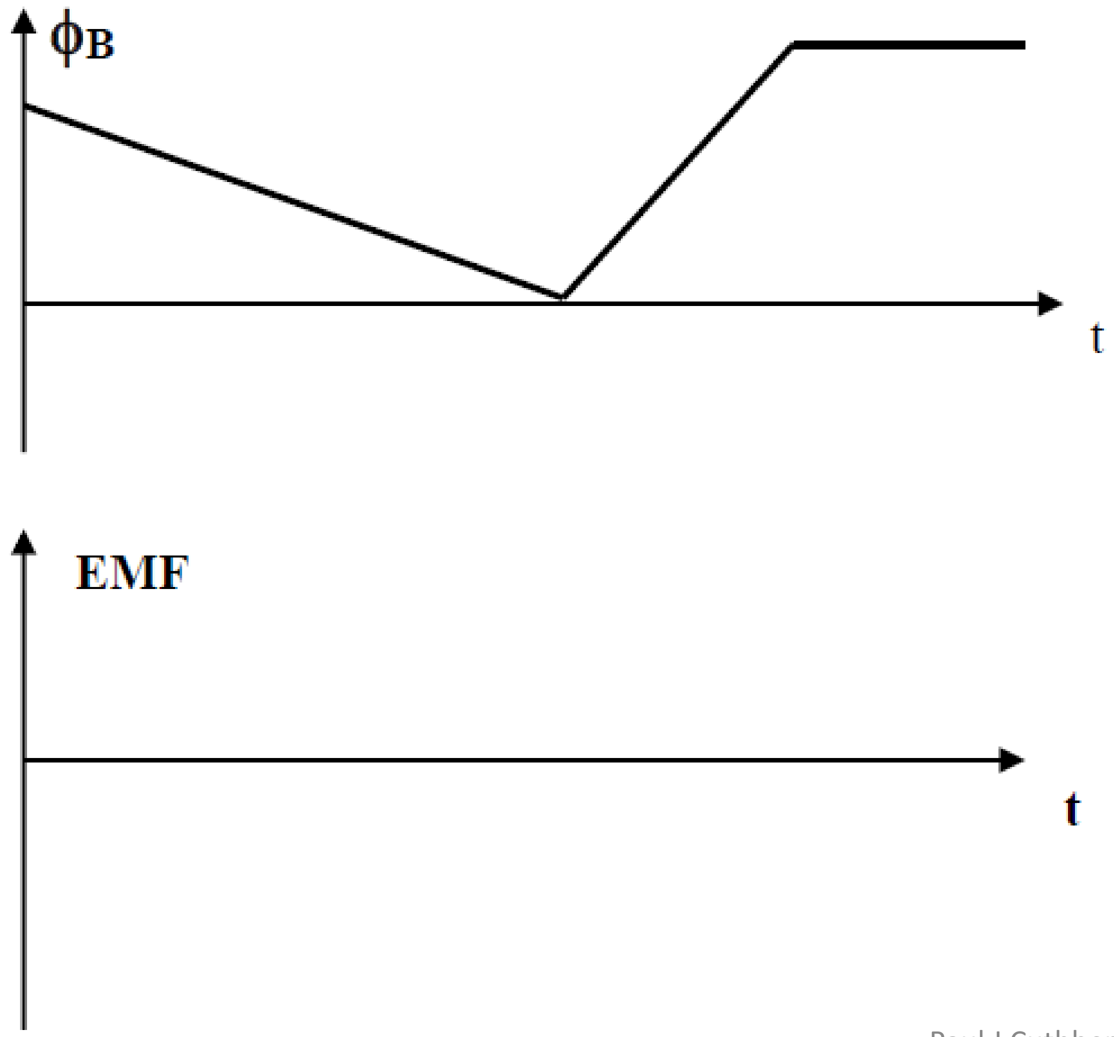
$$V = -N \times \frac{\Delta\Phi_B}{\Delta t}$$



Faraday's Law also represents the negative gradient of a Flux vs time graph

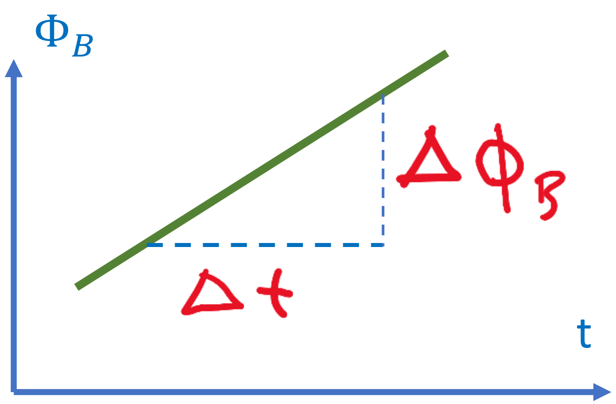
E.g.

1.



Faraday:

$$V = -\frac{\Delta\Phi_B}{\Delta t}$$

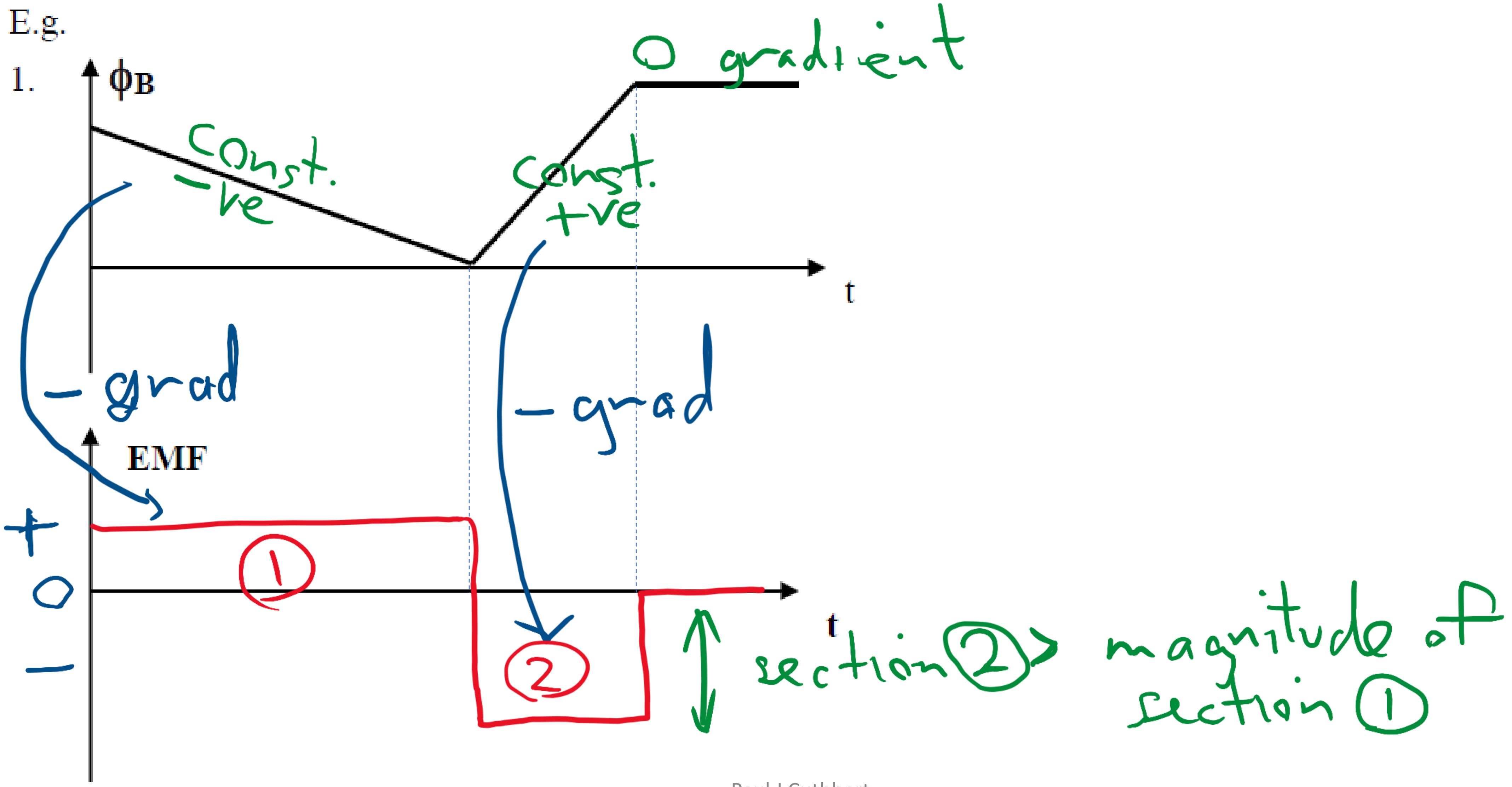


V = - gradient of Φ_B vs t graph

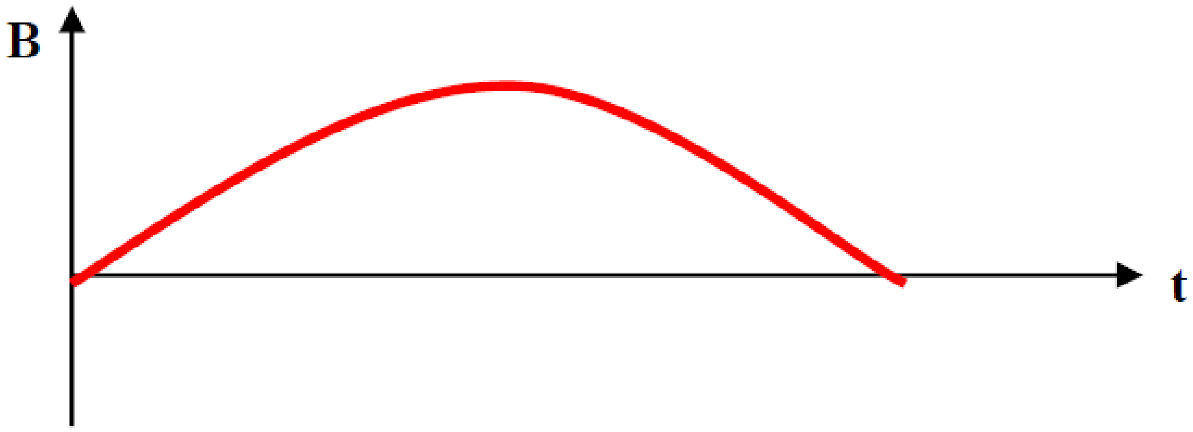
Solution:

E.g.

1.

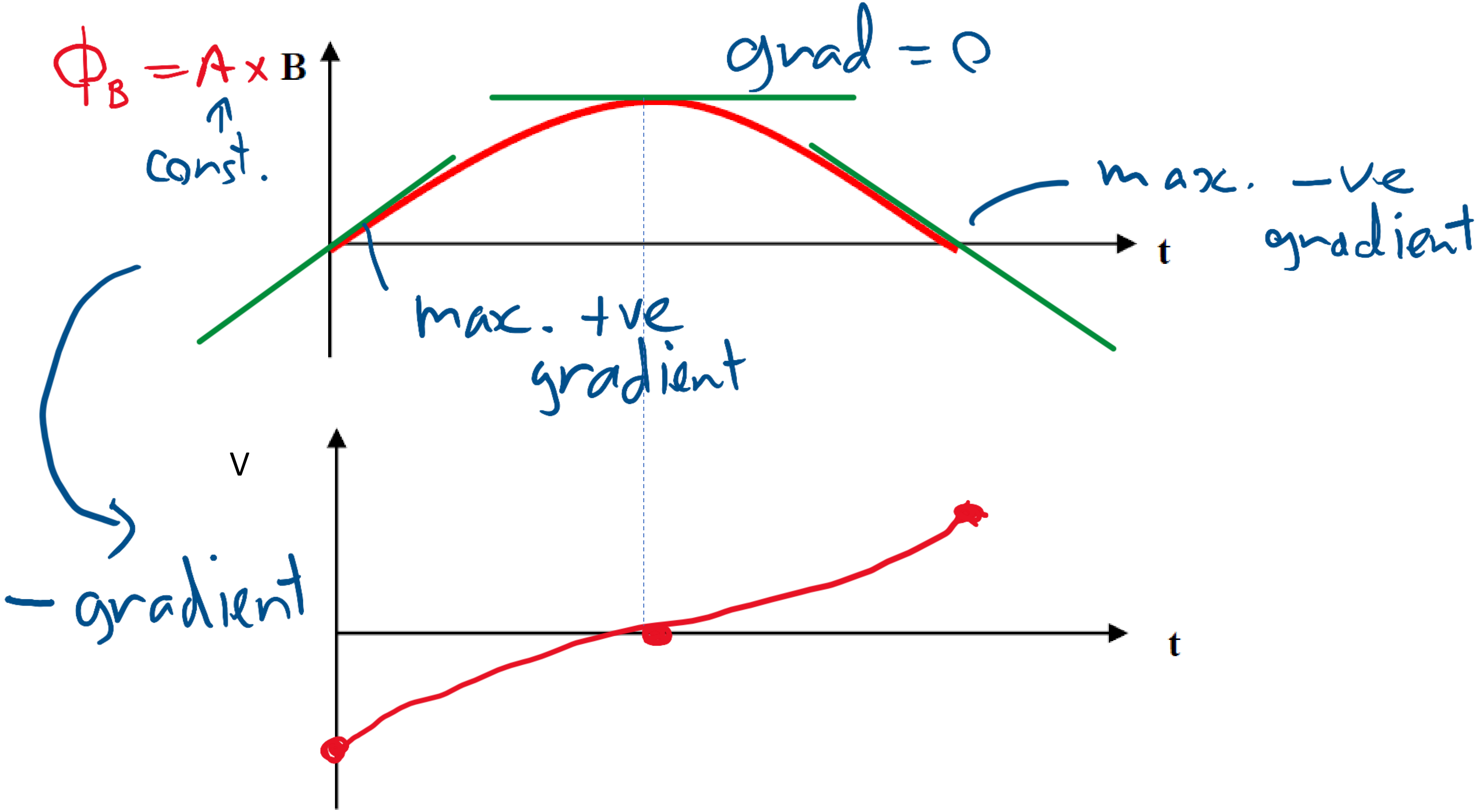


The magnetic field through a loop of wire of fixed area varies as shown:
Sketch the flux and EMF graphs:



Solution:

The magnetic field through a loop of wire of fixed area varies as shown: Sketch the flux and EMF graphs:



Lenz’s Law – determining the direction of the induced EMF and Current

- If the magnetic flux changes then there is an induced EMF (voltage):
  - that’s *Faraday’s* Law: $V = - N \times \Delta\Phi_B/\Delta t$ and it’s used to calculate the voltage (EMF)
- If the flux change occurs in a closed loop (a complete circuit) then a current will flow (but only while the *flux* is *changing*). The *direction* of the current induced is given by *Lenz’s Law*.
- So, there’s always 2 different magnetic fields (fluxes) involved: (1) the external source from a magnet or maybe another powered solenoid, whose flux was threading loop and at some point in time *changed*. Then, (2) there’s the induced magnetic flux in the loop from the induced current in the loop.
- Lenz’s Law is basically saying that the induced current will flow around the loop in whatever direction (clockwise or anticlockwise) it needs to, so that its own magnetic field will restore the initial situation: that is, either cancel out the extra field lines that appeared from an external source or put back the field lines that were reduced.

The application of Lenz's Law to determine the direction of current flow is a very common 'explain your reasoning' type question in exams. We expect to get one almost every exam.

To be allocated marks for your answer you must describe the directions of flux *change* that specifically address the diagram given in the question – eg. Up, Down, to the Left, to the Right, Into the page, Out of the page.

There are a couple of acceptable ways of stating the **direction** of the **change** in **flux**, $\Delta\Phi_B$, that are equivalent:

For example: 'the *change* in flux is to the Left'

OR: 'the initial flux is to the right and is decreasing' (sometimes this statement may be easier so say/figure out)

It is essential that you reference a *change* in the flux, not just flux. This is because you can have magnetic flux (eg, just leave a magnet pointing at a loop), but if the flux is constant, then no EMF is induced, and therefore no current will be induced.

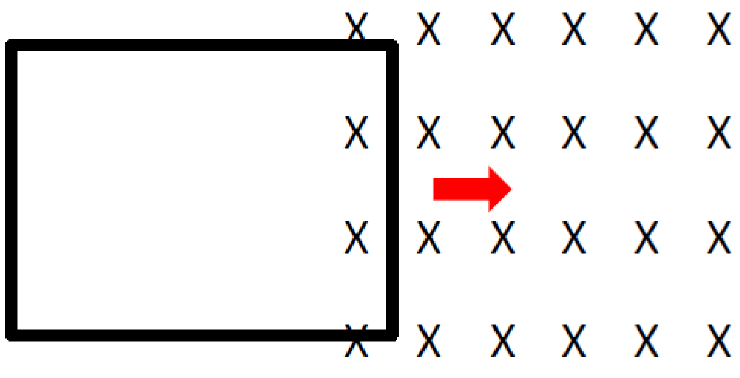
Once you've established the direction of $\Delta\phi_B$, then go on to explain the direction of I(induced), usually CW or ACW.

Examples:

1/ A square loop moves into a magnetic field, B, that is Into the page.

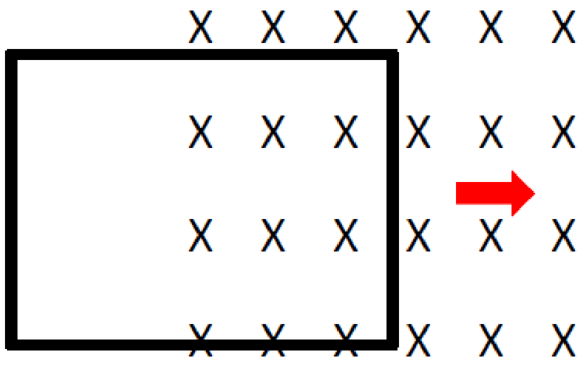
Problem: Determine the direction of the induced current that flows in the loop (Clockwise of Anti-Clockwise)

Initial, t = 0



B(into page)

t = later



B(into page)

Solution:

The final flux into the page is greater than the original (we could choose Into the Page as positive) so the flux change, $\Delta\Phi_B$ = final flux – initial flux: is *into* the *page*, still positive.

To the determine the direction of induced current flow and explain our reasoning:

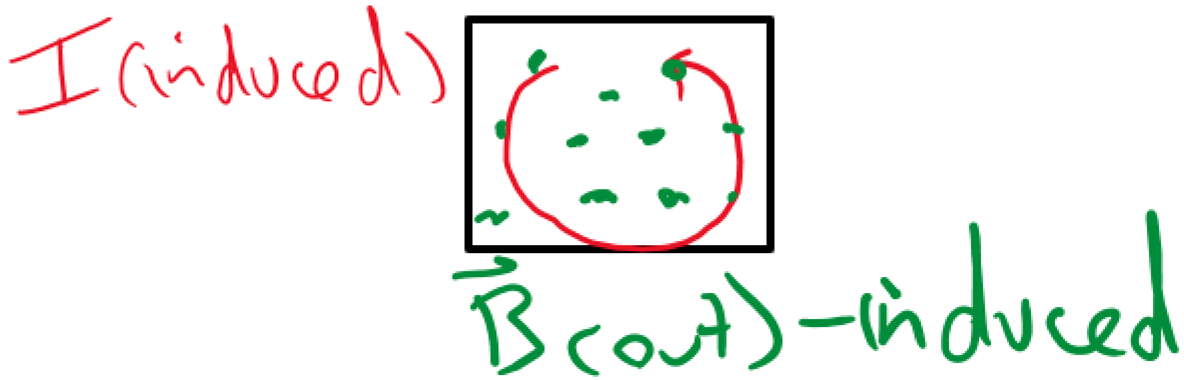
(i) "The *change* of flux is *into* the page"

OR – the equivalent statement:

"the initial flux is into the page and *increasing*" (Perhaps, this form is easier to state)

(ii) Therefore, by Lenz's Law, the induced current's magnetic flux will be Out of the Page, to oppose the change.

(iii) Therefore, using the right-hand curl (grip) rule, the induced current will be *Anti-Clockwise*.

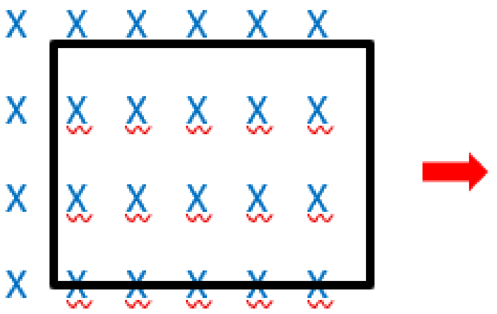


Note: if the **induced flux is *out of the page***- then the current will flow ***anticlockwise***.

-maybe put this diagram on your A3 sheet.

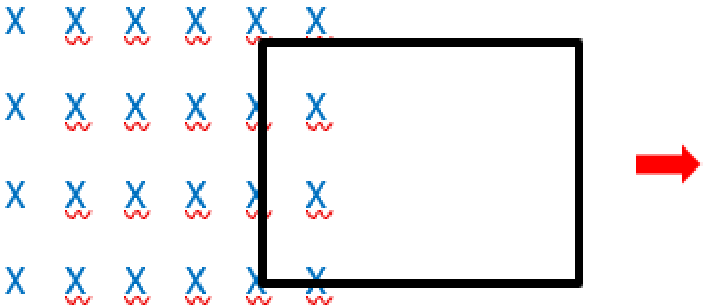
[So, these green field lines pointing out of the page have appeared so that they cancel out the extra field lines that were into the loop as it moves further into the field]

2/ t = 0



B(into page)

t = later

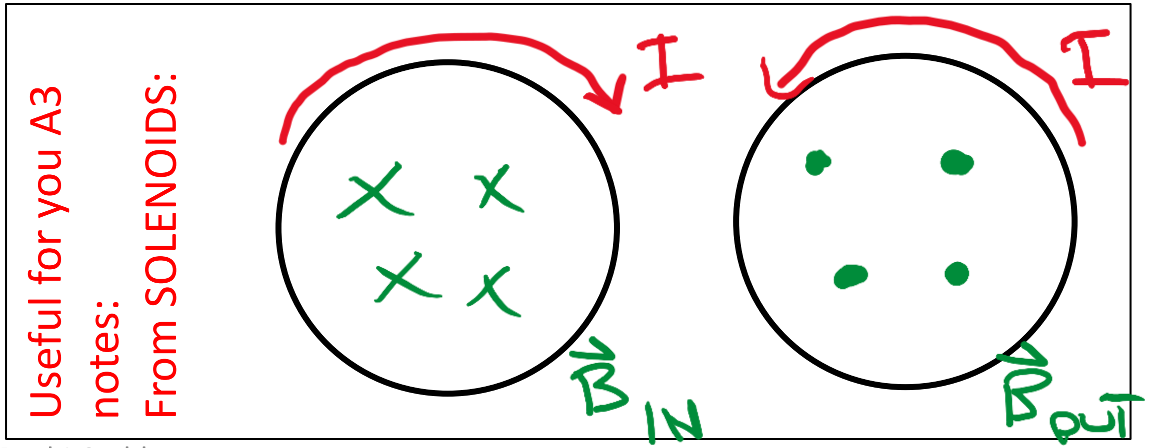


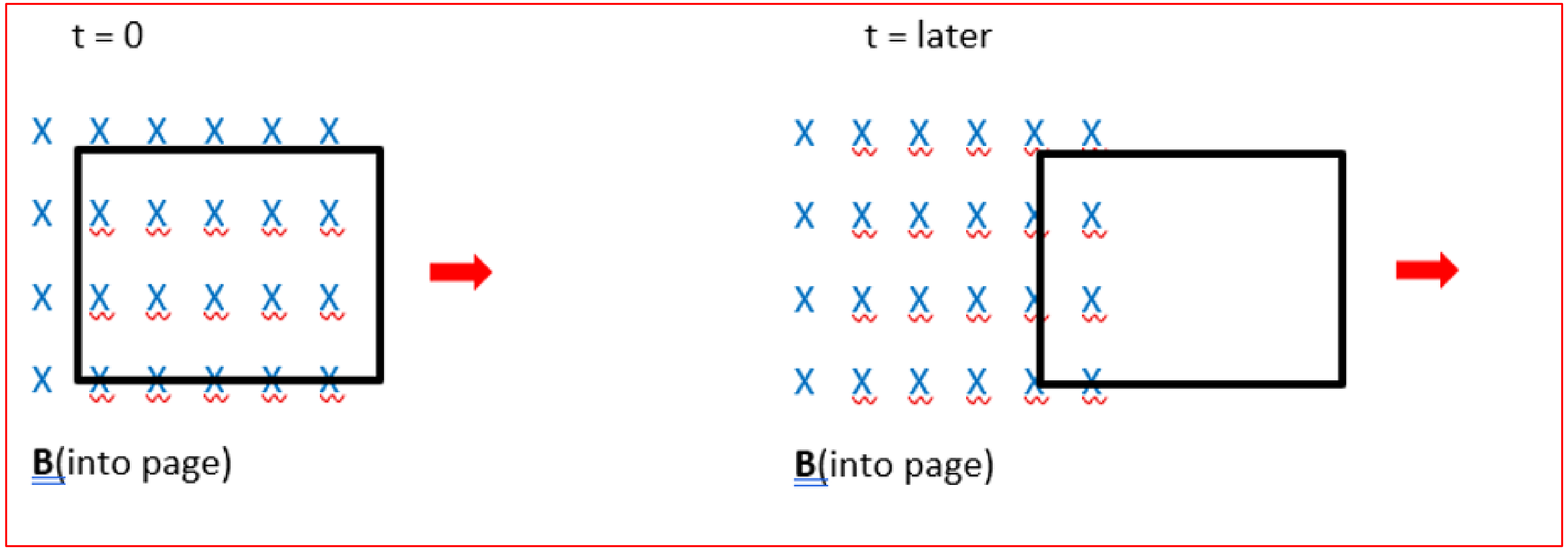
B(into page)

To the determine the direction of induced current flow and explain our reasoning:

(i) "The *change* of flux is Out of the page"

OR – the equivalent statement:

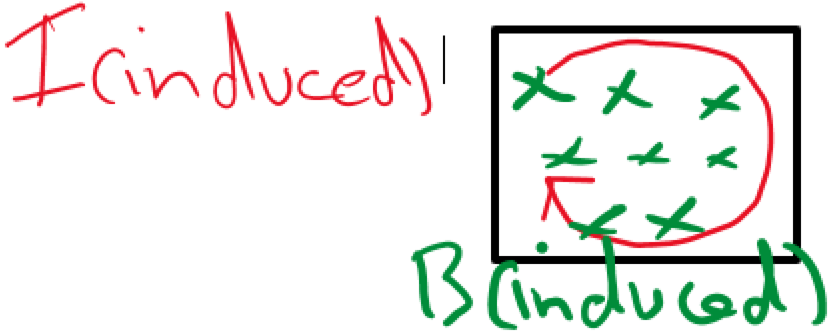




"The initial flux is into the page and *decreasing*"

(ii) Therefore, by Lenz's Law, the induced current's magnetic flux will be *Into* of the Page, to oppose the change.

(iii) Therefore, the right-hand curl rule, the induced current will be *Clockwise*.

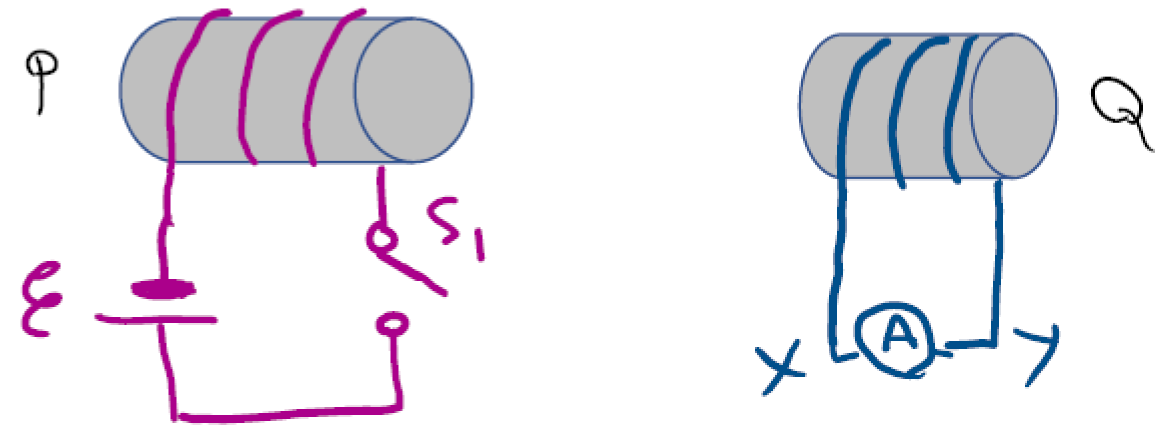


Note: if the **induced flux is *Into the page***- then the current will flow ***Clockwise***.

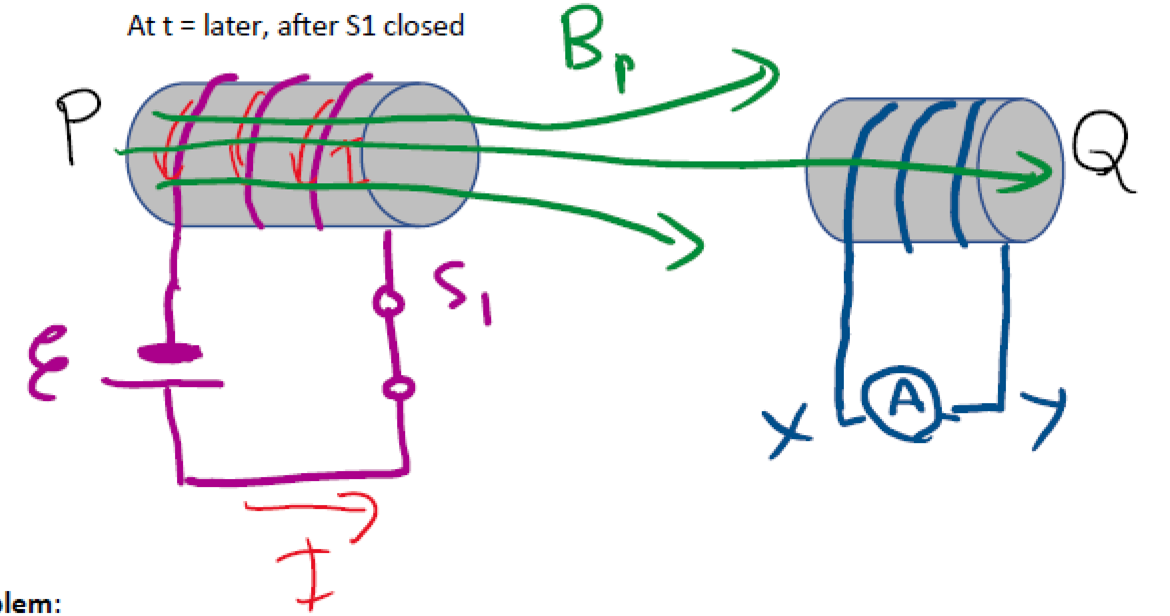
-maybe put this diagram on your A3 sheet.

3/ Example: a powered solenoid P and a nearby solenoid Q. When S1 is closed the magnetic flux in P will thread Q.

At t = 0



At t = later, after S1 closed

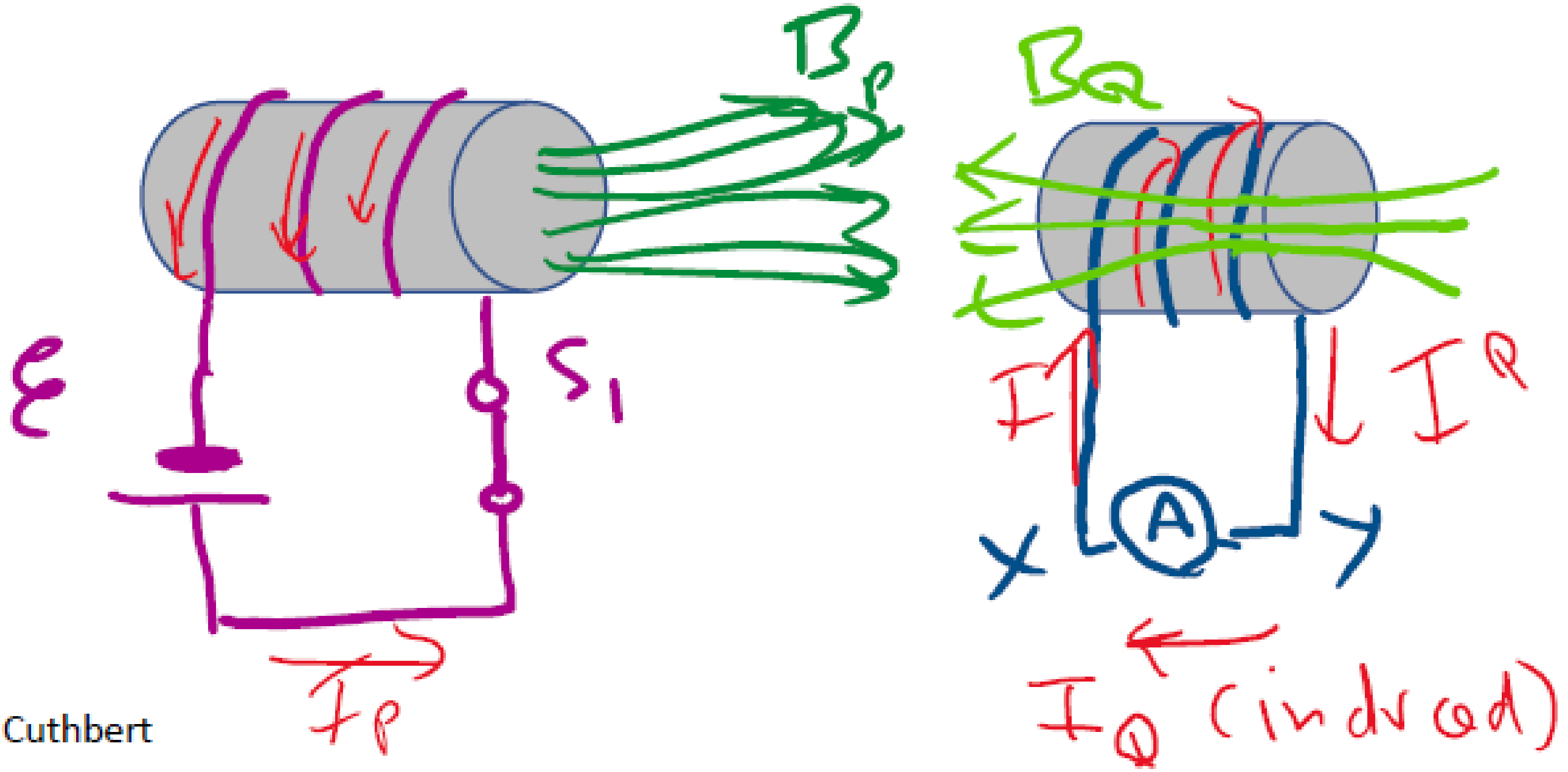


Problem:

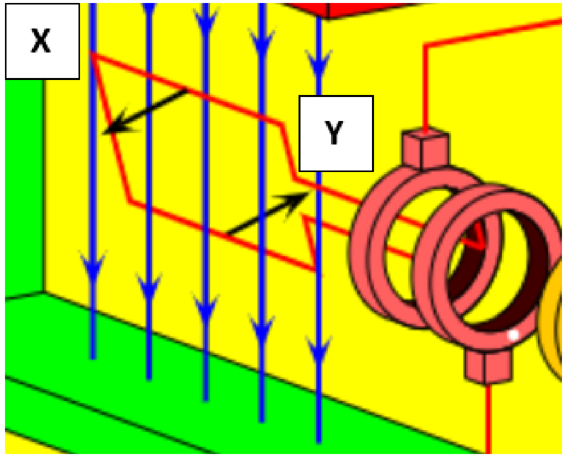
Determine the direction of the current through the ammeter in coil Q, when the switch S1 is closed.

Solution:

(i) the flux from P is to the right through Q and increasing (OR: the change in flux though Q is to the right)
(ii) the induced flux in Q will be to the Left to oppose this increase
(iii) using the RH curl rule (or solenoid rule) the induce current will flow from Y to X through A



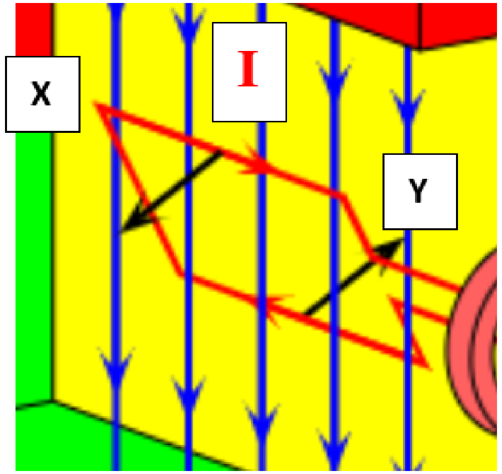
Paul J Cuthbert



Here the loop is rotating ACW (anti-clockwise) and in about 80 deg more rotation the loop will be perpendicular to the flux (B-Field) and the flux will be maximum. Which way will the current that's induced flow? X -> Y or Y -> X?

Answer:
-The flux is down the page and *increasing* through the loop.
-The induced current will flow so that its flux is up the page to oppose the increase.
-By the RH Curl Rule/or RH Solenoid rule, the induced current will flow **X -> Y.**

From the Walter-Fendt app, displaying the induced current:



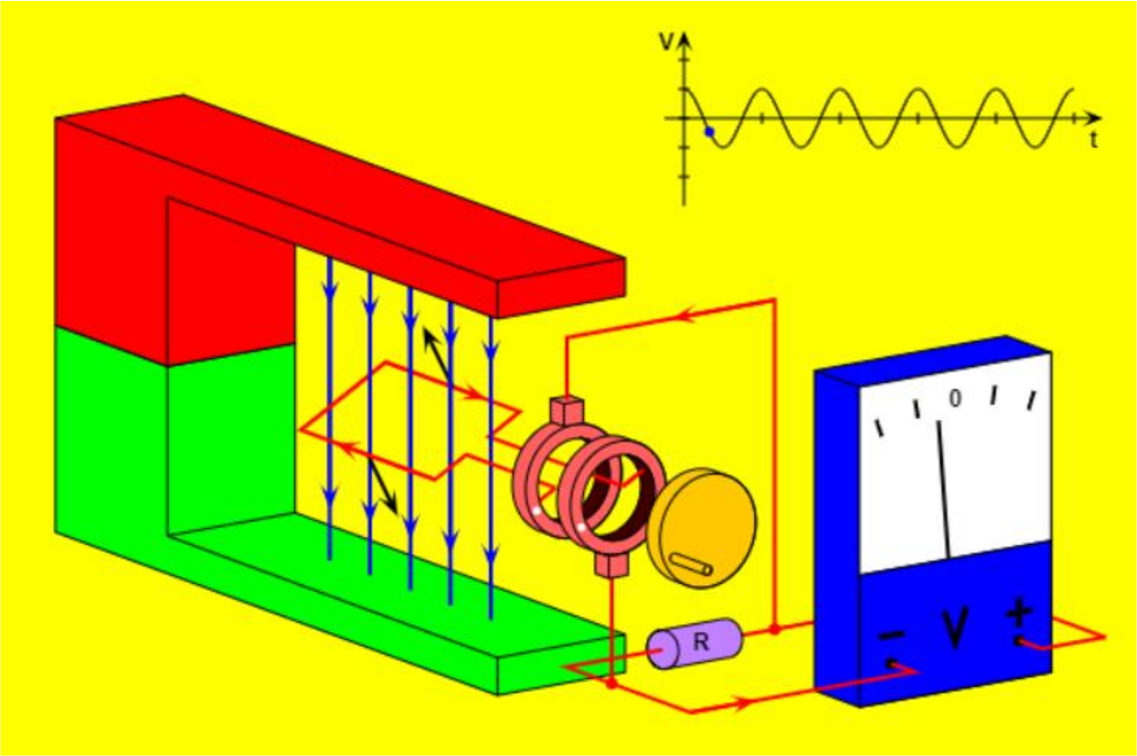
The Walter-Fendt app confirming the prediction that the induced current (red arrow) flows **X -> Y.**

https://www.walter-fendt.de/html5/phen/generator_en.htm

Generators

- As the loop of the armature rotate in the magnetic field, the induced current reverses direction every 180^0
- The flux in the loops is continuously changing and therefore an EMF is induced in the loops
- Slip rings maintain continuous contact with each side of the rotating loops to allow output of AC .
- A generator can be connected to either Slip Rings (output = AC) or a Split-Ring Commutator (output = DC)

In explanations of the output of generators it is essential that you understand the current in the rotating loops is already alternating. Students who suggest the connecting slip-rings or commutator to the rotating loop are the cause of the AC or DC being produced in the loops will generally be given zero marks.

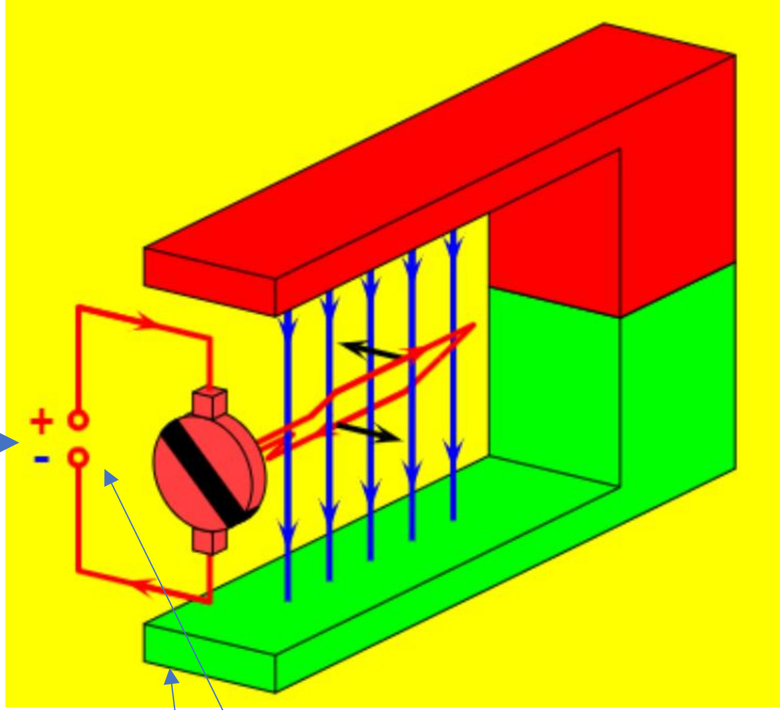


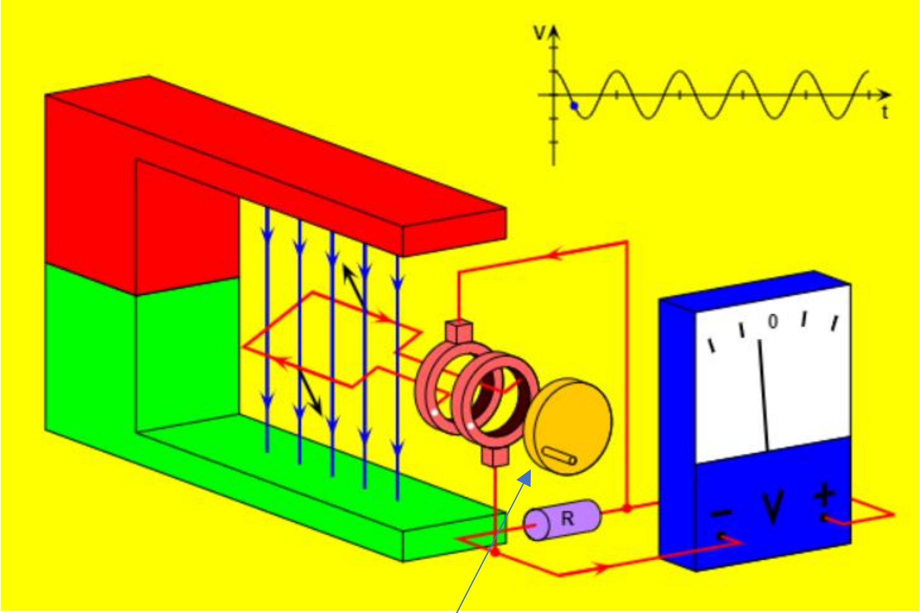
Walter Fendt - Generator

Motor

Generator

Power Supply



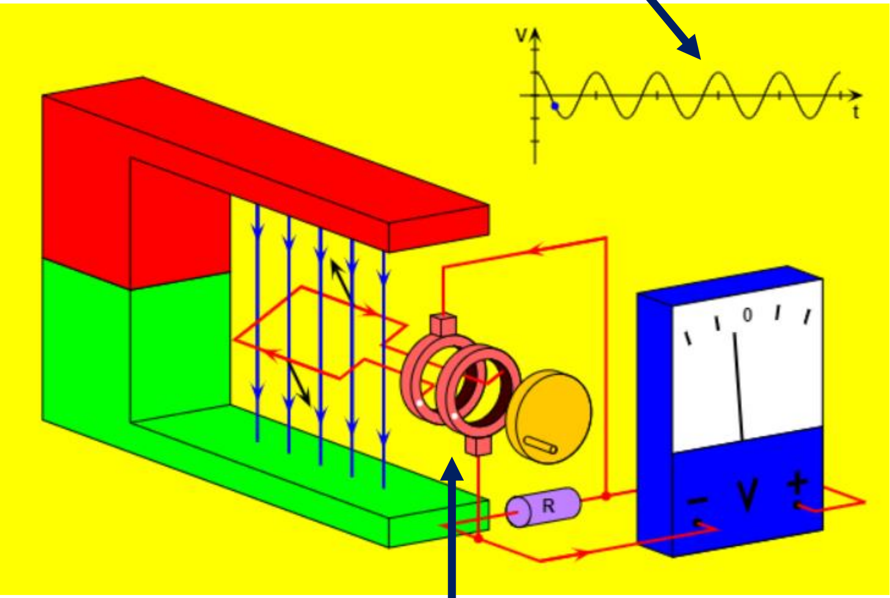


FBI

Supply B & I => F, for free

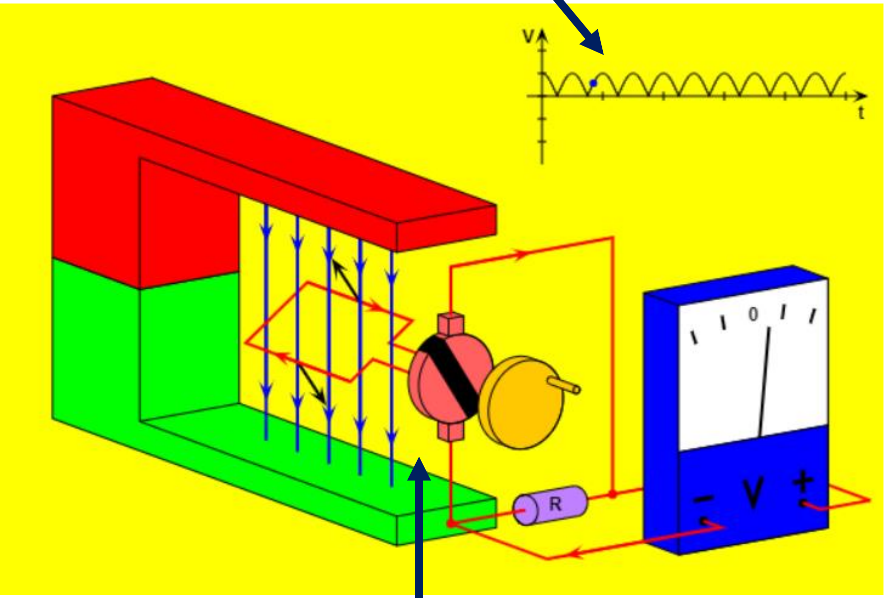
Supply F & B => I, for free

AC Output



Slip Rings

DC Output



Commutator

Problem:

In a generator, an armature consisting of 200 loops of wire, is rotating in a uniform magnetic Field of strength 0.40 T at a rate of 50Hz,
The dimensions of the loops are 10 cm x 10 cm.

Q/ What is the magnitude of the average EMF induced in the loops when they rotate 90^0 from the position of maximum flux (effective area of the loops parallel to the face of the magnet) to a position of zero flux (plane of the loops perpendicular to the face of the magnets)

Volts

Solution:

In a generator, an armature consisting of 200 loops of wire, is rotating in a uniform magnetic Field of strength 0.40 T at a rate of 50Hz,
The dimensions of the loops are 10 cm x 10 cm.

Q/ What is the magnitude of the average EMF induced in the loops when they rotate 90^0 from the position of maximum flux (effective area of the loops parallel to the face of the magnet) to a position of zero flux (plane of the loops perpendicular to the face of the magnets)

$T = 1/f = 1/50\ Hz = 0.02\ sec$

The time for a quarter of a turn = $\Delta t = ¼ \times 0.02 = 0.005\ sec$

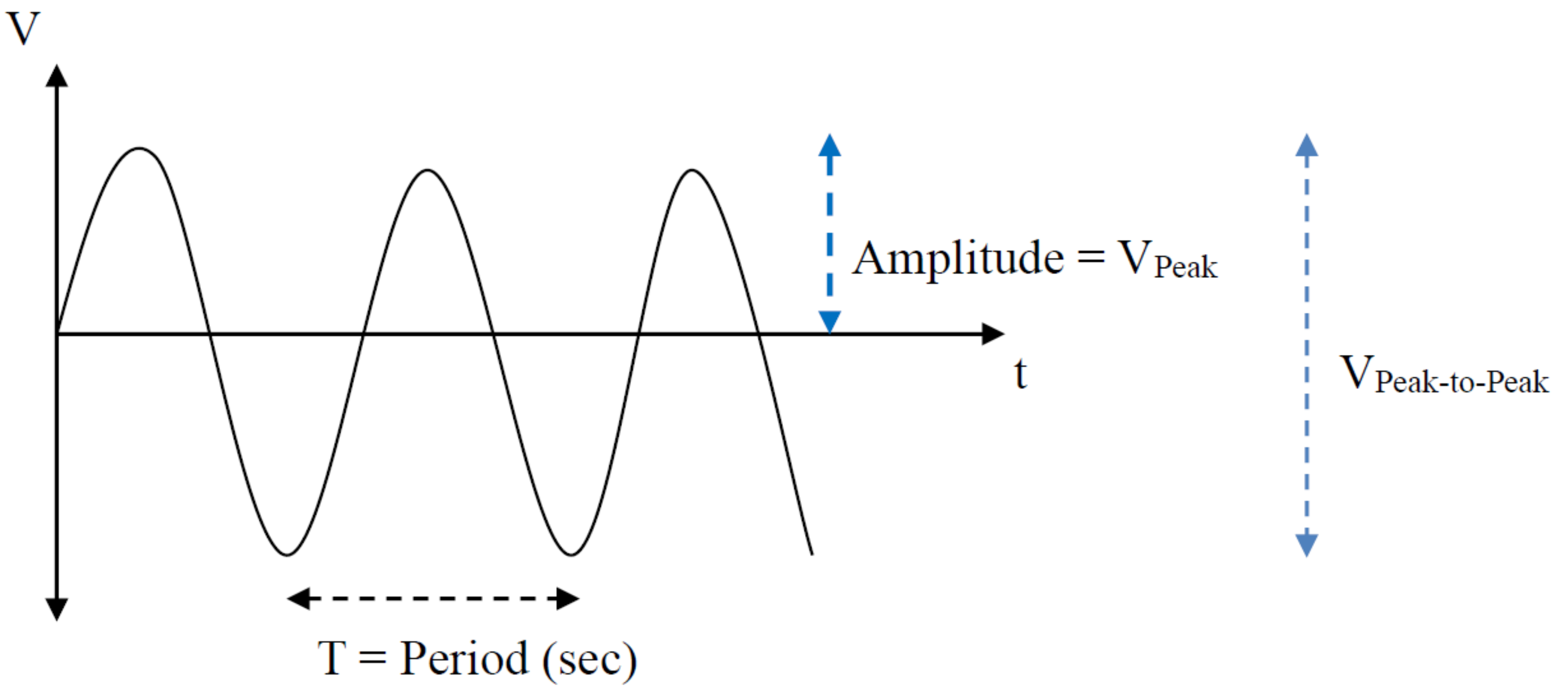
The maximum flux: $\phi_B = BA = 0.4T \times (0.1 \times 0.1)m^2$

Average EMF: (Faraday's Law)

$V = -N \times \Delta \phi_B / \Delta t = 200 \times 0.4 \times 0.1 \times 0.1/0.005 = -160$ volts

160 Volts

Peak and RMS values of AC voltages and Currents



RMS and Peak Values

Because the value of the voltage and current is constantly changing between 0 to the peak values, it is important to average both current and voltage. This is achieved by a mathematical process called "Root-Mean –Square" or RMS. The details of the process are beyond the scope of the course, only the results are important:

$$V(rms) = V_{Peak} / \sqrt{2} \quad \text{and} \quad I(rms) = I_{Peak} / \sqrt{2}$$

and this gives the expression of Electrical Power as:

$$P = V(rms) \times I(rms) = \tfrac{1}{2} V_{peak} \times I_{peak}$$

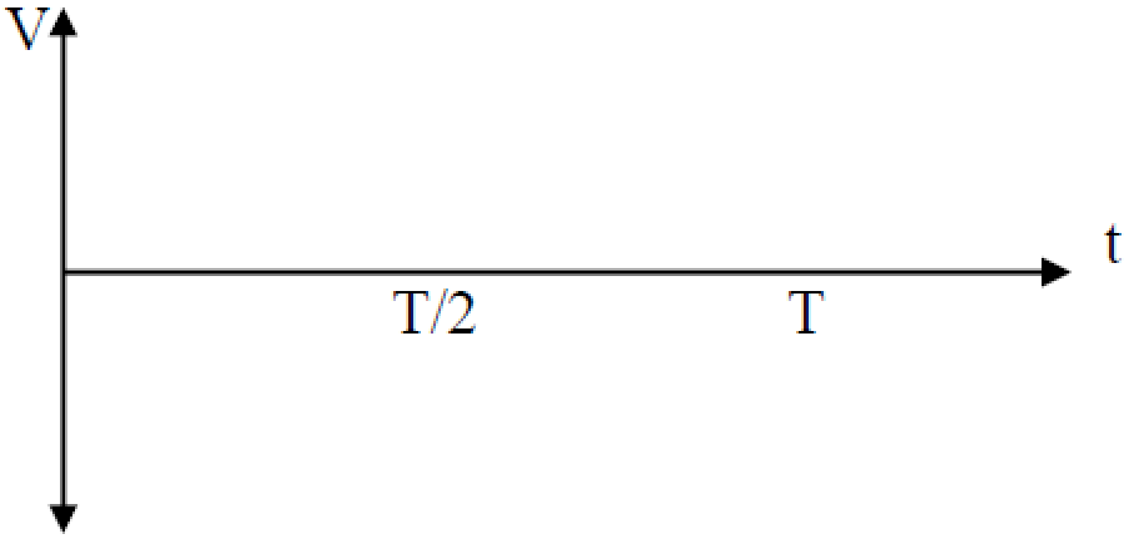
Problems:

1/ The voltage supplied to suburban homes in Australia is 240V(rms) A.C.

(i) What is the peak value of this? ________________________________

(ii) What is the Peak-to-Peak Voltage? ________________________________

(iii) Sketch the V – t graph for this: (T = period)



Solutions:

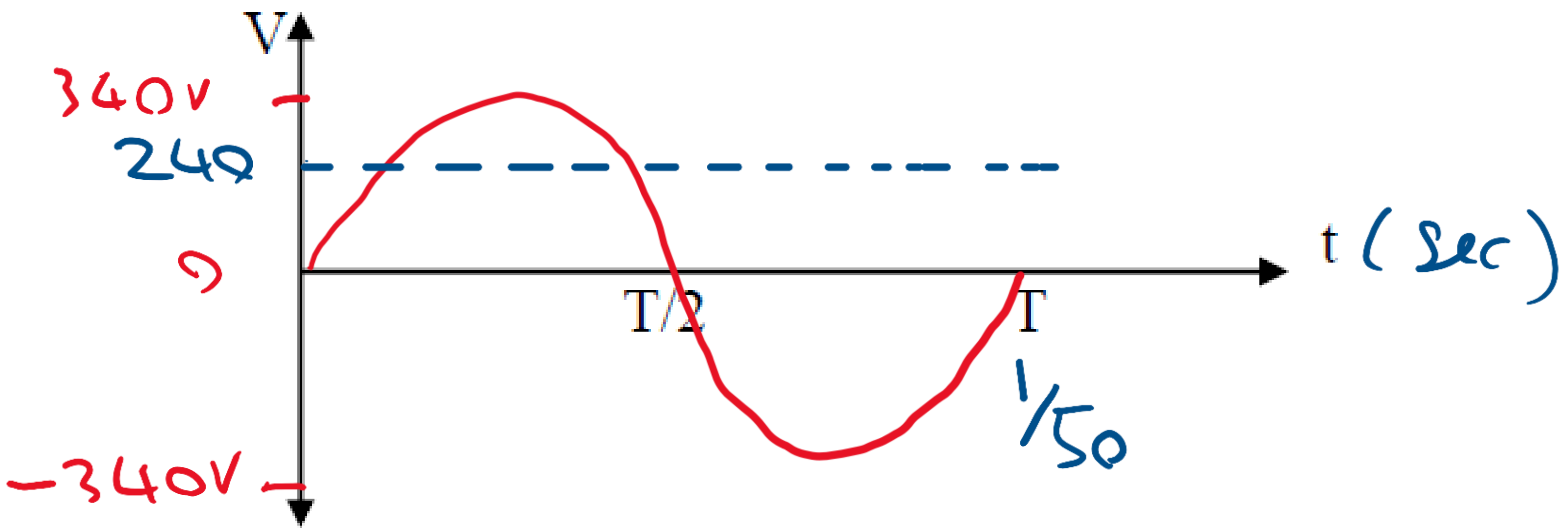
1/ The voltage supplied to suburban homes in Australia is 240V(rms) A.C.

(i) What is the peak value of this? $V_p = \sqrt{2} \times V_{rms} = \sqrt{2} \times 240 = 339\,V$

(ii) What is the Peak-to-Peak Voltage? $= 2V_p \sim 680\,V$

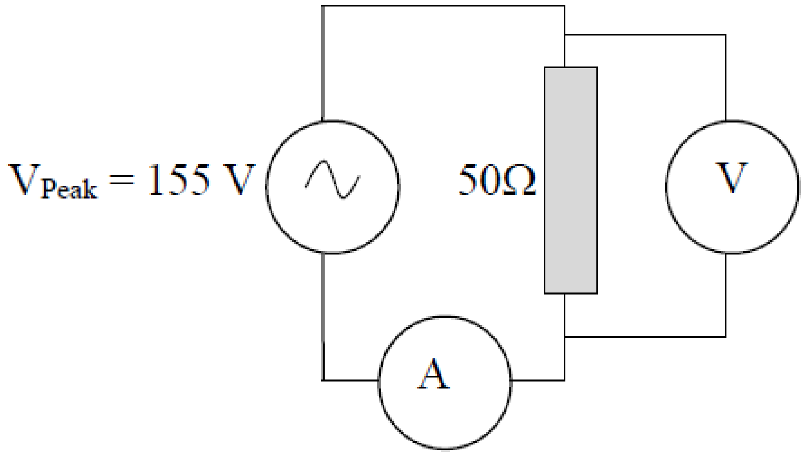
(iii) Sketch the V – t graph for this: (T = period)

$f = 50\,Hz$



2/ In the United States the Domestic Voltage is less than we use. Their voltage's peak value is $V_{Peak} = 155V$.

(a) Calculate the RMS voltage



(b) Calculate the RMS current

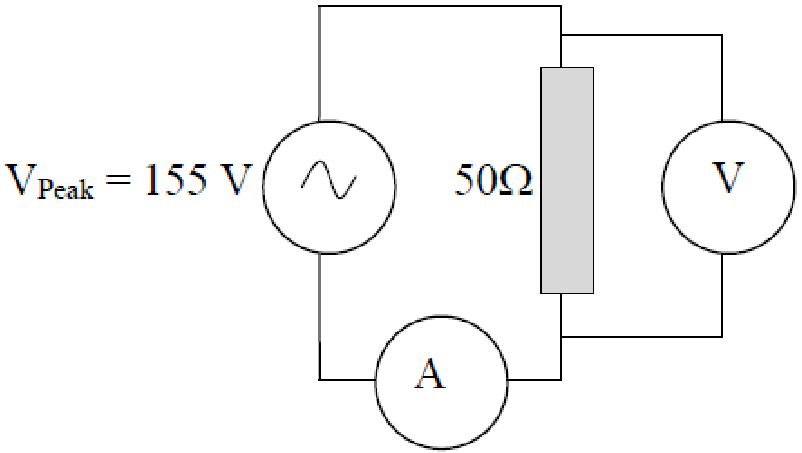
(c) Calculate the peak current

Solutions:

2/ In the United States the Domestic Voltage is less than we use. Their voltage's peak value is $V_{Peak} = 155V$.

(a) Calculate the RMS voltage

$$V_{RMS} = \frac{V_p}{\sqrt{2}} = \frac{155}{\sqrt{2}} = 110V$$



(b) Calculate the RMS current

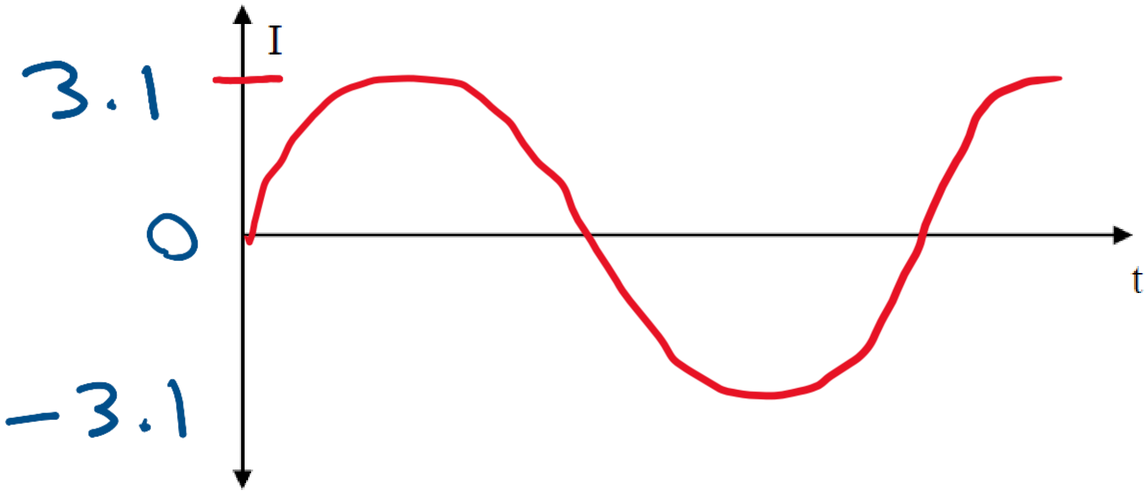
$$V = IR$$

$$110 = I \times 50 \,, \quad I_{RMS} = 2.2A$$

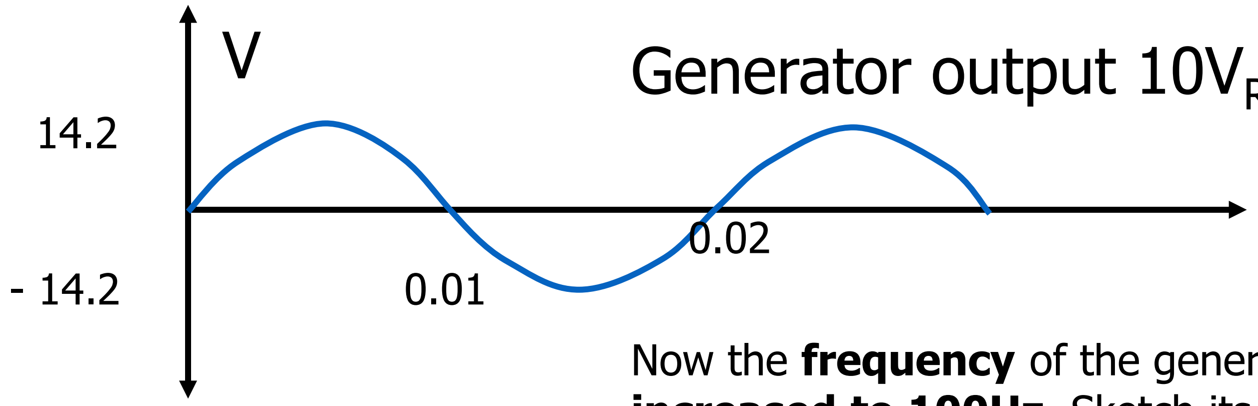
(c) Calculate the peak current

$$I_p = \sqrt{2} \times 2.2$$

$$= 3.1A$$



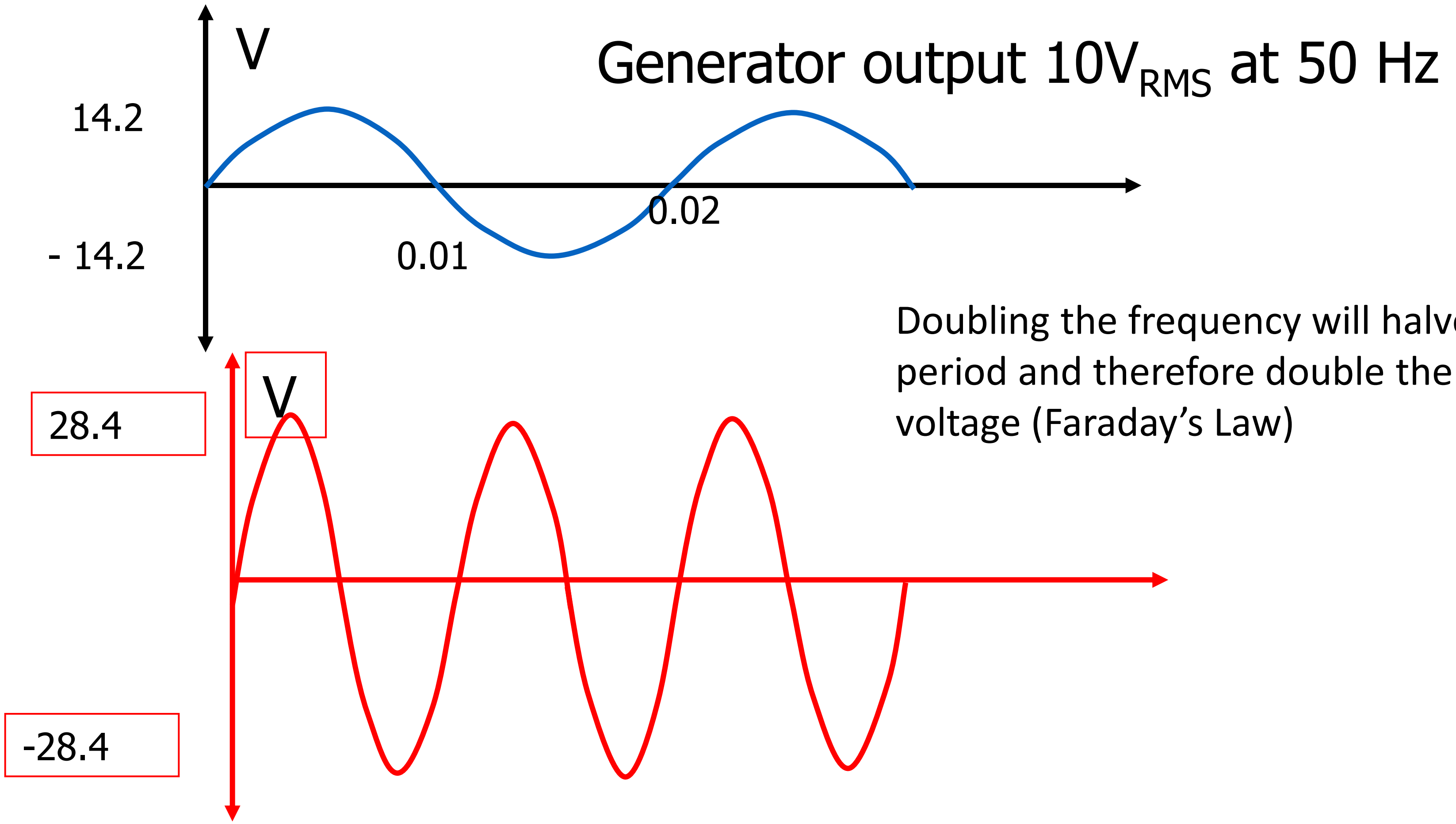
Generators



Generator output $10V_{RMS}$ at 50 Hz

Now the **frequency** of the generator is **increased to 100Hz**. Sketch its output:

Generators



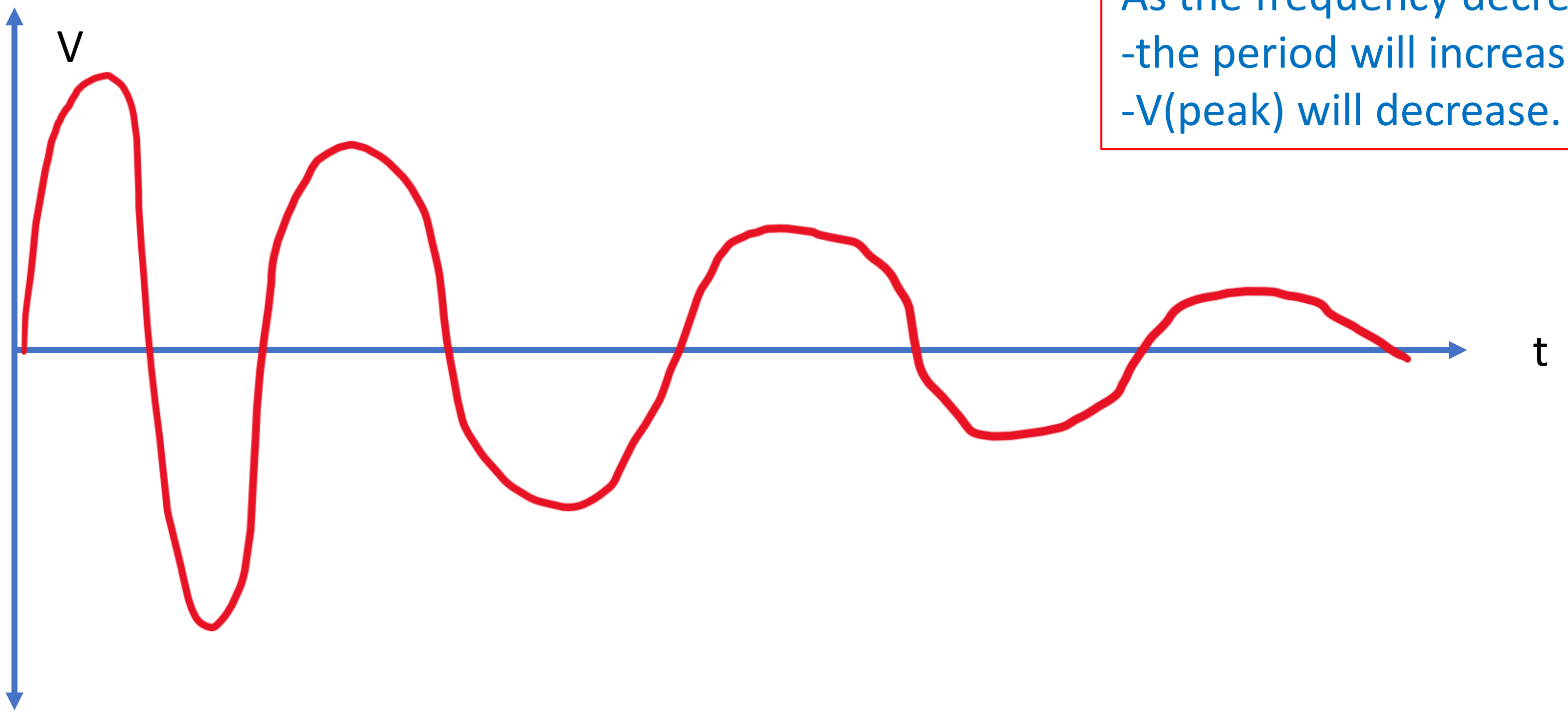
Doubling the frequency will halve the period and therefore double the peak voltage (Faraday's Law)

Problem:

A generator whose output was a constant AC value is switched off and gradually winds down.
Sketch the shape of the output:

Solution:

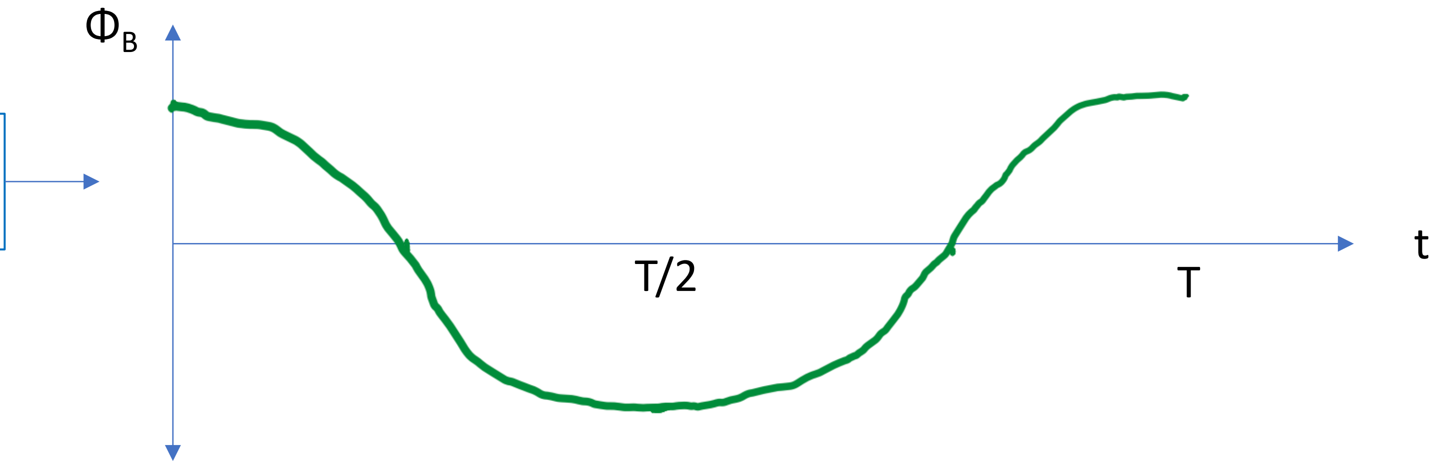
A generator whose output was a constant AC value is switched off and gradually winds down.
Sketch the shape of the output:



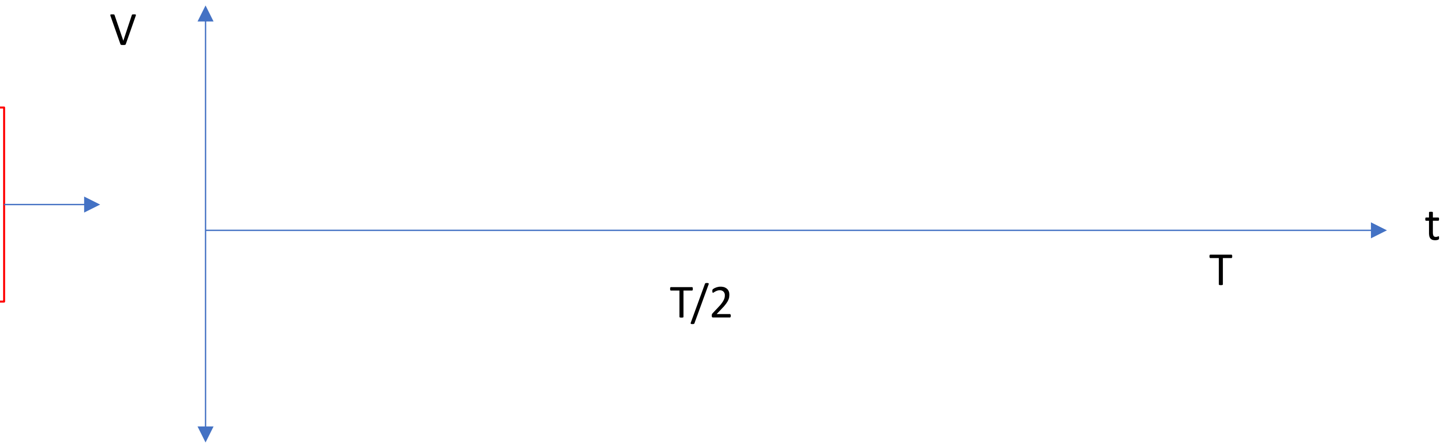
As the frequency decreases:
-the period will increase
-V(peak) will decrease.

Problem: AC Generation:

Flux vs time graph



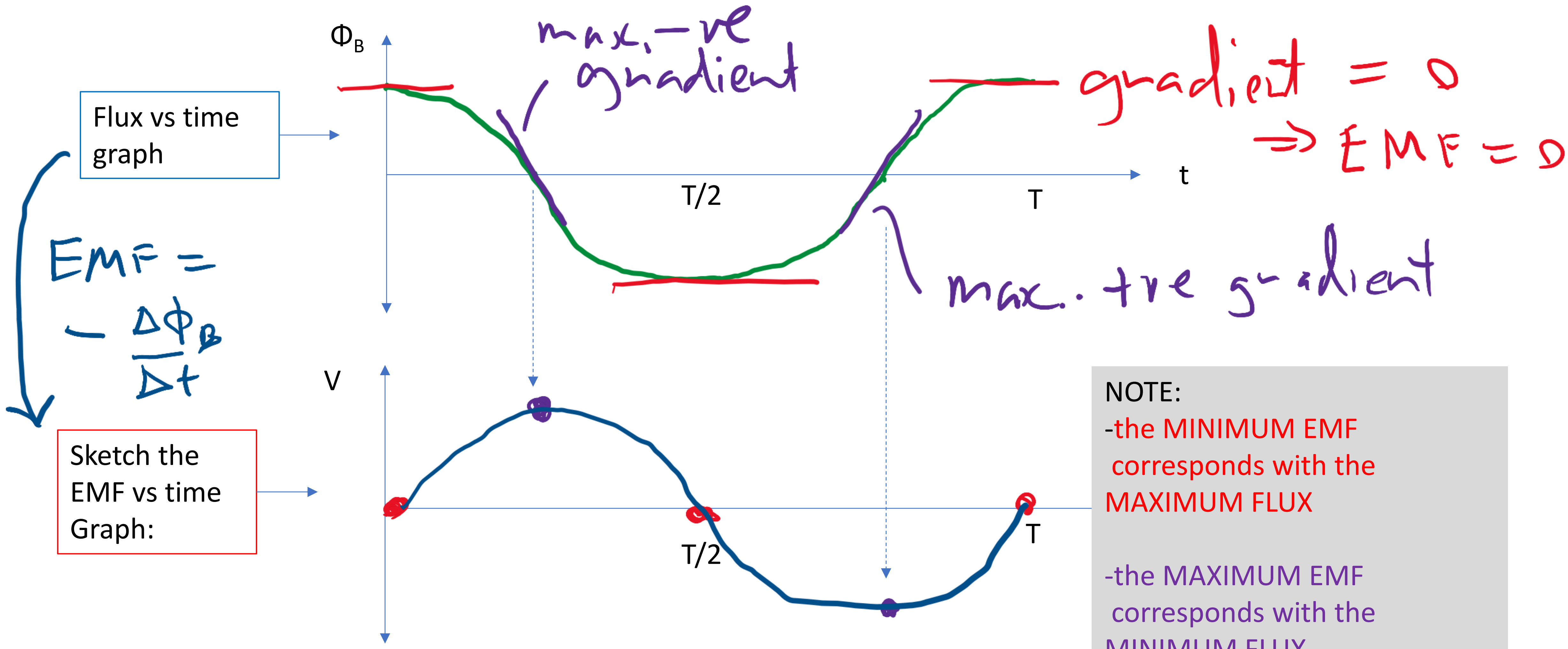
Sketch the EMF vs time Graph:



Problem: AC Generation:

Flux vs time graph

Sketch the EMF vs time Graph:



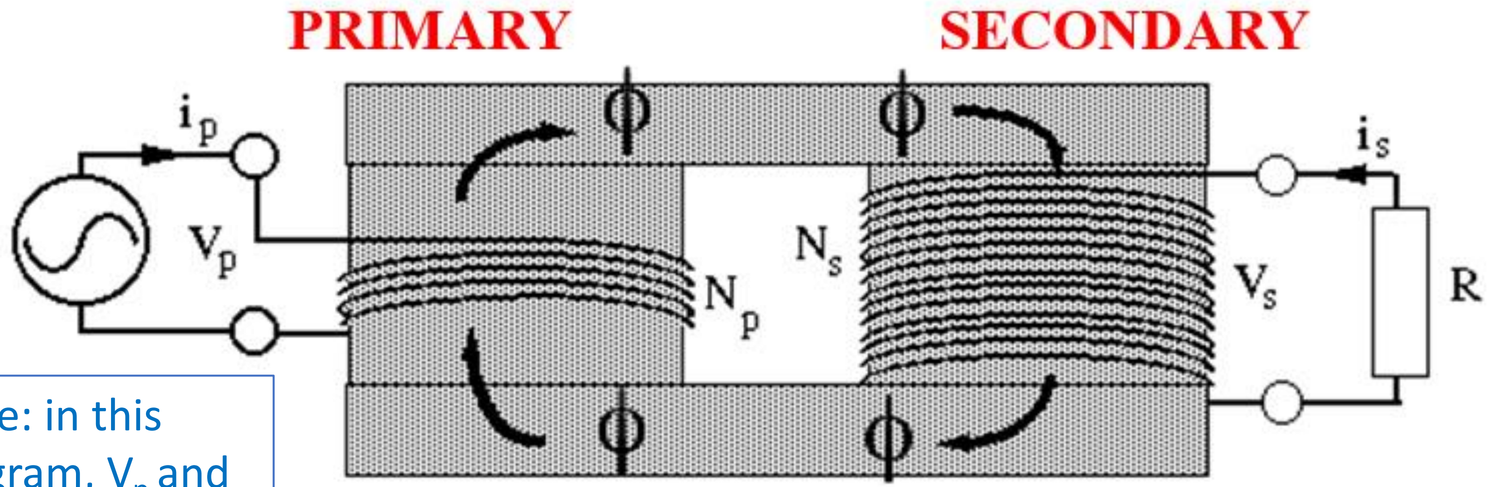
NOTE:

-the MINIMUM EMF corresponds with the MAXIMUM FLUX

-the MAXIMUM EMF corresponds with the MINIMUM FLUX

Transformers

Basic transformer:



Note: in this diagram, V_p and I_p stand for *primary* voltage and current respectively, *not the peak values*.

f(Hz) in = f(Hz) out

Assume an *Ideal* Transformer:

Power(in) = Power(out)

P = Primary (the side that is connected to the power supply)
S = Secondary (where the output is drawn from)

$$\frac{V_S}{V_P} = \frac{I_P}{I_S} = \frac{N_S}{N_P}$$

Turns Ratio TR = N_S / N_P

Power (primary) = Power (secondary)

Power = V(rms) x I(rms) = ½ V_{peak} x I_{peak}

V(rms) = V(peak) / √2 I(rms) = I(peak) / √2

Frequency at Primary = Frequency at Secondary

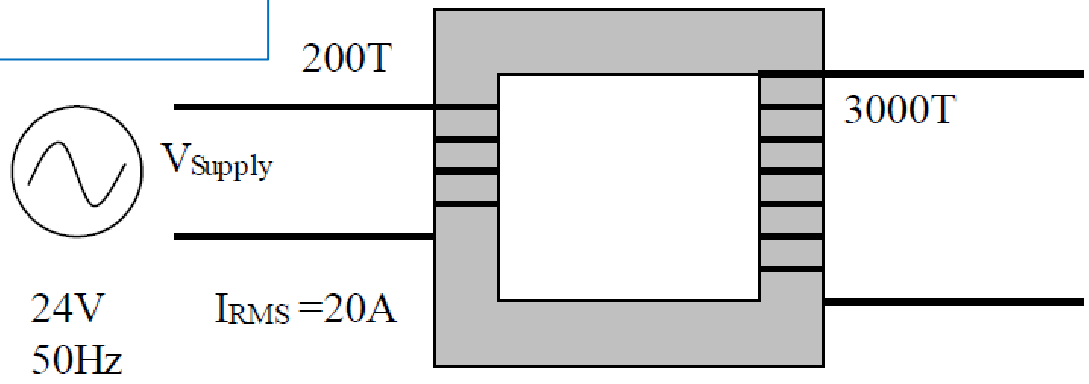
- If $\mathbf{N_s > N_P}$ (more turns on the secondary than the primary) then $V_S > V_P$

  This is a **Step-Up** Transformer

- If $\mathbf{N_s < N_P}$ (less turns on the secondary than the primary) then $V_S < V_P$

  This is a **Step-Down** Transformer

Problems:



$N_S > N_P$

Step-Up Transformer

(a) Calculate the Turns Ratio N_S / N_P

(b) Calculate the RMS voltage at the secondary:

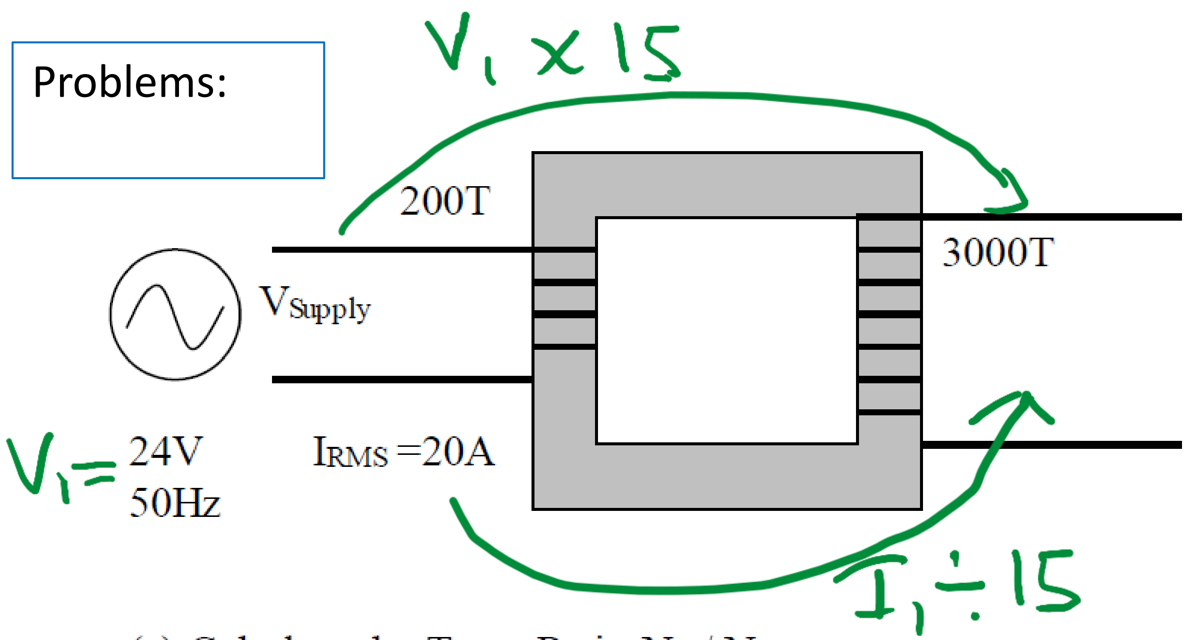
(c) What is the peak voltage at the secondary: V_{Peak} ?

(d) What current flows in the secondary windings?

(e) What power is supplied to this transformer's primary?

(f) What is the frequency of the AC output at the secondary?

Problems:



$N_S > N_P$

Step-Up Transformer

(a) Calculate the Turns Ratio N_S / N_P

$N_S/N_P = \frac{3000}{200} = 15$

(b) Calculate the RMS voltage at the secondary:

$24 \times 15 = 360V$

(c) What is the peak voltage at the secondary: V_{Peak} ?

$360 \times \sqrt{2} = 510V$

(d) What current flows in the secondary windings?

$20 \div 15 = 1.33A$

(e) What power is supplied to this transformer's primary?

$P = V_{Rms} \times I_{Rms} = 24 \times 20 = 480W$

(f) What is the frequency of the AC output at the secondary?

$f_{in} = f_{out} = 50Hz$

(g) The 24V AC Supply is now replaced with a 12V DC battery. What is the value of the voltage output from the secondary? Justify your answer.

(g) The 24V AC Supply is now replaced with a 12V DC battery. What is the value of the voltage output from the secondary? Justify your answer.

Solution:

The output will be **zero volts**, for a 12V DC input, or indeed, any DC input.

With DC there will be magnetic flux present in the primary and secondary, as there is a current carrying solenoid around the input, however, it is not *changing,* $\Delta\phi_B = 0$, and therefore no EMF is induced at the secondary.

OR: EMF(secondary) = $-N \times \frac{\Delta\Phi_B}{\Delta t} = 0$ when $\Delta\phi_B = 0$

Transmission lines

With the electric circuits in the devices we normally study that could fit on a desk top, we are always able to neglect the resistance of the wires as they are at most a few metres long and their resistance is usually negligible compared with other components in the circuits.

In the wires that make up the power network, the wires that cover the state and all the streets within it have many thousands of kilometres of wires and their resistance can no longer be ignored. Because of the very high currents that the wires carry, even a few ohms of resistance can produce significant power losses unless transformers are used.

The solution to reducing the losses is to use AC with transformers to step up the supply voltage and step down the line current.

The steps to follow in solving these problems are:

1/ Calculate the current in the line:

(i) Without a step-up transformer:
I(line) = P(generator)/V(generator)

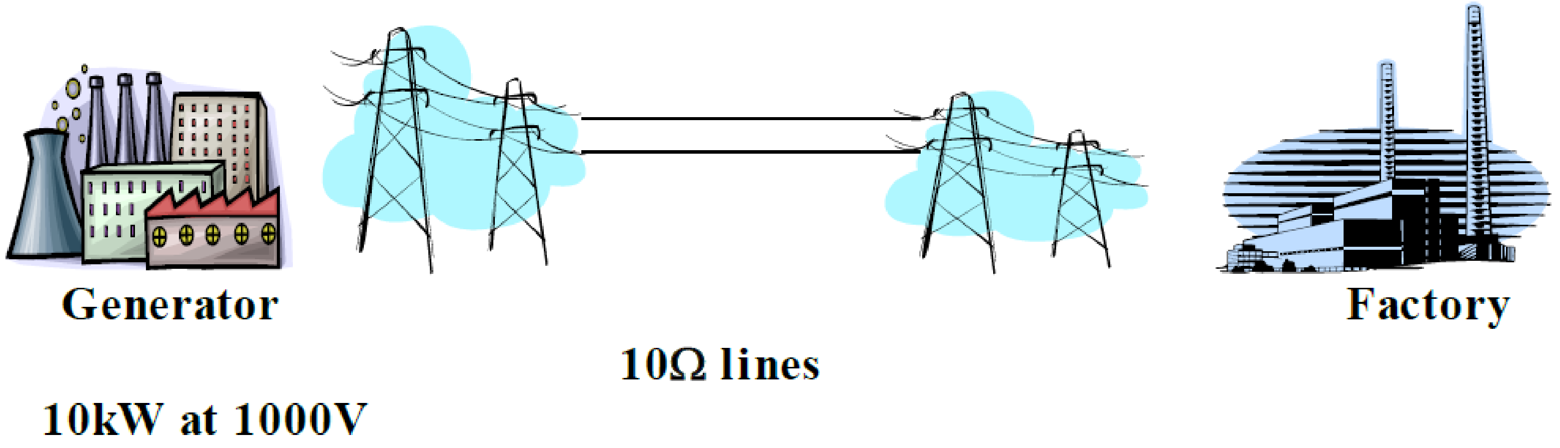
(ii) With a step-up transformer at the output of the generator:
I(line) = P(generator)/V(output of the step-up transformer)

2/ The Power Loss in the lines:
$P(loss) = I_{line}^2 \times R(lines)$

The reason that is better to deal with the line current than the voltage is that there are 3 voltages but only one current.
There is the voltage at the generator (usually specified), the voltage loss across the lines and the voltage than is available at the end of the line [= V(gen) – V(line loss)]
Too many students who try to calculate the power loss from P = VI choose the wrong voltage.
However, the current in the line is the same from generator to destination, so there's no chance for confusion when we use P(loss) = I^2R

1. Power transmission *without* transformers:

A generator produces 10kW of power at 1000V (RMS, A.C.). This is to be supplied to a small factory 20km away. The wires that connect the two have a total resistance of 10Ω.



Calculate:

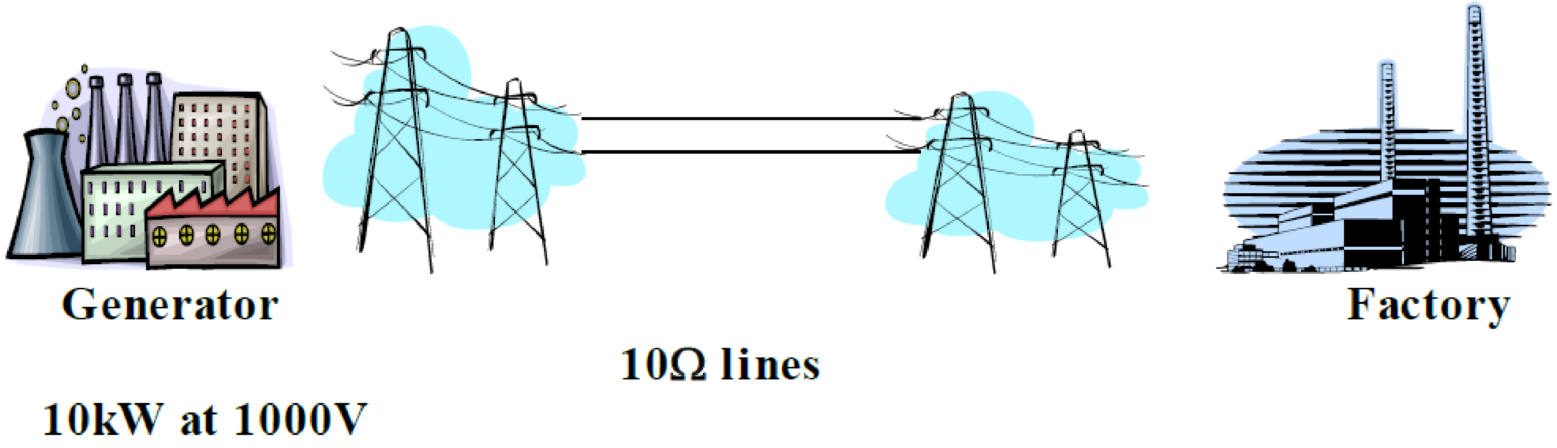
(i) The power loss in the line

(ii) The percentage power delivered to the factory

Solutions:

1. Power transmission *without* transformers:

A generator produces 10kW of power at 1000V (RMS, A.C.). This is to be supplied to a small factory 20km away. The wires that connect the two have a total resistance of 10Ω.



Calculate:

(i) The power loss in the line

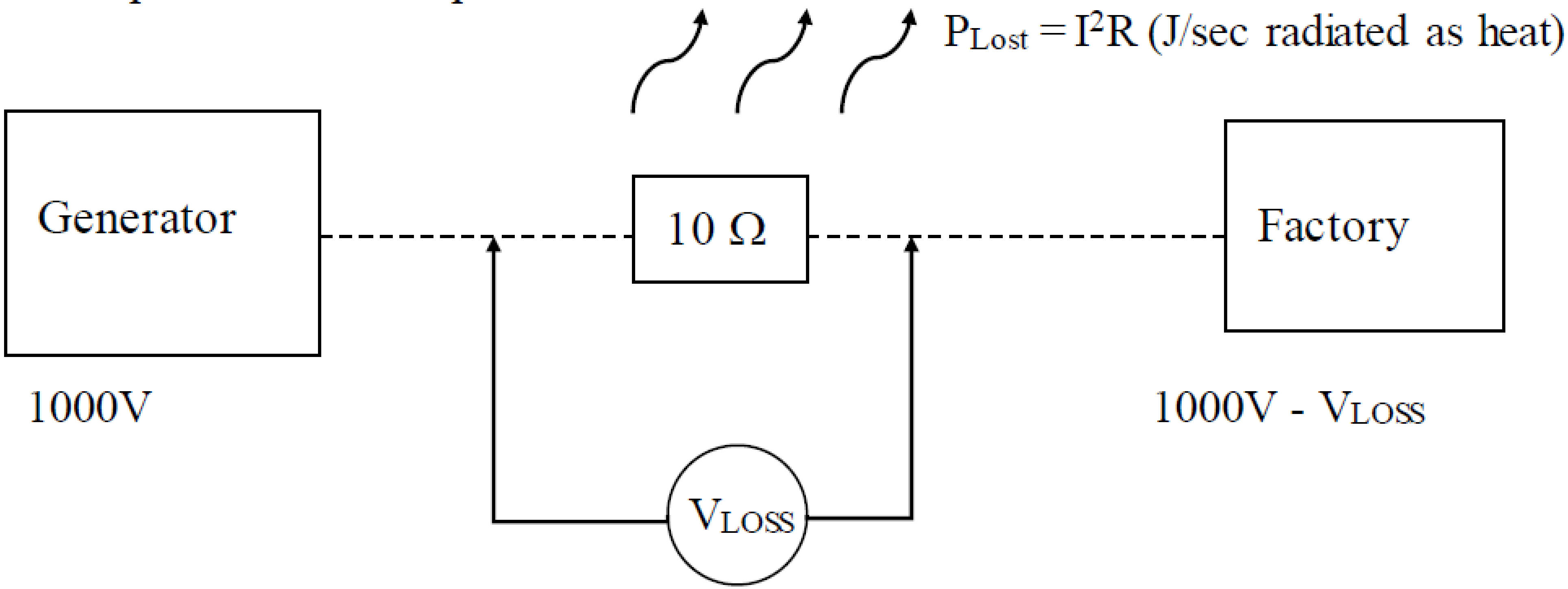
I(line) = P(generator)/V(generator) = 10,000/1000 = 10A

P(loss) = $I(line)^2R = 10^2 \times 10 = 1000$ W

(i) The percentage power delivered to the factory

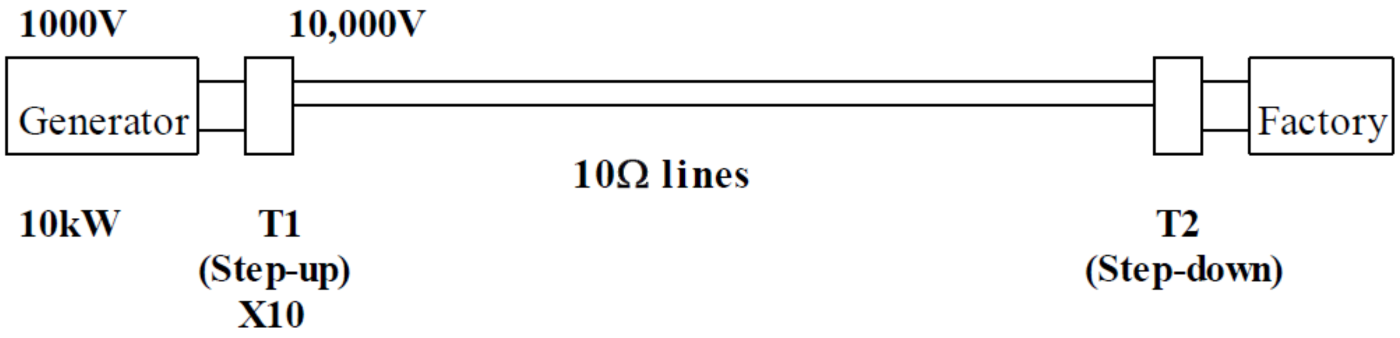
% loss = 1000W/10,000W x 100/1 => 10% => 90% delivered.

A simple model of the problem:



Now repeat the problem with the same lines only we introduce a step-up transformer and step-down transformer:

The percentage lost just calculated is considered unacceptable and so a step-up transformer (T1) is installed close to the generator to boost the supply voltage to 10kV (that is, increase the voltage by a factor of 10). A step-down transformer (T2) is installed close to the factory to reduce the voltage back to useable levels. There is still effectively 10km of cable between them.



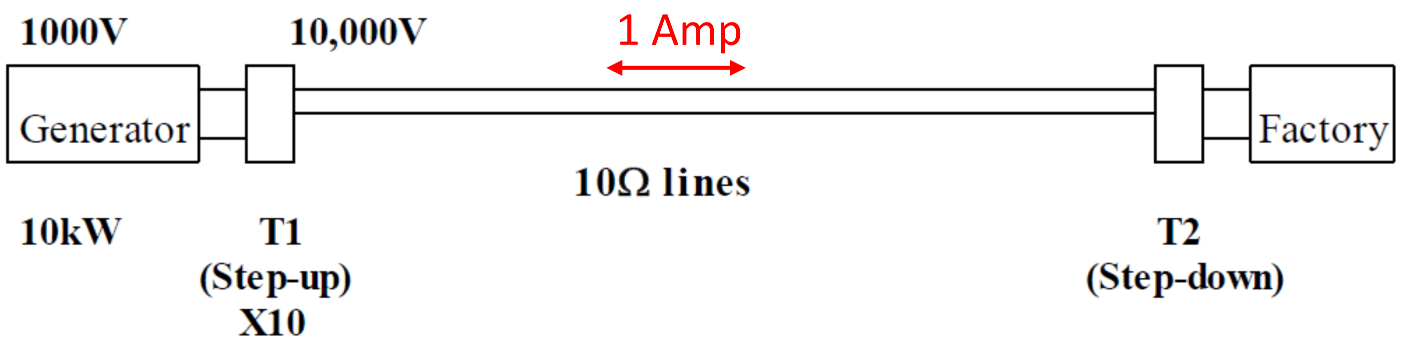
Calculate:

(i) The power loss in the line

(ii) The percentage power delivered to the factory

Now repeat the problem with the same lines only we introduce a step-up transformer and step-down transformer:

The percentage lost just calculated is considered unacceptable and so a step-up transformer (T1) is installed close to the generator to boost the supply voltage to 10kV (that is, increase the voltage by a factor of 10). A step-down transformer (T2) is installed close to the factory to reduce the voltage back to useable levels. There is still effectively 10km of cable between them.



Solutions:

Calculate:

(i) The power loss in the line

I(line) = P(generator)/V(T1 output) = 10,000/10000 = **1A**

P(loss) = I(line)^{2}R = **1**^{2} x 10 = 10 W

(ii) The percentage power delivered to the factory

% loss = 10W/10,000W x 100/1=> 0.1% => 99.9 % delivered.

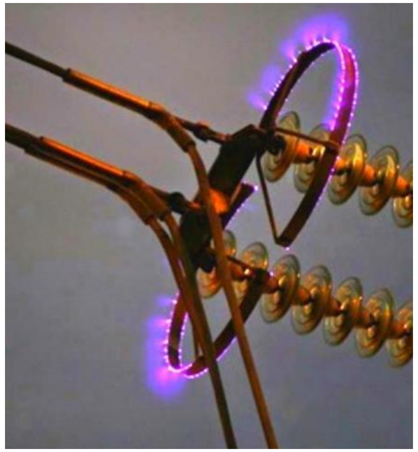
In general,

All transmission lines have resistance. Therefore there will be voltage and power losses across their length.

To reduce losses in transmission lines,

- Use AC because transformers only work with AC
- Use a step up transformer to increase the voltage that the lines are operating at.
- Since P = V x I and P is *constant*, increasing V will reduce I
- Since P(loss) in the lines = I^2R, reducing I, will reduce the power losses in the lines.

Note: there is a limit to how high line voltage can be, it's about 500 kV. Much above this and for uninsulated wires surrounded by air, there will be 'coronal discharge'. This is where the voltage is so high it will ionise the air around the line, and the consequent glow will dissipate energy from the line.

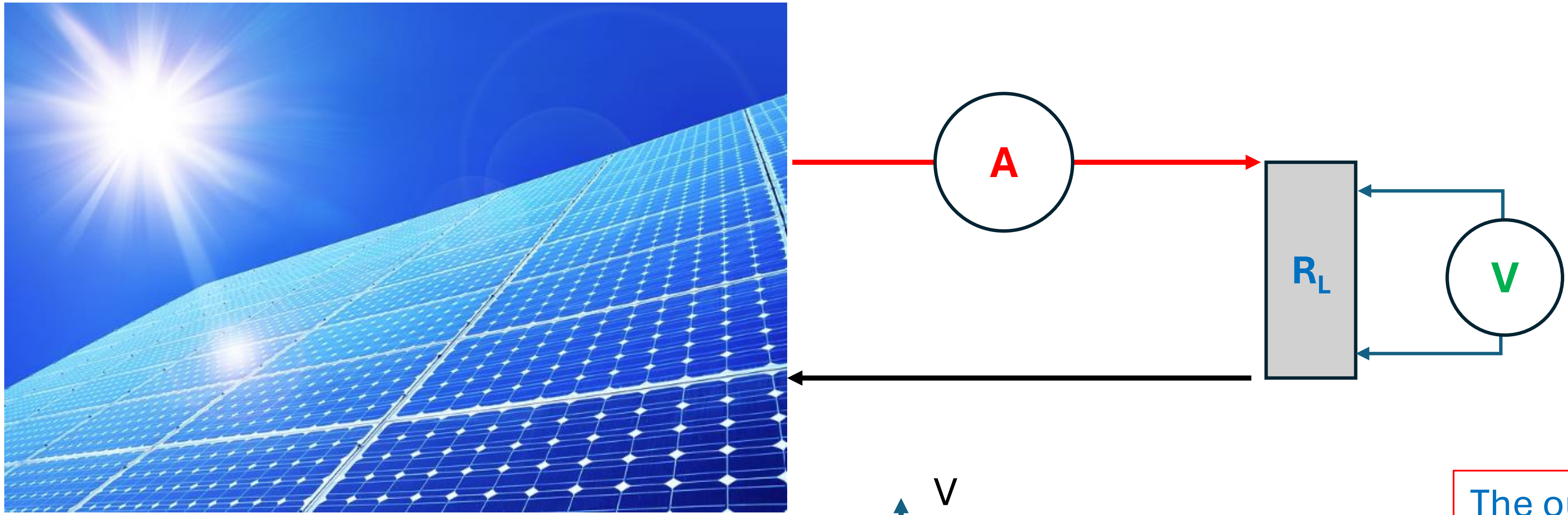


Photovoltaic Cells (PV Cells) and Inverters

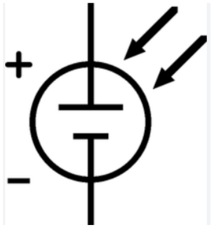
Physics U3 AoS3 Generation Principles

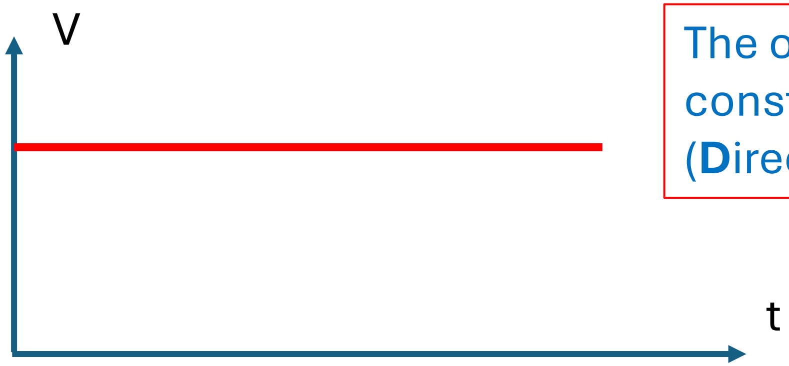
PJ Cuthbert

PV Cells covert light into electrical energy



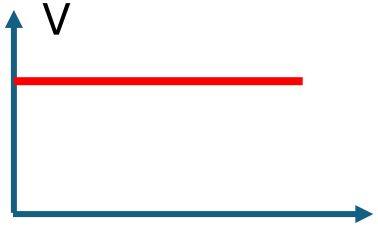
Symbol for a PV Cell:





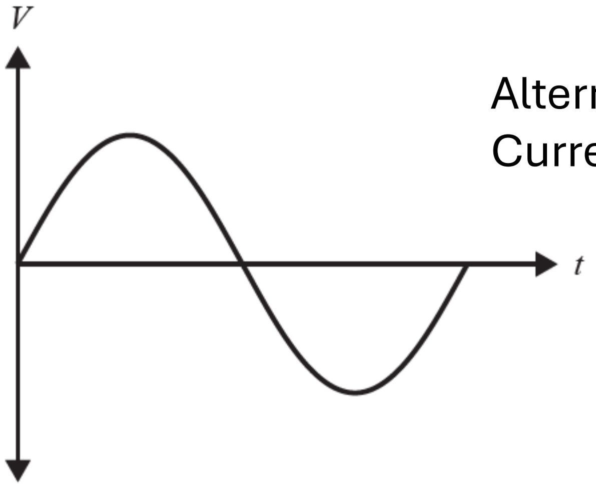
The output is constant DC (**D**irect **C**urrent)

PV Cell output:



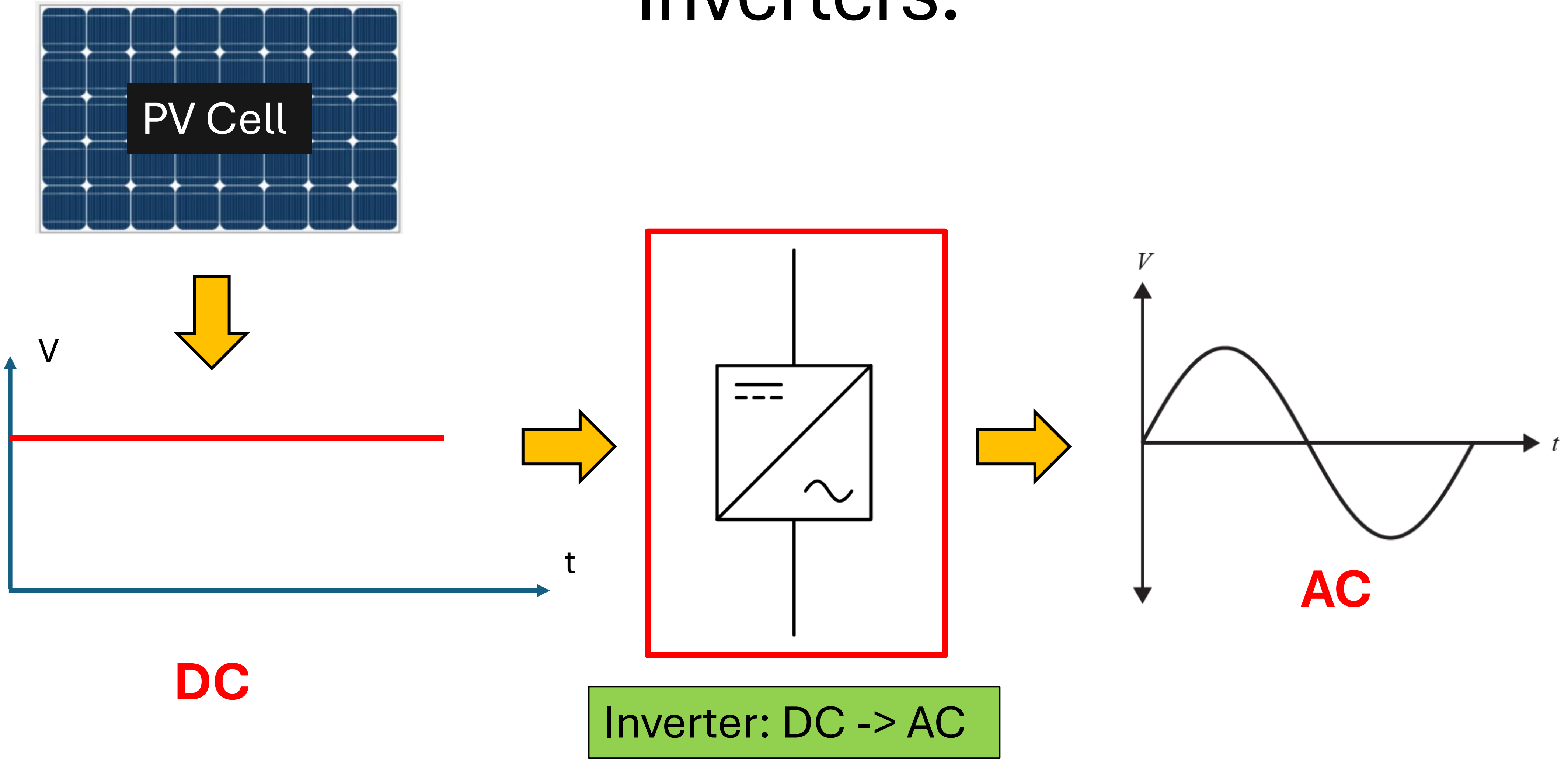
DC output:

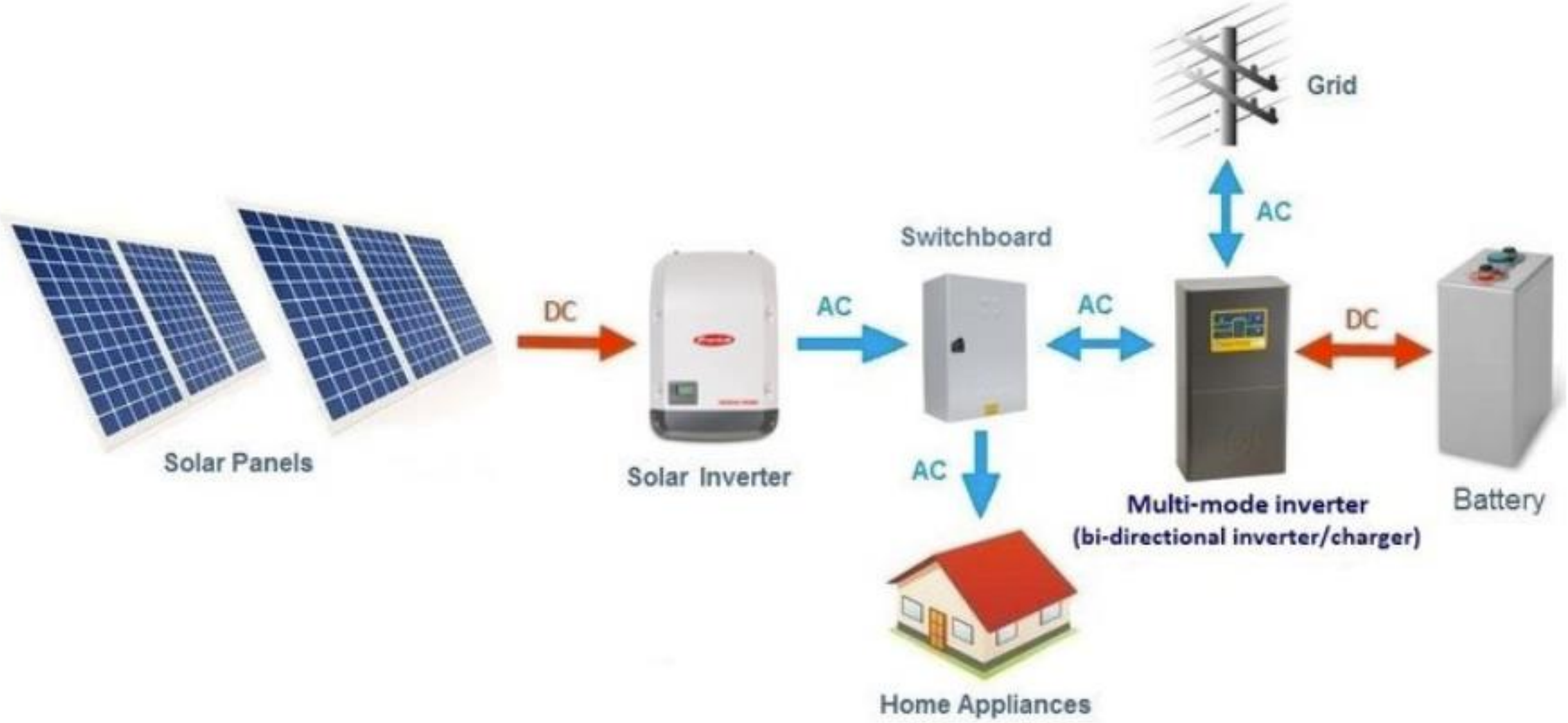
All household appliances require in input of 240 V mains AC:



Alternating Current, AC:

Inverters:

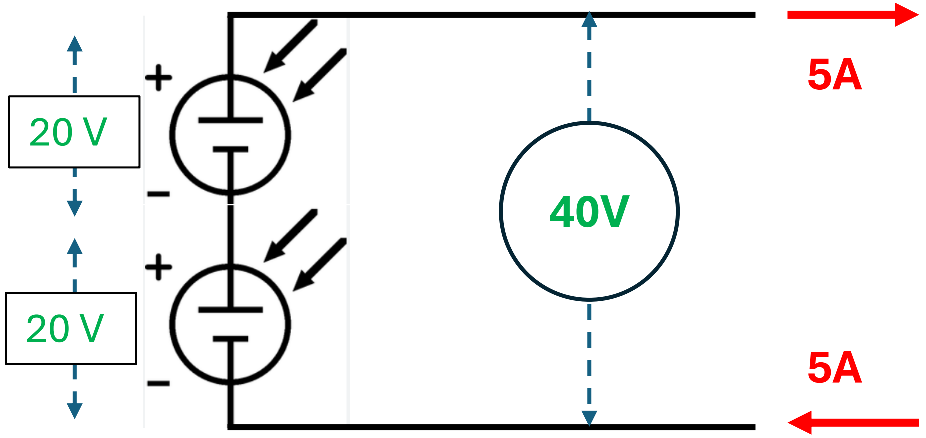



Grid
AC
Switchboard
DC
AC
AC
DC
Solar Panels
Solar Inverter
AC
Multi-mode inverter
(bi-directional inverter/charger)
Battery
Home Appliances

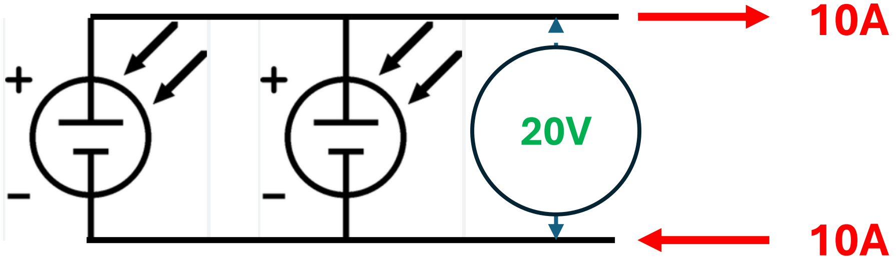
Parallel and series connections of power sources:

Assume you have two PV cells, **20 V** each with a current output of **5 A**:

1) **SERIES**: Voltages add, current stays the same:

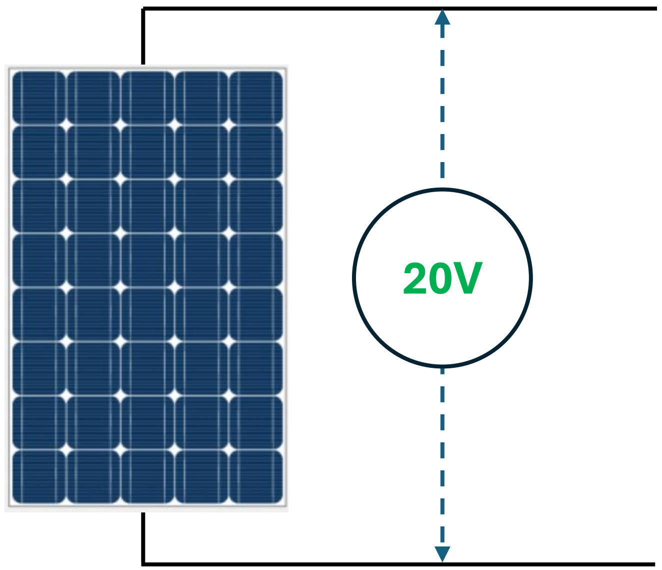


2) **PARALLEL**: Voltages stay the same, currents add:



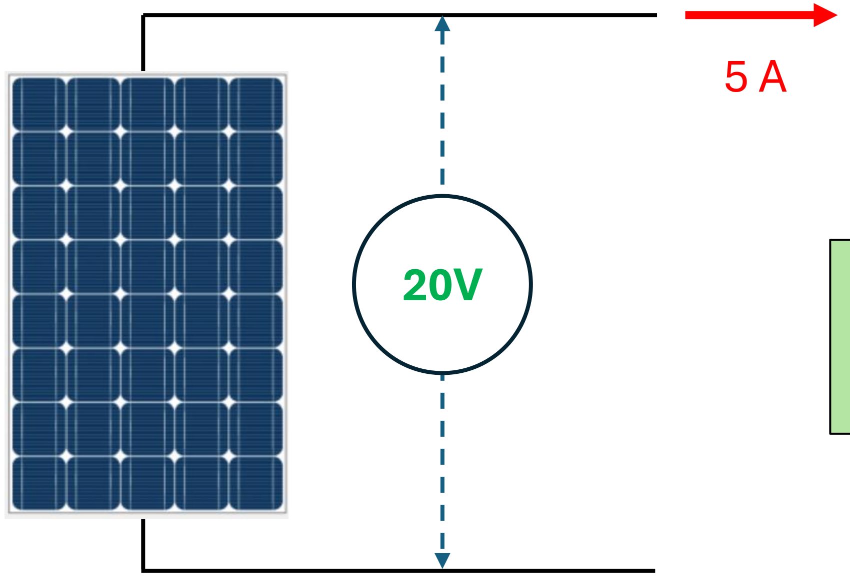
Parallel and Series connections-solar cells

This 100 Watt solar cell has a voltage output of 20 V. What is its **current** output?



Parallel and Series connections-solar cells

This 100 Watt solar cell has a voltage output of 20 V.
Q/ What is its **current** output?



P = V x I

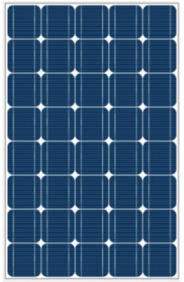
100 = 20 x I = > I = 100/20 = **5A**

Parallel and Series connections-solar cells

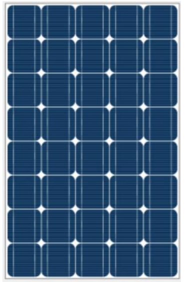
Consider a set of two solar cells under the same light conditions.

In each case, assume the voltage and current output from each, remains constant.

These two PV cells can be connected in either series or parallel to transmission lines that have a total resistance of 2 Ohms.



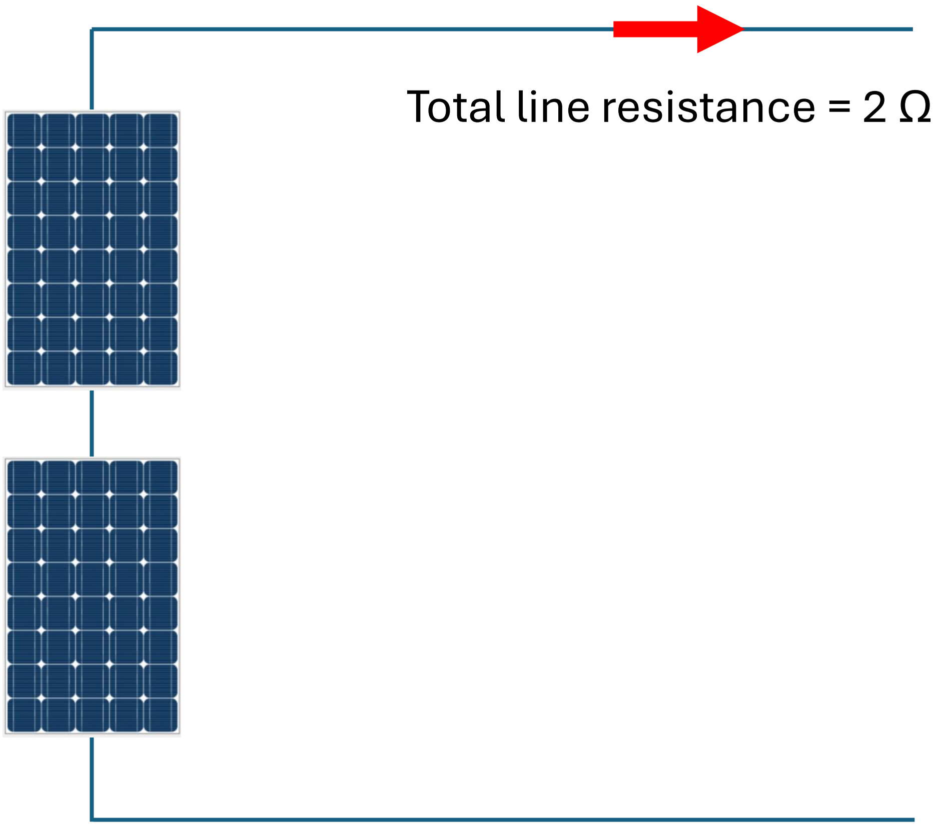
P = 100 W
V = 20 V
I = 5 A



P = 100 W
V = 20 V
I = 5 A

Transmission line losses with solar cells:

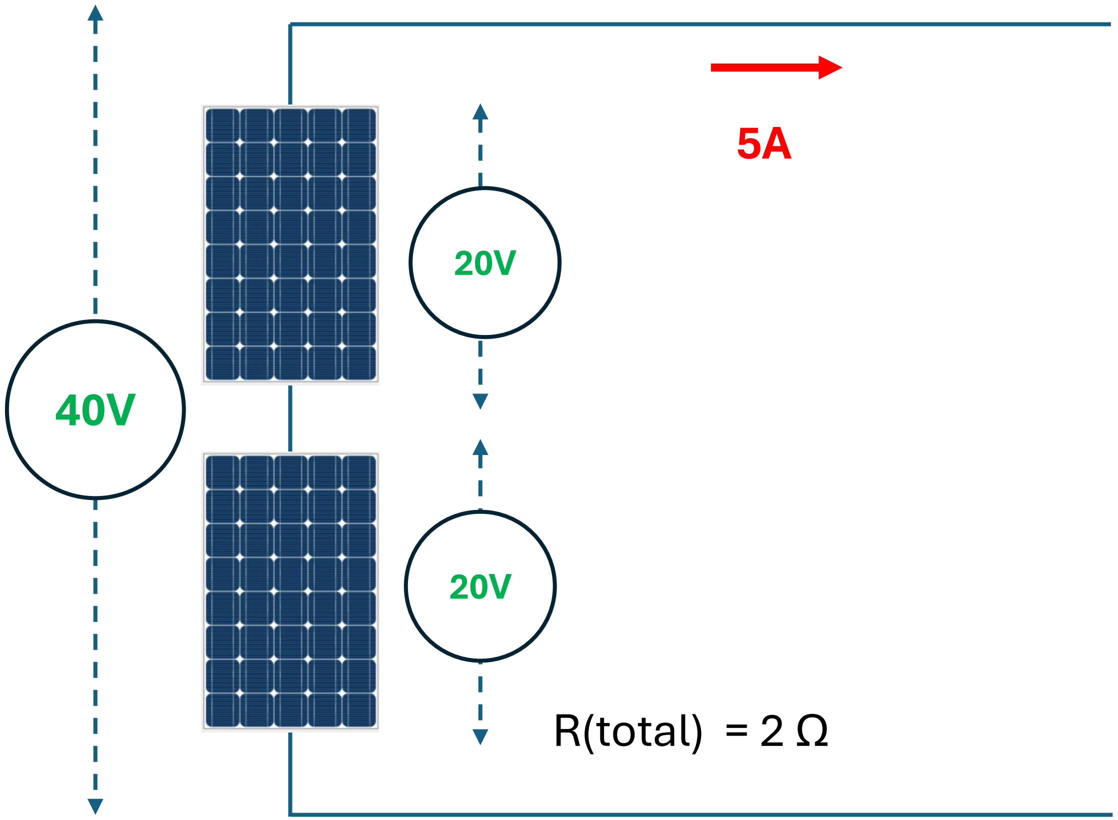
Series connection of two 100 W photovoltaic cells, each of output 20V, 5 A:



Calculate the power lost in the transmission lines:

Solution:

Series connection of two 100 W photovoltaic cells, each of output 20V, 5 A:



Calculate the power lost in the transmission lines:

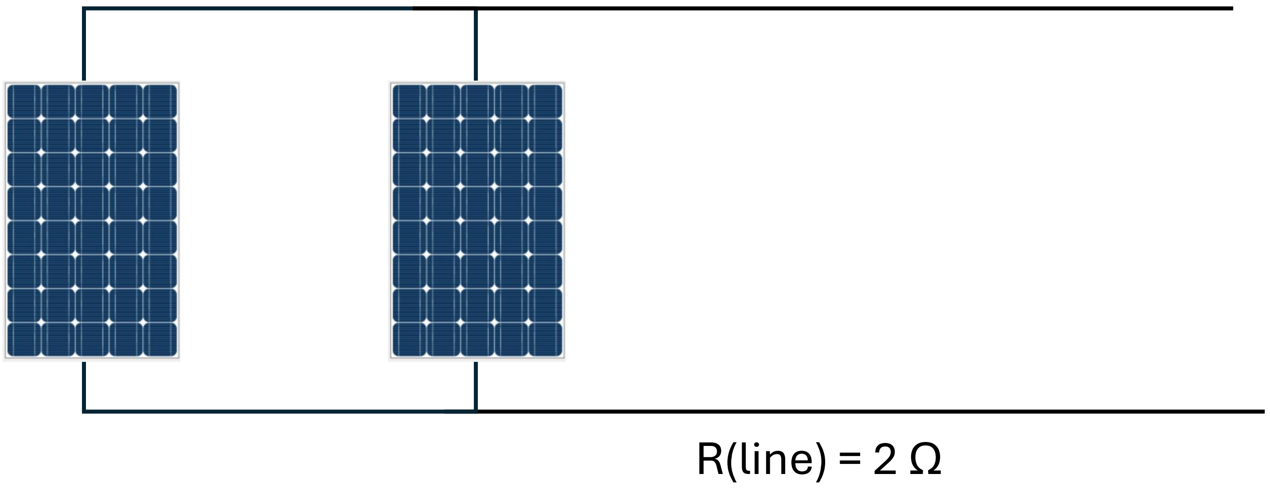
P(line loss) = I^2R

$= 5^2 \times 2 =$ **50 W**

Transmission line losses with solar cells:

Parallel connection of two 100 W photovoltaic cells, each of output 20V, 5 A:

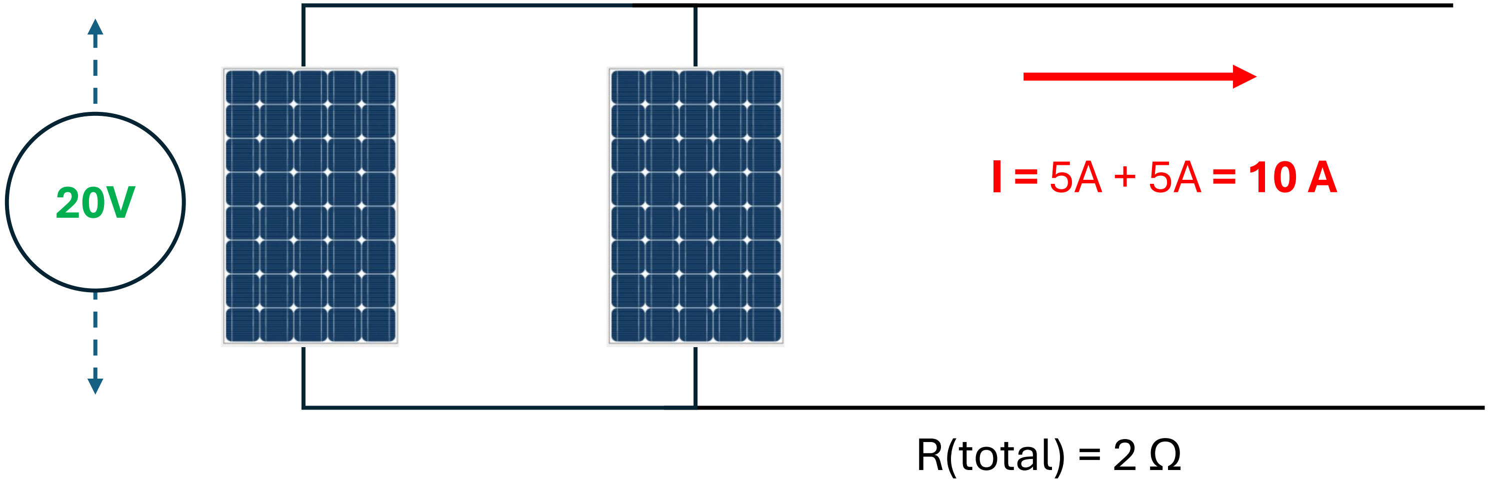
Calculate the power lost in the transmission lines:



Solution:

Parallel connection of two 100 W photovoltaic cells, each of output 20V, 5 A:

Calculate the power lost in the transmission lines:



P(line loss) = I^2R

= 10^2 x 2 = **200 W**

Note: with a parallel connection the current has doubled and therefore, as P(loss) ∝ $\mathbf{I}^2$, the loss is now 4 times higher.

Question:

Could we reduce the power loss in the transmission lines in the previous example of the two parallel-connected PV cells by connecting their output directly to a *step-up transformer?*

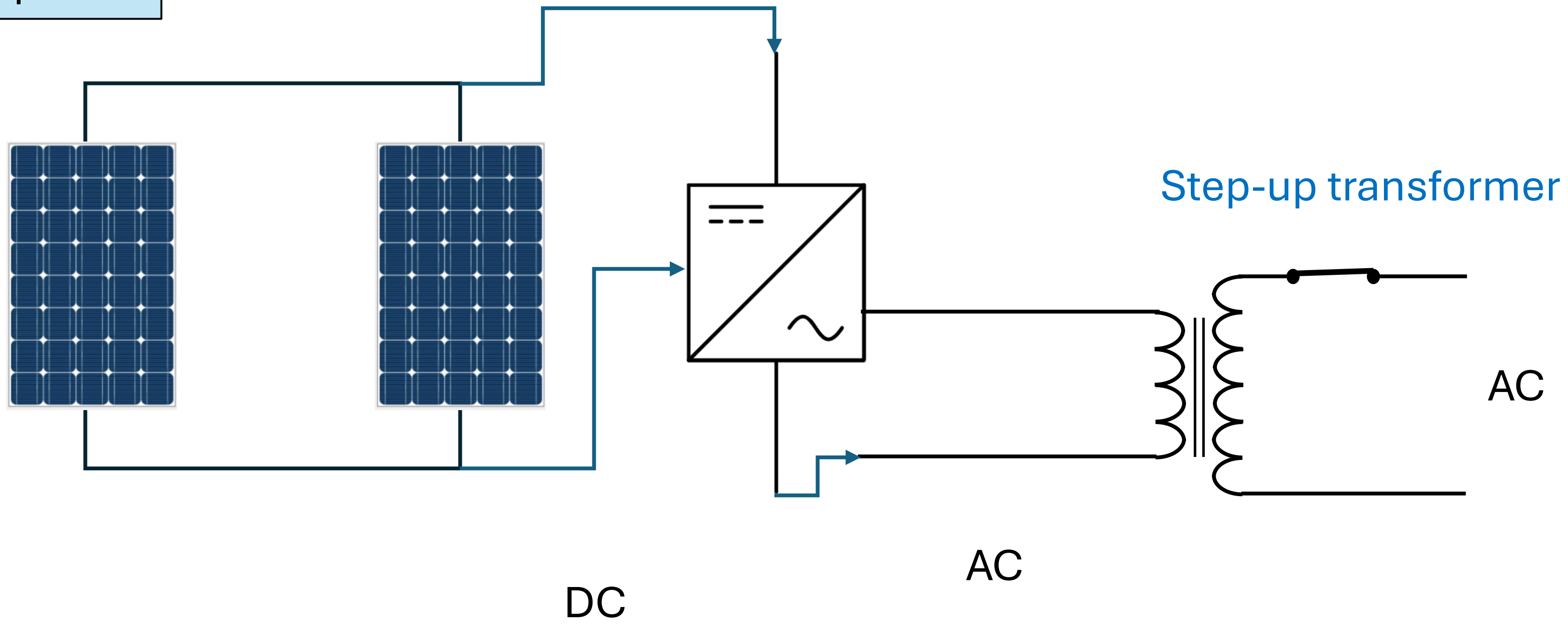
NO!

The output of PV Cells is constant DC and **transformers do not work with constant DC.**

However,

We could first convert the PV cell output from DC to AC by using an INVERTER, then connect the output of the inverter to a step-up transformer to then reduce the I^2R losses in the lines:

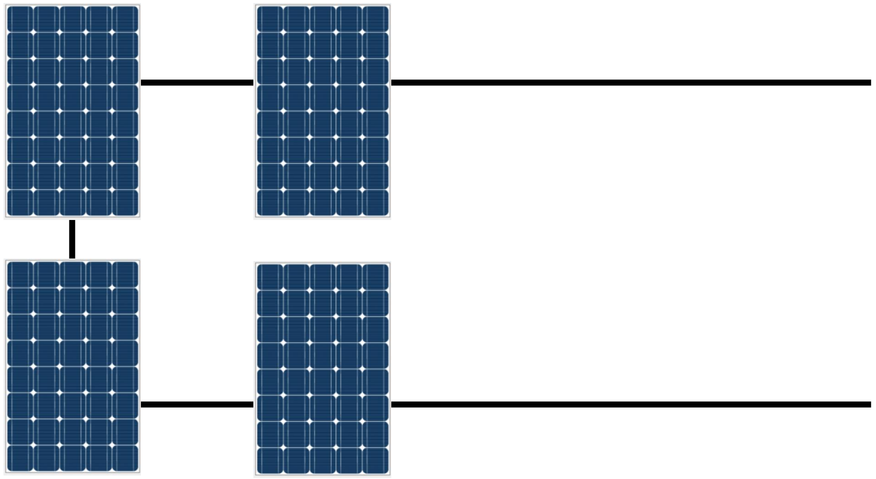
Example:



Problem-1:

Four solar batteries, each of power output 200 W and voltage output 20 V are connected in **series** to transmission lines of total resistance 2 Ohms.

Calculate the power loss in the transmission lines:

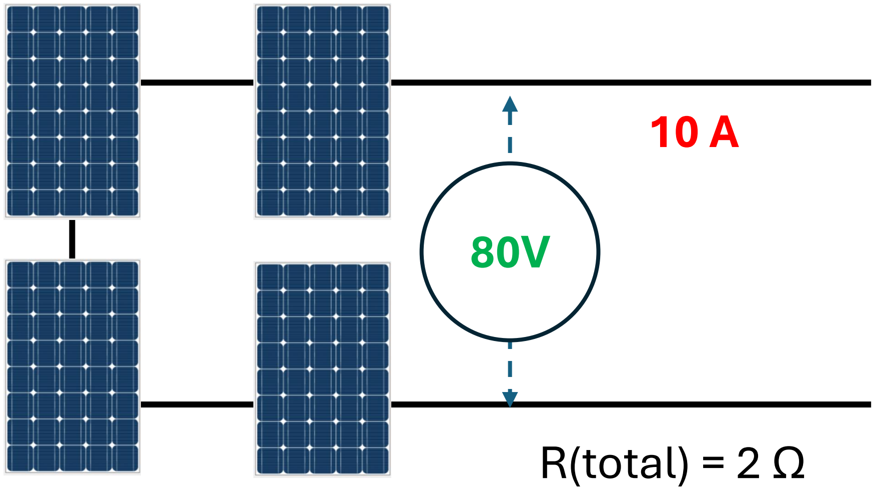


W

Solution:

Four solar batteries, each of power output 200 W and voltage output 20 V are connected in series to transmission lines of total resistance 2 Ohms.

Total power output = 4 x 200 = 800 W
OR: P = V x I = **80** x **10** = 800 W



I (each cell) = P/V = 200/20 = 10 A.

Series connection => voltages add, and current stays the same.

=> I(line) = 10 A

P(line loss) = $I^2R = 10^2 \times 2 = 200$ W

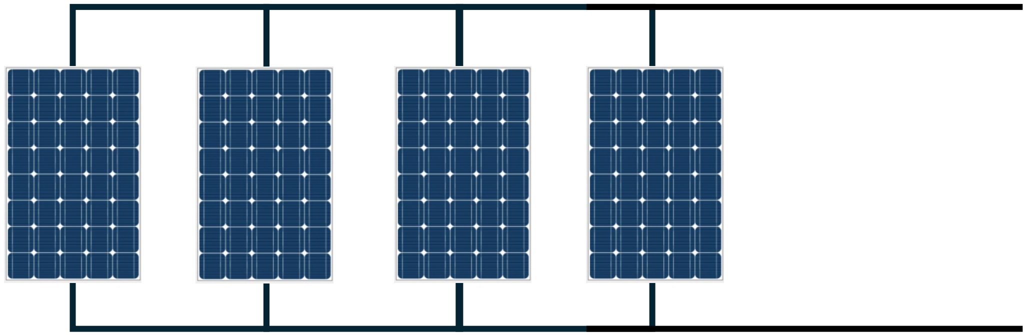
200 W

Note: Percent loss = 200/800 x 100 = **25%**

Problem-2:

Now the four solar batteries, each of power output 200 W and voltage output 20 V are connected in **parallel** to transmission lines of total resistance 2 Ohms.

Calculate the power loss in the transmission lines with this connection:



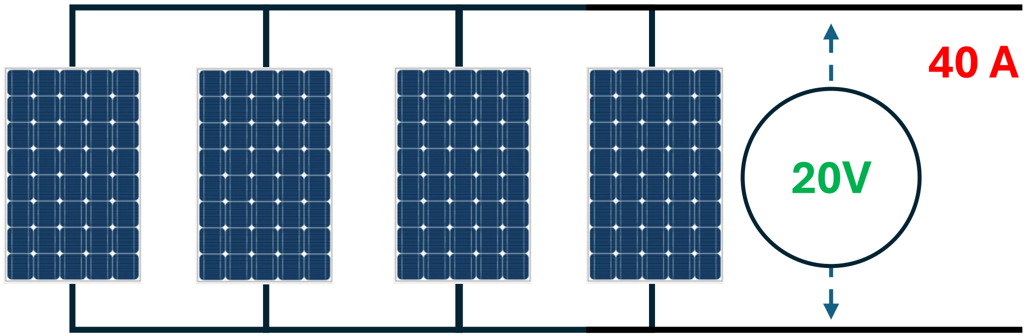
W

Solution:

Now the four solar batteries, each of power output 200 W and voltage output 20 V are connected in **parallel** to transmission lines of total resistance 2 Ohms.

Calculate the power loss in the transmission lines with this connection:

Total power output = 4 x 200 = 800 W
OR: P = V x I = **20** x 40 = 800 W



Again, I(each cell) = P/V = 200/20 = 10 A

Parallel connections => currents add
=> I(line) = 4 x 10 A = **40 A**

P(line loss) = I^2 x R = 40^2 x 2 = 3200 W

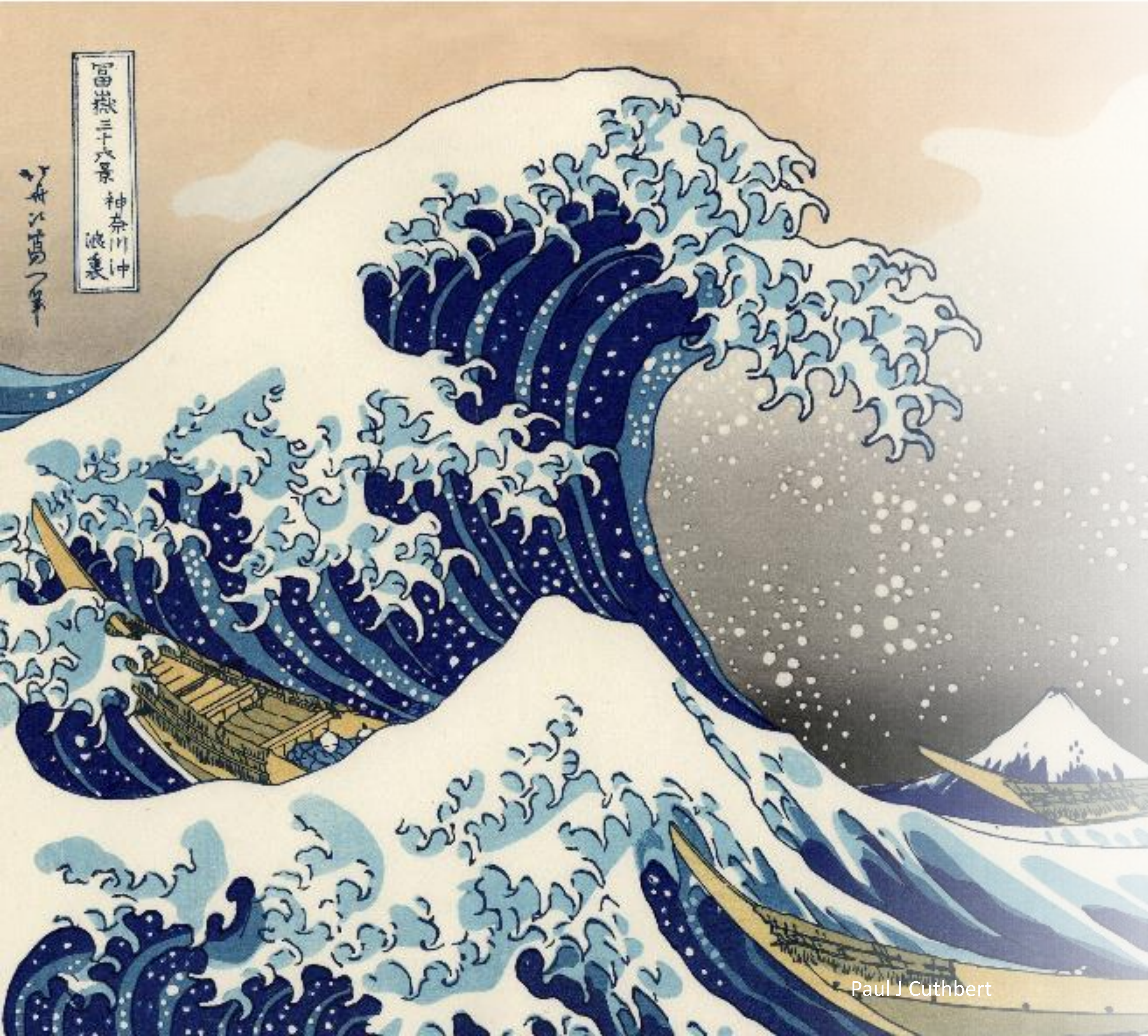
3200 W

Note: this loss exceeds the 800 W output. The system would not function.

Light & Waves
Unit 4 AoS#1-part 1

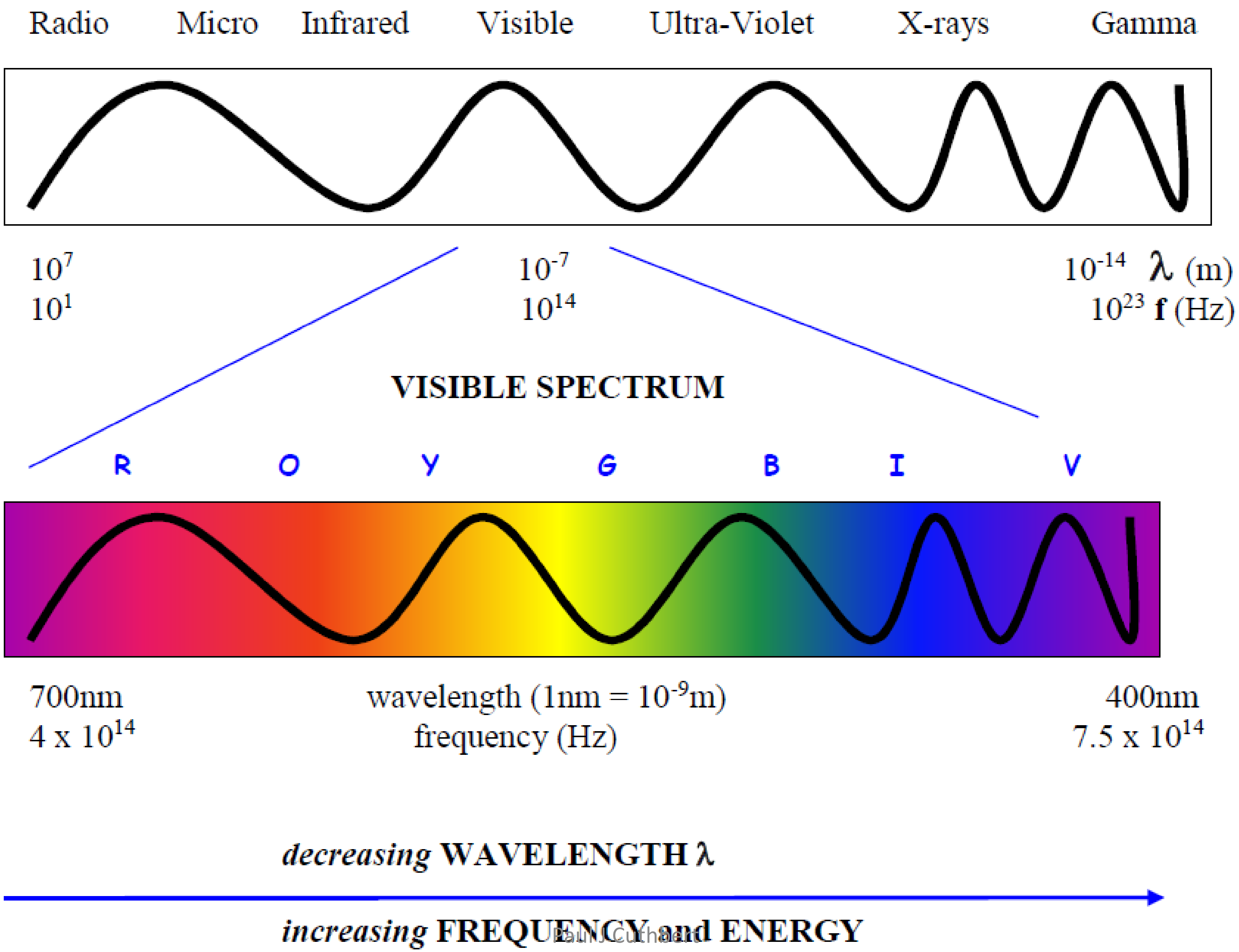
Monash University – Revision Lecture

2024



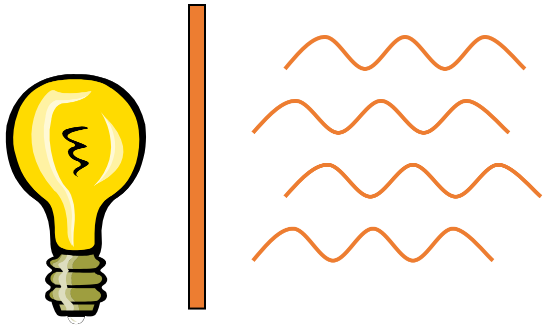
- **Contents:**
  - Definition
  - Types of waves
  - Pulses and waves
  - Reflection
  - Superposition
  - Standing waves and harmonics
  - Diffraction
  - Interference

The ELECTROMAGNETIC SPECTRUM:



Monochromatic Light

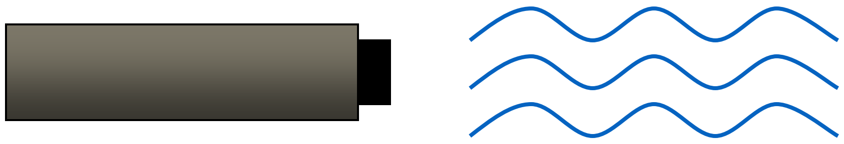
Normal Light:



Incoherent

Waves *not* in phase

Laser light:



Coherent

All Waves in phase

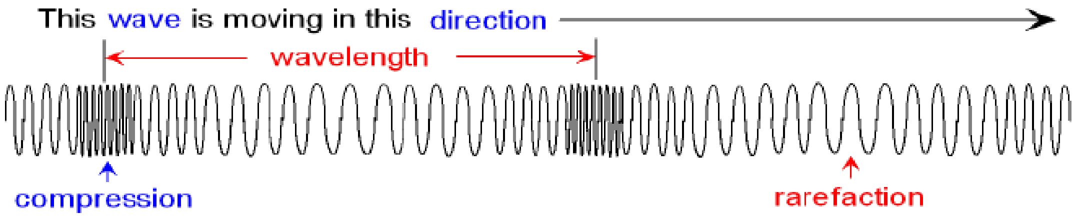
Definition:

All forms of wave motion allow the transfer of energy without the net transfer of matter.

Types of waves:

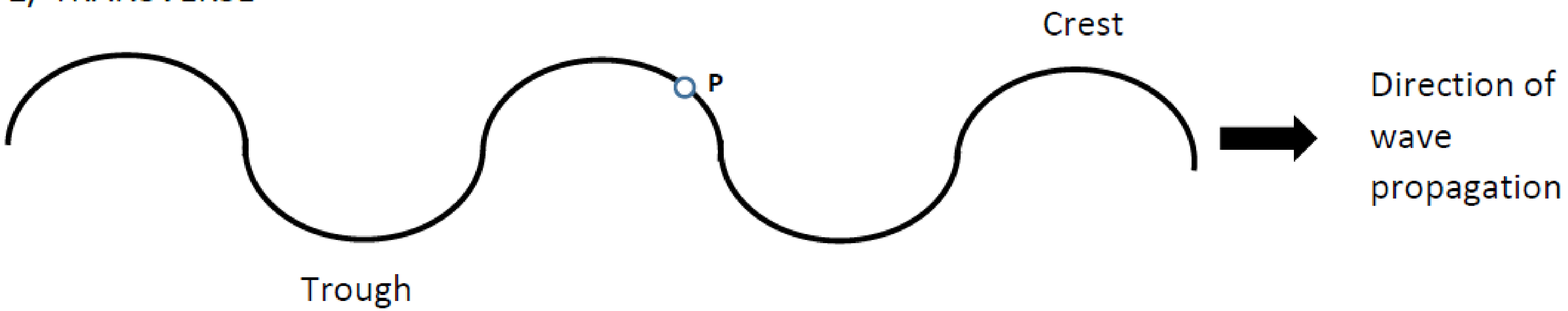
The only types of waves covered in the VCAA Unit 4 course are-

1/ LONGITUDINAL



The particle in the medium move back and forth in the same direction as the wave propagates.

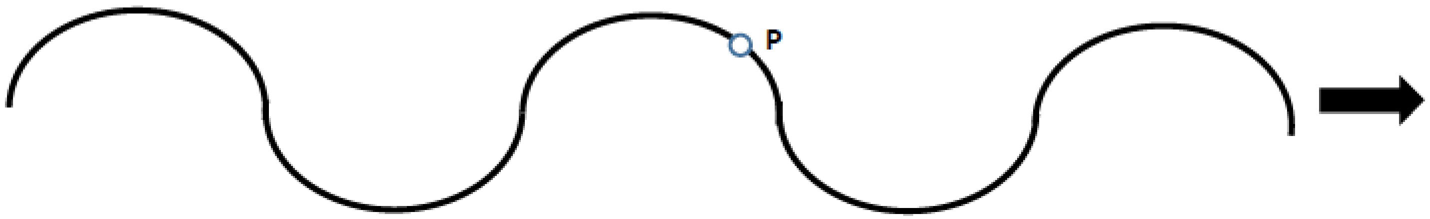
2/ TRANSVERSE



In transverse waves the particles in the medium move only perpendicular to the direction of wave propagation.

Paul J Cuthbert

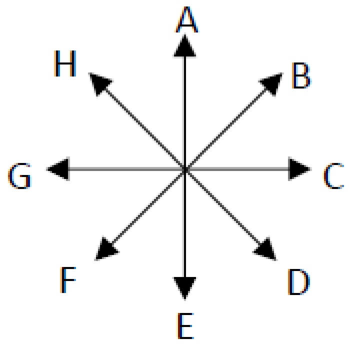
PROBLEM



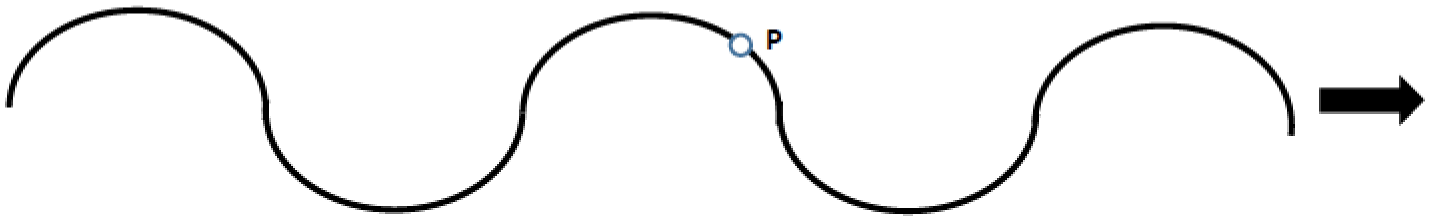
Direction of wave propagation

Problem:

In the diagram above, in what direction is the point **P** moving?

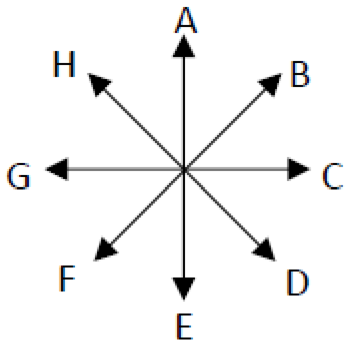


SOLUTION



Direction of wave propagation

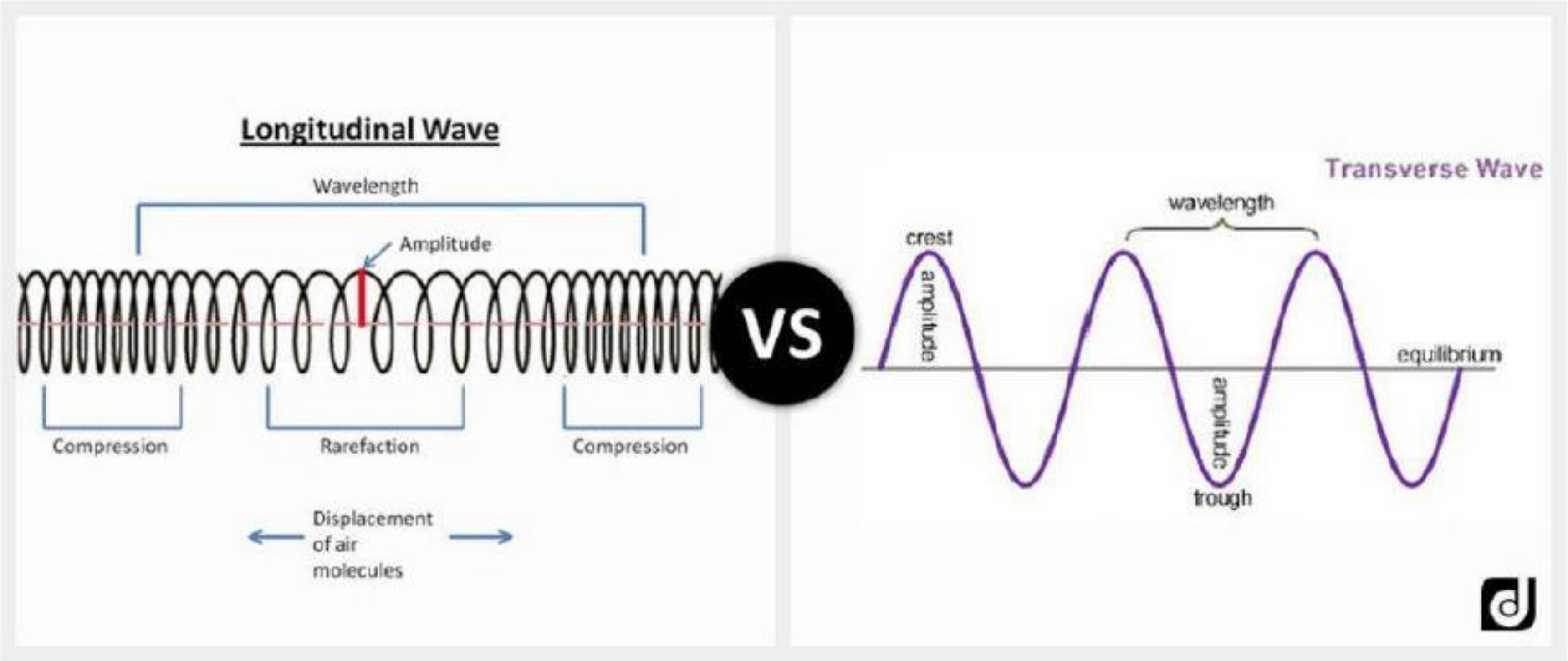
In the diagram above, in what direction is the point **P** moving?



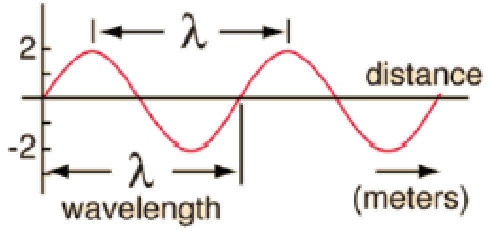
A

A crest is about to pass through so point is moving up.

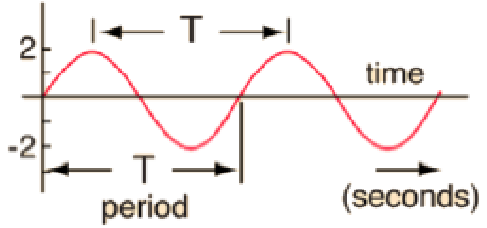
Amplitude and Wavelength, λ



Graphs of waves- there are 2 possible representations:

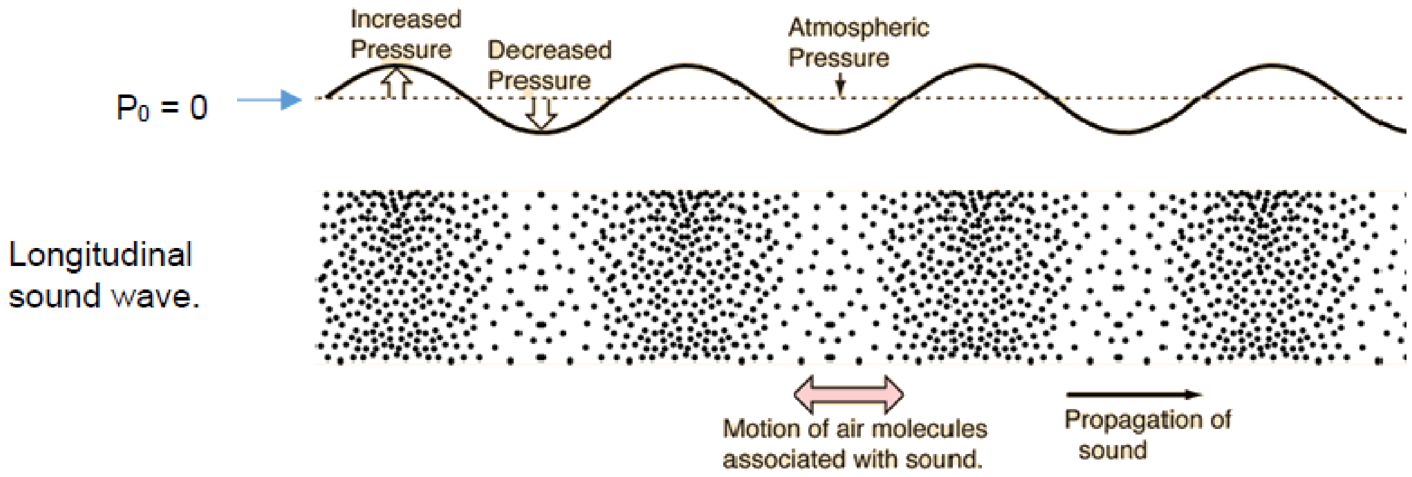


Displacement vs DISTANCE



Displacement vs TIME

For example *Sound Waves*:



Wave velocity:

The wave equation is $\boldsymbol{v} = \boldsymbol{f} \times \boldsymbol{\lambda} = \frac{\boldsymbol{\lambda}}{\boldsymbol{T}}, \boldsymbol{where}\ \boldsymbol{f} = \frac{\mathbf{1}}{\boldsymbol{T}}$

f = frequency (Hz = s^{-1}), T = Period (s)

Note: The SPEED of a wave **IS dependent** on:

- The properties of the medium

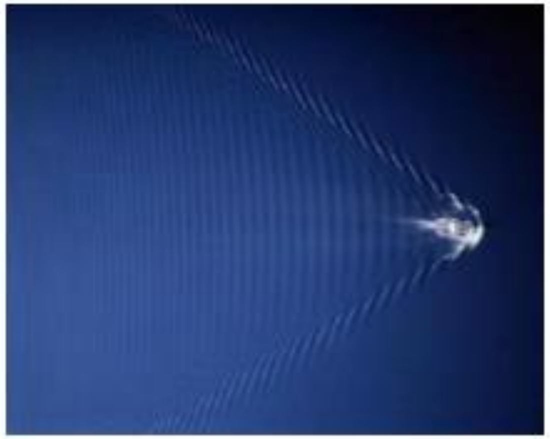
  E.g. For a spring – the density, spring constant and tension

  For sound waves – the type of gas, temperature (slightly), density and pressure

The SPEED of a wave **is NOT dependent** on:

- The speed of the source
- The amplitude
- The frequency

[Note: it is indeed fortunate that a wave's velocity in a medium is not altered by either its amplitude or frequency. Imagine listening to a concert, some distance from the stage. If the speed of sound waves (about $340ms^{-1}$) through the air between the stage and the listener were to be affected by amplitude or frequency then the music played, which is made up of a huge range of frequencies and amplitudes, would be completely scrambled by the time it reached the listener].

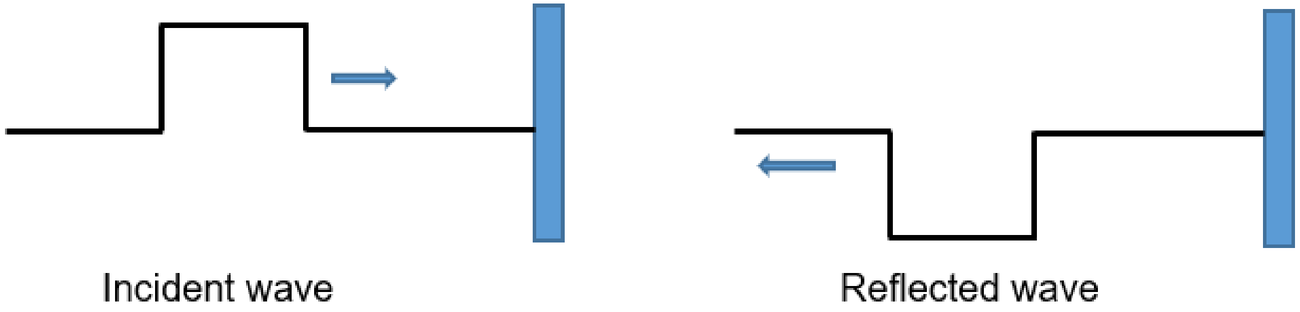


Wave reflections – solid boundaries

Note: in the 2023 to 2027 Study Design – only reflections from solid boundaries (fixed ends) are considered.

Reflection:

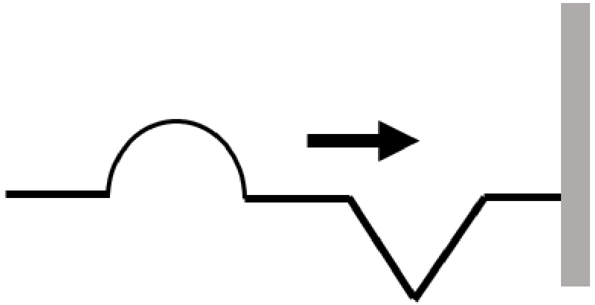
- When a pulse or wave reflect from a *fixed end*, the reflected wave is inverted:



Waves and Pulses invert when reflected from fixed boundaries.

Problems:

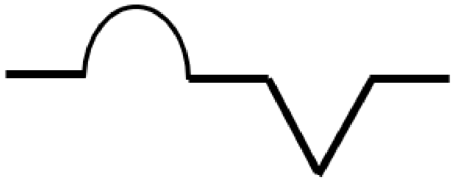
An incident pulse is progressing to the right when it hits a boundary and is reflected.



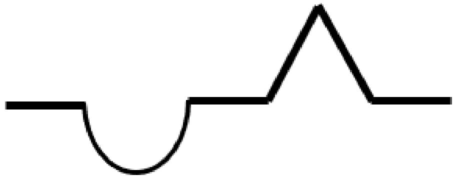
Which of these shapes would represent the reflected wave from a *fixed* (solid) boundary?

Answer key for the reflected pulse traveling to the left:

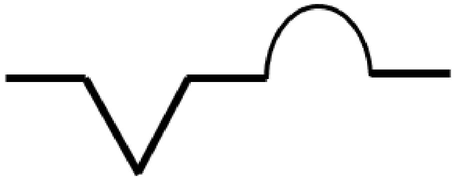
A.



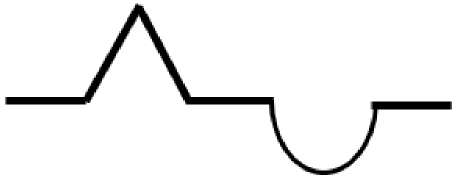
B.



C.

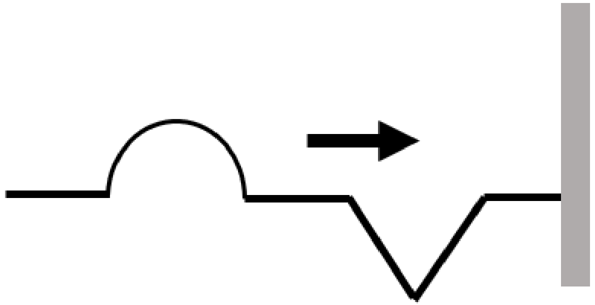


D.



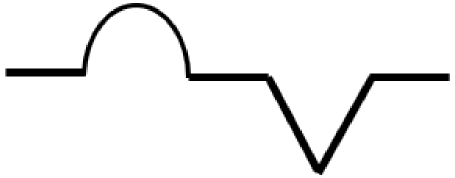
Problems: SOLUTION

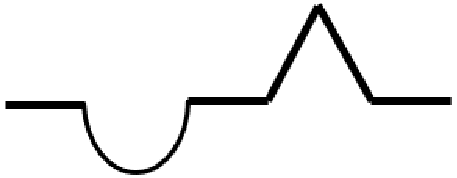
An incident pulse is progressing to the right when it hits a boundary and is reflected.

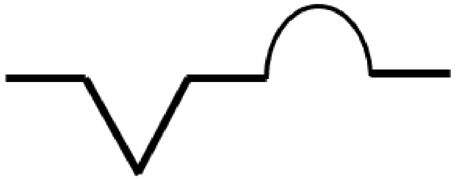


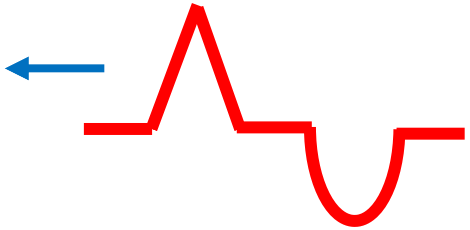
Which of these shapes would represent the reflected wave from a *fixed* (solid) boundary?

Answer key for the reflected pulse traveling to the left:

A. 

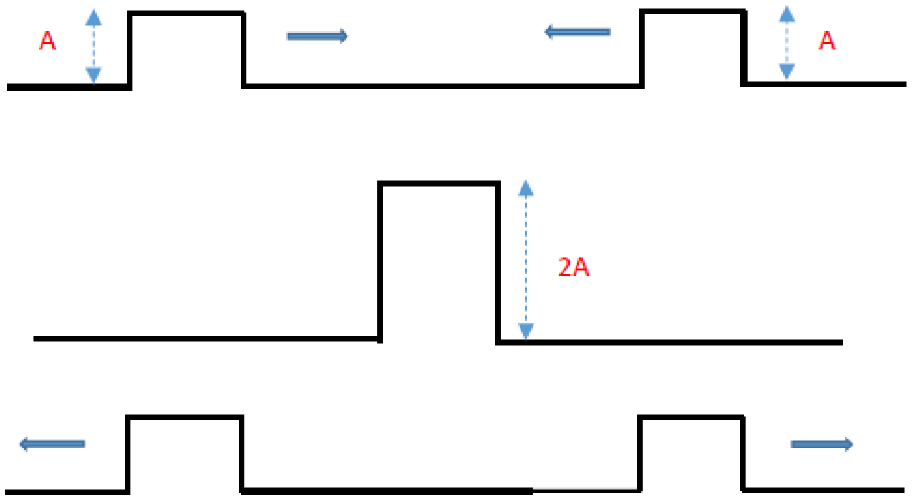
B. 

C. 

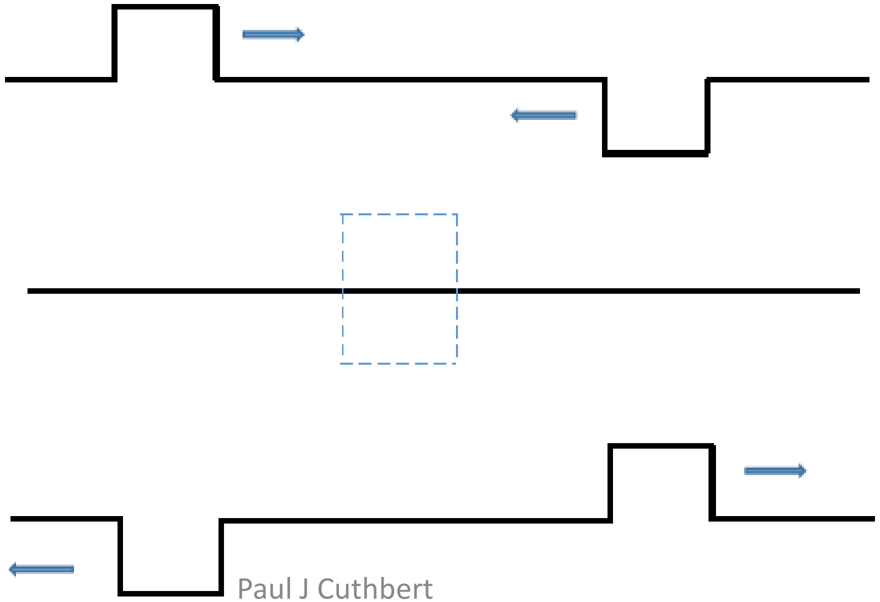
D. 

SUPERPOSITION

Superposition of 2 waves: CONSTRUCTIVE Interference:



Superposition of 2 waves: DESTRUCTIVE Interference:



Paul J Cuthbert

Standing Waves

And HARMONICS

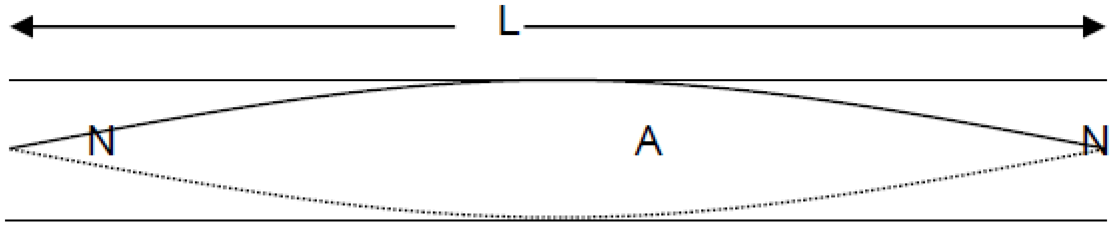
Useful equations and diagrams for your A3 sheet of notes

1-String/spring –Fixed at BOTH ENDS

Pressure variation (Open at both ends) – [same for a vibrating STRING]
First harmonic (fundamental frequency)

$\lambda_1 = 2L$

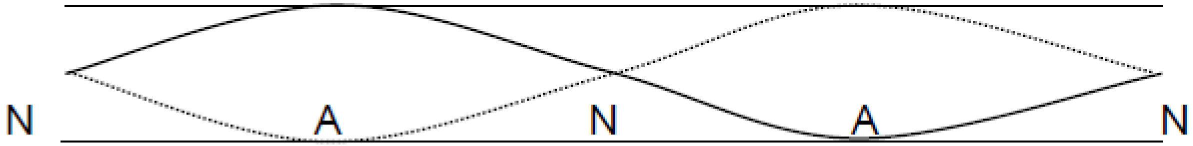
$f_1 = \frac{v}{2L}$



Second harmonic (first overtone)

$\lambda_2 = \frac{2L}{2} = L$

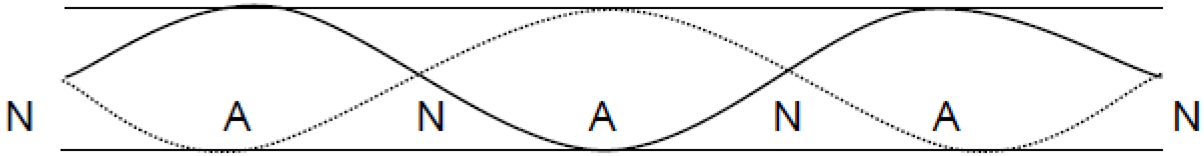
$f_2 = \frac{2v}{2L} = 2f_1$



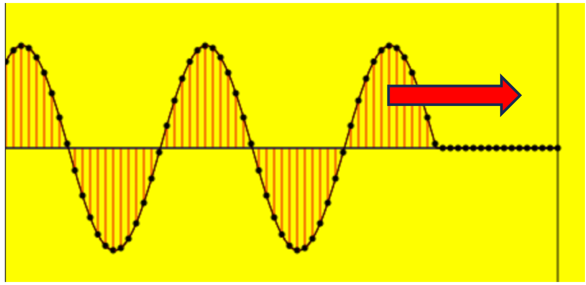
third harmonic (second overtone)

$\lambda_3 = \frac{2L}{3}$

$f_3 = \frac{3v}{2L} = 3f_1$

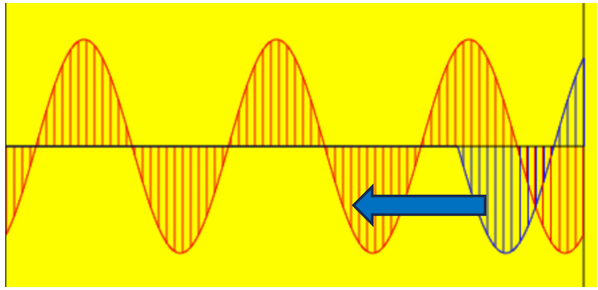


Formation of standing waves

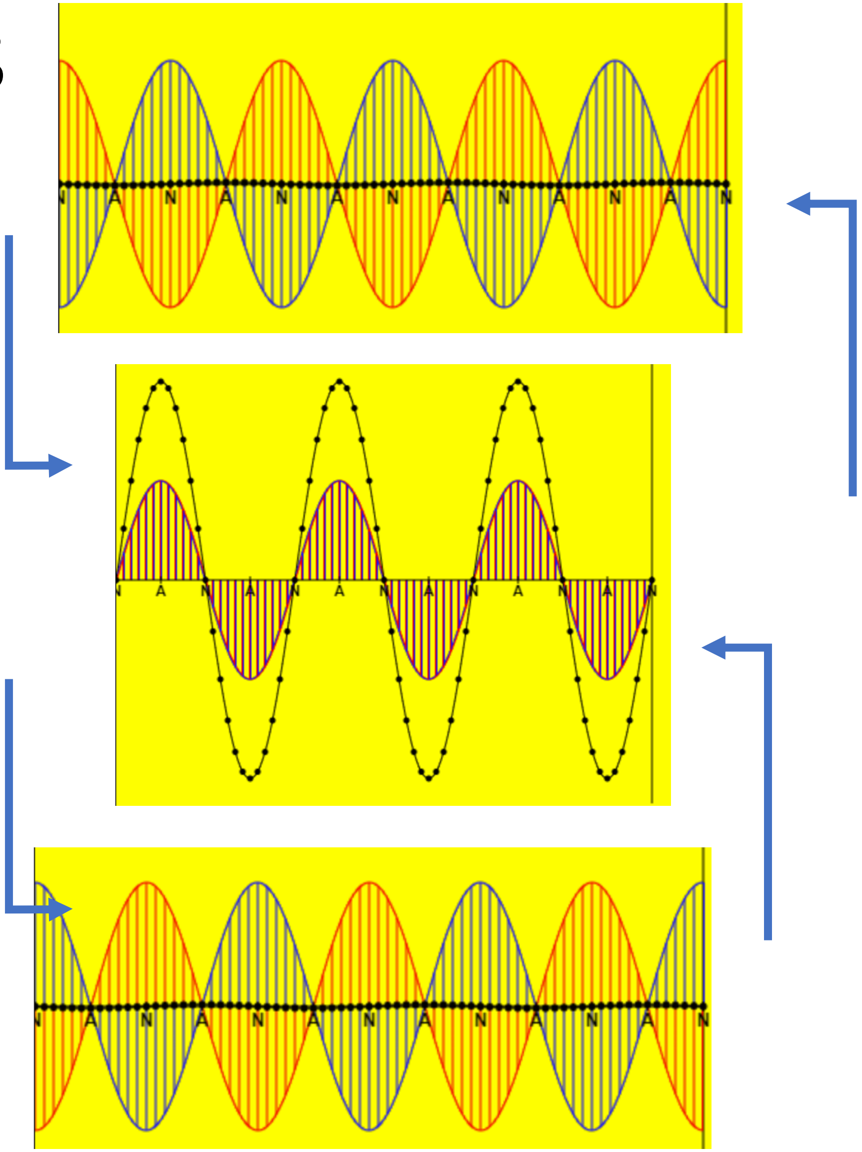


1/ Initial transmitted wave

Resultant Standing (stationary) wave: – it is the superposition of the transmitted and reflected waves that, at certain frequencies ($f_1 = v/2L$, $2xf_1$, $3xf_1$…) produces stable antinodes and nodes.

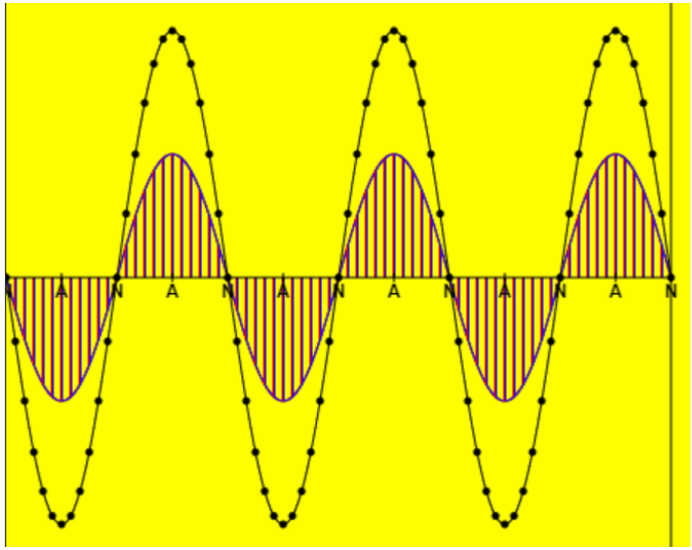


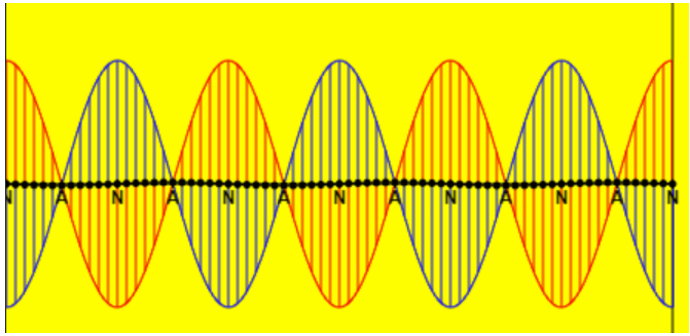
2/ Reflected wave



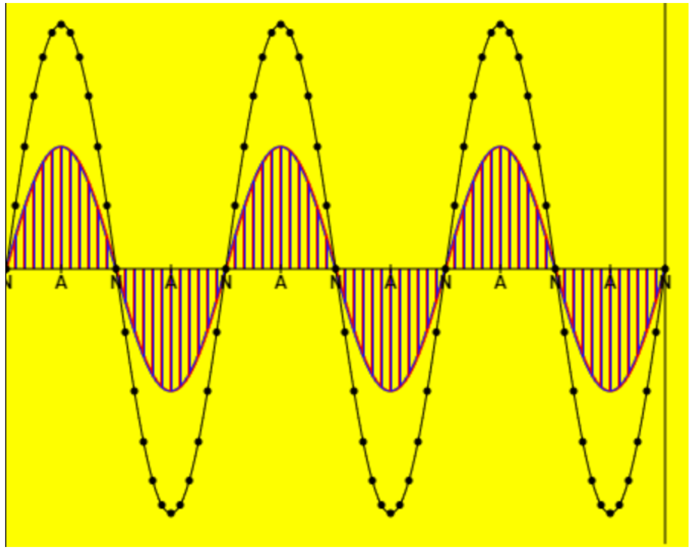
www.walter-fendt.de

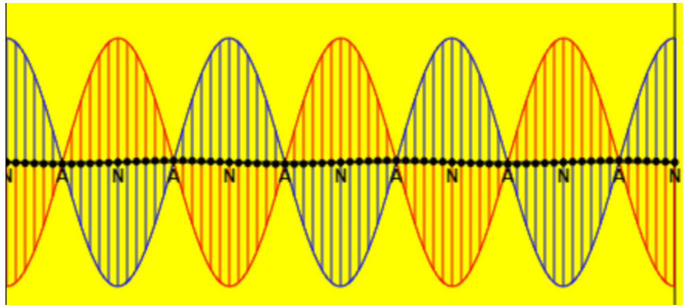
Formation of standing waves





Resultant Standing (stationary) wave: – it is the superposition of the transmitted and reflected waves that, at certain frequencies ($f_1 = v/2L$, $2xf_1$, $3xf_1$…) produces stable antinodes and nodes.





www.walter-fendt.de

PROBLEMS

STANDING WAVE PROBLEMS

1/ A string that is fixed at both ends has a length of 3.0 m.
It has its fixed end connected to a signal generator that has its output adjusted to produce a series of harmonics on the string that can be observed. If the wave speed in the string is measured as 180m/s. calculate:

(a) The fundamental frequency (1^{st} harmonic):

Hz

(b) the next harmonic (1^{st} overtone).

Hz

SOLUTION:

STANDING WAVE PROBLEMS

1/ A string that is fixed at both ends has a length of 3.0 m.
It has its fixed end connected to a signal generator that has its output adjusted to produce a series of harmonics on the string that can be observed. If the wave speed in the string is measured as 180m/s. calculate:

(a) The fundamental frequency (1st harmonic):

$$f_1 = \frac{v}{2L} = \frac{180}{2 \times 3}$$

$$= 30$$

Your A3 sheet:

$$f_1 = \frac{v}{2L}$$

30 Hz

(b) the next harmonic (1st overtone).

$$f_2 = 2 \times f_1 = 2 \times 30$$

60 Hz

NOTE: Resonance has been removed from the Study Design. However, an understanding of it useful for how standing waves can be produced.

Resonance:

Tacoma Narrow Bridge collapse
1940, Washington USA

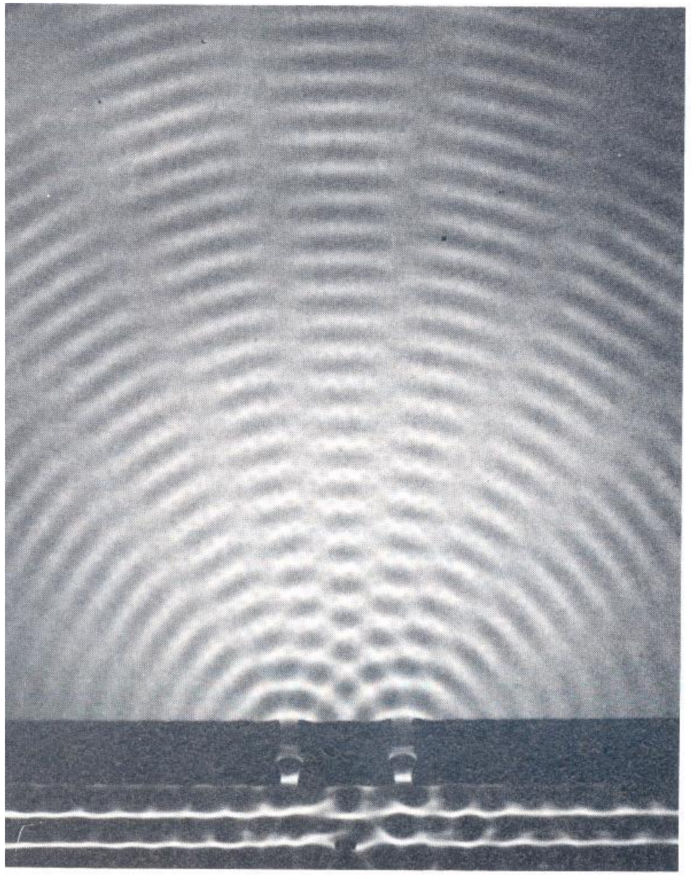
Every system has a NATURAL FREQUENCY (usually the fundamental) at which it will naturally oscillate (vibrate). If energy is fed into the system by an external source at this frequency then the amplitude of the oscillations can grow to be very large.

This can be useful – most musical instruments rely on resonance.

A gentle push, timed just right, at regular intervals matching the natural frequency of this swing (pendulum) can easily build up large amplitude oscillations.

Indeed, these two people could swap positions: the little child could very easily, by the same method, create large amplitude oscillations for the much heavier adult on the swing, much larger than would be possible with a single sustained push by the child.

Diffraction & Interference

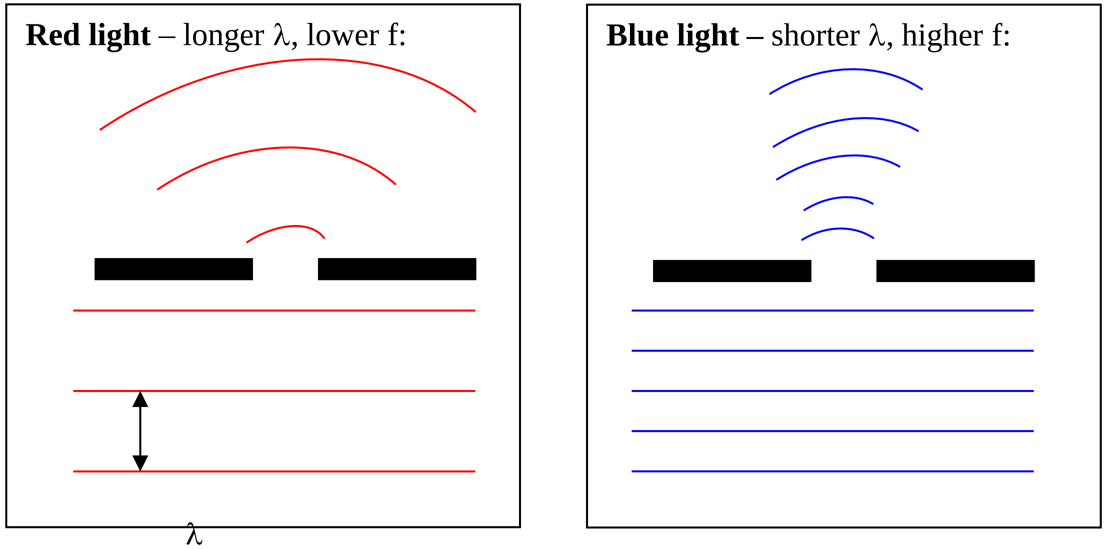


Diffraction

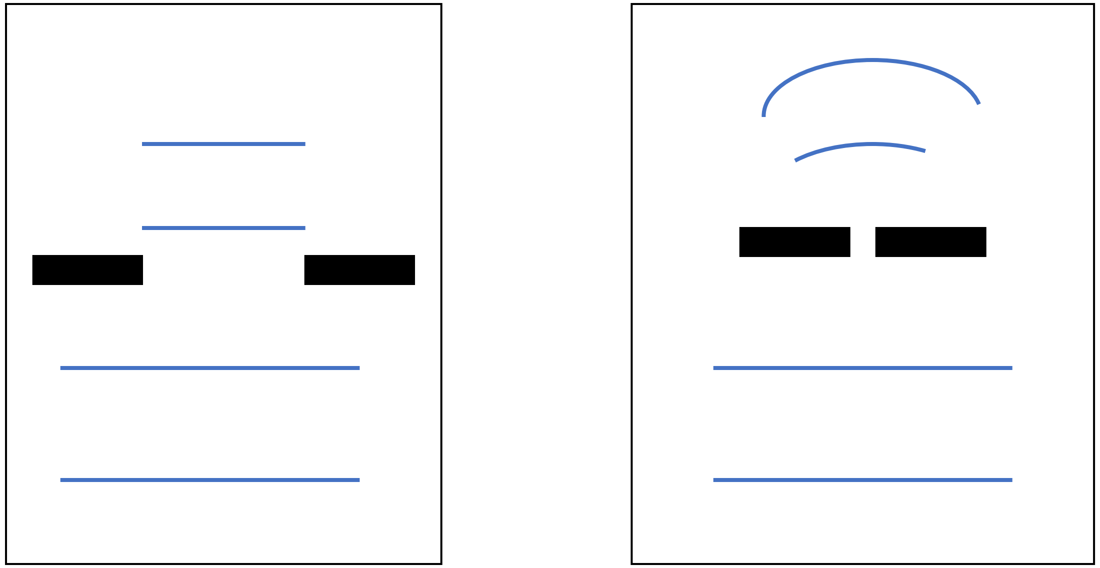
$$D \propto \frac{\lambda}{w}$$

Put on your A3 notes

Vary Wavelength, Gap width constant:



Same Wavelength, vary gap width:



Paul J Cuthbert

VCAA 2014 November Exam Q21(c)

The beam is incident on a small circular aperture and the resulting diffraction pattern is produced on a photon-sensitive screen behind the aperture. This pattern is shown in Figure 31.

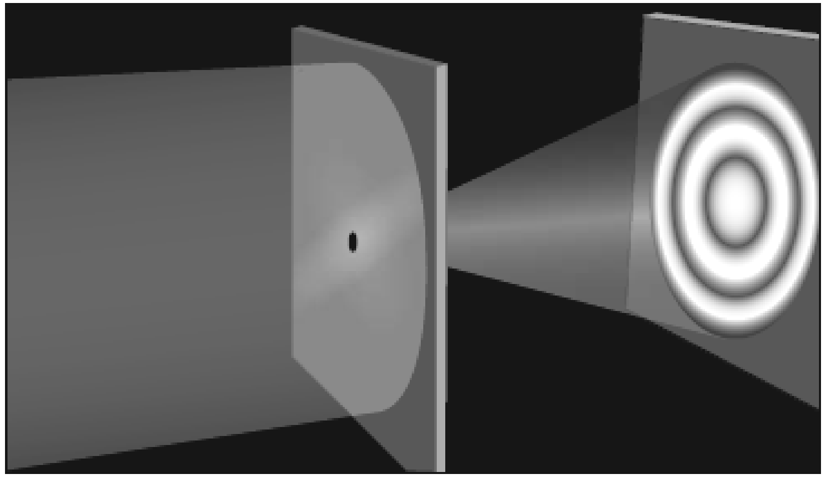


Figure 31

b. A second experiment is then performed with the same light beam incident on a circular aperture with a larger diameter.

Complete the following sentence by circling the correct words that are shown in **bold** font. 1 mark

Corresponding rings in the second diffraction pattern would have diameters that are **larger than / the same size as / smaller than** the rings in the original pattern.

Solution

VCAA 2014 November Exam
Q21(c)

The beam is incident on a small circular aperture and the resulting diffraction pattern is produced on a photon-sensitive screen behind the aperture. This pattern is shown in Figure 31.

① $\Delta x = \frac{\lambda L}{d}$

$d \uparrow \Rightarrow \Delta x \downarrow$

(same λ & L)

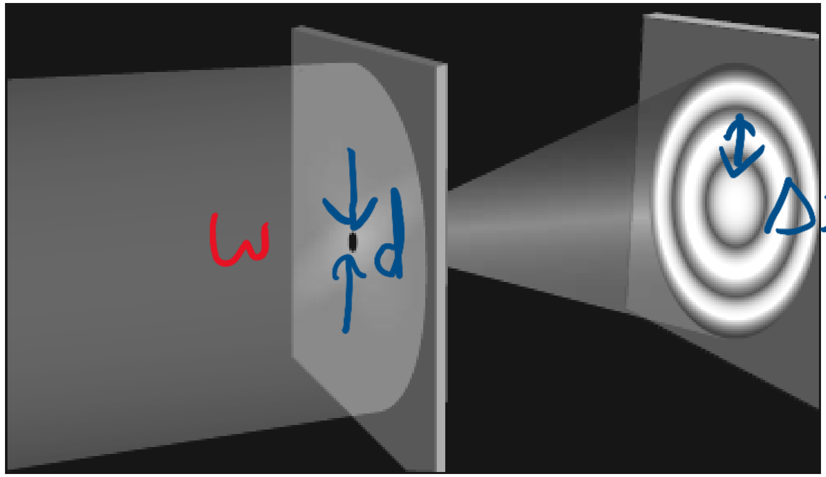


Figure 31

OR ② $D \propto \frac{\lambda}{w}$

$w \uparrow \Rightarrow D \downarrow$

(same λ)

b. A second experiment is then performed with the same light beam incident on a circular aperture with a larger diameter.

Complete the following sentence by circling the correct words that are shown in **bold** font. 1 mark

Corresponding rings in the second diffraction pattern would have diameters that are **larger than** / **the same size as** / **smaller than** the rings in the original pattern.

Paul J Cuthbert

VCAA 2007 Nov.

In an experiment, monochromatic laser light of wavelength 600 nm shines through a narrow slit, and the intensity of the transmitted light is recorded on the screen some distance away as shown in Figure 2a. The intensity pattern seen on the screen is shown in Figure 2b.

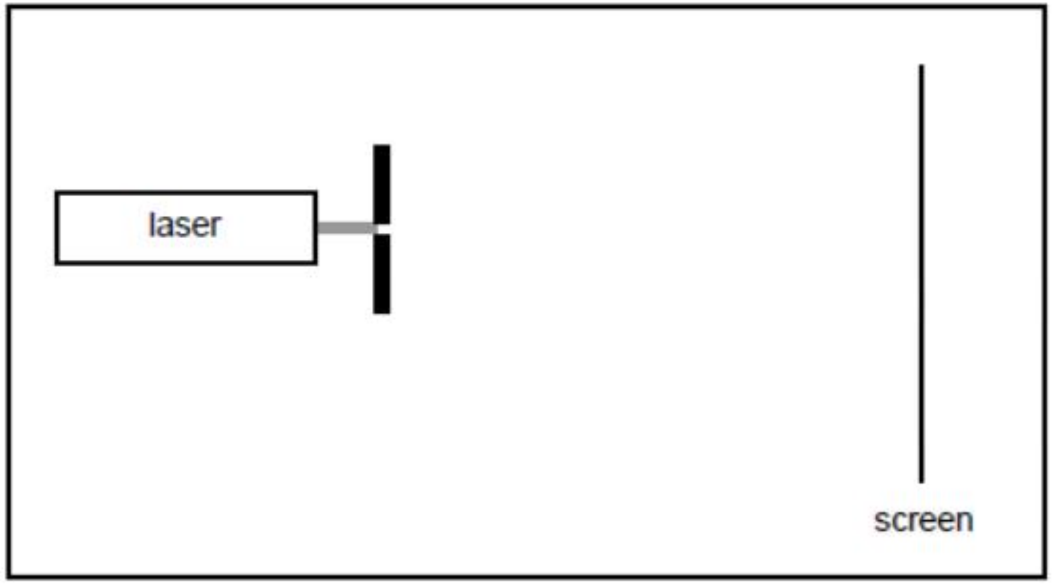


Figure 2a

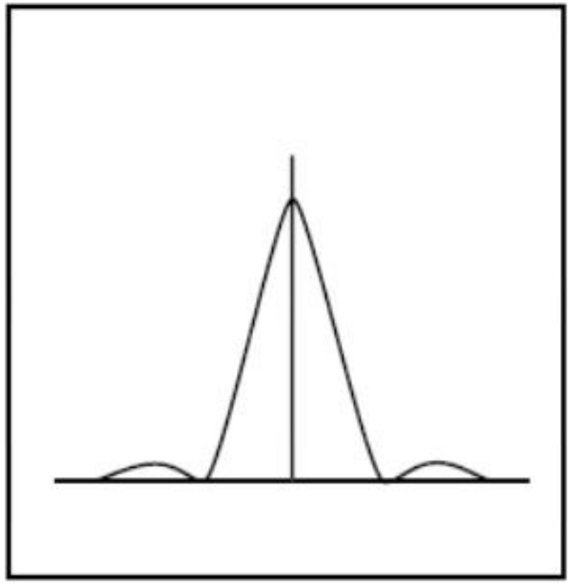
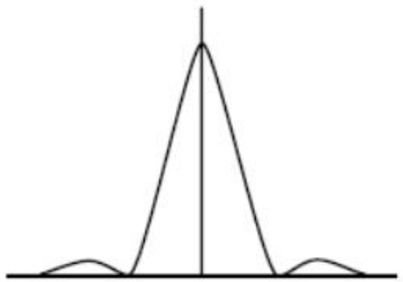


Figure 2b

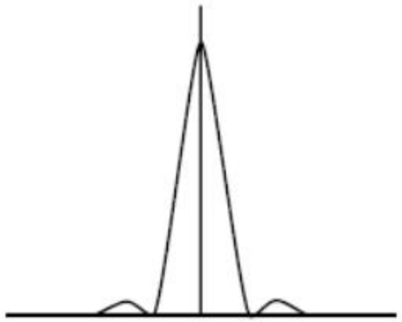
Question 6

Which one of the intensity patterns (A–D) below best indicates the pattern that would be seen if a wider slit was used?

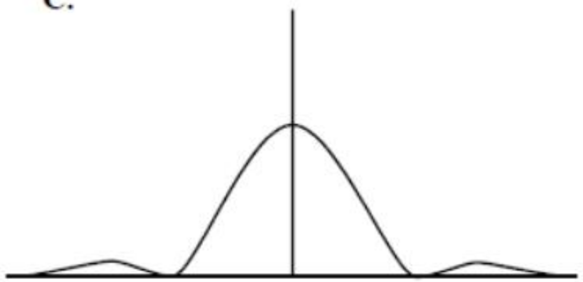
A.



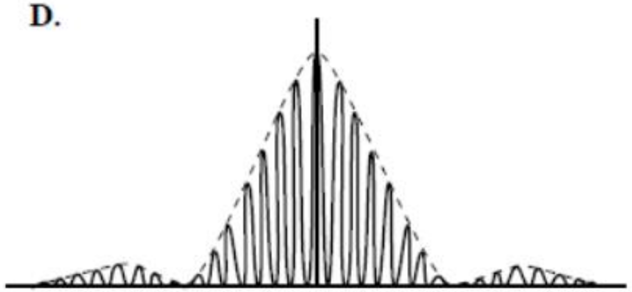
B.



C.



D.



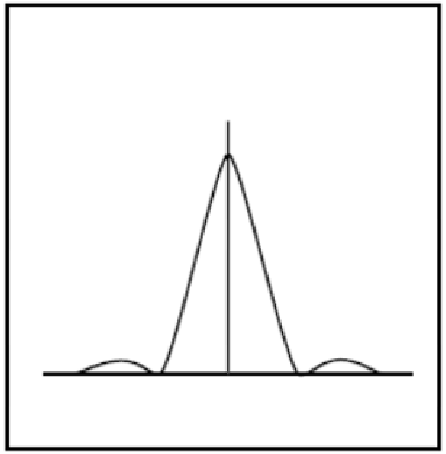
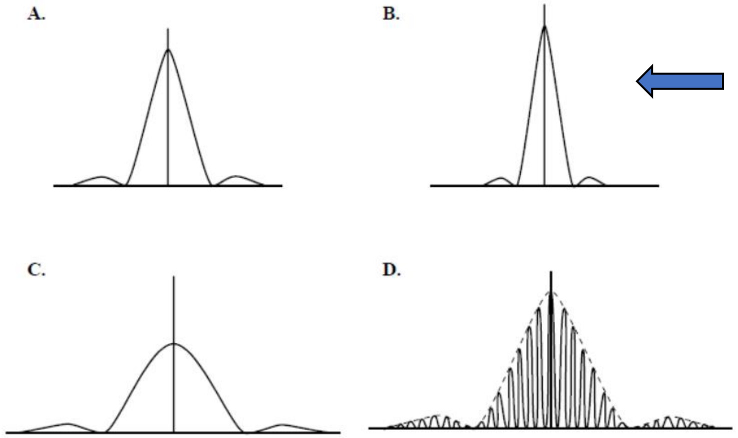


Figure 2b

2 marks

Question 6

Which one of the intensity patterns (A–D) below best indicates the pattern that would be seen if a wider slit was used?



2 marks

Question 6

Marks	0	1	2	Average
%	53	0	47	1.0

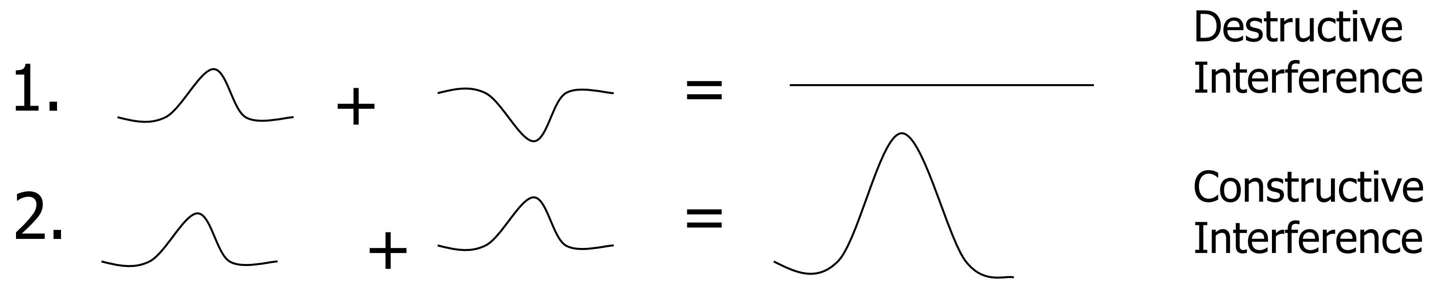
B

The wider the slit the narrower the pattern, so the answer was B. It was disappointing that fewer than half of the students were able to apply the simple relationship required to determine the answer. This may be related to the apparent confusion over diffraction patterns mentioned in the previous question.

Interference Patterns (fringe patterns)

Superposition – of *in phase* and *out of phase* waves.

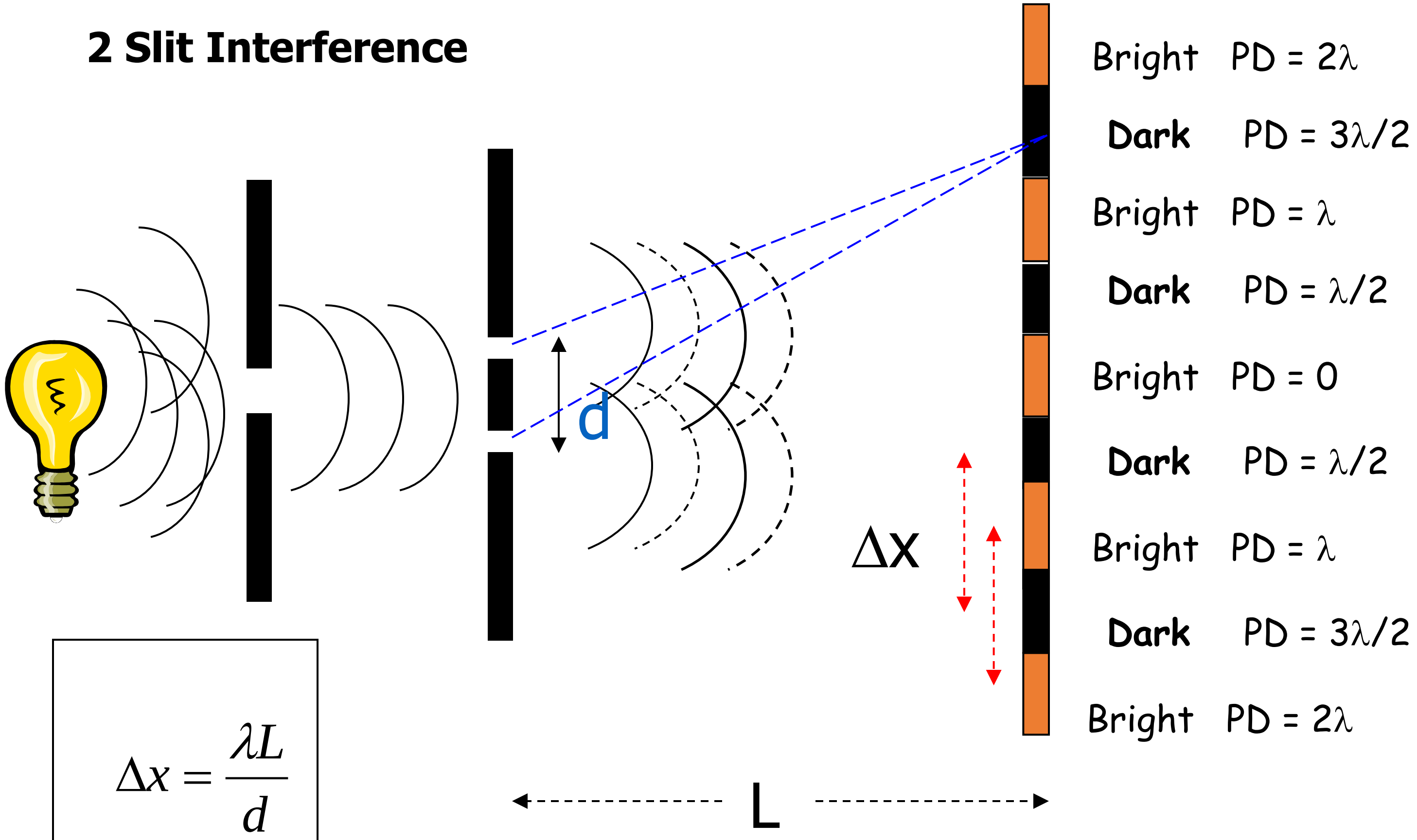
When waves cross each other, they **interfere** with each other:



This addition and cancellation of waves is observed with light, sound and water.

Interference – Thomas Young's Experiment

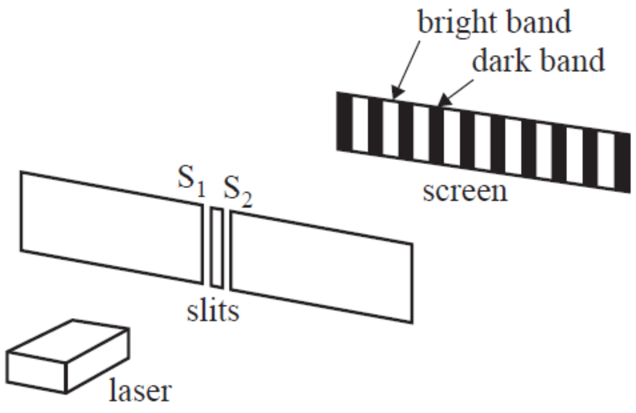
2 Slit Interference



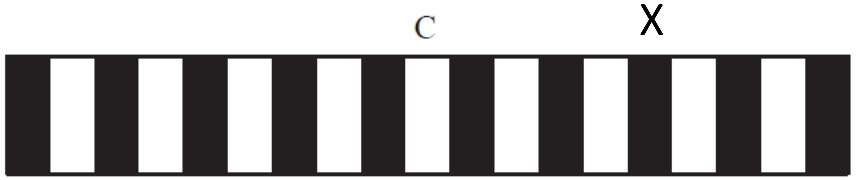
$$\Delta x = \frac{\lambda L}{d}$$

Paul J Cuthbert

Example Problem: Young's double slit Experiment



Laser: λ = 600 nm

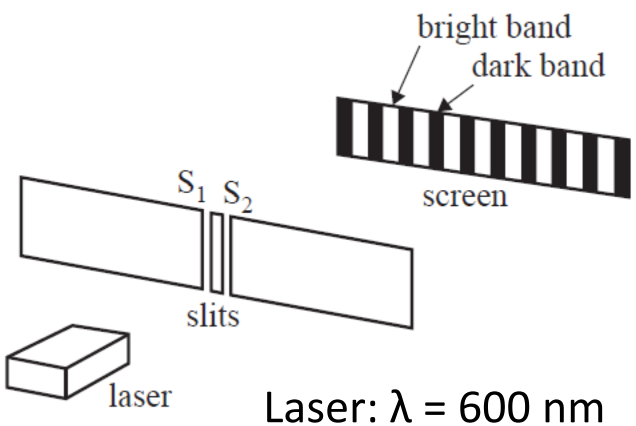


A laser of wavelength 600 nm is used to produce the interference pattern shown.

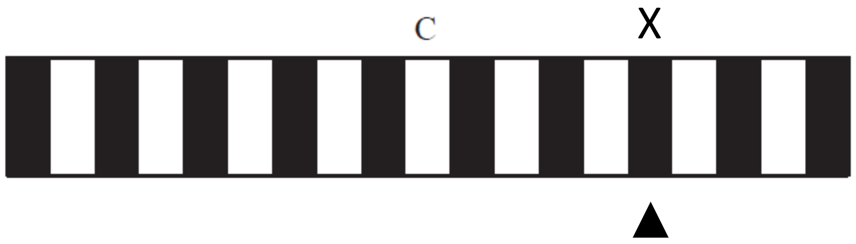
(a) Explain why the line marked C is a maximum:

(b) What is the path difference $XS_1 - XS_2$?

Example Problem: **SOLUTION**



Laser: λ = 600 nm



3rd minima

A laser of wavelength 600 nm is used to produce the interference pattern shown.

(a) Explain why the line marked C is a maximum:

(i) At C the Path difference **PD = 0**

(ii) Therefore, there is **constructive interference** at C

(b) What is the path difference $XS_1 - XS_2$?

The dark band at X, is the **3rd minima**

-1st minima: PD = ½ λ
-2nd minima: PD = 1½ λ

=> 3rd minima: PD = 2½ λ = 2.5 x 600nm = 1500nm

Comparing Standing (Stationary) Waves and 2-Slit Interference:
-similarities
-differences

-Similarities – Antinodes (maxima where constructive interference of waves occurs) and nodes (minima where destructive interference of waves occurs).

Differences:

Interference Patterns:

- the mid-point is *always* a Maxima (path difference = 0 and therefore there is Constructive Interference)
- The sources (speakers or slits) are not necessarily nodes.

Standing (Stationary) Waves

– the midpoint is an Antinode (Maxima) for all odd harmonics (f1, f3, f5, …) and a Node for all even harmonics (f2, f4, …)

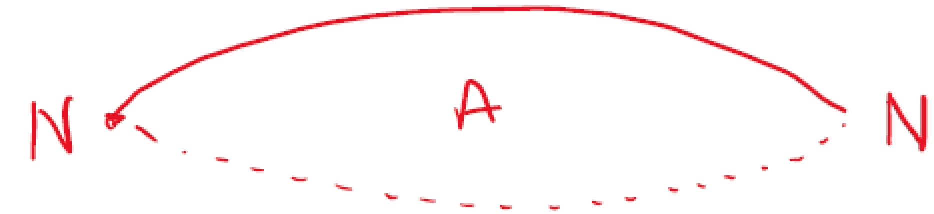
-the ends are always nodes (2 fixed ends) or a node and antinode (1 fixed end, 1 free end)

<u>STANDING (stationary) WAVES</u> on strings, for the following, I will use the example of a *string fixed at both ends:*

- the ends will always be nodes.

- Standing waves only occur at certain frequencies ($f_1 = v/2L$, $2f_1$, $3f_1$ etc)

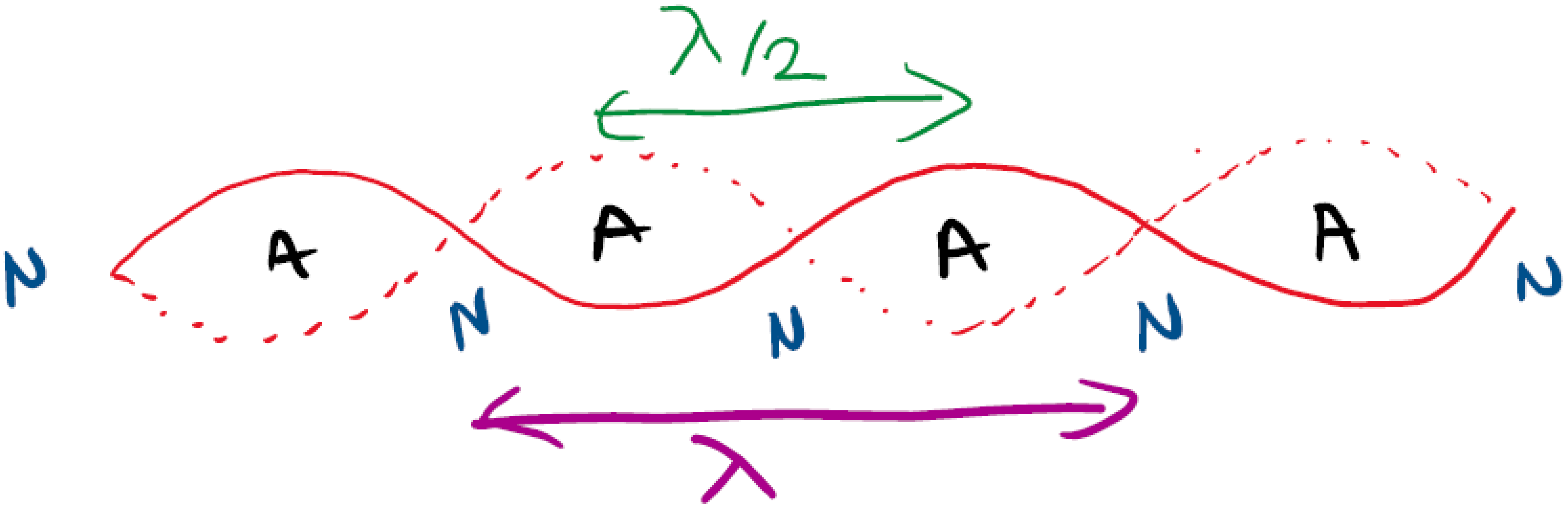
-the midpoint will be either a node, minima (all even harmonics), or antinode, maxima (fundamental and all odd harmonics) – draw a few more harmonics and convince yourself.



$$f_1 = \frac{v}{2L}$$

$$f_2 = 2 \times \frac{v}{2L}$$

-the spacing of adjacent nodes or adjacent antinodes in standing waves is *half a wavelength*.



-standing waves are the result of the interference of incident (progressive) waves and their reflected wave at certain frequencies to produce stable wave patterns of antinodes where constructive interference and nodes where destructive interference occurs.

VCAA 2018

Question 11 (4 marks)

Figure 13 shows two speakers, A and B, facing each other. The speakers are connected to the same signal generator/amplifier and the speakers are simultaneously producing the same 340 Hz sound.

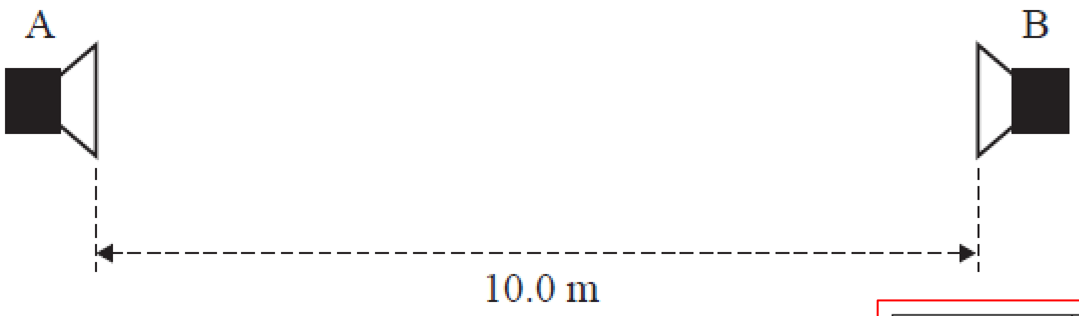


Figure 13

Marks	0	1	Average
%	8	92	0.9

Take the speed of sound to be 340 m s^{-1}.

a. Calculate the wavelength of the sound. 1 mark

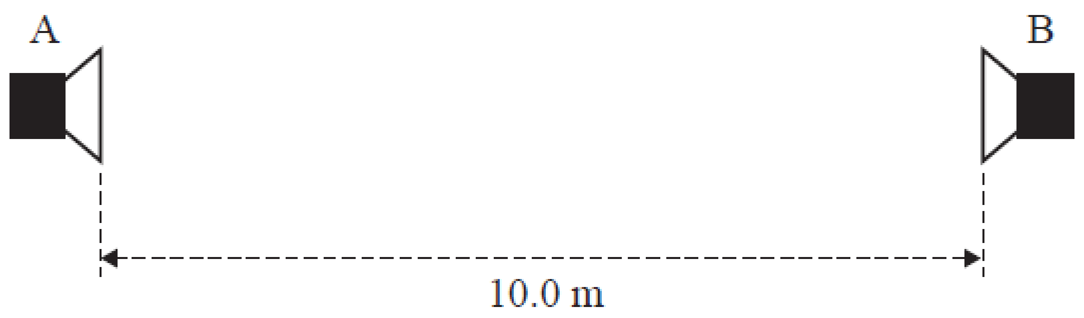
m

VCAA 2018

Question 11 (4 marks)

Figure 13 shows two speakers, A and B, facing each other. The speakers are connected to the same signal generator/amplifier and the speakers are simultaneously producing the same 340 Hz sound.

= f



SOLUTION

Figure 13

Marks	0	1	Average
%	8	92	0.9

Take the speed of sound to be 340 m s^{-1}.

a. Calculate the wavelength of the sound. 1 mark

$v = f \times \lambda$

$340 = 340 \times \lambda$

1 m

b. A student stands in the centre, equidistant from speakers A and B. He then moves towards speaker B and experiences a sequence of loud and quiet regions. He stops at the second region of quietness.

How far has the student moved from the centre? Explain your reasoning. 3 marks

m

____

____

____

Marks	0	1	2	3	Average
%	56	35	4	5	0.6

Solution

Must be an Antinode (PD=0)

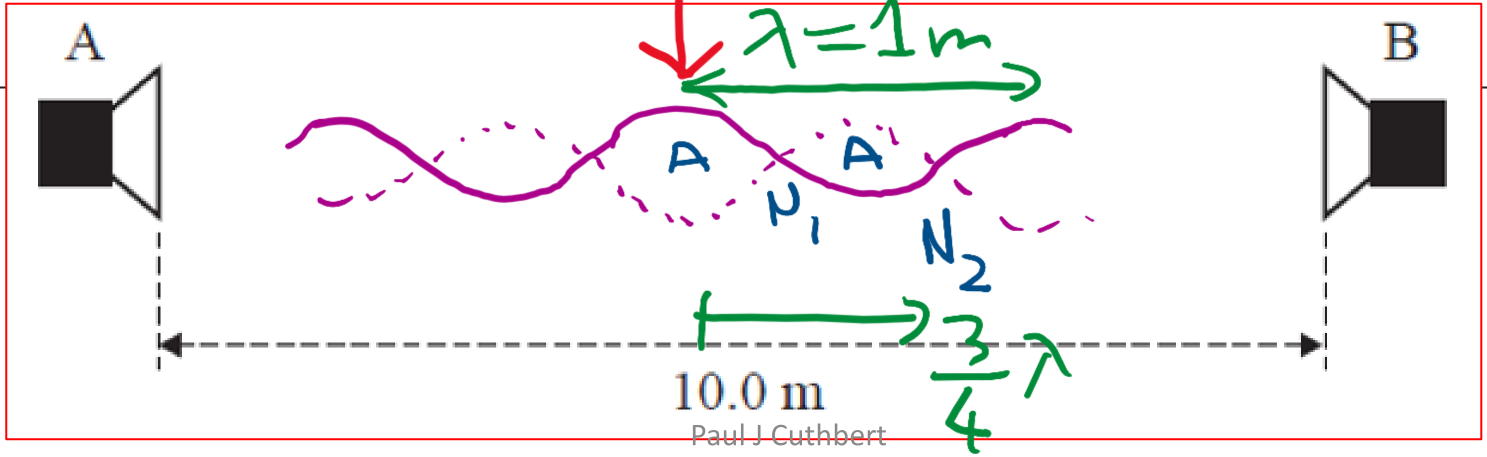
b. A student stands in the centre, equidistant from speakers A and B. He then moves towards speaker B and experiences a sequence of loud and quiet regions. He stops at the second region of quietness. N_2

How far has the student moved from the centre? Explain your reasoning. 3 marks

0.75 m

At 2^{nd} node, moved $\frac{3}{4}\lambda$

$= 3/4 \times 1$ m



END – Unit 4 AoS 1-part 1

Light & Matter
Unit 4 AoS#1

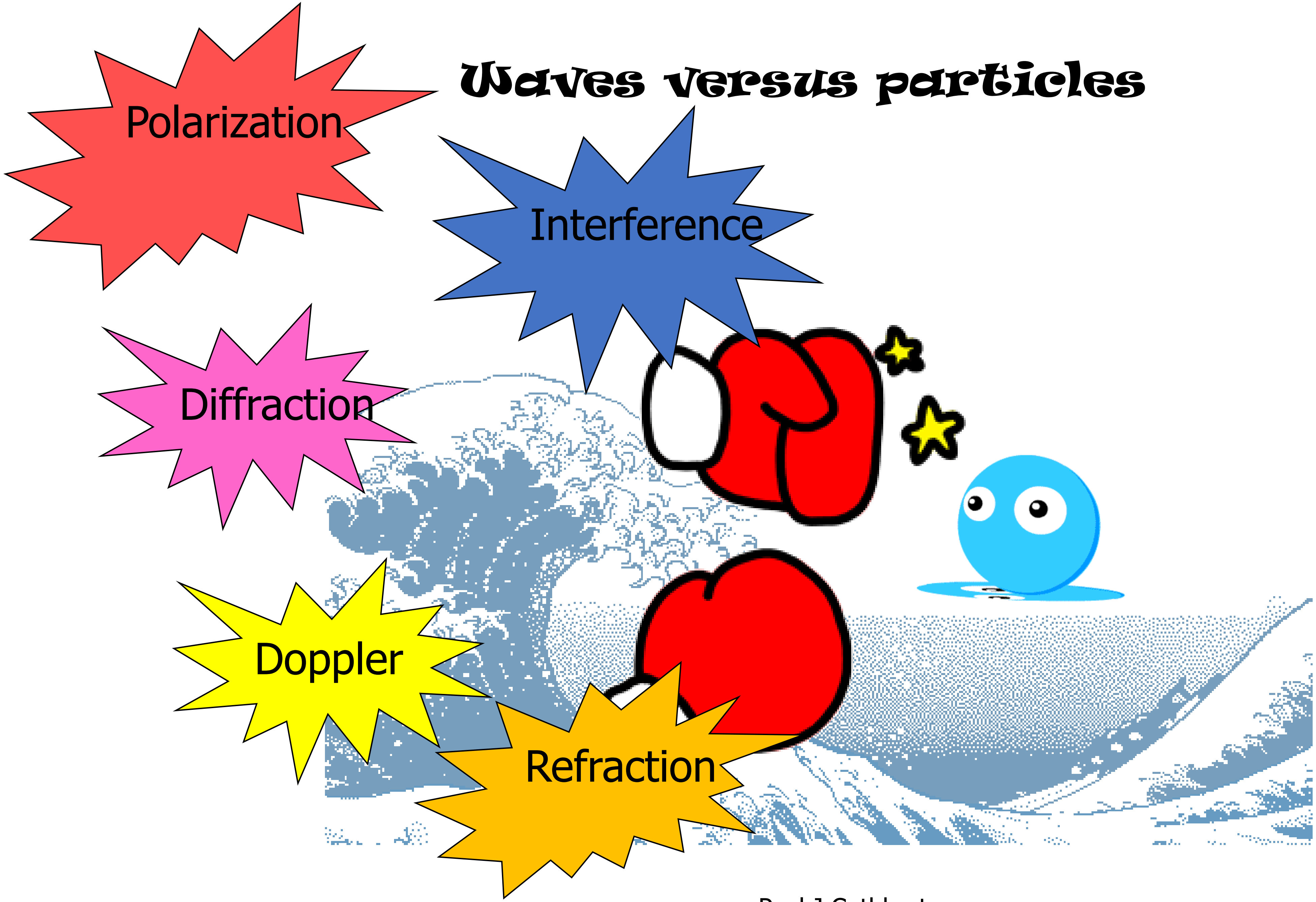
Monash University – Revision Lecture

Contents:

-Photoelectric Effect
-Atomic Spectra
-Matter Waves

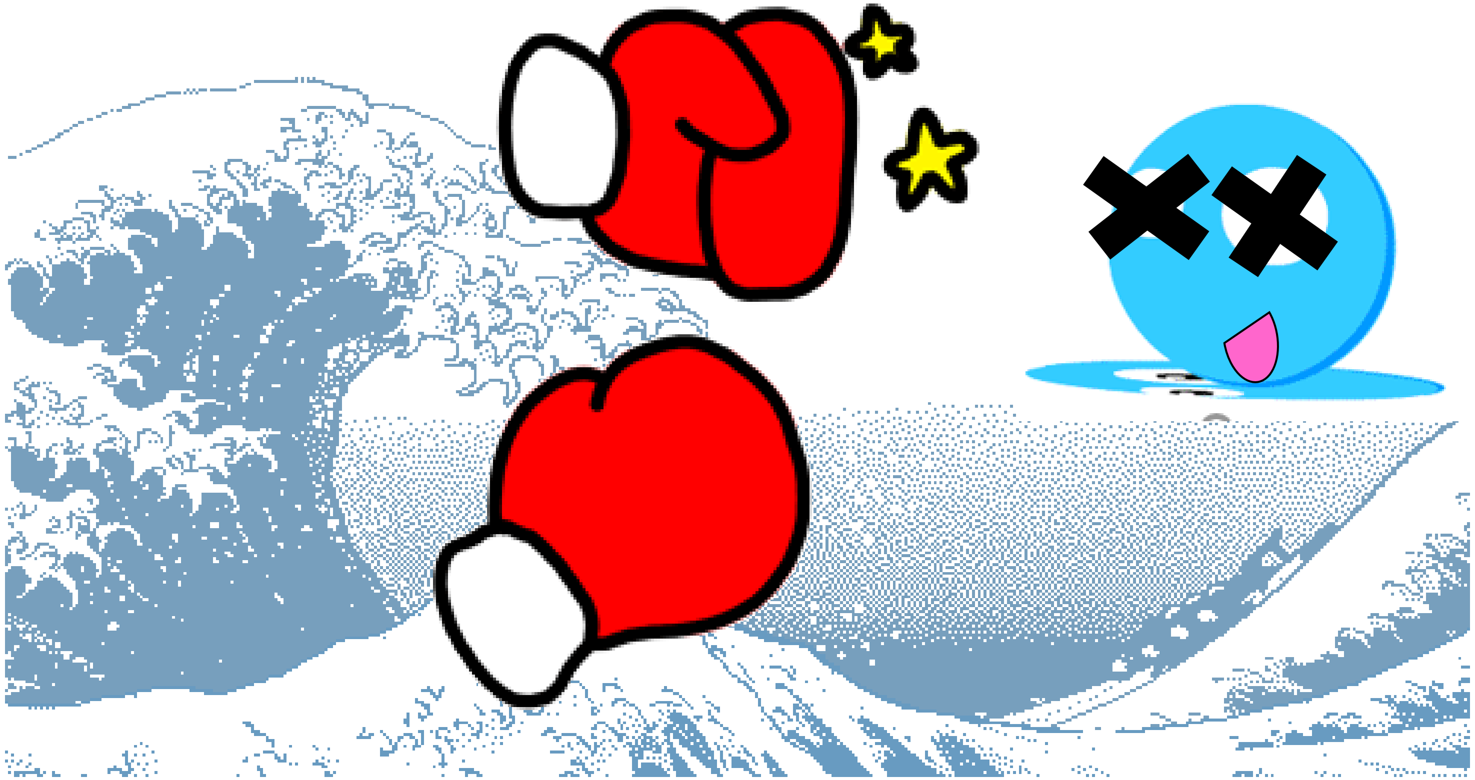
Paul J Cuthbert

Waves versus particles



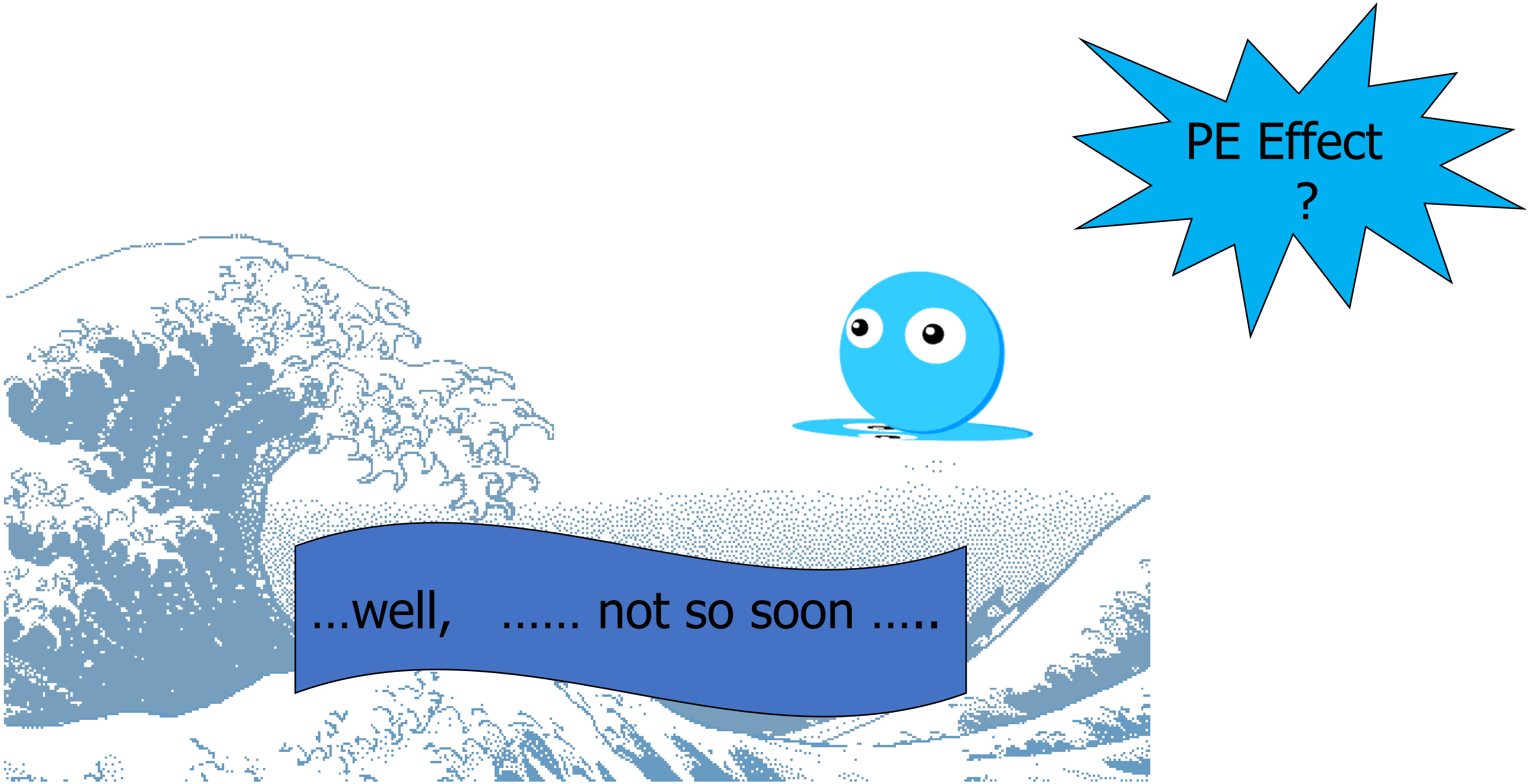
Paul J Cuthbert

And the WINNER is .....



Paul J Cuthbert

And the WINNER is .....

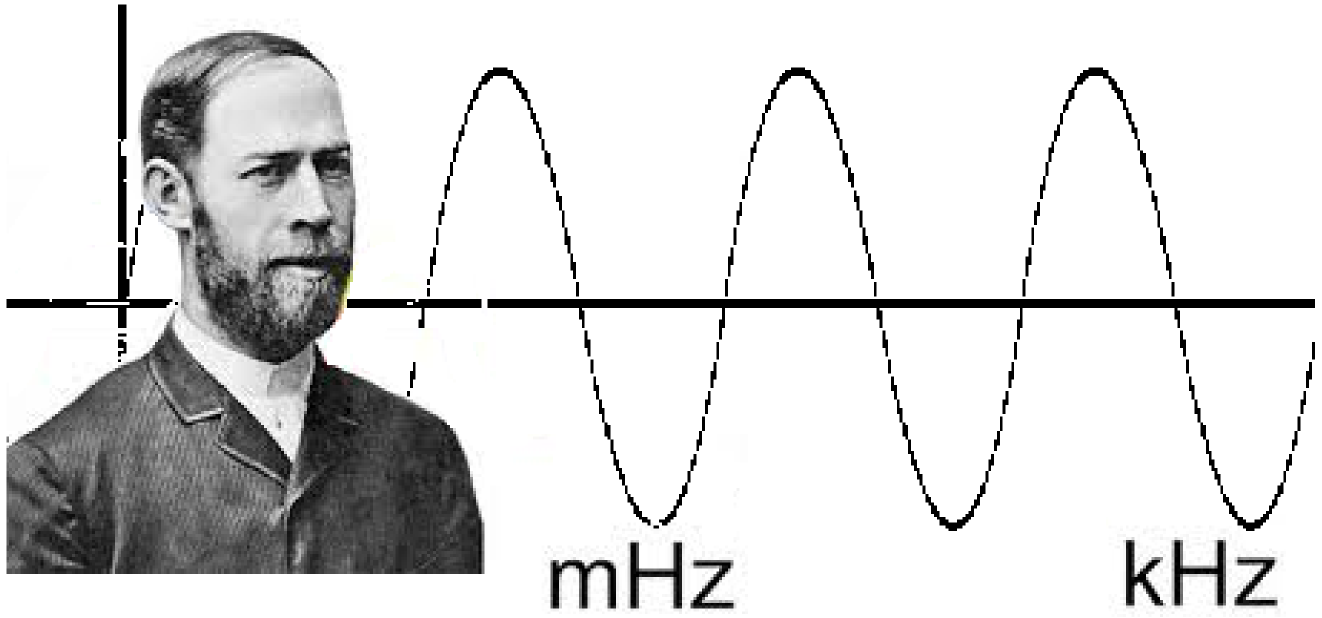


Paul J Cuthbert

Waves vs Particles

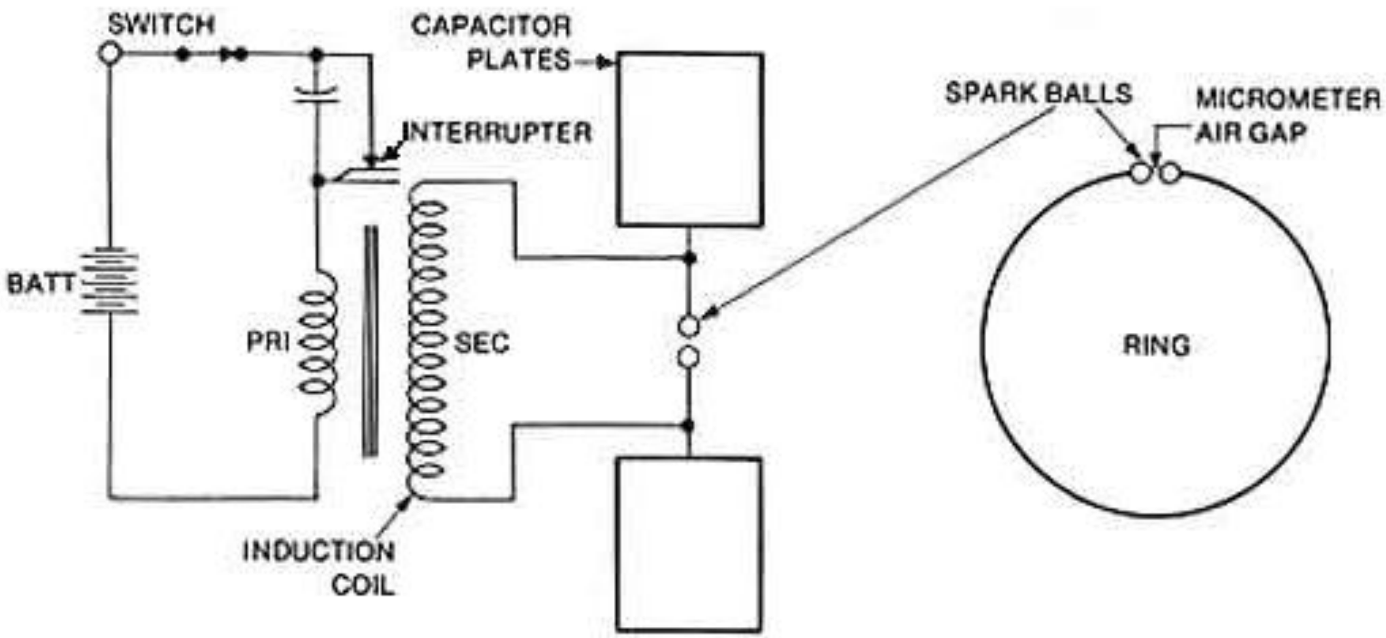
Property	Waves	Particles
light travels in straight lines & reflection (i = r)	Yes	Yes
Polarization	Yes	No
Refraction	Yes	No (requires v faster in more optically dense medium- e.g. slower in water, glass).
Diffraction	Yes	No
Interference	Yes	No
Photoelectric Effect	?	?

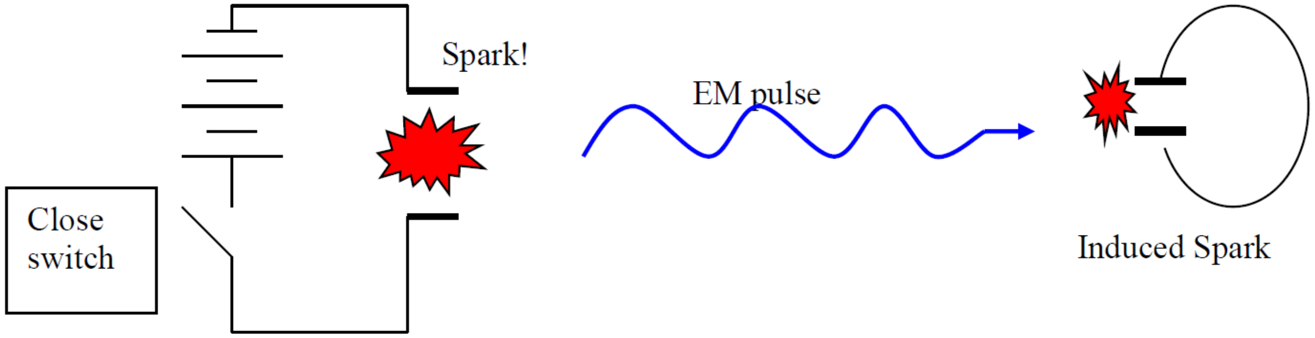
Heinrich Hertz (1857 – 1894)



German physicist. Died at the age of 36.

Hertz’s apparatus:





At the conclusion of this experiment Hertz had:

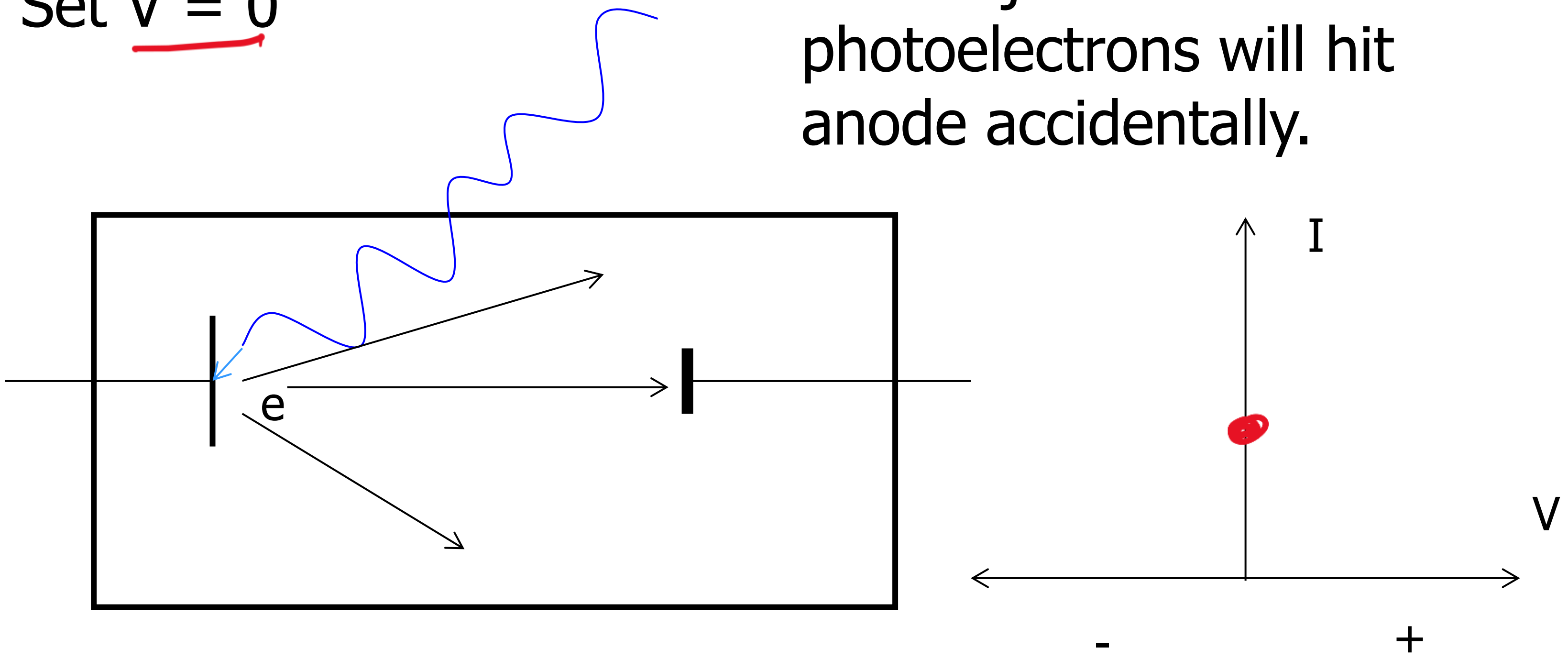
- Confirmed Maxwell's equations
- Produced the world's first artificially made radio waves
- Produced the first radio transmitter
- Produce the first radio receiver
- Discovered the Photoelectric Effect which would lead to Quantum Mechanics
- Had effectively made the first Solar Cell.

Not a bad day's work.

Photoelectric Effect

Set V = 0

Some ejected photoelectrons will hit anode accidentally.

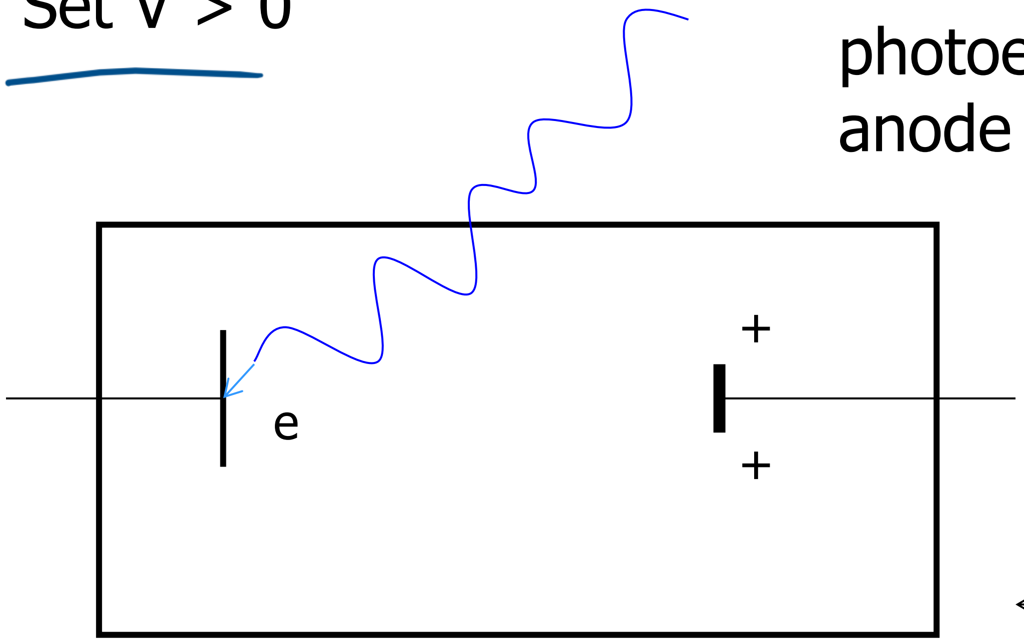


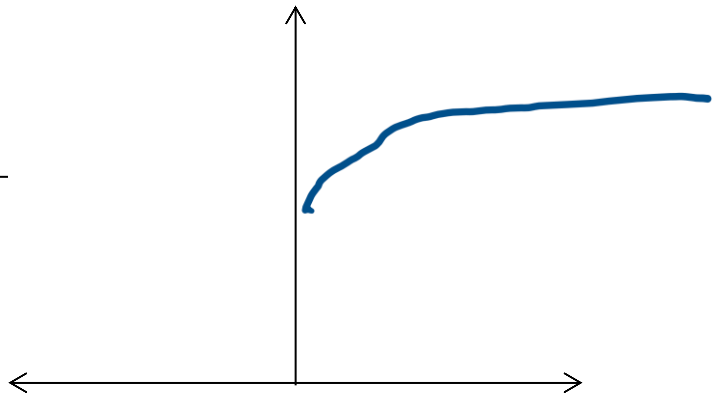
Photoelectric Current > 0

Photoelectric Effect

Set V > 0

Some ejected photoelectrons will hit anode accidentally.



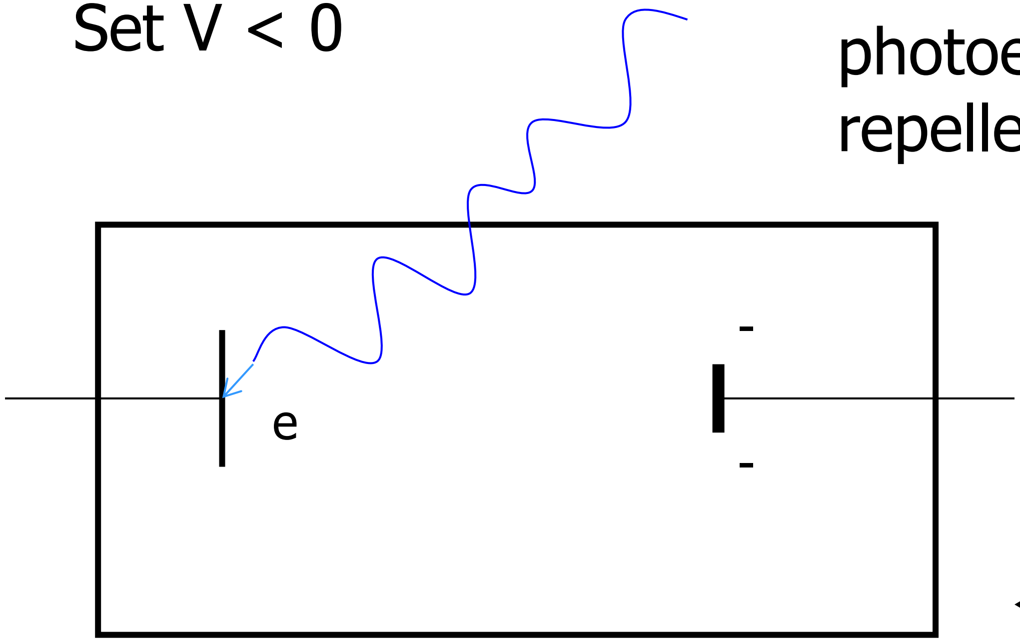


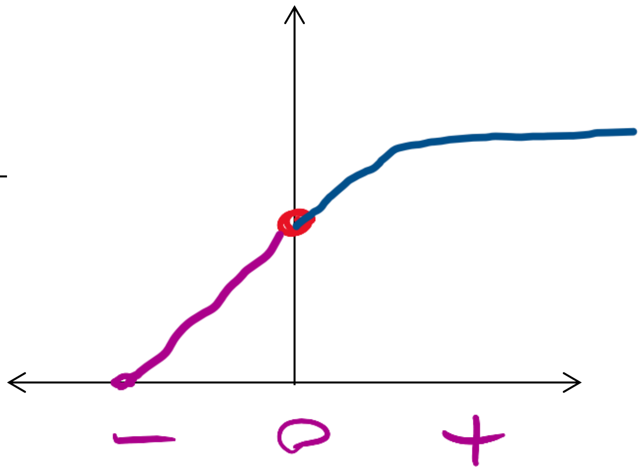
Photoelectric Current will increase

Photoelectric Effect

Set V < 0

Most ejected photoelectrons will be repelled from the anode.





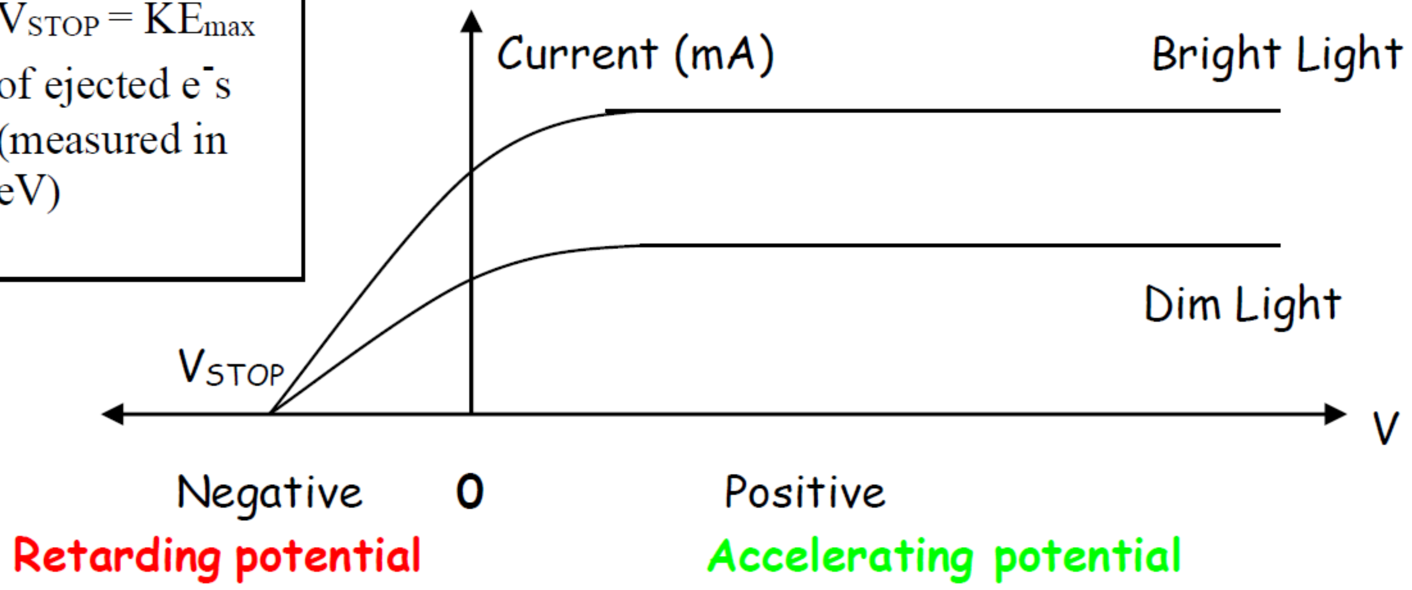
Photoelectric Current will *decrease.*

Features of this experiment:

- Varying the INTENSITY (brightness), keeping the light colour (frequency) constant:

CVs - f(Hz)
  - Cathode material
IV – Intensity (brightness)
DV – Stopping Voltage

$V_{STOP} = KE_{max}$ of ejected e^-s (measured in eV)



More intense light = Higher saturation current.

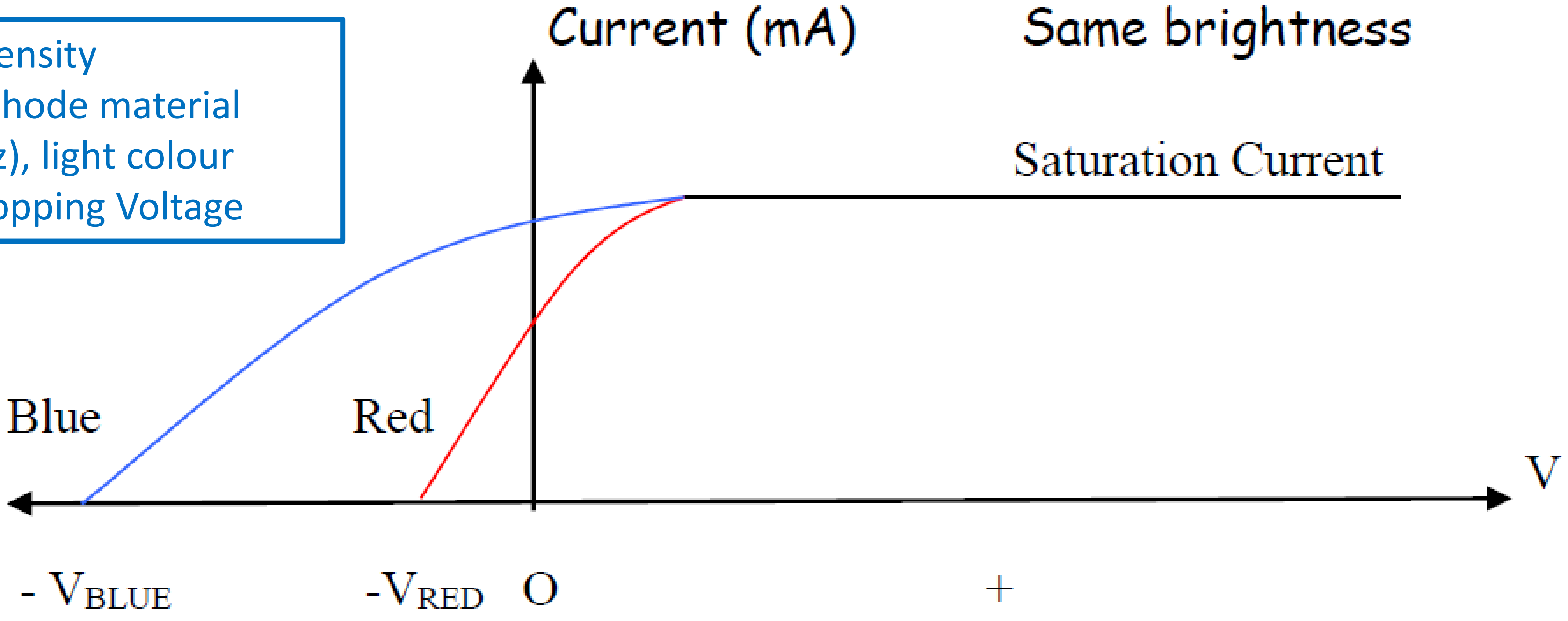
Ejected electrons all have the same KE_{MAX} no matter how bright or dim the light.

- Vary the FREQUENCY (colour), keeping intensity constant:

CVs -Intensity
- Cathode material

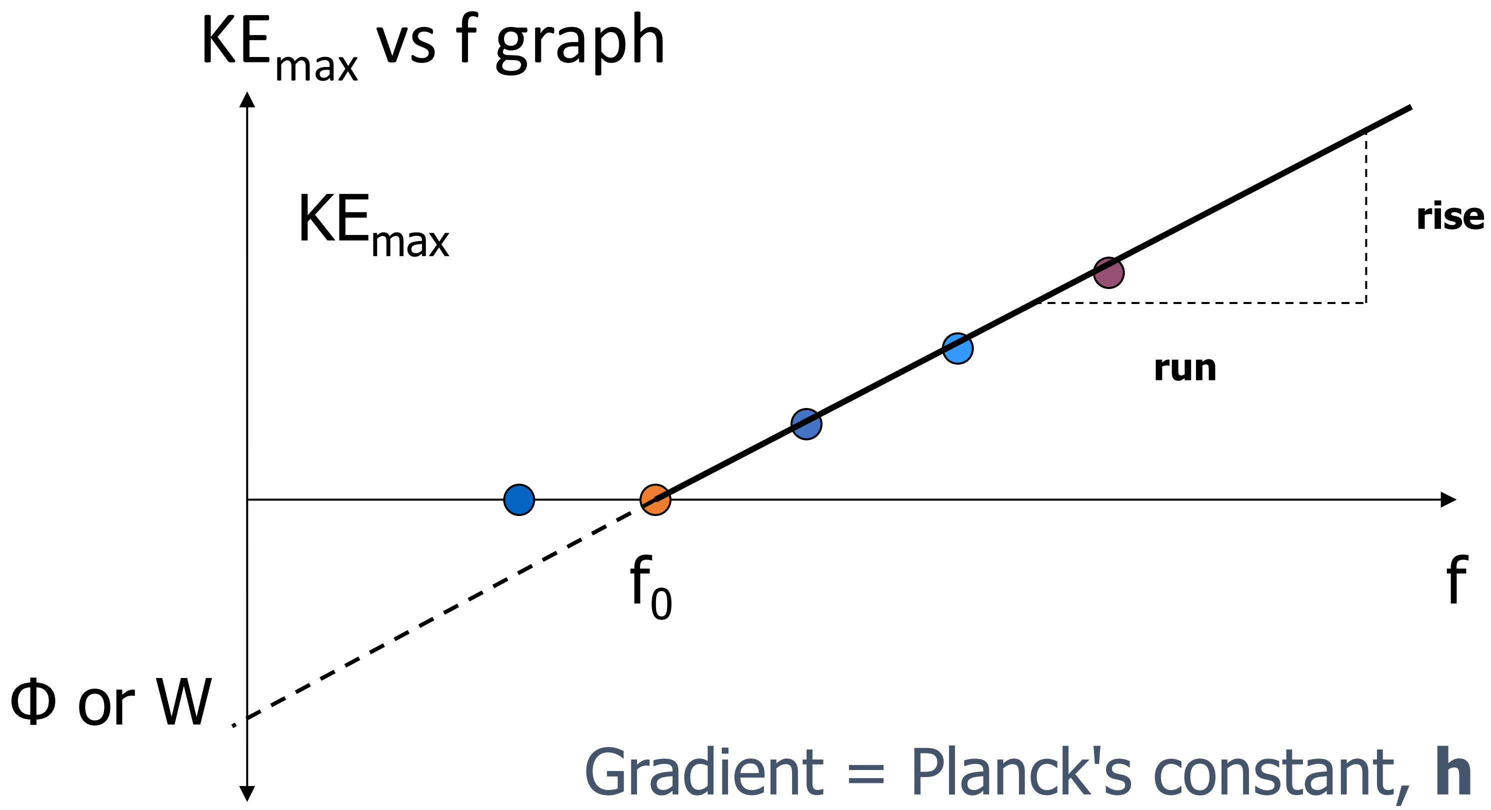
IV – f(Hz), light colour

DV – Stopping Voltage

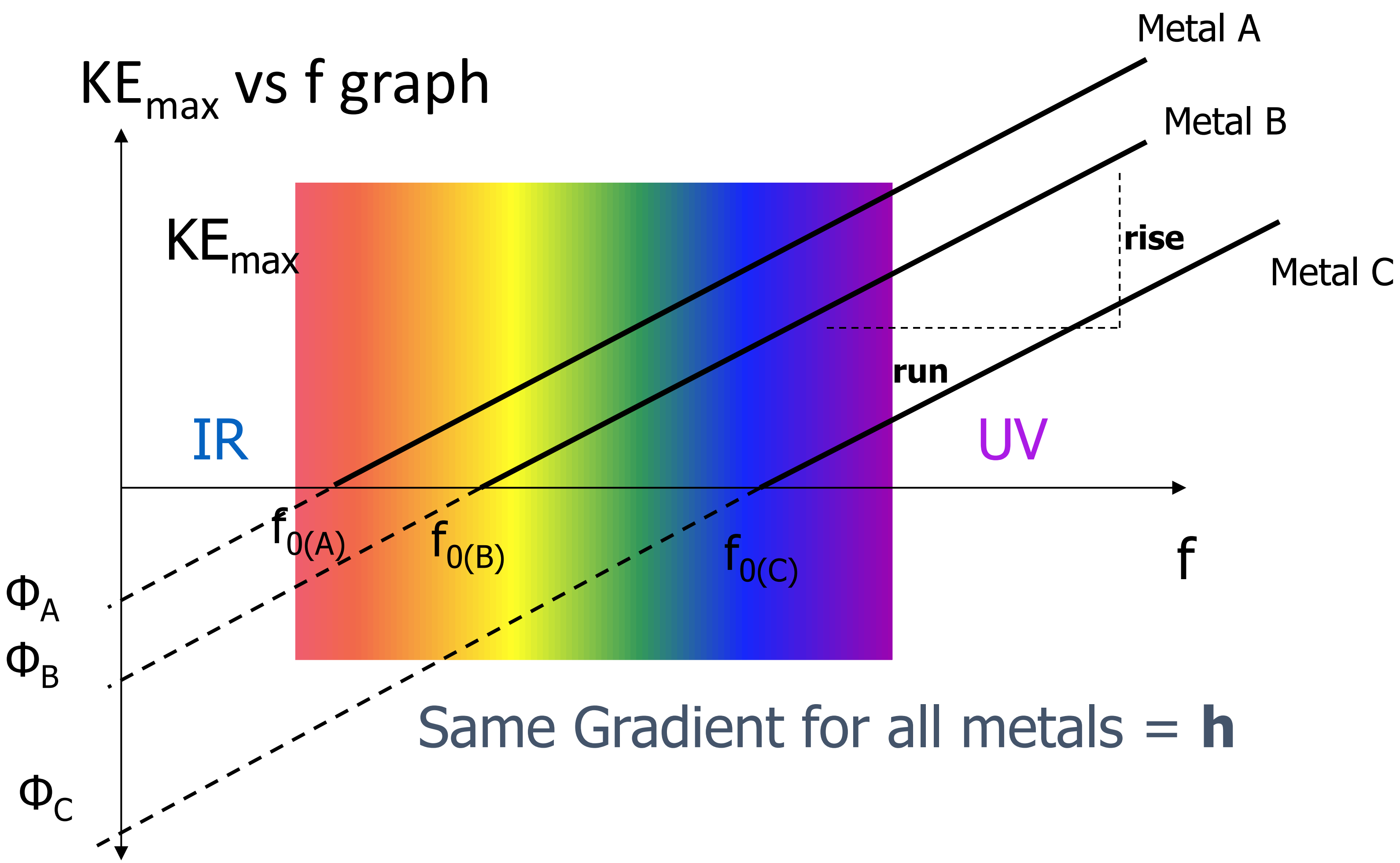


Higher frequency light (say, Blue) produces photoelectrons that are harder to stop (higher KE) than when lower frequency is shone on the cathode.

Photoelectric Effect

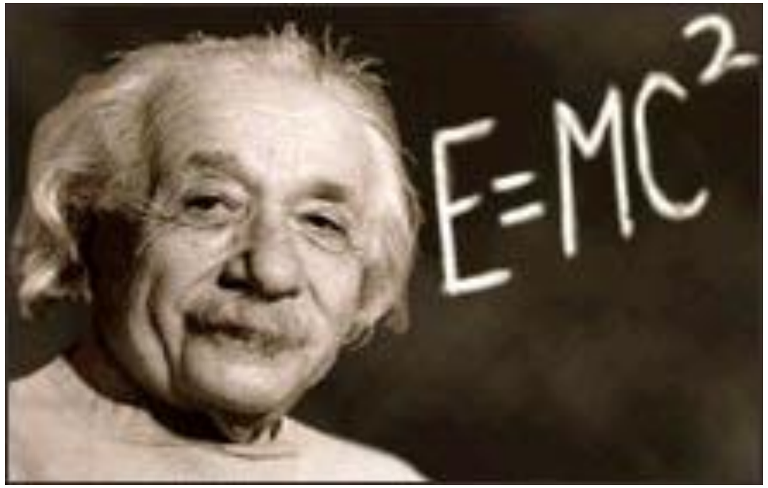


Photoelectric Effect



Photoelectric Effect

That's Relativity, but for Photoelectric Effect:



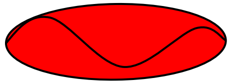
"Light has a *particle* nature too!"

Photoelectric Effect

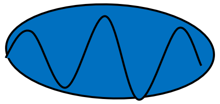
Einstein Model of Light: (1905, Nobel prize for it in 1921)

- Light is made of packets of energy: PHOTONS
- The energy of each Photon is $\propto$ to its frequency:

$$E = h \times f$$
$$= hc/\lambda$$



$$f_{RED} < f_{BLUE}$$
$$E_{RED} < E_{BLUE}$$



The constant, h, is Planck's constant:

- To calculate E in *Joules*: use $h = 6.63 \times 10^{-34}$ Joule.seconds
- To calculate E in *Electron Volts*: use $h = 4.14 \times 10^{-15}$ eV.seconds

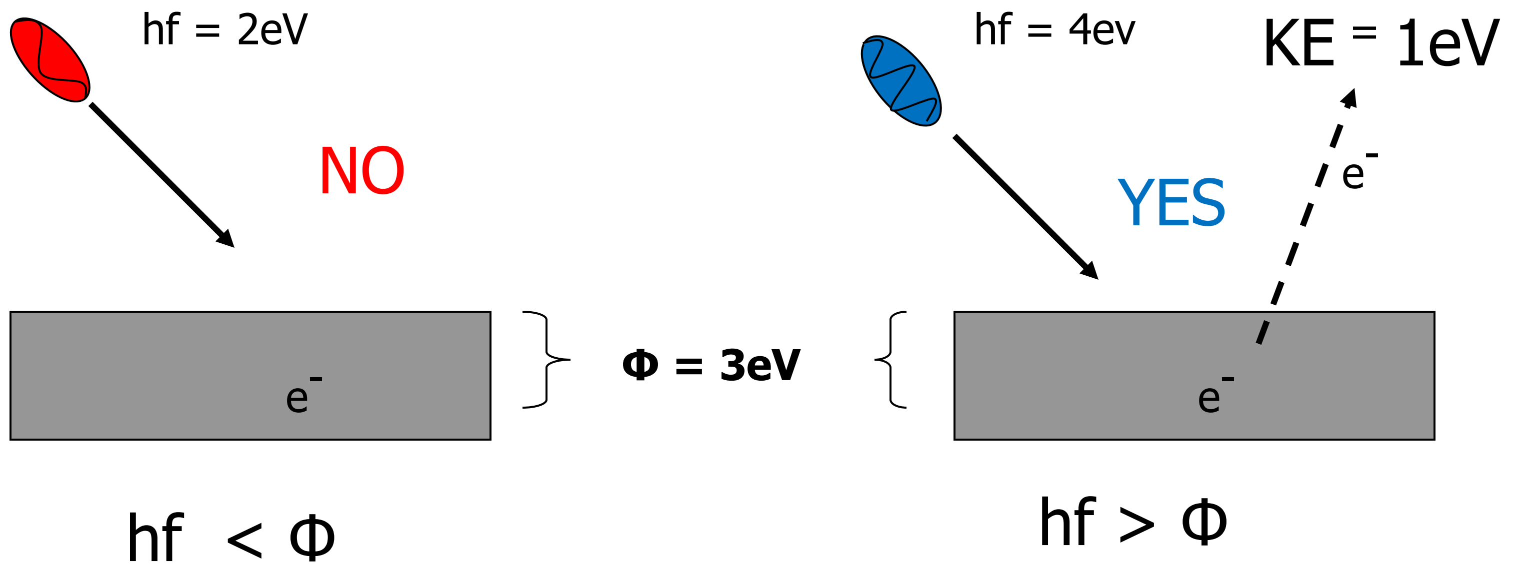
Photoelectric Effect

$$KE_{max} = hf - \Phi$$

1. Energy of incoming photon
2. Work function of metal
3. Energy of ejected electrons

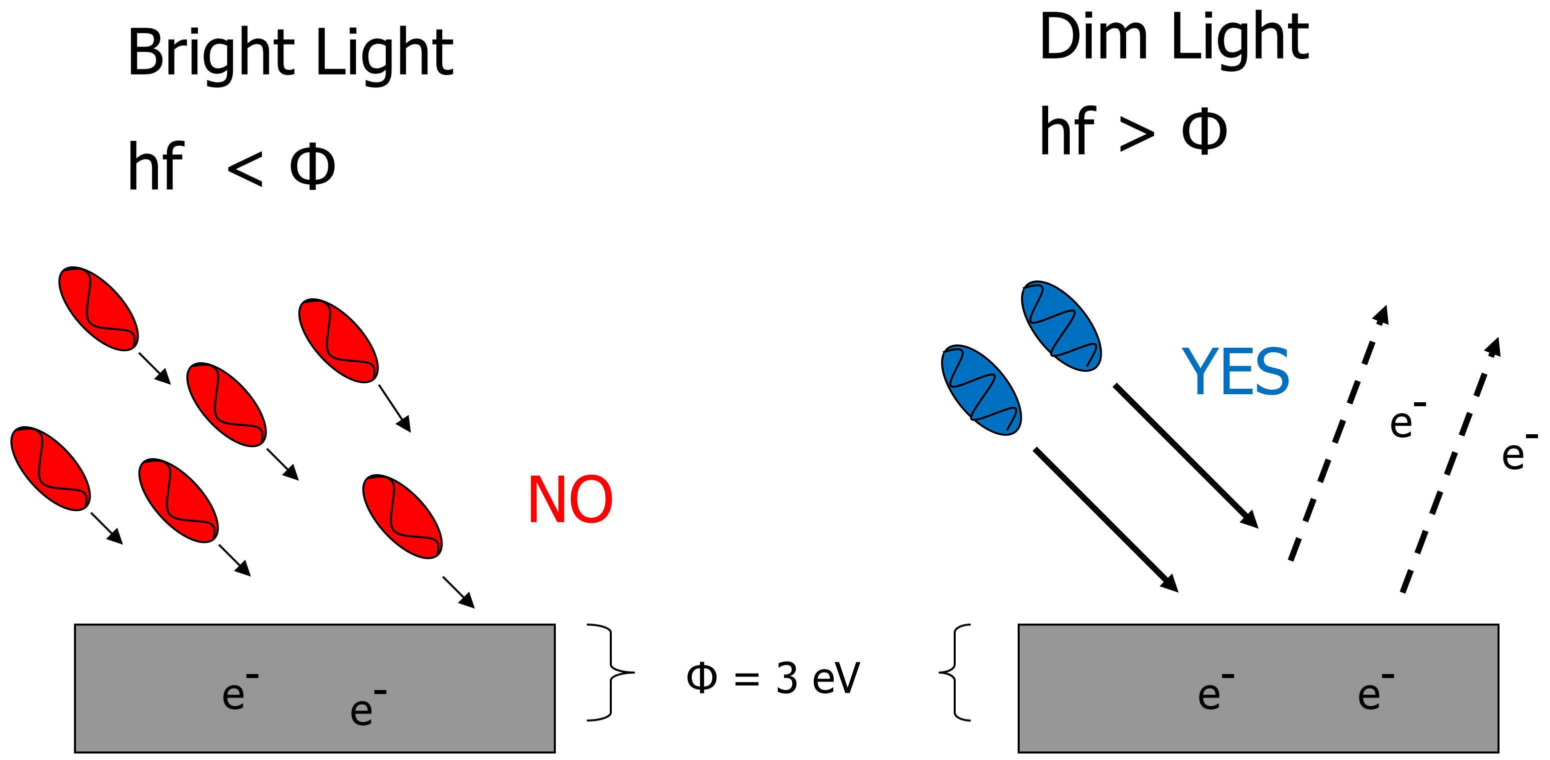
Photoelectric Effect

$$KE_{max} = hf - \Phi$$



Paul J Cuthbert

Photoelectric Effect



Paul J Cuthbert

PROBLEMS

7/ A metal cathode with a work function of 2.7eV is struck by a variety of photons. Calculate the **kinetic energy of the most energetic electrons** ejected from the cathode's surface for each of the following incident photons. If your calculation shows that no electrons are ejected write: NONE.

(i) Ultraviolet photon of frequency $f = 2.30 \times 10^{15}$ Hz:

eV

(ii) Red light of wavelength 640nm:

eV

SOLUTIONS

7/ A metal cathode with a work function of 2.7eV is struck by a variety of photons. Calculate the **kinetic energy of the most energetic electrons ejected** from the cathode's surface for each of the following incident photons. If your calculation shows that no electrons are ejected write: NONE.

(i) Ultraviolet photon of frequency f = 2.30 x 10^{15} Hz:

$$KE_{max} = hf - \Phi = 4.14\times10^{-15} \times 2.30\times10^{15} - 2.7$$

$$= 9.52 - 2.7$$

6.82 eV

(ii) Red light of wavelength 640nm:

$$KE_{max} = \frac{hc}{\lambda} - \Phi = \frac{4.14\times10^{-15} \times 3\times10^{8}}{640\times10^{-9}} - 2.7$$

$$= 1.94 - 2.7$$

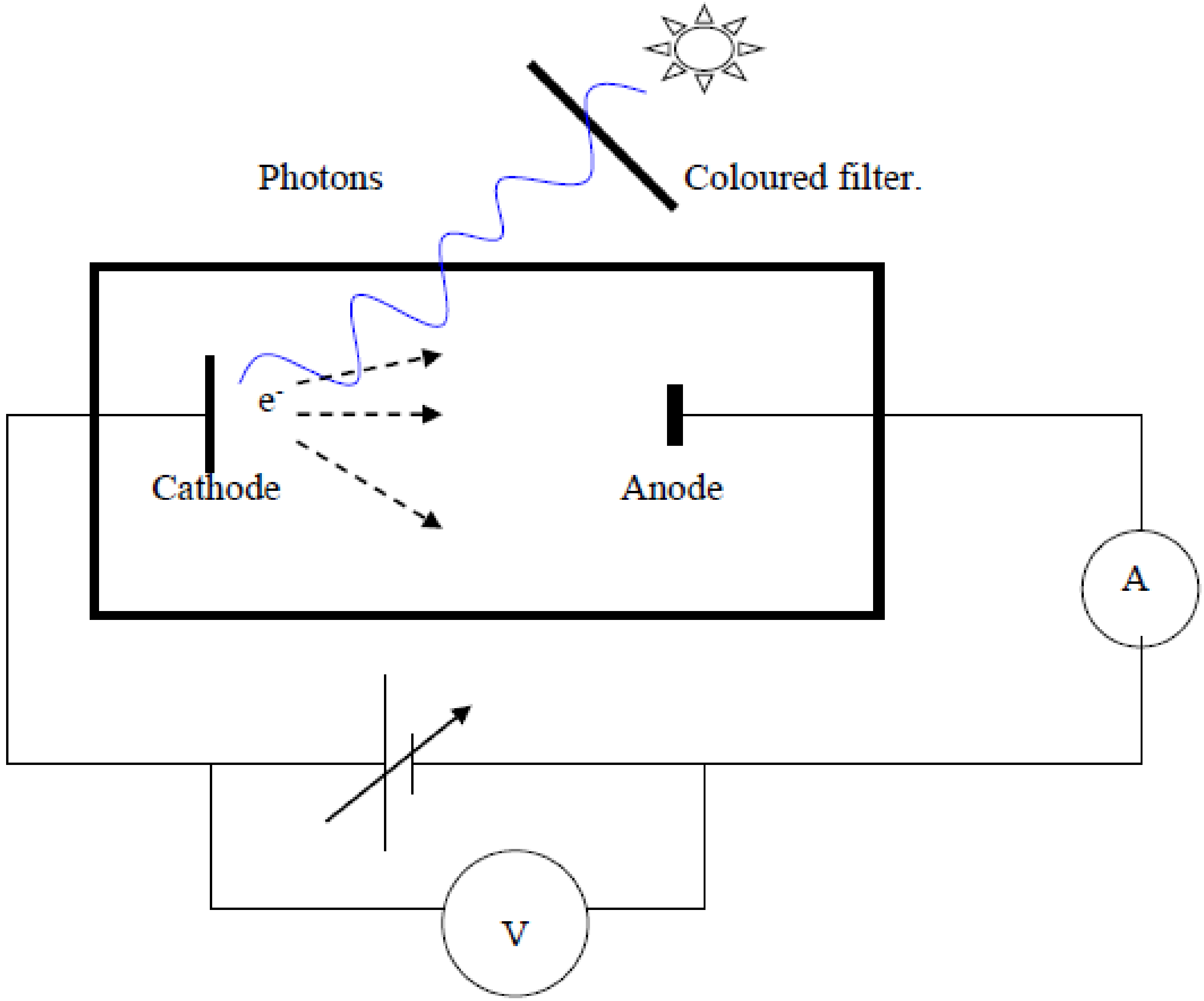
$$\Rightarrow E_{photon} < \Phi$$

NONE eV

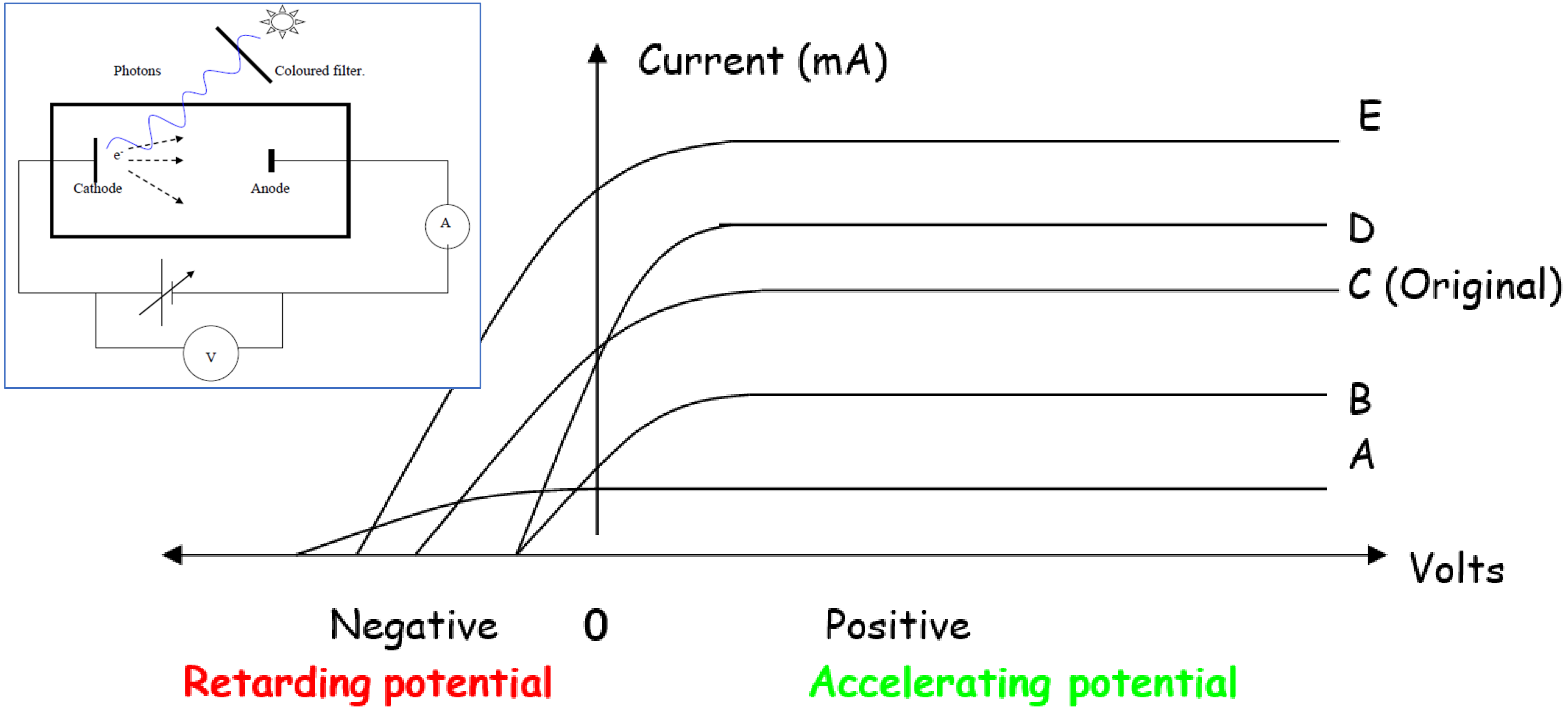
PJC

Problems

4/ An experimental apparatus is set up to examine the photoelectric effect. The equipment allows the user to vary the frequency of the light source, cathode metal, retarding and accelerating voltage and the light source's intensity.

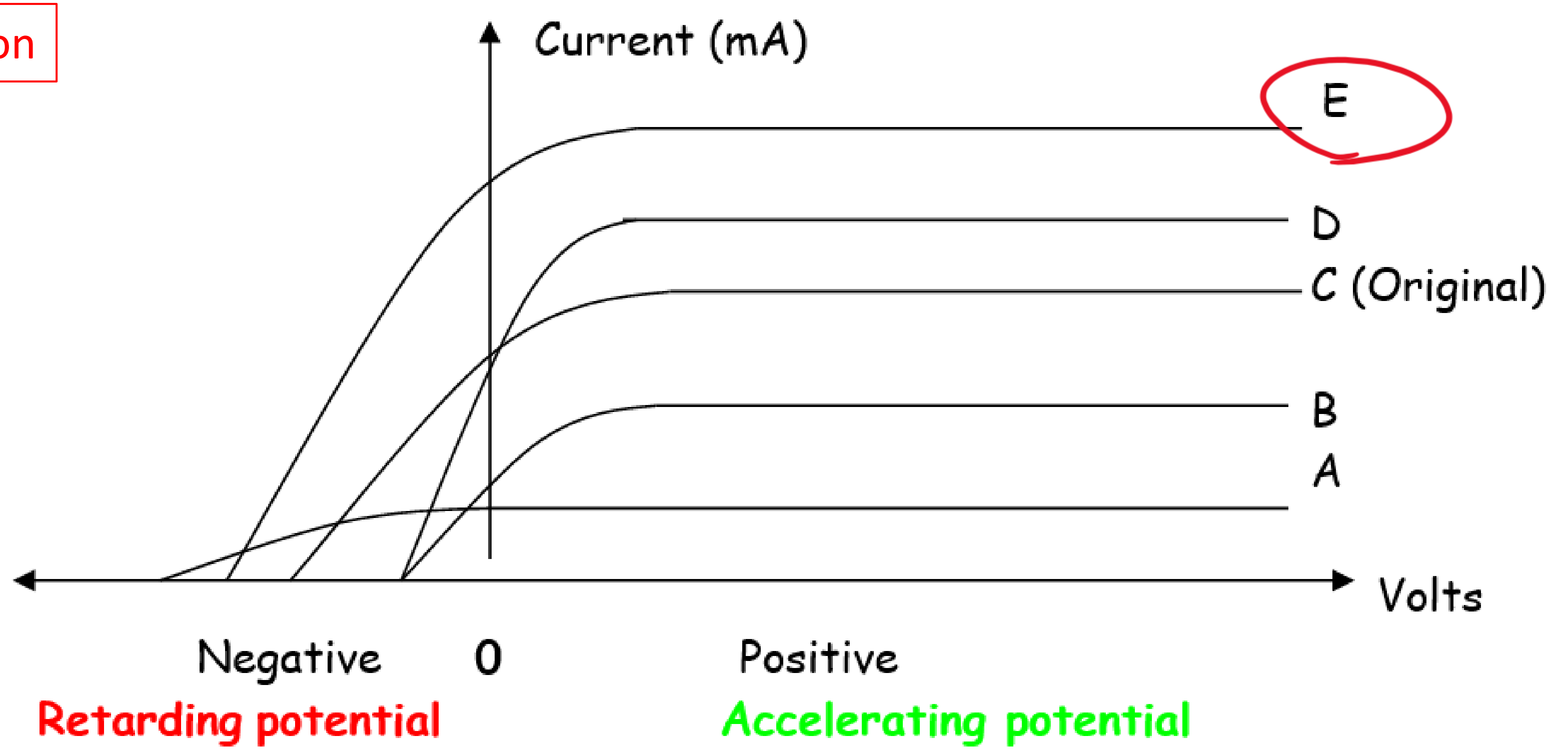


Graph for Q3(i) & (ii)



(i) The first curve obtained with a *yellow* light source is labeled **C**. Now the only changes made are the light source used is changed to *blue* and made *brighter*. The experiment is repeated. Which curve would represent this new condition?

Solution

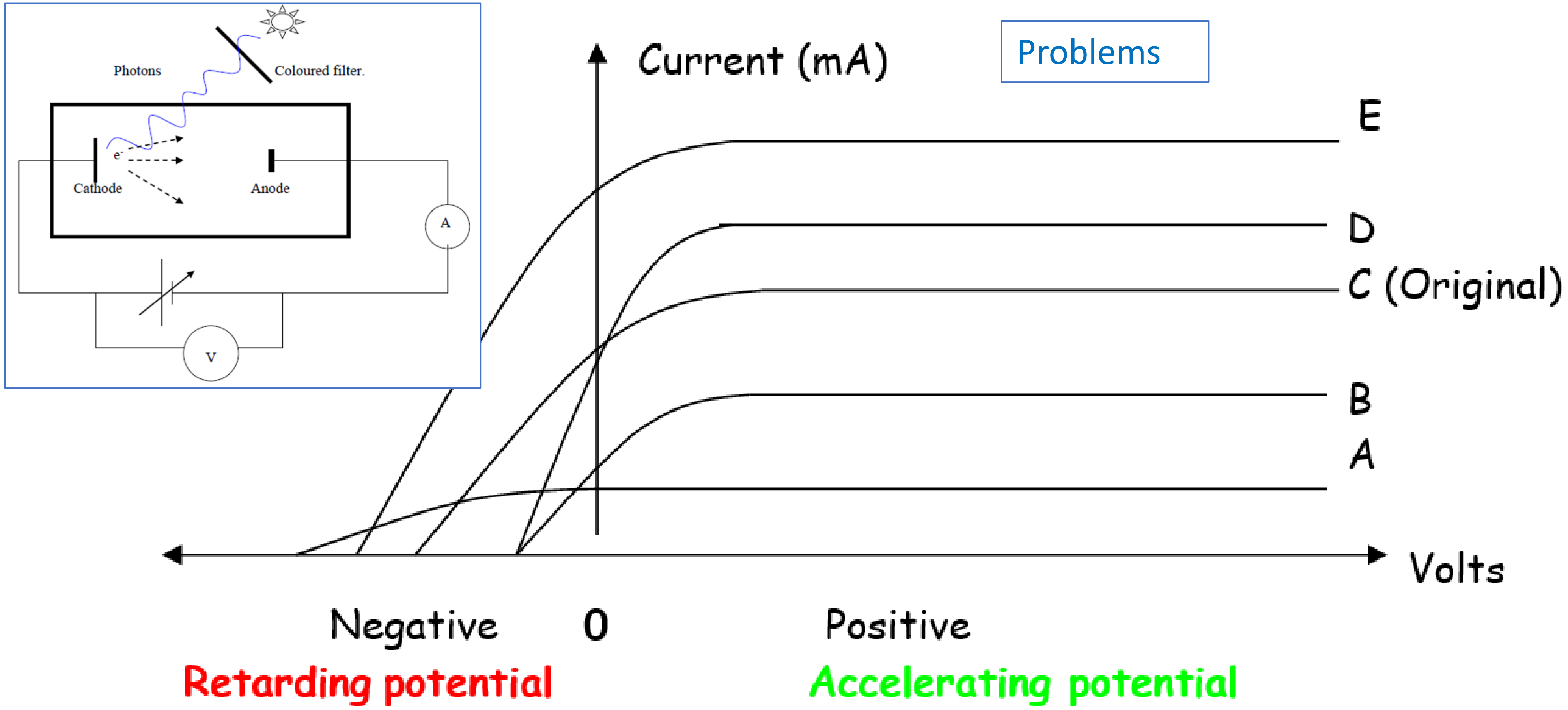


(i) The first curve obtained with a *yellow* light source is labeled **C**. Now the only changes made are the light source used is changed to *blue* and made *brighter*. The experiment is repeated. Which curve would represent this new condition?

E

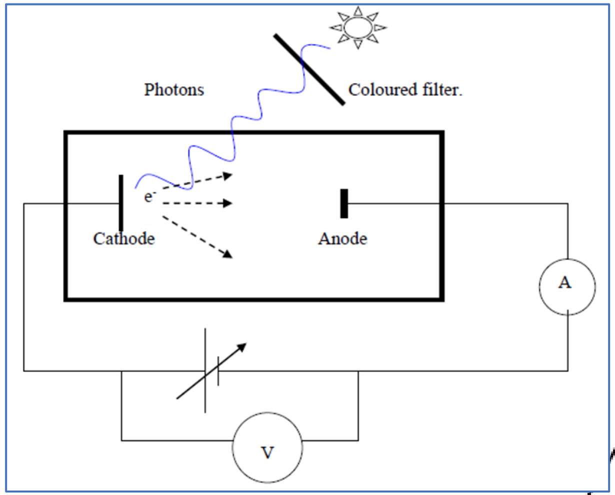
Blue light $\Rightarrow f \uparrow \Rightarrow V_{stop} \uparrow$

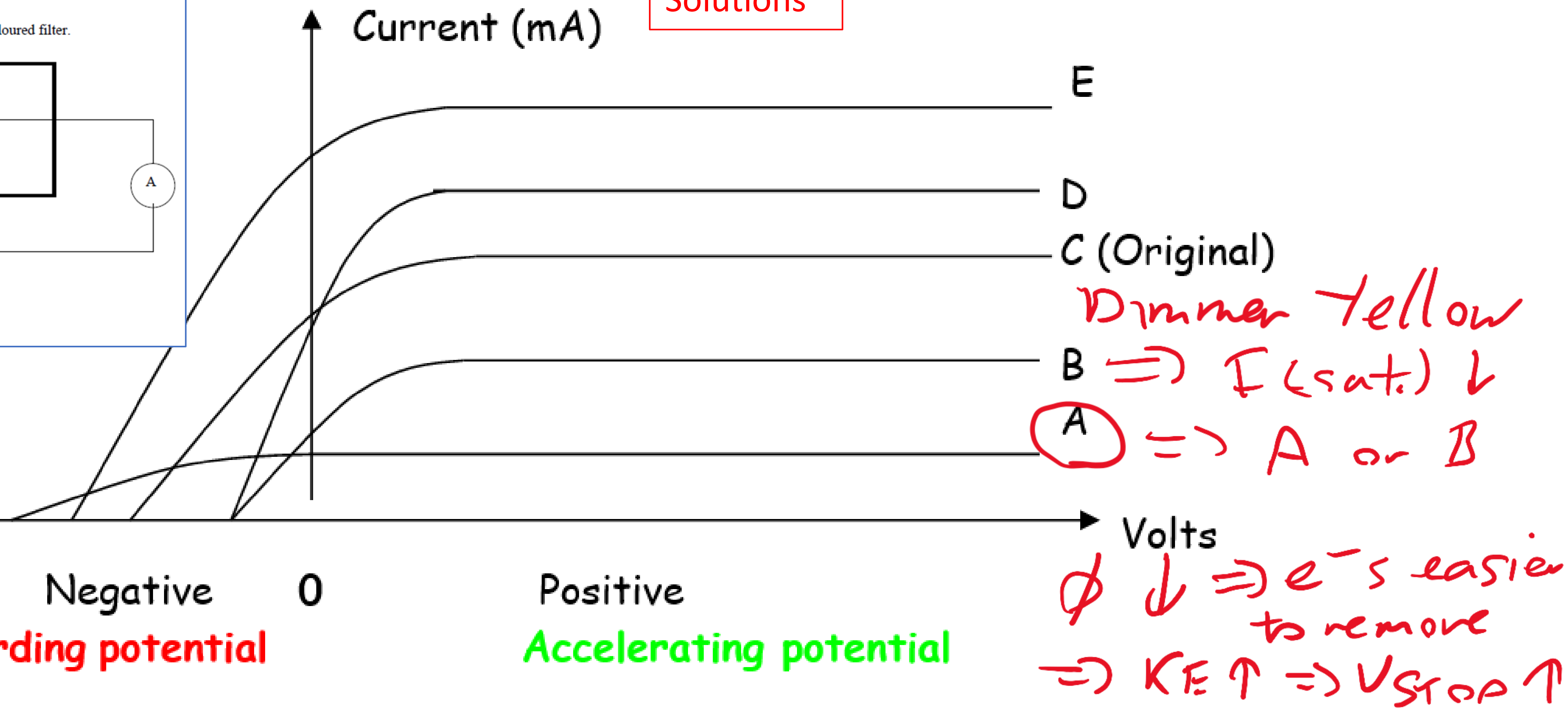
$\Rightarrow$ Either A or E. Brighter $\Rightarrow I(\text{saturation}) \uparrow \Rightarrow$ E



(ii) From the conditions that produces curve **C**, the set-up is now changed to a *dimmer* yellow light and the cathode material is now replaced with one with a *smaller* work function. Again, these are the only changes made. When the experiment is repeated which curve will result?

Solutions

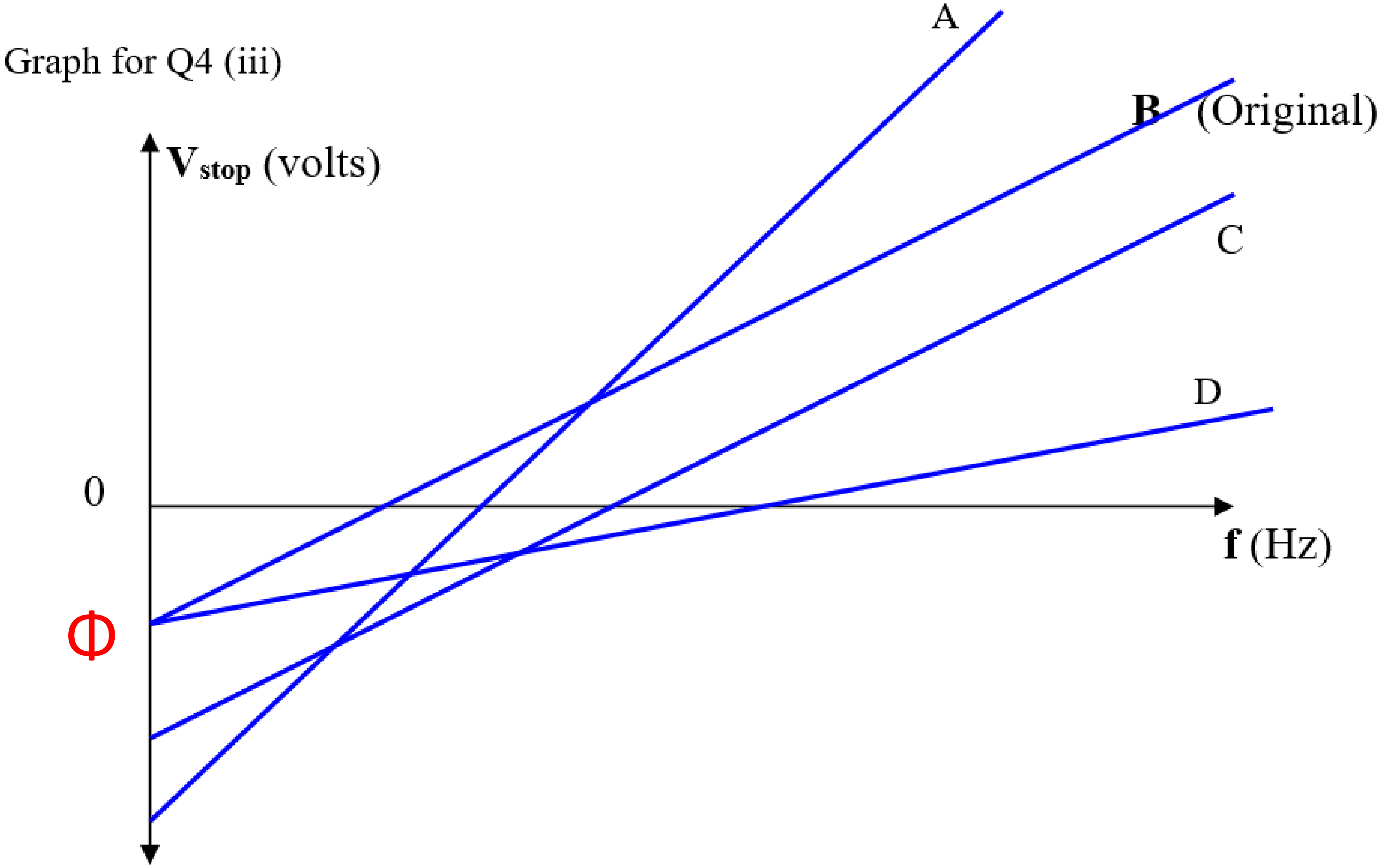


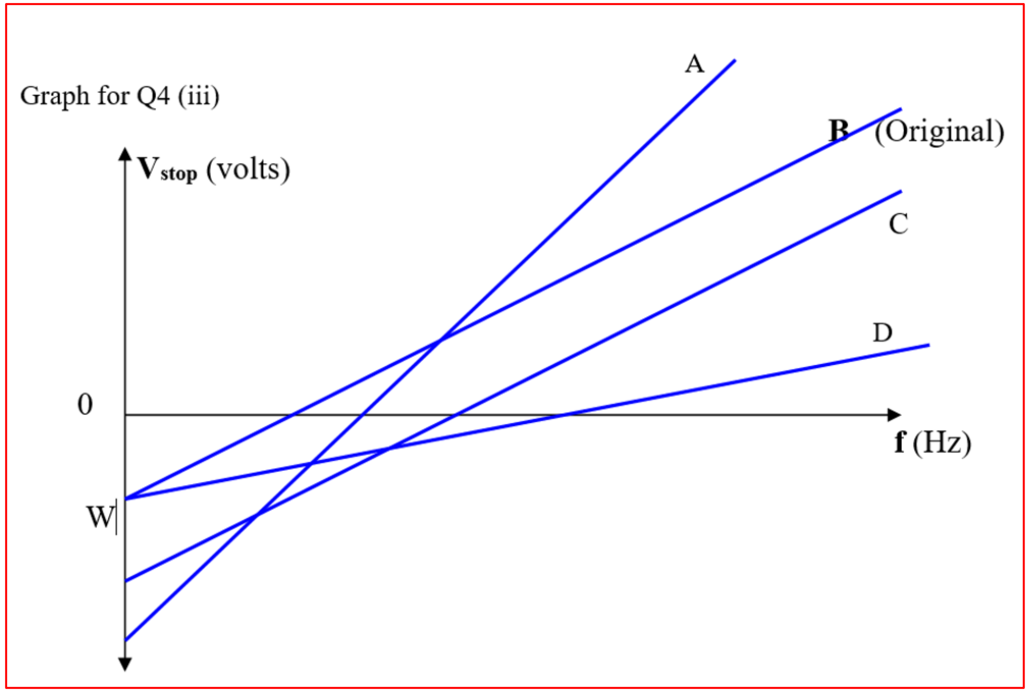


(ii) From the conditions that produces curve **C**, the set-up is now changed to a *dimmer* yellow light and the cathode material is now replaced with one with a *smaller* work function. Again, these are the only changes made. When the experiment is repeated which curve will result?

A

Problems





The graph of cut-off voltage vs frequency for this apparatus is shown in **curve B**. With a different cathode material, which other *graph* could also be produced.

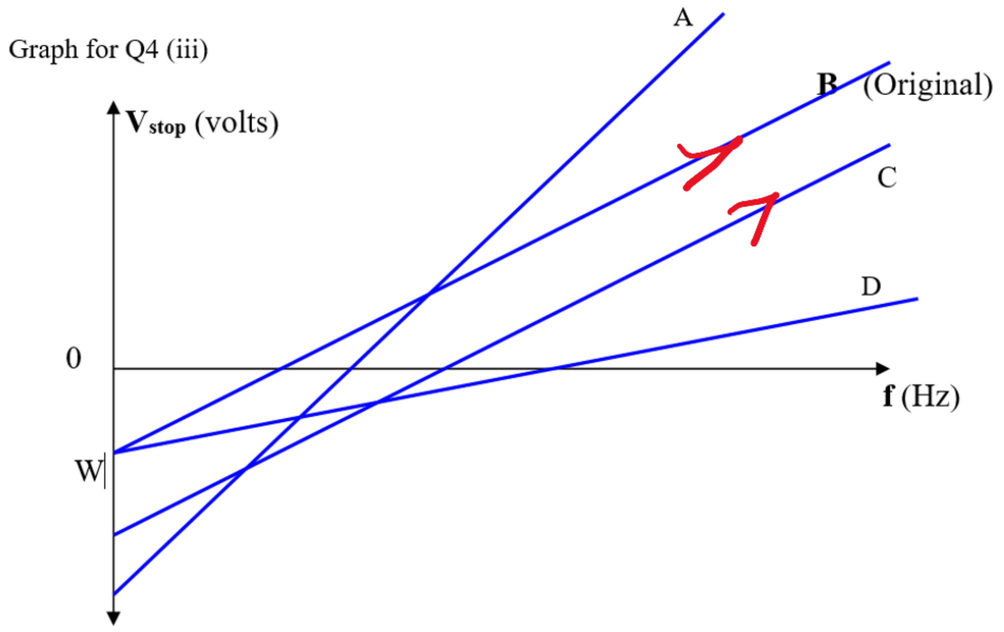
Given that the value of W for the cathode metal that produced curve B is -2.50 eV, what is value of the *lowest frequency* of light that will just eject electrons from this cathode material?

Hz

(v) When UV light of frequency 8.0×10^{14} Hz is shone onto this cathode material (curve B) what *retarding voltage* would be necessary to stop the fastest moving photoelectrons ejected in the apparatus?

V

Solutions



The graph of cut-off voltage vs frequency for this apparatus is shown in **curve B**. With a different cathode material, which other *graph* could also be produced.

Must have the same gradient (=h) as B

C

Given that the value of W for the cathode metal that produced curve B is -2.50 eV, what is value of the *lowest frequency* of light that will just eject electrons from this cathode material?

- $\phi = W = 2.5$ lowest frequency $= f_0$, $\phi = hf_0$
  $\Rightarrow 2.5 = 4.14\times10^{-15}\, h$,

6.03×10^{14} Hz

(v) When UV light of frequency 8.0×10^{14} Hz is shone onto this cathode material (curve B) what *retarding voltage* would be necessary to stop the fastest moving photoelectrons ejected in the apparatus?

- $KE_{max} = hf - \phi = 4.14\times10^{-15} \times 8\times10^{14} - 2.5$
  $= 3.31 - 2.5 = 0.81 = V_{stop}$

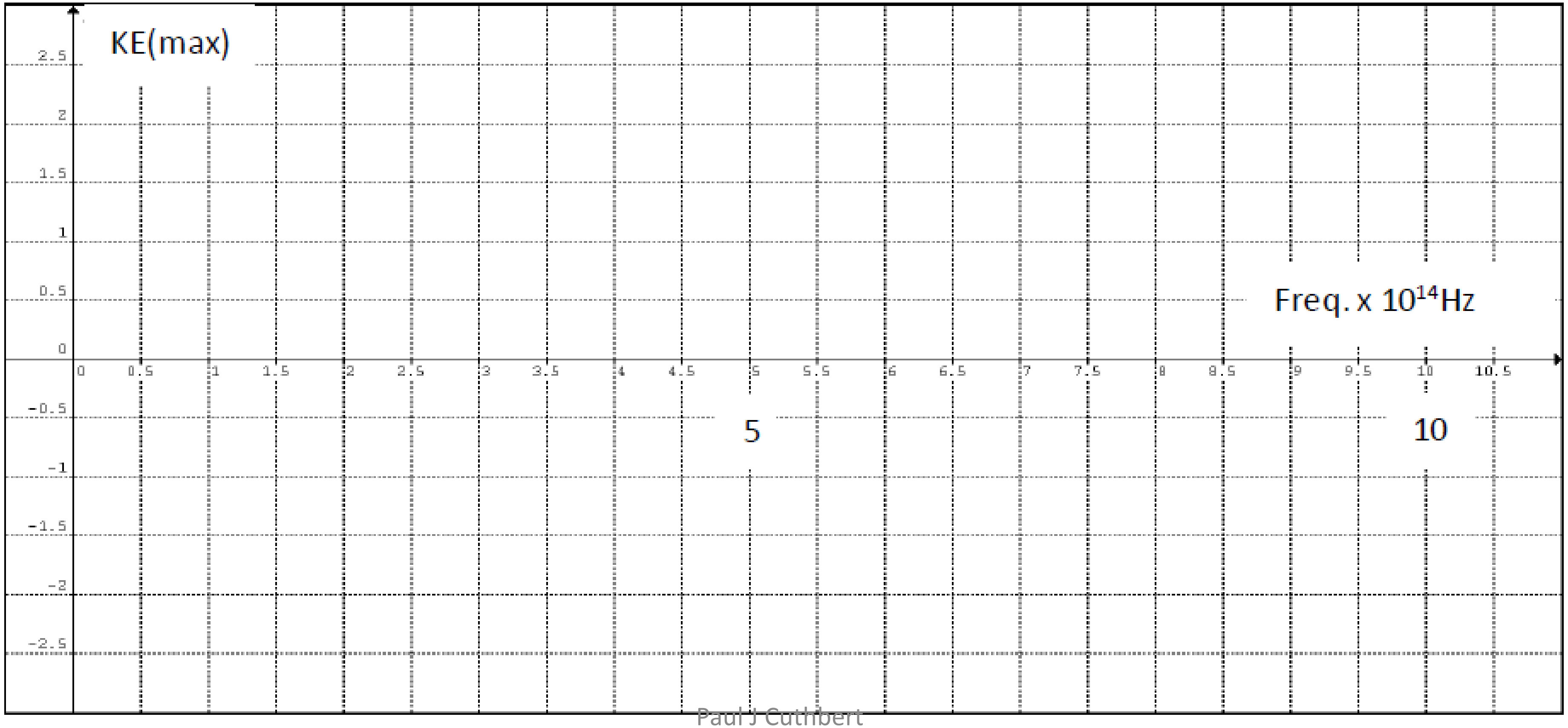
0.81 V

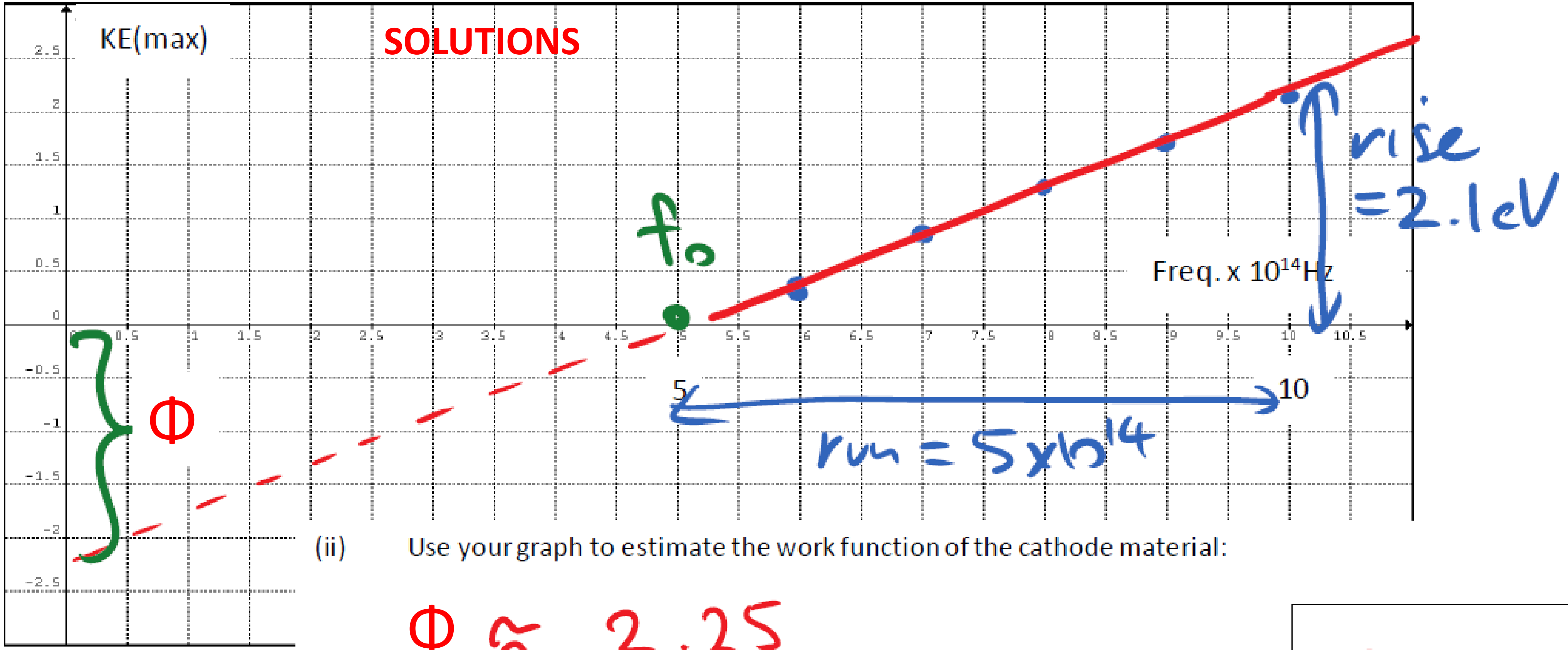
PROBLEMS

8/ A photoelectric apparatus is setup with a particular metal cathode. The apparatus is used to determine the magnitude of Planck's constant. The data collected from the experiment is shown in the table:

f(Hz)	6.0×10^{14}	7.0×10^{14}	8.0×10^{14}	9.0×10^{14}	1.0×10^{15}
$KE_{(max)}$ of ejected e^{-}s (eV)	0.38	0.80	1.25	1.7	2.1

(i) Graph these results (clearly plot the data points and rule a line-of-best-fit through them):





(ii) Use your graph to estimate the work function of the cathode material:

$\Phi \approx 2.25$

2.25 eV

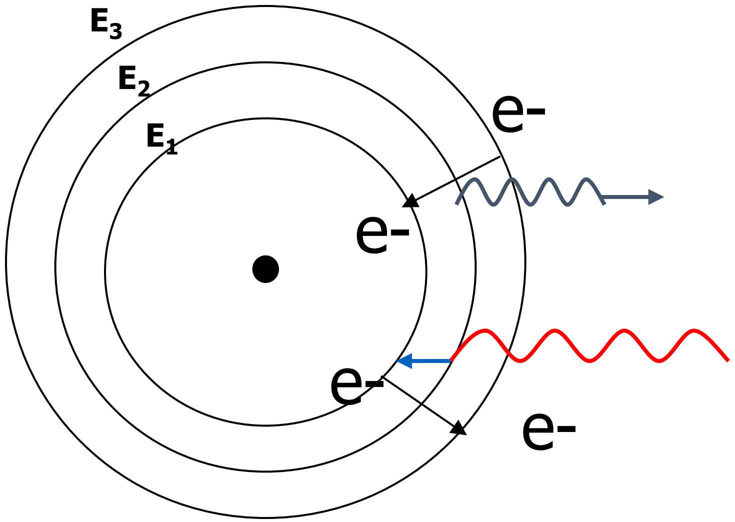
(iii) Use this graph to determine the value of Planck's constant:

$$h = \text{gradient} = \frac{2.1\,eV}{5\times10^{14}\,Hz}$$

$$= 4.2\times10^{-15}\,eVs$$

NOTE: the answer will NEVER be 4.14×10^{-15}, the value on the data sheet

Emission & Absorption Spectra



Emission

1. Electron falls to lower energy level.
2. Photon emitted of energy: $hf = E_3 - E_1$

Absorption

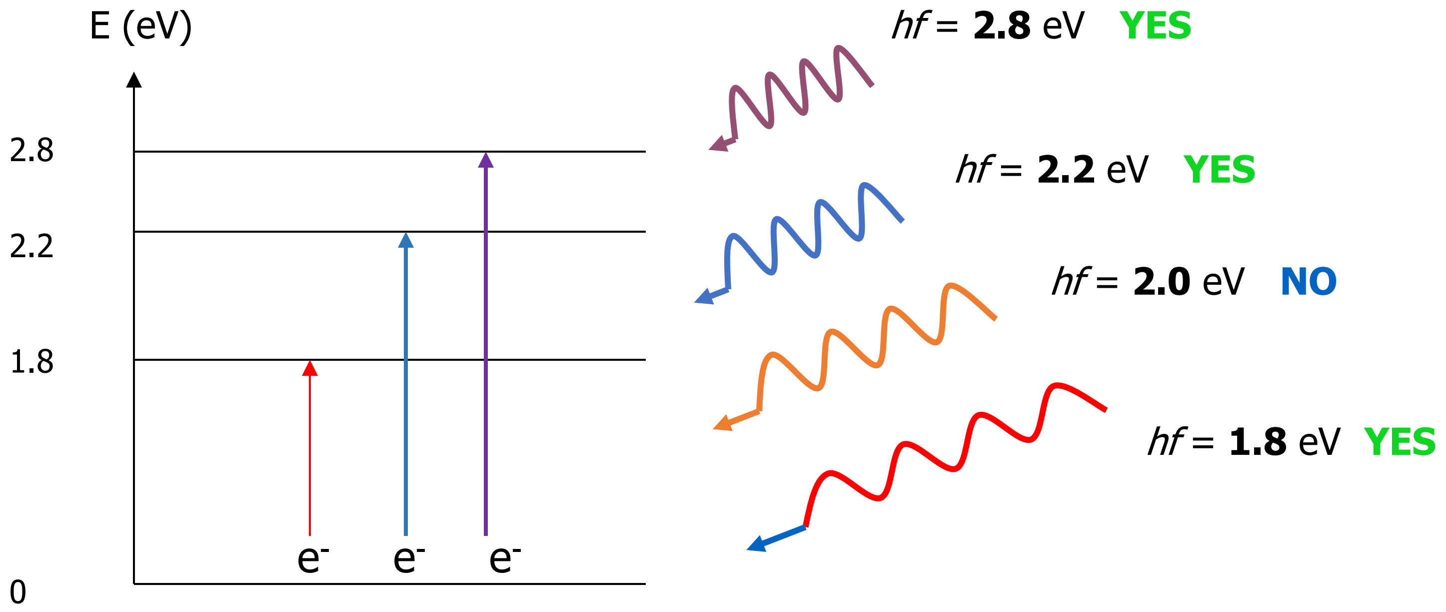
1. Photon absorbed of energy: $hf = E_3 - E_2$
2. Electron excited from level E_1 to E_3.

Paul J Cuthbert

Absorption Spectra

PHOTON absorption: *All or nothing*

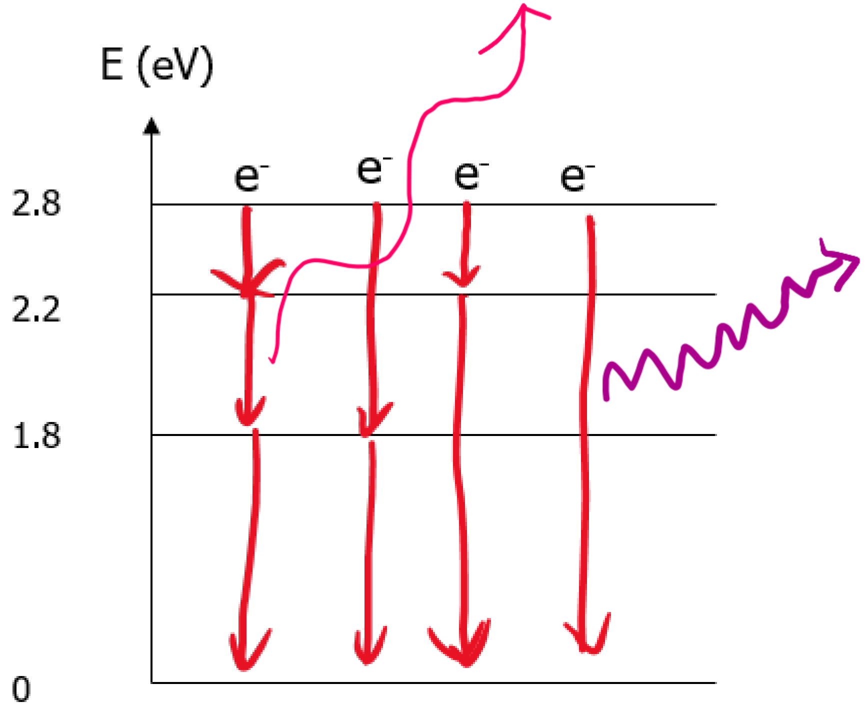
- An electron can be excited from energy level E_i to a higher energy level E_f if an incoming photon has energy $hf = E_f - E_i$



Paul J Cuthbert

Emission Spectra

For an electron in an excited state, a number of photons of different energies can be emitted as the electron de-excites to the ground state.



Photon Energies emitted:

2.8 – 2.2 = 0.6 eV
2.2 – 1.8 = 0.4 eV
1.8 – 0 = 1.8 eV
2.8 – 1.8 = 1.0 eV
2.2 – 0 = 2.2 eV
2.8 – 0 = 2.8 eV

Total = 6 different photons

Matter Waves

If the things that we usually think of as waves (like Light) can behave like particles (photoelectric effect), then maybe things we think of as particles (electrons, protons etc) can behave like waves.

Then they would have a wavelength given by:

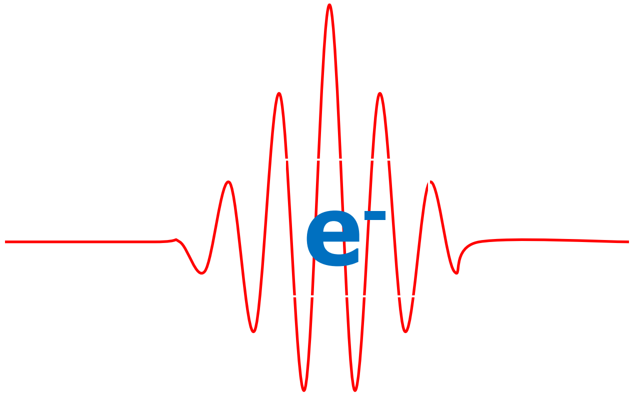
$$\lambda = \frac{h}{p} = \frac{h}{m \times v} = \frac{6.63 \times 10^{-34}}{m \times v}$$

For your A3 notes:

NOTE: for this equation,
h = 6.63 x 10^{-34} Js *ALWAYS*

*(we **never** use h = 4.14 x 10^{-15} eVs in de Boglie's equation).*

Prince Louis de Broglie



Problems:

Calculate the de Broglie wavelengths of

(i) a cricket ball of mass 0.4 kg moving at 20m/s

$\lambda = \frac{h}{p} = \frac{6.63 \times 10^{-34}}{0.4 \times 20}$ ~0 (< h)

(iii) an electron moving at 10^6 m/sec

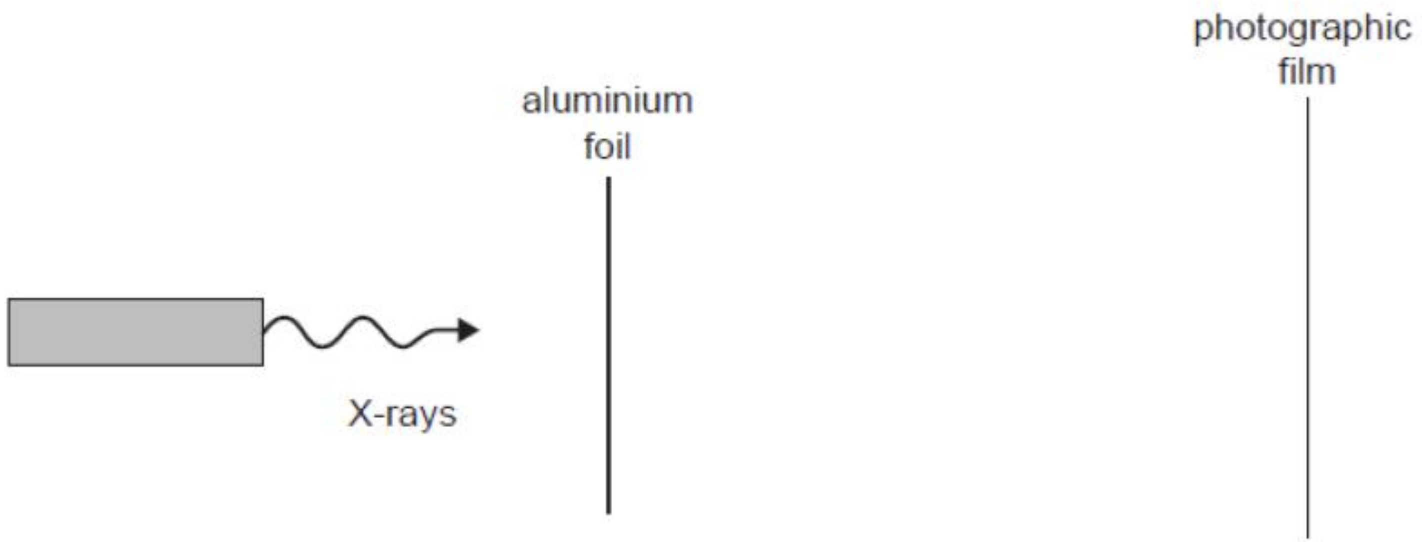
$\lambda = \frac{6.63 \times 10^{-34}}{9.1 \times 10^{-31} \times 10^6} = 7.3 \times 10^{-10}$ m (~ size of an atom)

[⇒ atoms will produce diffraction with electrons]

(v) Why don't we notice the wave-like properties of the objects around us?

λ (de Broglie) is extremely small, far smaller than the objects themselves.
The Diffraction ratio $\lambda/w \approx 0$ => interference and diffraction effects are not visible.

A beam of X-rays, wavelength $\lambda = 250$ pm (250×10^{-12} m), is directed onto a thin aluminium foil as shown in Figure 4a. The X-rays scatter from the foil onto the photographic film.



Question 9

Calculate the energy, in keV, of these X-rays.

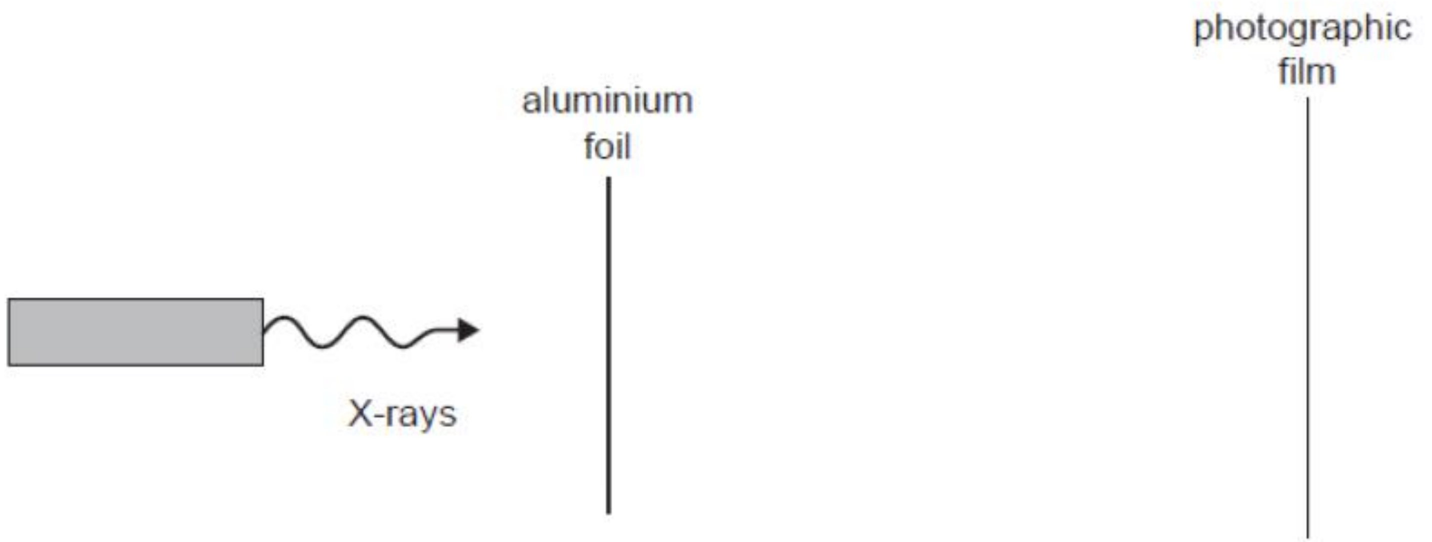
keV

2 marks

VCAA 2006 Exam 2

SOLUTION

A beam of X-rays, wavelength $\lambda = 250$ pm (250×10^{-12} m), is directed onto a thin aluminium foil as shown in Figure 4a. The X-rays scatter from the foil onto the photographic film.



Question 9

Calculate the energy, in keV, of these X-rays.

$$E = hf = \frac{hc}{\lambda} = \frac{4.14 \times 10^{-15} \times 3 \times 10^{8}}{250 \times 10^{-12}}$$

$$= 4968 \text{ eV} = 4.968 \times 10^{3} \text{ eV}$$

4.97 keV

(or 5 keV)

2 marks

After the X-rays pass through the foil, a diffraction pattern is formed as shown in Figure 4b.

In a later experiment, the X-rays are replaced with a beam of energetic electrons. Again, a diffraction pattern is observed which is very similar to the X-ray diffraction pattern. This is shown in Figure 4c.

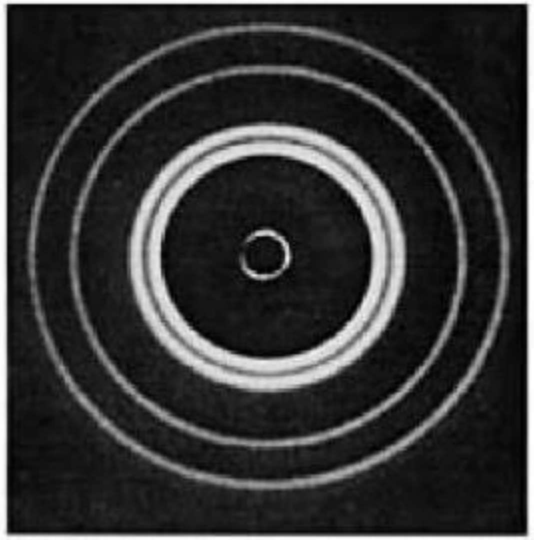


Figure 4b

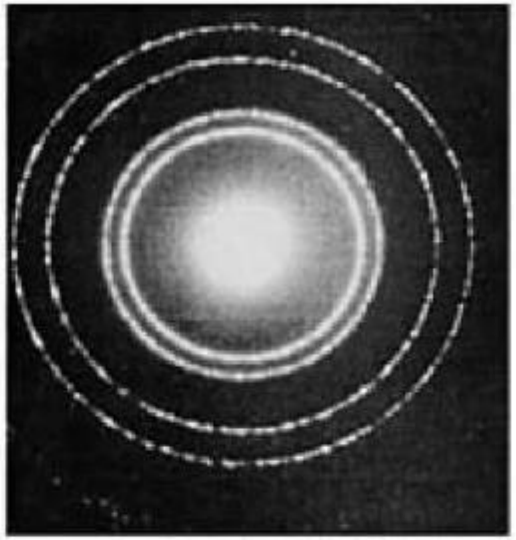


Figure 4c

Question 10

Explain why the electrons produce a diffraction pattern similar to that of the X-rays.

____

____

____

____

2 marks

SOLUTION

After the X-rays pass through the foil, a diffraction pattern is formed as shown in Figure 4b.

In a later experiment, the X-rays are replaced with a beam of energetic electrons. Again, a diffraction pattern is observed which is very similar to the X-ray diffraction pattern. This is shown in Figure 4c.

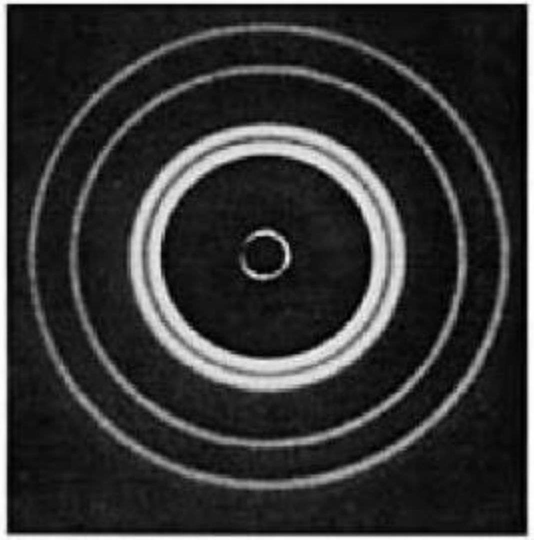


Figure 4b

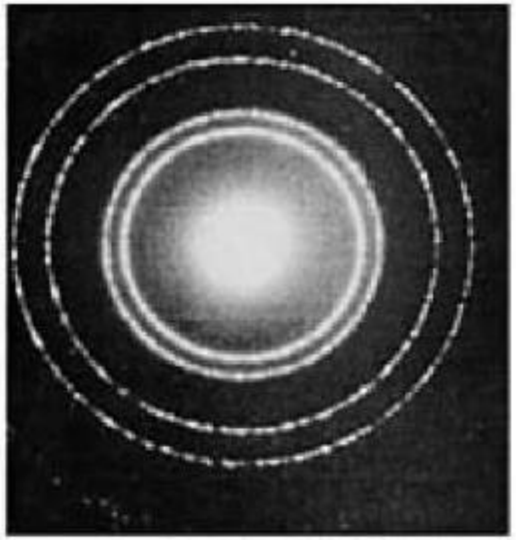


Figure 4c

Question 10

Explain why the electrons produce a diffraction pattern similar to that of the X-rays.

Question 10

Electrons have a de Broglie wavelength which was the same (or very similar) to the wavelength of the X-rays.

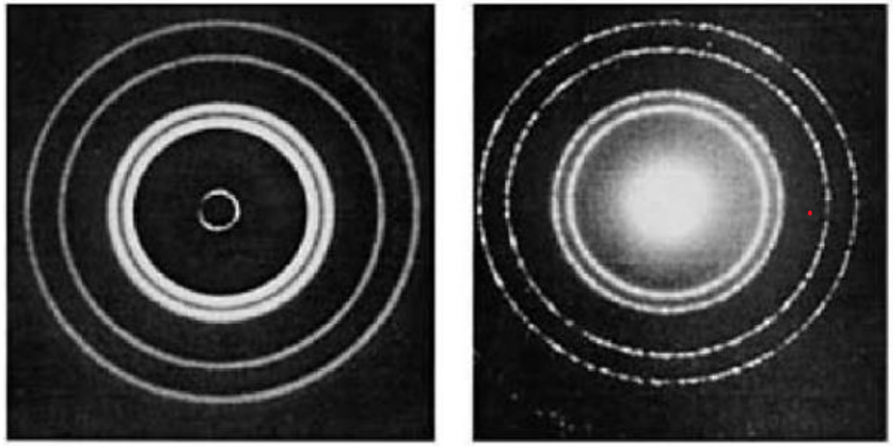
2 marks

Question 11

Assuming the two diffraction patterns are identical, estimate the momentum of the electrons. Include the unit.

3 marks

SOLUTION



Question 11

Assuming the two diffraction patterns are identical, estimate the momentum of the electrons. Include the unit.

- Fringe spacing is the same $\Rightarrow \lambda_{e^-} = \lambda_{xrays}$
  $= 250 \times 10^{-12}$ m
- $p = \frac{h}{\lambda} = \frac{6.63 \times 10^{-34}}{2.50 \times 10^{-12}}$

2.7×10^{-24} kg m s^{-1} (or Ns)

3 marks

Relativity
Unit 3 AoS#1

Monash University – Revision Lecture

Paul J Cuthbert

RELATIVITY:

- Einstein’s 2 Postulates
- Inertial Frames
- Lorentz (gamma) values
- Time dilation
- Length contraction
- Frames of reference
- Michelson Morley experiment – added in 2024

Suggestion – put these on your A3 notes for the exam

1. The laws of physics are the same for all observers in all inertial reference frames*. No frame is singled out as particular.

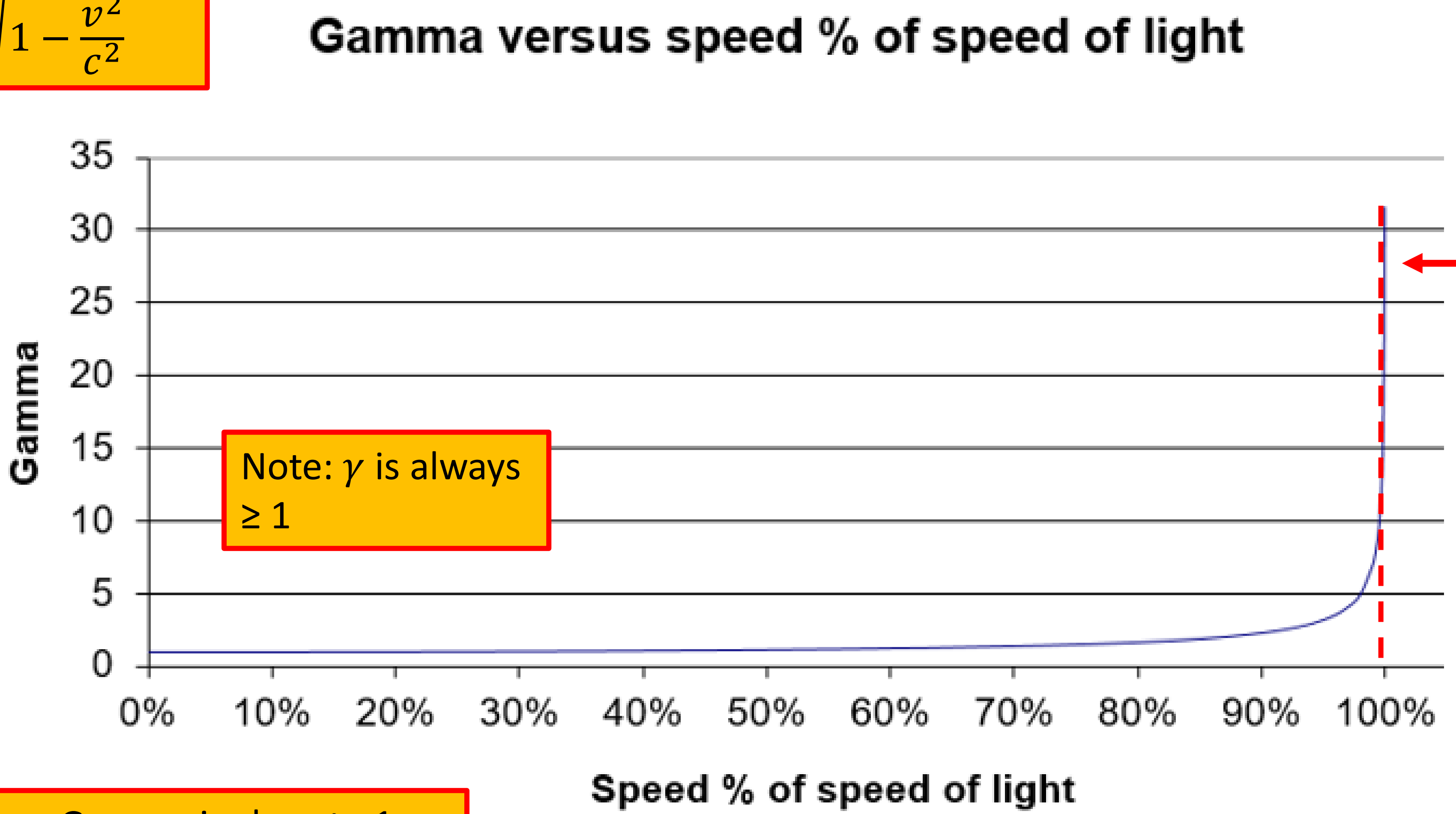
2. The speed of light in free space has the same value, c, in all directions and in all inertial reference frames.

* An inertial reference frame is one which is not accelerating.

Include a table like this on your A3 notes for the exam

% c (%speed of light)	v/c	Gamma value (γ)
1	0.01	1.0001
5	0.05	1.0013
10	0.1	1.005
20	0.2	1.021
30	0.3	1.048
40	0.4	1.091
50	0.5	1.155
60	0.6	1.250
70	0.7	1.400
80	0.8	1.667
86.6	0.866	2.000
90	0.90	2.294
99	0.99	7.089
99.9	0.999	22.386

$$\gamma = \frac{1}{\sqrt{1 - \frac{v^2}{c^2}}}$$



as $v \to c$,
$\gamma \to \infty$

Note: γ is always ≥ 1

Note: where Gamma is close to 1, we call this *Classical* or *Newtonian* physics.

VCAA June Exam 2006 – Relativity Detailed Study (Option)

A burglar alarm is sounding at house number 42. Lee and Sung are in cars travelling as shown in Figure 2. They are able to measure the speed of the sound emitted from the alarm sirens on top of the house. The air is at rest, and the speed of sound through the air is 340 m s^{-1}.

Figure 2

Question 5

In the box below write the speed of sound as measured by Lee and by Sung.

Lee	m s^{-1}	Sung	m s^{-1}

2 marks

Solution

$V_{Relative} = \vec{V}_1 - \vec{V}_2$

A burglar alarm is sounding at house number 42. Lee and Sung are in cars travelling as shown in Figure 2. They are able to measure the speed of the sound emitted from the alarm sirens on top of the house. The air is at rest, and the speed of sound through the air is 340 m s^{-1}.

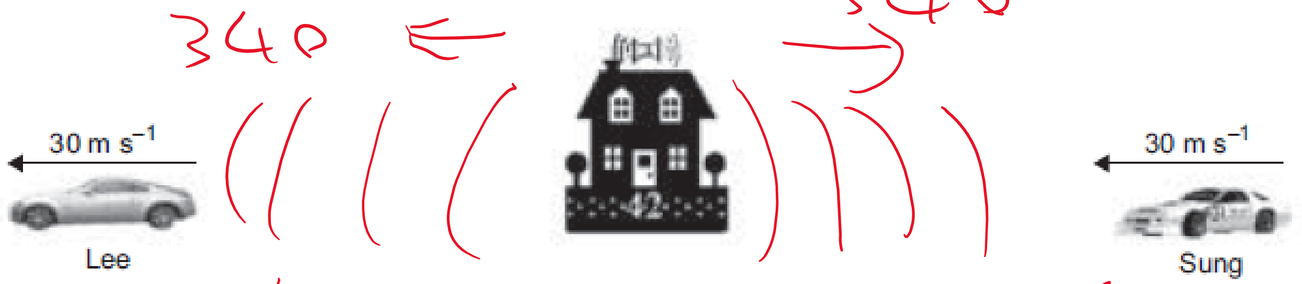


Figure 2

$340 - {+30}$ $\qquad$ $340 - {-30}$

Question 5

In the box below write the speed of sound as measured by Lee and by Sung.

$= 340 - 30$ $\qquad$ $= 340 + 30$

Lee 310 m s^{-1}	Sung 370 m s^{-1}

2 marks

A space station is emitting light from lasers fixed to it. Nilofa and Hadi are situated on two planets that are at rest relative to each other. They measure the speed of the light emitted from the lasers on the space station. Hadi is travelling towards the space station with a speed of 0.25c. Nilofa is travelling away from the space station with a speed of 0.25c. The speed of light through space is c.

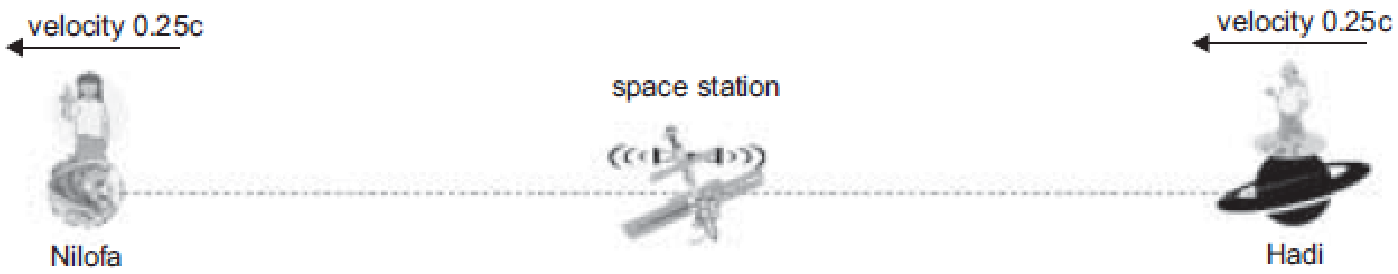


Figure 3

Question 6

Which of the statements (**A–D**) below gives the correct values for the velocity of light as measured by Nilofa and by Hadi?

A. Nilofa measures c and Hadi measures c.

B. Nilofa measures c and Hadi measures 1.5c.

C. Nilofa measures 1.25c and Hadi measures 0.75c.

D. Nilofa measures 0.75c and Hadi measures 1.25c.

2 marks

Solution

A space station is emitting light from lasers fixed to it. Nilofa and Hadi are situated on two planets that are at rest relative to each other. They measure the speed of the light emitted from the lasers on the space station. Hadi is travelling towards the space station with a speed of 0.25c. Nilofa is travelling away from the space station with a speed of 0.25c. The speed of light through space is c.

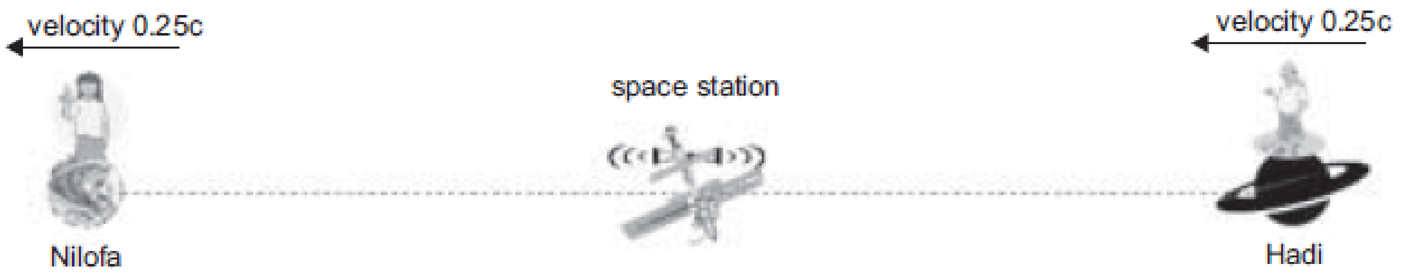


Figure 3

c = Same for all observers

Question 6

Which of the statements (**A–D**) below gives the correct values for the velocity of light as measured by Nilofa and by Hadi?

A. Nilofa measures c and Hadi measures c.

B. Nilofa measures c and Hadi measures 1.5c.

C. Nilofa measures 1.25c and Hadi measures 0.75c.

D. Nilofa measures 0.75c and Hadi measures 1.25c.

2 marks

Time dilation & Length contraction

General Advice:

- The **proper time** will always be the shortest time interval measured: $t = \gamma t_0$ and $\gamma > 1$
- The **proper length** will always be the longest length measured: $L = L_0/\gamma$ and $\gamma > 1$

- Always be very clear about the **frame of reference** you are referring to in every explanation.

VCAA 2017

Question 11 (7 marks)

Tests of relativistic time dilation have been made by observing the decay of short-lived particles. A muon, travelling from the edge of the atmosphere to the surface of Earth, is an example of such a particle.

To model this in the laboratory, another elementary particle with a shorter half-life is produced in a particle accelerator. It is travelling at $0.99875c$ ($\gamma = 20$). Scientists observe that this particle travels 9.14×10^{-5} m in a straight line from the point where it is made to the point where it decays into other particles. It is not accelerating.

a. Calculate the lifetime of the particle in the scientists' frame of reference. 2 marks

____

____

____

s

VCAA 2017

SOLUTION

Question 11 (7 marks)

Tests of relativistic time dilation have been made by observing the decay of short-lived particles. A muon, travelling from the edge of the atmosphere to the surface of Earth, is an example of such a particle.

To model this in the laboratory, another elementary particle with a shorter half-life is produced in a particle accelerator. It is travelling at $0.99875c$ ($\gamma = 20$). Scientists observe that this particle travels 9.14×10^{-5} m in a straight line from the point where it is made to the point where it decays into other particles. It is not accelerating.

a. Calculate the lifetime of the particle in the scientists' frame of reference. 2 marks

The scientists will measure the dilated time of the particle.

This measured time comes directly from the lab time to cover the 9.14×10^{-14} m (which is the proper length in the lab) at the speed 0.99875c.

Remember – different frames of reference measure different lengths and times, however, the **relative speed is the same for all observers**.

Solution:

Question 11a.

Marks	0	1	2	Average
%	55	3	42	0.9

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

$$t = \frac{9.14 \times 10^{-5}}{0.99875 \times (3 \times 10^{8})}$$

$$t = 3.05 \times 10^{-13}\ \text{s}$$

The most common error was to calculate the correct time then apply a time dilation to the result. This suggested that students did not understand how to interpret frames of reference.

VCAA 2017

b. Calculate the distance that the particle travels in the laboratory, as measured in the particle's frame of reference. 2 marks

______ m

Solution:

Question 11b.

Marks	0	1	2	Average
%	60	2	38	0.8

$$L = \frac{L_0}{\gamma}$$

$$L = \frac{9.14 \times 10^{-5}}{20}$$

$$L = 4.6 \times 10^{-6}\ \text{m}$$

VCAA 2017

c. Explain why the scientists would observe more particles at the end of the laboratory measuring range than classical physics would expect. 3 marks

VCAA 2017

c. Explain why the scientists would observe more particles at the end of the laboratory measuring range than classical physics would expect. 3 marks

This question can be answered from the point of view of either time dilation or length contraction.

Here it is essential that you make the frame of reference clear:
E.g. *In the particle's frame of reference*, the distance of 9.14×10^{-14} m is contacted to
to $9.14 \times 10^{-14} / \gamma$ = ….

OR: *In the scientist's frame of reference*, the particle's lifetime is dilated = $\gamma \times t_0$ = …

DON'T SAY:-
"The time is dilated …… " (the particle's time? In the lab frame? –not clear)
"The distance is contracted …… " (in the particle's frame? In the lab frame? –not clear)

Solution: Chief Assessor's report

Question 11c.

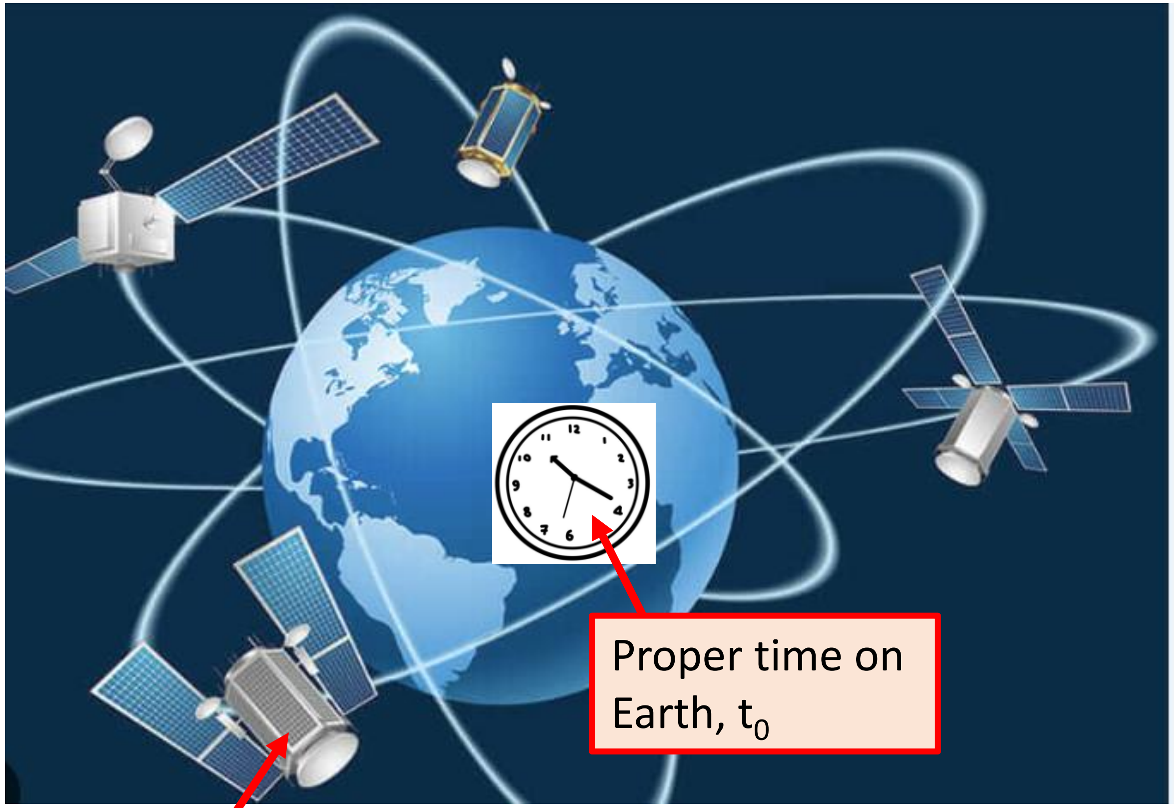
Marks	0	1	2	3	Average
%	54	21	17	8	0.8

Students were required to confirm that it was time dilation that was responsible for the scientists' results. Due to the particle's velocity, its half-life as measured in the scientists' frame of reference is increased. Therefore, fewer particles will decay before reaching the detector and more particles will be detected.

It was possible for students to explain the scientists' results by applying length contraction. In that case they needed to identify that due to the particle's velocity the distance to the detector, as measured in the particles' frame of reference, is reduced. Therefore, more particles will be able to reach the detector before they decay and more particles will be detected.

It was clear that the majority of students had no understanding of these phenomena. Many responses simply stated that 'due to time dilation and length contraction the particles last longer and travel a shorter distance'. Many students explained the results by applying both time dilation and length contraction at the same time, which generally resulted in a confused response that indicated the students were not aware of which frame of reference they were referring to.

GPS system – time dilation effects



Added to the Study Design in 2024

-it is an application of what you already know about time dilation, $t = \gamma t_0$

-the GPS clocks are moving relative to the Earth based clocks that use the time signals for navigation.

-therefore, relative to the clocks on Earth, the GPS clocks ‘run slower’ => 1 sec on the GPS satellite would be measured at $t = \gamma \times 1$ sec on Earth ($\gamma > 1$)

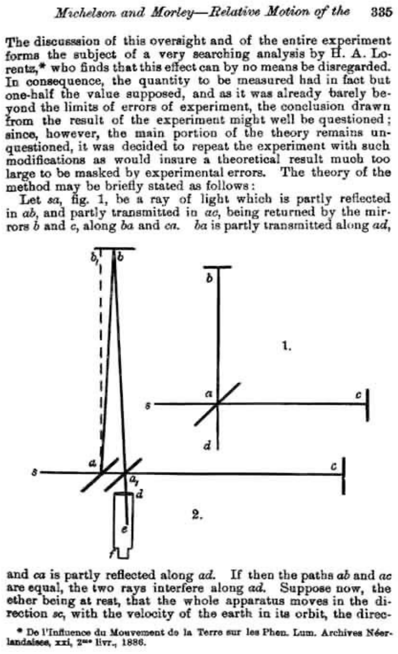
Therefore, to synchronize, the GPS clocks have to run slightly faster to compensate.

The Ether (also spelt *Aether*)

- If empty space really was empty, then how could an Electromagnetic wave propagate through it? What did the waves "wiggle" on.
- A solution put forward at the time – the universe must be filled with a mysterious substance, invisible and undetected. Scientists called it the AETHER.
- A problem immediately obvious was that light was a transverse wave and these only travel in solids!
- The next challenge was to detect it.

Michelson-Morley Experiment.

- Trying to detect the Aether wind:

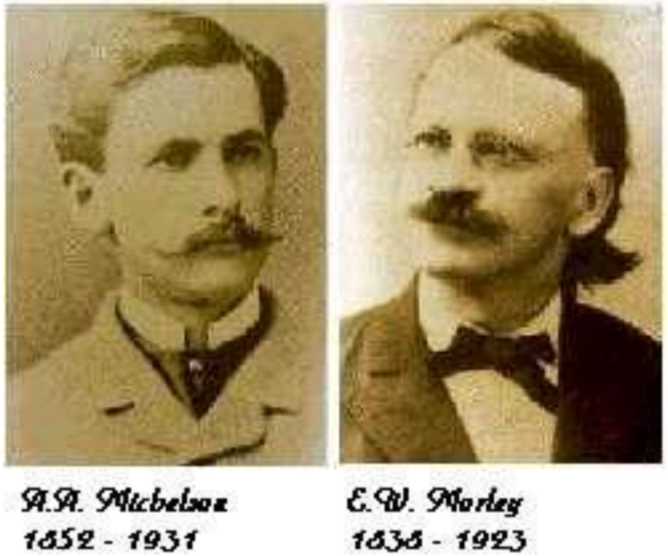


Michelson and Morley—Relative Motion of the 335

The discussion of this oversight and of the entire experiment forms the subject of a very searching analysis by H. A. Lorentz,* who finds that this effect can by no means be disregarded. In consequence, the quantity to be measured had in fact but one-half the value supposed, and as it was already barely beyond the limits of errors of experiment, the conclusion drawn from the result of the experiment might well be questioned; since, however, the main portion of the theory remains unquestioned, it was decided to repeat the experiment with such modifications as would insure a theoretical result much too large to be masked by experimental errors. The theory of the method may be briefly stated as follows:

Let *sa*, fig. 1, be a ray of light which is partly reflected in *ab*, and partly transmitted in *ac*, being returned by the mirrors *b* and *c*, along *ba* and *ca*. *ba* is partly transmitted along *ad*, and *ca* is partly reflected along *ad*. If then the paths *ab* and *ac* are equal, the two rays interfere along *ad*. Suppose now, the ether being at rest, that the whole apparatus moves in the direction *sc*, with the velocity of the earth in its orbit, the direc-

* De l'Influence du Mouvement de la Terre sur les Phen. Lum. Archives Néerlandaises, xxi, 2me livr., 1886.



The effect of a wind

- Consider an out-and-back bicycle ride:

Firstly – **no wind**:

10m/s

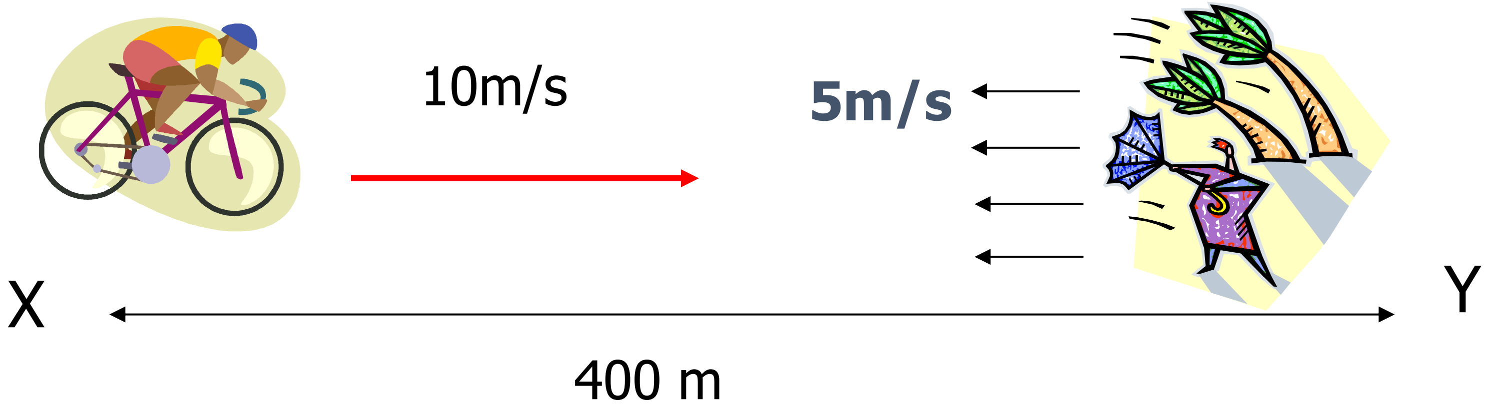
400 m

The total trip should take time t = $800m/10ms^{-1}$

= 80s

The effect of wind

- Now if there is a 5 m/s wind:



Speed *out* (X to Y) = 10 – 5 = 5 m/s

Speed *back* (Y to X) = 10 + 5 = 15 m/s

The effect of wind

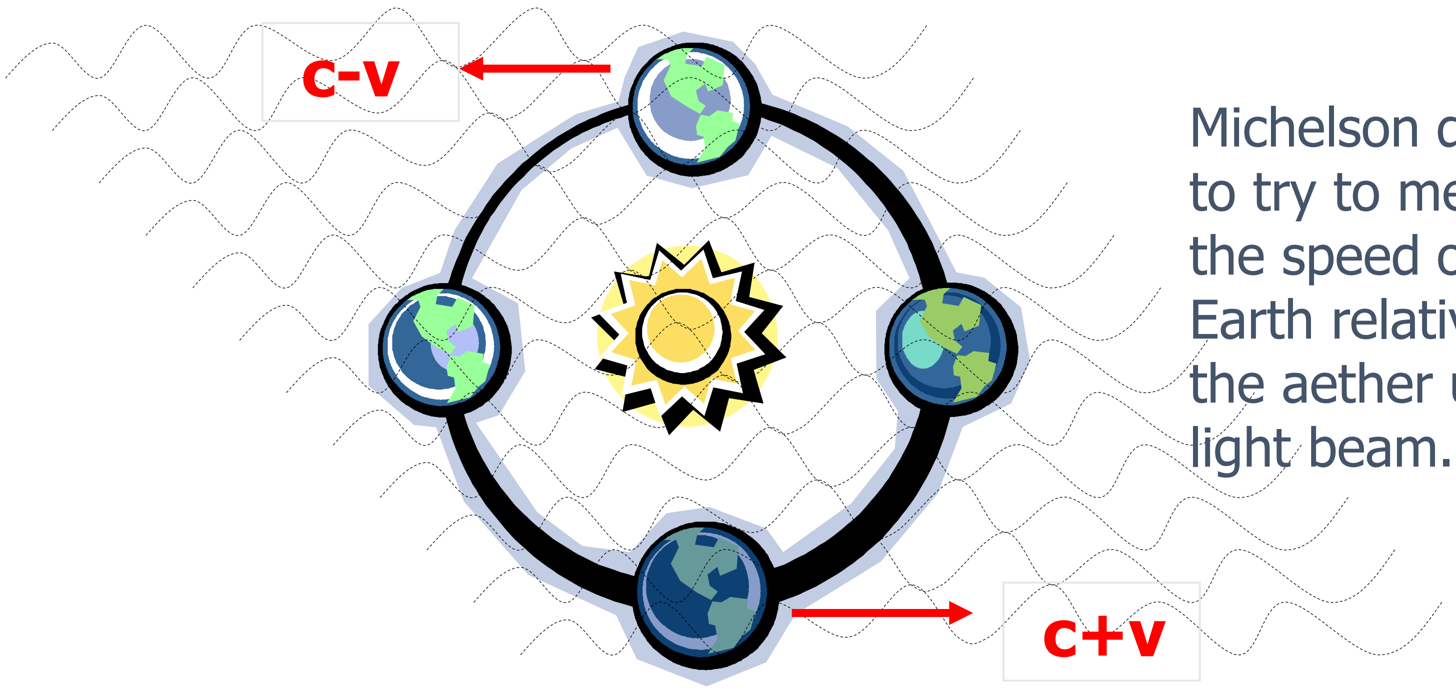
- Total time with head wind and tail wind:
  t = d / v

$$t = \frac{400}{5} + \frac{400}{15} = 80 + 27 = 107s$$

- The tail wind back *never* compensates for the headwind out!
- A no-wind journey is *always* quicker.

Search for the Aether

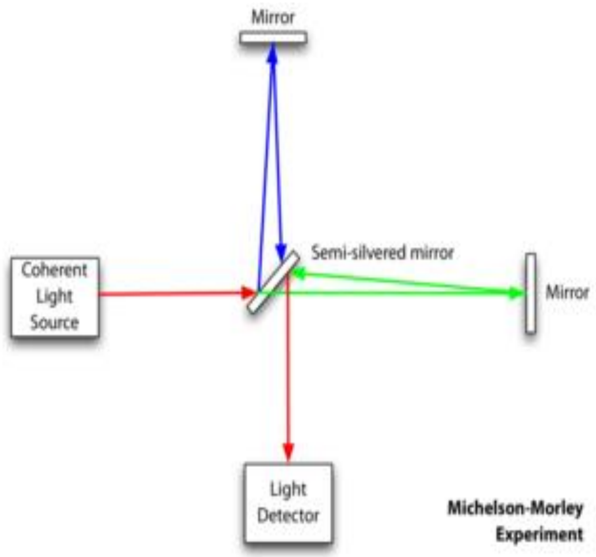
- An aether wind should blow over the Earth as we move around the sun at v = 30km/sec:

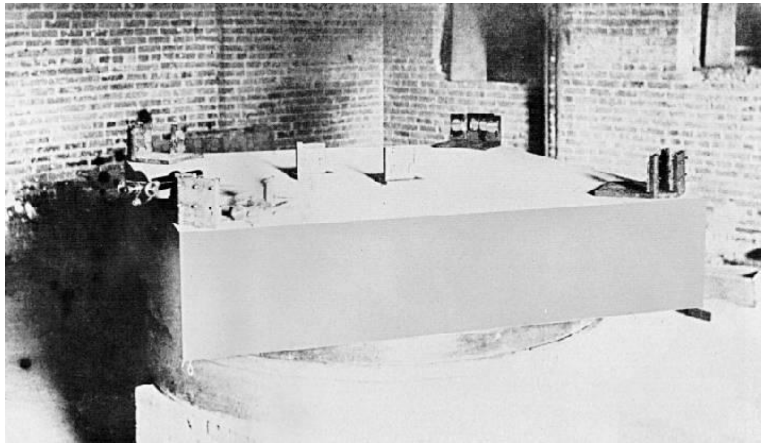


Michelson decided to try to measure the speed of the Earth relative to the aether using a light beam.

Michelson Morley apparatus

- Racing light beams against each other:

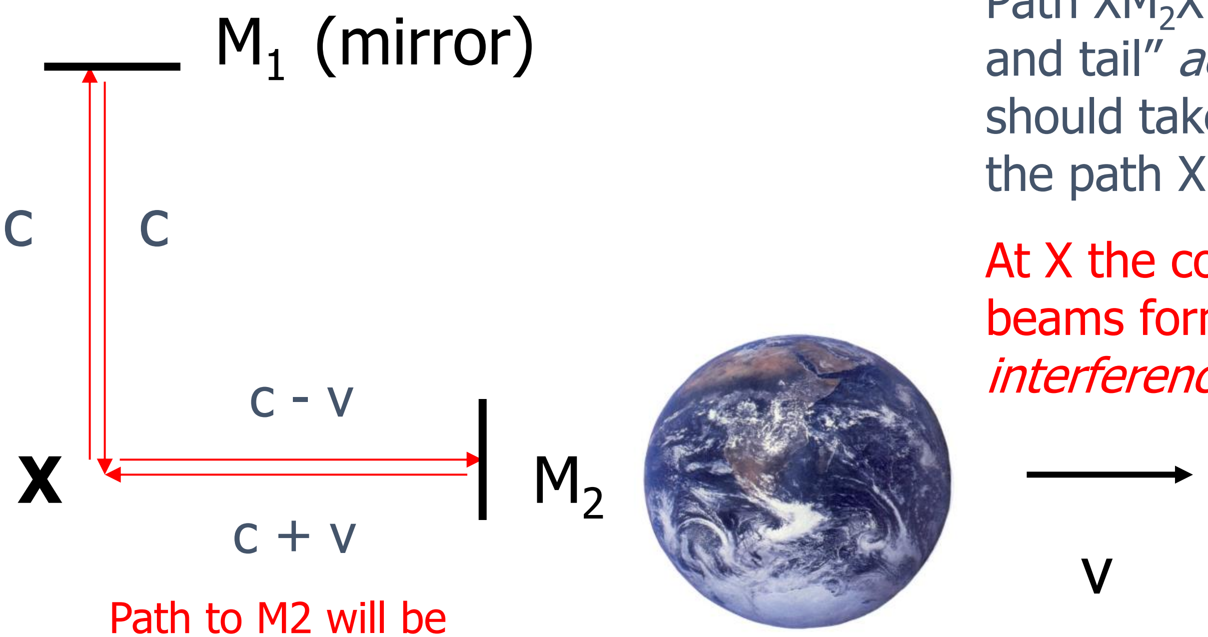




Granite block mounted on a mercury bath

Earth's speed relative to the Luminiferous Aether

- The paths at right-angles should take different times:



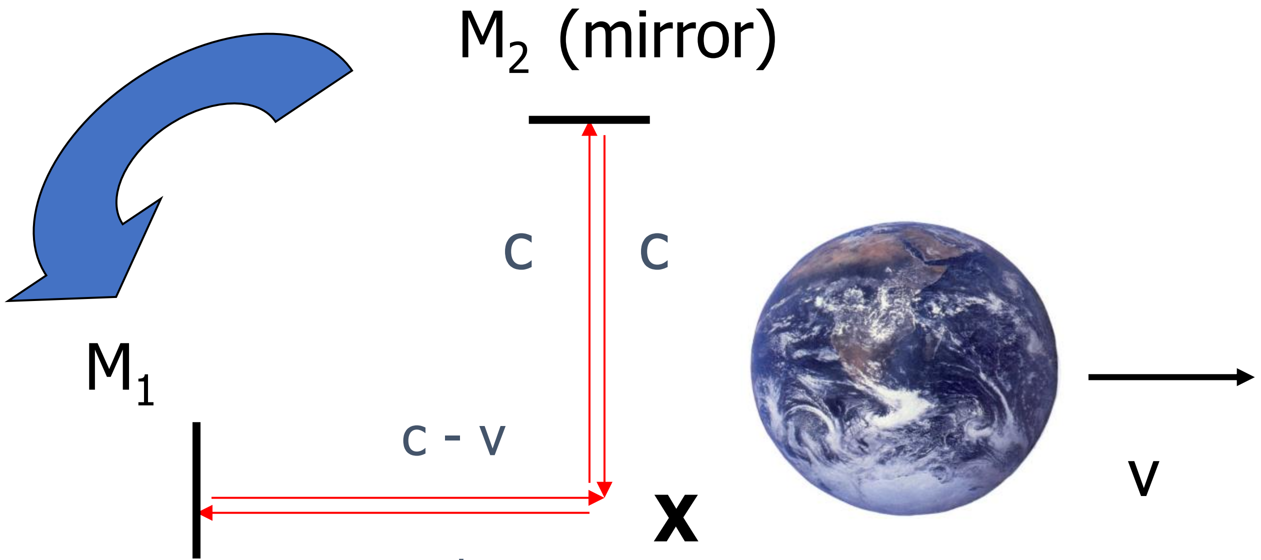
Path XM_2X with the "head and tail" *aether wind* should take longer than the path XM_1X.

At X the colliding light beams formed an *interference pattern*.

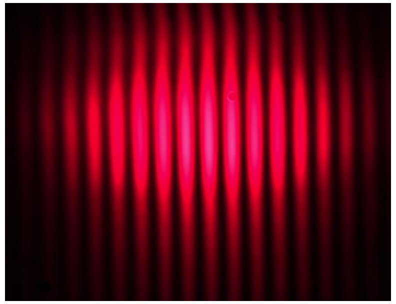
Path to M2 will be slower.

Earth's speed relative to the Luminiferous Aether

- The apparatus was rotated 90^0. They looked for a shift in the interference pattern.



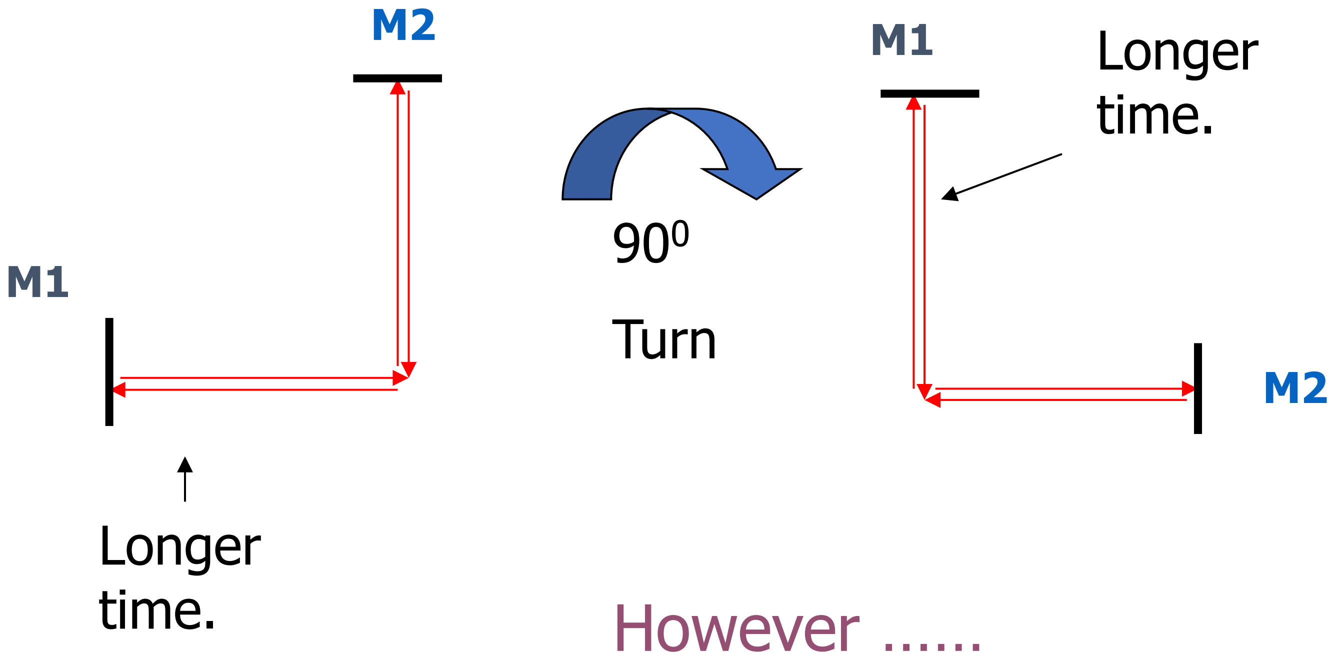
Now path to M1 should be slower.



At **X:** the intersecting light beams form an interference pattern

Search for the Aether

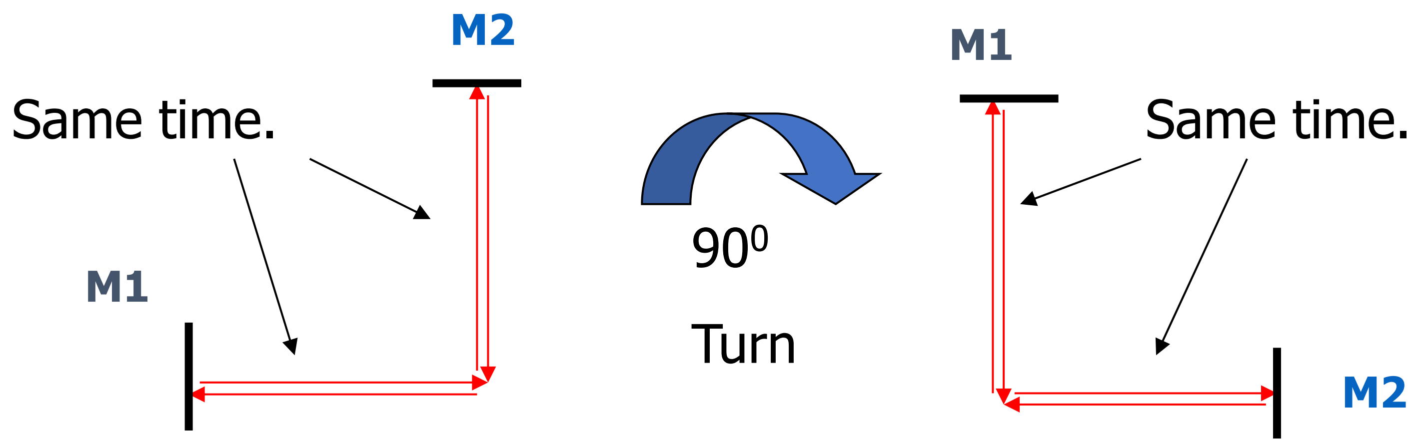
If the Aether Existed:



However ……

Search for the Aether

However:-



The path times for the light beams were *always* the same for every angle and every position of the earth in its orbit.

The NULL RESULT

- No difference was detected then or ever.
- The time for each light path was the same no matter what the orientation of the apparatus or time of year.
- The conclusion was – **no Aether exists**, Electromagnetic waves can travel through empty space.
- Michelson never gave up though, he continued looking for the Aether for the rest of his life and went to his grave believing it existed.

Michelson Morley Experiment

The aim of the Michelson-Morley experiment was to:

A. Determine Earth's velocity relative to the Aether.

B. Measure the speed of light.

C. Test Einstein's Special Theory of Relativity.

D. Accurately measure the Earth's speed in its orbit around the sun.

Michelson Morley Experiment

The aim of the Michelson-Morley experiment was to:

A. **Determine Earth's velocity relative to the Aether**.

B. Measure the speed of light.

C. Test Einstein's Special Theory of Relativity.

D. Accurately measure the Earth's speed in its orbit around the sun.

Solution:

Ans: **A.** Note: the experiment was performed in 1887, when Einstein was an eight-year-old boy, so this experiment was not performed to confirm his 1905 theory of Special Relativity.

Exam Advice

Colin Hopkins

Sandor Kazi

Paul Cuthbert

Chief Assessors report on past exams

Students still struggle to convert g to kg, and cm and mm to m.

Students are responding to explanation questions with text copied directly from commercially available reference sheets. These pre-prepared statements will never be able to adequately respond to the specifics of the questions and students are advised not to waste their time copying them onto the paper.

Students are rounding excessively during their working.

Students are finding graphing data difficult and interpreting graphical data even more difficult.

Make sure students read the question and check that they have responded specifically.

Use the number of marks as a guide to the level of detail required

Significant figures

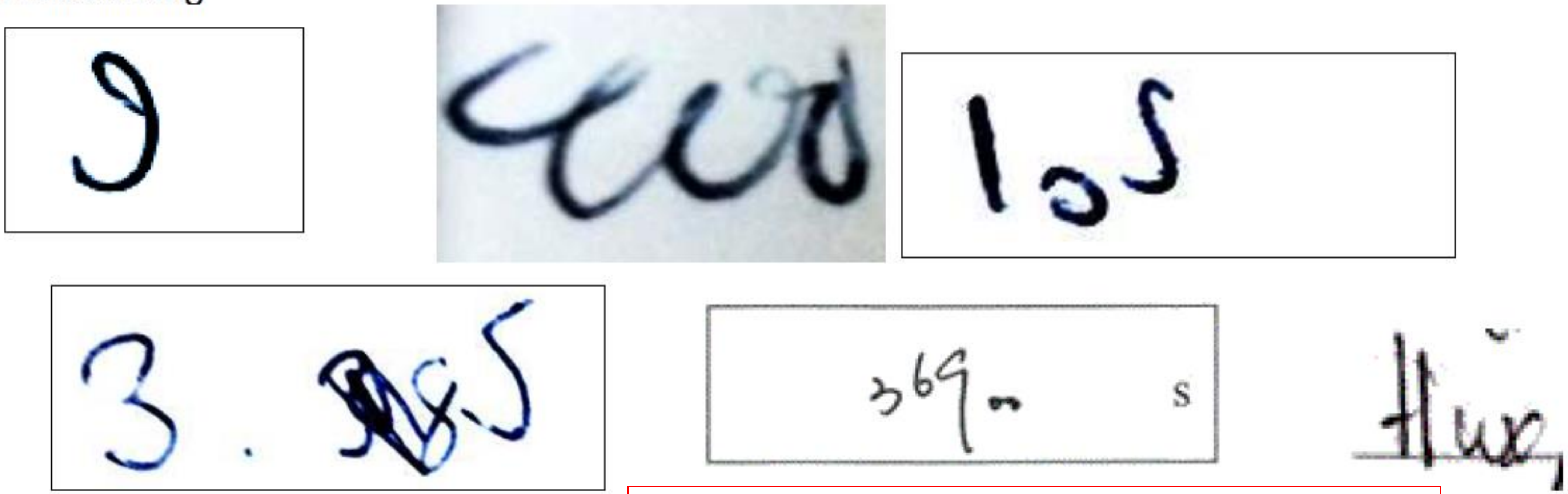
“Non-zero digits in data are always considered significant. Leading zeros are never significant whereas **following zeros and zeros between non-zero digits are always significant.** For example, 075.0210 contains six significant figures with the zero at the beginning not considered significant. A whole number may be a counting number, or a measurement and determination of significant figures varies in the literature.

Whole numbers

For the purpose of the *VCE Physics Study Design*, whole numbers will have the same significant figures as number of digits, for example 400 has three significant figures while 400.0 has four.”

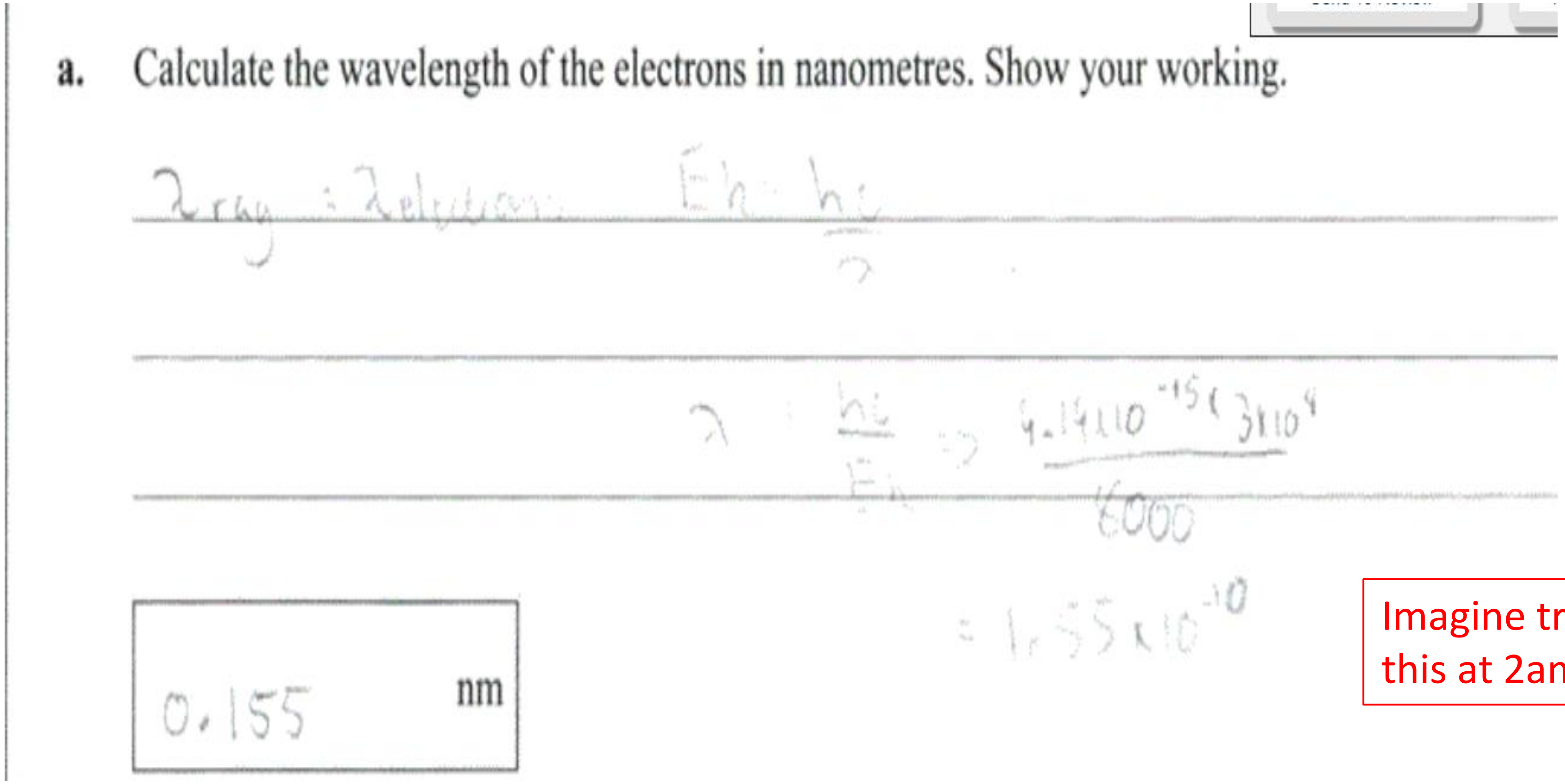
Examiners comments on recent papers

Written responses.

- Only give one answer, neatly cross out mistakes.
- Students should be encouraged to set out their work clearly, so assessors can follow what they have done.
- Where an answer box has a unit printed in it, give your answer in that unit.
- Handwriting
- 

Take a few extra seconds to write your final answer **clearly**.

Write clearly!


a. Calculate the wavelength of the electrons in nanometres. Show your working.

λray = λelectron   E = hc/λ

λ = hc/E ⇒ 4.14x10^-15 (3x10^8) / 6000

= 1.55x10^-10

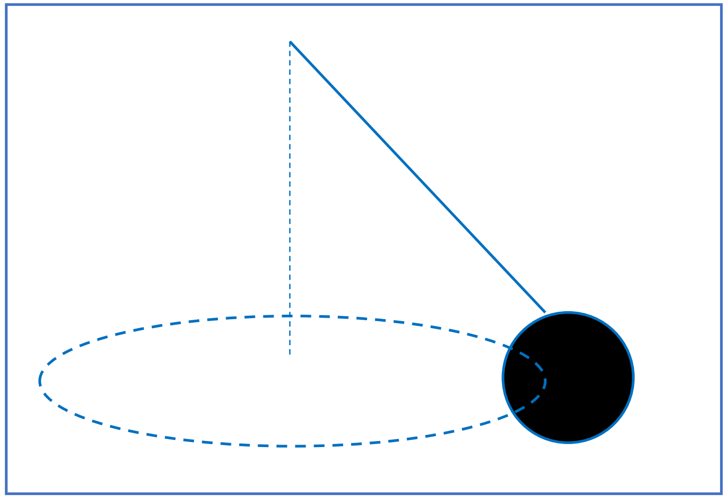
0.155 nm

Imagine trying to mark this at 2am??!!!

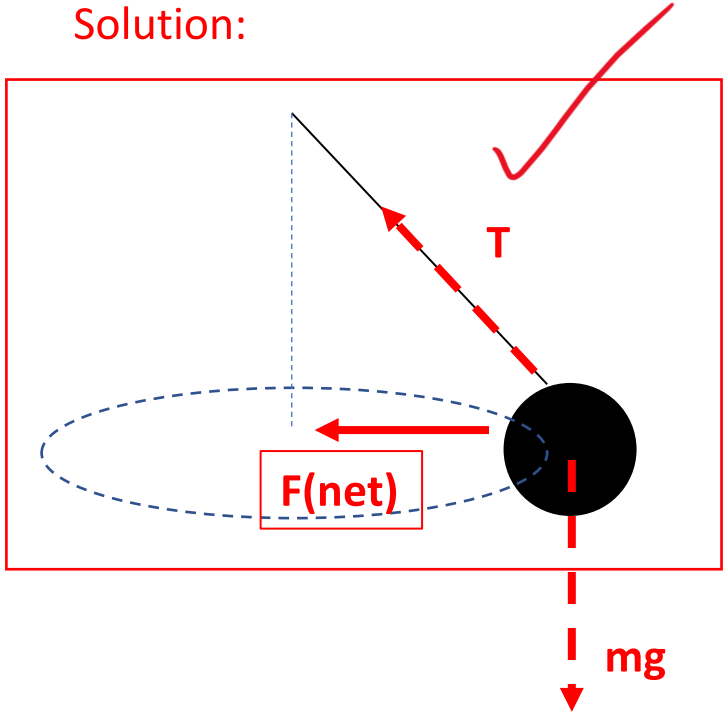
When **labelling forces on diagrams** – put the force vectors where they act, not off to the side of the page or somewhere else. If it says 'label' the forces, then make sure you do.

E.g. Label the force(s) acting on the mass in the conical pendulum in the diagram below using dotted/dashed arrows and then draw the net force with a solid line, labelled F(net). 2 marks

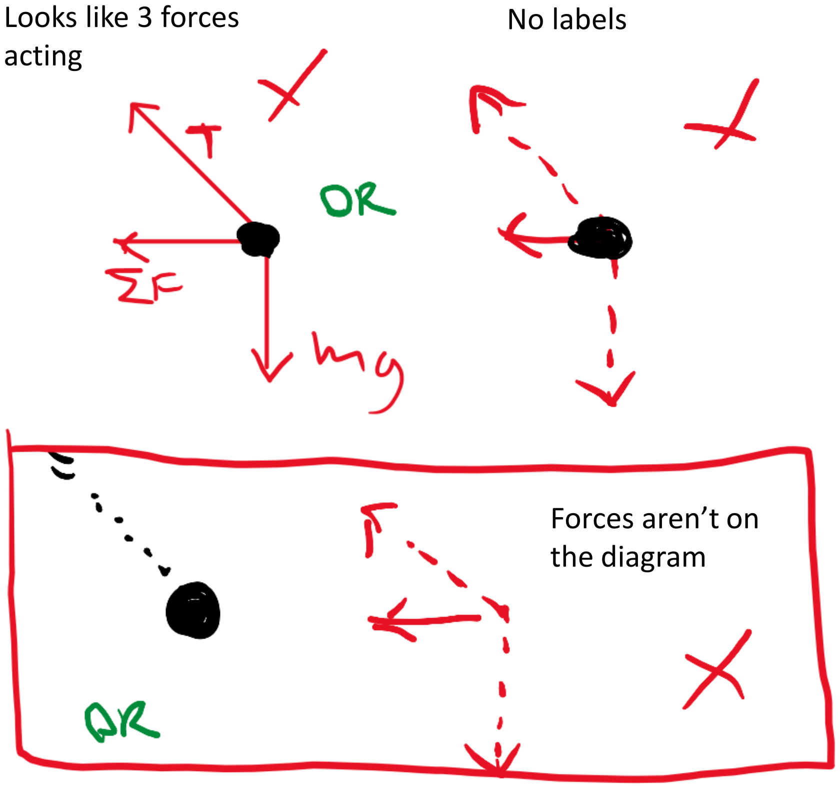
Question:



Solution:



NOT:

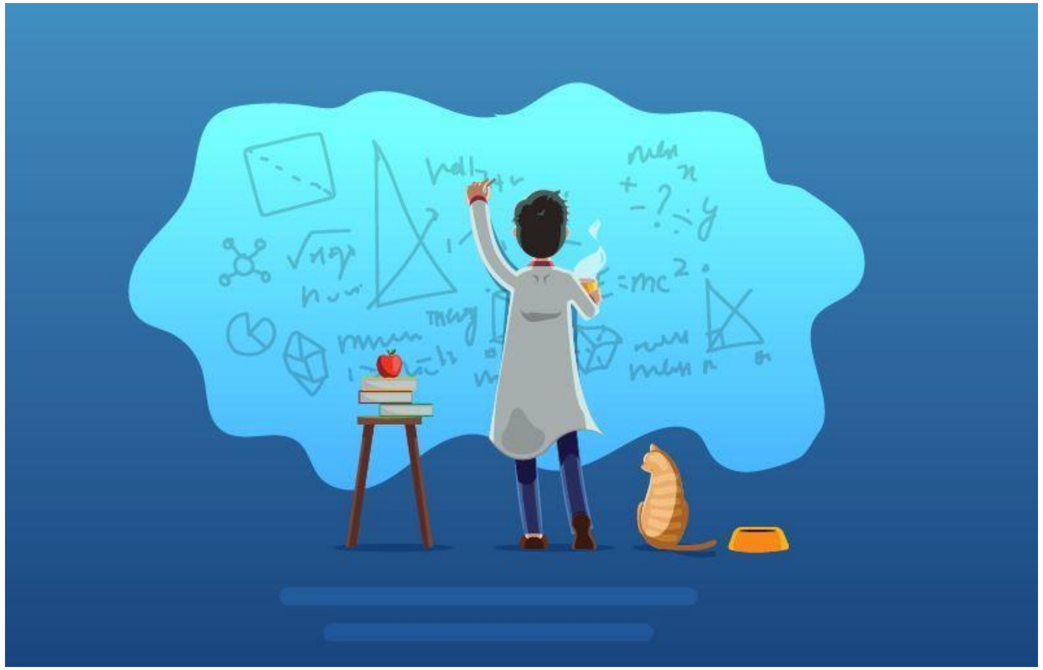


Explain questions advice

- Expect at least 40% of the short answer to require explanation
- Be concise
- Read the question carefully and answer it specifically
- Don’t contradict yourself
- Diagrams, formulas can be useful to help explain
- Consider dot point explanations
- Refer to mark allocation
- Study design tells us which concepts need to be explained

Explain – stem verbs

- Explain
- Discuss
- Describe
- Give reasons
- Justify
- **Evaluate**
- State which…
- Outline two aspects…



Explain questions

- Students should carefully consider what the question is asking and answer accordingly.
- They should not simply copy information from their A3 sheet of notes as this can result in the inclusion of irrelevant, contradictory or incorrect material.
- There is no need to restate the question in an answer.
- Many students gave extended responses that contained significant amounts of incorrect or irrelevant material.
- The use of equations or diagrams in questions that require an explanation can sometimes assist.
- It is important that diagrams are sufficiently large and clearly labelled.
- Graphs and sketches should be drawn with some care.

Have a copy of the vcaa formula sheet with when doing problems

-you need to be familiar with where the various formulas and data values are located, there isn’t time in the exam to be scanning it for something you need.

Motion and related energy transformations

velocity; acceleration	$v = \frac{\Delta s}{\Delta t}$; $a = \frac{\Delta v}{\Delta t}$
equations for constant acceleration	$v = u + at$ $s = ut + \frac{1}{2}at^2$ $s = vt - \frac{1}{2}at^2$ $v^2 = u^2 + 2as$ $s = \frac{1}{2}(u+v)t$
Newton’s second law	$\Sigma F = ma$
uniform circular motion	$F_{net} = \frac{mv^2}{r}$ $v = \frac{2\pi r}{T}$
Hooke’s law	$F = -kx$
elastic potential energy	$E_s = \frac{1}{2}kx^2$
gravitational potential energy	$E_g = mg\Delta h$
kinetic energy	$E_k = \frac{1}{2}mv^2$
Newton’s law of universal gravitation	$F_g = G\frac{m_1 m_2}{r^2}$
gravitational field	$g = G\frac{M}{r^2}$
impulse	$F\Delta t = m\Delta v$
momentum	$p = mv$

Einstein’s special theory of relativity

Lorentz factor	$\gamma = \frac{1}{\sqrt{1 - \frac{v^2}{c^2}}}$
time dilation	$t = \gamma t_0$
length contraction	$L = \frac{L_0}{\gamma}$
relativistic rest energy	$E_0 = mc^2$
relativistic total energy	$E_{total} = E_k + E_0 = \gamma mc^2$
relativistic kinetic energy	$E_k = (\gamma - 1)mc^2$

Fields and application of field concepts

uniform electric field between charged plates	$E = \frac{V}{d}$
energy transformations of charges in an electric field	$\frac{1}{2}mv^2 = qV$
field of a point charge	$E = k\frac{Q}{r^2}$
electric force on a charged particle	$F = qE$
Coulomb’s law	$F = k\frac{q_1 q_2}{r^2}$
magnetic force on a moving charge	$F = qvB$
magnetic force on a current-carrying conductor	$F = nIlB$
radius of a charged particle in a uniform magnetic field	$r = \frac{mv}{qB}$

Generation and transmission of electricity

current; power	$I = \frac{V}{R}$; $P = VI$
resistors in series	$R_T = R_1 + R_2 + \ldots$
resistors in parallel	$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \ldots$
ideal transformer action	$\frac{N_1}{N_2} = \frac{V_1}{V_2} = \frac{I_2}{I_1}$
AC voltage and current	$V_{RMS} = \frac{1}{\sqrt{2}}V_{peak}$ $I_{RMS} = \frac{1}{\sqrt{2}}I_{peak}$
electromagnetic induction	$\varepsilon = -N\frac{\Delta\Phi_B}{\Delta t}$ $\Phi_B = B_{\perp}A$
transmission losses	$V_{drop} = I_{line}R_{line}$ $P_{loss} = I^2_{line}R_{line}$

Waves

wave equation	$v = f\lambda$
constructive interference	path difference $= n\lambda$
destructive interference	path difference $= \left(n + \frac{1}{2}\right)\lambda$
interference pattern spacing	$\Delta x = \frac{\lambda L}{d}$ when $L >> d$

Calculation questions worth > 1 mark

Victorian Certificate of Education 2018

SUPERVISOR TO ATTACH PROCESSING LABEL HERE

STUDENT NUMBER | Letter

PHYSICS
Written examination

Wednesday 14 November 2018

Reading time: 9.00 am to 9.15 am (15 minutes)
Writing time: 9.15 am to 11.45 am (2 hours 30 minutes)

SECTION B

Instructions for Section B

Answer **all** questions in the spaces provided. Write using blue or black pen.

Where an answer box is provided, write your final answer in the box.

If an answer box has a unit printed in it, give your answer in that unit.

In questions where more than one mark is available, appropriate working **must** be shown.

Unless otherwise indicated, the diagrams in this book are **not** drawn to scale.

Take the value of g to be 9.8 m s^{-2}.

Calculation questions – tips:

A recent Chief Assessor's report- the June 2019 NHT paper.

2019 VCE Physics (NHT) examination report

What is '*appropriate working*'?

General comments

- Students should be aware of the Section B instructions, specifically, 'In questions where more than one mark is available, appropriate working **must** be shown.' Responses that do not include a formula and a full substitution may not be awarded full marks.
- Students should take care to ensure they are responding in the correct units. If a unit is provided in an answer box, students must respond in that unit.
- Answers should be given in decimal form and not in fractions or surds.
- When plotting graphs, students should take care when marking out and labelling their axes.

Calculation questions – tips:

- No marks are given for equations *already* supplied in the formula sheet:
- Eg: what will be the final impact velocity of an electron (mass 9.1×10^{-31} kg, charge 1.6×10^{-19} C) accelerated by a potential difference of 25 Volts? (2 marks)
- Use $qV = \frac{1}{2} mv^2$ (as this formula is already supplied it is only the *working out* that will be marked).
- Eg: $1.6 \times 10^{-19} \times 25 = \frac{1}{2} (9.1 \times 10^{-31}) v^2$ -> 1 mark

  $v = 2.96 \times 10^6$ m/s -> 1 mark

WHEN DO YOU GET A MARK FOR A FORMULA?

A satellite of mass 250kg orbits the Earth (mass 5.98 E24kg, radius of the Earth is 6400km) at an altitude of 800km. Assume the orbit is circular. Find the Period, T, of the satellite. (3 marks)

Now the solution combines Newton's Law of gravitation and Circular Motion:

$F_{grav} = \frac{GMm}{R^2}, \quad F_{centripetal} = \frac{4\pi^2 Rm}{T^2}$ (no marks as both formulae are already supplied)

➔ $\frac{GMm}{R^2} = \frac{4\pi^2 Rm}{T^2} \text{ or } T^2 = \frac{4\pi^2}{GM} R^3$ 1 mark – This formula is not supplied so there is (usually) a mark awarded for it.

However, you'll already have this formula (the second one) on your A3-summary-sheet so you'll be given a mark for simply copying it across to the answer space on the exam!

$$T^2 = \frac{4\pi^2}{6.67 \times 10^{-11} \times 5.98 \times 10^{24}} (6400 \times 10^3 + 800 \times 10^3)^3$$ 1 mark

$$T = \sqrt{36{,}942{,}834} = 6{,}080 \; sec$$

6,080 **s**

1 mark

Significant figures

In the 2019 exam all questions that were marked for the number of significant figures (about 2 questions) stated very clearly '**give your answer to** (say) **3 significant figures**'.

Example: 2019 VCAA Exam:

Question 5 (5 marks)

Navigation in vehicles or on mobile phones uses a network of global positioning system (GPS) satellites. The GPS consists of 31 satellites that orbit Earth.

In December 2018, one satellite of mass 2270 kg, from the GPS Block IIIA series, was launched into a circular orbit at an altitude of 20 000 km above Earth's surface.

b. Calculate the period of the satellite to three significant figures. You may use data from the table below in your calculations. Show your working. 3 marks

ANSWER: T = 42,600 seconds [This is 5 sig. figs.] (this numerically correct answer gets 2 out of 3 marks)

To get full marks => 3 s.f. you MUST write this as 4.26×10^4 This counts as 3 s.f and gets 3 / 3 marks

NOTE: when **setting out your working** for a calculation question you are statistically likely to pick up MORE marks if you:

-substitute first

-transpose second (instead of transpose 1st, substitute 2nd, this is because of the marking scheme)

For example, from a previous problem, the electron's speed crossing the 25V potential difference:

Both the following methods contain the *same error* - incorrectly transposing the formula:

Method 1: Substituted first, then transposed

Step 1: $qV = \frac{1}{2} mv^2$ 0 marks- formula supplied

Step 2: $1.6 \times 10^{-19} \times 25 = \frac{1}{2} (9.1 \times 10^{-31}) v^2$ 1 mark

Step 3: $v = \sqrt{\frac{1}{2} \times \frac{1.6 \times 10^{-19} \times 25}{9.1 \times 10^{-31}}}$ = 1.48×10^6 m/s 0 marks

Transposition ERROR
Should be "2 x"

Total = 1 out of 2

Method 2: Transposed first, then substituted

Step 1: $qV = \frac{1}{2} mv^2$ 0 marks (as before)

Step 2: $v = \sqrt{\frac{1}{2} \times \frac{qV}{m}}$ 0 marks

Step 3: $v = \sqrt{\frac{1}{2} \times \frac{1.6 \times 10^{-19} \times 25}{9.1 \times 10^{-31}}}$ = 1.48×10^6 m/s

0 marks

Total = 0 out of 2

NOTE: when setting out your working for a calculation question you are statistically likely to pick up MORE marks if you:

-substitute first

-transpose second (instead of transpose 1st, substitute 2nd , this is because of the marking scheme)

For example, from a previous problem, the electron's speed crossing the 25V potential difference.

Both the following methods contain the *same error* - incorrectly transposing the formula:

OK, Wrong but…..

Method 1:

Step 1: $qV = ½ mv^2$ 0 mark- formula supplied

Step 2: $1.6 \times 10^{-19} \times 25 = ½ (9.1 \times 10^{-31}) v^2$ 1 mark

Step 3: $v = \sqrt{\frac{1}{2} \times \frac{1.6 \times 10^{-19} \times 25}{9.1 \times 10^{-31}}}$ = 1.48×10^6 m/s 0 marks

Transposition ERROR Should be "2 x"

Total = 1 out of 2

Even WRONGER!

Method 2:

Step 1: $qV = ½ mv^2$ 0 marks (as before)

Step 2: $v = \sqrt{\frac{1}{2} \times \frac{qV}{m}}$ 0 marks

Step 3: $v = \sqrt{\frac{1}{2} \times \frac{1.6 \times 10^{-19} \times 25}{9.1 \times 10^{-31}}}$ = 1.48×10^6 m/s

0 marks

Total = 0 out of 2

Examples from past VCAA Exams

Explain questions

- Make a different point for each mark the question is worth.
- Example: a question worth 3 marks will most likely require 3 separate points to be made in your explanation. The marking scheme will reflect this.

Some advice from Colin Hopkins:

If an explanation requires you to also state, say, a name of who's correct in an argument, or which way an induced current flows, or which model out of the wave or particle model is appropriate for a situation- put this FIRST, then explain your reasoning.

E.g. "the induced current flows *clockwise*. This is because … etc"
Or "Betty is correct (and John is wrong), because …."

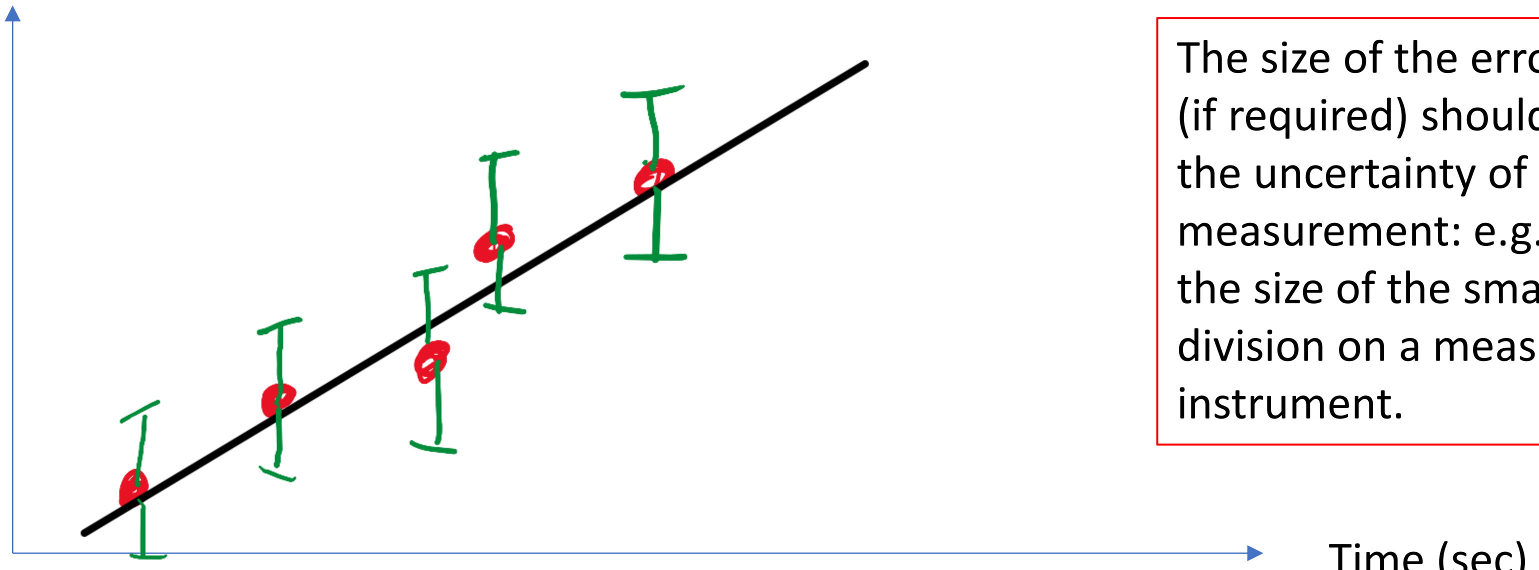
This way, you have established to the assessor at the outset that you know the answer, and then if your explanation is a little meandering or difficult to follow then the assessor is more likely to interpret it favourably.

Principles of Practical Investigation

General Advice:

- Graph the data points so that they remain clearly visible even after you have drawn your curve/line of best fit
- For linear relationships – use a ruler for your line-of-best-fit
- Choose scale that will use > 50% of the graph are available.
- If the axes aren't labelled, then make sure you label them with both QUANTITY and UNIT.

  E.g. *Velocity (m/s)*



The size of the error bars (if required) should equal the uncertainty of the measurement: e.g. half the size of the smallest division on a measuring instrument.

Practice Exams:

- Use the reading time for at least 1 paper- so spend 15 mins reading a paper before you pick up a pen and start writing.
- Do at least one paper twice.
- Always complete the ‘Practical Investigation’ question-the graph question (that probably also asks you to identify the variables; IV, DV, CV(s) and find the gradient etc. There’s usually lots of very accessible marks in this question. So if you’re running low on time-skip to this question.