PHYSICS

KEY.POINTS

Exam Guide

O LEVEL

SYLLABUS
- Learning Objectives
- Useful Websites
- Overview Of The Topic
- ExamTIPs
- Stop & Think
- Challenging Questions
- Solutions & Explanations

For O Levels

NEW SOLUTIONS. NEW MINDS.

REDSPOT PUBLISHING

CONTENTS

TOPIC 1

PHYSICAL QUANTITIES, UNITS AND MEASUREMENT

LEARNING OBJECTIVES

Candidates should be able to:

🕮	Show understanding that all physical quantities consist of a numerical magnitude and a unit
🕮	Recall the following base quantities and their units: mass (kg), length (m), time (s), current (A), temperature (K), amount of substance (mol)
🕮	Use the following prefixes and their symbols to indicate decimal sub-multiples and multiples of the SI units: nano (n), micro (μ), milli (m), centi (c), deci (d), kilo (k), mega (M)
🕮	Show an understanding of the orders of magnitude of the sizes of common objects ranging from a typical atom to the Earth
🕮	State what is meant by *scalar* and *vector* quantities and give common examples of each
🕮	Add two vectors to determine a resultant by a graphical method
🕮	Describe how to measure a variety of lengths with appropriate accuracy by means of tapes, rules, micrometers and calipers, using a vernier as necessary
🕮	Describe how to measure a short interval of time including the period of a simple pendulum with appropriate accuracy using stopwatches or appropriate instruments

USEFUL WEBSITES

- http://www.chemie.fu-berlin.de/chemistry/general/index_en.html
  (Fundamental Physical Constants, SI units, Prefixes)
- http://www.glenbrook.k12.il.us/gbssci/phys/Class/1Dkin/U1L1b.html
  (Scalars and Vectors)
- http://www.physics.uoguelph.ca/applets/Intro_physics/Vector_Add/vectortest.htm
  (Vector addition java applet)
- http://phoenix.phys.clemson.edu/labs/cupol/vernier/index.html
  (Learn how to use vernier calipers)
- http://www.phy.ntnu.edu.tw/ntnujava/index.php?topic=52
  (Vernier calipers simulation)
- http://en.wikipedia.org/wiki/Micrometer
  (Learn how to use micrometer screw gauge)
- http://www.upscale.utoronto.ca/PVB/Harrison/Micrometer/Flash/MicSimulation.html
  (Micrometer simulation)

OVERVIEW OF THE TOPIC

PHYSICAL QUANTITIES, UNITS AND MEASUREMENT *4 key areas*	PHYSICAL QUANTITIES	• Base and derived quantities • SI units • Prefixes
	SCALARS AND VECTORS	• Scalars • Vectors • Addition of vectors
	MEASUREMENT OF LENGTH	• Rulers and tapes • Vernier calipers • Micrometer screw gauge
	MEASUREMENT OF TIME	• A simple pendulum

PHYSICAL QUANTITIES

Base and Derived Quantities

☑ PHYSICS is sometimes called the science of MEASUREMENT.

☑ Most of the FACTS (or discoveries) are obtained by measuring physical quantities.

☑ A physical quantity consist of a numerical MAGNITUDE and a UNIT. In topic 1, the physical quantities to be learned are:

- ☐ length (unit is metre, m) and
- ☐ time (unit is second, s).

☑ All physical quantities can be grouped under base quantities and derived quantities.

☑

The 7 chosen base quantities	$\underbrace{\text{Length, time, mass, temperature, current,}}_{\text{(only these 5 have to be learned)}}$ luminous intensity and amount of substance.

☑

Derived quantities	They are expressed by combining suitable (the five) base quantities.

e.g.	FACT		EQUATION	UNIT
❶	Area	=	length (m) × width (m)	m^2
❷	Volume	=	length (m) × width (m) × height (m)	m^3
❸	Speed	=	$\dfrac{\text{distance travelled (m)}}{\text{time (s)}}$	metre per second, $m\,s^{-1}$

SI Units

☑ The magnitude (or value) of a physical quantity is written as a number followed by a suitable unit. In Physics, we adopt SI units (International System of Units).

☑ For example, the 5 base quantities have

the 5 base quantities have	SI unit	symbol used
length	metre	m
time	second	s
mass	kilogram	kg
temperature	kelvin	K
current	ampere	A

Exam Tip

It is important to use SI units. A physical quantity without the appropriate unit is ambiguous, e.g. 5 units of length can represent 5 cm, 5 m or 5 km.

Many students are not careful enough in writing symbols. Do not use Kg (capital letter K) for kilogram and M for metre.

Prefixes

☑ When physical quantities have values that are too big or too small to be conveniently expressed in basic units, we use <u>prefixes</u>.

☑ *Prefixes and their symbols:*

		meaning	(standard form)
mega	M	1 000 000	10^{6}
kilo	k	1000	10^{3}
deci	d	0.1	10^{-1}
centi	c	0.01	10^{-2}
milli	m	0.001	10^{-3}
micro	μ	0.000 001	10^{-6}
nano	n	0.000 000 001	10^{-9}

Exam Tip

Common e.g. of SI units using prefixes: **milli**metre (mm), **centi**metre (cm), **kilo**metre (km), etc. Candidates must remember all the prefixes, their symbols and meanings.

SCALARS AND VECTORS

☑ Sometimes physical quantities need DIRECTION to distinguish themselves.

e.g. **We can say the distance travelled is 10 km.**

We can also say the distance travelled is 5 km to the west then 5 km back to the starting point, a total of 10 km.

If we want to distinguish the two cases, besides 'distance travelled', we need to use another physical quantity known as 'displacement' which takes into consideration the direction of travelling.

Scalars

☑

Definition	<u>Scalars</u> refer to those *physical quantities having magnitude only*.
e.g.	length, time, mass, distance, speed, volume, density, energy, etc

☑ Because no direction is involved, scalars can simply be added or subtracted.

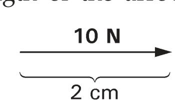
Vectors

☑

Definition	<u>Vectors</u> refer to those *physical quantities having both magnitude and direction*.
e.g.	displacement, velocity, acceleration, weight, force, moment, etc

☑ Vectors can be represented graphically by arrows.

☑ The length of the arrow represents the magnitude. The arrow head represents its direction.

e.g. 

A <u>force</u> of 10 N pointing to the right using a scale of 1 cm : 5 N.

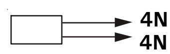
Addition of Vectors

☑ Two vectors can be added to form a <u>resultant</u> vector. There are two methods.

① ***Simple algebraic addition method:***

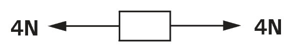
- ☐ <u>Direction of vectors</u> : When both vectors are parallel (same or opposite direction).

e.g. ❶



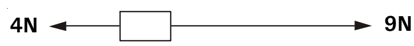
Resultant force = 8 N to the right

e.g. ❷



Resultant force = (–4 N) + 4 N = 0 N (opposite direction becomes negative)

e.g. ❸



Resultant force = 5 N to the right

② ***Parallelogram addition method:***

- ☐ <u>Direction of vectors</u> : When both vectors are not in the same straight line.
- ☐ In this situation, the resultant vector is represented in both magnitude and direction by the DIAGONAL of a parallelogram with the two given vectors as adjacent sides.
- ☐ That is, joining the two tails of the vectors first, then complete the parallelogram and lastly draw the diagonal.
- ☐ After drawing the parallelogram, only one of the diagonals is the correct resultant.
- ☐ The two vectors and the CORRECT RESULTANT should start at the same point of the parallelogram.
- ☐ Remember to use the scale given to draw the parallelogram.

e.g. **Fig. 1 shows two forces 4 N and 5 N acting on a body with an angle of 45° between them. The resultant (R) of the two forces is determined graphically by drawing the diagonal of the parallelogram with 4 N and 5 N as the adjacent sides using a scale of 1 cm : 1 N.**

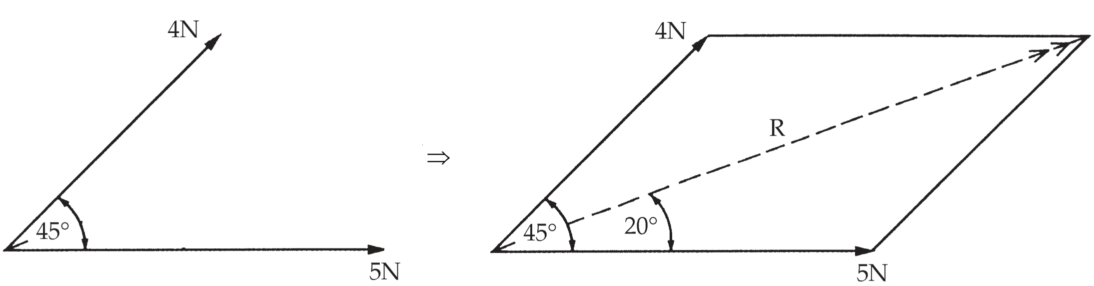


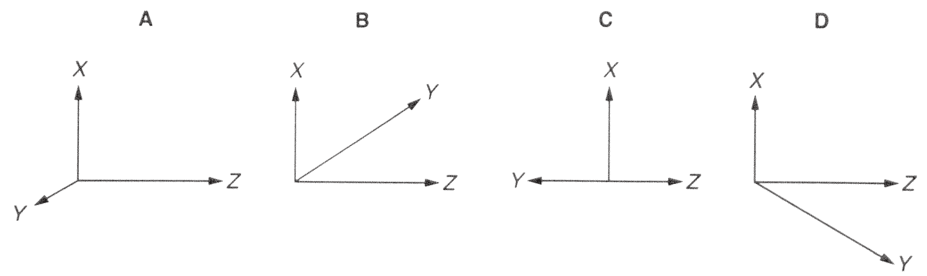
Fig. 1 **The resultant R is 8.4 N (20° from 5 N) by measuring.**

ExamTip

The length of the diagonal in the diagram is not the actual resultant in most cases. Candidates need to refer to the scale chosen to calculate the resultant.

STOP & THINK

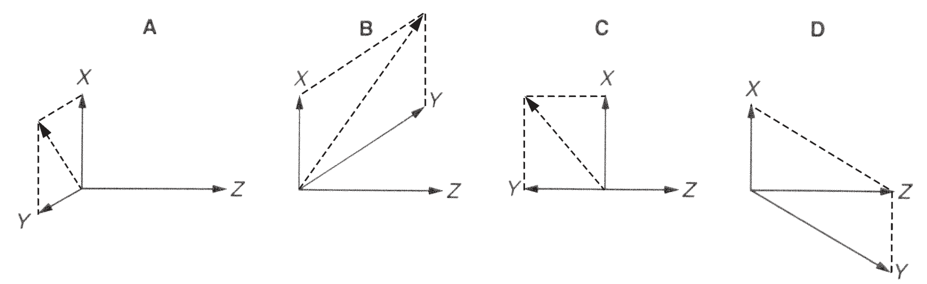
[Q] Which diagram represents the directions of vectors X and Y and their resultant Z?



[Ans] **D** By the parallelogram law, the resultant of two forces is the diagonal of the parallelogram with the two forces as the adjacent sides.

Exam Tip

After drawing the parallelogram, there are two diagonals. The resultant force is the diagonal which starts from the same point as the two forces.



STOP & THINK

[Q] A student studies some equations. How many different vector quantities are contained in the equations?

power = work ÷ time

force = mass × acceleration

velocity = displacement ÷ time

A 1 **B** 2 **C** 3 **D** 4

[Ans] **D** Displacement, velocity, acceleration and force have direction.

Exam Tip

Candidates will learn the above 3 equations in the coming topics.

MEASUREMENT OF LENGTH

- ☑ Physical quantity: Length
- ☑ **SI unit of length:** metre (m)
- ☑

Measuring instruments for different range of lengths	Measuring tapes, metre rulers, vernier calipers and micrometer screw gauge.

☑

	Length to be measured:		instrument used	accuracy	example
①	very short	(0 to 2.5 cm)	micrometer screw gauge	0.01 mm	diameter of a metal wire
②	short	(0 to 15 cm)	vernier calipers	0.01 cm	diameter of a measuring cylinder
③	medium	(0 to 1 m)	metre rulers	0.1 cm	image distance of a lens
④	long	(0 to 5 m)	measuring tapes	0.1 cm	length of Physics laboratory

Measuring instruments for different range of lengths

STOP & THINK

[Q] A student has been asked to calculate the volume of a piece of wire, which is about 80 cm long and about 0.2 cm in diameter.

Which measuring instruments should the student use?

	Length	*Diameter*
A	metre rule	micrometer
B	metre rule	vernier calipers
C	micrometer	vernier calipers
D	vernier calipers	micrometer

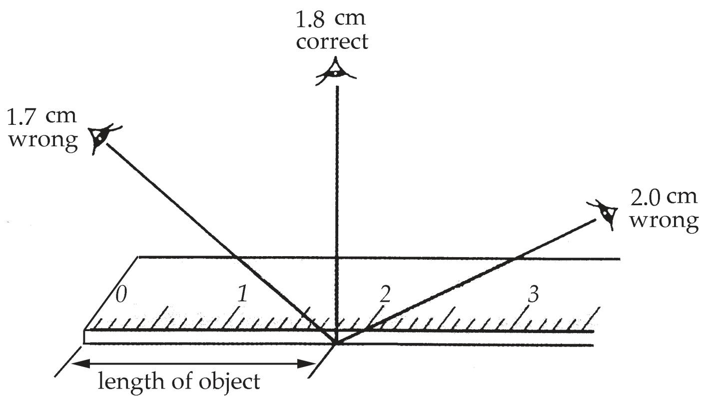
[Ans] **A** The length of 80 cm is beyond the measuring range of micrometer and vernier calipers. The small diameter 0.2 cm requires a more accurate instrument like micrometer.

Exam Tip

To answer a question like this, candidates need to know the accuracy of different measuring instruments.

Metre Rulers and Measuring Tapes (length 1 m and 5 m, accurary 0.1 cm)

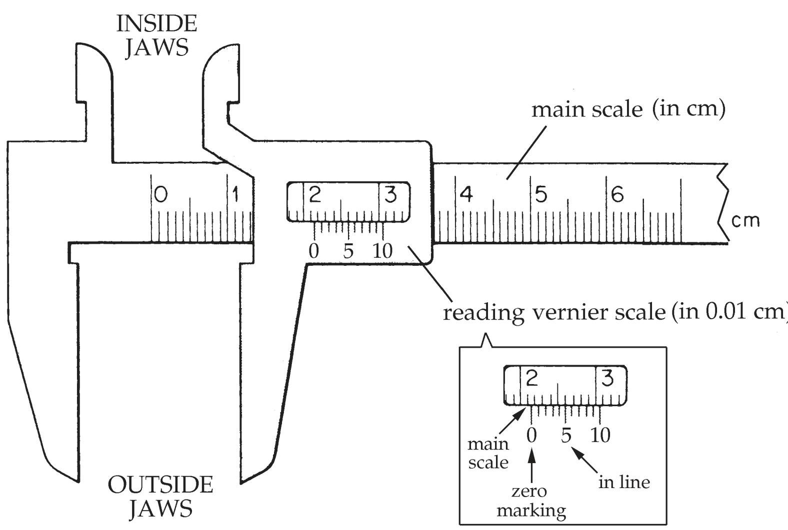
☑ The correct way to read the scale of rulers or tapes is to ***place the eye vertically above the mark on the scale***. This is to avoid parallax error.



Vernier Calipers (length 15 cm, accurary 0.01 cm)

☑ A pair of vernier calipers consists of a main scale and a vernier scale.

☑ To measure, gently grip the object with the straight edges of the outside or inside jaws.



☑ ***How to read a vernier caliper:***

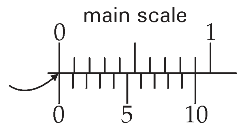
- ☐ Read the main scale before the zero marking for the 1st place of decimal. (2.1 cm)
- ☐ For the 2nd place of decimal, look at the vernier scale. Find a marking on the vernier scale that is in line with the main scale. (0.05 cm)
- ☐ To get the correct reading, simply add up these two decimal numbers. (2.15 cm)

Exam Tip

The INSIDE jaws of a pair of vernier calipers can be used to measure the internal diameter of measuring cylinder and beaker.

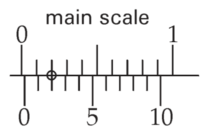
☑ Check for ZERO ERROR (by closing the jaws):

no
zero error



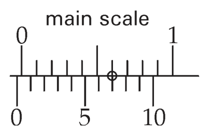
----> no adjustment

Right side:
zero error is +0.02 cm



----> correct reading
= observed reading – (+0.02 cm)

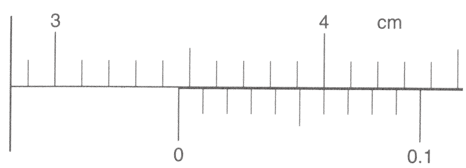
Left side:
zero error is −0.03 cm
(0.07 – 0.10)



----> correct reading
= observed reading – (–0.03 cm)

STOP & THINK

[Q] The diagram shows a vernier scale.



Which reading is shown?

A 3.44 cm

B 3.46 cm

C 3.60 cm

D 4.00 cm

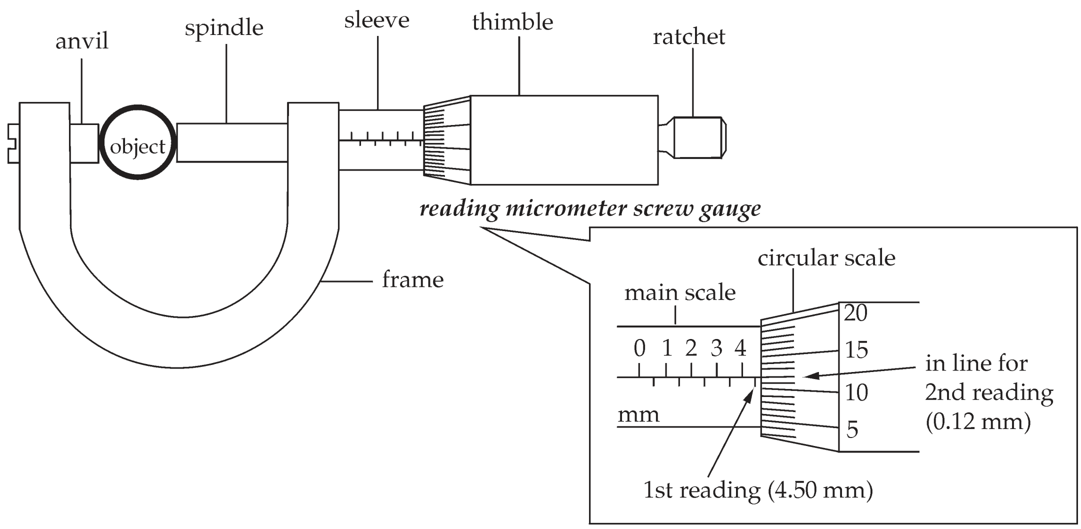
[Ans] **B** Reading = 3.4 + 0.06 = 3.46 cm

Exam Tip

The reading obtained from a vernier calipers is the sum of the main scale and the vernier scale. Candidates should be careful when they obtain the two scales. One division on the vernier scale is 0.01 cm. The unit for the reading is cm.

Micrometer Screw Gauge (length 2.5 cm, accurary 0.01 mm)

- A micrometer screw gauge has two scales: the main scale on the sleeve and the circular scale on the thimble. Each division on the thimble represents a distance of 0.01 mm.

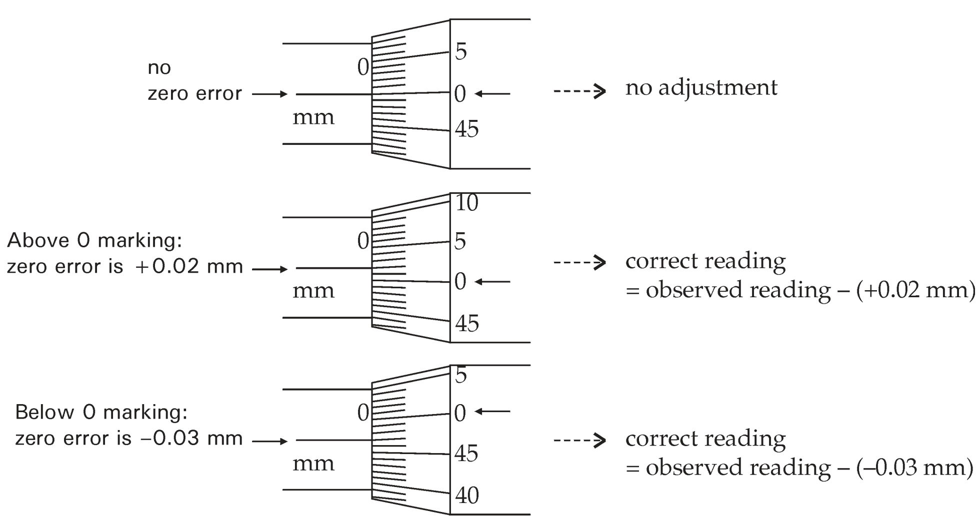


- ***How to read a micrometer:***
  - Thimble is turned until the object is gripped very gently.
  - Read the main scale on the sleeve for the 1st of decimal. (4.50 mm)
  - For the 2nd place of decimal, look at the circular scale on the thimble. Find a marking on the circular scale that is in line with the horizontal line of the main scale. (0.12 mm)
  - To get the correct reading, simply add up the two decimal numbers. (4.62 mm)

Exam Tip

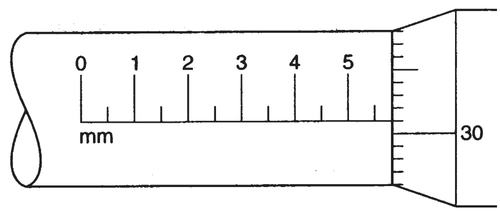
The micrometer should never be tightened too much. This may damage it. The ratchet at the end of the micrometer is fitted to avoid this. There will be 'tic' sounds if the ratchet is turned when the micrometer has been tightened.

- Check for ZERO ERROR:



STOP & THINK

[Q] The diagram shows part of a micrometer screw gauge.



What is the reading shown?

A 5.31 mm **B** 5.79 mm **C** 5.81 mm **D** 6.31 mm

[Ans] **C** Reading = 5.5 + 0.31 = 5.81 mm

Exam Tip

The reading of a micrometer screw gauge is the sum of the main scale and the circular scale. Candidates should be careful when they obtain the two scales especially the circular scale. One division on the circular scale is 0.01 mm. The numbers are increasing from the bottom to the top of the thimble.

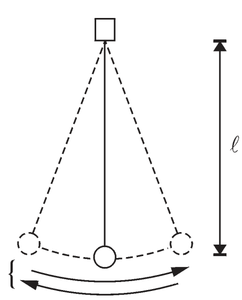
MEASUREMENT OF TIME

- ☑ Physical quantity: Time
- ☑ **SI unit of time:** second (s)
- ☑

Measuring instruments for measuring time	① pendulum clock ② clock ③ stopwatch

A Simple Pendulum

- ☑ The diagram below shows a simple pendulum with length (ℓ).



- ☐ A simple pendulum makes use of the regular swing, also known as <u>oscillation</u> of the bob for timing. ***One complete oscillation refers to a swing of the bob from left to right and back to its starting position.***

Definition	The period (T) of the pendulum is the ***time taken for one complete oscillation***.

- The period (T) of the pendulum will vary depending on:
  ① The length of the pendulum (increases with length).
  ② Acceleration due to gravity (g) (decreases with increasing g).

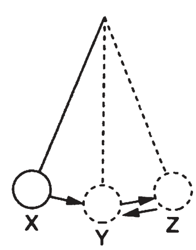
Definition	The frequency is the ***number of complete oscillations made by the pendulum per second***.

To find the period (T) of oscillation of a pendulum with a known length (ℓ):

- Let the pendulum swings for 20 oscillations (it would not be accurate to measure the time taken for just 1 oscillation of a pendulum).
- Use a stopwatch to take the timing, t_1.
- Period (T) of the pendulum = $\dfrac{t_1}{20}$.
- Again, to account for human timing error, repeat the whole process for 5 times.
- Find the average period (T): $\dfrac{\dfrac{t_1}{20}+\dfrac{t_2}{20}+\dfrac{t_3}{20}+\dfrac{t_4}{20}+\dfrac{t_5}{20}}{5}$

STOP & THINK

[Q] The diagram shows a pendulum oscillating between positions X and Z. It takes 1.5 s to go from X to Z and back to the mid-point Y. What is the period of the pendulum?



A 0.5 s
B 1.0 s
C 1.5 s
D 2.0 s

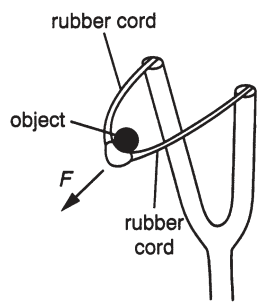
[Ans] **D** Time for the pendulum to go from X to Z and back to Y is 3 quarters of an oscillation. Therefore period = 1.5 × 4/3 = 2.0 s

Exam Tip

Candidates should realise that one oscillation is from X to Z and back to X. They also need to know that time for one oscillation is called period, T. The time for the pendulum to complete half oscillation is T/2.

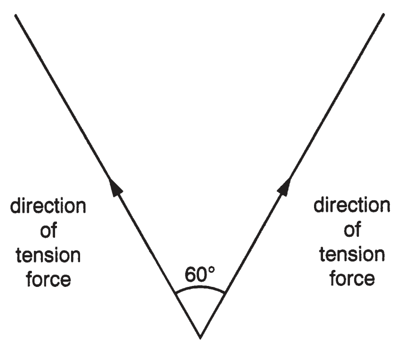
CHALLENGING QUESTIONS

1. The figure shows a catapult used to project an object. Force F pulls back the object, creating tension in the rubber cords.



(a) The tension force in each rubber cord is 20 N and the two cords are at 60° to each other. The figure below shows the direction of the two tension forces acting on the object.

By making a scale drawing on the figure, or otherwise, find the resultant of these two tension forces acting on the object. If you draw a scale drawing, state the scale that you use. [3]



(b) When the object is pulled back, the average value of the force F is 16 N and the object moves a distance 0.20 m in the direction of F. Calculate the work done. State clearly the equation that you use. [2]

2. Force is a vector quantity.

(a) State which two of the following are also vector quantities.

Acceleration, distance, mass, speed, velocity [1]

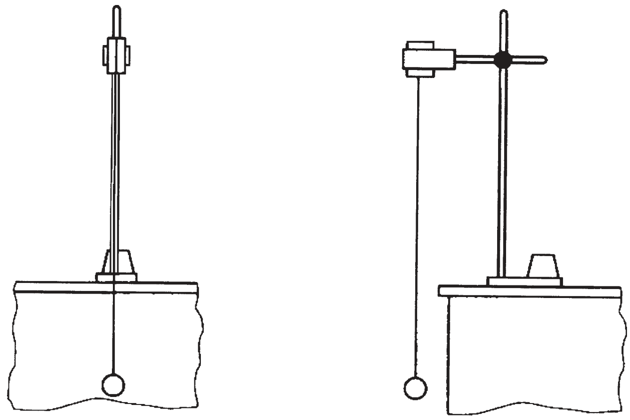
(b) When two forces of 5 N are added, they may produce a resultant force that has any value between 0 and 10 N.

(i) Describe how it is possible to produce a zero resultant force from two forces of 5 N.

(ii) Describe how it is possible to produce a resultant force of 10 N from two forces of 5 N.

(iii) Draw a vector diagram to show how a resultant force of about 5 N may be obtained from the two 5 N forces. Clearly label the forces and the resultant. [4]

3. The figure below shows a simple pendulum suspended from a clamp.



front view side view

(a) Describe briefly how you would use a stopwatch or a stopclock to determine, as reliably as possible, the period of oscillation of the pendulum. [3]

(b) A student obtains the following values for the time for 20 complete oscillations of a pendulum.

14.6 s 14.7 s 14.5 s 14.6 s 14.7 s

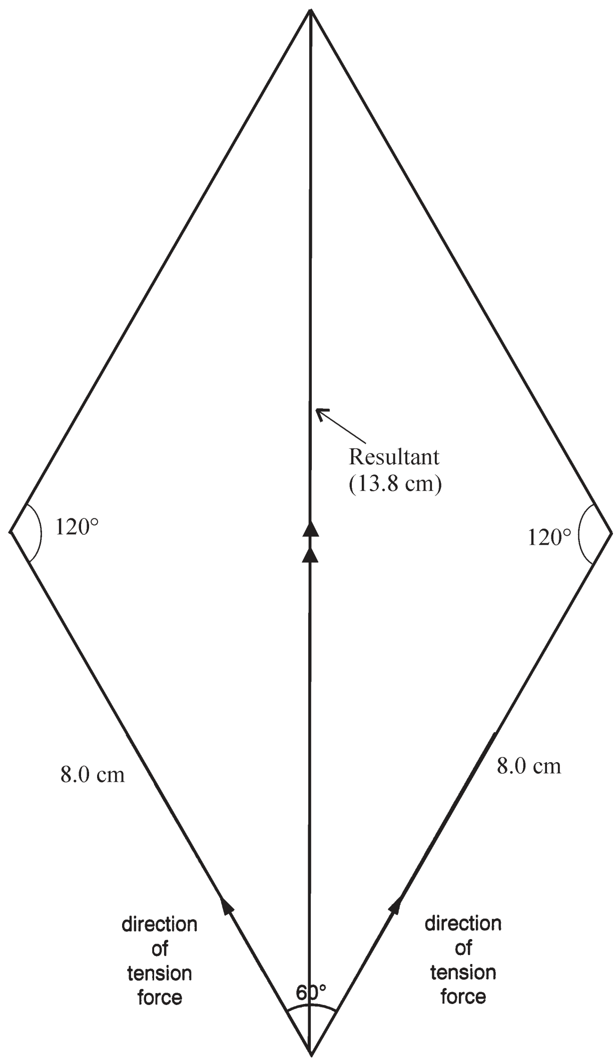
Determine the period of the pendulum. [3]

SOLUTIONS AND EXPLANATIONS

1. (a) Scale: 1 cm represents 2.5 N

Resultant force = 13.8 × 2.5 = 34.5 N

(b) Work done = force × distance moved
= (16)(0.20)
= 3.2 J



Exam Tip

(a) Candidates are advised to choose a scale such that a large vector diagram can be drawn. This will result in a more accurate answer obtained. After the vector diagram is drawn, the resultant force is the diagonal which starts from the same point as the two 20 N forces. Remember to change the length of the resultant to a force by referring to the scale chosen. Don't give the length of the resultant as the answer.

(b) Many candidates can remember that the formula for work done is force x distance travelled. However, they forget that the distance travelled must be in the direction of force.

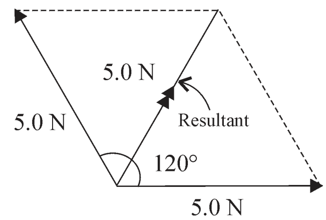
A special case: Work done is zero when the force is perpendicular to the distance travelled.

2. (a) acceleration and velocity

(b) (i) Both forces are in directly opposite directions.

(ii) Both forces are in the same direction.

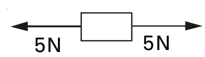
(iii)



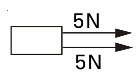
Exam Tip

(a) Only acceleration and velocity have both magnitude and direction. The other quantities have only magnitude.

(b) (i)



(ii)



(iii) To obtain a resultant of 5.0 N, the diagonal of the parallelogram must be 5.0 N. Since the two forces are also 5.0 N, two equilateral triangles are formed. For an equilateral triangle, each angle is 60°. Hence the angle between the two 5.0 N is 120°.

3. (a) Measure the time taken for twenty oscillations using the stopwatch and record it as t. Period of the pendulum = $\frac{t}{20}$. Repeat the experiment to obtain several readings and calculate the average.

(b) Average time for 20 complete oscillations

$$= \frac{14.6 + 14.7 + 14.5 + 14.6 + 14.7}{5}$$

$$= 14.62$$

$$\text{Period of pendulum} = \frac{14.62}{20} = 0.73 \text{ s}$$

Exam Tip

(a) Period is the time taken for the pendulum to complete one oscillation. It is a normal practice to measure the time for 20 oscillations instead of 1 oscillation. It is because the time for 1 oscillation is too short to be measured accurately.

If candidates are required to calculate the average value of a physical quantity, they need to repeat the measurements several times and then find the average of all these readings.

(b) Candidates should not choose one value to determine the period. All the given readings should be used for calculation of the period.

TOPIC 7 ENERGY, WORK AND POWER

LEARNING OBJECTIVES

Candidates should be able to:

📖	Show understanding that kinetic energy, elastic potential energy, gravitational potential energy and chemical potential energy are examples of different forms of energy
📖	State the principle of the conservation of energy
📖	Apply the principle of the conservation of energy to new situations or to solve related problems
📖	State that kinetic energy $E_k = \frac{1}{2} mv^2$ and gravitational potential energy $E_p = mgh$ (for potential energy changes near the Earth's surface)
📖	Apply the relationships for kinetic energy and potential energy to new situations or to solve related problems
📖	Recall and apply the relationship *work done = force × distance moved in the direction of the force* to new situations or to solve related problems
📖	Recall and apply the relationship *power = work done / time taken* to new situations or to solve related problems

USEFUL WEBSITES

- ☐ http://www.glenbrook.k12.il.us/gbssci/phys/Class/energy/u5l1a.html
  (Definition and Mathematics of work)
- ☐ http://www.glenbrook.k12.il.us/gbssci/phys/Class/energy/u5l1aa.html
  (Calculating the amount of work done by a force)
- ☐ http://www.glenbrook.k12.il.us/gbssci/phys/Class/energy/u5l1b.html#elastic
  (Potential energy)
- ☐ http://www.glenbrook.k12.il.us/gbssci/phys/Class/energy/u5l1c.html
  (Kinetic energy)
- ☐ http://www.glenbrook.k12.il.us/gbssci/phys/Class/energy/u5l1d.html
  (Mechanical energy)
- ☐ http://www.glenbrook.k12.il.us/gbssci/phys/Class/energy/u5l1e.html
  (Power)
- ☐ http://www.glenbrook.k12.il.us/gbssci/phys/Class/energy/u5l2a.html
  (Work - energy Theorem)
- ☐ http://www.bbc.co.uk/schools/ks3bitesize/science/physics/energy_transfer_intro.shtml
  (Revision notes and quizzes on energy resources and energy transfer)

OVERVIEW OF THE TOPIC

ENERGY, WORK AND POWER *3 key areas*	ENERGY	• Different forms of energy
		• Kinetic Energy
		• Gravitational Potential Energy
		• Conservation of energy
	WORK	
	POWER	

ENERGY

Different Forms of Energy

☑ Definition | Energy is the *capacity to do work*.

☑ ENERGY HAS THE ABILITY TO CHANGE FROM ONE FORM TO ANOTHER.

☑ It has no direction so it is a scalar.

☑ **SI unit of energy:** joule (J)

☑ Everything around us has energy which exists in different forms.

☑ *Forms of energy:*

	Forms of energy:	**Some common examples**
①	Chemical energy	Fuels (oil, coal, petrol), electric cells, food, explosives.
②	Electrical energy	The energy associated with the current in an electric drill, electric motors, an immersion heater and electrical appliances.
③	Mechanical energy ❶ Kinetic energy (K.E.) ❷ Potential energy (P.E.) (i) Gravitational potential energy (ii) Elastic potential energy	 All objects in motion have kinetic energy, e.g. a moving car, a flying aeroplane. (i) a waterfall, raised objects (ii) compressed or stretched springs or rubber bands
④	Nuclear energy	The energy released from nuclear reactions like fission and fusion.

STOP & THINK

[Q] Which example best illustrates the conversion of electrical energy to chemical energy?

A melting a fuse

B charging an accumulator

C starting a car

D generating hydro-electric power

[Ans] **B** Charging an accumulator is to convert the electrical energy from the power source to the chemical energy stored inside the accumulator.

Exam Tip

Accumulator is a kind of battery.

KINETIC ENERGY

☑ All moving objects have ENERGY OF MOTION called kinetic energy.

☑ Kinetic energy is the energy about movement. When an object is AT REST, it has NO kinetic energy.

☑

Take note	Kinetic energy depends on an object's MASS and SPEED.

e.g. **A running elephant has more kinetic energy than a running man because it has more mass. A racing car has more kinetic energy than a family car because it has a higher speed.**

☑ To measure kinetic energy, apply the following equation:

Equation	K.E. $= \frac{1}{2}mv^2$	where K.E.: kinetic energy (in J) m: mass (in kg) v: speed (in $m\,s^{-1}$)

GRAVITATIONAL POTENTIAL ENERGY

☑ The ENERGY OF POSITION is called potential energy.

☑ When an object is lifted to a higher position, it gains gravitational potential energy.

☑ This is stored energy which can be converted to kinetic energy when the object falls down.

e.g. **Water stored behind a dam. A pole-vaulter at his maximum height.**

☑

Take note	Potential energy depends on an object's MASS and HEIGHT.

☑ To measure potential energy, apply the following equation:

Equation	P.E. = mgh	where P.E.: potential energy (in J) m: mass (in kg) g: gravitational field strength (in $N\,kg^{-1}$) h: height (in m)

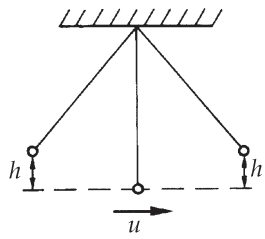
Exam Tip

Potential energy is the energy about position. When we calculate potential energy, there must be a reference level. It is very often that we use the ground level for P.E. = 0.

STOP & THINK

[Q] A pendulum bob of mass m, attached to a light string, is released from rest at a height h above its lowest point. The speed of the bob at its lowest point is u.

What will be the kinetic energy of the bob when it reaches a height h on the other side?



A zero **C** ½ mu^2

B mgh **D** mu^2

[continued]

[Ans] **A** At the highest point, the bob is momentarily at rest and so the kinetic energy is zero.

Exam Tip

Kinetic energy is the energy of motion. There is no kinetic energy if the object is at rest. It is potential energy at h.

Conservation of Energy

- ☑ ***When energy changes from one form to another, the total amount of energy always stays the same.***
- ☑ We say it is conserved. This fact is known as the Principle of Conservation of Energy.
- ☑

Principle of Conservation of Energy	**Energy can be changed from one form to another, but it can neither be created nor destroyed.**

An example:

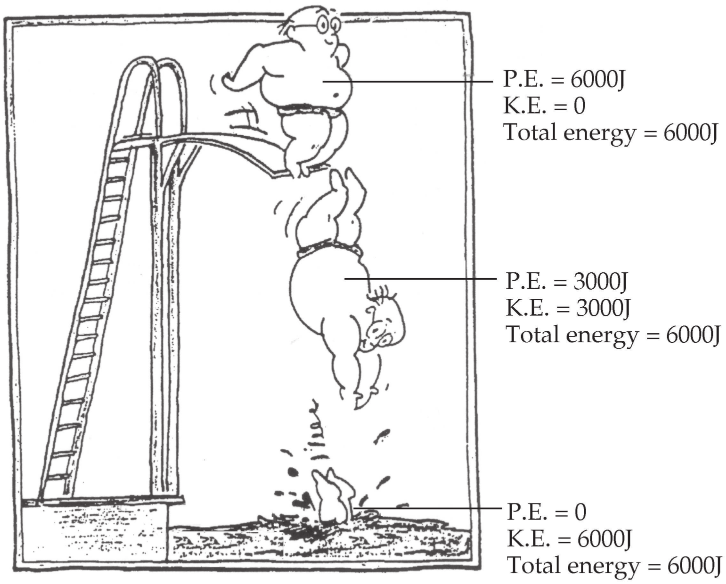
We assume that a diver has 6000 J of gravitational potential energy before the dive. There is no kinetic energy yet. Total energy is 6000 J.

As the diver takes off, there is only one direction, i.e. downwards, so he loses potential energy and gains kinetic energy.

At midway, if potential energy is assumed to drop to 3000 J, kinetic energy must be increased to 3000 J. The total amount of energy is still 6000 J.

At ground level (water surface), potential energy becomes 0 J. Kinetic energy is 6000 J.

The form of energy has changed, but there is no change in the total amount of energy throughout his action.



STOP & THINK

[Q] A car accelerates up a hill. What happens to its kinetic energy and to its potential energy?

	kinetic energy	potential energy
A	decreases	increases
B	increases	decreases
C	increases	increases
D	unchanged	decreases

[Ans] **C** The speed of the car increases and so the kinetic energy is increasing. Accelerating up a hill implies an increase in vertical height and so the potential energy increases.

Exam Tip

In some questions, the potential energy increases when kinetic energy decreases so that the total energy is conserved. However it does not apply to this question as the car engine continues to supply energy to the car.

WORK

☑ If you exert a FORCE on an object and make it MOVE in the SAME DIRECTION as the applied force, we say WORK IS DONE on the object. ***(Energy is converted during the process.)***

☑

Definition	The amount of <u>work done</u> by a constant force is the ***product of the force and the distance moved in the direction of the force***.

☑

Equation	$W = F \times s$	where W: work done by a constant force (in J) F: force (in N) s: distance moved in the direction of the force (in m)

☑ **SI unit of work done:** newton metre (N m) or joule (J)

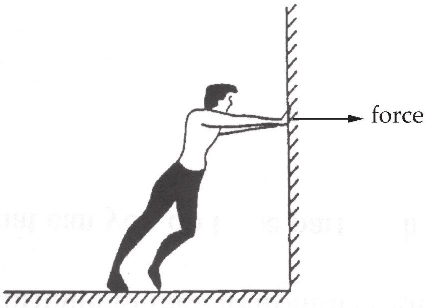
☑ $1\,J = 1\,N\,m$

Exam Tip

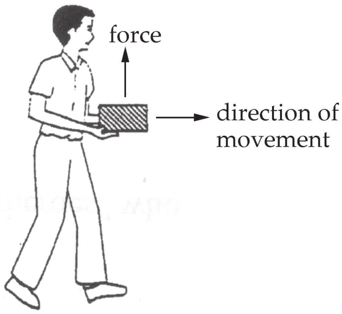
No work is done when:

(a) The force is applied on the object but the object does not move.

(b) The direction of the applied force and the direction in which the object moves are perpendicular to one another.



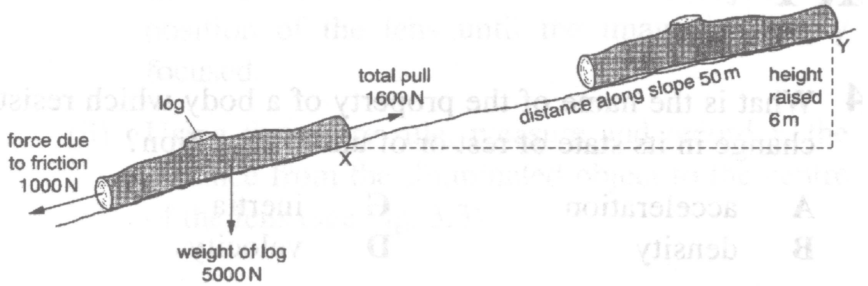
No work done because wall remains at rest



No work done because force is perpendicular to direction of movement

STOP & THINK

[Q] The diagram shows a log being pulled up an earth slope from X to Y. How much work is done against friction?



A 6000 J **B** 9600 J **C** 50000 J **D** 80000 J

[Ans] **C** Work done against friction $= \text{friction} \times \text{distance moved}$

$= 1000 \times 50$

$= 50000 \text{ J}$

Exam Tip

Work done against friction is the energy used to overcome friction. It is equal to the work done by the friction.

POWER

☑ If two cars of the same weight climb up the same hill, they have same amount of WORK DONE. But if car A climbs the hill in a shorter TIME than car B, we say it has a greater POWER.

☑

Definition	Power is the *rate of work done (or rate of converting energy).*

☑ Hence, $\text{power} = \dfrac{\text{work done}}{\text{time taken}} = \dfrac{\text{energy converted}}{\text{time taken}}$

☑

Equation	$P = \dfrac{W}{t} = \dfrac{E}{t}$	where P: power W: work done (in J) E: energy converted (in J) t: time taken (in s)

☑ **SI unit of power:** joule per second ($J\,s^{-1}$) or watt (W)

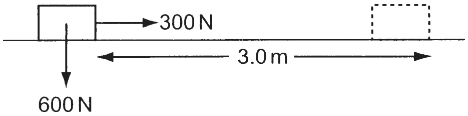
☑ $1\ W = 1\ J\,s^{-1}$

Exam Tip

Power is not energy. Many candidates misuse the term 'Power' when they describe changes in energy. Power is not a thing that can be transferred like energy. It is merely a rate.

STOP & THINK

[Q] When a 300 N force is applied to a box weighing 600 N, the box moves 3.0 m horizontally in 20 s.



What is the average power?

A 45 W **C** 900 W

B 90 W **D** 1800 W

[Ans] **A** $P = \dfrac{\text{work done}}{\text{time}}$

$= \dfrac{300 \times 3}{20}$

$= 45\ \text{W}$

Exam Tip

Work done is the force × distance moved in the direction of force. 600 N is the weight of the box which is a vertical force. It is not included in the calculation of work done by the 300 N force.

STOP & THINK

[Q] A windmill is used to raise water from a well. The depth of the well is 5 m. The windmill raises 200 kg of water every day. What is the useful power extracted from the wind? (g = 10 N/kg)

A $\dfrac{200 \times 10 \times 4}{5}$ W **C** $\dfrac{200 \times 10}{5 \times 24}$ W

B $\dfrac{200 \times 10 \times 5}{24 \times 60 \times 60}$ W **D** $\dfrac{200 \times 5}{24 \times 60}$ W

[Ans] **B** Power $P = \dfrac{E}{t}$

$P = \dfrac{F \times s}{t}$

$= \dfrac{200 \times 10 \times 5}{24 \times 60 \times 60}$

Exam Tip

Candidates need to convert 1 day to 24 × 60 × 60 seconds. The force is the weight of the water 200 × 10 N.

CHALLENGING QUESTIONS

1. (a) (i) Define *work* and give the name and symbol for an SI unit in which it is measured.

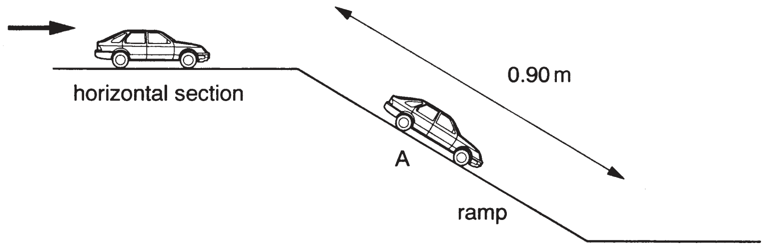
   (ii) Define *power* and give the name and symbol for an SI unit in which it is measured. [4]

   (b) A student of mass 60 kg runs up a flight of stairs of height 4.0 m in a time of 3.0 s. Calculate, assuming that the gravitational force on a mass of 1.00 kg is 10.0 N,

   (i) the student's gain in potential energy,

   (ii) the useful power developed by the student in climbing the stairs. [3]

2. A toy car is given a *brief* initial push which sends it along a horizontal section of runway. The force of gravity then accelerates the car down the ramp which is shown in the figure below. In this question the only force due to friction that acts on the car is air resistance.



   (a) On the figure, where the car is moving down the ramp at A, draw labelled arrows to show

   (i) the direction of the force due to gravity on the car,

   (ii) the direction of the force due to friction on the car. [1]

   (b) State the effect that friction has on the motion of the car

   (i) while the car is moving along the horizontal section,

   (ii) while the car is accelerating down the ramp. [2]

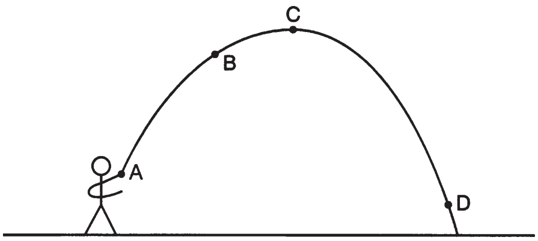
   (c) The length of the ramp is 0.90 m and the average force of friction is 0.11 N.

   (i) Calculate the work done by the car against friction as it moves down the ramp.

   (ii) The car has 0.30 J of kinetic energy at the top of the ramp and loses 0.50 J of potential energy as it moves from the top to the bottom of the ramp.

   Calculate the kinetic energy of the car at the bottom of the ramp. [4]

3. The figure below shows the path of a ball thrown into the air.



(a) (i) State at which point A, B, C or D the ball travels the slowest.

(ii) Explain your choice in (i). You should write about the kinetic energy and the potential energy of the ball. [3]

(b) The mass of the ball is 0.20 kg. At point A, the ball has kinetic energy 2.5 J. Taking the gravitational force on a mass of 1.0 kg to be 10 N, calculate

(i) the weight of the ball,

(ii) the speed of the ball at point A. [4]

4. Fig. 4.1 shows a wind turbine used to produce electricity. The turbine blades are turned by the wind and are connected to an electrical generator.

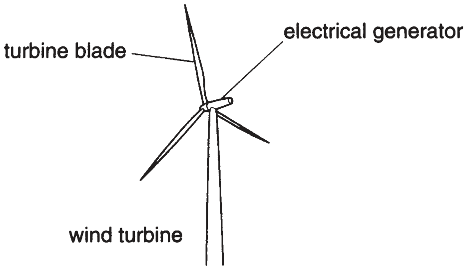


Fig. 4.1

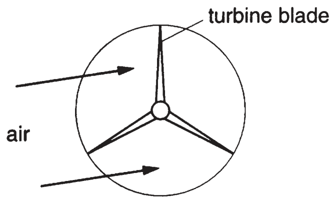


Fig. 4.2

(a) Energy can be converted from one form into another.

(i) State the useful energy transformations that occur during the operation of a wind turbine.

(ii) Describe briefly why more energy is produced per second if

1. the wind blows faster,

2. the turbine blades are longer,

3. the turbine is more efficient.

(iii) State one other energy transformation that produces electricity on a large scale and in which fuel is not burnt. [6]

(b) In one revolution the blades sweep out a circle, as shown in Fig. 4.2. In 60 s a volume of 540 000 m^3 of air travelling at a speed of 6.0 m/s is incident at right angles on that circle. The density of air is 1.2 kg/m^3.

Calculate

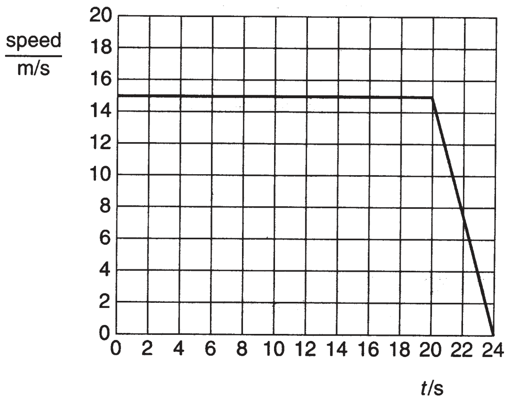
(i) the mass of air that passes through this circle in 60 s,

(ii) the initial kinetic energy of this mass of air,

(iii) the maximum input power available to the wind turbine. [9]

5. The graph shows the variation with time of the speed of a car as it travels along a level road. The car brakes when the time t = 20 s, and comes to rest when t = 24 s.

The car has a mass of 800 kg and the forward driving force on the wheels is 1200 N.



(a) For the first 20 s of the motion shown in the graph

calculate

(i) the distance travelled,

(ii) the work done by the driving force,

(iii) the power supplied by the driving force. [6]

(b) (i) Calculate the kinetic energy of the car while it is travelling at the constant top speed.

(ii) When the car is travelling at a constant speed there is no change in its kinetic energy.

1. Explain why the car engine is needed to maintain this constant speed.

2. Suggest what happens to the energy that is provided by the engine. [5]

(c) During braking the speed of the car decreases uniformly. The engine no longer provides a driving force.

(i) Calculate the deceleration of the car between t = 20 s and t = 24 s.

(ii) Calculate the total braking force acting on the car during this period.

(iii) Explain why the power dissipated in the brakes to slow the car is greater at the beginning of the braking period than at the end. [4]

SOLUTIONS AND EXPLANATIONS

1. (a) (i) Work done by a force is the magnitude of the force multiplied by the distance moved in the direction of the force.
SI unit of work done: Joule
Symbol: J

(ii) Power is the rate at which work is done.
SI unit of power: Watt
Symbol: W

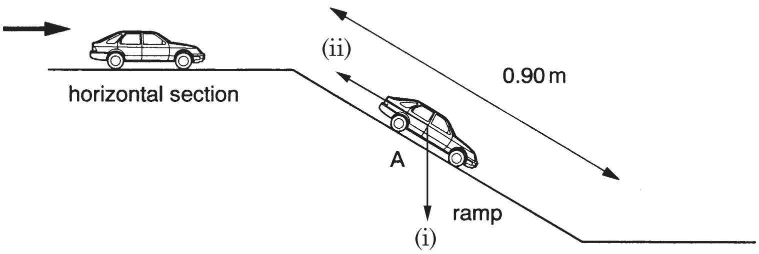
(b) (i) gain in P.E. $= mgh$
$= 60 \times 10.0 \times 4.0$
$= 2400$ J

(ii) Useful power $= \dfrac{\text{gain in P.E.}}{\text{time}}$
$= \dfrac{2400}{3.0}$
$= 800$ W

Exam Tip

Candidates are advised to remember the definition of some important physical quantities.

2. (a) (i) (ii)



(b) (i) The car decelerates and the speed of the car decreases.

(ii) The acceleration of the car decreases.

(c) (i) Work done against friction $=$ friction force $\times$ distance moved by the car
$= 0.11 \times 0.90$
$= 0.099$ J

(ii) By conservation of energy,

P.E. at the top + K.E. at the top = P.E. at the bottom + K.E. at the bottom + work done against friction

P.E. loss + K.E. at the top = K.E. at the bottom + work done against friction

K.E. at the bottom $=$ P.E. loss $+$ K.E. at the top $-$ work done against friction
$= 0.50 + 0.30 - 0.099$
$= 0.701$ J

Exam Tip

(a) (i) (ii) Forces must be drawn at the appropriate positions. Gravity is the weight of the car which acts vertically downwards at the centre of gravity. The direction of air resistance is in the opposite direction of motion of the car.

(b) When candidates are required to describe motion of an object, they should mention about the change in velocity and acceleration.

(i) Friction is in the opposite direction of the motion. It will reduce the speed and cause deceleration.

(ii) The resultant force = component of weight down the slope – air resistance

Since air resistance increases with speed, the resultant force decreases and thus the acceleration decreases.

(c) (i) Work done by friction = friction x distance moved in the opposite direction of friction

(ii) Conservation of energy is an important principle which is applied to many questions relating to change of energy and work done.

3. (a) (i) C

(ii) As the ball moves upwards, its kinetic energy is converted to potential energy. At point C, the ball is at its highest point. Therefore its potential energy is the maximum and its kinetic energy is the minimum. The ball is slowest in speed.

(b) (i) Weight W

$$\begin{aligned} W &= mg \\ &= 0.20 \times 10 \\ &= 2.0\text{ N} \end{aligned}$$

(ii)

$$\begin{aligned} \text{K.E.} &= \frac{1}{2}mv^2 \\ v &= \sqrt{\frac{2\text{K.E.}}{m}} \\ &= \sqrt{\frac{2 \times 2.5}{0.20}} \\ &= 5.0\text{ m / s} \end{aligned}$$

Exam Tip

(a) The speed of the ball is decreasing when it is travelling upwards. It is because the kinetic energy is converted to potential energy. Thus the kinetic energy of the ball is the lowest at the highest point. However the kinetic energy is not zero at point C as the ball has a horizontal speed. This is different from the case that the ball is thrown vertically upwards.

4. (a) (i) Kinetic energy of the wind is converted to kinetic energy of the turbine which is finally converted to electrical energy.

(ii) 1. The turbine turns faster and thus more kinetic energy is converted to electrical energy per second.

2. The mass of air passing through the turbine per second increases.

3. If the turbine is more efficient, more kinetic energy of the wind is converted to electrical energy.

(iii) Nuclear energy from a nuclear reactor in the nuclear power station is converted to electrical energy.

(b) (i) mass

$$\begin{aligned} \text{mass} &= \text{density} \times \text{volume} \\ &= 1.2 \times 540000 \\ &= 6.48 \times 10^5\text{ kg} \end{aligned}$$

(ii)

$$\begin{aligned} \text{K.E.} &= \frac{1}{2}mv^2 \\ &= \frac{1}{2} \times 6.48 \times 10^5 \times 6^2 \\ &= 1.17 \times 10^7\text{ J} \end{aligned}$$

(iii)

$$\begin{aligned} \text{Power} &= \frac{\text{energy}}{\text{time}} \\ &= \frac{1.17 \times 10^7}{60} \\ &= 1.95 \times 10^5\text{ W} \end{aligned}$$

Exam Tip

(a) (i) Only the useful energy transformation should be mentioned here. The wasted and non-useful energy like heat is not involved.

(ii) 1 and 2
Output power is dependent on the force acting on the blade and the speed of the turbine.

(ii) 3
A higher efficiency means more useful energy during the conversion of energy.

(iii) Another possible answer is hydroelectric power where gravitational potential energy of water is converted to electrical energy.

(b) All three questions here are straightforward, but candidates still need to take note that all answers should be corrected to 2 s.f. as the data is given to 2 s.f..

5. (a) (i) distance travelled $= \text{area under the graph}$
$= 15 \times 20$
$= 300 \text{ m}$

(ii) work done $= \text{force} \times \text{distance travelled}$
$= 1200 \times 300$
$= 360000 \text{ J}$

(iii) power $= \dfrac{\text{work done}}{\text{time}}$
$= \dfrac{360000}{20}$
$= 18000 \text{ W}$

(b) (i) kinetic energy $= \dfrac{1}{2}mv^2$
$= \dfrac{1}{2} \times 800 \times 15^2$
$= 90000 \text{ J}$

(ii) 1. The car engine is needed to maintain the constant speed because energy is required to overcome friction and air resistance.

2. The energy provided by the engine is converted to internal energy.

(c) (i) $a = \dfrac{v-u}{t}$
$= \dfrac{0-15}{4}$
$= -3.75 \text{ m/s}^2$

deceleration of the car = 3.75 m/s^2

(ii) total braking force $= ma$
$= 800 \times 3.75$
$= 3000 \text{ N}$

(iii) The loss in kinetic energy at the beginning is larger than the loss in kinetic energy towards the end of the car's journey.

ExamTip

(a) (i) Distance travelled is the area under the graph.

(b) (i) The top speed is the greatest speed which can be found from the graph.

(ii) Internal energy should be used here as heat energy is only used during the transfer of energy. Objects gain internal energy but not heat energy, but when two objects at different temperatures are in contact, heat energy is transferred from the hotter object to the colder object.

(c) (i) The –ve sign for the answer means deceleration. You can remove the negative sign from the answer when specifying deceleration.

(ii) You do not have to include the –ve sign for the acceleration when you apply Newton's 2nd Law here.

(iii) We can find the speed of the car at t = 20 s, 22 s and 24 s from the speed-time graph. After that, we calculate the kinetic energy of the car at t = 20 s, 22 s and 24 s. Loss in kinetic energy from t = 20 s to t = 22 s is 67500 J which is 3 times that of the loss in kinetic energy from t = 22 s to t = 24 s.

TOPIC 22

ELECTROMAGNETIC INDUCTION

LEARNING OBJECTIVES

Candidates should be able to:

🕮	Deduce from Faraday's experiments on electromagnetic induction or other appropriate experiments: (i) that a changing magnetic field can induce an e.m.f. in a circuit (ii) that the direction of the induced e.m.f. opposes the change producing it (iii)the factors affecting the magnitude of the induced e.m.f.
🕮	Describe a simple form of a.c. generator (rotating coil or rotating magnet) and the use of slip rings (where needed)
🕮	Sketch a graph of voltage output against time for a simple a.c. generator
🕮	Describe the structure and principle of operation of a simple iron-cored transformer as used for voltage transformations
🕮	Recall and apply the equations $V_p / V_s = N_p / N_s$ and $V_pI_p = V_sI_s$ to new situations or to solve related problems (for ideal transformer)
🕮	Describe the energy loss in cables and deduce the advantages of high voltage transmission

USEFUL WEBSITES

- http://sol.sci.uop.edu/~jfalward/electromagneticinduction/electromagneticinduction.html
  (Details about Electromagnetic Induction: Explanation, Faraday's Law, Lenz's Law and Generator)
- http://micro.magnet.fsu.edu/electromag/java/faraday2/
  (A Java Applet to show Electromagnetic Induction)
- http://micro.magnet.fsu.edu/electromag/java/lenzlaw/
  (A Java Applet to show Lenz's Law)
- http://www.wvic.com/how-gen-works.htm
  (How a generator works?)
- http://micro.magnet.fsu.edu/electromag/java/generator/ac.html
  (A Java Applet to demonstrate A.C. Generator)
- http://micro.magnet.fsu.edu/electromag/java/transformer/
  (A Java Applet to demonstrate Transformer)
- http://www.bbc.co.uk/scotland/education/bitesize/standard/physics/electricity/generating_electricity_rev1.shtml
  (Revision notes on Induced Voltage, Generator, Transformer and National Grid)
- http://www.bsharp.org/physics/stuff/xmission.html
  (Explanation of high voltage transmission lines)

OVERVIEW OF THE TOPIC

ELECTROMAGNETIC INDUCTION *3 key areas*	PRINCIPLES OF ELECTROMAGNETIC INDUCTION	• Faraday's Law of Electromagnetic Induction
		• Lenz's Law
		• Fleming's Right Hand Rule
	SIMPLE A.C. GENERATOR	
	TRANSFORMERS	• Principle of a transformer
		• Power transmission

PRINCIPLES OF ELECTROMAGNETIC INDUCTION

Faraday's Law of Electromagnetic Induction

☑

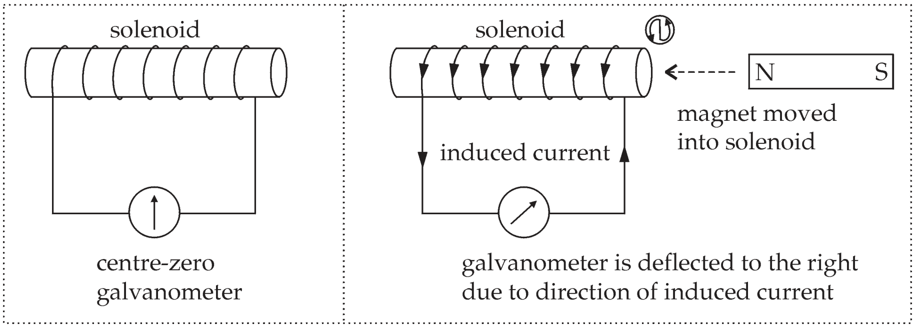
Concept	A current can be produced in a conductor by the motion of magnetic field.

☑

Definition	Electromagnetic induction occurs ① when there is a changing or varying magnetic field near a close circuit, ② the magnetic lines of force linking the circuit induces an electromotive force (e.m.f.), and an induced current is produced.

☑ ***Explanation:***

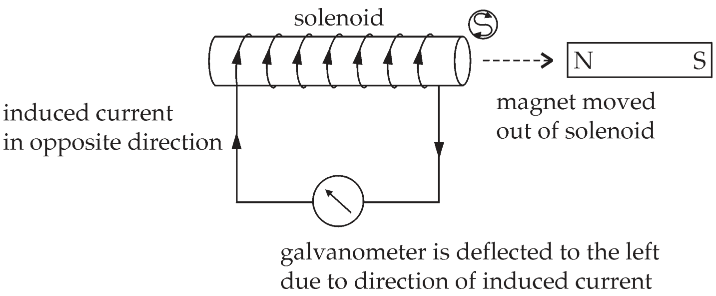
- ☐ In the figure below, a zero-current solenoid is set up with a centre-zero galvanometer.
- ☐ A stationary bar magnet is to be inserted into the solenoid.
- ☐ When the magnet (with known poles) is moved INTO the solenoid, the pointer of the galvanometer is deflected in one direction (or the other) by an induced current.
- ☐ This shows that an induced e.m.f. is produced in the solenoid.



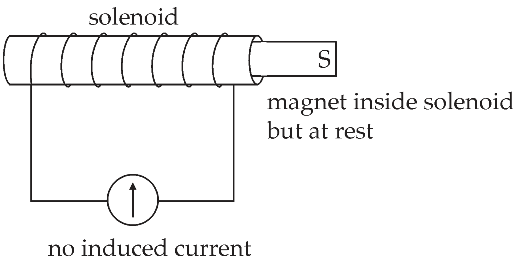
Exam Tip

- ☐ We can keep the magnet at rest and move the solenoid towards the magnet. The pointer of the galvanometer will also be deflected.
- ☐ Apply Lenz's Law to determine the direction of the induced current when different poles of the magnet is inserted.

- ☐ The direction of induced current is REVERSED when the same magnet is moved OUT (backtrack) of the solenoid.



- NO e.m.f. is induced if:
  - the magnet is at rest outside or inside the solenoid;
  - the magnet and the solenoid move with the same speed in the same direction (no relative motion between the two).



- The magnitude of the induced e.m.f. increases (greater deflection in the galvanometer) when:
  ① the magnet is moved more quickly;
  ② the number of turns in the solenoid is increased;
  ③ the strength of the magnet is increased.

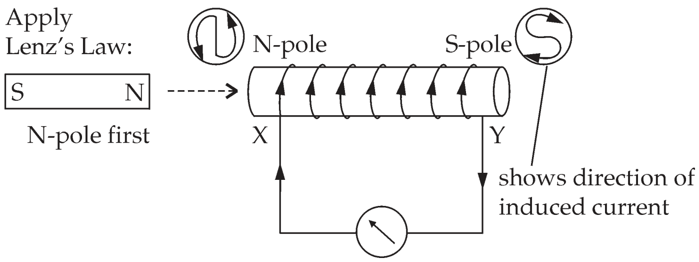
Faraday's Law of Electromagnetic Induction	**The strength of the induced e.m.f. is proportional to the rate of change of magnetic lines of force linking the circuit.**

LENZ'S LAW

- The direction of the induced current can be determined by Lenz's Law.

Lenz's Law	**An induced current flows in a direction so as to OPPOSE the change or motion producing it.**

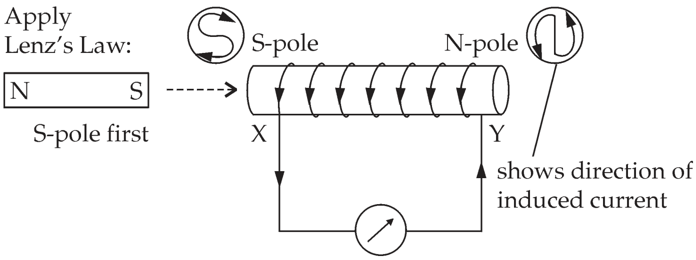
- If it is the N-pole that is moved into the solenoid first, to OPPOSE this motion, the induced current must produce a N-pole at end X (and S-pole at end Y) of the solenoid.



Take note

If the magnet is moved out from end Y, Y becomes N - pole.

- If it is the S-pole that is moved into the solenoid first, to OPPOSE this motion, the induced current must produce a S-pole at end X (and N-pole at end Y) of the solenoid.

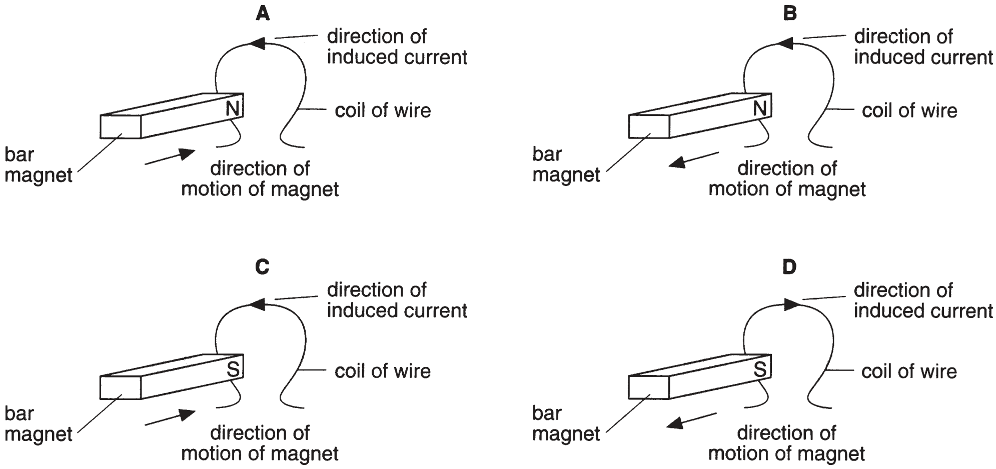


Take note

If the magnet is moved out from end Y, Y becomes S - pole.

STOP & THINK

[Q] Which diagram correctly gives the direction of the induced current when the magnet is moved as shown? In each case, the coil of wire is connected in a complete circuit.



[Ans] **A** According to Lenz's Law, when the N-pole of the magnet is approaching the coil, the N-pole of the magnetic field due to the coil must face the N-pole of the magnet in order to oppose the change.

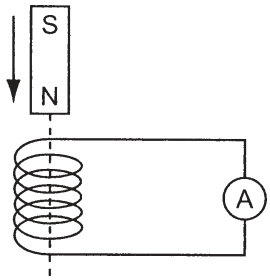
ExamTip

The direction of induced current is reversed when the magnet is moved out (backtrack).

STOP & THINK

[Q] A small coil is connected to a sensitive ammeter. The ammeter needle can move to either side of the zero position. When the magnet is allowed to fall towards the coil, the ammeter needle moves quickly to the right of the zero position.

The magnet moves through the coil. How does the ammeter needle move as the magnet falls away from the coil?



A It does not move.

B It gives a steady reading to the right.

C It moves quickly to the left of the zero position and then returns to zero.

D It moves quickly to the right of the zero position and then returns to zero.

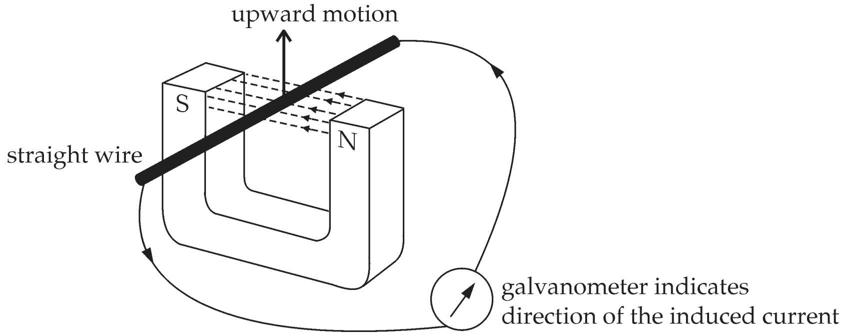
[Ans] **C** When the magnet falls towards the coil, a N-pole is induced at the upper end of the coil according to Lenz's Law. When the magnet falls away from the coil, the induced N-pole is at the lower end of the coil to attract the magnet. Hence, the current is reversed.

ExamTip

When N-pole is at upper end, the direction of induced current is anticlockwise. When the current is reversed, it becomes clockwise.

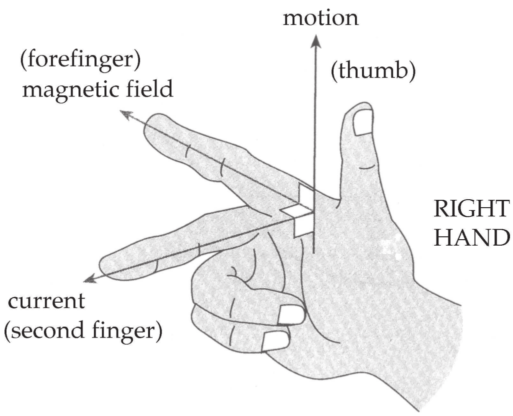
Fleming's Right Hand Rule

☑ When a straight wire is moved inside a magnetic field and the magnetic field lines are cut by the upward motion of the wire, an induced e.m.f. is produced and the induced current flows through the galvanometer.



☑ Without using the galvanometer, ***the direction of the induced current*** in the straight wire can be determined by using Fleming's Right Hand Rule or Dynamo Rule.

☑ Fleming's Right Hand Rule	If the thumb and the first two fingers of your RIGHT HAND are held at right angles to each other, ① with the thumb pointing in the direction of the motion and ② the forefinger pointing in the direction of the magnetic field, ③ then the second finger will point in the direction of the induced current.

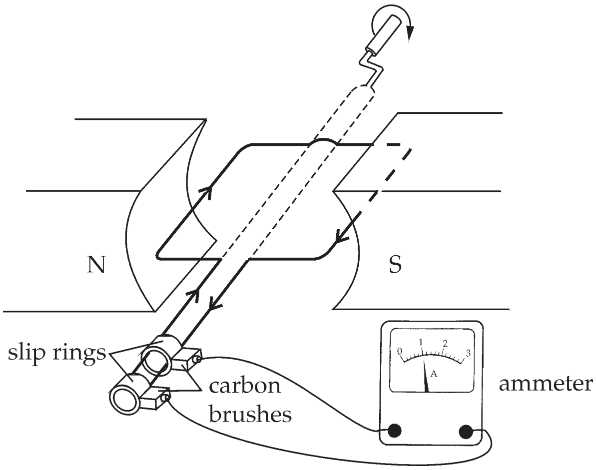


Exam Tip

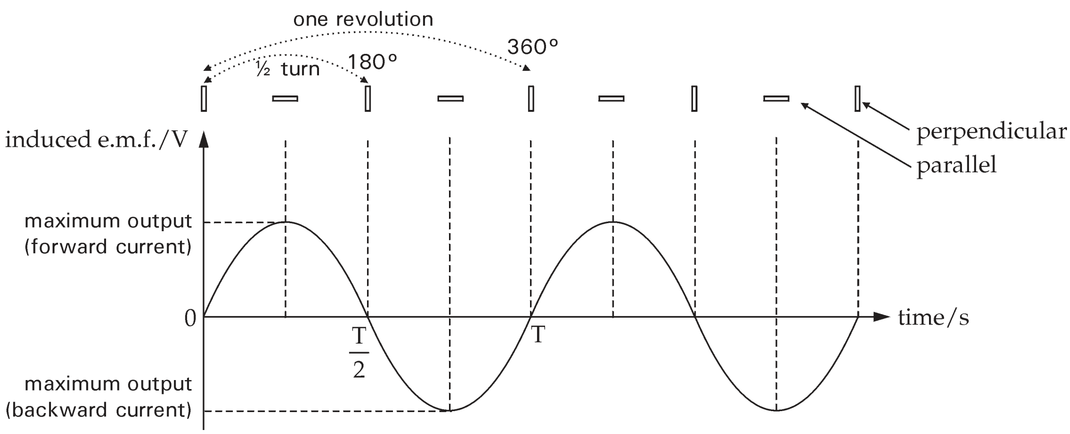
Fleming's Right Hand Rule relates to INDUCED current.
Fleming's Left Hand Rule relates to ELECTRIC current.

SIMPLE A.C. GENERATOR

- ☑ A simple alternating current (a.c.) generator consists of:
  - ☐ two permanent magnets with circular poles (N and S),
  - ☐ a rectangular coil of wire mounted on an axle with a handle,
  - ☐ a pair of slip rings and carbon brushes.
- ☑ *Explanation:*
  - ☐ By turning the handle, the coil rotates between the poles (N and S) of the magnets. The pair of slip rings rotate with the coil.
  - ☐ The carbon brushes are in continuous contact with the slip rings when the axle is rotating.
  - ☐ As the coil rotates, the upward as well as downward motions of the arms cut the magnetic field lines and an alternating e.m.f. is induced.
  - ☐ The alternating induced current passes through the carbon brushes to the external circuit (such as an ammeter).



- ☑ *Conclusion:*
  - ☐ The ***direction*** of the induced current changes ***every half turn*** of the coil.
  - ☐ The induced e.m.f. has MAXIMUM output when the plane of the coil is PARALLEL to the magnetic field. There is NO induced e.m.f. when the plane of the coil is PERPENDICULAR to the magnetic field.



☐ The ***period*** is the time taken for one revolution of the coil. The ***frequency*** of rotation is the number of revolutions of the coil per second.

Equation	$f = \dfrac{1}{T}$	where f: frequency T: period

☐ The induced e.m.f. can be increased by:

① rotating the coil faster i.e. increasing the frequency of rotation;

② increasing the number of turns on the coil;

③ winding the coil round a soft iron core so that the magnetic field is stronger;

④ using a stronger magnet, or using a powerful electromagnet to make the field stronger.

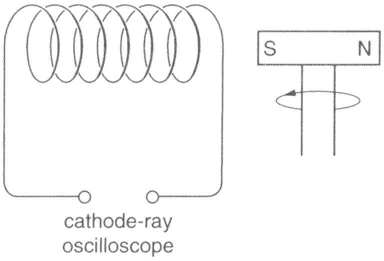
Exam Tip

☐ Double the frequency of rotation will double the maximum output but halve the period.

☐ With same frequency, double the number of turns on the coil will double the maximum output.

STOP & THINK

[Q] A bar magnet is rotated on a shaft near to a coil as shown.



A cathode-ray oscilloscope connected to the coil indicates the induced e.m.f.

Which change does not increase the size of the induced e.m.f.?

A moving the magnet closer to the coil

B turning the magnet in the opposite direction at the same speed

C turning the magnet in the same direction at a greater speed

D using a coil with more turns

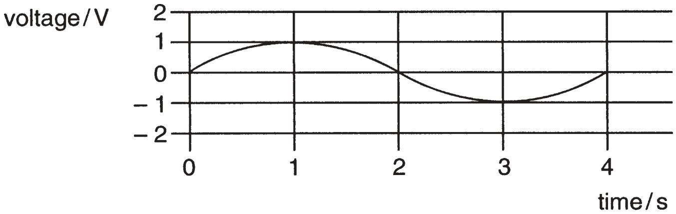
[Ans] **B** The direction of rotation of the magnet does not affect the magnitude of the induced e.m.f. It only changes the direction of the induced e.m.f.

Exam Tip

The turning speed of the magnet, magnetic field strength and number of turns of the coil will affect the magnitude of the induced e.m.f.

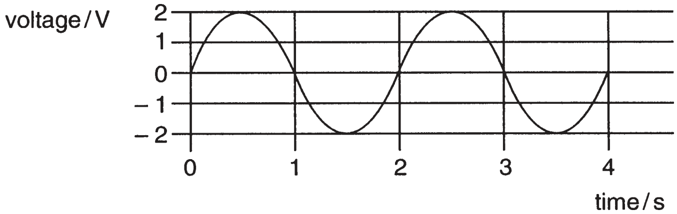
STOP & THINK

[Q] A simple a.c. generator produces a voltage that varies with time as shown.

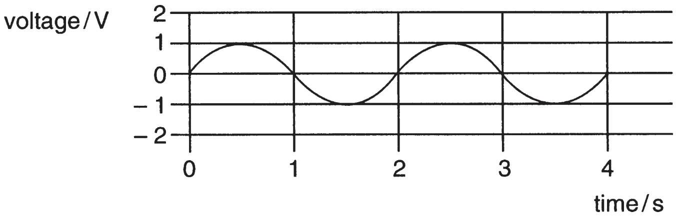


Which graph shows how the voltage varies with time when the generator rotates at twice the original speed?

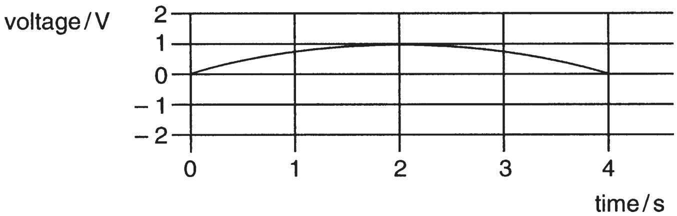
A



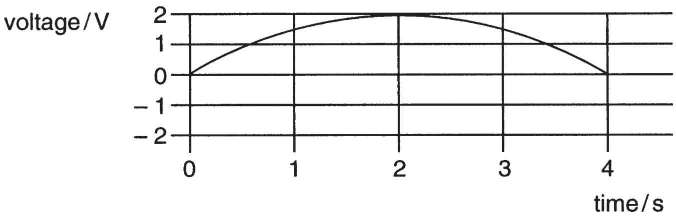
B



C



D



[Ans] **A** Since the speed is doubled, the amplitude or maximum output of the a.c. voltage is doubled and the period (T) of the voltage is halved.

Exam Tip

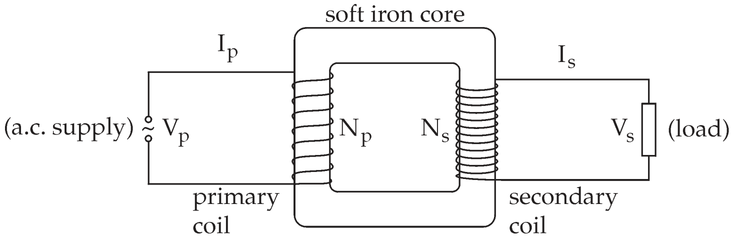
At twice the original speed means two cycles are observed for the same time interval. The increase in the rate of motion doubles the induced e.m.f.

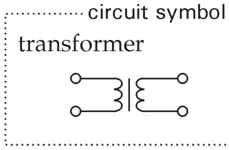
TRANSFORMERS

PRINCIPLE OF A TRANSFORMER

☑ A <u>transformer</u> is a device used to VARY the voltage of an a.c. supply.

☑ The basic structure of a transformer consists of a primary coil and a secondary coil wound on a soft iron core.





where
V_p = primary input voltage
I_p = alternating current in primary coil
N_p = number of turns in primary coil
N_s = number of turns in secondary coil
I_s = alternating induced current in secondary coil
V_s = secondary output voltage

☑ ***Working principle:***

- ☐ An alternating current supply (input voltage, V_p) is needed in a transformer.
- ☐ The alternating current (I_p) flows in the primary coil and ***sets up a changing magnetic field***.
- ☐ In the secondary coil, ***an alternating e.m.f. is induced***. The alternating induced current (I_s) then flows to the load (output voltage V_s).

☑ The induced e.m.f. in the secondary coil may be GREATER OR LESS THAN the e.m.f. of the primary coil depending on the number of turns, N_s and N_p.

- ☐ If $N_s > N_p$ then $V_s > V_p$: this is a STEP-UP transformer.
- ☐ If $N_s < N_p$ then $V_s < V_p$: this is a STEP-DOWN transformer.
- ☐ Therefore $\frac{V_s}{V_p}$ is directly proportional to $\frac{\text{number of turns in secondary coil}}{\text{number of turns in primary coil}}$ or $\frac{V_s}{V_p} = \frac{N_s}{N_p}$.

☑ If a transformer is 100% efficient, then OUTPUT POWER = INPUT POWER.

Equation (100% efficient)	output power = input power $V_s I_s = V_p I_p$ (or) $\frac{V_s}{V_p} = \frac{I_p}{I_s}$ (and) $\frac{V_s}{V_p} = \frac{N_s}{N_p} = \frac{I_p}{I_s}$	by applying Equation $P = VI$

STOP & THINK

[Q] Which statement about the action of a transformer is correct?

A An alternating current always flows in the secondary coil when an alternating voltage is applied to the primary coil.

B The current in the secondary coil is always larger than the current in the primary coil.

C An e.m.f. is induced in the secondary coil when an alternating voltage is applied to the primary coil.

D An e.m.f. is induced in the secondary coil when a steady direct current flows in the primary coil.

[Ans] **C** The alternating voltage applied to the primary coil sets up a changing magnetic field, thus an alternating e.m.f. is induced in the secondary coil.

Exam Tip

A: Only induced current flows in the secondary coil.

D: A steady current cannot induce an e.m.f. in the secondary coil as there is no change in the magnetic flux linkage.

STOP & THINK

[Q] A transformer consists of one coil with 1200 turns and a second coil, with a total of 120 turns, which can be tapped at various places.

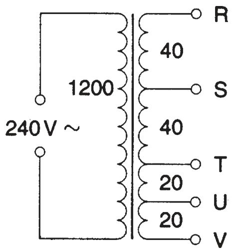
Which pair of terminals should be connected to a 12 V, 24 W lamp for it to be lit normally?

A RT

B RV

C SU

D TV



[Ans] **C** Since $\dfrac{N_s}{N_p} = \dfrac{V_s}{V_p}$, $N_s = \dfrac{12}{240} \times 1200 = 60$

The number of turns needed in the secondary coil is 60.

Exam Tip

The input voltage: 240 V. The output voltage: 12 V.

RT: 80 turns. RV: 120 turns. TV: 40 turns.

☑ The efficiency of a real transformer is always less than 100%.

Equation (less than 100% efficient)	$\text{efficiency} = \dfrac{\text{output power}}{\text{input power}} \times 100\% = \dfrac{V_s I_s}{V_p I_p} \times 100\%$

e.g. If a transformer is only 90% efficient, then $\dfrac{V_s I_s}{V_p I_p} = 0.9$.

☑ There are two reasons:

① Energy is lost in the form of heat in the primary and secondary coils, and in the soft iron core.

② There is leakage of magnetic field lines between the primary and the secondary coils.

☑ To increase the efficiency of a transformer:

① Use low-resistance (thicker) copper wire for primary and secondary coils so that the heating effect is reduced.

② Primary and secondary coils are wound on the same part of the soft iron core to reduce leakage of magnetic flux.

POWER TRANSMISSION

☑ A transformer is a useful electrical device that is essential for:

☐ Electrical power transmission from power station to the consuming loads (households and factories).

☐ Regulating voltages for proper operation of electrical appliances such as mains-operated television and record player.

☑ *Energy loss:*

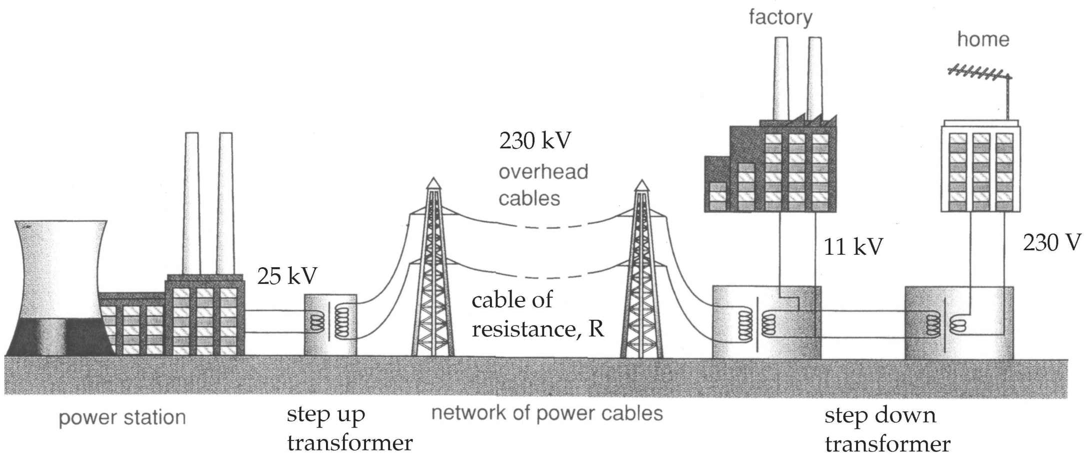
☐ Electrical energy generated in a power station is transmitted through long cables.

☐ Due to resistance in the cables, some energy is lost in the form of heat.

☐ To reduce power loss due to resistance, the output a.c. voltage from the generator in the power station is stepped up to a very high voltage (e.g. 230 kV) by a step-up transformer.

☐ The current in the cables is reduced and this reduces power loss.

☐ The high voltage is then stepped down to 230 V by a series of step-down transformer so that it is safe for consuming.



☑ ***Conclusion:***

☐ ***Advantage of using a.c.:***

The main advantage of using alternating current (a.c.) is that it can be stepped up and stepped down easily by transformers. This is not possible if using direct current (d.c.).

☐ ***Advantage of high voltage transmission:***

Using high voltage for power transmission reduces the power loss in the transmission cables.

☐ ***The power loss in the cables can be calculated using:***

Equation	$P = I^2R$	where P: power loss in the cables I: current in the cables R: resistance of the cables

STOP & THINK

[Q] Electrical energy is transmitted at high alternating voltages.

Which of the following is not a valid reason for doing this?

A At high voltage, a.c. is safer than d.c.

B For a given power, there is a lower current with a higher voltage.

C There is a smaller energy loss at higher voltage and lower current.

D The transmission lines can be thinner with a lower current.

[Ans] **A** At high voltages, both a.c. and d.c. cause electric shock. Both of them are dangerous.

ExamTip

The reason for using high voltage is to reduce power loss in the transmission cables by having a smaller current.

The reason for using a.c. is because it can be easily stepped up or stepped down by transformers.