Chapter 22 – Electromagnetic Induction

Content

- Principles of electromagnetic induction
- The a.c. generator
- Use of cathode-ray oscilloscope
- The transformer

Definitions

Term	Definition
Electromagnetic induction	Produce induced e.m.f. in conductor due to changing magnetic field
Transformer	Device that changes high alternating voltage (at low current) to low alternating voltage (at high current), or vice versa

Principles

Principle	Definition
Faraday's Law of electromagnetic induction	Magnitude of induced e.m.f. $\propto$ rate of change of magnetic flux
Lenz's Law of electromagnetic induction	Direction of induced e.m.f. (and hence direction of induced current in closed circuit) is such that its magnetic effect always opposes the change causing it
Fleming's right-hand rule	(determine direction of induced current in coil of a.c. generator)

Subject content:

Content

- Principles of electromagnetic induction
- The a.c. generator
- Use of cathode-ray oscilloscope
- The transformer

Learning outcomes

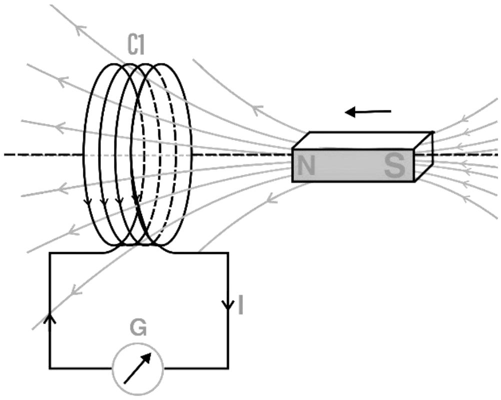
- deduce from Faraday's experiments on electromagnetic induction or other appropriate experiments:
  (i) that a changing magnetic field can induce an e.m.f. in a circuit
  (ii) that the direction of the induced e.m.f. opposes the change producing it
  (iii) the factors affecting the magnitude of the 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 use of a cathode-ray oscilloscope (c.r.o.) to display waveforms and to measure potential differences and short intervals of time (detailed circuits, structure and operation of the c.r.o. are not required)
- interpret c.r.o. displays of waveforms, potential differences and time intervals to solve related problems
- 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 an ideal transformer)
- describe the energy loss in cables and deduce the advantages of high-voltage transmission

22.1 Principles of electromagnetic induction

Faraday's law of electromagnetic induction

Magnitude of induced emf is directly proportional to rate at which magnetic field lines cuts wire (rate at which magnetic flux linking wire changes)

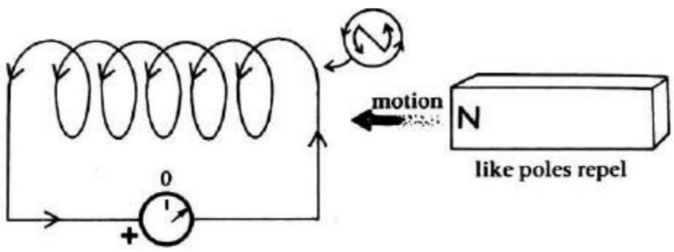
Relative movement b/w solenoid & magnet
→ change in no. of magnetic field lines linking coil of solenoid
→ induce e.m.f. → induced current in closed circuit

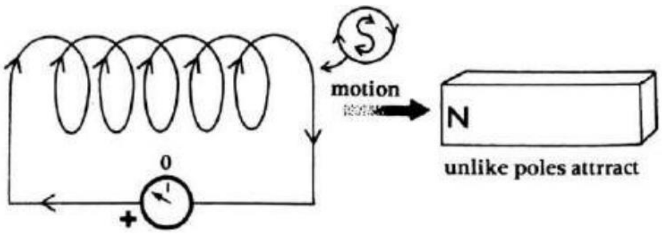


Increase magnitude of induced e.m.f.
1. no. of turns in solenoid
2. strength of magnet
3. speed of moving magnet with respect to solenoid

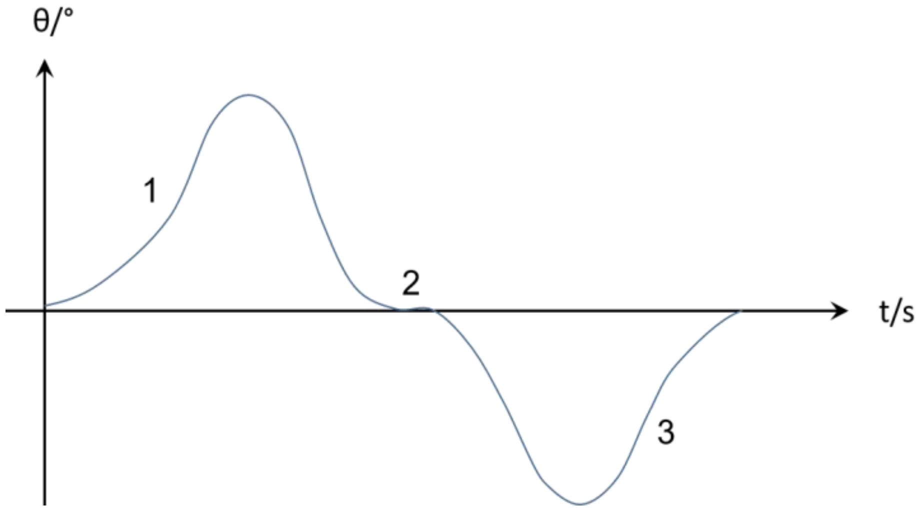
Lenz's law

Direction of induced e.m.f. (and hence direction of induced current) is such that its magnetic effect always opposes the change causing it





Graph of galvanometer needle deflection θ against time t

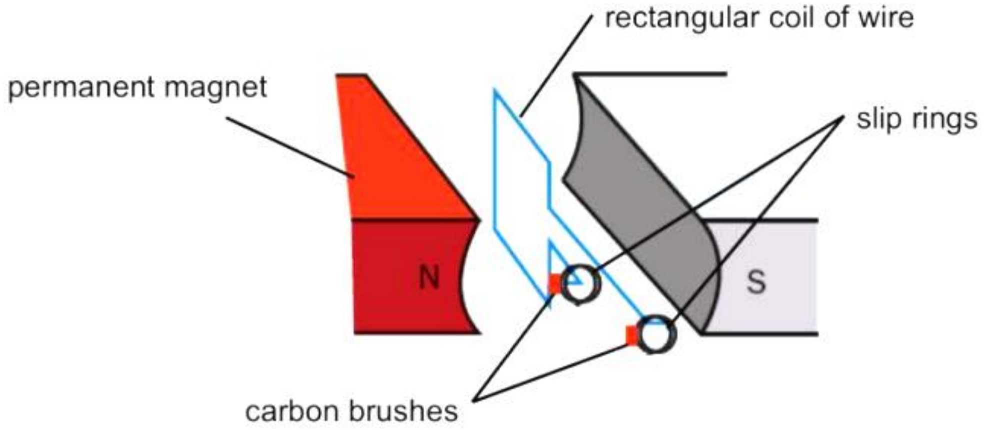


1	• **F:** <u>N-pole enter</u> → change in no. of magnetic field lines linking coils of solenoid (magnetic flux linkage increase) → induced e.m.f. → <u>induced current</u> • **L:** induced current induce <u>N-pole</u> at right end of solenoid to <u>oppose incoming N-pole</u> → galvanometer needle deflect momentarily to one side
2	• **F:** Magnet travel past <u>mid length point of solenoid</u> → no change in no. of magnetic field lines linking coils of solenoid (magnetic flux linkage is maximum, hence rate of change is now zero) → no induced e.m.f. → no induced current → no deflection
3	• **F:** <u>S-pole exit</u> → change in no. of magnetic field lines linking coils of solenoid (magnetic flux linkage decrease) → induced e.m.f. → <u>induced current</u> • **L:** induced current induce <u>N-pole</u> at left end of the solenoid to <u>oppose outgoing S-pole</u> → galvanometer needle deflect momentarily in opposite direction

22.2 Alternating current (a.c.) generator

Simple a.c. generator

Fixed magnet / rotating coil:



1. Rotate coil b/w two permanent magnets
2. Coil cut magnetic field lines of magnet continuously (magnetic flux linkage within coil change) → induced e.m.f. → induce current in coil
3. Slip rings: always in contact with carbon brush as coil rotate → induced current in coil transferred to external circuit
4. Induced current power electrical load connected to external circuit → lamp light up

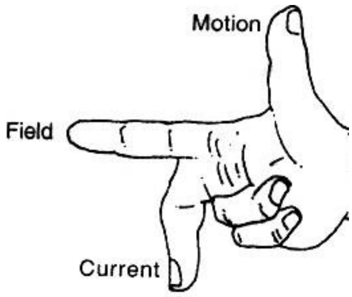
Slip rings: direct contact b/w coil & external circuit → induced current flow from coil into circuit (If a split ring commutator is used, reverse direction of output emf to the external circuit every half a cycle, d.c. output is obtained)

Diff in functions of parts in d.c. motor & a.c. generator

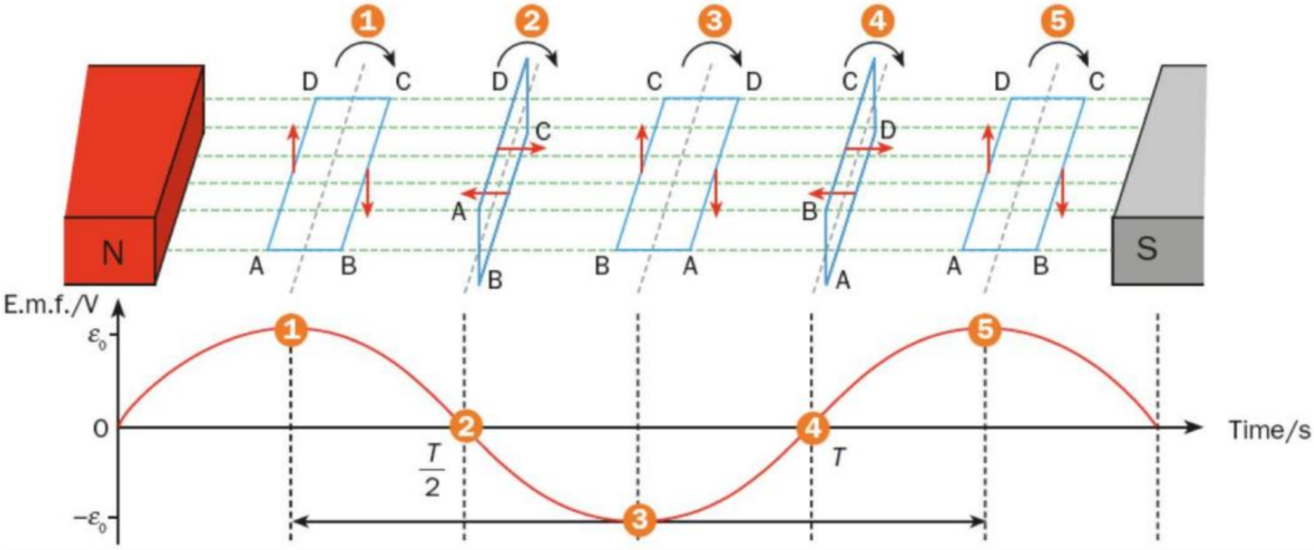
Part	d.c. motor	a.c. generator
Arm of coil (armature)	Rotate to convert electrical → kinetic energy	Rotate to convert kinetic → electrical energy
Magnets	Provide field → interaction with the field induced by current → produce force for turning effect on coil	Provide field → induce current in rotating coil
Coil	Carry supply current	Move in magnetic field to induce current
Split-ring commutator / slip rings	Change direction of supply current every half rotation → moment produced + coil rotate in same direction	Provide contact b/w rotating coil & external circuit → a.c. generated
Carbon brush	Provide connection: from supply current to coil	Provide connection: for output current

Fleming's right hand rule

- Thumb: force/motion
- Index finger: magnetic field
- Middle finger: current **(induced)**



Output voltage against time graph



one revolution

Increase magnitude of induced e.m.f.

1. Increase no. of turns in coil
2. Use stronger permanent magnets
3. Increase frequency of rotation of coil → shorten period
4. Wind coil around soft iron core to strengthen magnetic flux linking coil

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

Practical design

Fixed coil / rotating magnet:

<table>
<tr>
<td>
Bicycle dynamo
1. Wheel rotate → magnet rotate
2. Change in magnetic flux linking coil → induce e.m.f. → induce current
3. Induced current flow to external circuit

Advantages:
● Carbon brushes not required - wear out easily & need to replace frequently
● Less likely to break down from overheating - eroded connection b/w slip rings and carbon brushes has increased resistance, generate heat
● More compact - smaller in size
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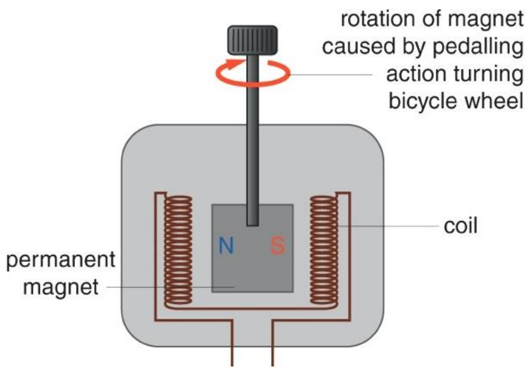

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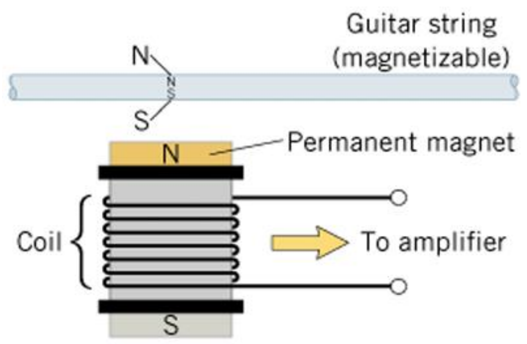
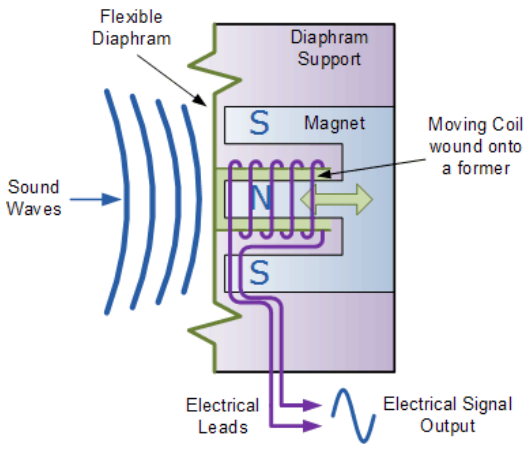
Electric guitar pickup
1. Steel guitar string magnetised by permanent magnet
2. String plucked → vibrate
3. Change magnetic flux linking coil → induce e.m.f. → induce current
4. Induce current fed to amplifier

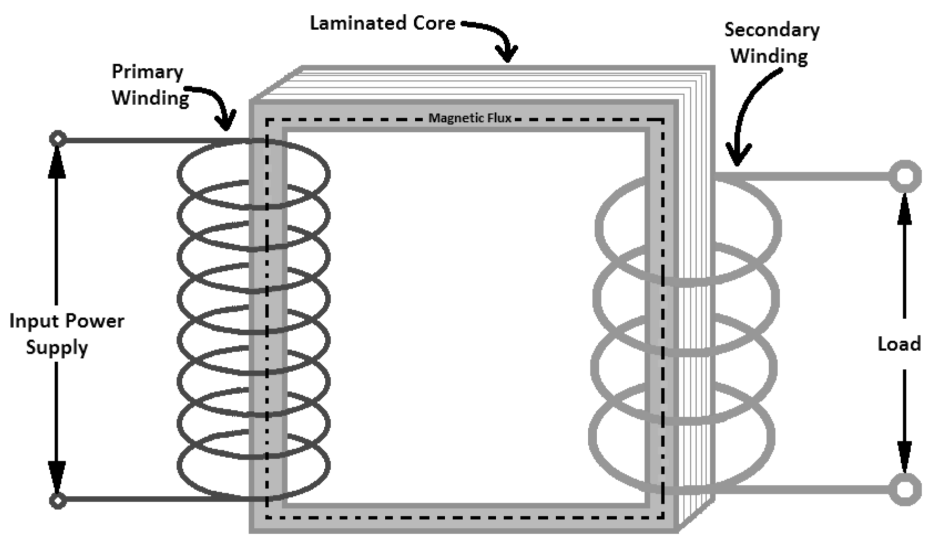


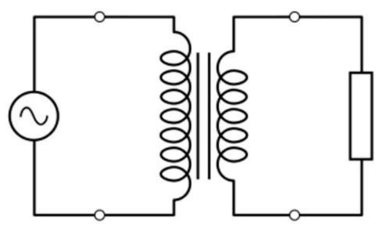
Microphone
1. Ssound wave strike diaphragm → coil vibrate
2. Change magnetic flux linking coil → induce e.m.f. → induce current
3. Induce current fed to amplifier, sent to speaker



22.3 Transformer

Transformer



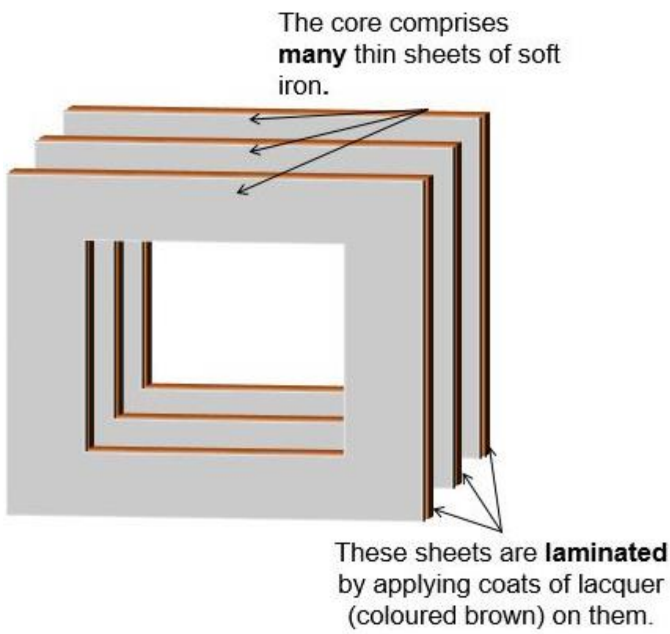


1. Alternating voltage in primary coil (**V**$_P$) sets up alternating magnetic field
2. Soft iron core concentrate magnetic field lines + link them to secondary coil

3. Alternating magnetic field lines in iron core cut/link secondary coil continuously → induce alternating emf across secondary coil (**V_S**)

Transformer core

Feature	Explanation
1. **Soft iron**	Soft magnetic material - easily magnetised and demagnetised - do not retain magnetism
2. **Laminated thin sheets**	Reduce eddy currents from flowing in core → less heat generated → reduce thermal energy loss from iron core to surroundings

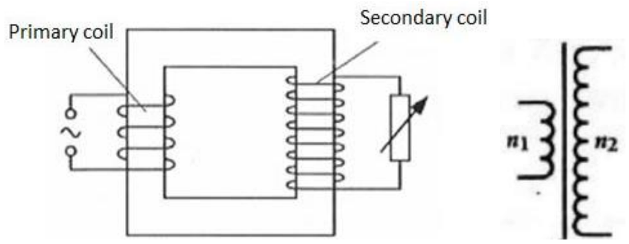
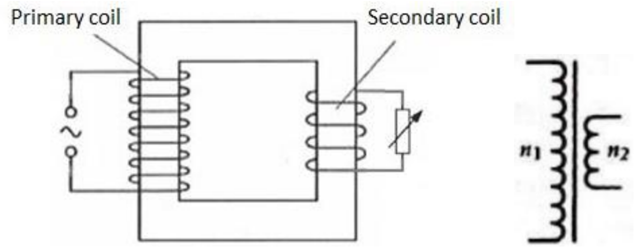


Turn ratio:
Assuming 100% magnetic flux linkage b/w primary & secondary coil,

$$\boxed{\frac{V_S}{V_P} = \frac{N_S}{N_P}}$$

where N_S = no. of turns in secondary coil
N_P = no. of turns in primary coil
V_S = secondary voltage
V_P = primary voltage

Types:

Step up transformer	Step down transformer
	
$N_S > N_P$	$N_S < N_P$
$V_S > V_P$	$V_S < V_P$
$I_S < I_P$	$I_S > I_P$

Power transmission

Ideal transformer: no power loss (100% efficiency)

$$P_{in} = P_{out}$$
$$V_S I_S = V_P I_P$$

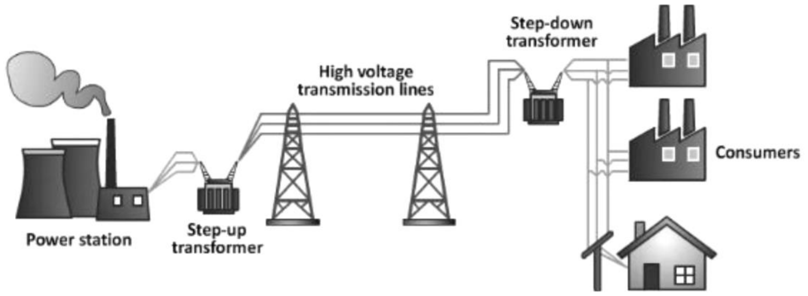
where V_S = secondary voltage

V_P = primary voltage

I_S = current in secondary coil

I_P = current in primary coil

Use: Transmission of electricity



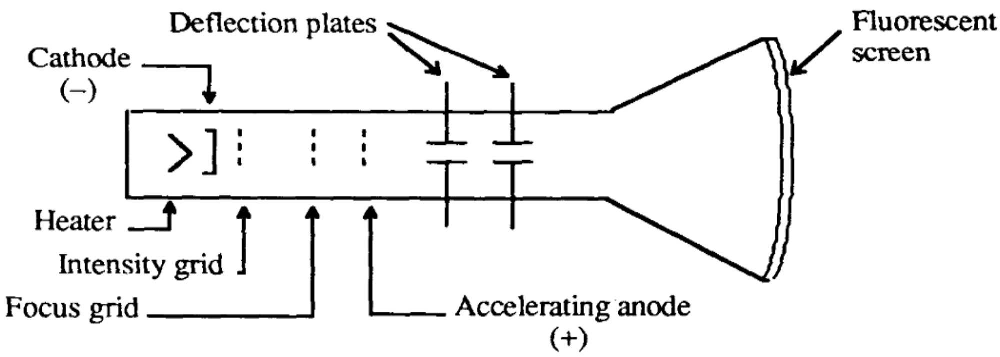
Transformer	Function
Step up	Step up voltage from power station for transmission across long distances → lower current → lower power loss ($P = I^2R$)
Step down	Step down voltage for consumer use / household consumption (e.g. 240 V)

Use: Regulate voltage for electrical appliances

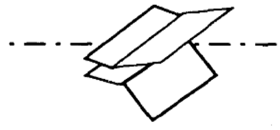
Transformer	Function
Step down	Step down voltage to suitable operating voltage for appliance

22.4 Cathode-ray oscilloscope (c.r.o.)

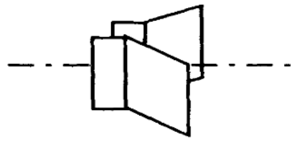
Cathode-ray tube:



Y-plates:



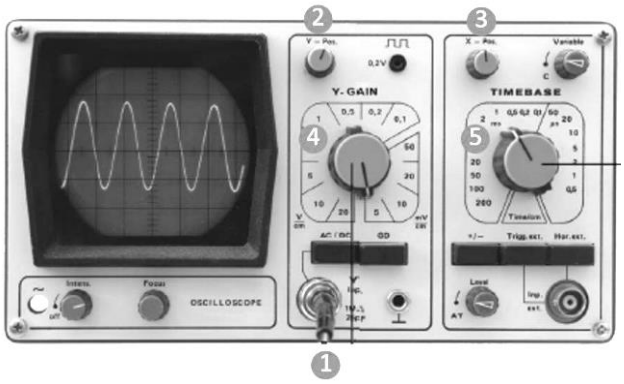
X-plates:



Feature	Description
cathode	High voltage → high temp → produce beam of electrons
electron gun	Emit electron beam
deflecting system	Vary voltage across **<u>Y-plates</u>**: change vertical deflection Vary voltage across **<u>X-plates</u>**: change horizontal deflection
fluorescent screen	Coated with zinc sulfide – glow when electrons strike More electrons strike screen, spot brighter

<u>Diagram</u>

1. Input voltage
2. Y-shift or Y-offset – shifts entire trace **vertically** up or down
3. X-shift – shifts entire trace **horizontally** left or right
4. Y-gain control – amplifies height of electron beam
5. Time base control – controls speed at which electron beam sweeps across the screen



Y gain (V/div on y-axis)

- Determine height of trace

Time base (ms/div on x-axis)

- Vary voltage connected to X-deflection plates

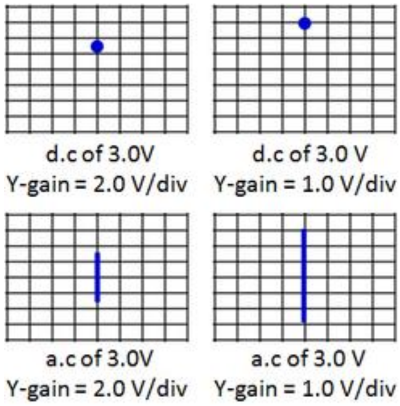
Time base frequency (Hz)

- No. of times the spot travels across screen from left to right in one second
- e.g. timebase frequency 25 Hz: spot sweep across screen 25 times in 1 second

No. of cycles = $\dfrac{frequency\ of\ a.c.input}{frequency\ of\ time\ base}$

Common uses

1. **Measure voltage**

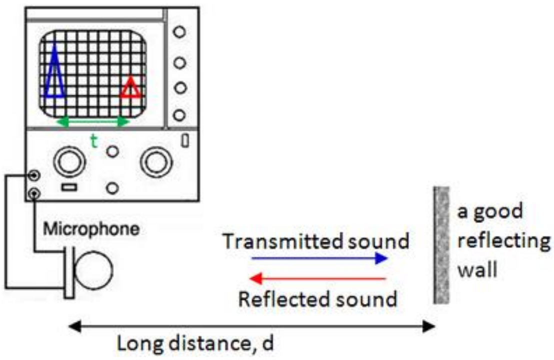


- used as voltmeter when time base is off
- Voltage to be measured: applied to Y-plates → electric field set up b/w Y-plates → electron beam sweep towards positively charged Y-plate → deflection of electron beam by electric field ∝ voltage applied
- adjust Y-gain: magnify height of trace → easily read off magnitude

2. **Display voltage waveforms**

	Time base	
	off	on
d.c.		
a.c.		

3. **Measure short time interval**



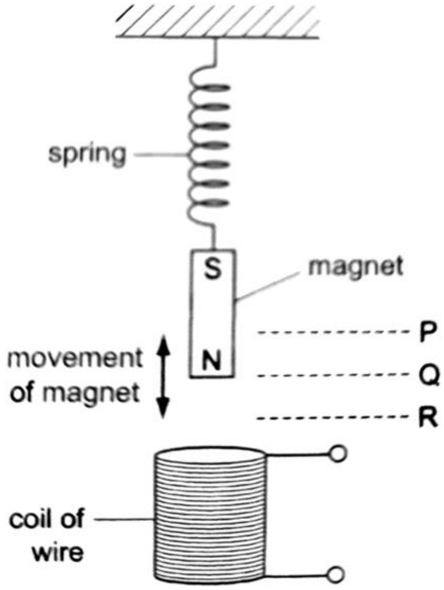
1) Microphone receive pulse of sound (1st pulse)
2) Pulse reflected by wall, received again by microphone (2nd pulse)
3) Distance t b/w two pulses = time taken for sound to travel from microphone to wall and back
4) Speed of sound = 2d / t

Note: height of second pulse is smaller than first pulse because some energy is lost to the medium and reflecting wall

Typical questions

Multiple-choice questions

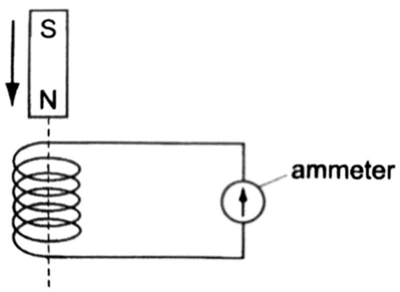
1 A magnet moves up and down above a coil of wire.



The bottom of the magnet moves up and down between P and R.
Where is the bottom of the magnet when there is no induced electromotive force (e.m.f.) in the coil? (2011 P1 Q36)

A at P and at Q
B <u>at P and at R</u>
C at Q only
D at R only

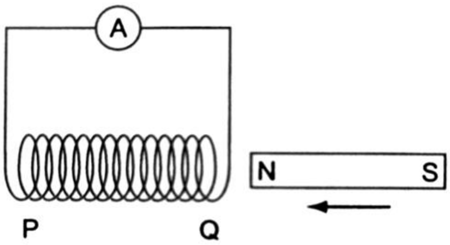
2 A small vertical coil is connected to a sensitive ammeter. The ammeter needle can move to either side of the zero position.
As a magnet falls towards the coil, the ammeter needle moves quickly to the right.



The magnet falls through the coil.
How does the ammeter needle move as the magnet falls away from the coil? (2012 P1 Q38)

A It gives a steady reading to the left of the zero position.
B It gives a steady reading to the right of the zero position.
C <u>It moves quickly to the left of the zero position and then returns to zero.</u>
D It moves quickly to the right of the zero position and then returns to zero.

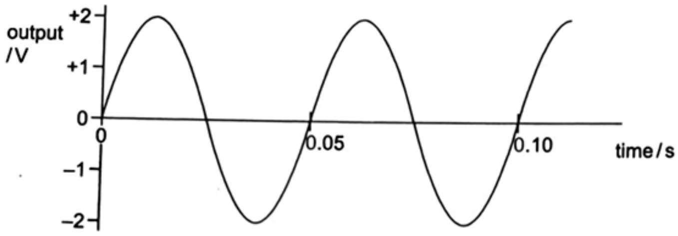
3 A student pushes the N-pole of a bar magnet into end Q of a long solenoid and observes a deflection to the right on the centre-zero ammeter.



What produces a deflection in the same direction? (2014 P1 Q37)

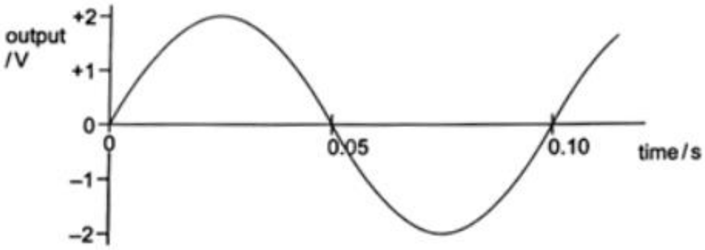
- **A** pulling the N-pole out of end Q
- **B** pulling the S-pole out of end P
- **C** pushing the N-pole into end P
- **D** <u>pushing the S-pole into end P</u>

4 The graph shows the output of an a.c. generator. The coil in the generator rotates 20 times in one second.

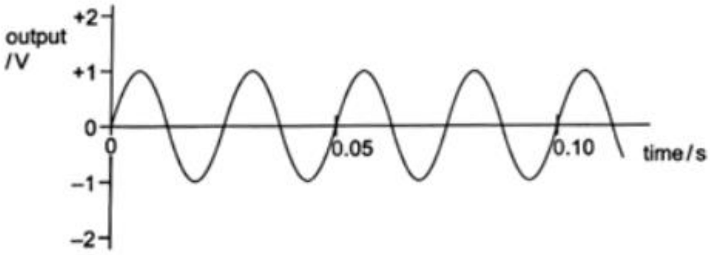


Which graph shows the output when the coil rotates 10 times in one second? (2014 P1 Q38)

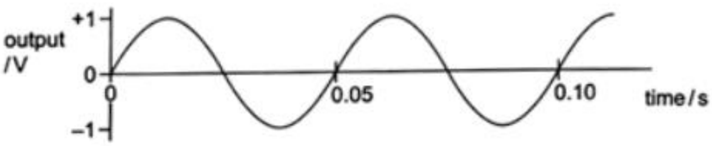
A



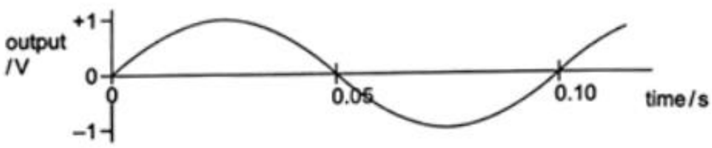
B



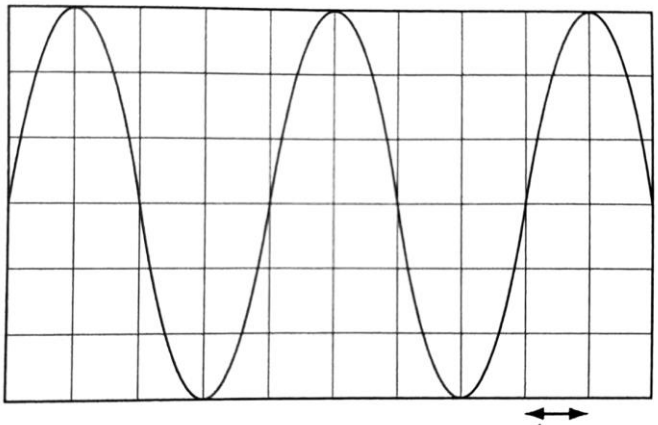
C



D



5 An alternating supply with a period of 0.020s is connected to a cathode-ray oscilloscope (c.r.o.).



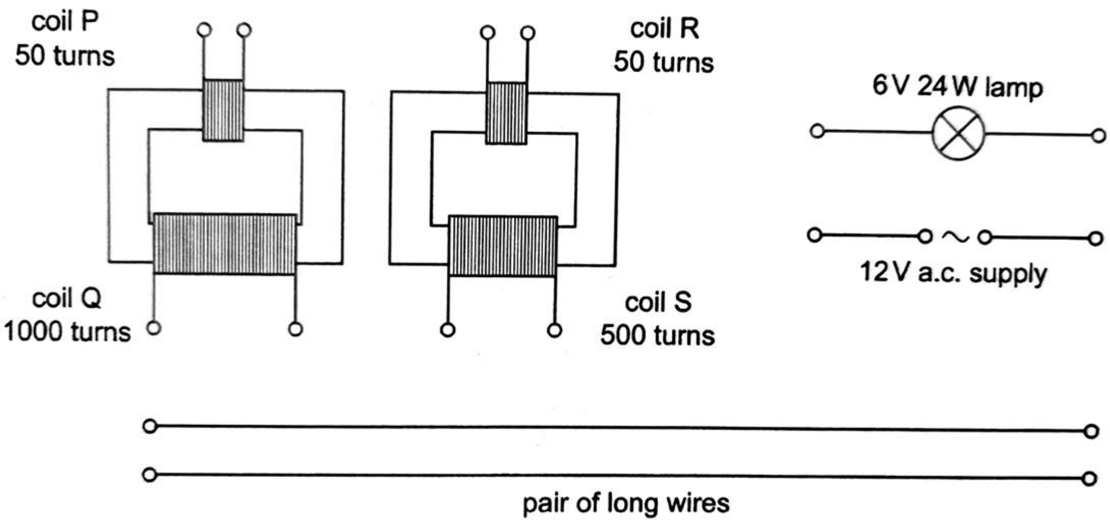
What is the time-base setting of the c.r.o.? (2015 P1 Q40)

A 0.2 ms/cm
B 0.5 ms/cm
C 2 ms/cm
D 5 ms/cm

6 Why is a high voltage used to transmit electrical energy along cables from a power station? (2017 P1 Q40)

A It makes the current in the cables greater.
B It reduces the resistance of the cables.
C Less thermal energy is produced in the cables.
D No energy is lost in the transformers at the ends of the cables.

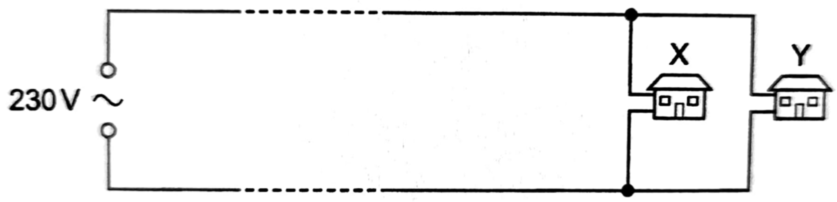
7 A demonstration power line is to be set up from the following equipment: a 12V a.c. supply, a pair of long wires for the power line, a 6V 24W lamp and two transformers.
One transformer has a coil P with 50 turns and a coil Q with 1000 turns.
The other transformer has coil R with 50 turns and a coil S with 500 turns.



Which arrangement gives a satisfactory demonstration in which the lamp lights at normal brightness? (2011 P1 Q37)

	coil attached to a.c. supply	coils attached to the power line	coil attached to lamp
A	P	Q and R	S
B	P	Q and S	R
C	R	S and P	Q
<u>**D**</u>	<u>R</u>	<u>S and Q</u>	<u>P</u>

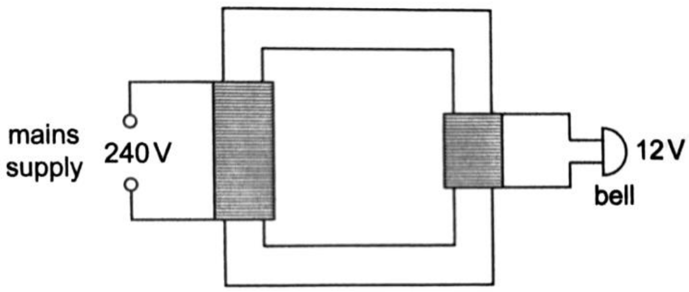
8 The diagram shows a long transmission line supplying energy at 230V to two houses X and Y without using transformers. In both houses, electric heaters are switched on.



The occupier of house X switches off the heaters in his house.
What happens in house Y? (2013 P1 Q40)

- **A** There is a fall in the voltage supplied and in the power used.
- **B** There is a fall in the voltage supplied but no change in the power used.
- **C** <u>There is a rise in the voltage supplied and in the power used.</u>
- **D** There is a rise in the voltage supplied but no change in the power used.

9 The diagram shows an ideal transformer operating a door bell. The mains supply of 240V is connected to the transformer.



The bell has a resistance of 8.0Ω and the output voltage from the transformer is 12V.
What is the current in the mains supply? (2015 P1 Q39)

- **A** <u>0.075 A</u>
- **B** 0.40 A
- **C** 1.5 A
- **D** 30 A

10 Which statement about a transformer is correct? (2016 P1 Q39)

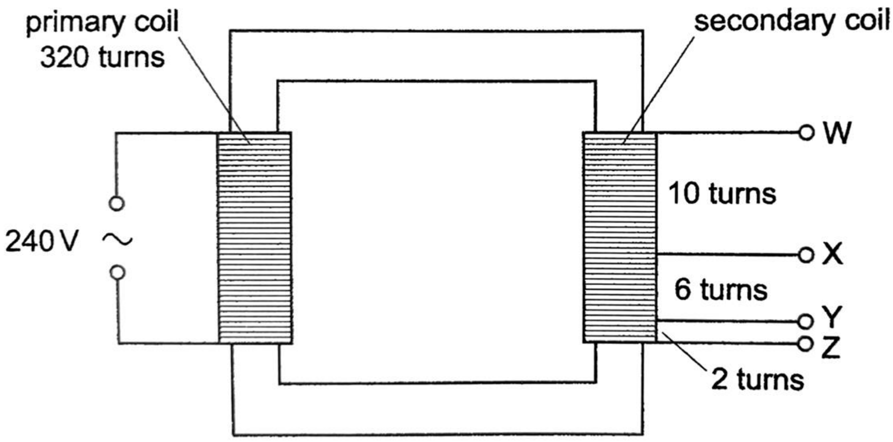
- **A** The core of the transformer is made of iron because iron is a good electrical conductor.

B <u>The direction of the induced e.m.f. in the secondary coil opposes the change that produces it.</u>
C The transformer converts alternating current to direct current.
D The transformer converts direct current to alternating current.

11 An imported device is designed to operate when connected to a 110V mains supply. When connected to a transformer, the current in the device is 19A and it operates normally.
The transformer is connected to the 240V mains supply and it has an efficiency of 100%.
What is the input current to the transformer? (2017 P1 Q37)

A <u>8.7 A</u>
B 13 A
C 19 A
D 41 A

12 The diagram shows an ideal transformer.



There are 320 turns on the primary coil. There are 18 turns on the secondary coil between terminal W and terminal Z. There are also two other terminals X and Y between terminals W and Z.
A 12V, 24W lamp is connected to two terminals of the secondary coil.
The lamp lights at normal brightness.
Between which terminals is the lamp connected? (2018 P1 Q39)

A W and X
B <u>W and Y</u>
C W and Z
D X and Z

13 A transmission cable delivers a constant power over a long distance. Transformers are used to increase the voltage at one end and to decrease the voltage to 240V at the other end.
Why is the voltage increased before transmission? (2018 P1 Q40)

A to increase the current in the cable
B to increase the frequency of the voltage supply
C to reduce the energy loss in the cable
D to reduce the resistance of the cable

14 Which material is used for the core of a transformer and what is the reason? (2019 P1 Q39)

	material	reason
A	copper	good conductor of electricity
B	copper	easy to magnetise and demagnetise
C	iron	good conductor of electricity
D	iron	easy to magnetise and demagnetise

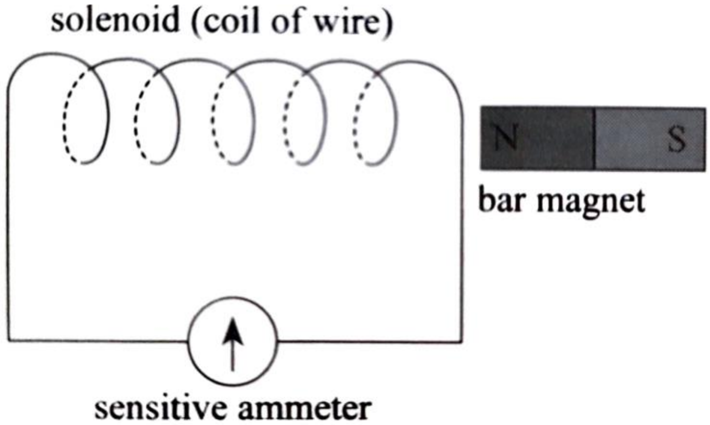
15 Electric power cables transmit electrical energy over large distances using high-voltage, alternating current.
What are the advantages of using a high voltage and of using an alternating current?
(2019 P1 Q40)

	advantage of using a high voltage	advantage of using an alternating current
A	high current is produced in cables	resistance of cables is reduced
B	high current is produced in cables	voltage can be changed using transformer
C	less energy is wasted in cables	resistance of cables is reduced
D	less energy is wasted in cables	voltage can be changed using transformer

Structured questions

1 Electromagnetic induction can be demonstrated using a bar magnet, a coil of wire, a sensitive ammeter and connecting wires. (2013 P2A Q9)

(a) In the space below, draw a labelled diagram showing how this apparatus is used to demonstrate electromagnetic induction. [1]



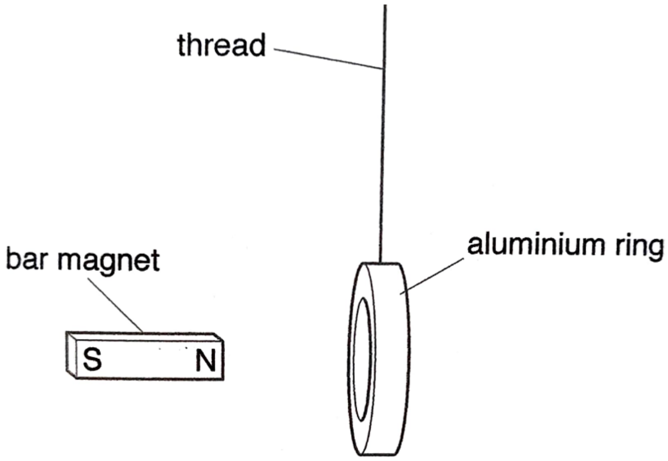
(b) Describe how the apparatus is used to produce an induced current. [1]

When the bar magnet is pushed towards and into the coil of wire quickly, an induced current is produced in the circuit.

(c) Explain why a current is induced in your experiment. [2]

- When the bar magnet is pushed towards and into the coil of wire quickly, there is a change in magnetic flux linkage between the bar magnet and the coil of wire.
- By Faraday's law of electromagnetic induction, an induced current is produced in the coil, thus causing an induced current to flow in the circuit. (The induced current flows in such a way that creates an induced magnet to oppose the change.)

2 The figure below shows an aluminium ring suspended by a thread, close to a bar magnet.



When the N-pole of the bar magnet is moved quickly towards the aluminium ring, there is an induced current in the ring and the ring moves away from the bar magnet. (2017 P2A Q8)

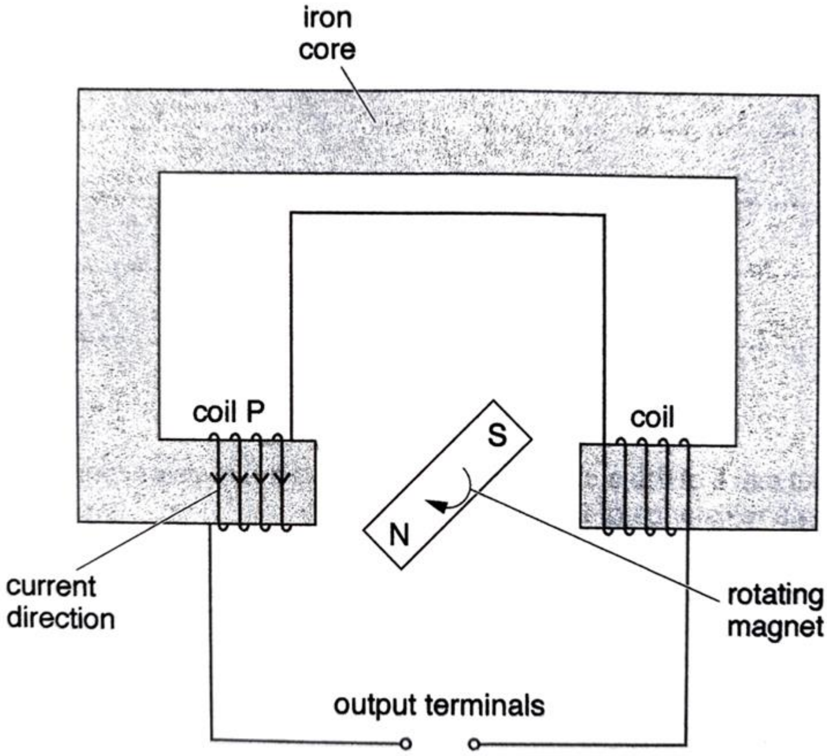
(a) Explain why a current is induced in the aluminium ring. [2]

- There is a change in magnetic flux linkage (changing magnetic field) between the magnet and the aluminium ring.
- By Faraday's law of electromagnetic induction, an e.m.f. is induced, which causes an induced current to flow in the ring.

(b) Explain why the aluminium ring moves away from the magnet. [2]

- By Lenz's law, the induced current causes a magnetic effect that opposes the change causing it.
- A N-pole is induced on the left side of the ring, to oppose the incoming N-pole of the bar magnet.

3 One type of a.c. generator uses a rotating magnet and two fixed coils wound on an iron core, as shown in the figure below.



(2015 P2B Q11 OR)

(a) When the magnet rotates, an electromotive force (e.m.f.) is induced in the coils.

(i) Explain why an e.m.f. is induced. [1]

- As the magnet is rotated, there is a change in the magnetic flux linkage between the magnetic field and the coil.
- By Faraday's law of electromagnetic induction, an e.m.f. is induced.

(ii) Suggest one reason for using an iron core in the a.c. generator. [1]

The iron core helps concentrate magnetic field lines, which allows for better flux linkage with the coils.

(b) The output terminals are connected to a resistor and there is a current in the coil as the magnet turns.

(i) When the N-pole of the magnet approaches coil P in the figure, the direction of the current in coil P is shown by the arrows.
Explain why the current is in the direction shown. [2]

- Lenz's law states that the induced current flows in a direction to oppose the change that causes it.
- When the current in coil P is in the direction as shown, applying right-hand grip rule, a N-pole is induced at the end of coil nearest to approaching N-pole of magnet. This induced N-pole repels the approaching N-pole.

(ii) The maximum output e.m.f. of the a.c. generator is 20 V and the resistor connected to the output terminals has a resistance of 2.5 kΩ.
Calculate the maximum power produced in the resistor. [3]

$I = V / R = 20 / 2500 = 0.008$ A
$P = I^2R = (0.008)^2(2500) = 0.16$ W

4 Fig 1 below shows the structure of an a.c. generator. The coil turns at a constant speed.

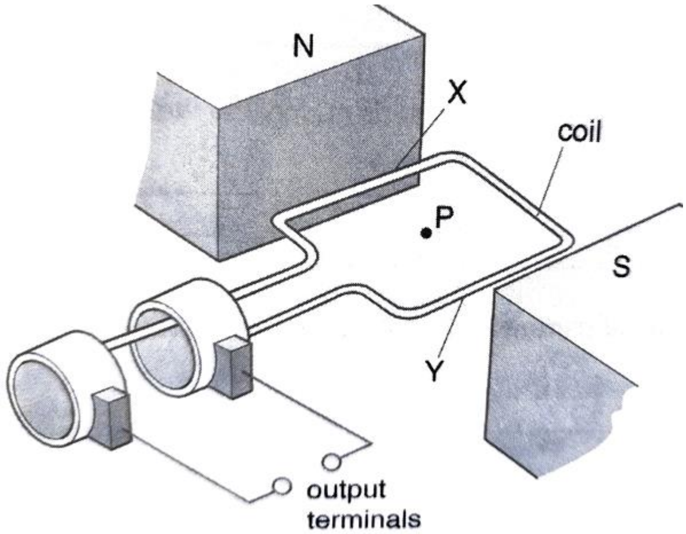


Fig 1

(2018 P2A Q7)

(a) On the figure above, draw an arrow to show the direction of the magnetic field at point P caused by the poles of the magnet. [1]

(b) Fig 2 shows how the output voltage of the generator varies with time.

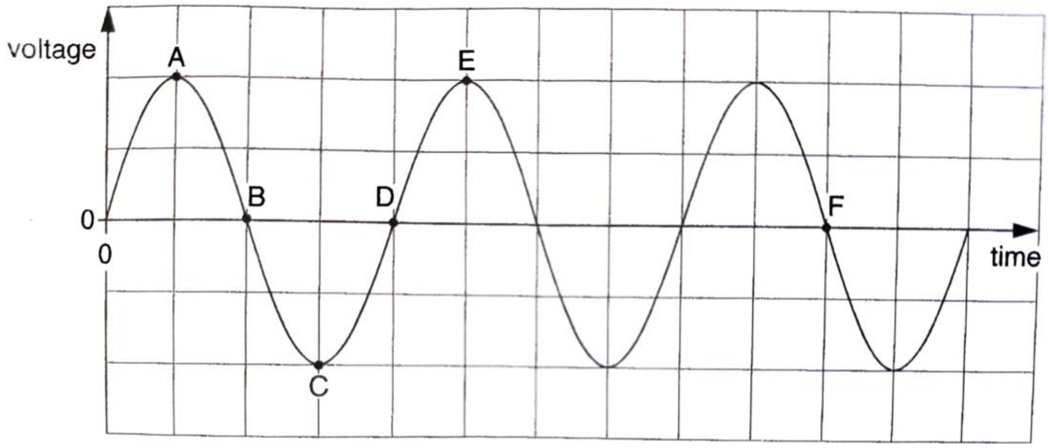


Fig 2

Fig 1 shows the coil is horizontal with side X near the N-pole of the magnet. At this position, the voltage produced is shown as point A on Fig 2.

(i) Explain why an output voltage is produced. [2]

- As the coil rotates, there is a change in magnetic flux linkage between the magnetic field and coil.
- By Faraday's law of electromagnetic induction, an e.m.f. (output voltage) is induced.

(ii) State which point on Fig 2 shows the voltage when the coil is horizontal, with side X near the S-pole of the magnet. [1]

C

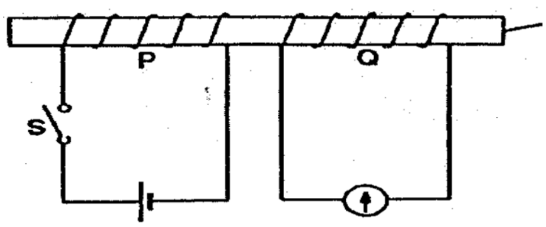
(iii) Describe the position of the coil that produces the voltage shown as point F on Fig 2. [1]

The coil is in a vertical position, where the coil is perpendicular to direction of magnetic field.

(c) Describe how an output current from the a.c. generator is different from a current produced by a battery. [1]

- The output current from an a.c. generator changes direction according to the frequency of the rotation of the coil.
- The current produced by a battery flows from the positive to the negative terminal of the battery.

5 The diagram below shows two coils of copper wire wound on a hollow cardboard. Each coil can slide easily on the rod. Coil P is connected in series to a battery and a switch S. Coil Q is connected to a galvanometer. As S is closed, a deflection is seen on the galvanometer for a short time.



(a) Explain briefly why there is a deflection on the galvanometer.

The current that starts flowing in P produces a magnetic field which increases from zero to a maximum value very quickly. The changing magnetic field lines cut coil Q and induces an emf and hence current in Q (causing galvanometer to deflect to one side momentarily).

(b) State what you observed in the coils of copper wire.

The coils slide apart a little.

(c) Explain your observation in **(b)**.

The direction of the induced current in Q will be such that its magnetic effect will oppose the change causing it. Since the right side of P is a south pole, the left side of Q will have an induced south pole to repel P.

(d) State and explain what you would expect to observed when the switch is left on.

No deflection is observed.
When the switch is left on, the current and hence the magnetic field in P will remain constant. The magnetic field linked to Q is unchanged hence there is no induced e.m.f.

(e) State and explain what you would expect to observe as S is opened.

The galvanometer deflects in the opposite direction. The coils slide towards each other.
When S is opened, the magnetic field in P decreases from its maximum value to zero. The changing magnetic field lines cut Q and this induces a current in Q that will flow in a direction such that a north pole is induced at the left end of Q. Since unlike poles attract, the coils slide towards each other.

(f) Explain what effect, if any, there would be on the deflection in **(a)** if the coils are moved closer.

The rate of change of magnetic lines that are linked to Q increases when coils are closer. Hence, a larger / faster deflection (in the opposite direction to (e)) will be observed.

(g) What would be the effect on the change you have described in part (a) if the hollow cardboard was removed and replaced with an iron rod?

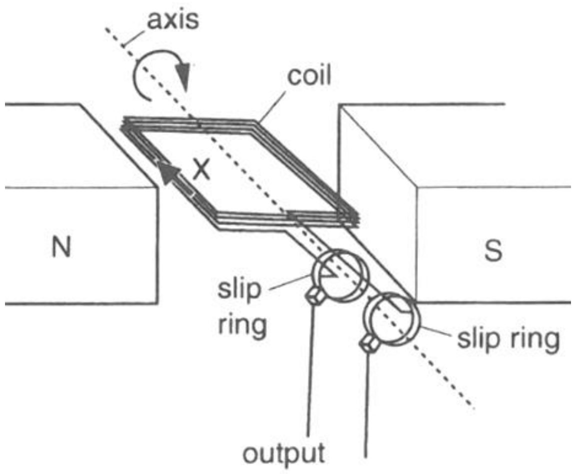
The deflection will be larger.

The iron rod concentrates the magnetic field lines in P and linked them to Q. Hence the rate of change of the magnetic field lines linked to Q will be larger when the switch is opened or closed.

(h) What would you expect to happen if the d.c voltage source connected to A was replaced by a 5Hz alternating voltage source?

The deflection changes direction 10 times per second continuously.

6 The figure below shows the structure of a simple a.c. generator.

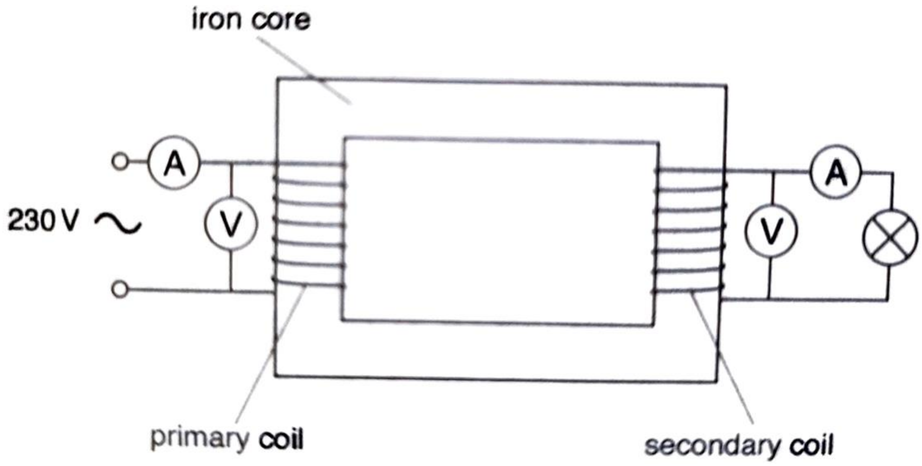


A resistor is connected to the output. On the figure above, an arrow indicates the direction of the current at point X. Explain how a current in this direction opposes the rotation of coil. [3]

(2011 P2A Q8)

- As coil rotates clockwise, arm of coil at X moves upwards.
- Current in X produces downward force
- due to interaction of two magnetic fields (from permanent magnet & current at X) OR predicted using FLH rule.

7 The figure below represents the basic structure of a transformer.



An alternating voltage of 230V is applied to the primary coil and a voltage is induced in the secondary coil. The secondary coil is connected to a lamp. (2016 P2B Q11)

(a) **(i)** Describe what is meant by an *alternating voltage*. [1]

An input voltage that is sinusoidal with a maximum of 230V and minimum of –230V.

(ii) State how the magnetic field in the iron core induces a voltage in the secondary coil. [1]

- Due to the alternating voltage, and hence alternating current, there is a changing magnetic field around the primary coil, and this is concentrated in the iron core.
- By Faraday's law of electromagnetic induction, the change in flux linkage induces a voltage (e.m.f.).

(iii) State the purpose of the iron core. [1]

Concentrate magnetic field lines to improve magnetic flux linkage between primary and secondary coil

(b) The primary coil has 480 turns.
Calculate the smallest number of complete turns in the secondary coil that would give an induced voltage of at least 8.0V in the secondary coil. [2]

$N_P/N_S = V_P/V_S$
$480/N_S = 230/8.0$
NS = 16.7

Minimum number of turns is 17.

(c) A student determines the input and output power of the transformer and calculates the efficiency of the transformer.

(i) The student uses voltmeters and ammeters that measure alternating voltages and currents. On the figure above, draw two voltmeters and two ammeters that enable the input power and the output power of the transformer to be determined. [2]

(ii) State what is meant by *efficiency*. [1]

Efficiency is the ratio of the useful output energy, compared to the energy input.

(iii) The current in the primary coil is 0.022A. The current in the secondary coil is 0.50A and the output voltage of the transformer is 8.0V.
Calculate the efficiency of the transformer. [2]

P_{in} = VI = (230)(0.022) = 5.06 W
P_{out} = VI = (8.0)(0.50) = 4.0 W
Efficiency = 4.0/5.06 x 100% = 79.0%