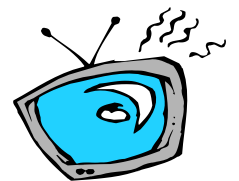


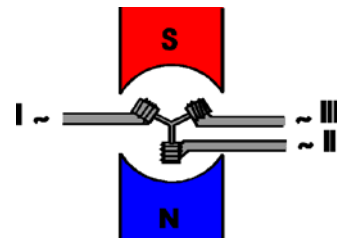
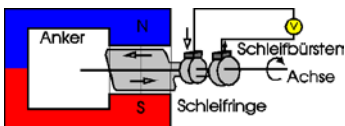
VCE - PHYSICS

UNIT 4



TOPIC 1

ELECTRIC POWER



TOPIC NOTES

Unit Outline

This unit covers the following areas:

1. Apply a field model to magnetic phenomena including shapes and directions produced by bar magnets and by currents in wires, coils and solenoids
2. Quantify magnetic forces on current carrying wires using $F = I\ell B$, where the direction of I and B are either perpendicular to, or parallel to, each other.
3. Describe the operation of simple DC motors.
4. Apply a field model to define magnetic flux Φ using $\Phi = BA$ and the qualitative effect of differing angles between the coil and the field.
5. Explain the generation of voltage, including AC voltage, in terms of rate of change of magnetic flux (Faraday's Law) the direction of the induced current (Lenz's Law) and the number of loops through which the flux passes including calculations using induced $\mathcal{E} = -N d\Phi/dt$
6. Describe the production of Voltage in generators and AC voltages in alternators including in the use of commutators and slip rings
7. Compare sinusoidal AC voltages produced as a result of uniform rotation of a loop in a constant magnetic flux in terms of frequency, period, amplitude, peak to peak voltage and peak to peak current.
8. Use RMS values for a sinusoidal AC voltage $V_{RMS} = V_p/\sqrt{2}$ and $I_{RMS} = I_p/\sqrt{2}$ and interpret RMS in terms of the DC supply that provides the same power as an AC supply
9. Compare and contrast DC motors generators and alternators
10. Explain transformer action modelled in terms of electromagnetic induction for an ideal transformer qualitatively and using the number of turns in the primary and secondary coils voltage and current
11. Model mathematically power supplied as $P = VI$ and transmission losses using voltage drop $V = IR$ and power loss $p = I^2R$
12. Explain the use of transformers in an electricity distribution system.
13. Use safe and responsible practices when working with electricity and electrical measurement

Chapter 1

1.0 Magnetic Fields

All magnets have poles labelled as North and South:

Like poles _____

Unlike poles _____

Magnets generate _____ in the space surrounding them.

The concept of "a field" is an important concept in our study of Physics.

A Field is defined as a "region of _____".

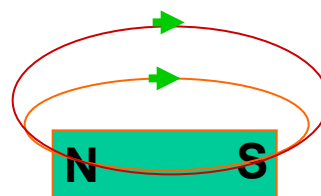
In a Magnetic Field, magnetically susceptible materials are subject to an influence.

They will experience a _____ when placed in the field.

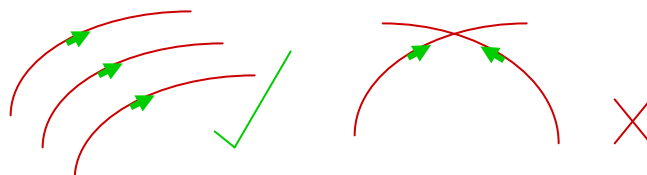
The _____ of the magnetic field is determined by the size of the force experienced by a Unit North Pole* placed at the point of interest.

*Does not yet exist, but physicists hope to produce one soon.

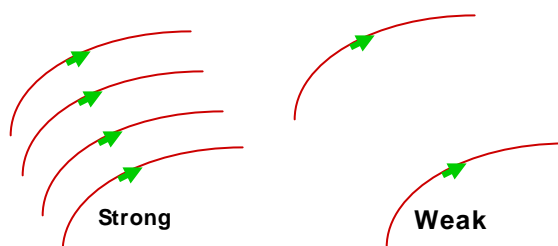
1. Field Lines form _____ Loops



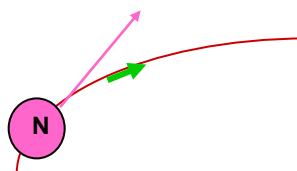
2. Field Lines NEVER _____



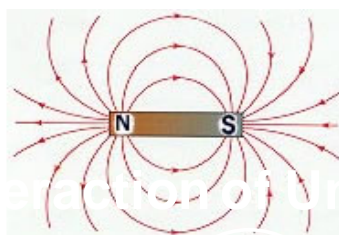
3. Spacing between Field Lines indicates Field _____



4. Direction of Field = Direction of Force on the Unit North Pole



1.1 **Magnetic Fields around Permanent Magnets**



The Arrow Convention



Out of Page



Into Page

Questions

Question 1

The left side of Figure 6 shows three sources of magnetic fields. The right side of Figure 6 shows three possible magnetic field patterns of the shaded planes.

For each of the three sources, draw a line linking the source to the magnetic field pattern it produces in the shaded region.

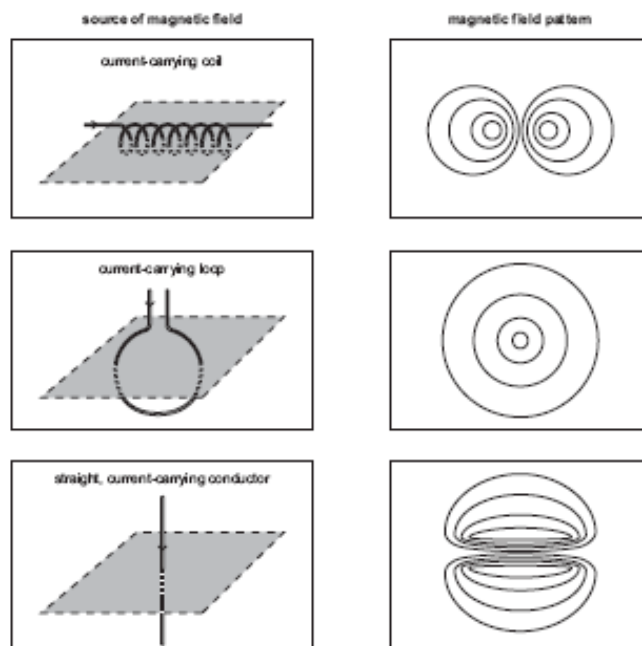
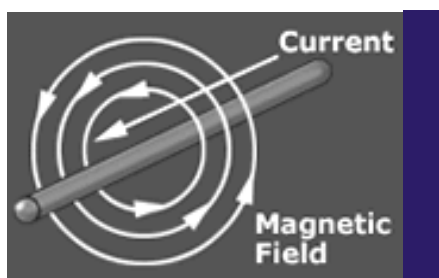


Figure 6

1.2 Magnetic Field around A Current Carrying Wire

Any wire carrying an Electric Current has a Magnetic Field around it



The direction of the Magnetic Field can be determined using the:

“Right Hand _____ Rule”

The _____ points in direction of CONVENTIONAL CURRENT

The _____ CURL in direction of MAGNETIC FIELD

Questions

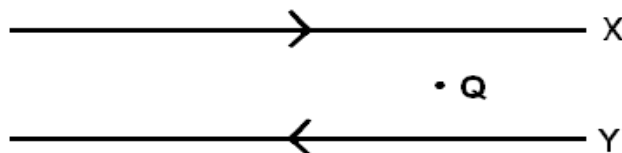
Question 2:

Draw the lines representing the magnetic field resulting from the straight current-carrying conductor in the figure below. A cross-section of the conductor is shown with the current direction indicated by a dot. You should show give an indication of field shape, direction & relative field strength.



Question 3:

Two wires carry current in opposite directions as shown in the diagram below. The current in wire Y is twice the current in wire X. Point Q is midway between wires X and Y.



Which of the following best describes the direction of the resultant magnetic field at point Q

Use the following key for your answers:

- A. To the right
- B. To the left
- C. Up
- D. Down
- E. Into the page
- F. Out of the Page
- G. Zero

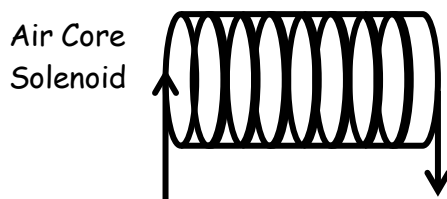
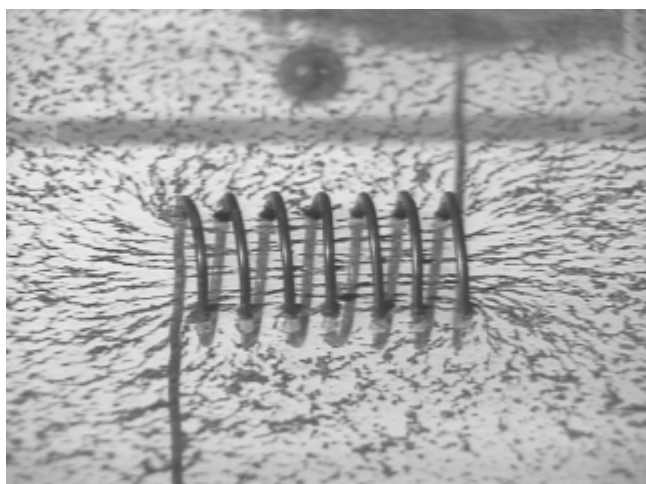
Question 4:

The current in wire X is reversed. Both conductors now have current passing from right to left. Which alternative would now represent the resultant magnetic field?

1.3 Magnetic Fields around Solenoids

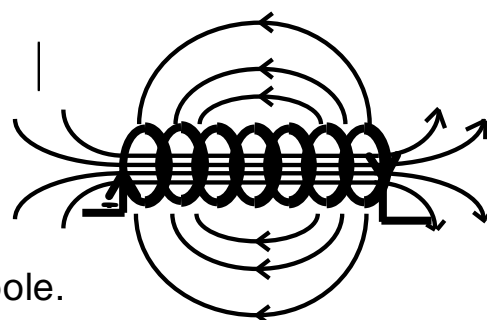
A _____ is, by definition, a series of loops of wire placed side by side to form a coil. In reality, solenoids are produced by winding a single piece of wire around a cylindrical “former”. When a _____ flows through the wire, a strong, uniform _____ field is produced down the centre of the cylinder.

The strength of this central magnetic field can be increased by filling the space in the centre of the cylinder with magnetically susceptible material, eg. Soft iron
The solenoid remains a magnet while the current continues to flow. This is a so called _____



1.4 The North Pole of a Solenoid

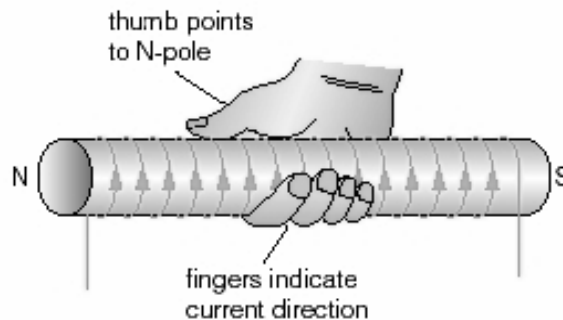
Electromagnets generate magnetic fields.
Magnetic fields have of a North and South pole.
So an electromagnet must have a North and a South pole.
How do you determine which end of the electromagnet is North ?



It's easy using a modified version of the Right Hand Grip Rule
In this form the rule is:

_____ CURL in the direction of the

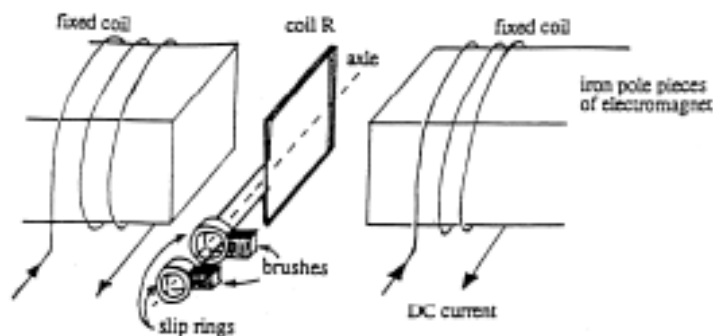
CURRENT through the coil.
 _____ points to the
 NORTH pole of the solenoid



Questions

Question 5

The following diagram shows a simple generator, which consists of coil R that can be rotated in a magnetic field. Electric contact is made with the coil through a pair of slip rings. The magnetic field is produced by passing a DC current through two fixed coils wound on two iron pole pieces to form an electromagnet. The magnetic field strength is 0.1 T. The rotating coil R has an area of $4.0 \times 10^{-3} \text{ m}^2$. It consists of 40 turns of wire.



- What is the direction of the magnetic field passing through coil R?
- A To the left
 - B To the right
 - C Up
 - D Down

Figure 1 opposite shows a solenoid powered by a battery.

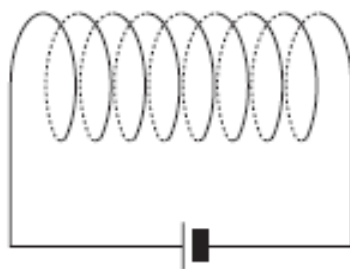


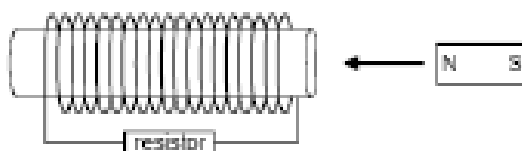
Figure 1

Question 6:

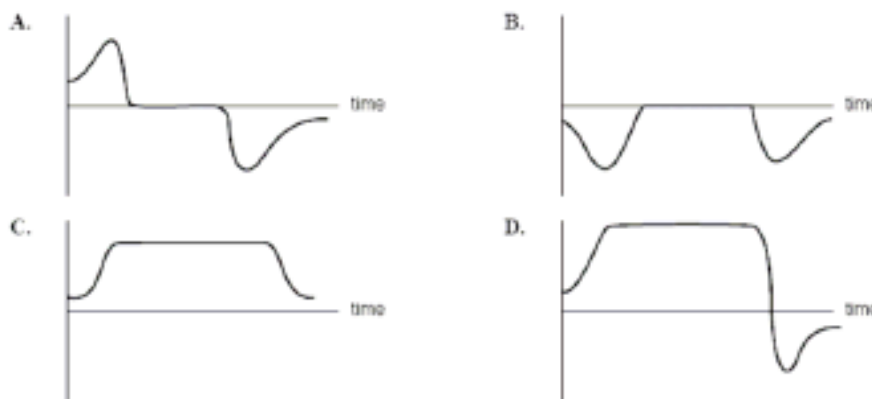
Complete the diagram above by sketching five magnetic field lines created by the solenoid.
 Make sure that you clearly show the direction of the field, including both inside and outside the solenoid.

Question 7

A magnet is moved through a coil at constant speed and out the other side.

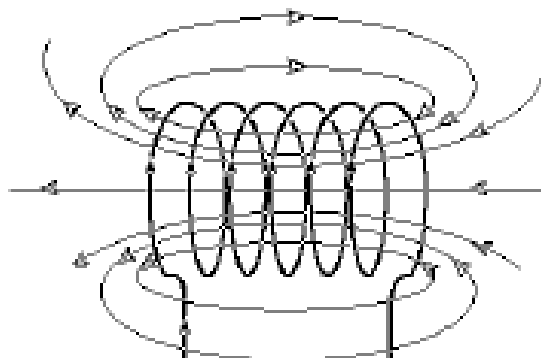


Which one of the diagrams (A – D) best shows how the current through the coil varies with time?



Question 8:

The solenoid in the Figure is merely a series of coils lined up parallel to each other so that each of the individual coil's magnetic fields add together to produce a stronger magnetic field.
 Describe two ways that we could further increase the magnetic field strength within the solenoid?



Chapter 2

2.0 Magnetic Field Strength

To fully describe the strength of a Magnetic Field at any point, both a magnitude and direction need to be specified.

Thus the Magnetic Field Strength is a _____ quantity.

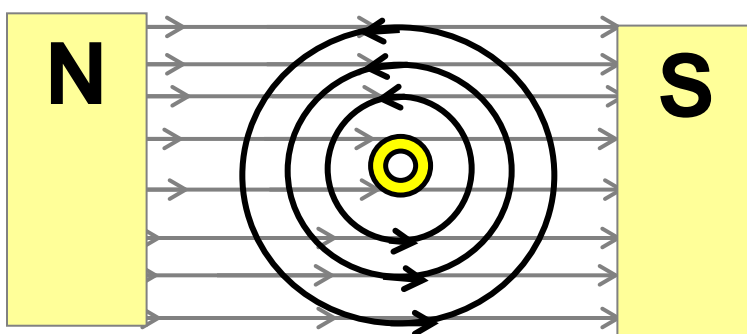
This vector is actually called the _____
_____, symbol B, unit TESLA (T).

However the vector is often (incorrectly) labelled the Magnetic Field Strength.

2.1 Magnetic Interactions

A current carrying wire is placed in an external magnetic field.

The magnetic field surrounding the wire and the external field interact to produce a _____ which is experienced by the wire.



2.2 Magnetic Force on a Current carrying Wire

The SIZE of the Force experienced by the wire is determined from:

$$F_{MAG} = ILB$$

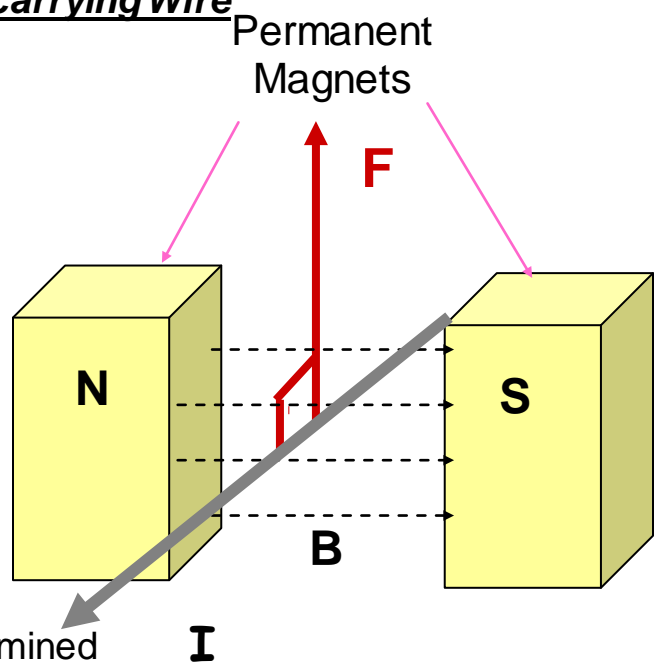
where:

F_{MAG} = Magnetic Force (N)

I = Current (A)

L = Length of Wire (m)

B = Magnetic Flux Density (T)



The _____ of the Force is determined by using the Right Hand Palm Rule.(see next section)

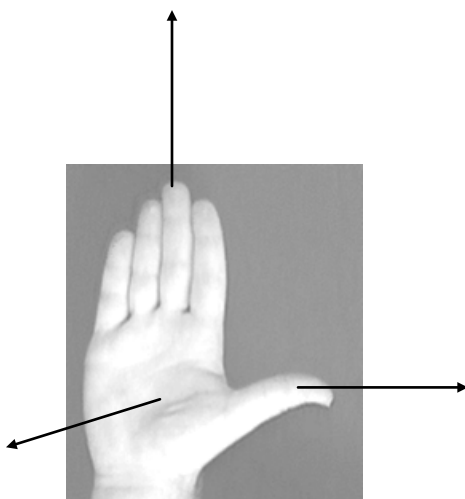
2.3 The Right Hand Palm Rule

The “Right Hand Palm Rule” allows the _____ of the Force experienced by a current carrying wire in an external magnetic field to be determined.

The _____ points in the direction of the CONVENTIONAL CURRENT

The _____ point in the direction of the EXTERNAL FIELD.

Out of the _____ emerges the MAGNETIC FORCE.



N.B. The FORCE is MAXIMUM WHEN THE EXTERNAL FIELD (B) is _____ to the CURRENT (I).

N.B. The FORCE is ZERO when the FIELD and CURRENT are _____

Questions

Question 9:

Figure 3 shows a power line at a mining site that carries a DC current of 2000 A running from west to east.

The Earth's magnetic field at the mining site is 4.0×10^{-5} T, running horizontally from south to north.

An engineer is concerned about the electromagnetic force due to the earth's magnetic field on the wire between the two support poles, which are 20 m apart.

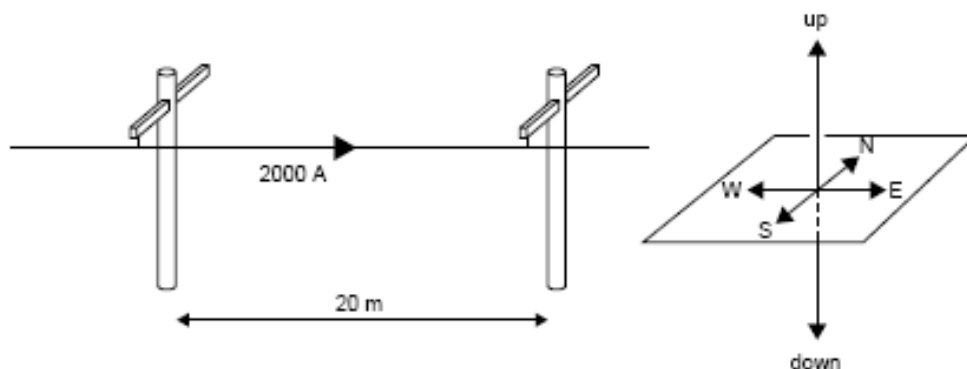
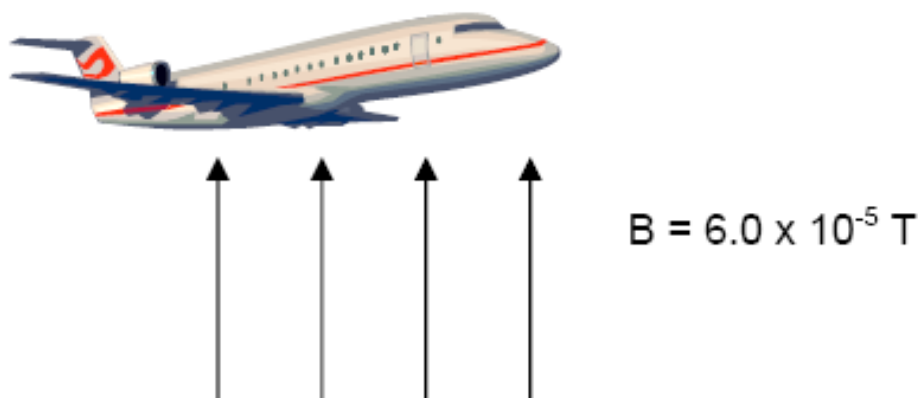


Figure 3

Calculate the magnitude and direction (north, south, east, west, up, down) of the force due to the earth's magnetic field on the 20 m section of wire between the two poles.

Question 10:

An aeroplane with a wing span of 25 metres is flying over the south magnetic pole located within the Antarctic, at 540 km hr^{-1} . The magnetic field within this region is vertically orientated and the magnetic field strength is 6.0×10^{-5} T.



Which wing is positive? The left or the right?

Question 11:

The magnetic field strength in the solenoid is $2.0 \times 10^{-2} \text{ T (Wb m}^{-2}\text{)}$.

A U-shaped conducting wire (a, b, c, d), carrying a current of 5.0 A in the direction $a \rightarrow d$, is placed inside the solenoid as shown in Figure 2a below.

The highlighted segment, abcd, of size $6.0 \text{ cm} \times 2.0 \text{ cm}$ is completely immersed in the magnetic field as shown in Figure 2a also.

In Questions use the key, PQRSTU, in Figure 2b to indicate direction. If there is no direction, write none.

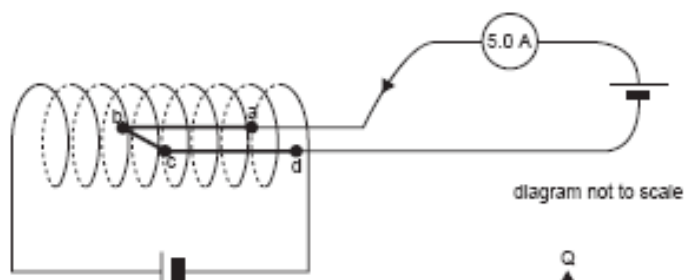


Figure 2a

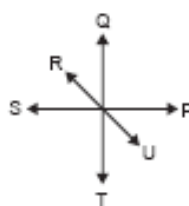


Figure 2b

What is the force (magnitude and direction) on the 6.0 cm section of wire, cd, in Figure 2a?

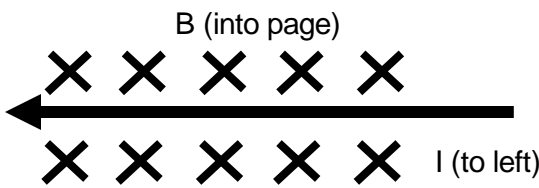
Question 12:

What is the force (magnitude and direction) on the 2.0 cm section of wire, bc, in Figure 2a?

2.4 Palm Rule Applications

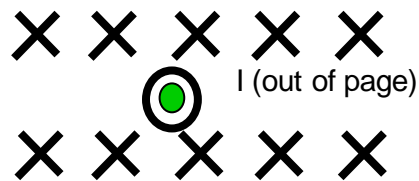
Current and Field

Mutually Perpendicular



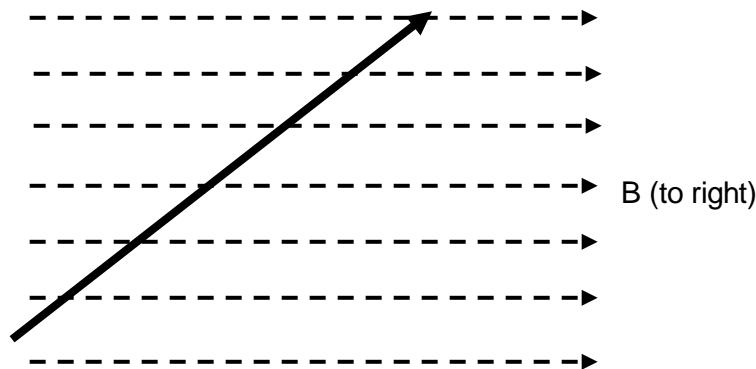
Current and Field Parallel

B (into page)



Current and Field Angled

I (angled up to right)



Questions

Question 13:

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

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

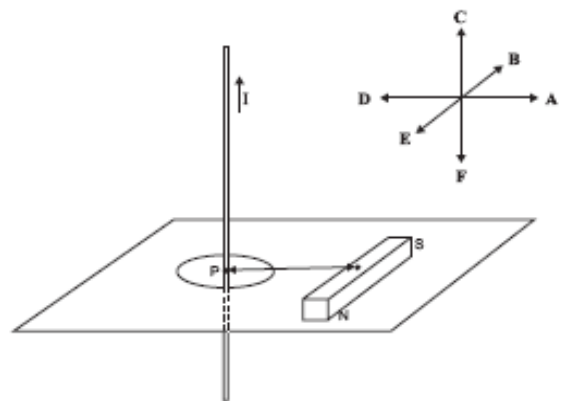
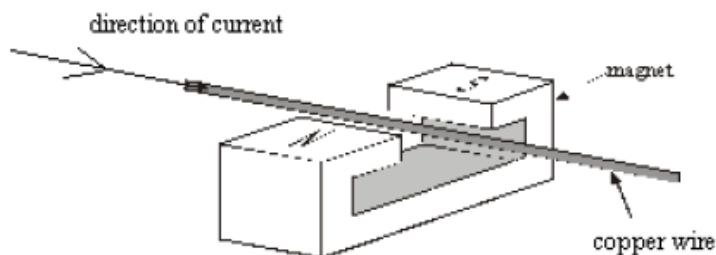


Figure 1

Question 14:

A strip of copper wire is positioned between the poles of a strong magnet, as shown below



When a current is passed through the copper wire in the direction shown, the wire is deflected. In which direction is this deflection?

- A. Vertically downwards
- B. Vertically upwards
- C. Towards the North pole of the magnet
- D. Towards the South pole of the magnet

2.5 Magnetic Force on a Moving Charge

When a current carrying wire is placed in an external magnetic field it experiences a force.

This force actually arises because each of the _____

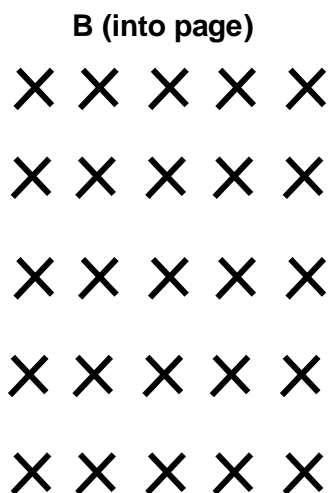
_____ moving through the wire is subject to its own individual force.

The total force experienced by the wire is the sum of the individual forces experienced by all the charge carriers.

When an isolated charge carrier (eg an electron or a proton), enters a magnetic field, moving at velocity v , the force it experiences tends to _____, or change its direction of motion, since it is not constrained to move along a wire.

The Force, acting at _____ to the velocity, will force the proton to follow a circular path.

Proton Moving Through a Magnetic Field

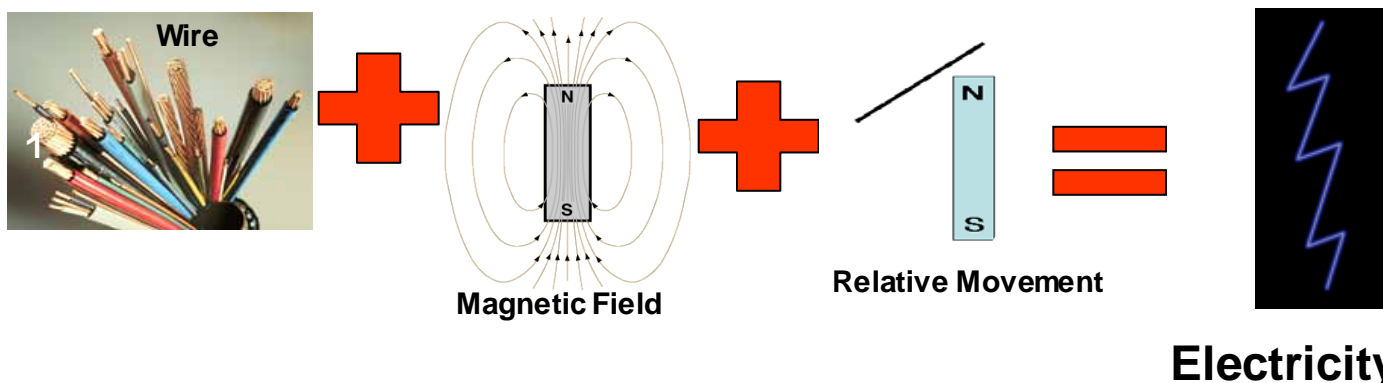


The size of the force experienced by an individual charge is found from:

$$F_{\text{mag}} = qvB$$

4.0 **Generation Of Electricity**

In order to generate electricity only _____ criteria need to be met:



The Relative Movement can be met in various ways:

Move the _____ through the magnetic field.

Move the _____ past the wire.

Increase or decrease the _____ of the field by using an electromagnet and varying current flowing through the coils.

4.1 **Producing an EMF**

To get a current to flow along a wire, a _____ force is required.

This driving force is **VOLTAGE DIFFERENCE** between the ends of the wire.

This voltage supplies the charge carriers with the _____ required to travel the length of the wire.

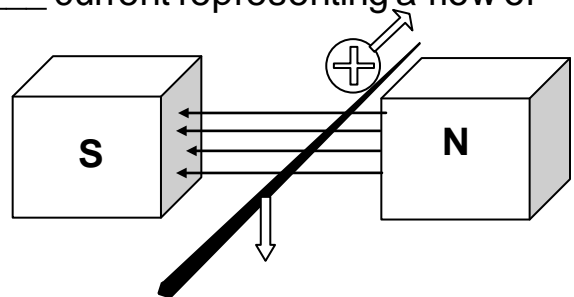
This supplier of energy is given a special name and is called the **ELECTROMOTIVE FORCE (EMF)**

When a wire “_____” magnetic field lines, an EMF is produced between the ends of the wire.

The EMF produced in this situation is called “**INDUCED EMF**”.

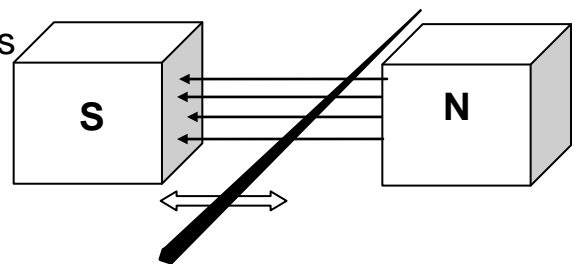
(As always we deal with _____ current representing a flow of positive charges)

With the wire moving down “cutting” the field lines positive charges in the wire will be forced to move in the direction shown.



This separation of charge will result in opposite electric charges accumulating at each end of the wire, generating an EMF

Wire moving side to side does not “cut” any field lines, so _____ EMF is induced
EMF is only generated if wire “CUTS” field lines

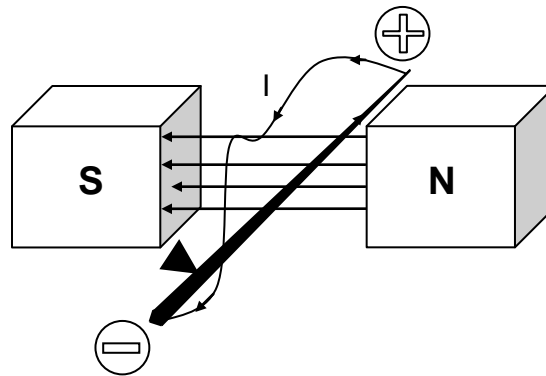


4.2 Induced EMF & Magnetic Flux

As shown previously, a wire is cutting across magnetic field lines, produces an _____ EMF between the ends of the wire.

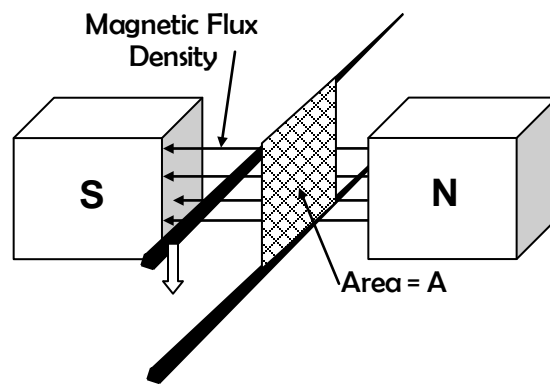
This, in effect, turns the original wire into a “_____” capable of driving a current around an external circuit.

If now, an external wire is connected between the ends of the original wire, a _____ will flow along that external wire.



The Area (A) swept out by the original wire in passing through the field multiplied by the Magnetic Flux Density (B) is called the **MAGNETIC FLUX** symbol (Φ)

Mathematically:



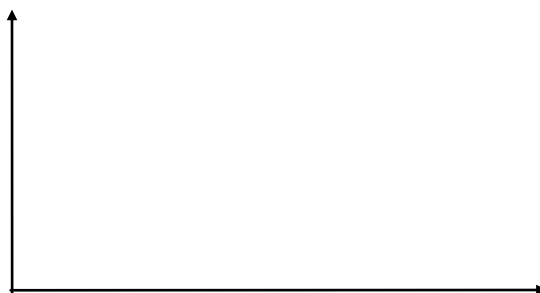
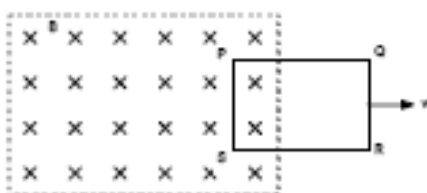
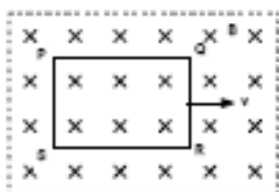
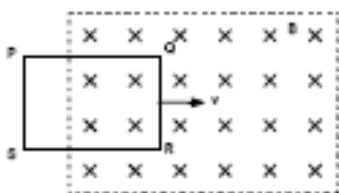
$$\Phi = BA$$

- Where
- Φ = Magnetic Flux (Weber, Wb)
 - B = Magnetic Flux Density (Tesla, T)
 - A = Area (m^2)

Questions

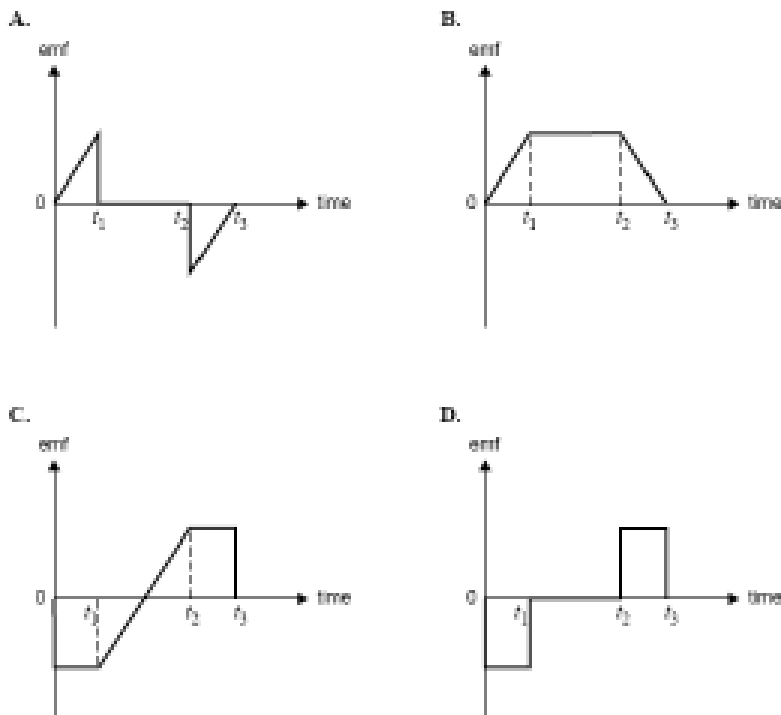
Question 15:

A small coil is passed through a perpendicular magnetic field and the induced emf is monitored on an oscilloscope. On the following axes, show how the magnetic flux threading the loop varies with time, as the loop first enters the field and passes completely through.



Question 16:

Which of the following best shows the variation of emf with time?



Question 17

Some students are studying the EMF induced by a magnetic field in a coil of wire. Their experimental apparatus consists of a coil of 100 turns of wire in a magnetic field of 2.0×10^{-2} T as shown in Figure 2. With the coil vertical as shown in Figure 2, the flux through the coil is 8×10^{-6} Wb.

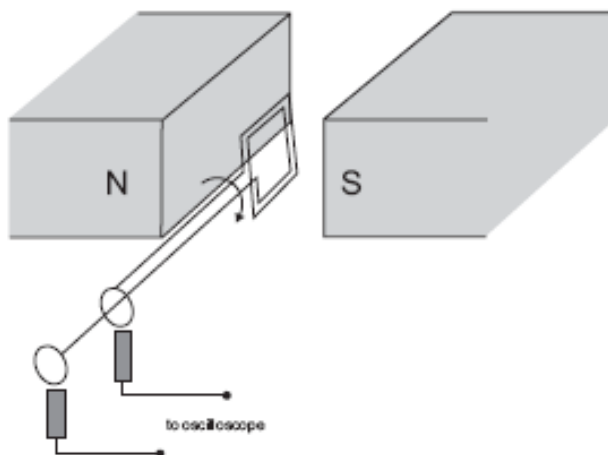


Figure 2

What is the area of the coil?

3.3 Faraday's Law

Michael Faraday is the father of electro-magnetic induction, diamagnetism and field theory to name but some of his discoveries. He discovered the SIZE of the INDUCED EMF is proportional to the Time Rate of Change of MAGNETIC FLUX.

$$\text{EMF} \propto - \Delta\Phi/\Delta t$$

The negative sign is a consequence of _____ conservation requirements and will be discussed later.

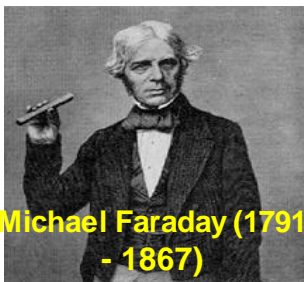
When an EMF is generated in this way it is normally done with a coil or loop of wire made up of many turns (N turns).

So the Total EMF is N times the EMF generated in a single loop. Faraday's Law thus becomes:

$$\text{EMF} = - N \Delta\Phi/\Delta t$$

If the AREA remains CONSTANT but B is changing the formula becomes:

$$\text{EMF} = - N A \Delta B/\Delta t$$



If FIELD remains CONSTANT but A is changing over time the formula is:

$$\text{EMF} = - N B \Delta A/\Delta t$$

It is important to note that the Induced EMF will only be generated when “_____” are occurring, either in the magnetic flux density B or the area A through which B is passing.

Questions

Question 18:

Some students are studying the EMF induced by a magnetic field in a coil of wire. Their experimental apparatus consists of a coil of 100 turns of wire in a magnetic field of 2.0×10^{-2} T as shown in Figure 2.

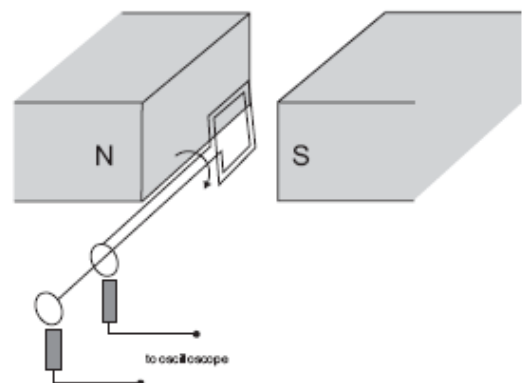


Figure 2

With the coil vertical as shown in Figure 2, the flux through the coil is 8×10^{-6} Wb. Calculate the average EMF observed over the time interval T_{QR} .

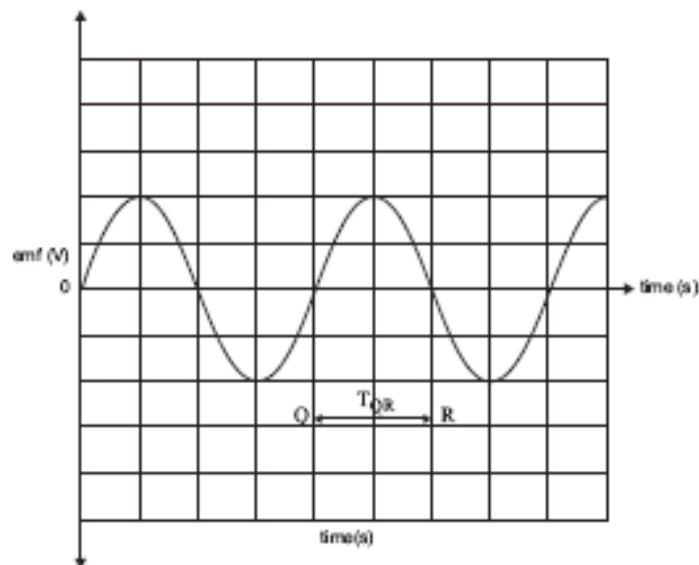


Figure 3

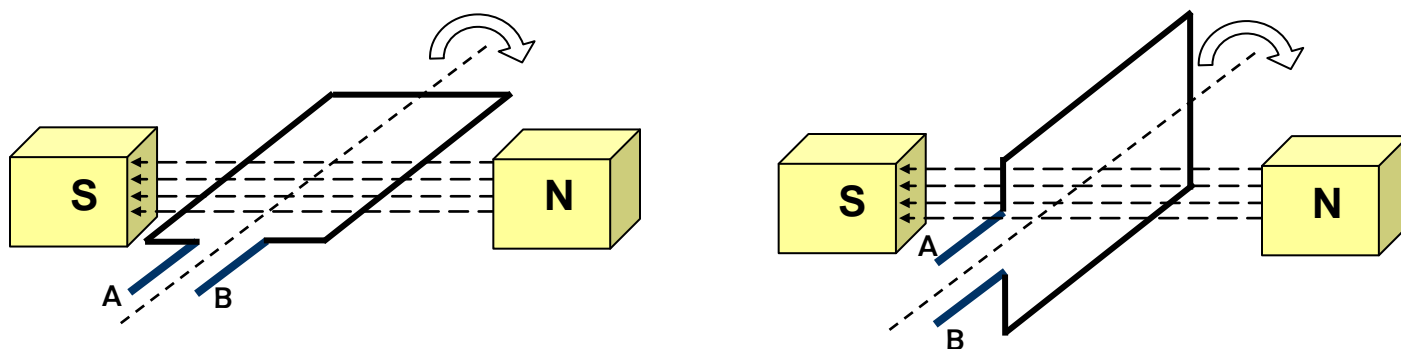
3.4 Faraday Illustrated

Emf can be generated by

- (a) Changing The _____ Strength
- (b) Changing The _____
- (c) _____ the Coil in a Constant Field

3.5 Variation in Induced EMF

Our piece of wire is now replaced by a rectangular loop of wire.



In the orientation shown on the left no magnetic field lines pass through the _____ of the loop, therefore the Flux $\Phi = BA = 0$.

The coil rotates around the dotted axis in the direction shown to the position on the right.

The coil has rotated through 90° or $\frac{1}{4}$ of a cycle ($\frac{1}{4}T$) the number of field lines passing through the loop is a maximum and the Flux $\Phi = BA = a$

_____.

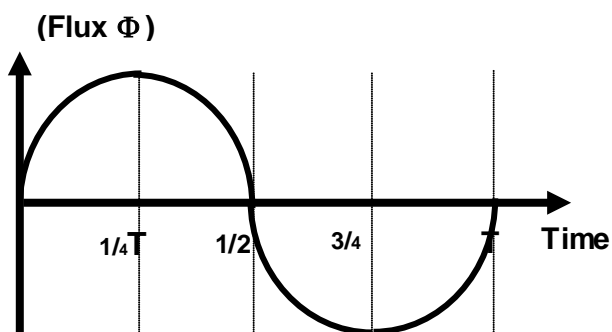
Further rotation by 90° brings the loop back to parallel with the field and the Flux is again zero.

The Flux again passes through a maximum before returning to its original position and zero Flux.

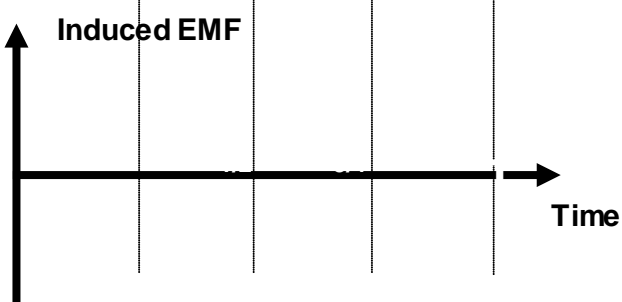
3.6 Flux & Induced EMF

The Flux through the loop varies because it is _____.

As a consequence the EMF (= negative time rate of change of flux) induced between the ends of the loop A and B also varies.



Graph 1



Graph 2

3.7 Another View of Variation in Induced EMF

As the rectangular loop rotates, the Flux through it varies in a sinusoidal manner as shown in Graph 1.

The Induced EMF is dependent upon the “time rate of change” of the flux through the loop, ie. $(\Phi \Delta / \Delta t)$.

Another way of saying this is the Induced EMF is calculated from the differential of Flux with respect to time.

Since the Flux is a Sine type relation the Induced EMF will be a Cosine type relation, (the differential of a Sine term is Cosine term).

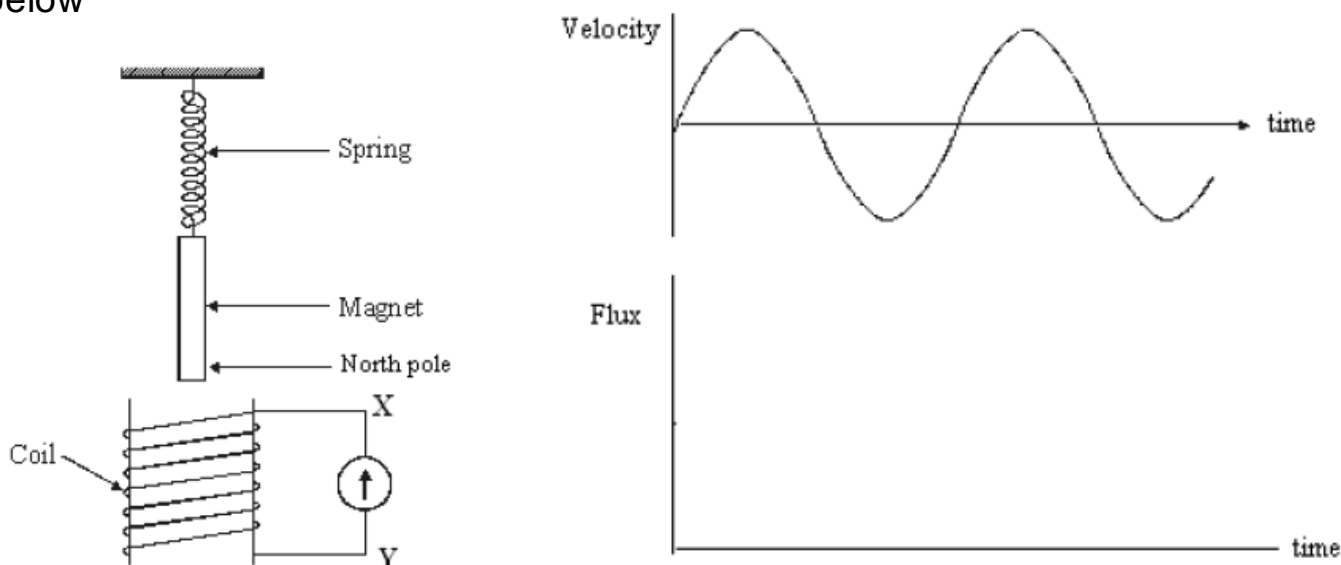
Thus, a graph of the Induced EMF will be as shown in Graph 2

N.B. The Induced EMF is only generated while the amount of Flux through the loop is _____.

Questions

Question 19:

A bar magnet is suspended above a coil of wire by means of a spring, as shown below. The end of the bar magnet closest to the solenoid is a north pole. The ends of the coil are connected to a sensitive galvanometer. The bar magnet is pulled down so that its north pole is level with the top of the coil. The magnet is released and the variation with time t of the velocity v of the magnet is shown below



On the axes provided, draw a flux – time graph for the flux measured at the top of the coil (the point of release of the magnet)

Question 20:

When the magnet is initially released, does current flow from X to Y through the galvanometer, or from Y to X? Justify your choice.

3.8 Induced EMF and Frequency Changes

A favourite question of the examiners is to ask what happens to the Induced EMF if the rate of rotation of the coil is doubled?

A doubling of the _____ means a _____ of the time (period) of oscillation

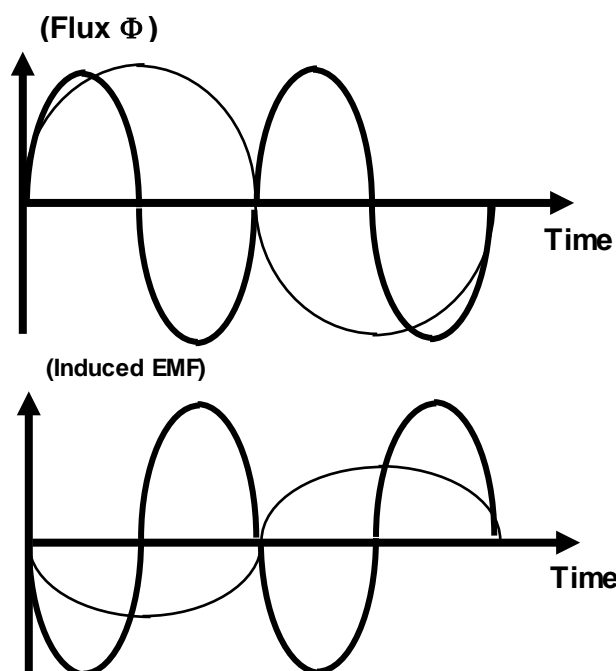
This then means the change in flux will now occur in $\Delta t/2$

Since $EMF = -n\Delta\Phi/\Delta t$

the new $EMF = -n\Delta\Phi/\Delta t/2$

$$= 2(-n\Delta\Phi/\Delta t)$$

So the EMF is now _____ as large.



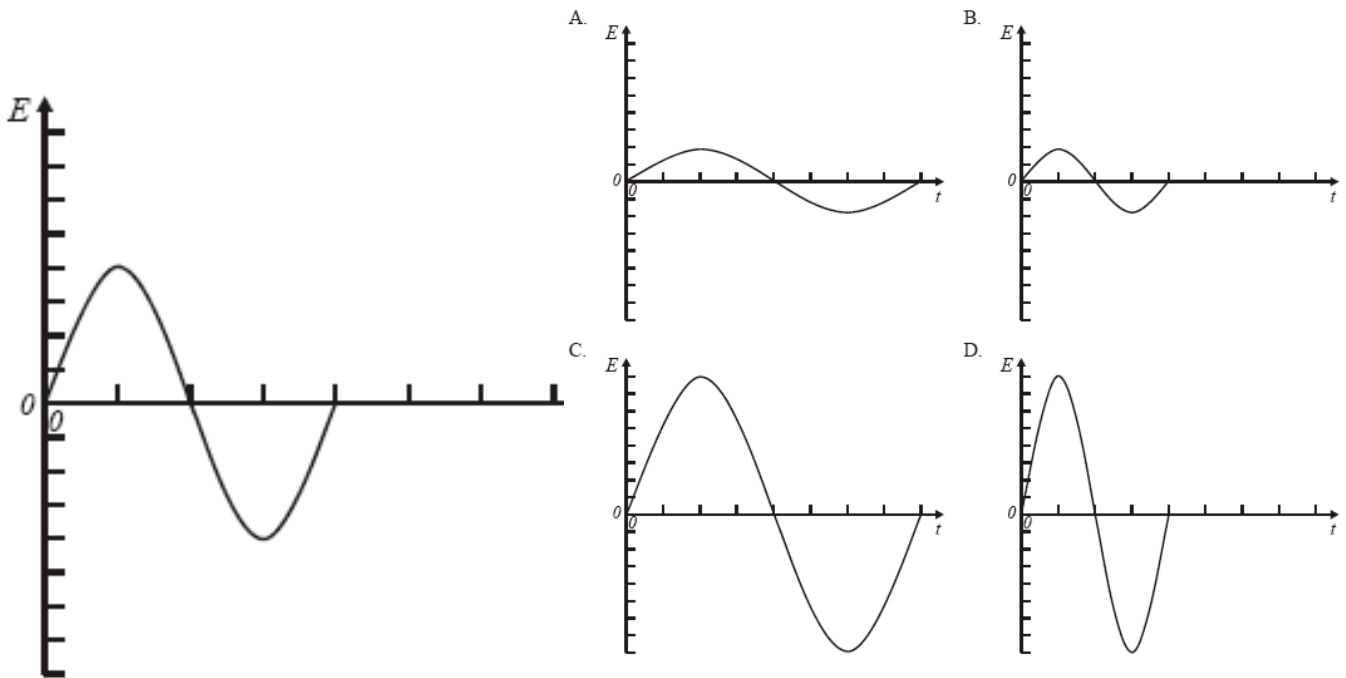
Questions

Question 21:

When a coil is rotated in a uniform magnetic field at a certain frequency, the variation with time t of the induced e.m.f. E is as shown below.

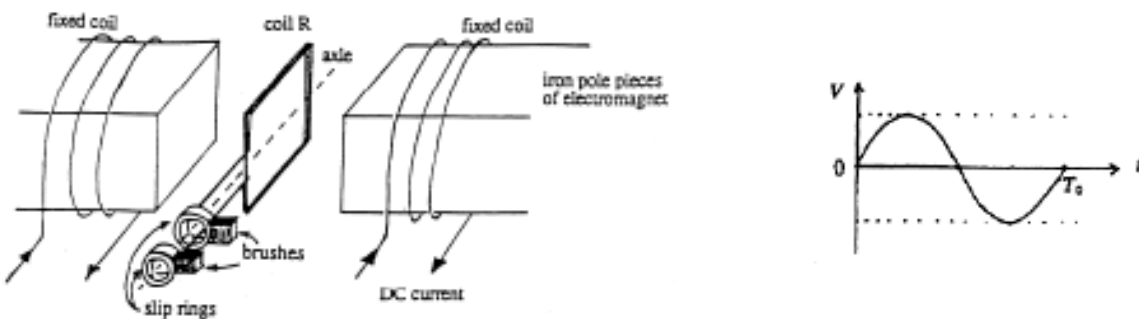
The frequency of rotation of the coil is reduced to one half of its initial value.

Which one of the following graphs correctly shows the new variation with time t of the induced e.m.f. E ?



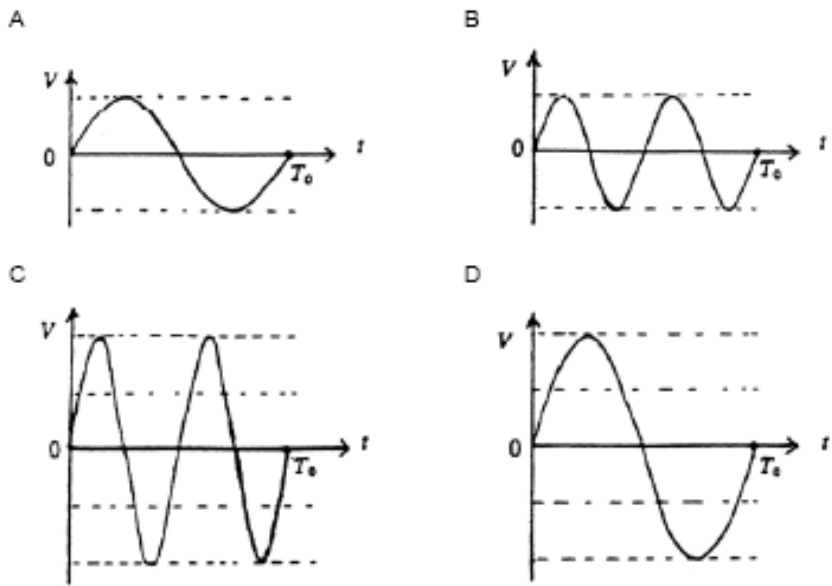
Question 22:

The following diagram shows a simple generator, which consists of coil R that can be rotated in a magnetic field. Electric contact is made with the coil through a pair of slip rings. The magnetic field is produced by passing a DC current through two fixed coils wound on two iron pole pieces to form an electromagnet. The magnetic field strength is 0.1 T. The rotating coil R has an area of $4.0 \times 10^{-3} \text{ m}^2$. It consists of 40 turns of wire.



As the coil is rotated the voltage measured between the slip rings varies with time as shown in the graph above right.

If the frequency of rotation is doubled, which of the graphs below best shows how the voltage now varies with time?



3.9 Lenz's Law (1)

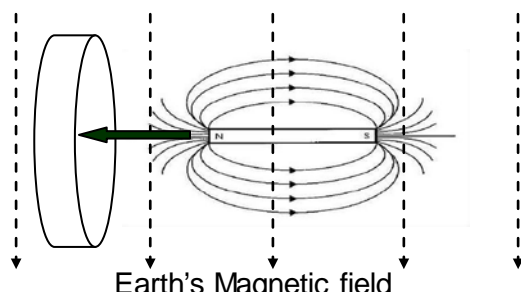
The negative sign in the Induced EMF formula, $EMF = -N (\Phi \Delta/\Delta t)$ is a consequence of Lenz's Law, which is usually stated as: "AN INDUCED CURRENT IS IN SUCH A DIRECTION AS TO _____ THE CHANGE CAUSING IT".

This is best illustrated with an example:

Imagine a LOOP OF WIRE sitting in space, subject only to the Earth's constant Magnetic Field.

The NORTH POLE of a Permanent Magnet is now pushed in toward the centre of the loop.

THE LOOP IS SUBJECT TO A CHANGING (INCREASING) MAGNETIC FIELD, DUE TO THE INCOMING PERMANENT MAGNET .



3.10 Lenz's Law (2)

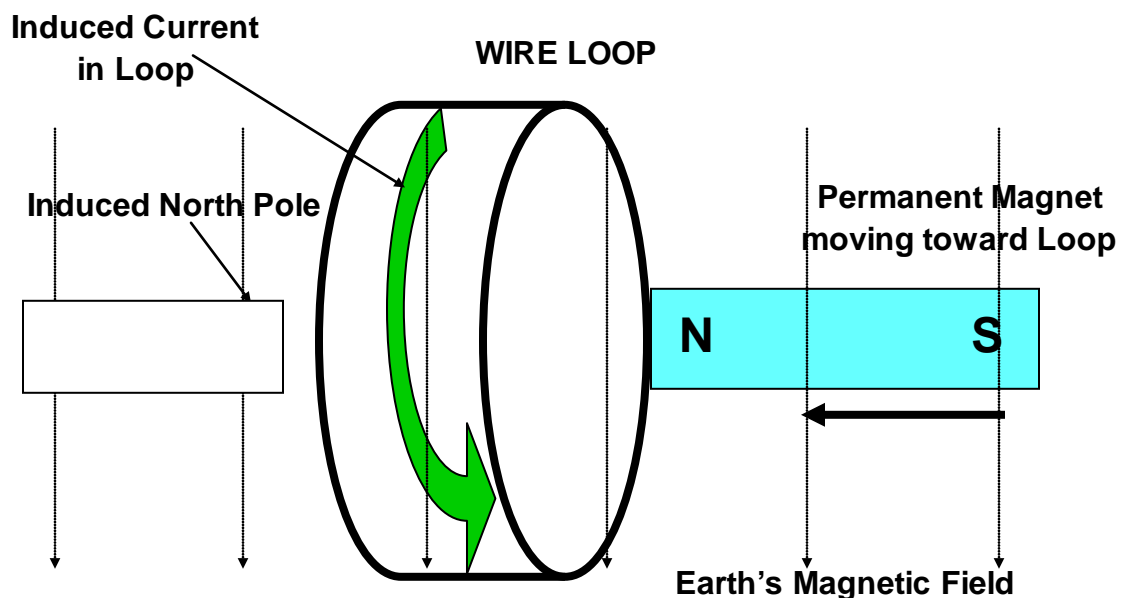
The loop wants to remain in its _____ state (ie. subject only to the Earth's magnetic field), so it sets about _____ the change it is undergoing.

The change being an increase in the magnetic field due to the incoming permanent magnet.

The loop responds to the increase in magnetic field by setting up a current in such a direction as to produce an induced magnetic field to _____ the field from the incoming permanent magnet. (Remember the field around like magnetic poles)

THUS THE LOOP IS RESPONDING BY CAUSING A CURRENT TO BE PRODUCED IN A DIRECTION WHICH RESULTS A FIELD OPPOSING THE INITIAL CHANGE.

LENZ'S LAW HAS BEEN MET.



3.11 Lenz's Law (3)

The _____ of the Induced Current in the loop depends upon the _____ of the incoming permanent magnet.

The FASTER the permanent magnet moves the _____ the Induced Current in the loop.

Lenz's Law is really a restatement of the Law of Conservation of Energy.

Consider the following:

The induced current gives rise to an Induced Magnetic Field and thus to the Flux threading the loop.

If this Induced Flux ADDED to the flux due to the incoming permanent magnet, Total Flux would rise producing a larger induced current which in turn would increase the Flux through the loop producing a larger current producing a larger Flux producing a larger current etc. etc. etc. and all this without expending any energy at all.....

This is an untenable situation, and would, and could, not occur in nature.

YOU GET NOTHING FOR NOTHING IN THIS WORLD.

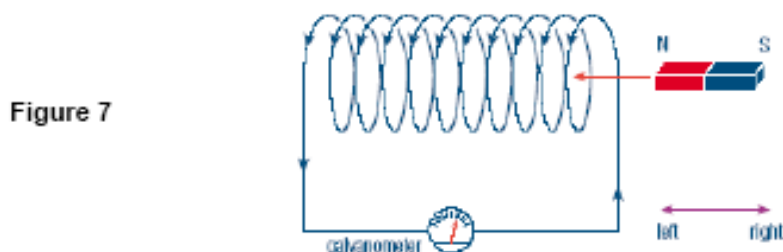
Thus, the induced current MUST be in such a direction as to produce a flux to oppose the flux of the incoming permanent magnet in order to meet the Conservation of Energy requirement.

THE WORK DONE IN PUSHING THE PERMANENT MAGNET INTO THE LOOP SUPPLIES THE ENERGY NEEDED TO GENERATE THE INDUCED CURRENT.

Questions

Question 23:

A coil of wire connected to a galvanometer forms a circuit, as shown in the Figure 7. When a bar magnet is placed near the coil and moved to the left as illustrated, the galvanometer indicates a current to the right through the galvanometer.



For each of the following situations state whether the current through the galvanometer will zero, to the left or to the right.

- The coil is stationary and the magnet is stationary.
- The coil is stationary and the magnet is moved to the right.

- c. The coil is moved to the right and the magnet is stationary.
d. The coil is moved to the left and the magnet is stationary.

Chapter 4

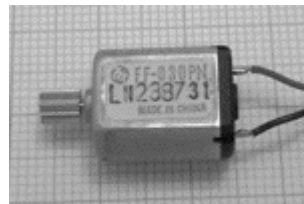
4.0 Simple DC Motors

Simple Direct Current (DC) Electric Motors consist of:

- (a) A rotating or spinning coil of wires called a _____

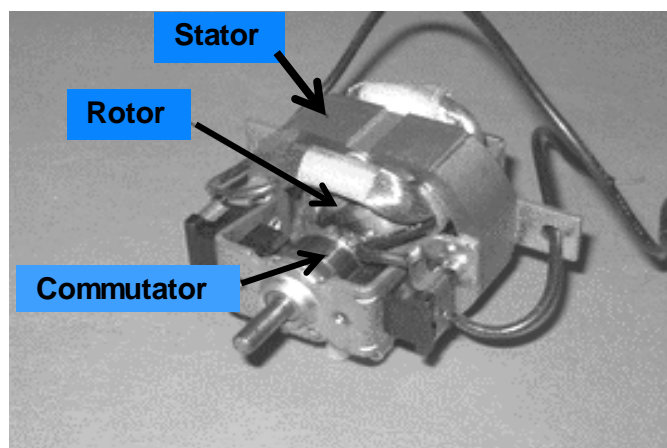
b) A stationary magnet (either permanent or electromagnet) called the _____.

In Motors, Electrical Energy is supplied from an outside source and Mechanical Energy in the form of rotation is extracted.

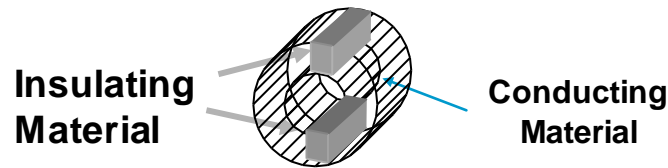


4.1 The Commutator

In Electric Motors with an electromagnetic stator (as shown), there is direct electrical connection between the Stator and Rotor.



Split Ring Commutator

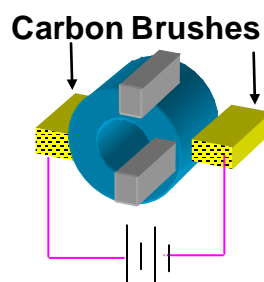


This is achieved by using a “_____ Commutator”.

This is a rotating _____, with sections of insulating material separating conducting material.

It is rigidly connected to the rotor.

Electrical contact between the Rotating Commutator and the rest of the Motor is through a pair of _____ Brushes, which rub against the Commutator segments.

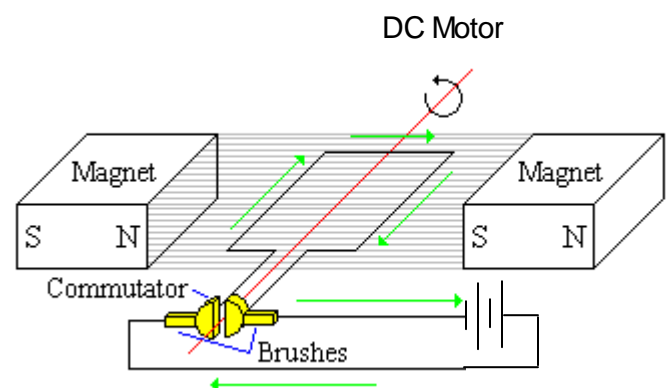


The Carbon Brushes are connected to a D.C. supply which allows the electrical energy into the motor

4.2 ***Motor Operation***

To examine the operation of the Simple DC motor, let us look at a single coil rotor placed inside a permanent magnet stator.

When a current flows through the



Brushes and Commutator into the Rotor, the sides of the coil each experience a Force - (F_{MAG}).

The direction of the force is found using the Right Hand Palm Rule.

Under the action of F_{MAG} the coil rotates until it reaches the vertical orientation. At this point the insulating material in the commutator cuts off the current to the loop.

As the loop is moving, it has inertia, which will carry it past the vertical at which point the current will again flow, but in the _____ direction

F_{MAG} acts to continue rotation in the same direction. The Commutator maintains the current flow in the same direction in the rotor coil, so it always rotates in the same direction.

Questions

Question 24:

Figure 4 shows a schematic diagram of a DC motor.

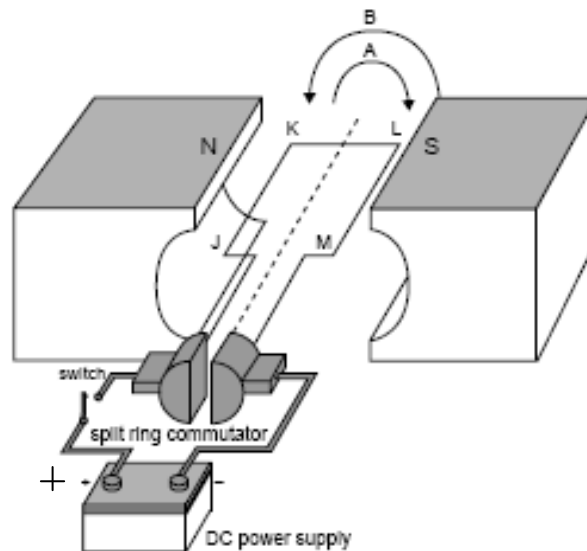


Figure 4

The motor is initially stationary as shown in Figure 4.

In which direction, A (clockwise) or B (anticlockwise), will the motor rotate when the switch is closed?

Question 25:

Explain your answer.

Question 26:

Why is the split ring commutator necessary for the motor to operate correctly?
Explain the operation of the commutator.

4.3 Electric Motors & Generators

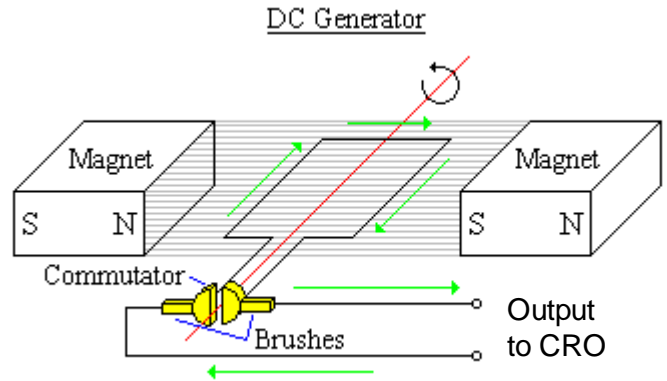
- Electric Motors and Electric Generators are the _____ DEVICE but operated in different ways.
- Both consist of:
 - (a) A rotating or spinning coil of wires called a ROTOR
 - (b) A stationary magnet (either permanent or electromagnet) called the STATOR.

When the device is operated as a MOTOR, Electrical _____ is supplied from an outside source and _____ Energy in the form of rotation is extracted.

When operated as a GENERATOR, Mechanical Energy is supplied from an outside source and Electrical Energy is _____.

4.4 The Commutator - Generators

When part of a Generating System, the _____ Commutator is used to extract Electrical Energy from the rotor which is spun by an external force.

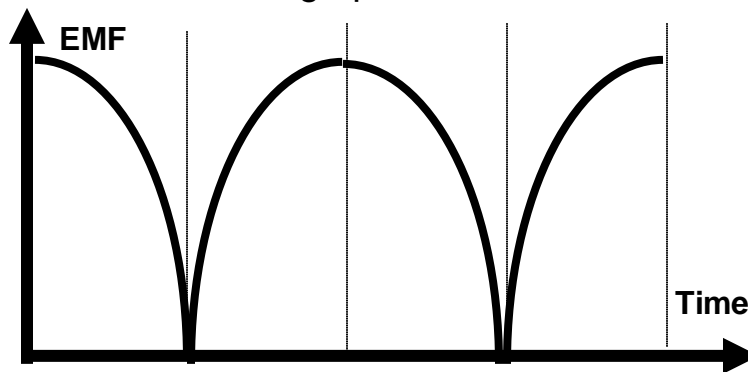


At $T = 0$, in the orientation shown, the generated EMF is at its maximum value.

In the next $\frac{1}{4}$ cycle (or 90°) the EMF generated will have fallen to 0.

Between $t = \frac{1}{4}T$ and $t = \frac{1}{2}T$, the EMF rises to its maximum value.

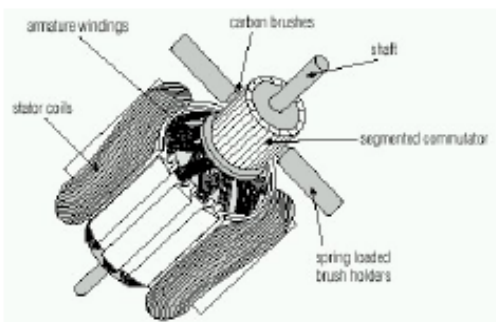
As the coil continues to rotate the EMF continues to rise and fall as shown. Thus, the output from the Split Ring Commutator is a Pulsating D.C. (Direct Current) signal as shown on the graph.



Questions

Question 27:

In the following description of a D.C. generator circle the most correct option each time alternative words are presented in *Italic font*.



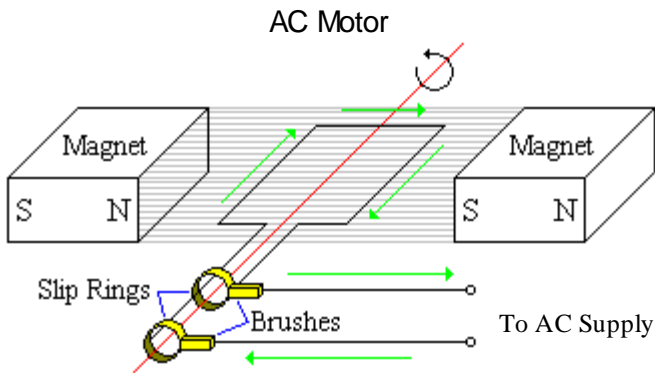
“As the armature rotates the commutator/ carbon brushes/ stator coils reverse the direction of the current leaving the generator every half a cycle resulting in Alternating /Direct/Conventional Current being fed to the external circuit.”

Figure 6

4.5 Slip Rings - Motors

In Electric Motors, _____ Rings (like commutators) are used to maintain electrical contact between an A.C. Supply and the Rotor.

Each slip ring is connected to _____ END of the Coil ONLY.



The slip rings are connected to an A.C. Supply via Carbon _____.

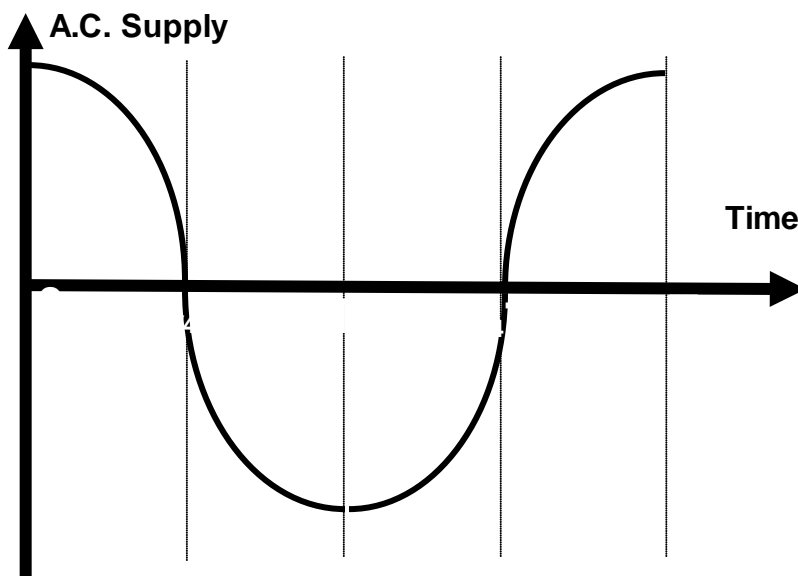
Initially, the coil has large current flowing, in the direction shown, due to the A.C. Supply being at its maximum positive value.

As the supply voltage falls to zero (at ¼T) the loop has travelled through a ¼ turn (90°) and the current falls to zero.

The A.C. Supply now changes polarity.

This means the current direction in the loop remains the same, providing an F_{MAG} to maintain the rotation.

This process continues through the subsequent positions of the loop.



4.6 Slip Rings - Generators

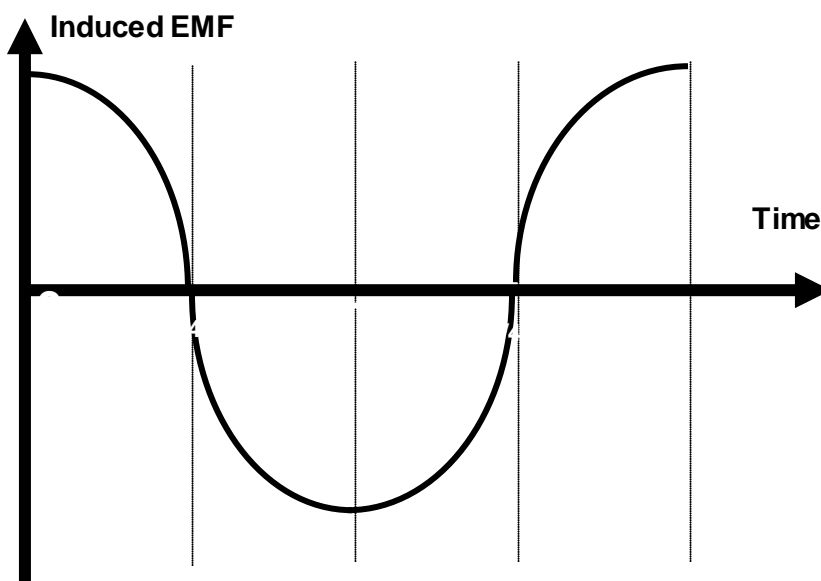
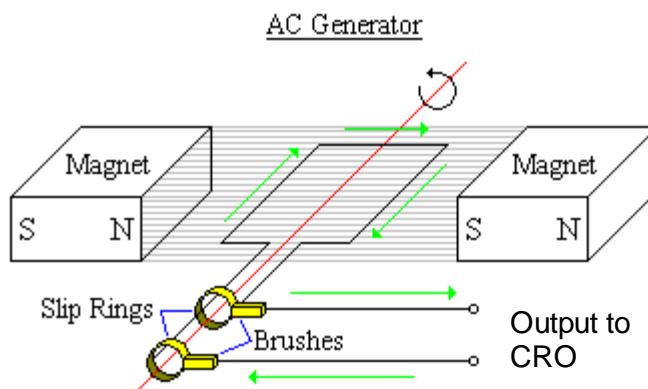
When part of a Generating System, the Slip Rings are used to _____
Electrical Energy from the Rotor which rotate by some external force.

At $T = 0$, in the orientation shown on diagram, the Induced EMF is at its Maximum.

Between $T = 0$ and $T = \frac{1}{4}T$, the coil v travel through a $\frac{1}{4}$ cycle (or 90°) and the Induced EMF generated will fall to zero.

At $T = \frac{1}{4}T$, the current direction in the coil is reversed and this is reflected in the EMF being negative for the next $\frac{1}{2}$ a cycle.

The output, ie. The Induced EMF, as measured across the Slip Rings is a true AC signal.

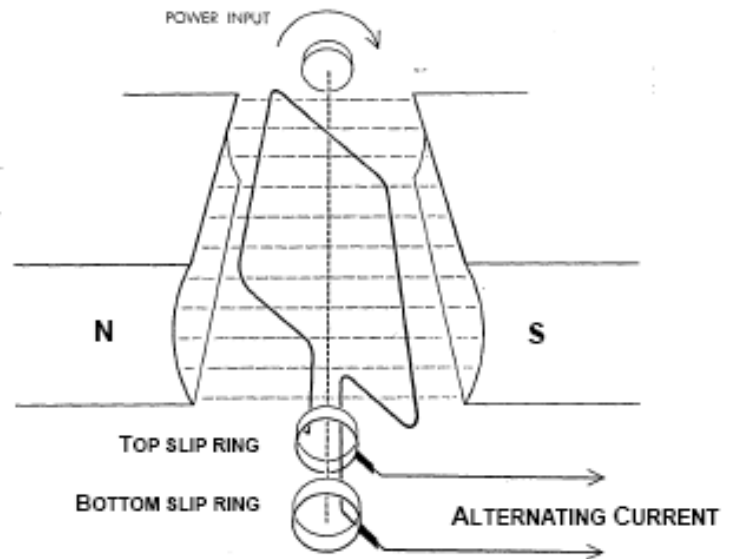


Questions

Question 28

At the instant shown in Figure 8 Is the magnitude of the magnetic flux through the loop increasing or decreasing?

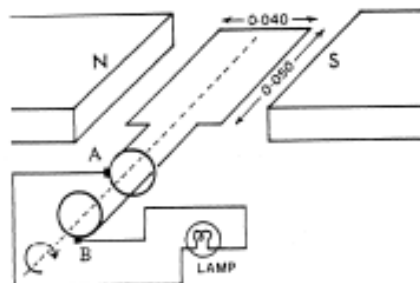
Figure 8



Question 29:

Does the induced current leave the generator through the top slip ring or the bottom one ?

A student makes a model AC electric generator by winding a rectangular coil of 100 turns, each of length 0.05m and width 0.04m. The field strength in the region between the poles of the magnet is 0.4T. The coil is rotated clockwise at a rate of 2.0 Hertz.



Question 30:

instant shown, is the positive terminal A or B?

Question 31:

Why does the lamp flicker as the generator rotates?

4.7 Alternators

Alternators are “electrical generators” which supply electrical energy in motor vehicles.

Alternators contains:

A rotating field winding - the rotor.

A stationary induction winding - the stator.

A diode assembly called the rectifier bridge or diode pack.

A control device called the voltage regulator.

Two internal fans to promote air circulation.

A spinning rotor alone will _____ generate an output voltage.

A current must also be flowing through the rotor to generate an alternating magnetic field.

Initially, this current is supplied by the battery through the “alternator light” circuit.

Once going, the alternator _____ off some of the current from the stator circuit and thus becomes “self sustaining”

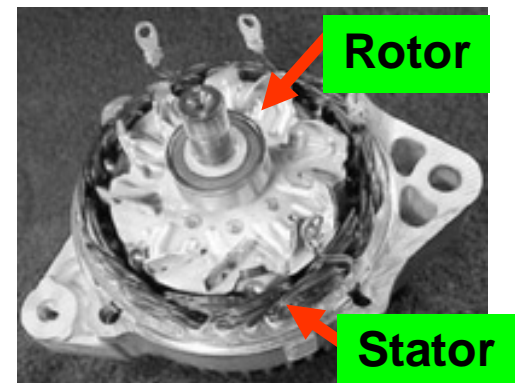
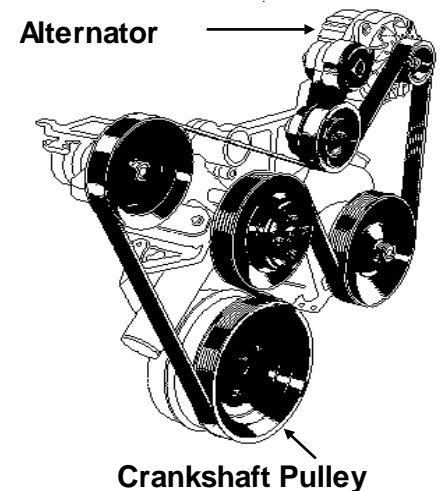
The slip rings and brushes are the pathway allowing current flow through the _____.

As the rotor assembly rotates within the stator winding:

The alternating magnetic field from the spinning rotor induces an alternating voltage into the stator winding. The strength of the magnetic field and the speed of the rotor affect the size of voltage induced in the stator.

The AC voltage created is then converted to DC via the diode pack as voltage leaves the alternator on its way to the battery and the electrical loads.

The voltage regulator maintains a _____ voltage irrespective of the load.



Questions

Question 32:

Figure 5 shows an alternator consisting of a rectangular coil with sides of 0.20 m × 0.30 m, and 1000 turns rotating in a uniform magnetic field. The magnetic flux through the coil in the position shown is 3.0×10^{-4} Wb.

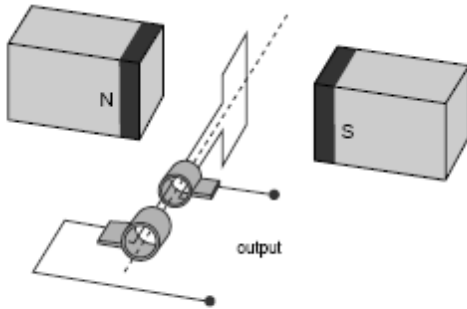


Figure 5

What is the magnitude of the magnetic field? Include a unit.

Question 33:

The coil rotates a quarter of a revolution in 0.01 s from the starting position shown in Figure 5.

Calculate the magnitude of the average induced emf in the coil in this time.

You must show your working.

Question 34:

An alternator is driven by a water turbine, as shown in Figure 7.

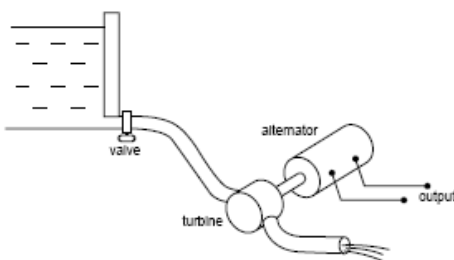


Figure 7

When the valve is opened, water begins to flow and the alternator gradually speeds up from stationary.

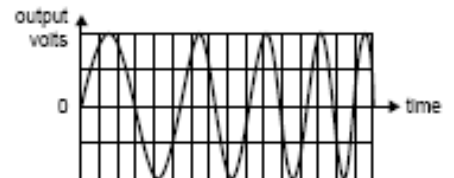
Which one of the following graphs (A to D) best represents the shape of the output

voltage as the alternator speeds up from rest?

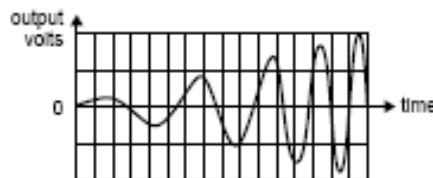
A.



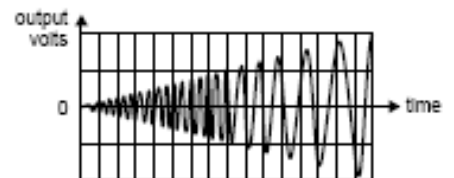
B.



C.



D.

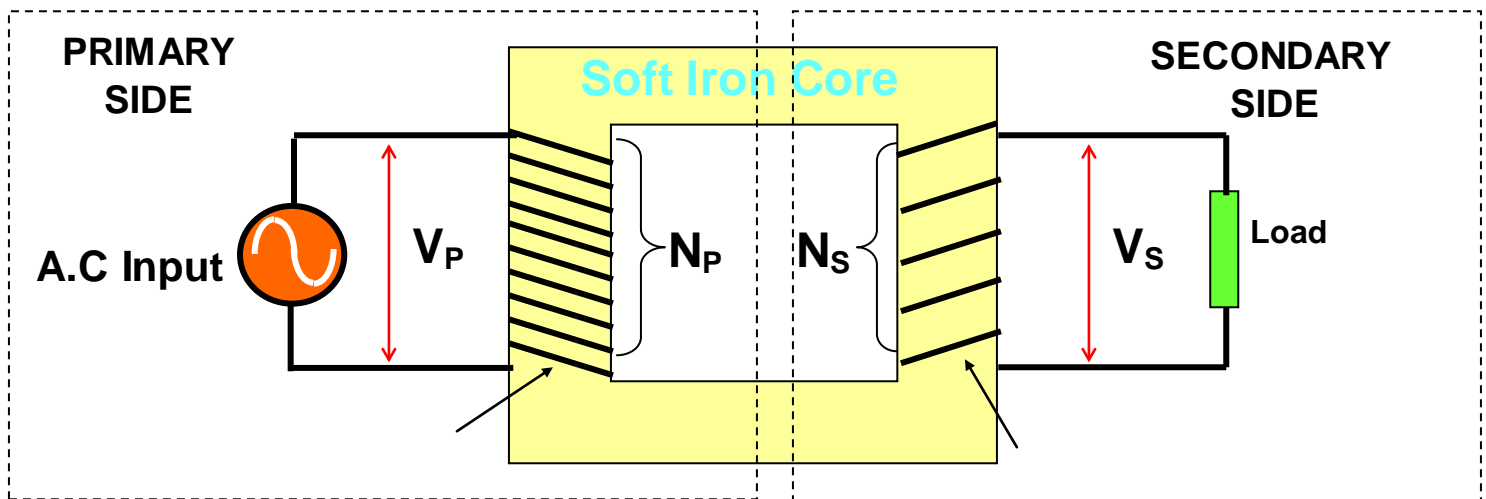


Chapter 5

5.0 Transformers

Transformers are devices which are capable of _____ or _____ the voltage of (and thus the current available from) an input signal.

Transformers consist of 2 separate coils of wire (called “_____”) held close together and usually wrapped around a “soft iron” core (which is highly susceptible to magnetisation).



The primary windings are connected to an A.C. Input of V_P volts

The secondary windings are connected to a load designed to operate at a voltage (V_S) different from (in this case smaller than) the input voltage.

The ratio of Input voltage (V_P) to Output voltage (V_S) is proportional to the ratio of the number of coils or turns in the primary windings (N_P) compared to the number of secondary turns (N_S).

Mathematically:

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

5.1 Transformer Operation

Transformers rely on the principal of Electromagnetic _____ for their operation.

The A.C. Supply forces a current through the primary winding, creating an associated magnetic field.

As the Voltage of the supply increases a larger current flows in the primary winding, generating a stronger magnetic field.

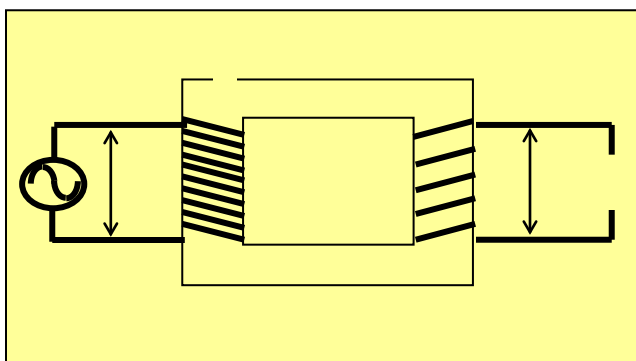
This _____ Magnetic Field induces a current to flow secondary winding and hence through the circuit connected to it.

As the polarity of the Supply reverses the same process occurs with the current and magnetic field, again inducing a current in the secondary circuit but this time in the opposite direction.

Electromagnetic Induction only occurs when _____ (in current or magnetic field) are occurring.

The A.C. supply is producing these _____ constantly, thus the transformer will operate satisfactorily.

TRANSFORMERS CAN ONLY OPERATE UNDER A.C. CONDITIONS.



5.2 Transformer Types

The relationship between Voltage and the Number of Turns in the primary and secondary sides has already been defined as:

$$V_p/V_s = N_p/N_s$$

Ideal Transformers suffer no losses across the transformer thus:

Power delivered to the primary side _____ Power generated in the secondary side.

Mathematically:

$$P_p = P_s$$

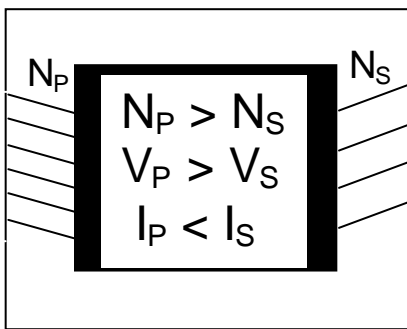
thus: $V_p I_p = V_s I_s$

Combining all formulae we get:

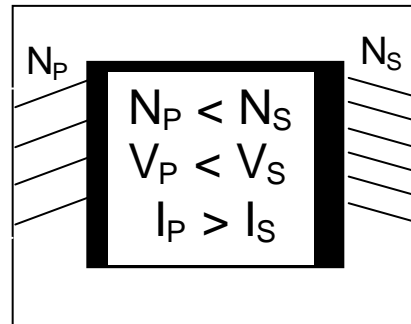
$$V_p/V_s = N_p/N_s = I_s/I_p$$

There are two basic types of transformers:

Step Down Transformer



Step Up Transformer



- REMEMBER: TRANSFORMERS ONLY WORK WITH AN _____ INPUT

Questions

Question 35:

Joan found an old transformer in her grandfather’s shed and performed some simple tests to see if it was still working using the circuit shown in Figure 5. These tests included voltage and current measurements, and the data obtained is summarised below in Table 1. Joan’s conclusion was that the transformer still worked, but for safety reasons she chose not to measure the current in the primary coil and assumed the voltage to be 240 V_{RMS}.

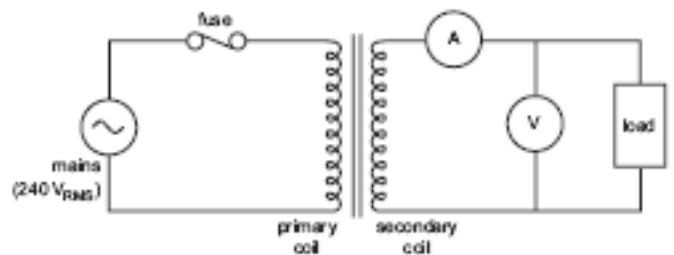


Figure 5

Assuming the transformer is ideal, calculate the RMS current in the primary coil.

Table 1

Primary Coil		Secondary Coil	
$I_{p \text{ rms}}$	$V_{p \text{ rms}}$	$I_{s \text{ rms}}$	$V_{s \text{ rms}}$
	240 V_{p rms}	22 A_{rms}	11.3 V_{rms}

Question 36:

Joan and her grandfather were discussing how a transformer works and this led to a discussion about Faraday's and Lenz's laws. Joan's grandfather stated that the two laws were essentially the same, but Joan disagreed.

Compare and contrast Faraday's law and Lenz's law.

As a final test of the transformer, Joan increases the load on the secondary side of the transformer. Suddenly, it stops working. She suspects that the fuse in the primary circuit has blown and intends to replace it.

Question 37:

In order to replace the fuse as safely as possible, which of the following is the best precaution for Joan to take?

- A. stand on a rubber mat
- B. switch off the mains supply
- C. disconnect the transformer from the mains supply
- D. remove the load from the transformer

6.3 A.C. Electricity

There are two basic types of current electricity:

- (a) D.C. (Direct Current) electricity where the current flows in one direction only.
- (b) A.C. (Alternating Current) where the current changes _____ in a regular and periodic fashion.

The Electricity Grid supplies domestic and industrial users with A.C. electricity.

A.C. is favoured because:

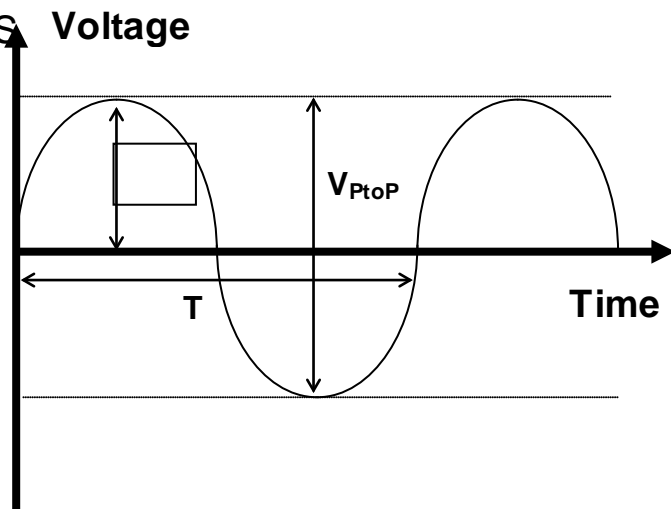
it is cheap and easy to generate

it can be “transformed”; its voltage can be raised or lowered at will by passage through a transformer.

The only large scale use of high voltage D.C. electricity is in public transport, i.e. trams and trains.

A.C. ELECTRICITY - PROPERTIES

- V_P = “Peak Voltage”
for Domestic Supply $V_P = 339 \text{ V}$
- V_{PtoP} = “Peak to Peak Voltage”
for Domestic Supply $V_{PtoP} = 678 \text{ V}$
- T = “Period”
for Domestic Supply $T = 0.02 \text{ sec}$



5.4 R.M.S. Voltage and Current

With an A.C. supply, the average values for both voltage and current = 0, so V_{av} and I_{av} cannot be used by the Power Companies to calculate the amount of electric power consumed by its customers.

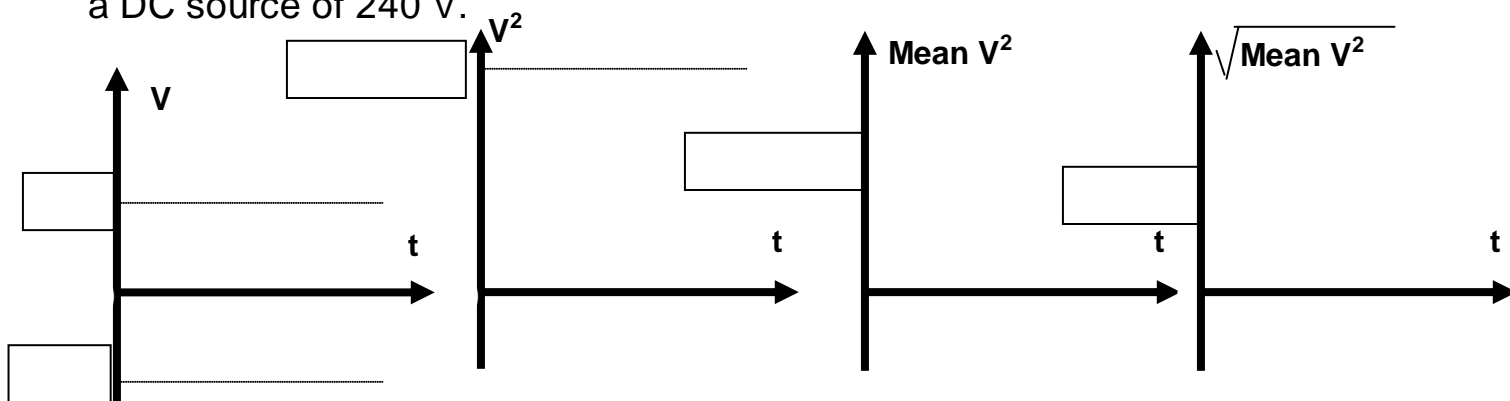
Yet, AC circuits do consume power, so a method of calculating it had to be found.

To get around this problem R.M.S. or _____ values for AC voltage and current were developed.

RMS values are DEFINED as:

The AC Voltage/Current which delivers the same voltage/current to an electrical device as a numerically equal D.C. supply would deliver

An AC source operating at 240 V RMS delivers the same power to a device as a DC source of 240 V.



6.5 Peak versus RMS Values

In AC supplies, the Peak and RMS values are related through simple formulae:

For Voltage:

$$V_{\text{RMS}} = V_{\text{P}}/\sqrt{2}$$

For Current:

$$I_{\text{RMS}} = I_{\text{P}}/\sqrt{2}$$

In Australia Domestic Electricity is supplied at 240 V, 50 Hz

The Voltage quoted is the RMS value for the AC supply.

Thus the Peak value for voltage is

$$\begin{aligned} V_{\text{P}} &= V_{\text{RMS}} \times \sqrt{2} \\ &= 240 \times 1.414 \\ &= 339 \text{ V} \end{aligned}$$

Questions

Question 38:

At a particular speed of rotation, the output of an alternator is as shown in Figure 6 below.

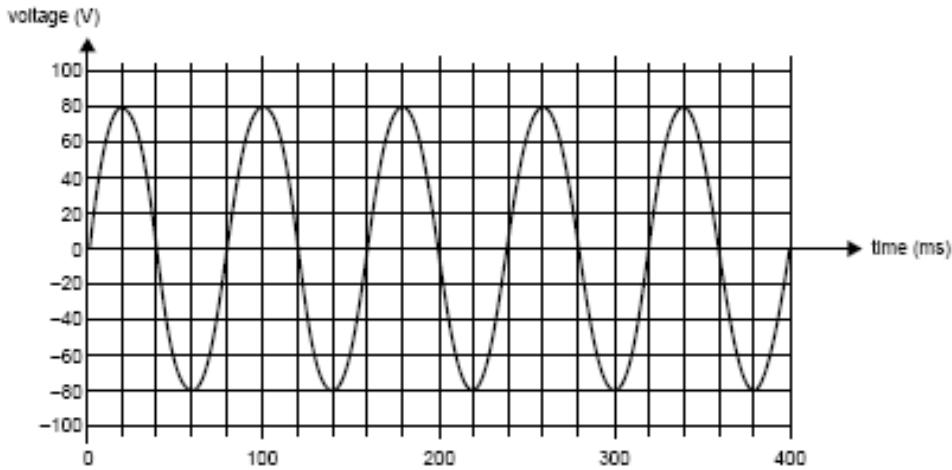


Figure 6

What is the RMS value of the output voltage?

6.6 Transmission Losses

When electricity is transmitted over long distances on power lines, a certain amount of power is lost along the way, generally in the form of _____ losses.

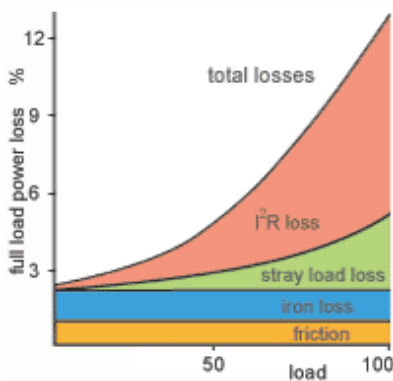
The amount of power lost can be calculated from the power formula: $P_{\text{LOSS}} = I^2R$

Notice the power lost is proportional to the resistance of the wires and the _____ of the current in the wires, so losses can be minimised by sending power at as low a current as possible through wires with the least possible resistance.

Because Power is also the product of V and I ; ($P = VI$), a _____ current necessarily means a _____ voltage to deliver the same amount of power.

As the load increases I^2R losses increase exponentially and are by far the major source of loss.

The Power Companies use step up transformers at the power stations and step down transformers at the customer end to deliver power with minimum losses.

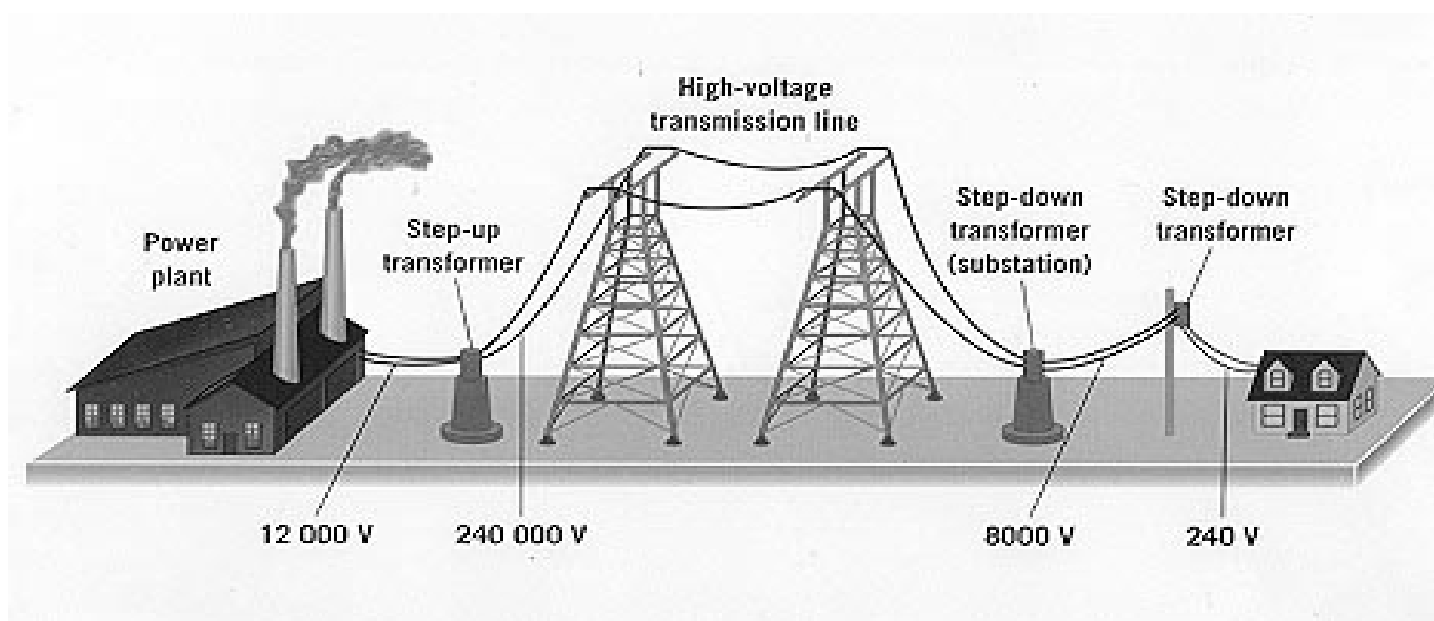


6.7 Transformers in the Grid

Electricity from power stations is transmitted through the national grid at very high voltages (up to 500 kV in Australia). The high voltages are necessary to minimise energy loss due to I^2R heating loss in the transmission wires as the energy is carried over great distances.

Transmission lines operate at voltages very much higher than those required to operate most industrial and domestic equipment and appliances. These operate at low voltages, typically 240 V single phase, the cost of insulation is affordable and operation is safer.

The role of transformers in electricity sub-stations is to progressively reduce the voltage as it comes closer to the consumer. At each stage, the output voltage is chosen to match the power demand and the distances over which supply is needed.



Questions

Electrical power is delivered to a city through a $4.0\ \Omega$ resistance cable at $500\ \text{kV}$.

Question 39:

$40\ \text{MW}$ is transmitted, what current must be flowing through the cable?

Question 40:

Calculate the percentage power loss

Question 41:

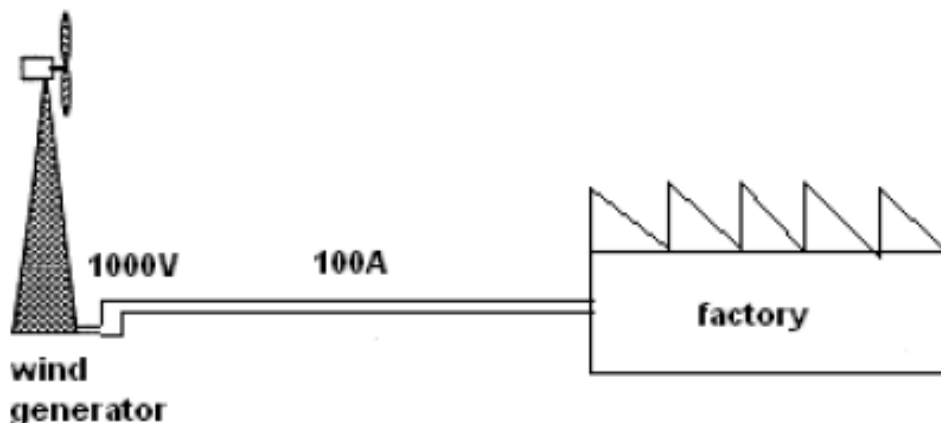
What is the voltage drop across the transmission system?

Question 42:

Explain why it is advantageous to transmit at a very high voltage

Question 43:

A factory acquires electricity from a wind generator located 2km away. The generator supplies a constant 1000V and 100A when there is a moderate wind blowing. The resistance of the transmission system is 2 ohms.



What power is supplied by the generator?

Question 44:

How much power is lost in the transmission system?

Question 45:

Describe one method for reducing the power lost through the transmission system?

Question 46:

An electrician is planning a new power supply to a farm house. The house is 1.0 km from the existing supply.

At this supply point there is a choice of either a high voltage 11 000 VRMS AC or a lower voltage 240 VRMS AC supply. All of the appliances in the house require 240 VRMS AC and the expected maximum power demand (load) is 12 000 W. The owner is keen to avoid the cost of a transformer, and so initially plans to use a 1.0 km supply line to the house from the 240 VRMS supply.

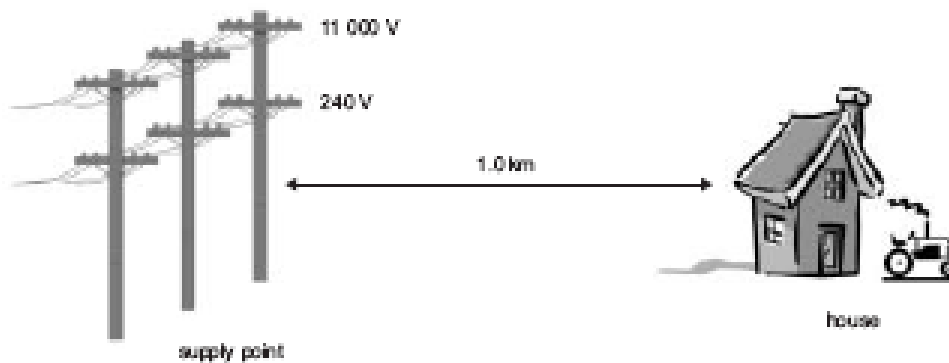


Figure 4

The electrician connects the house to the 240 VRMS supply using lines with a total resistance of 2.0Ω . Some of the appliances in the house are turned on to test the new supply. Measurements reveal that, under these test conditions, the current flowing is 30 A. Calculate the power loss in the supply lines from the road to the house when the current flowing is 30 A.

Question 47 :

What would be the voltage measured at the house when the current is 30 A?

Question 48:

The electrician suggests that using the 11 000 VRMS supply with a step-down transformer at the house could deliver the same amount of power to the house, with a significant reduction in the power loss in the supply lines. Comment