Unit 4
Electromagnetism

Introduction

- Electromagnetism: is one of the fundamental forces in nature consisting of the elements electricity and magnetism.
    - It involves the study of electromagnetic force.
    - The electromagnetic force is carried by electromagnetic fields composed of electric fields and magnetic fields.
- When electrically charged particles, such as electrons, are put into motion, they create a magnetic field.
    - When these particles are made to oscillate, they create electromagnetic radiation such as radio waves.
- The discovery of electromagnetism marked the birth of modern science and technology

4.1 Magnets and Magnetic field

- A magnet generates a magnetic field which represents the magnetic force existing in the region around the magnet.
    - Every magnet has two poles: a north pole (N) and a south pole (S)
    - Like poles (N-N or S-S) repel each other, and
    - opposite poles (N-S) attract each other
- The force between two magnetic poles is similar to the force between two electric charges,
    - Electric charges can be isolated (as a positive and negative charge), whereas
    - It is not possible to separate the north and south poles of a magnet.
    - Magnetic poles are always found in pairs.
    - No matter how many times a permanent magnet is cut in to two, each piece always has a north and a south pole.
- Permanent and electromagnet: are the two major types of materials that exhibit magnetic properties.
- Permanent magnets are materials where the magnetic field is generated by the internal structure of the material itself.
    - Thus, once the permanent magnets are magnetized then they hold their magnetic property for a very long time.
- Electromagnets usually consist of wire wound into a coil.
    - The electromagnet generates a magnetic field when an electric current is provided to it

- It loses its magnetism when the current is off.

- Magnetic Field is the region around a magnet or a moving electric charge within which the force of magnetism acts.
    - It is a vector quantity and the vector points in the direction that a compass would point.

Differences between Electric Field and Magnetic Field

- The SI unit of an electric field is Newton/coulomb, whereas the SI unit of magnetic field is Tesla.
- The region around the electric charge where the electric force exists is called an electric field.
- The region around the magnet where the pole of the magnet exhibits a force of attraction or repulsion is called a magnetic field.
- The electric field produces by a unit pole charge, i.e., either by a positive or through a negative charge, whereas the magnetic field caused by a dipole of the magnet (i.e., the North and South Pole).
- The electric field lines start on a positive charge and end on a negative charge, whereas the magnetic field lines do not have starting and ending point.
- The electric field lines do not form a loop whereas the magnetic field lines form a closed loop.

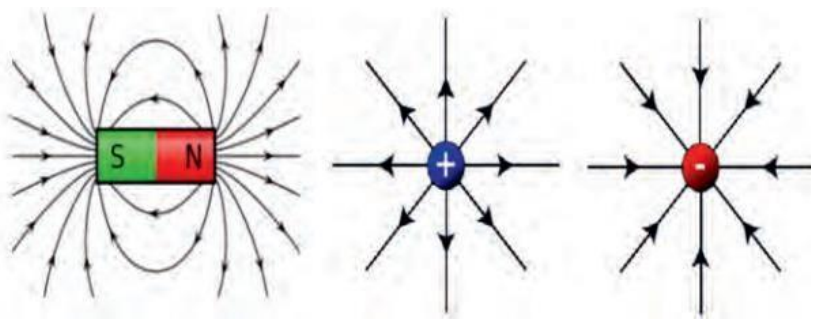

Figure 4.1Comparison of Magnetic and electric field lines.

Exercise 4.1:

1. Which one of the following is false about magnets ? A. A magnet generates a magnetic field. B. Every magnet has two poles. C. Like poles attract each other. D. The magnetic field is stronger at the poles.
2. An electromagnet loses its magnetism when the electric current is off. A. True B. False
3. Define magnetic field.
4. Mention some difference between electric field and magnetic field.
5. Explain the difference between permanent magnet and electromagnet.

4.2 Magnetic field lines

- Magnetic field lines are imaginary lines or a visual tool used to represent magnetic fields.
  - The density of the lines indicates the magnitude of the field

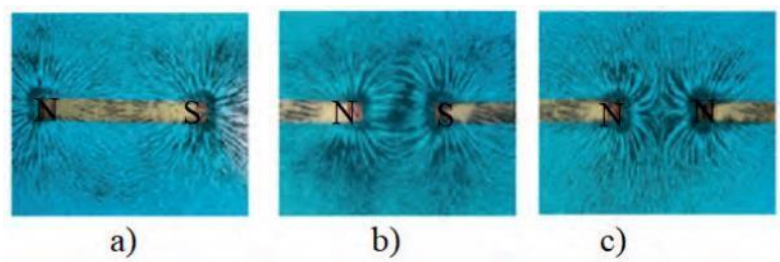

Figure 4.1 a) Magnetic field pattern surrounding a bar magnet b) Magnetic field pattern between opposite poles (N–S) of two bar magnets and c) Magnetic field pattern between like poles (N–N) of two bar magnets.

Properties of Magnetic Field Lines

- Field lines have both direction and magnitude at any point on the field.
  - The direction of the magnetic field is tangent to the field line at any point in space.
  - A small compass placed in a magnetic field will point in the direction of the field line.
- The strength of the field is proportional to the closeness of the lines.
- Magnetic field lines can never cross each other, meaning that the field is unique at any point in space.
- Unlike electric field lines, magnetic field lines are continuous, forming closed loops without beginning or end.
- The field lines emerge from North Pole and merge at the South Pole (note the arrows marked on the field lines in Figure 4.2).
  - Inside the magnet, the direction of field lines is from its south pole to its north pole. Thus the magnetic field lines are closed curves.

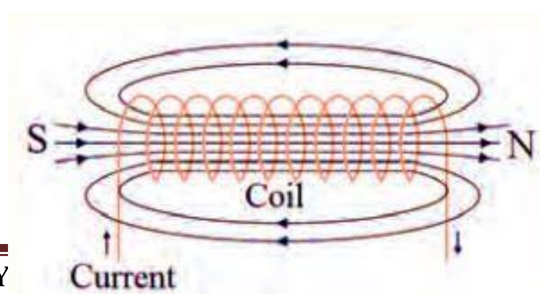

Figure 4.2 Magnetic field lines of electromagnet.

Exercise 4.2

1. Define magnetic field lines.
2. The magnetic field lines are denser where the magnetic field is stronger. A. True B. False
3. Mention som properties of magnetic field lines.
4. Which of the following is true about magnetic field lines ? A. They form closed loops. B. They never intersect each other. C. The magnetic field lines are crowded near the pole. D. All are true

4.3 Current and Magnetism

- Whenever a current passes through a conductor, a magnetic field is produced.
  - A compass placed near a current-carrying conductor will always point in the direction of the magnetic field lines produced.
  - As soon as the current is off there is no magnetic field. This is because the magnetic field is generated by the electric current (moving charges).

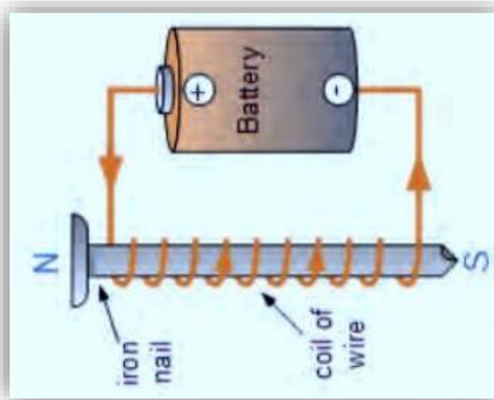

Figure 4.3 a basic configuration of electromagnet.

Ampere's law: can be stated as:

- ✓ "The magnetic field created by an electric current is proportional to the size of that electric current with a constant of proportionality equal to the permeability of free space."
- ✓ As the current through the conductor increases, the magnetic field increases proportionally.

Magnetic Field Created by a Long Straight Current-Carrying Wire

- The magnitude of the magnetic field at a point a distance r from a long straight current carrying wire is given by:

$$\mathbf{B} = \frac{\mu_0 I}{2\pi r}$$

  Where μ_0 is permeability of free space, $\mu_0 = 4\pi\times10^{-7}$ T.m/A and
  r is the distance from the wire where the magnetic field is calculated.
  I is the current through the wire.
- The SI unit of magnetic field is Tesla (T). The other common unit of magnetic field is gauss (G). Gauss is related to the Tesla through the conversion $1T = 10^4$ G.
- The magnetic field has both magnitude and direction.
  - The direction of magnetic field is determined by the right hand rule
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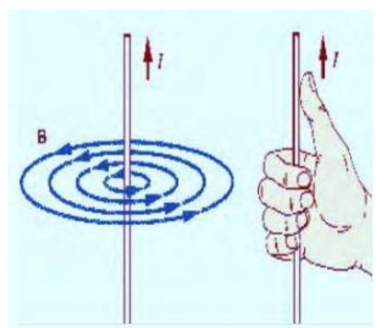


Figure 4.4 applying the right hand rule to find the direction of the magnetic field around a currentcarrying wire.

- The magnetic fields produced by a current flowing in a straight wire have the following properties.
  - The magnetic field lines form a circular pattern.
  - The magnetic field strength increases when current increases.
  - The magnetic field strength is stronger near the wire and weaker further away.
  - When the direction of the current is reversed, the direction of the magnetic field is reversed too.

Magnetic force

- A current-carrying wire that has a magnetic field perpendicular to it will experience a force.
  - F = B × I × L
  - The strength of the magnetic field, which is given the symbol B, produced by a current-carrying wire, depends on:
  - the force, F

- the current flowing through the wire, I
- the length of the wire,

Magnetic force between two parallel current–carrying conductors

- Two parallel wires each carrying a current will interact with each other.
- If the currents are both flowing the same way, they attract one another;
- with currents going opposite ways they rep

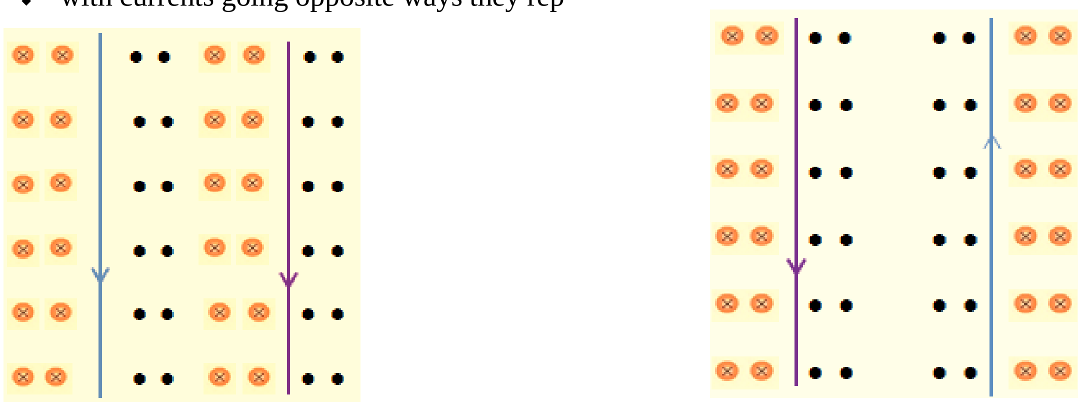


Figure 4.5 Magnetic forces between two parallel current carrying conductors.

Magnetic fields and the centripetal force

- A charged particle moving in a magnetic field will move in a circular path.

$$F = Bqv$$

- We know that the centripetal force can be found using the equation:

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

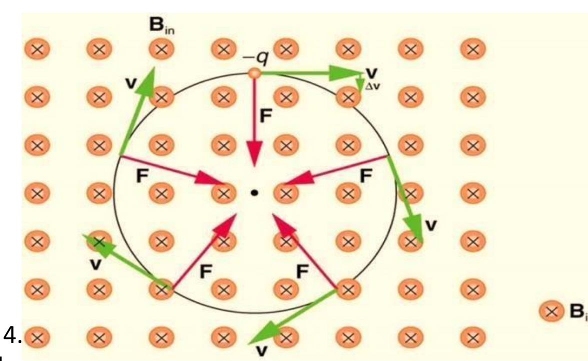


Figure 4. magneticfield

- If we make the two equations equal (that is, we assume that the force is the same in both), we can say that:

$$Bqv = \frac{mv^2}{r} \Rightarrow B = \frac{mvq}{r}$$

Magnetic field of a solenoid

- A solenoid is a coil of wire that has a number of loops
  - The currents in each side of the coil both contribute to the overall magnetic field.

- The field is strong in the center of the coil but weaker outside the coil

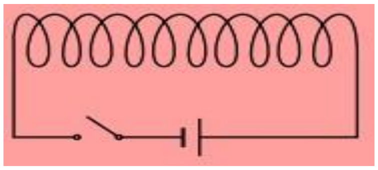


Figure 4.7 A solenoid can be attached to a switch to allow current to be passed through.

The strength of the magnetic field in a solenoid depends on:

- The number of turns of wire per meter of length, n.
- The permeability of free space, μ.
- the current flowing through the wire, I
- $B = \mu_0 nI$ where $n = \frac{N}{l}$

Example: A solenoid has 1000 turns per meter and has a current of 2 A passing through it. Work out thefield strength at its center. The permeability of free space is $4\pi \times 10^{-7}$ H/m.

Example 4.1

Find the current in a long straight wire that would produce a magnetic field twicethe strength of the Earth's magnetic field (The Earth's magnetic field is about$5.0{\times}10^{-5}T$) at a distance of 5.0 cm from the wire

Solution:

Magnetic field due the earth (B_E) is $5x10^{-5}$ T.

Magnetic field due the current carryng wire B is $B=2B_E = 2x5x10^{-5}$ T$=1x10^{-4}$ T. The equation $B = \mu_0 I/2\pi r$ can be used to find I, since all other quantities areknown. Solving for I and entering known values gives

$$I = \frac{2\pi r B}{\mu_0}$$

$$I = \frac{2\pi(5\,X10^{-2}\ m)(1\,x\,10^{-4}\,T}{4\pi\ x\ 10^{-7}T.m/A} = 25A$$

Table 4.1 shows some Approximate magnitudes of magnetic fields

Source of field	**Field Magnitude (T)**
Strong superconducting laboratory Magnet	30
Strong conventional laboratory magnet	2
Medical MRI unit	1.5
Bar magnet	10^{-2}
Surface of the sun	10-2
Surface of the Earth	$0.5x10^{-4}$
Inside human brain (due to nerve impulses)	10^{-13}

4.4 Electromagnetic Induction

- 1831, Michael Faraday discovered that magnets could be used to generate electricity.
- A changing or variable magnetic field can produce an electromotive force (emf).
  - ✓ This e.m.f produces an induced current in a closed circuit.
  - ✓ this effect is called electromagnetic induction
  - ✓ Electromagnetic induction the production of voltage across a conductor moving through a stationary magnetic field
  - ✓ Electromagnetic induction, also known as the dynamo effect

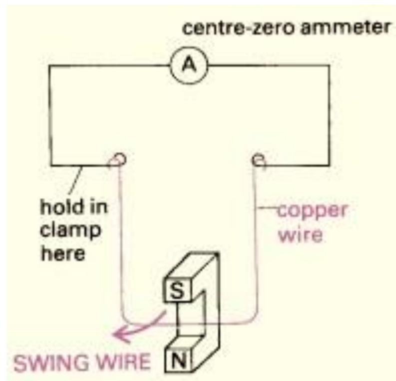


Figure 4.8 How to demonstrate the dynamo effect

- ✓ induced e.m.f. voltage produced by electromagnetic induction

MAGNETIC FLUX

Magnetic flux: is a measurement of the total magnetic lines of force which passes through a given area A

$\Phi_B = B.A = B\,A\cos\theta$

Where θ is the angle between B and A

Figure 4.9 A plane of surface area Aplaced in a uniform magnetic field.

The SI unit of magnetic flux is weber (wb)

Example 4.2 A square loop of side 3 cm is positioned in a uniform magnetic field of magnitude 0.5 T so that the plane of the loop makes an angle of 60° with the magnetic field . Find the flux passing through the square loop?

Given

r= 3 cm =3 x10^{-2} m A =r ^{2} =[3 x 10^{-2} m)]^2 = 9 x 10^{-4} m^2 (since the loop is square)

B=0.5 T

$\alpha = 60°$ (The angle between the plane and magnetic field)

Therefore $\theta = 30°$ (since always the normal line of the plane and surface area are perpendicular to each other ,the angle between magnetic field and area surface become $90° - 60° = 30°$)

Required

$\emptyset$=?

Solution

$\emptyset = BAcos\theta$ = 0.5 T X 9 x 10^{-4} m^2 cos30° = 0.39 mWb

Exercise 4.4:

1. Define magnetic flux.
2. A circular loop of area 200 cm^2 sits in the xz plane. If a uniform magnetic field of $\vec{B}$= 0.5 T is applied on it. Determine the magnetic flux through the square loop?
3. The magnetic flux is maximum when the angle between magnetic field lines and the line perpendicular to the plane of the area is:
A. 0^o B.90^0 C .45^0 D.30^0
4. A magnetic field of 2.5T passes perpendicular through a disc of radius 2cm. Find the magnetic flux

4.5 Faraday's Law of electromagnetic induction

associated with the disc.

- The dynamo effect occurs when the conductor cuts through a magnetic field (magnetic flux lines.)

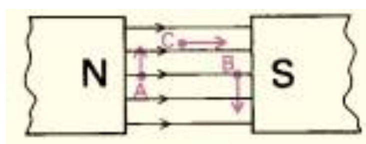


Figure 4.10 An end-on view of a wire being moved between the poles of a magnet.

Faraday's law states that the magnitude of the induced electromotive force (emf) is directly proportional to the rate of change of the magnetic flux in a closed coil.

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

- In the case of a closely wound coil of N turns, change of flux associated with each

$$\varepsilon = -N\frac{\Delta\Phi_B}{\Delta t}$$

Where ε is induced e.m.f.

$\Delta\Phi_B$ is change on magnetic flux

Δt is change in time

The negative sign is involved according to Lenz's law.

- Lenz's law states that the direction of the induced current in the coil is such that it opposes the change that causes the induced emf.
- Lenz's law depends on the principle of conservation of energy and Newton's third law.
- There are three ways to double the voltage that is generated.
  - ✓ Move the magnet in at twice the speed (Faraday's law).
  - ✓ Use a magnet that is twice as strong (Faraday's law again).
  - ✓ Have twice as many turns on the coil

Example 4.3: A square loop of side 10 cm and resistance 0.5 Ω is placed vertically in the east-west plane. A uniform magnetic field of 0.10 T is set up across the plane in the northeast direction. The magnetic field is decreased to zero in 0.70 s at a steady rate. Determine the magnitudes of induced emf and current during this time-interval.

Solution: The angle θ made by the area vector of the coil with the magnetic field is 45° . From the Equation of magnetic flux:

$\emptyset = BA\cos\theta$

the initial magnetic flux is:

$\emptyset i = B_i A\cos\theta$

$\emptyset i = \frac{0.1\,T \, x\, 10^{-2} m^2}{\sqrt{2}} = 7.1 \, x \, 10^{-4} \, wb$

$\emptyset f = 0$

The change in flux is brought about in 0.70 s. The magnitude of the induced emf is given by:

$$\varepsilon = -\frac{|\Delta\emptyset_B|}{\Delta t} = \frac{|\emptyset_f - \emptyset_i|}{\Delta t} = \frac{7.1 \, x \, 10^{-4} wb}{0.7 \, s} = 1.01\text{mV}$$

And the magnitude of the current is :-

$$I = \frac{\varepsilon}{R} = \frac{1.01mV}{0.5\Omega} = 2.01\text{mA}$$

Inductors

- An inductor is essentially an electromagnet. The iron core that becomes magnetized when you send a current through a solenoid is not part of the actual circuit, but instead relies on the magnetic field associated with the electric current flowing round the coil
- The symbol for an air-cored inductor is

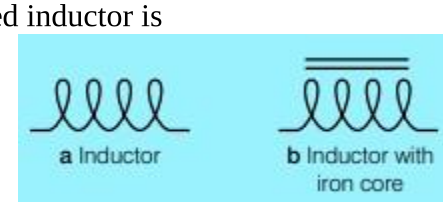


Figure 4.11 a Air-cored inductor b iron-cored inductor

- All electromagnets possess inductance
- Inductance is defined as the property in an electrical circuit where a change in the electric current through that circuit induces an e.m.f. that opposes the change in current.

Self-inductance

- Self-inductance the ratio of the electromotive force produced in a circuit by self-induction to the rate of change of current producing it.
  - ✓ The induced e.m.f. depends on the rate at which the current in the coil is changing.
  - ✓ Induced e.m.f. = a constant × the rate of change of the current.
  - ✓ induced e.m.f. = L × the rate of change of current through the coil

$$\varepsilon_{\mathbf{in}} = \frac{L\Delta I}{\Delta t}$$

  - ✓ The SI unit of inductance will be V/A s, which is named the henry, H.
- The value of that constant depends on
  - ✓ the coil itself
  - ✓ its geometry,
  - ✓ the number of turns on it, what its core is made from − and
  - ✓ Represents its self-inductance.

MUTUAL INDUCTANCE

- Two coils in separate circuits can show what is called not self-inductance but mutual inductance.
  - ✓ When the current is changing in one circuit, its changing magnetic field cuts through the other circuit and induces a voltage in it.
  - ✓ The faster the current in one changes, the greater the e.m.f. induced in the other. This linkage between the two circuits is described as mutual inductance
- The mutual inductance M of a pair of circuits is defined by:
  - ✓ e.m.f. induced in one circuit = M × (rate of change of current in the other circuit)

$$\varepsilon_{\mathbf{ind}} = \frac{M\,\Delta I_2}{\Delta t}$$

  - ✓ The unit of M will also be the henry, H.

Exercise 4.5

The emf induced in a coil can be increased by: A. increasing the numberof turns in the coil (N). B. increasing magnetic field strength surroundingthe coil. C. increasing the speed of the relative motion between the coil and the magnet. D. All

Faraday's Law states that the induced voltage or emf is proportional to:
A. the resistance of the coil B. the cross sectional area of the coil. C. therate of change of the magnetic flux in the coil. D. All

3. Lenz's law is the result of the law of conservation of: A. mass B. charge
C. energy D. Momentum

In Lenz's law the induced emf opposes the magnetic flux. A. True B. False

a) Calculate the induced emf when a coil of 100 turns is subjected to a magnetic flux change at the rate of 0.04Wb/s. b) Calculate the induced current if the resistance of the coil is 0.08Ohm.

4.6 Transformers

- Transformer is an electrical device that transfers electrical energy from one circuit to another through the process of electromagnetic induction.
- It is most commonly used to increase ('step up') or decrease ('step down') voltage levels between circuits without altering the frequency.
- the main purpose of transformers is to change the size of a voltage
- A transformer is simply a pair of coils wound on the same core.
  - ✓ The core is often shaped as a square loop with primary and secondary coils wound on opposite sides.
  - ✓ The construction of a transformer allows the magnetic flux generated by a current changing in one coil to induce a current in the neighboring coil

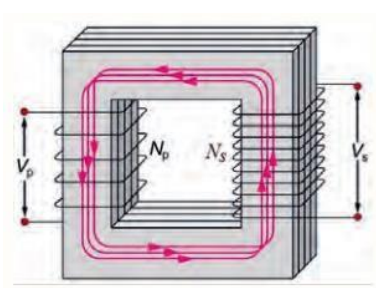


Figure 4.12 Transformers.

- The operating principle of a transformer is based on electromagnetic induction.
- The current from the electrical supply that is connected to the primary coil is an alternating current.
  - ✓ An alternating current is a current whose magnitude and direction varies or

changes continuously at a certain frequency.

- ✓ The alternating current produces a flux or magnetic field lines which link the primary and the secondary coils.

- ❖ The magnetic flux varies in magnitude and direction.

Types of transformer

1. A Step-up Transformer
   - ✓ Converts the low primary voltage to a high secondary voltage and steps up the input voltage.
   - ✓ In Step-up Transformer secondary coil has the greater number of turns than primary coil $N_s > N_p$ and $V_s > V_p$
2. A step-down transformer
   - ✓ Steps down the input voltage.

$N_p > N_s$ and $V_p > V_s$

- ❖ The primary and secondary windings are electrically isolated from each other but are magnetically linked through the common core allowing electrical power to be transferred from one coil to the other.
- ➢ The relationship between the voltage applied to the primary winding V_P and the voltage produced on the secondary winding V_S is given by

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

Where N_P and N_S are number of primary and secondary turns V_P and V_S are primary and secondary volts respectively.

- ➢ For a transformer operating at a constant AC voltage and frequency its efficiency can be as high as 98%. The efficiency, η of a transformer is given as:

$$\textbf{Efficiency, } \eta = \frac{\textbf{Output power}}{\textbf{Input power}} \times 100\%$$

Example 4.4: A transformer has a primary and a secondary coil with the number of loops of 500 and 5000 respectively. If the input voltage is 220 V. What is the output voltage?

The ideal transformer equation

- There are two ways in which a transformer may heat up:
  - ✓ Eddy currents may be induced in the iron core. Laminating the core has very nearly solved this problem.
  - ✓ The resistance (in ohms) of the windings of the coils themselves could cause heating. However, the wires are made from a low resistance metal, such as copper, and are thick enough to cope with the currents expected.
    In general, therefore, for a transformer:

$$V_{out} \times I_{out} = V_{in} \times I_i$$

$$\frac{I_{out}}{I_{in}} = \frac{V_{in}}{V_s} = \frac{N_p}{N_s}$$

Working principles of Transformer in house appliances

- Transformer in real life is a commonly used circuit that can either step up the voltage of incoming current or step down the voltage of incoming current.
- Transformers are used in various fields like
  - ✓ Power generation grid,
  - ✓ Distribution sector,
  - ✓ Transmission and electric energy consumption.

- Transformer in Chargers: There are many appliances that use transformers in their circuit.
  - ✓ Your phone, laptop, computer, tablet power supplies have transformers in them. They step the voltage down to a safe voltage that will not harm you to charge your device battery.

  - ✓ A mobile phone charger also contains a rectifier. After Stepping down the voltage, AC is converted to DC using the rectifier.
- Microwave uses a step up transformer to provide a high voltage to make microwaves to cook food.

Exercise 4.6

1. A transformer has primary coil with 1200 loops and secondary coil with 1000 loops. If the current in the primary coil is 4 Ampere, then what is the current in the secondary coil.
2. Calculate the turn ratio to step 110 V AC down to 20 V AC.
3. Why does a transformer can not raise or lower the voltage of a DC supply? Explain your answer.

4.7 Applications and safety of Electromagnetism

Over the last 200 years, physicists have discovered a lot about the natural world. A lot of the time, when that knowledge is first discovered it seems pretty useless, but it almost always leads to applications later.

Now the modern society has numerous applications of electromagnetism. Some computer hard drives apply the principle of electromagnetism to record information. Historically, reading these data was made to work on the principle of electromagnetic induction. However, most input information today is carried in digital rather than analogue form a series of 0s or 1s are written upon the spinning hard drive.

Figure 4.17 A tablet with a specially designed pen to write with is another application of magnetic induction.

Graphics tablets, or tablet computers where a specially designed pen is used to draw digital images, also applies electromagnetic induction principles. This tablets is different than the touch tablets and phones many of us use regularly, but it is still be found when signing your signature at a cash register. Underneath the screen, shown in Figure 4.17, there are tiny wires running across the length and width of the screen. The pen has a tiny magnetic field coming from the tip. As the tip brushes across the screen, a changing magnetic field is felt in the wires which translates into an induced emf that is converted into the line you just drew.

APPLICATIONS OF ELECTROMAGNETISM

- Today, there are countless applications for electromagnetism, ranging from large scale industrial machinery, to small-scale electronic components.
- These machines can be electric motors, generators, transformers or other similar devices.
- All of these work with the principles related to electromagnetism.
- The principle of Ampere's law is used in solenoid, straight wire,cylindrical conductor and toroidal solenoid.

Electromagnets at Home or School

- Electromagnets are used for various purposes on a day-to-day basis. For example,
  - ✓ in electric bells,
  - ✓ headphones,
  - ✓ loudspeakers,
  - ✓ Magnetic relays,
  - ✓ MRI machines,
  - ✓ electric fan,
  - ✓ electric doorbell,
  - ✓ magnetic locks, and others

A magnetic relay: is a switch or circuit breaker that can be activated into the 'ON' and 'OFF' positions magnetically. One example is the low-power reed relay used in telephone equipment, which consists of two flat nickel–iron blades separated by a small gap.

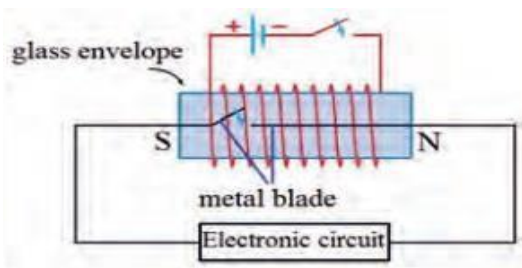
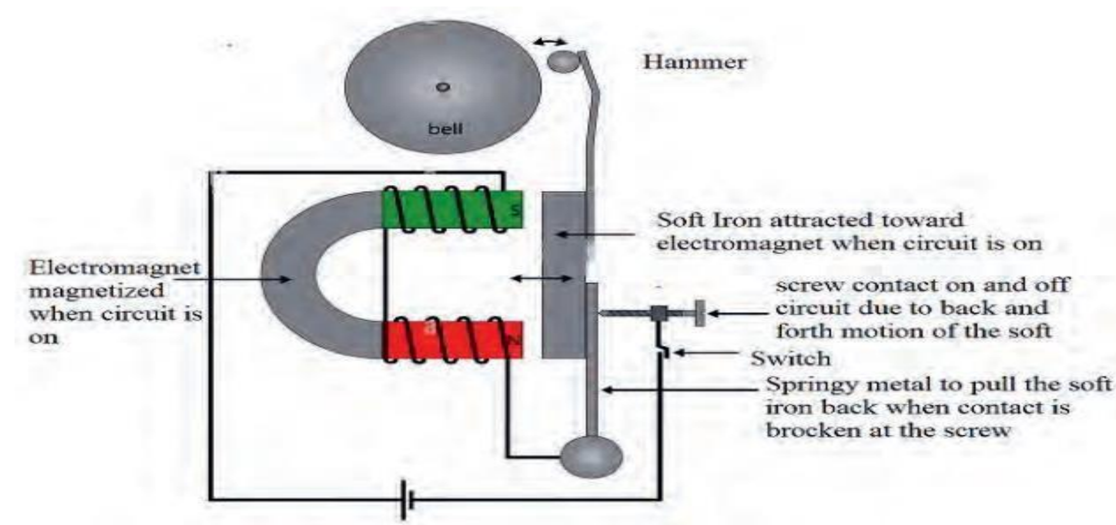


Figure 4.13 Magnetic switch circuits

Electric bell: is based on the principle of electromagnetism. When the switch is pressed on, the electromagnet is activated and it attracts the soft iron towards the electromagnet. At this time, the hammer moves and hits the bell.



ELECTROMAGNETISM

Figure 4.14 Electric bell

DC Electric Motor: Freely rotating loop is placed between two permanent magnets whose poles facing each other with a sufficient space between them to allow rotation of the loop. Connecting the ends of the loop to battery terminals makes the loop an electromagnet.

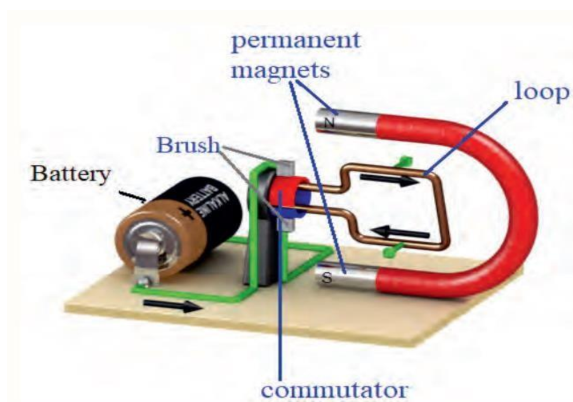


Figure 4.15 DC electric motor.

AC generator is a mechanical device that converts mechanical energy into electrical energy in the form of alternate electromotive force (emf).

- ✓ For example, the electricity generated at various power plants is produced by the generators installed there.
- ✓ Faraday's Law of electromagnetic induction governs the operation of an AC generator.

An electromagnet: can affect monitors for computers or television sets. For classic cathode ray tube (CRT) television sets, powerful magnets can distort the images on the screen when they come close to them. This is because the magnets deflect the beam of electrons that the television sends to produce an image.

Unit summary

- Magnetic Field is the region around a magnetic material or a moving electric charge within which the force of magnetism acts.
- A magnetic pole is the part of a magnet that exerts the strongest force on other magnets or magnetic material.
- Like poles (N-N or S-S) repel each other, and unlike poles (N-S) attract each other.
- Magnetic poles are always found in pairs. No matter how many times a permanent magnet is cut in two, each piece always has a north and a south pole.
- Once permanent magnets are magnetized then they hold their magnetic property for a very long time.
- An electromagnet generates a magnetic field when an electric current is provided to it and it loses its magnetism when the current is off.
- The Earth magnetic field behaves like a giant bar magnet inside the Earth.
- Magnetic field lines are imaginary lines used to represent magnetic fields.
- When we sprinkle iron filings around a magnet, the iron filings will orient themselves along the magnetic field lines.
- The strength of the field is proportional to the closeness of the lines.
- Magnetic field lines can never cross, meaning that the field is unique at any point in space.
- Magnetic field lines are continuous, forming closed loops without beginning or end.
- Ampere’s law states that the magnetic field around an electric current is proportional to the current.
- The SI unit of magnetic field is Tesla(T):
- The direction of a magnetic field around a wire carrying a current is given by Fleming’s Right Hand Rule.
- The principle of Ampere’s law is applied in solenoid, straight wire,cylindrical conductor and toroidal solenoid.

- Michael Faraday showed that a changing magnetic field can produce an electromotive force in a closed circuit.
- Electromagnetic induction is a phenomenon in which the relative motion between a conductor and a magnetic field produces an emf across the conductor.
- Magnetic flux is a measurement of the total magnetic lines of force which passes through a given area *A*.
- For a plane of surface area *A* placed in a uniform magnetic field *B*, magnetic flux Φ is mathematically written as:

  $\Phi = B.A = BA \cos \theta$
- The SI unit of magnetic flusx is Weber(Wb).
- Faraday's law of electromagnetic induction states that whenever a conductor is placed in a varying magnetic field, an electromotive force is induced. If the conductor circuit is closed, a current is induced, which is called induced current.
- The time rate of change of magnetic flux through a circuit induces emf in it given by:

  $\varepsilon = \frac{\Delta \emptyset_B}{\Delta t}$
- The direction of induced current in the coil is such that it opposes the change that causes the induced emf
- Lenz' s law confirms the general principle of the law conservation of energy.
- A transformer is an electrical device that transfers electrical energy from one circuit to another through the process of electromagnetic induction.
- It is commonly used to increase (step up) or decrease (step down) voltage levels between circuits with out altering the frequency.
- A Step-up Transformer steps up the input voltage. On the other hand, a step-down transformer steps down the input voltage.
- The operating principle of a transformer is based on electromagnetic induction.
- The relationship between the voltage applied to the primary winding V_P

and the voltage produced on the secondary winding V_S is given by

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

- Electromagnets are used in generators, motors, transformers, electric bells, headphones, loudspeakers, relays, MRI machines and others.

- Some electromagnet uses in the home include an electric fan, electric doorbell, induction cooker, magnetic locks, etc

End of unit questions and problems

1. A long straight wire carries a current of 10 A. At what distance from the wire will a magnetic field of 8 x 10^{-4} T be produced?
2. A closed coil of 40 turns and of area 200 cm^2, is rotated in a magnetic fieldof flux density 2 Wb m^{-2}. It rotates from a position where its planemakes an angle of 30^0 with the field to a position perpendicular tothe field in a time 0.2 sec. Find the magnitude of the emf induced in the coil due to its rotation.
3. A portable x-ray unit has a step-up transformer, the 120 V input of whichis transformed to the 100 kV output needed by the x-ray tube. primary has 50 loops and draws a current of 10.00 A when in use. (a) What is the number of loops in the secondary? (b) Find the current output of the secondary.
4. A 500 turns coil develops an average induced voltage of 60 V. Over what time interval must a flux change of 0.06 Wb occur to produce such a voltage?
5. Calculate the voltage output by the secondary winding of a transformer if the primary voltage is 35 volts, the secondary winding has 4500 turns, and the primary winding has 355 turns.
6. A circular loop with a radius of 20 cm is positioned perpendicular to a uniform magnetic field, the magnetic flux that passes through the loop is $1.9x10^{-2}Wb$. What is the magnetic flux density?
7. A uniform magnetic field has a magnitude of 0.1T. What is the flux through a rectangular piece of cardboard of sides 3cm by 2cm perpendicular to the field?
8. A coil of wire 1250 turns is cutting a flux of 5mWb. The flux is reversed in an interval of 0.125 sec. Calculate the average value of the induced emf in the coil.
9. A 150 W transformer has an input voltage of 10V and an output current of 5A. a). is this step-upmor step down transformer? b). what is the ratio of Vout to Vin?
10. Determine the magnetic field strength at a point 5cm from a wire carrying a current of 10A