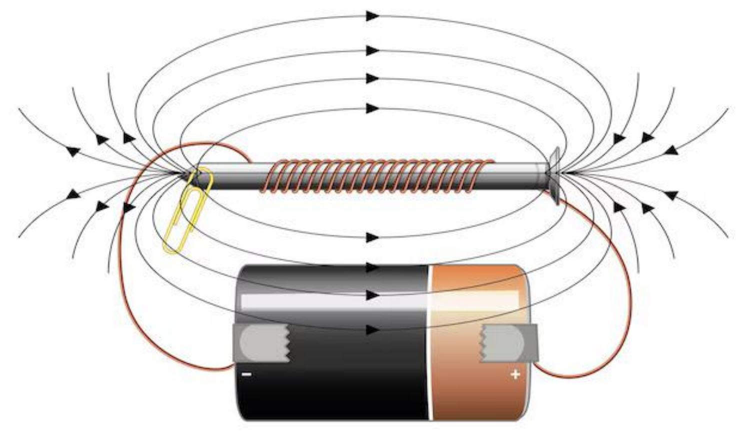
DYNAMO

Grade 12 I Physics I Unit 4

Electromagnetism



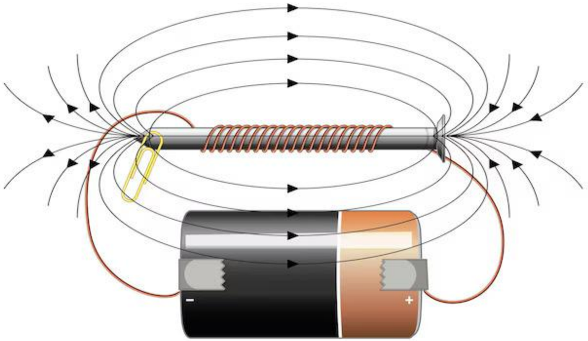
- Introduction
- 4.1 Magnets and Magnetic field

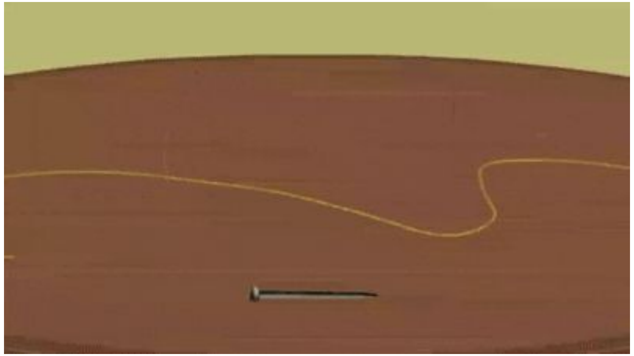
Introduction

- Electromagnetism is one of the fundamental force in nature consisting of the elements electricity and magnetism.

- Electromagnetism is related to the electromagnetic force that causes the attraction and repulsion of electrically charged particles.

- When electrically charged particles, such as electrons ,are put into motion,they create a magnetic field.

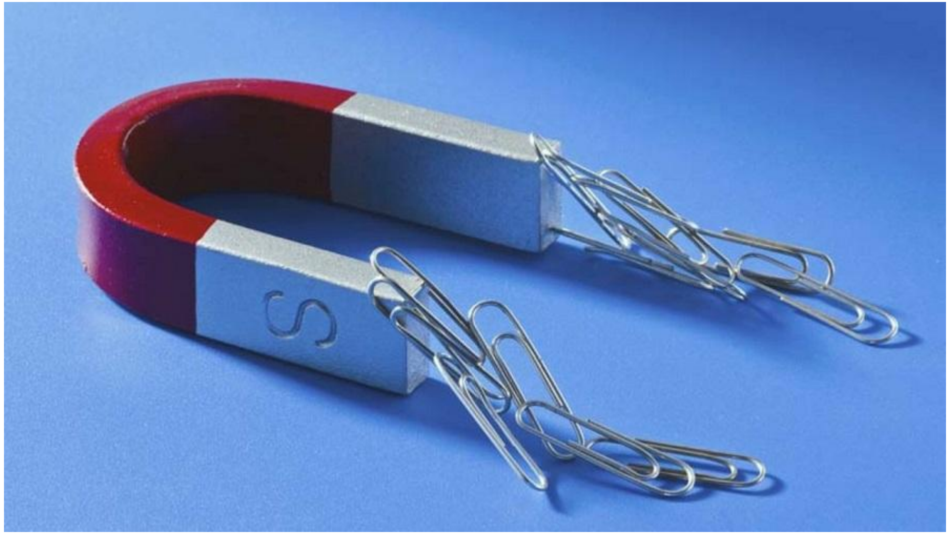




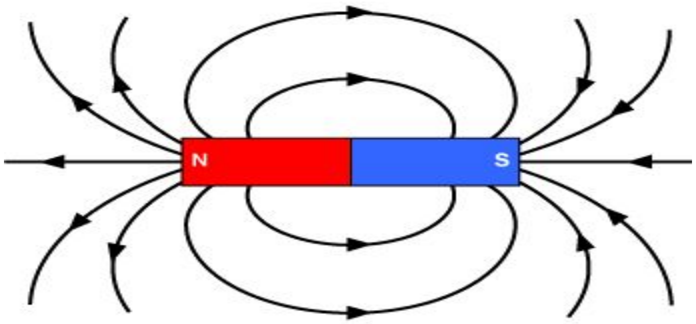
- Devices such radios, televisions, computers, tape recorders, CD players, electric motors, and generators, use the principles of electromagnetism.

4.1 Magnets and Magnetic field

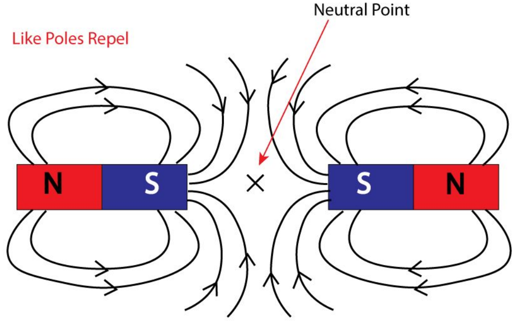
- A magnet generates a magnetic field which represents the magnetic force existing in the region around the magnet.
- A magnetic pole is the part of a magnet that exerts the strongest force on other magnets or magnetic material, such as iron,nickel and cobalt.



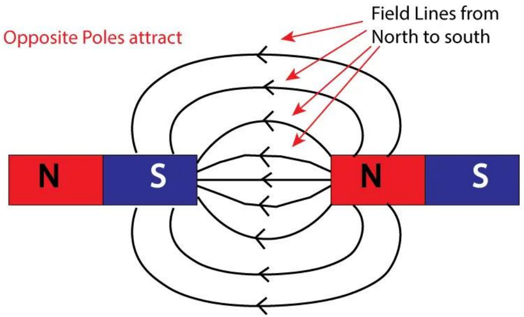
➢ Every magnet has two poles: a north pole(N) and a south pole(S).



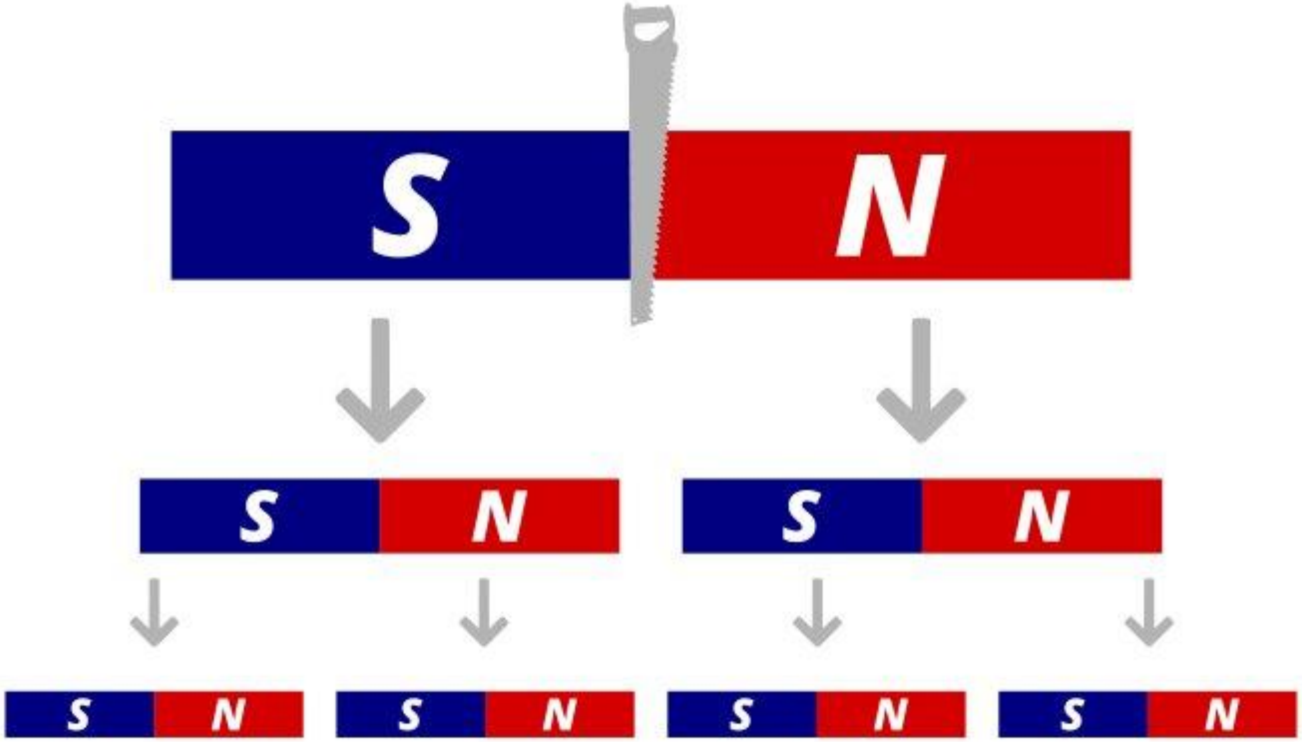
- Like poles(N-N or S-S) repel each other



- Opposite poles (N-S) attract each other

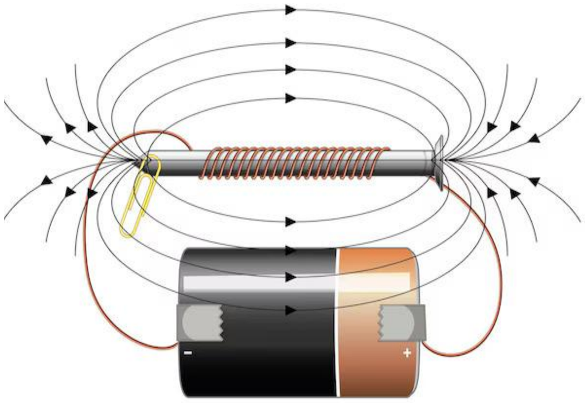


Magnetic poles are always found in pairs. No matter how many times a permanent magnet is cut into two each piece always has a north and a southpole.



➢ **Permanent magnets** are materials where the magnetic field is generated by the internal structure of the material itself.

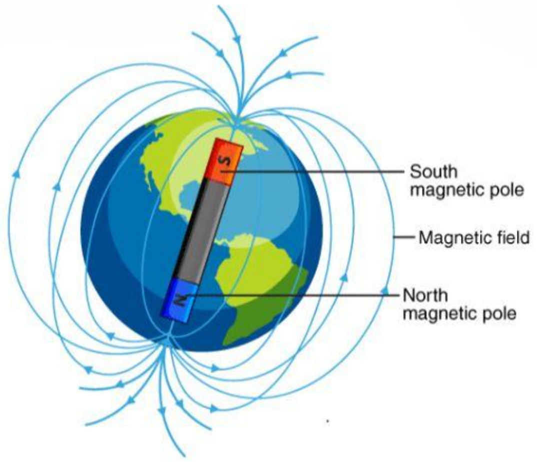
➢ **An electro magnets** usually consist of wire wound into a coil.it generates a magnetic field when an electric current is provided to it.



➢ The Earth has a magnetic field. The magnetic field behaves like a giant bar magnet.

➢ Inside the Earth,with the North magnetic pole corresponding to the South Geographic Pole and vice versa.

➢ Magnetic field is a vector quantity and the vector points in the direction that a compass would point.



Differences Between Electric Field and Magnetic Field

Electric field	Magnetic field
SI unit Newton/coulomb	SI unit Tesla.
Produced by a unit pole charge Either by a positive or through a negative charge	Caused by a dipole of the magnet
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.
lines start on a positive charge and end on a negative charge	line do not have starting and ending point
Lines Do not form a loop	lines form a closed loop

Exercise 4.1

1. Which one of the following is false about magnets?

   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 electro magnet loses its magnetism when the electric current is off.

   A. True B. False

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Exercise 4.1

3. Define magnetic field.

Answer

- Magnetic field is the region around magnet where magnetic force is detected.

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Exercise 4.1

4. Mention some difference between electric field and magnetic field.

Electric field	Magnetic field
SI unit Newton/coulomb	SI unit Tesla.
Produced by a unit pole charge Either by a positive or through a negative charge	Caused by a dipole of the magnet
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.
lines start on a positive charge and end on a negative charge	line do not have starting and ending point
Lines Do not form a loop	lines form a closed loop

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Exercise 4.1

5. Explain the difference between permanent magnet and electromagnet.

Answer

- Permanent magnets are materials where the magnetic field generated by the internal structure of the material itself.

- The electromagnet generates a magnetic field when an electric current is provided to it and it loses magnetism when the current is off.

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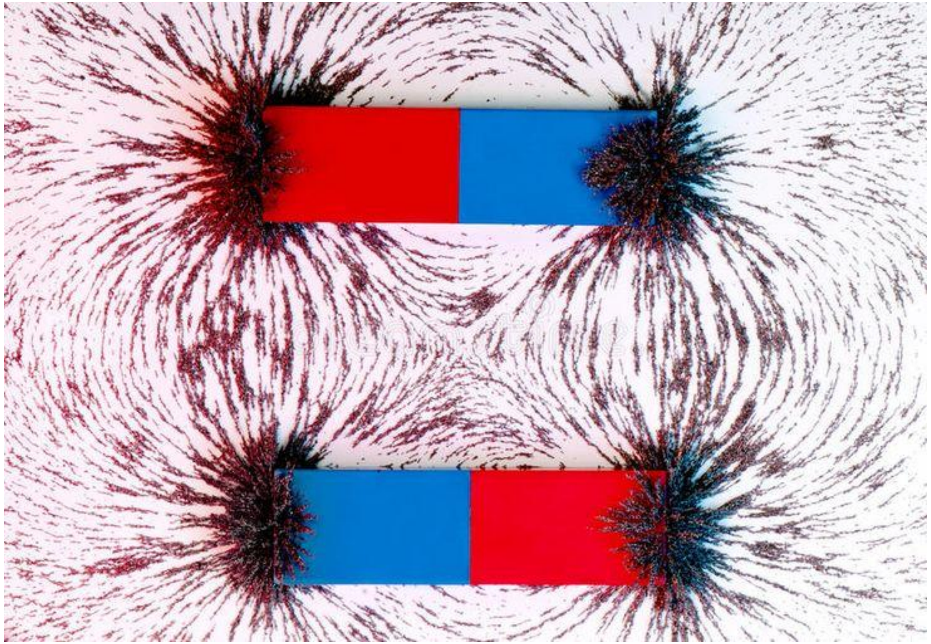
Electromagnetism

- 4.2 Magnetic field lines
- Exercise 4.2

4.2 Magnetic field lines

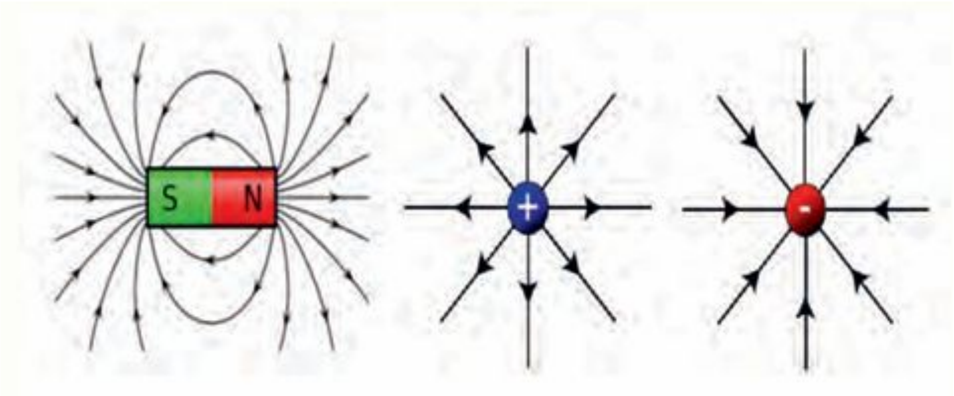
Magnetic field lines are imaginary lines or a visual tool used to represent magnetic fields. The density of the lines indicates the magnitude of the field. As with electric fields,



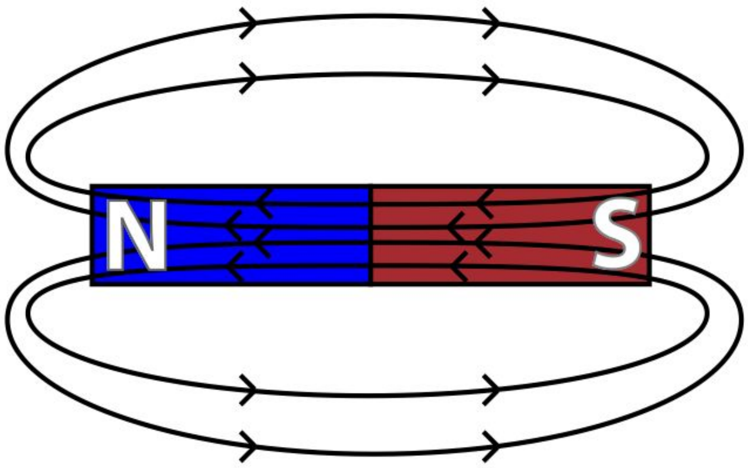
Properties of Magnetic Field Lines

- Field lines have both direction and magnitude at any point on the field.
- The strength of the field is proportional to the closeness of the lines.
- Magnetic field lines can never cross each other.
- Unlike Electric Field Lines,magnetic field lines are continuous, forming closed loop

  without beginning or end.



- The field lines emerge from north pole and merge at the south pole
- 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



Exercise 4.2

1. Define magnetic field lines.

Answer

- The magnetic field lines are imaginary lines used to represent magnetic fields.
- They describe the direction of magnetic force.
- The existence of magnetic field can be described by the magnetic field lines or magnetic lines of force or lines of magnetic flux

Exercise 4.2

2. The magnetic field lines are denser where the magnetic field is stronger.

A. True

B. False

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Exercise 4.2

3. Mention some properties of magnetic field lines.

Answer

- Magnetic field lines never cross or intersect each other.
- Magnetic field lines leave the north pole of the magnet and enter the south pole outside the magnet and run from south pole to north pole inside the magnet to make a closed loop
- magnetic field don't have origins or terminating / ending points

Exercise 4.2

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

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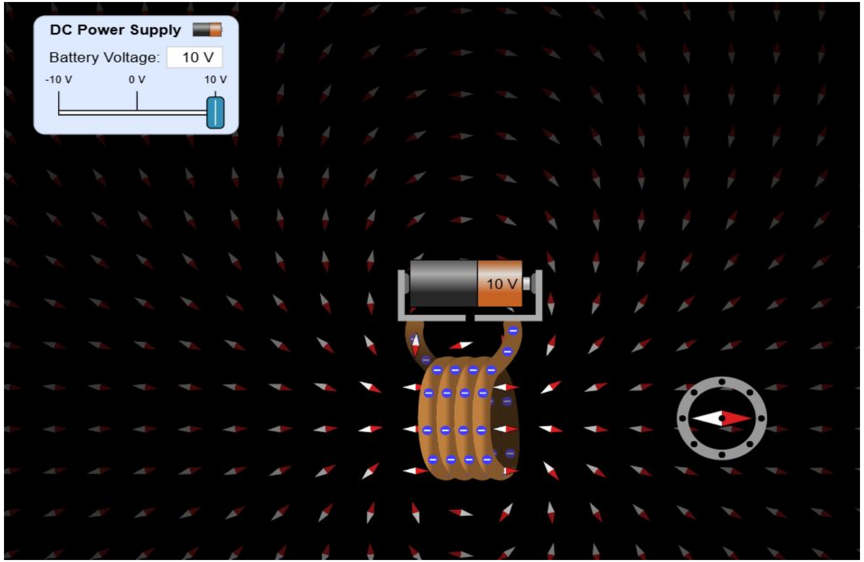
Electromagnetism

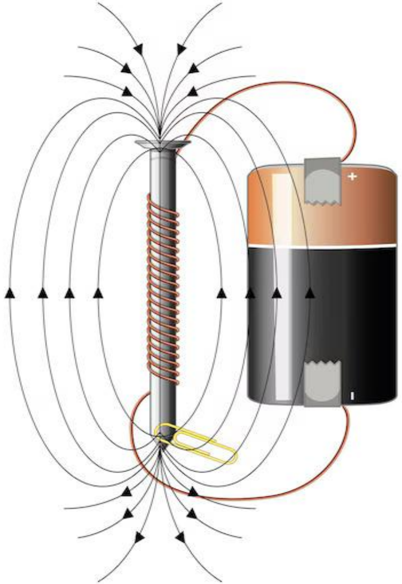
4.3 Current and Magnetism

4.3 Current and Magnetism

The magnetic field is generated by the electric current (moving charges). As soon as the current is off there is no magnetic field.



Simulation



Ampere’s law

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."

Magnetic Field Created by a Long Straight Current-Carrying Wire

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- As the current through the conductor increases,the magnetic field increases proportionally. When we move further away from the wire,the magnetic field decreases with the distance.

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

(for long straight wire)

- Where μ_0 is permeability of free space, $\mu_0 = 4\pi \times 10^{-7}$ Tm/A

- The SI unit of magnetic field is Tesla (T). The other common unit of magnetic field is gauss(G).

$$1T = 10^4\ G$$

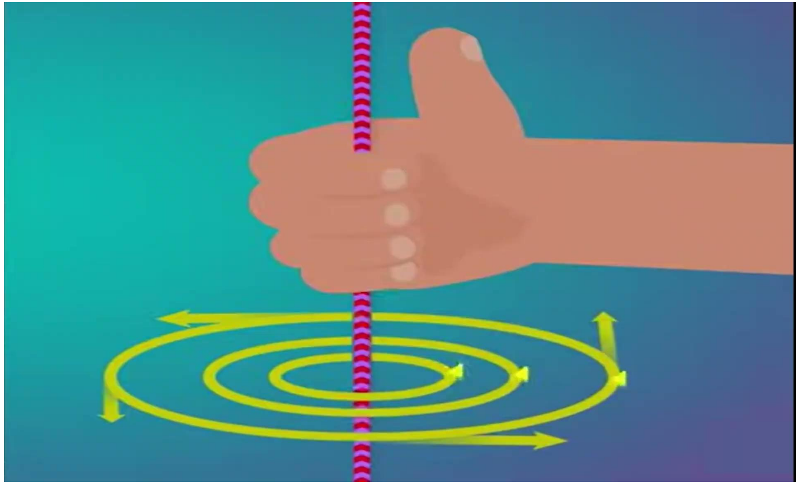
The magnetic field produced by a current flowing in a straight wire have the following properties.

- 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.

The direction of a magnetic field around a wire carrying a current is given by **Fleming's Right Hand Rule.**

This rule states that,

- Thumb points in the direction of the current,
- Fingers wrapped around the wire will point in the direction of the magnetic field lines



Example 4.1

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

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
Barmagnet	10^{-2}
Surface Thesun	10^{-2}
Surface of the Earth	$0.5x10^{-4}$
Inside human brain (due to nerve impulses)	10^{-13}

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Exercise 4.3

1. Along straight wire carrying a current produces a magnetic field of 0.8T at a distance 0.5cm from the wire. Find the magnetic field at a distance of 1 cm.

Exercise 4.3

2. Which one of the following does not affect the magnetic field produced by along straight wire?

   A. The current in the wire

   B. The distance from the wire

   C. The type of thewire

   D. None

Exercise 4.3

3. The magnetic field B at a distance r from along straight wire carrying current I is directly proportional to r.

A. True

B. False

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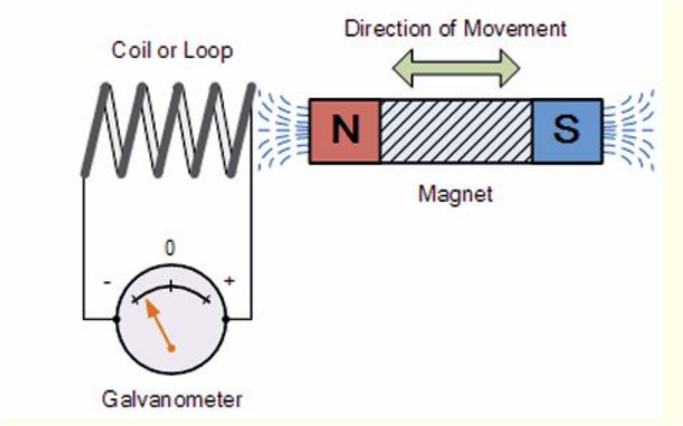
4.4 Electromagnetic Induction

In 1831, Michael Faraday discovered that magnets could be used to generate electricity.

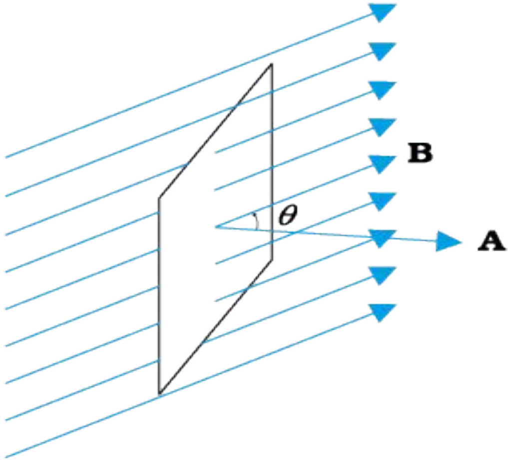
He showed that a changing or variable magnetic field can produce an electromotive force (emf).This e.m.f produces an induced current in a closed circuit. We call this effect electromagnetic induction.



Simulation

Magnetic flux

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



$$\Phi = BA = BA\cos\theta$$

Where θ is angle between B andA.

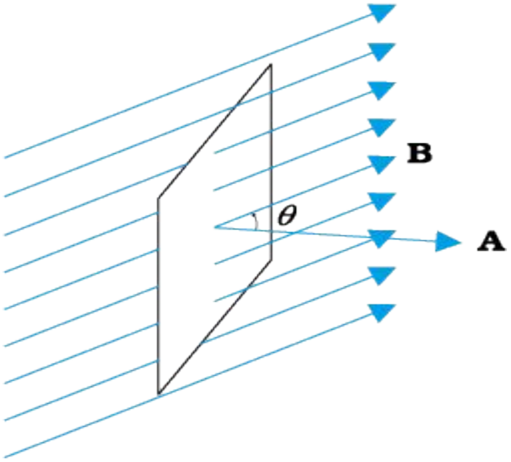
Magnetic flux is scalar quantity and The SI unit of is Weber (Wb).

$1\ Wb = 1\ Tm^2$

Example 4.2

A square loop of side 3cm is positioned in a uniform magnetic field of magnitude 0.5T so that the plane of the loop makes an angle of 600 with the magnetic field as shown in the Figure

Find the flux passing through the square loop?



Exercise 4.4

1. Define magnetic flux.

Exercise 4.4

2. A circular loop of area 200 cm^2 sits in the xz plane.If a uniform magnetic field of B=0.5T is applied on it. Determine the magnetic flux through the square loop?

Exercise 4.4

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^{o} C. 45^{o} D. 30^{o}

Exercise 4.4

4. A magnetic field of 2.5T passes perpendicular through a disc of radius 2cm. Find the magnetic flux associated with the disc.

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Electromagnetism

4.5 Faraday’s Law of electromagnetic Induction

Faraday's law of electromagnetic induction and Lenz's Law

Faraday's law considers how the changing magnetic fields can cause current to flow in wires. Lenz's law tells about the direction of the current.

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.

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

Where, ε is the induced voltage (also known as electromotive force) is change in magnetic flux and t Change in time.

In the case of a closely wound coil of N turns,

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

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

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.

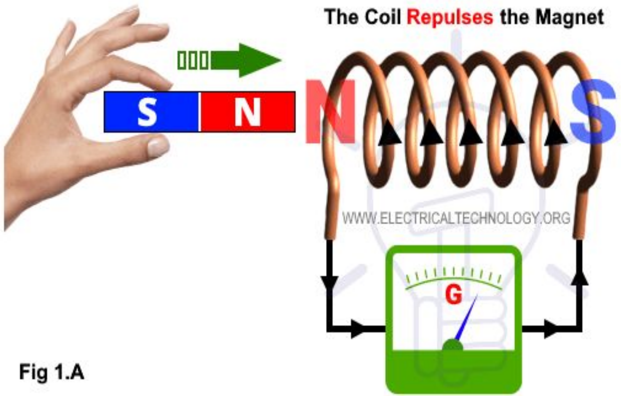

Fig 1.A

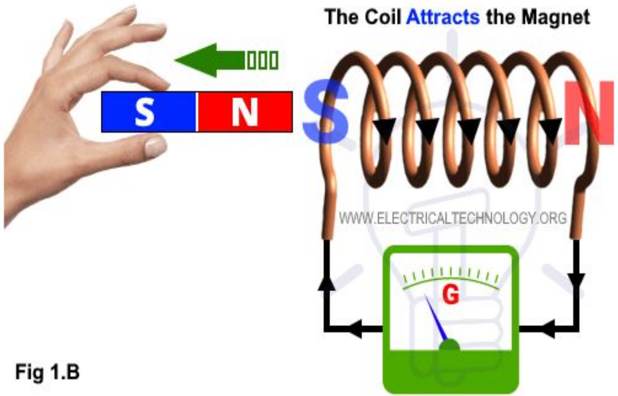

Fig 1.B

https://phet.colorado.edu/sims/html/faradays-electromagnetic-lab/latest/faradays-electromagnetic-lab_all.html

Example 4.3

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

Exercise 4.5

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1. The emf induced in a coil can be increased by:

   A. increasing the number of turns in the coil(N).
   B. increasing magnetic field strength surrounding the coil.
   C. increasing the speed of the relative motion between the coil and the magnet.
   D. All

2. 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. the rate of change of the magnetic flux in the coil.
   D. All

Exercise 4.5

3. Lenz's law is the result of the law of conservation of:

A. mass
B. charge
C. energy
D. Momentum

4. In Lenz's law the induced emf opposes the magnetic flux.

A. True
B. False

Exercise 4.5

5. 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.

Exercise 4.5

5. b) Calculate the induced current if the resistance of the coil is 0.08Ohm.

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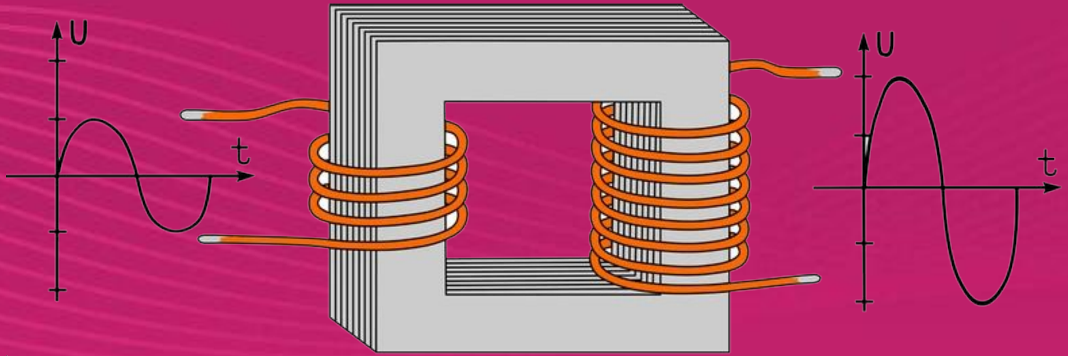

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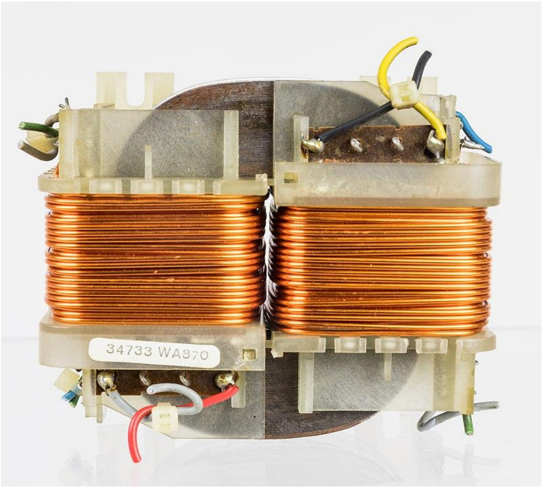
Electromagnetism

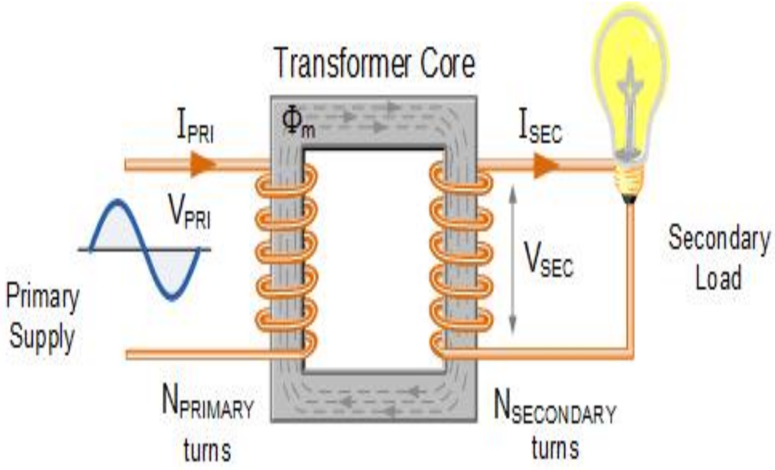
4.6 Transformers

4.6 Transformers

- A 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 ('stepup') or decrease ('step down') voltage levels between circuits without altering the frequency.



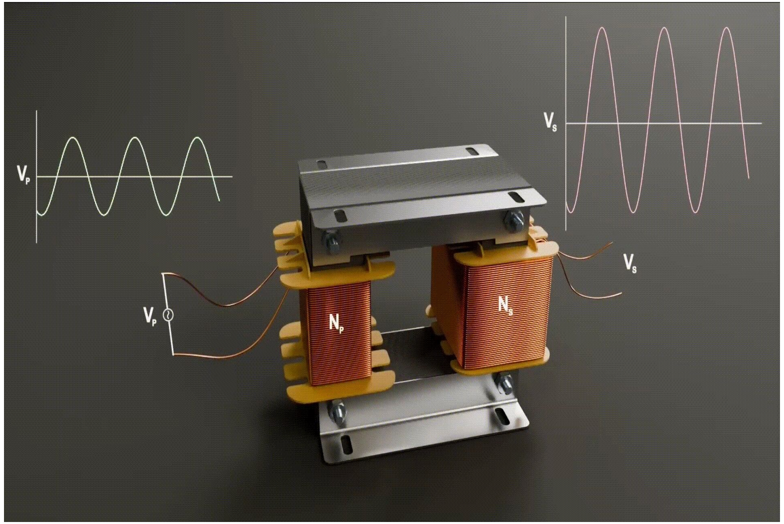


The operating principle of a transformer is based on electromagnetic induction. The current from the electrical supply that is connected to the primary coil is an alternating current.

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

https://phet.colorado.edu/sims/html/faradays-electromagnetic-lab/latest/faradays-electromagnetic-lab_all.html

- The number of coil turns in the primary winding(NP) compared to the number of coil turns on the secondary winding(NS) can determine the voltage difference between primary and secondary winding.



$$\frac{N_p}{N_s} = \frac{V_p}{V_s} = \textbf{Turns Ratio}$$

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

Efficiency, □ = $\dfrac{\text{output power}}{\text{Input power}} \times 100^{0}$

Where input and output are all expressed in units of power

Example

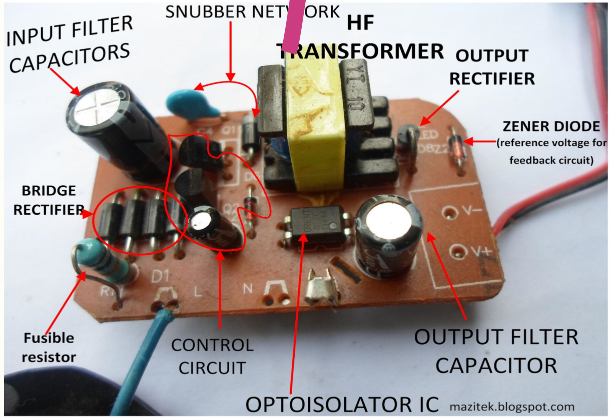
1. A transformer has a primary and a secondary coil with the number of loops of 500 and 5000 respectively. If the input voltage is 220V. What is the output voltage?

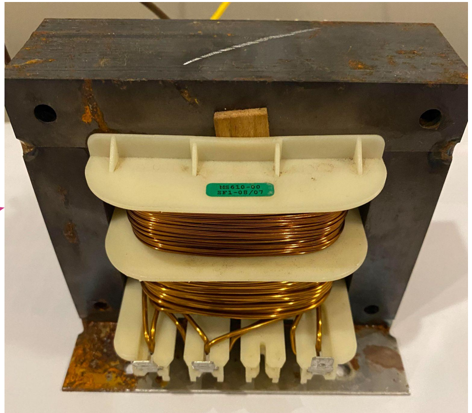
Example

2. A transformer increases a 300v to 600v. The current in the primary coil is 6A,and the current in the secondary coil is 2A. What is the efficiency of the transformer?

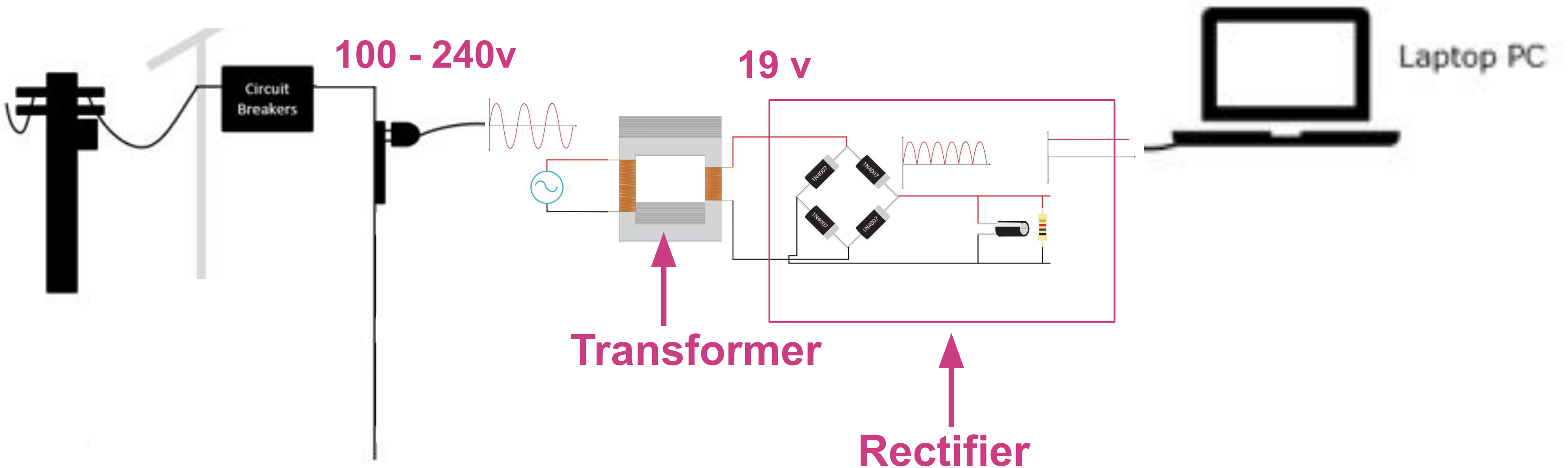
Working principle of transformer in house appliances

- There are many appliances that use transformers in their circuity. Your phone, laptop, computer, tablet **power supplies** have transformers in them.





The electronics in your mobile phone or laptop are designed to work at low voltages compared to the electric current you get in wall outlets.



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.

Exercise 4.6

2. Calculate the turn ratio to step 110VAC down to 20VAC.

Exercise 4.6

3. Why does a transformer can not raise or lower the voltage of a DC supply? Explain your answer.

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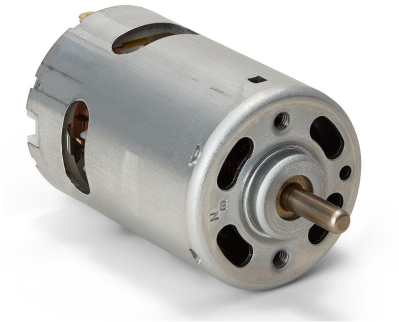
4.7 Application and safety

4.7 Application and safety

Applications of electromagnetism

Electromagnetism is applicable in different devices like electric motors, generators, transformers or other similar devices.

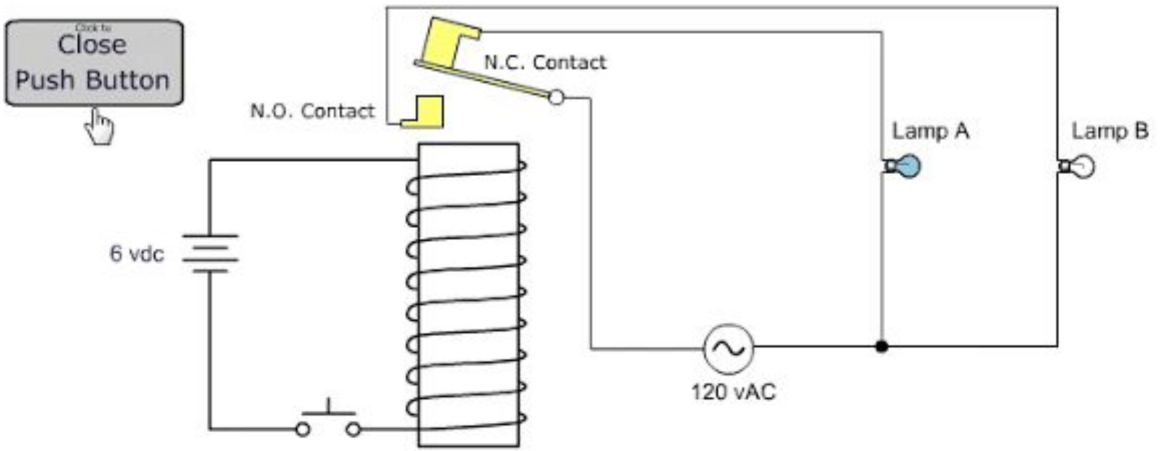


Electromagnets at Home or School

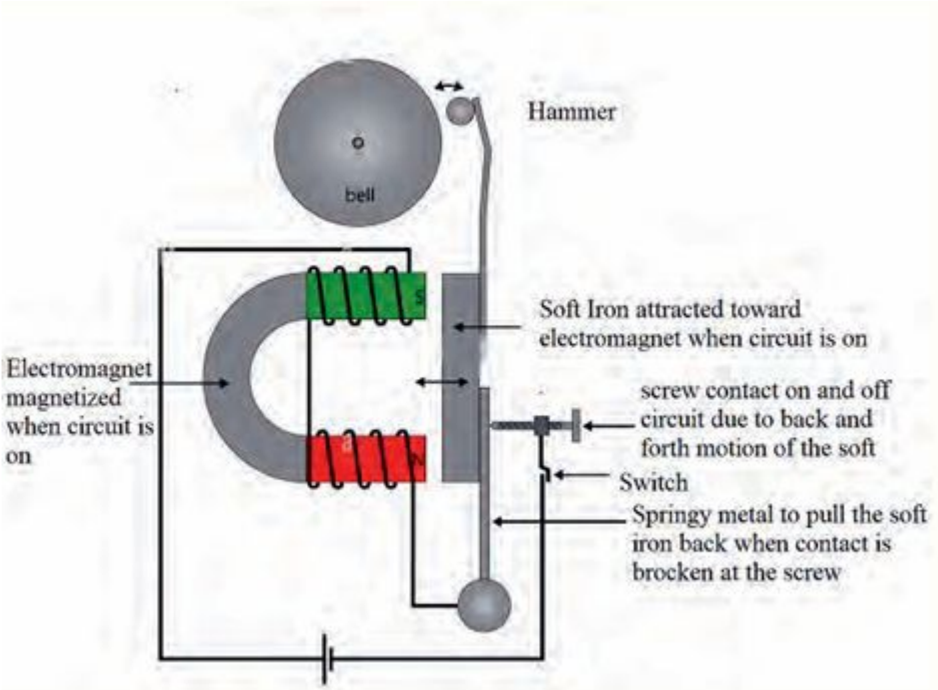
Electric bells, headphones, loud speakers, relays, MRI machines, electric fan, electric door bell,magnetic locks, and others.

Magnetic Relays

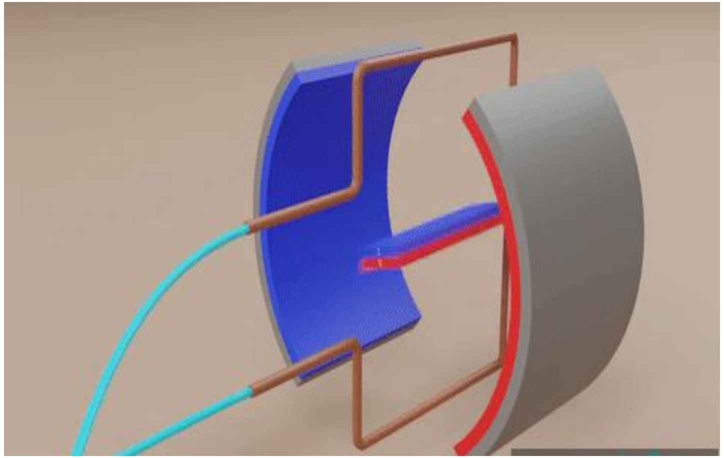
A magnetic relay is a switch or circuit breaker that can be activated into the 'ON' and 'OFF' positions magnetically.

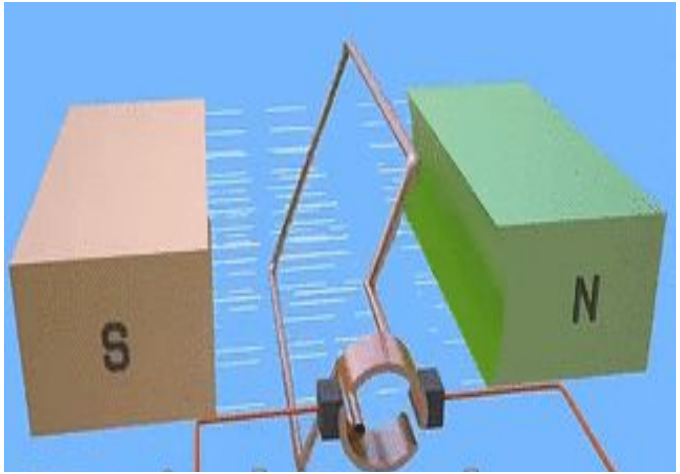


Electric bell



DC Electric Motor





AC Generator

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Electromagnetism

End of unit questions and problems

End of unit questions and problems

1. Along straight wire carries a current of 10A.At what distance from the wire will a magnetic field of $8x10^{-4}$ T be produced?

End of unit questions and problems

2. A closed coil of 40 turns and of area $200cm^2$, is rotated in a magnetic field of flux density $2Wbm^2$. It rotates from a position where its plane makes an angle of 300 with the field to a position perpendicular to the field in a time 0.2sec. Find the magnitude of the emf induced in the coil due to its rotation.

End of unit questions and problems

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3. A portable x-ray unit has a step-up transformer, the120V input of which is transformed to the 100 kV output needed by the x-ray tube. The primary has 50 loops and draws a current of 10.00A when in use.

   (a) What is the number of loops in the secondary?
   (b) Find the current output of the secondary.

End of unit questions and problems

4. A 500 turns coil develops an average induced voltage of 60V. Over what time interval must a flux change of 0.06Wb occur to produce such a voltage?

End of unit questions and problems

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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.

End of unit questions and problems

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6. A circular loop with a radius of 20cm is positioned perpendicular to a uniform magnetic field, the magnetic flux that passes through the loop is 1.9x10 2Wb. What is the magnetic flux density?

End of unit questions and problems

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?

End of unit questions and problems

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.

End of unit questions and problems

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9. A 150W transformer has an input voltage of 10V and an output current of 5A.

   a). Is this step-up or step down transformer?
   b). what is the ratio of Vout to Vin?

End of unit questions and problems

10. Determine the magnetic field strength at a point 5 cm from a wire carrying a current of 10A.

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