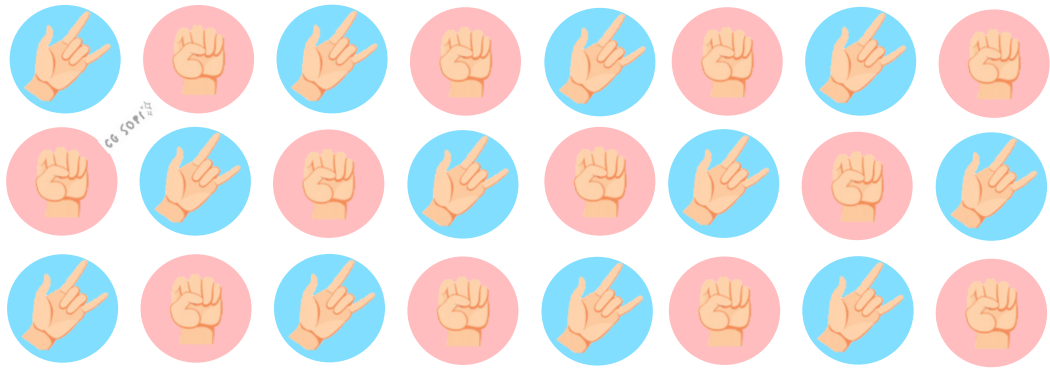


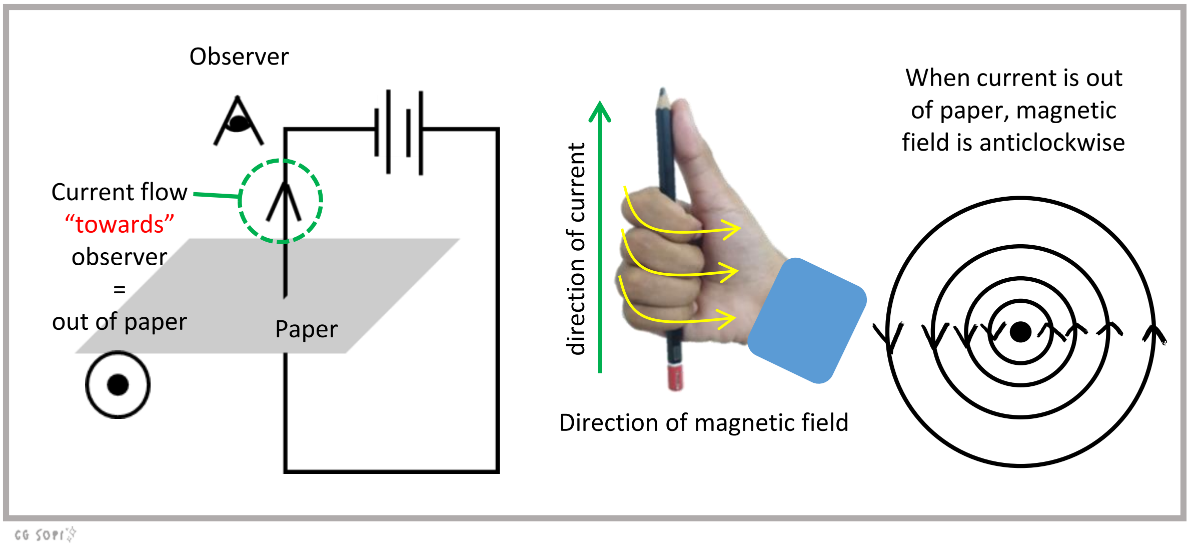
	Content standard	Learning standard
4.1	Force on a Current-carrying Conductor in a Magnetic Field	• Describe the effect of a current-carrying conductor in a magnetic field • Draw the pattern of the combined magnetic field (catapult field) to indicate the direction of force on a current-carrying conductor in a magnetic field • Explain factors that affect the magnitude of force on a current-carrying conductor in a magnetic field • Describe the effect of a current-carrying coil in a magnetic field • Describe the working principle of a direct current motor • Describe factors that affect the speed of rotation in an electric motor
4.2	Electromagnetic Induction	• Describe electromagnetic induction in : (i)straight wire (ii)solenoid • Explain factors that affect magnitude of induced emf • Determine the direction of induced current in : (i)straight wire (ii)solenoid • Design a direct current and alternating current generator
4.3	Transformer	• Describe the working principle of a simple transformer • Describe an ideal transformer • Describe energy loss and ways to increase the efficiency of a transformer • Communicate about the use of transformers in daily life

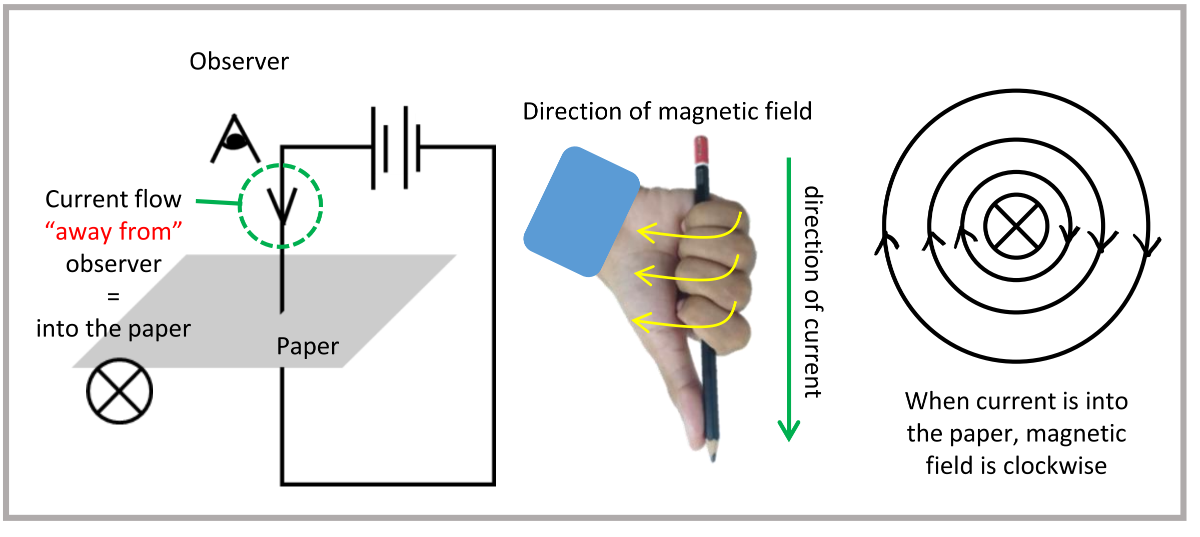
RECAP: Basic electromagnet

Electromagnet: Temporary magnet when current flows through a conductor

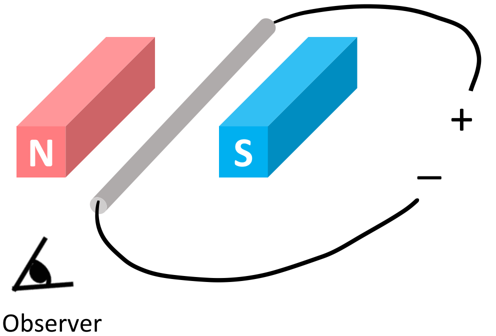
Right hand grip rule: to determine the direction of magnetic field around a straight wire conductor

RECAP





Exercise



Based on the diagram, draw the magnetic field due to current flow in the conductor. Include appropriate symbol to represent the direction of current flow and the direction of magnetic field produced by the current-carrying conductor.

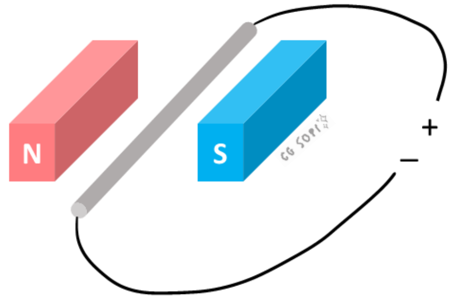
4.1 Force on a Current-carrying Conductor in a Magnetic Field

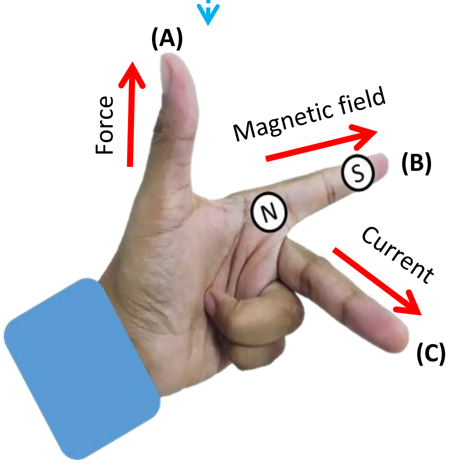
Catapult field: Resultant magnetic field produced by the interaction between the magnetic field from a current-carrying conductor and the magnetic field from a permanent magnet

Magnetic field from permanent magnet + Magnetic field from current in conductor = Catapult field

How to know which direction?

Fleming's left hand rule

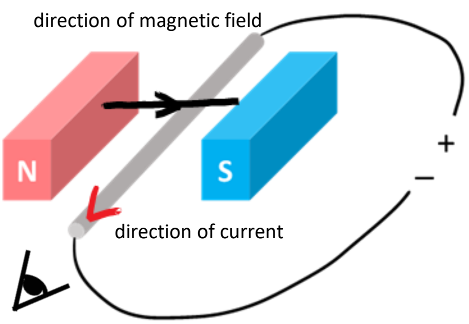




Steps to use Fleming's left hand rule.

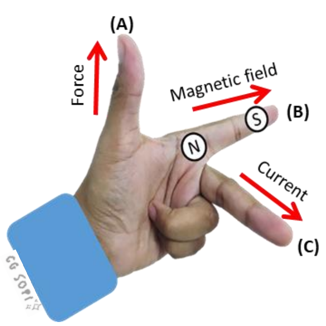
1. Identify direction of magnetic field of permanent magnet (North to South). Index finger (B) must be pointing South.
2. Identify direction of current flow. Tip of middle finger (C) must be in the direction of current flow.
3. The direction which the thumb (A) is pointing is the direction of the force.

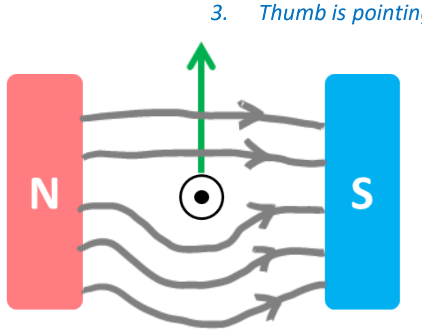
Example



What is the direction of the force acting on the conductor in the diagram?

1. *Direction of magnetic field of the permanent magnet is from left to right (North to South), so index finger must point to the right.*
2. *Current flow direction is towards the observer so the middle finger must be pointing towards us.*
3. *Thumb is pointing up. So the force must be upwards.*

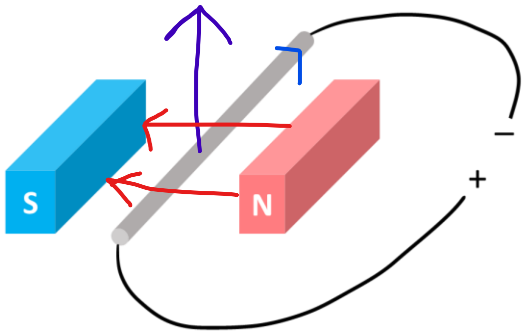




Fleming's LHR

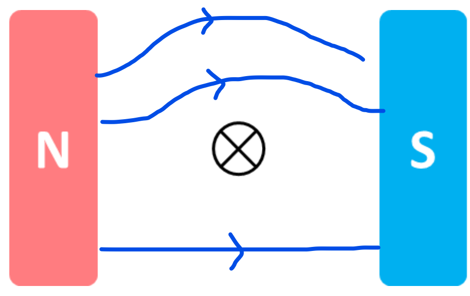
Exercise

1. What is the direction of the force acting on the conductor in the diagram?

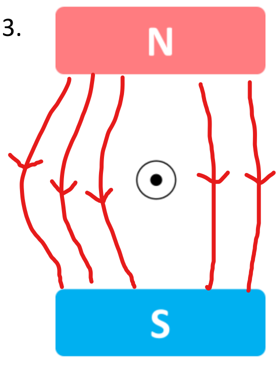


upwards

2. Complete the diagram below.



3.



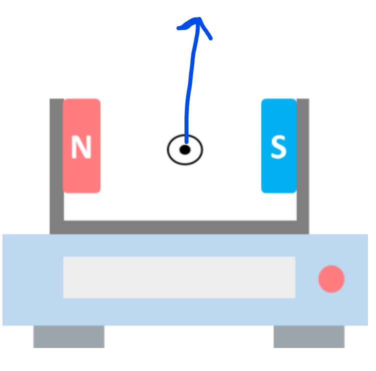
a. Complete the diagram to show the direction of motion of the conductor.

b. Suggest two changes that can be done to make the conductor move in the opposite direction from in (a).

Factors Affecting the Magnitude of the Force

1. Current → The larger the current, the stronger the force
2. Magnetic field strength → The stronger the strength of magnetic field, the stronger the force

Activities to investigate factors affecting magnitude of force



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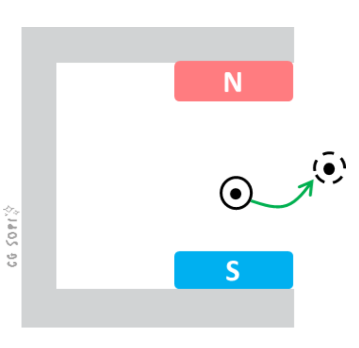

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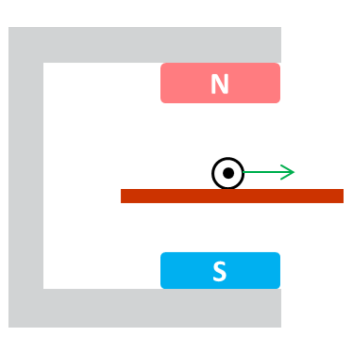

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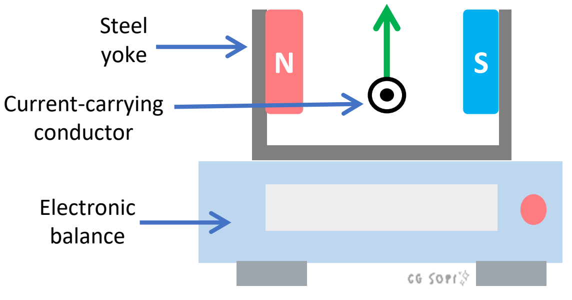
Factors Affecting the Magnitude of the Force (cont.)

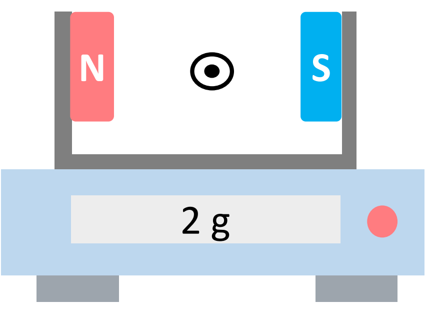
ACTIVITY 1

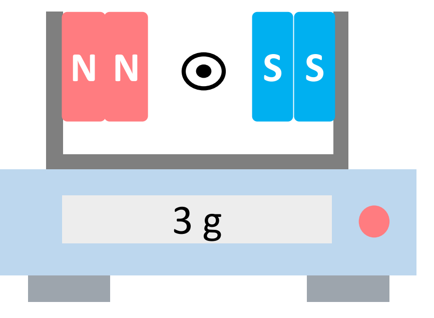
(Textbook page 140)



1. Catapult field exerts a force vertically upwards on the current-carrying conductor.
2. Magnadur magnets experience a reaction force with the same magnitude but in the opposite direction. (Newton's 3rd law of motion).
3. This force acts on the pan of the electronic balance (downwards).
4. The reading of the balance represents magnitude of the force.
5. Larger force will produce a larger reading.

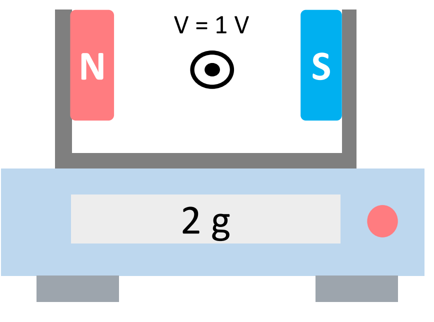
Strength of magnetic field

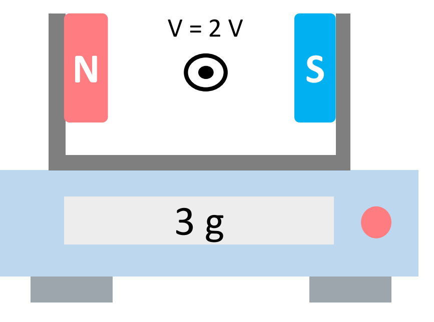




Number of magnet increases (strength of magnetic field increases) → Reading of balance increases (force increases)

Magnitude of current





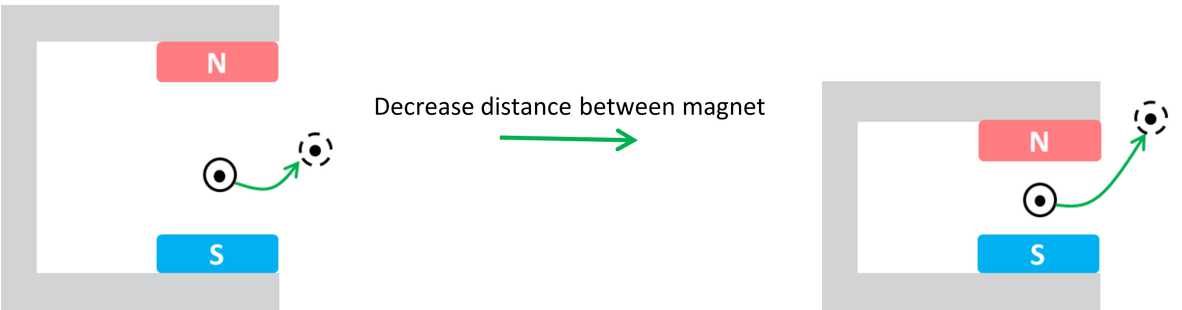
Voltage increases (current increases) → Reading of balance increases (force increases)

Factors Affecting the Magnitude of the Force (cont.)

ACTIVITY 2

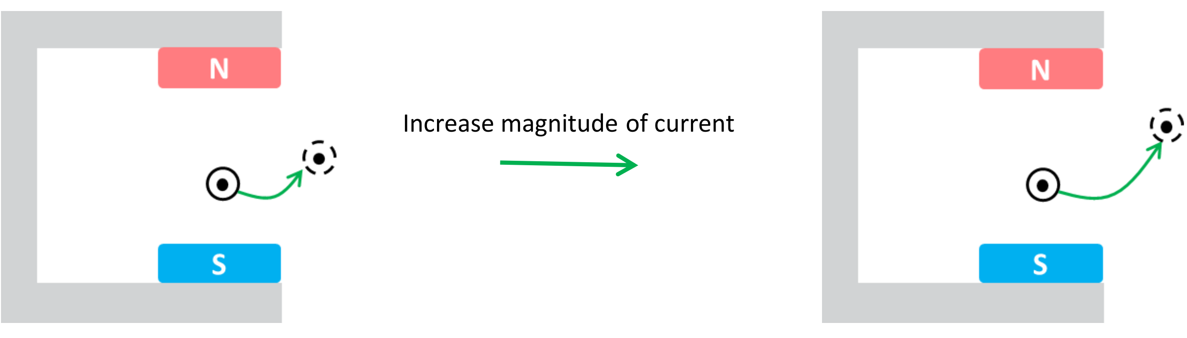
(Textbook page 141)

Strength of magnetic field



Stronger magnetic field.
Larger force produces larger swing

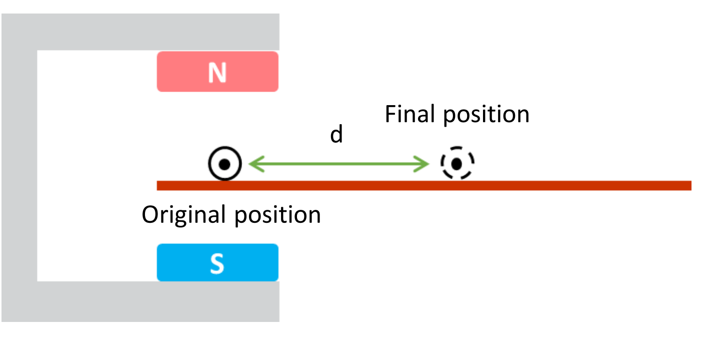
Magnitude of current



Larger force produces larger swing

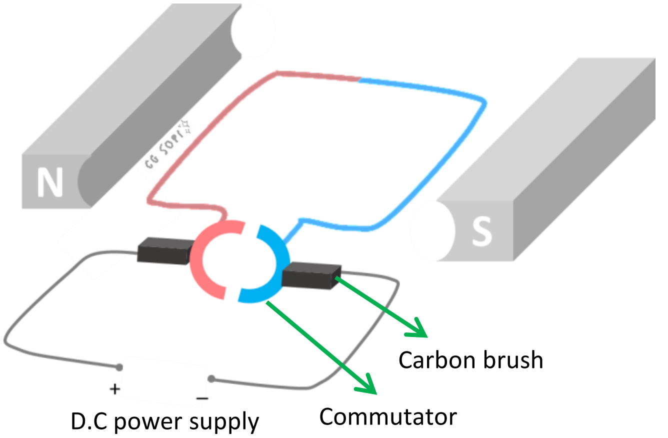
ACTIVITY 3

(Textbook page 141)



- The stronger the magnetic field, the larger the force
- The bigger the magnitude of current, the larger the force
- The larger the force, the longer the value of d

Direct current motor

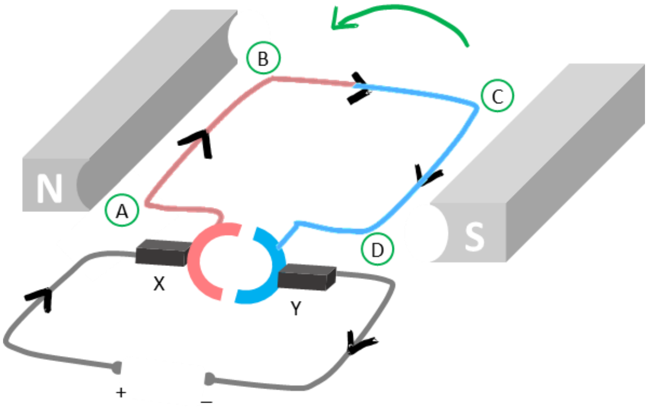


- changes electrical energy to kinetic energy
- use turning effect of a current-carrying coil in a magnetic field

Working principle

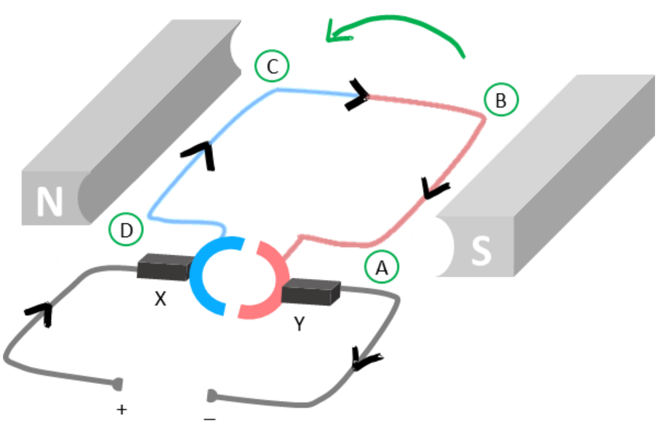
Working principle

First half rotation



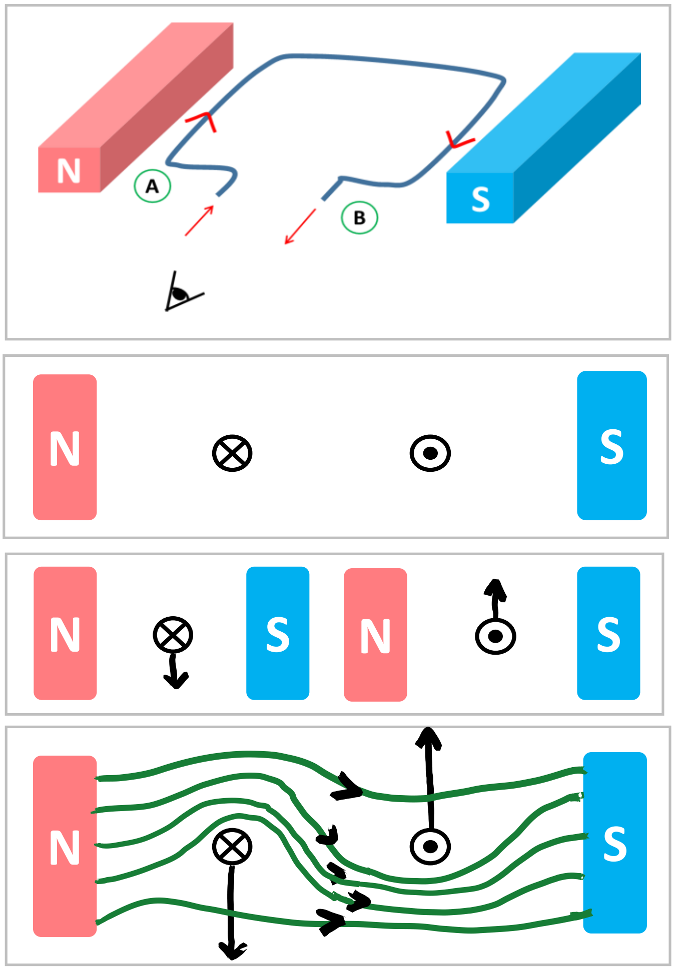
1. X is in contact with red half of the commutator
2. Y is in contact with blue half of the commutator
3. Current flows in coil in the direction of ABCD
4. Force acts downwards on AB. Force acts upwards on CD
5. Coil rotates anticlockwise

Second half rotation



1. X is in contact with blue half of the commutator
2. Y is in contact with red half of the commutator
3. Current flows in coil in the direction of DCBA
4. Force acts upwards on AB
   Force acts downwards on CD
5. Coil rotates anticlockwise (same with first half)

Determining direction of rotation



1. Determine the direction of current on each side of the coil. In this example, A is away from observer (into paper) and B is towards the observer (out of paper).
2. Simplify the diagram
3. Use Fleming's left hand rule to determine the direction of force acting on each side of the coil.
4. Sketch the magnetic field line accordingly. In this example, the coil will rotate anticlockwise.

Exercise

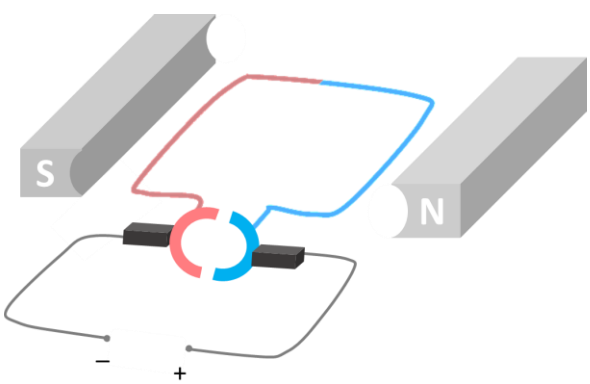


Diagram shows a direct current motor. Determine the direction of rotation of the coil.

Factors Affecting the Speed of Rotation of an Electric Motor

- Current in the coil → the larger the current, the faster the rotation
- Strength of magnetic field → the stronger the field, the faster the rotation
- Turns of coil → the more the number of turn, the faster the rotation

Reversing the Direction of Rotation of an Electric Motor

- Change the direction of current in the coil
- Change the direction of magnetic field

Exercise

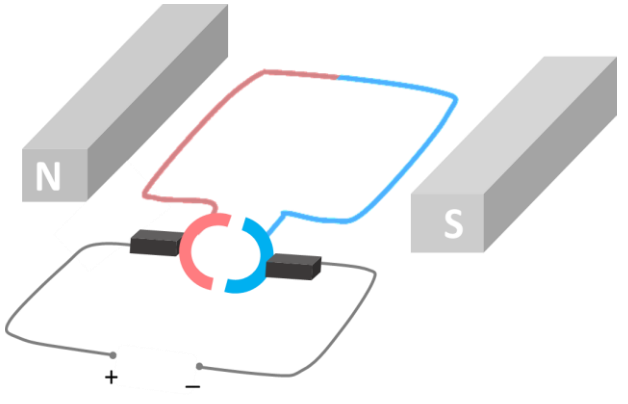
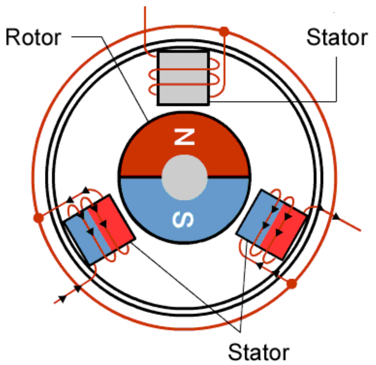
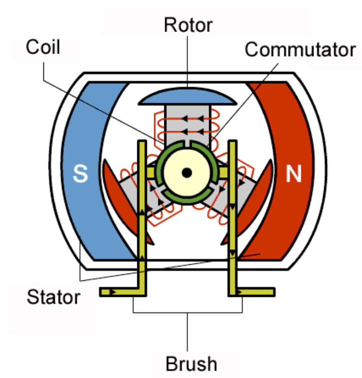


Diagram shows a direct current motor. When power supply is connected, the coil will rotate anticlockwise. Based on your knowledge on factors affecting speed and direction of direct current motor, state changes that can be made to make rotate faster and in clockwise direction.

Brushless vs brushed motor

<table>
<tr><th>Brushless motor</th><th>Brushed motor</th></tr>
<tr><td>

https://fab.cba.mit.edu/</td><td>

http://fabacademy.org/</td></tr>
<tr><td colspan="2">Similarities</td></tr>
<tr><td colspan="2">Has a magnet and a coil</td></tr>
<tr><td colspan="2">Uses magnetic force to produce rotation</td></tr>
<tr><td colspan="2">Differences</td></tr>
<tr><td>Coil is stationary, magnet rotates</td><td>Magnet is stationary, coil rotates</td></tr>
<tr><td>No carbon brushes, therefore no friction between the brushes and the commutator</td><td>Friction between the carbon brush and the commutator causes the carbon brush to wear out</td></tr>
<tr><td>No sparking at the commutator</td><td>Sparking at the commutator</td></tr>
<tr><td>Soft operational sound</td><td>Louder operational noise</td></tr>
</table>

4.2 Electromagnetic induction

Electromagnetic induction: Production of an induced electromotive force (e.m.f) in a conductor when there is relative motion between the conductor and a magnetic field or when the conductor is in a changing magnetic field.

Relative motion between two objects is the motion that results in the two objects becoming closer to each other or further away from each other.

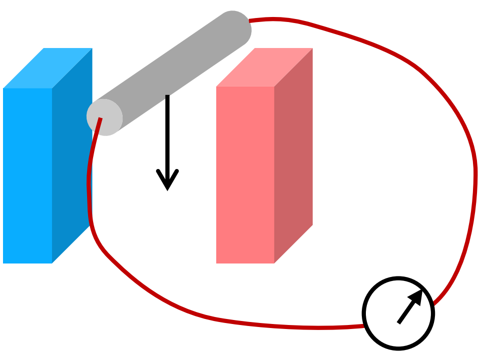
Magnetic field from permanent magnet	+	Force (relative motion)	=	Induced e.m.f

There is a relative motion because A and B become closer

A and B are moving with same speed

There is no relative motion because distance between A and B does not change

Straight wire + magnet



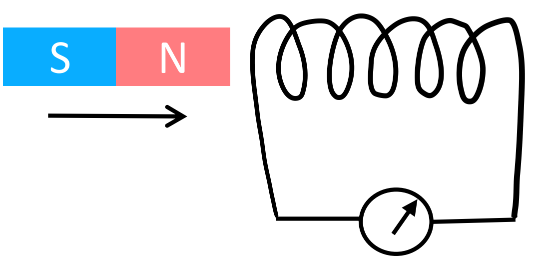
Galvanometer

- Copper wire is moved across magnetic flux.
- e.m.f. is induced in the wire due to EM induction
- Galvanometer pointer deflects.
- Induced current is produced.

Solenoid + magnet

- Bar magnet is moved towards or away from a solenoid
- Magnetic field lines are cut by turns of the solenoid
- e.m.f. is induced due to electromagnetic induction
- Induced e.m.f produce induced current
- Galvanometer pointer shows a deflection

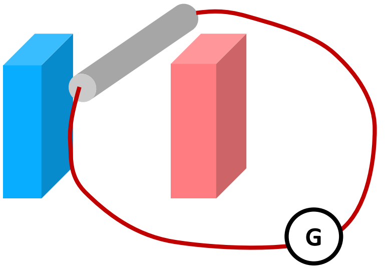
Solenoid



Galvanometer

Factors Affecting the Magnitude of the Induced e.m.f.

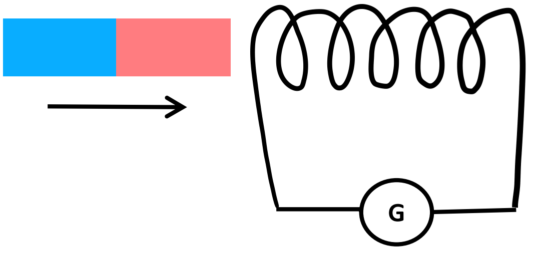
Straight wire + magnet



- speed of relative motion
- strength of the magnetic field

Solenoid + magnet

- speed of relative motion
- number of turns of the solenoid
- strength of the magnetic field



more magnetic field lines are cut in a certain period of time

↓

magnitude of e.m.f. increases

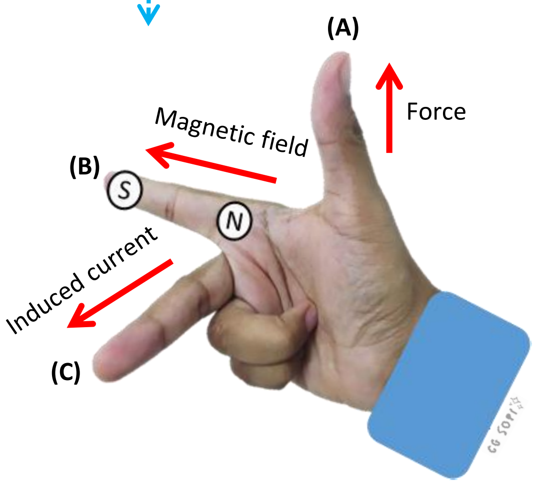
Faraday's law states that the magnitude of induced e.m.f. is directly proportional to the rate of cutting of magnetic flux.

Direction of Induced Current in a Straight Wire

Magnetic field from permanent magnet + Force (relative motion) = Induced e.m.f

Induced current → How to know which direction? → Fleming's right hand rule

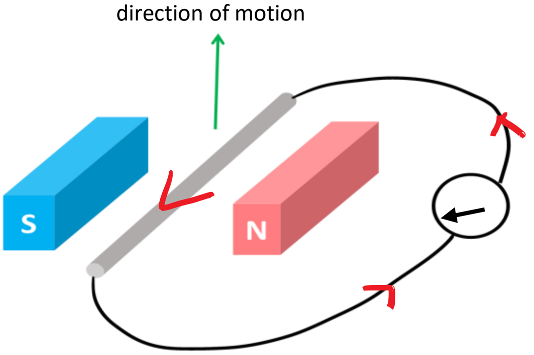
Fleming's RHR

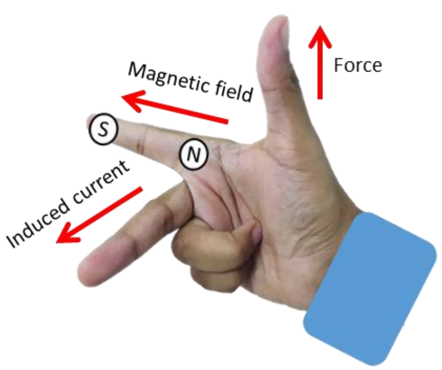


Steps to use Fleming's right hand rule.

1. Identify direction of magnetic field of permanent magnet (North to South). Index finger (B) must be pointing South.
2. Identify direction of force (motion of conductor). Tip of thumb (A) must be in the direction of the force.
3. The direction which middle finger (C) is pointing is the direction of induced current.

Example



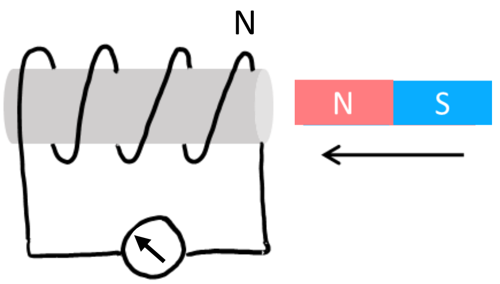


Determine the direction of current induced in the conductor in the diagram?

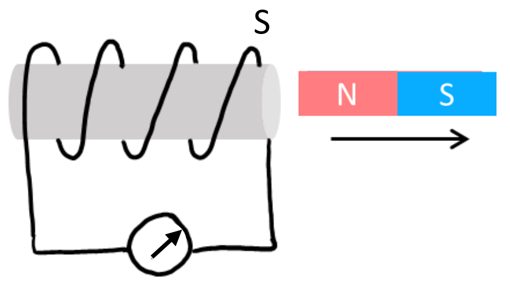
1. *Direction of magnetic field of the permanent magnet is from right to left (North to South), so index finger must point to the left.*
2. *Thumb is pointing upward because the wire is moving upwards.*
3. *Middle finger is pointing towards us. This means that the direction of induced current is towards the observer.*
4. *The direction of deflection of galvanometer pointer is opposite to the direction of current flow.*

Direction of Induced Current in a Solenoid

Lenz's law states that the induced current always flows in a direction that opposes the change of magnetic flux that causes it.



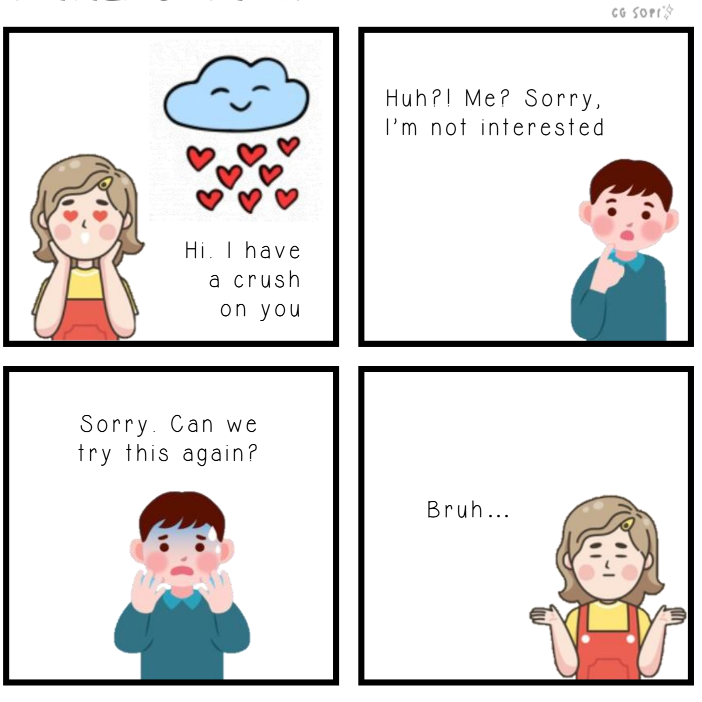
- Magnet pushed towards solenoid
- Induced current produces a north pole at the end of the solenoid to repel the magnet moving towards the solenoid

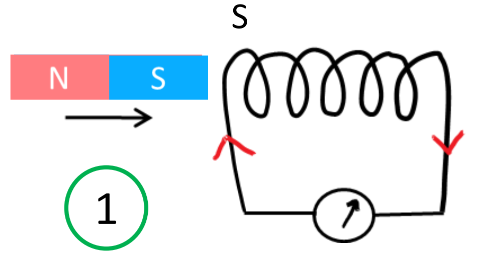


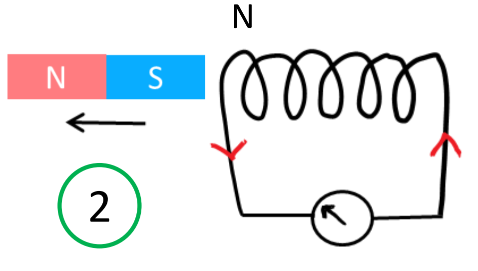
- Magnet pulled away from solenoid
- Induced current produces a south pole at the end of the solenoid to attract the magnet moving towards the solenoid

ANALOGY

LENZ'S LAW







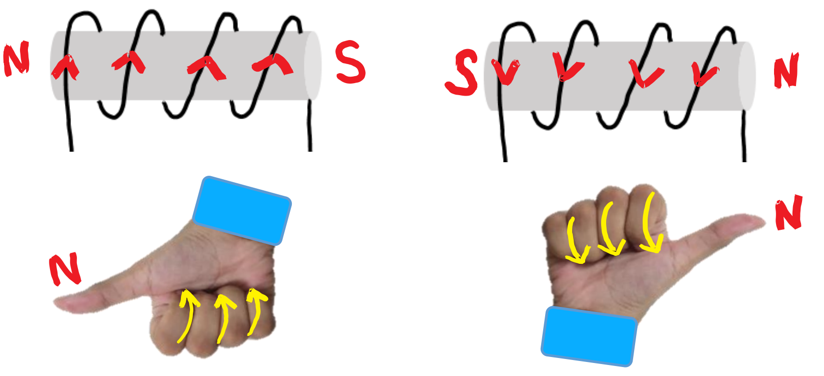
1. A girl (magnet) confesses (move towards) to a boy (solenoid) and got rejected (solenoid repel magnet by changing its pole).
2. When the girl wants to move on (move away), the boy tries to "pull" her back (solenoid changes pole to attract magnet)

Lenz's Law

Direction of Induced Current in a Solenoid (cont.)

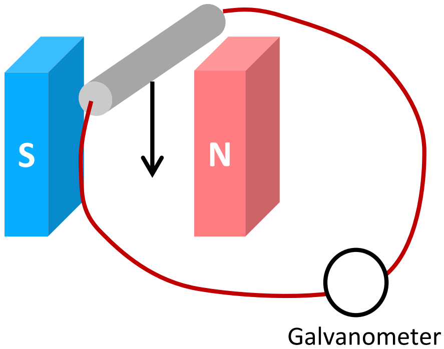
Right hand grip.

- Thumb = north
- Others = direction of current

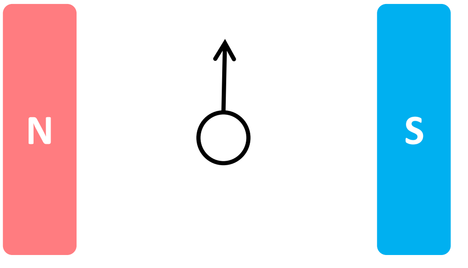


Exercise

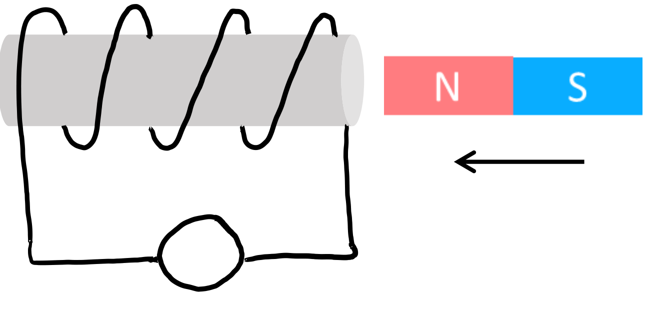
1. Show the direction of the deflection of the pointer if the conductor is moved downwards.



2. Draw the symbol on the conductor to that represents the direction of induced current when conductor is moved upwards.

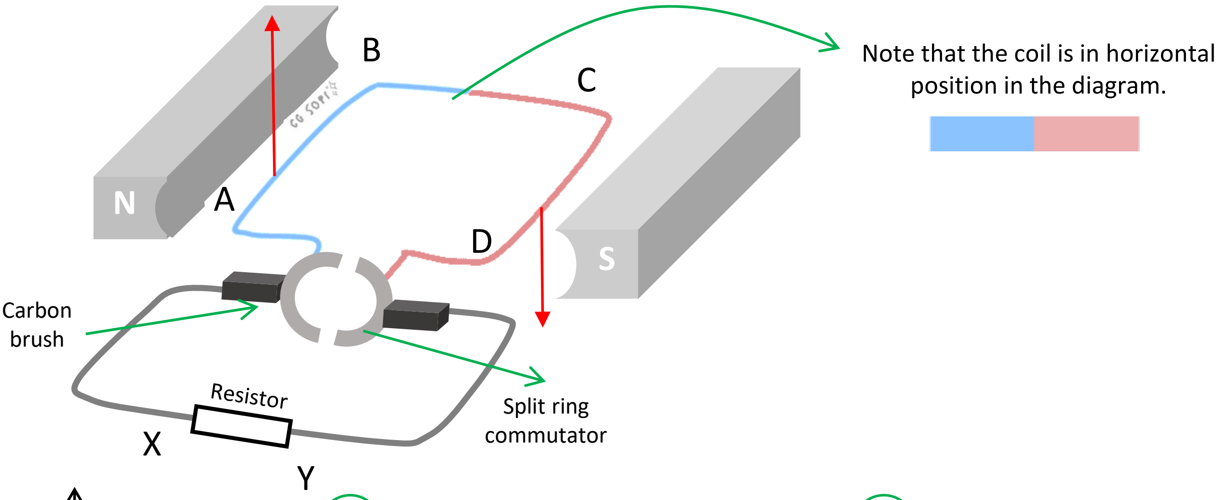


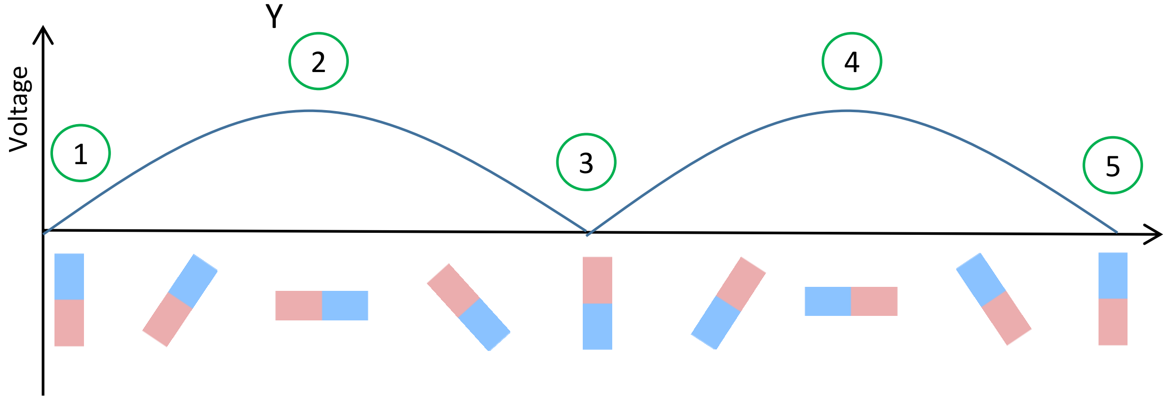
3. Diagram shows a magnet being moved towards a solenoid.



   a. Show the direction of the deflection of the pointer.
   b. The magnet is moved away with from the solenoid while maintaining its original speed.
      i. State the direction and magnitude of deflection of the pointer with respect to (a).
      ii. What is the law related to b(i)?
   c. The magnet is moved faster towards the solenoid.
      i. State the direction and magnitude of deflection of the pointer with respect to (a).
      ii. What is the law related to c(i)?

Working Principle of Direct Current Generator





1. Coil is vertical (0°)
    a. no cutting of magnetic flux
    b. E.m.f is not induced in coil → V = 0
    c. As the coil rotates, there is more cutting of magnetic flux. Induced e.m.f increases.

2. Coil is horizontal (90°)
    a. maximum cutting of magnetic flux
    b. Maximum e.m.f is induced in coil → $V = V_{max}$
    c. Current in coil : DCBA; Current in resistor : YX
    d. As the coil rotates, rate of cutting of magnetic flux decreases. Induced e.m.f decreases.

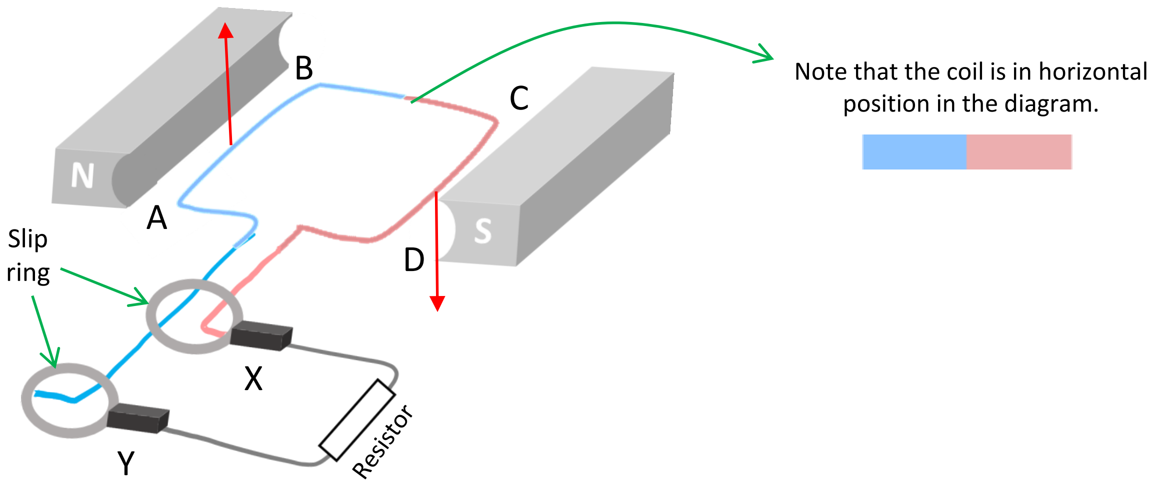
3. Coil is vertical (180°)
    a. no cutting of magnetic flux
    b. E.m.f is not induced in coil → V = 0
    c. As the coil rotates, there is more cutting of magnetic flux. Induced e.m.f increases.

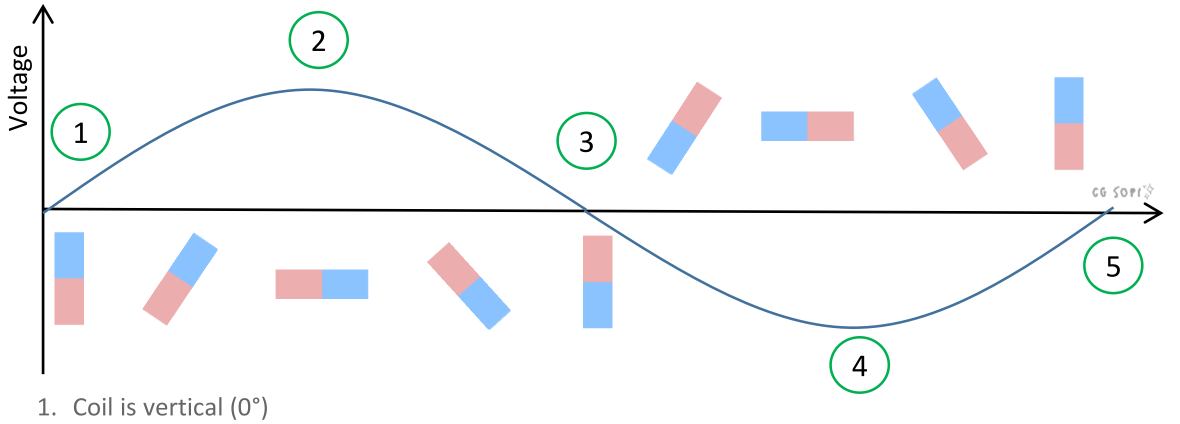
4. Coil is horizontal (270°)
    a. maximum cutting of magnetic flux
    b. Maximum e.m.f induced in coil → $V = V_{max}$
    c. Current in coil : ABCD; Current in resistor : YX
    d. As the coil rotates, rate of cutting of magnetic flux decreases. Induced e.m.f decreases.

5. Coil is vertical (360°)
    a. no cutting of magnetic flux
    b. E.m.f is not induced in coil → V = 0

- Use Fleming's Right-Hand Rule to determine the direction of the induced current
- current across resistor always flows in one direction (direct current)

Working Principle of Alternating Current Generator





1. Coil is vertical (0°)
   a. no cutting of magnetic flux
   b. E.m.f is not induced in coil → V = 0
   c. As the coil rotates, there is more cutting of magnetic flux. Induced e.m.f increases.

2. Coil is horizontal (90°)
   a. maximum cutting of magnetic flux
   b. Maximum e.m.f is induced in coil → $V = V_{max}$
   c. Current in coil : DCBA; Current in resistor : YX
   d. As the coil rotates, rate of cutting of magnetic flux decreases. Induced e.m.f decreases.

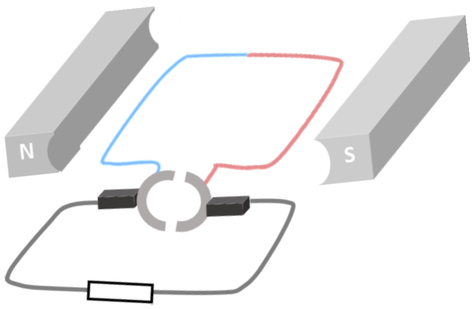
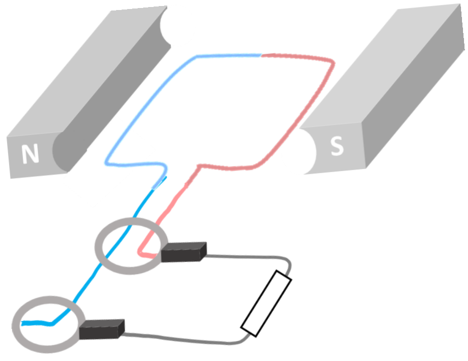
3. Coil is vertical (180°)
   a. no cutting of magnetic flux
   b. E.m.f is not induced in coil → V = 0
   c. As the coil rotates, there is more cutting of magnetic flux. Induced e.m.f increases.

4. Coil is horizontal (270°)
   a. maximum cutting of magnetic flux
   b. Maximum e.m.f induced in coil → $V = V_{max}$
   c. Current in coil : ABCD; Current in resistor : XY
   d. As the coil rotates, rate of cutting of magnetic flux decreases. Induced e.m.f decreases.

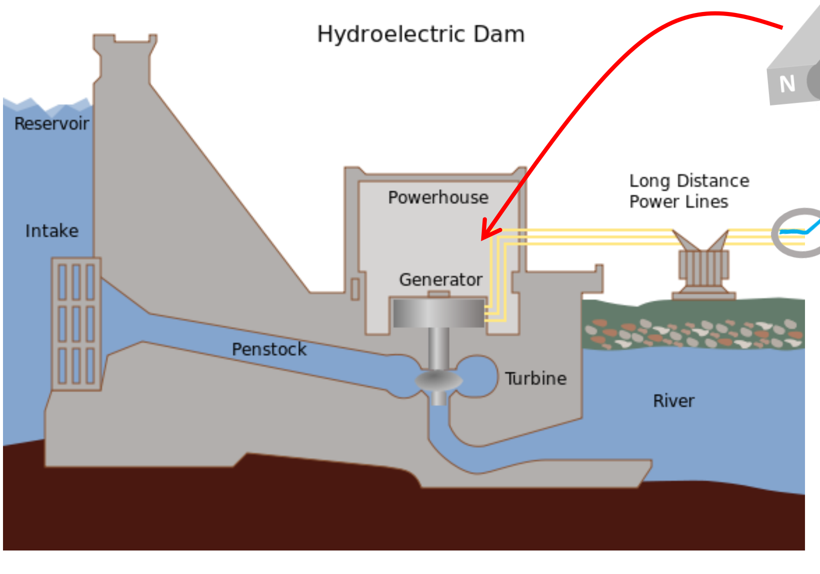
5. Coil is vertical (360°)
   a. no cutting of magnetic flux
   b. E.m.f is not induced in coil → V = 0

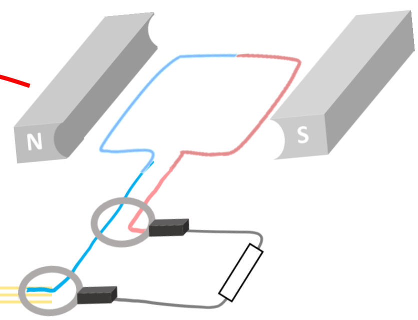
- Use Fleming's Right-Hand Rule to determine the direction of the induced current
- current across resistor always flows in two direction (alternating current)

DC vs AC Generator

Direct Current Generator	Alternating Current Generator
	
Similarities	
Applies electromagnetic induction Coil is rotated by an external force Coil cuts magnetic flux e.m.f. is induced in the coil	
Differences	
Ends of the coil are connected to a split ring commutator	Ends of the coil are connected to two slip rings
The two sections of the commutator exchange contact with the carbon brush every half rotation	Slip rings are connected to the same carbon brush
Output is direct current	Output is alternating current

AC Generator in Hydroelectric





https://commons.wikimedia.org/wiki/File:Hydroelectric_dam.svg

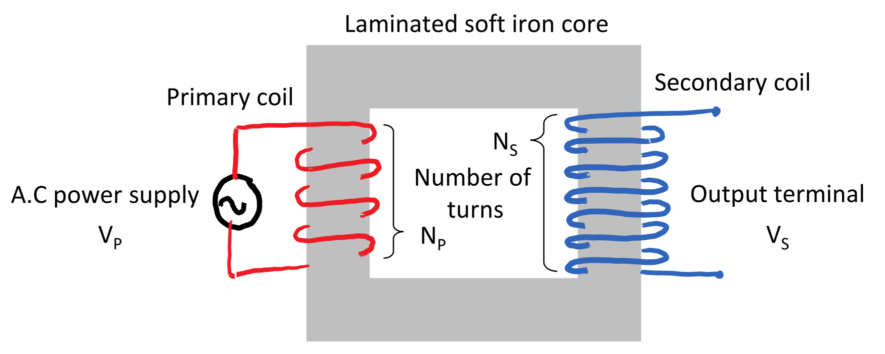
- Potential energy of water is transformed into mechanical energy.
- Turbine is turned which will turn the generator.
- Current is induced.
- Current passes through transformer to increase voltage.

4.3 Transformer

A device that change voltage

- Step-up transformer → V ↑
- Step-down transformer → V ↓

Structure of a transformer



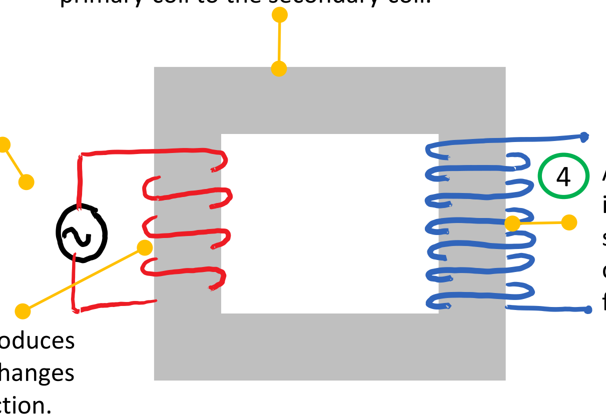
Step-up transformer: $N_S > N_P \longrightarrow V_S > V_P$

Step-down transformer: $N_S < N_P \longrightarrow V_S < V_P$

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

Working principle of a simple transformer

3. Soft iron core link magnetic flux from the primary coil to the secondary coil.



1. A.C. power supply produces alternating current in primary coil.
2. Alternating current produces a magnetic field that changes in magnitude and direction.
4. Alternating voltage is induced across secondary coil due to changing magnetic field.

Exercise

1. Voltage of A.C power supply is 12 V and the number of turn in secondary coil is 200 turns. Calculate the number of turns in primary coil to produce 60 V across secondary coil.

2. 15 V is generated across secondary coil with 50 turns. If the number of turns of primary coil is 750 turns, calculate the voltage supplied by AC power supply.

Efficiency of transformer

$$\boxed{\eta = \frac{P_{out}}{P_{in}} \times 100\%}$$

P_{out} = Output power (secondary)
P_{in} = Input power (primary)

$\left.\right\}$ P = VI (from chapter 3)

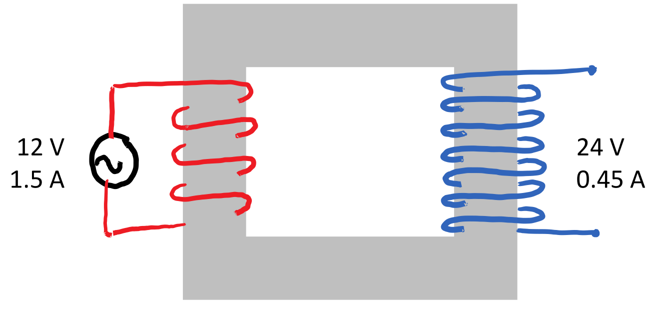
Ideal transformer

- a transformer that does not experience any loss of energy
- efficiency, η = 100%.

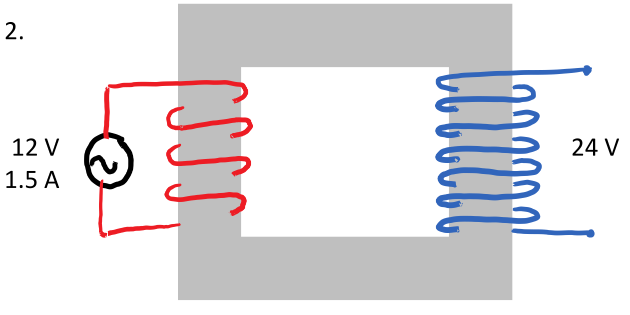
$$\eta = 100\%. \longrightarrow \frac{P_{out}}{P_{in}} \times 100 = 100 \longrightarrow P_{out} = P_{in} \xrightarrow{P\,=\,VI} \boxed{V_P I_P = V_S I_S}$$

Exercise

1. Calculate the efficiency of the transformer.

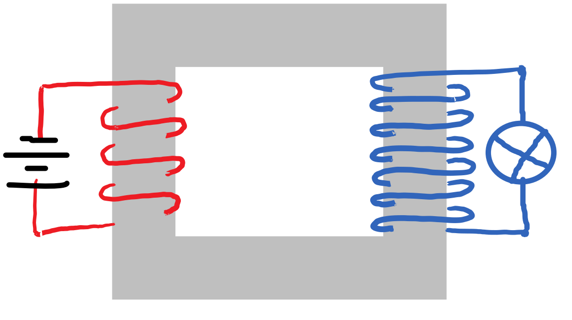


2.



Calculate the current flow in the secondary coil of the ideal transformer.

3. A student constructs a transformer as shown on the right. She notices that the bulb doesn't light up. Explain why.



Ways to Increase the Efficiency of a Transformer

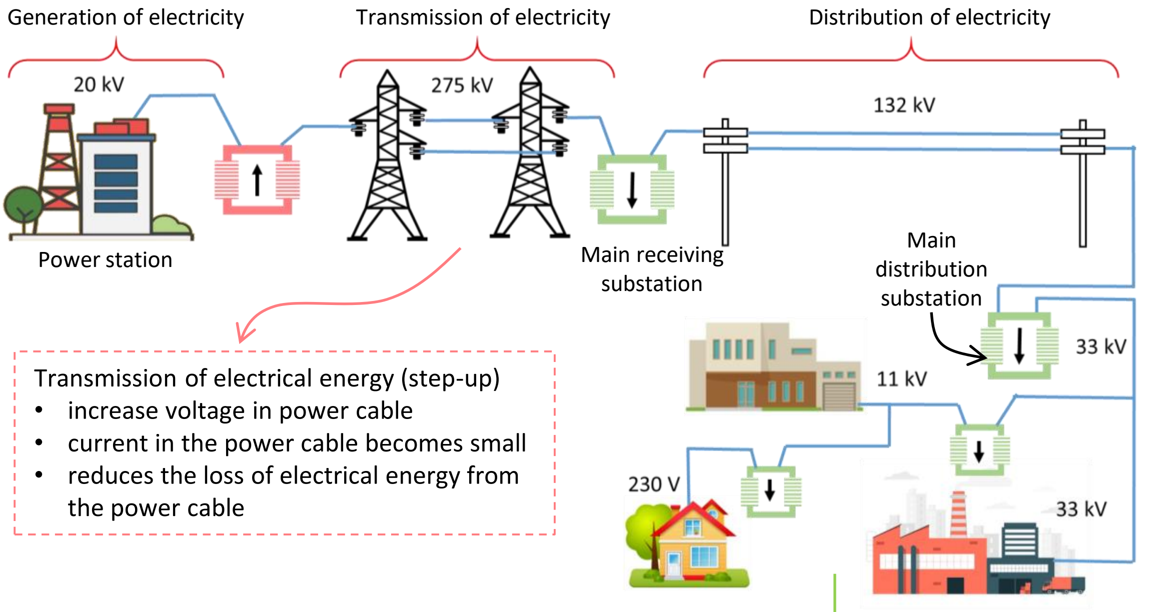
Causes of energy loss	Effects	Ways to reduce energy loss
Resistance of coils	• Coils are very long, so have resistance when current flow. • Coil heats up. • Heating of coil cause heat energy to be released to surrounding.	• Use thick copper wire to reduce resistance.
Hysteresis	• Iron core is continuously magnetised and demagnetised by the changing magnetic field. • Energy supplied for magnetisation is not fully recovered during demagnetisation. • Difference in energy is transferred to the iron core. • Iron core heats up.	• Use soft iron as the core. Soft iron requires a smaller amount of energy to be magnetised.
Leakage of magnetic	• Magnetic flux produced by primary current is not fully linked to secondary coil.	• The secondary coil is wound on the primary coil. • All magnetic flux produced by the primary current will pass through secondary coil.
Eddy currents	• Eddy currents are induced in the iron core due to changing magnetic field. • Iron core heats up. • Heating of iron core cause heat energy to be released to surrounding.	• Use a laminated iron core (thin iron sheets glued together with insulation glue)

Can be useful in daily lives for example its application in induction cooker. (Textbook page 165)

Uses of Transformers in Daily Life

Step-down transformer	Step-up transformer
Notebook computer charger Photocopy machine Welding machine	Microwave oven Defibrillator X-ray machine

Electrical Energy Transmission and Distribution System



Transmission of electrical energy (step-up)
- increase voltage in power cable
- current in the power cable becomes small
- reduces the loss of electrical energy from the power cable

Distribution of electrical energy (step-down)
- decrease the voltage in the power cable in stages
- produce suitable value for industrial and residential consumers