Nelson Mandela Metropolitan University
for tomorrow

CAPS Physical Science

GRADE 12

Video Series

ELECTRICITY AND MAGNETISM

Lesson 1: Electrical Machines

Nelson Mandela Metropolitan University

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Video Series

GRADE 12

CAPS Physical Science

Electrodynamics

Electrical Machines

Electrical Machines that we will study, can be divided into two main groups:

Electric Motor

Electric Generator

Motors vs. Generators

Electric Motors and Generators have the same basic components and operate on the same basic principles:

Components:

- Magnets
- Conducting Coil
- Slip or Split Rings

Principle:

- A changing magnetic field induces an electric field.
- Magnetic fields interact with one another.

The basic difference:

- **Electric Motors** convert **electrical energy into mechanical energy** (e.g. an electric fan);
- **Electric Generators** convert **mechanical energy into electrical energy** (e.g. a bicycle lamp).

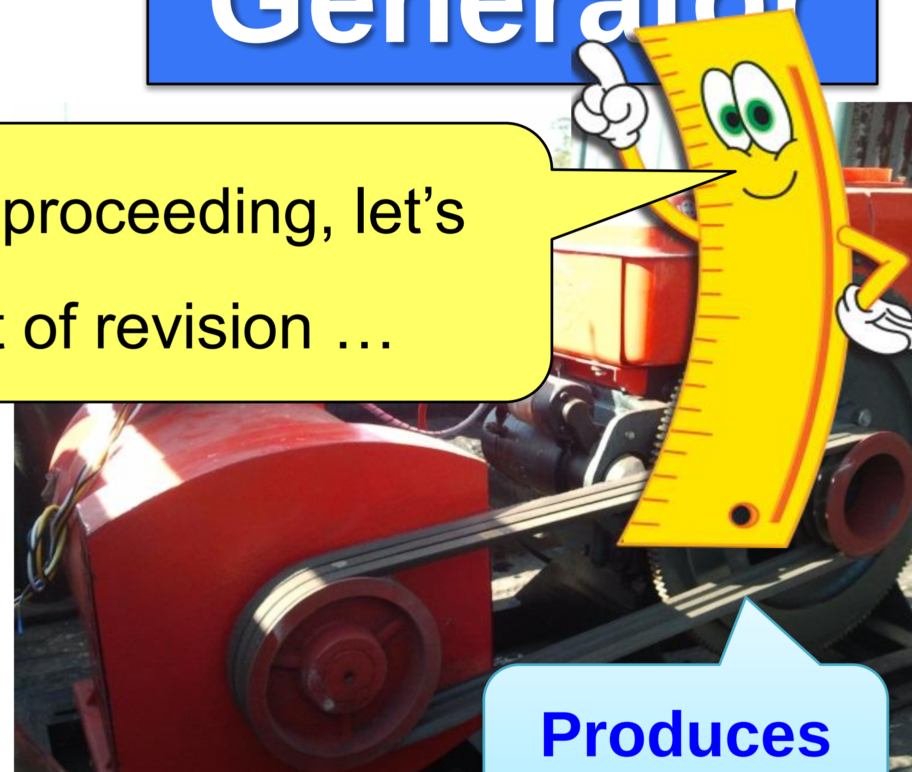
Main Difference

Electric Motor

en:User:C_J_Cowie

Works with electricity!

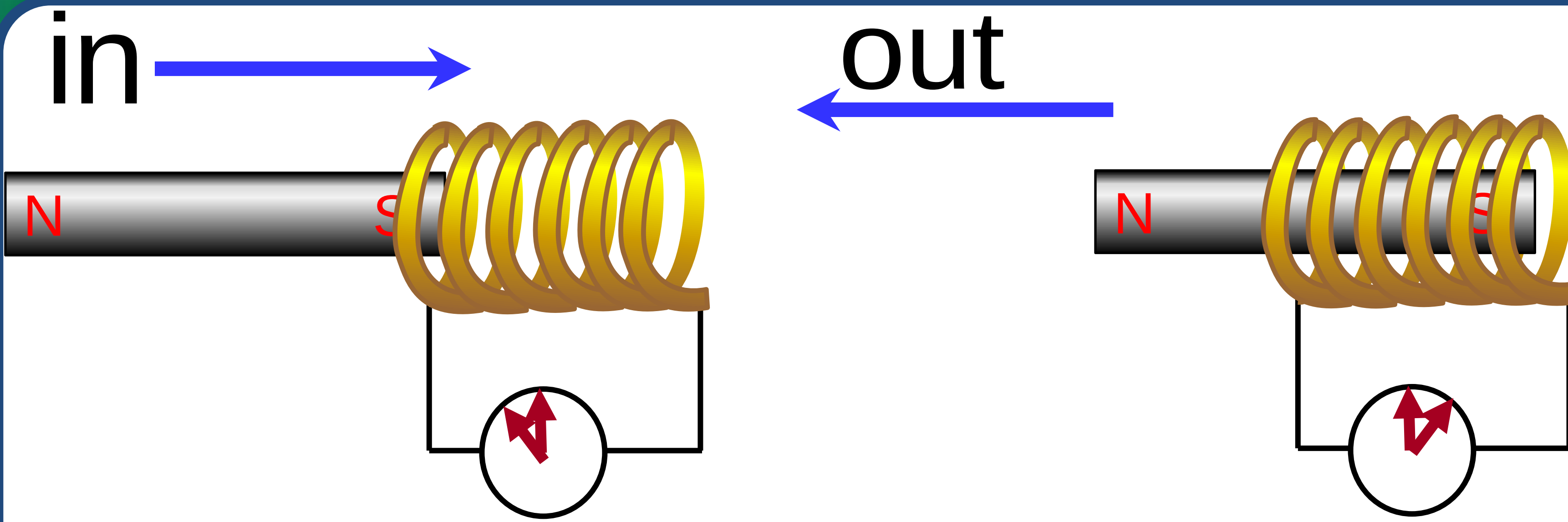
Electric Generator



Before proceeding, let's do a bit of revision …

Produces electricity!

Magnet Moving in Coil



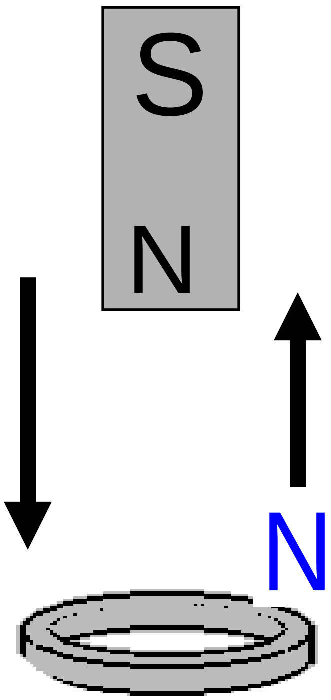
If a magnet is moved relative to a coil, an emf is induced.

If the coil is connected to a closed circuit, there will be a current in the circuit.

When the **direction of movement** changes, the **direction** of the **induced emf** changes.

Induced Current

The direction of the induced current is such that the magnetic field it establishes tends to **oppose the cause of the induction**.

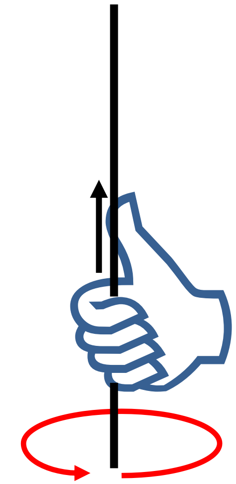


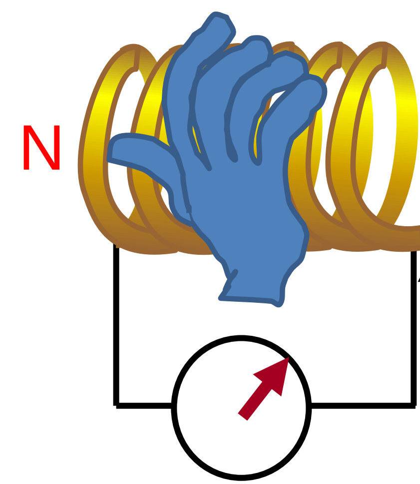
- If a N-pole approaches the coil, a N-pole is induced in the coil in order to **oppose** (repel) the **approaching** magnet.
- If the N-pole is withdrawn, the top end of the coil becomes a S-pole in order to **attract** the **leaving** magnet.

The **RIGHT HAND RULE** is used to determine the direction of the current in the ring.

Right Hand Rule

The **RIGHT HAND RULE** states that the magnetic field lines produced by **a straight current-carrying wire** will be oriented in the same direction as the curled fingers of a person's right hand, with the thumb pointing in the direction of the current flow.

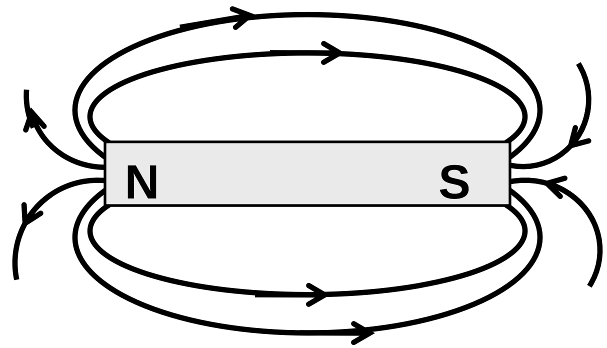




OR the variation of the RIGHT HAND RULE:
If you make the fingers of your right hand follow the direction of the **current in a loop**, your thumb will point in the direction of the north pole.

Magnetic Flux

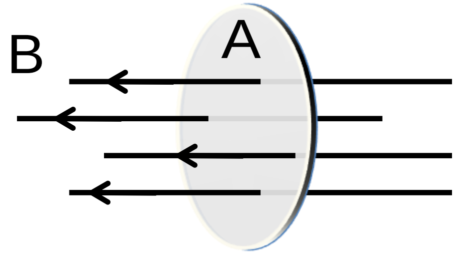
MAGNETIC FLUX represents an imaginary fluid that flows in the direction of the magnetic field.



The **strength** of the magnetic field depends on the density of the flux.

- Where the field is strong, the field (flux) lines are close together.

$$\Phi = BA$$



Φ : magnetic flux **(weber, Wb)**

A: area perpindicular to flux lines **(m^2)**

B: magnetic field strength or flux density **(Tesla, T)**

Faraday's Law

When a coil is placed inside a magnetic field, the magnetic flux can link to the coil.

- **Moving** the coil into or out of the magnetic field, **changes the flux linkage** which induces a current.

FARADAY' LAW OF ELECTROMAGNETIC INDUCTION states that the induced emf, **ε**, is directly proportional to the change in flux ΔΦ and inversely proportional to Δt.

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

ε: induced emf (V)

ΔΦ : change in flux (Wb)

Δt: time taken (s)

N: number of loops on coil

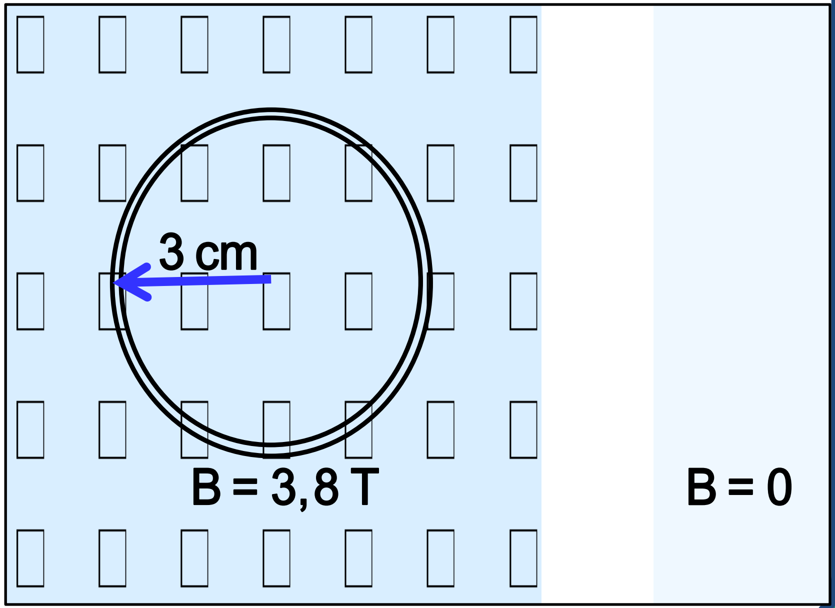
Challenge 1

A circular coil of radius 3 cm contains 150 loops and has a resistance of 10 Ω. It is positioned perpendicular to a magnetic field of strength 3,8 T.

The coil is pulled from the field in 0,2 s to a point where there is no magnetic field.

Calculate:

1. The change in magnetic flux in the coil.
2. The induced emf in the coil.
3. The induced current in the coil.



Solution

1. magnetic flux in the field:

$$\Phi = B \times A = (3{,}8\ \text{T}) \times (\pi \cdot (0.03\ \text{m})^2)$$

$$= 0{,}011\ \text{Wb}$$

magnetic flux outside the field:

$$\Phi = 0\ \text{Wb}$$

$$\therefore\ \Delta\Phi = 0 - 0{,}011 = -0{,}011\ \text{Wb}$$

$B = 3{,}8$ T

$R = 10\ \Omega$

$A = \pi \cdot (3\ \text{cm})^2$

$N = 150$

$\Delta t = 0{,}2$ s

2.

$$\varepsilon = -N\frac{\Delta\Phi}{\Delta t} = -150\frac{(-0{,}011\ \text{Wb})}{0{,}2\ \text{s}}$$

$$= 8{,}25\ \text{V}$$

3. Current in coil

$$\varepsilon = IR$$

$$\therefore I = \frac{\varepsilon}{R} = \frac{8{,}25\ \text{V}}{10\ \Omega}$$

$$= 0{,}825\ \text{A}$$

Generating Electricity

Two things are important to note here:

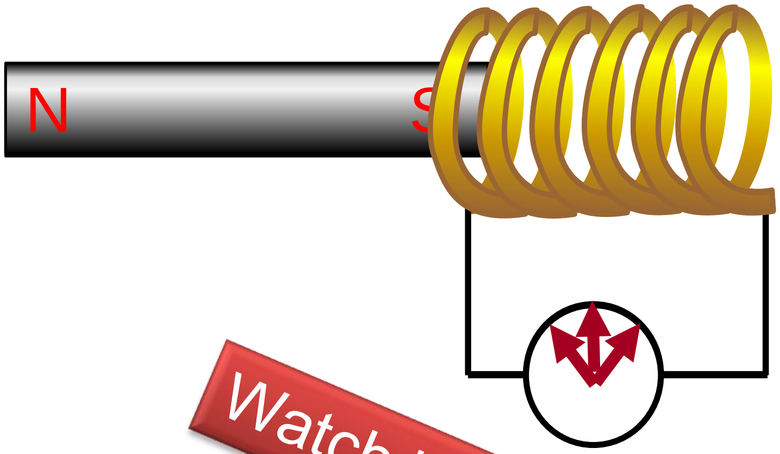
1. There must be a **change in flux linkage** to the coil **for current to be induced**;
2. The **maximum emf** is induced when the **area of the coil is perpendicular to the flux lines**.

That brings us to a different wording of EM induction:

> **ELECTROMAGNETIC INDUCTION** is the process of **generating electricity** by <u>changing the magnetic field</u> acting on a conductor.

Electromagnetic Induction

When the movement of the magnet is continued, current is continuously induced.



The induced current is an

Alternating current

Watch it again!

In **ALTERNATING CURRENT (AC),** the movement of electric charge periodically reverses direction.

In **DIRECT CURRENT (DC),** the flow of electric charge is only in one direction (e.g. where a battery supplies energy to the circuit).

Alternating Current

Current is only induced while the magnetic field moves relative to the solenoid i.e. when there is a change in the magnetic flux linkage with the solenoid.

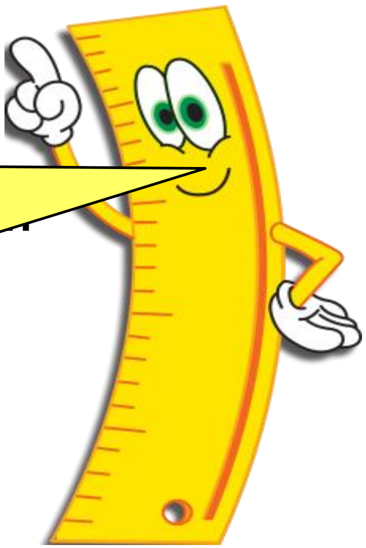
Its direction keeps changing, hence it is called alternating current AC

The strength of

- The speed of
- A stronger magnet is used
- The number of turns in the coil increases.

More about that in Lesson 5:

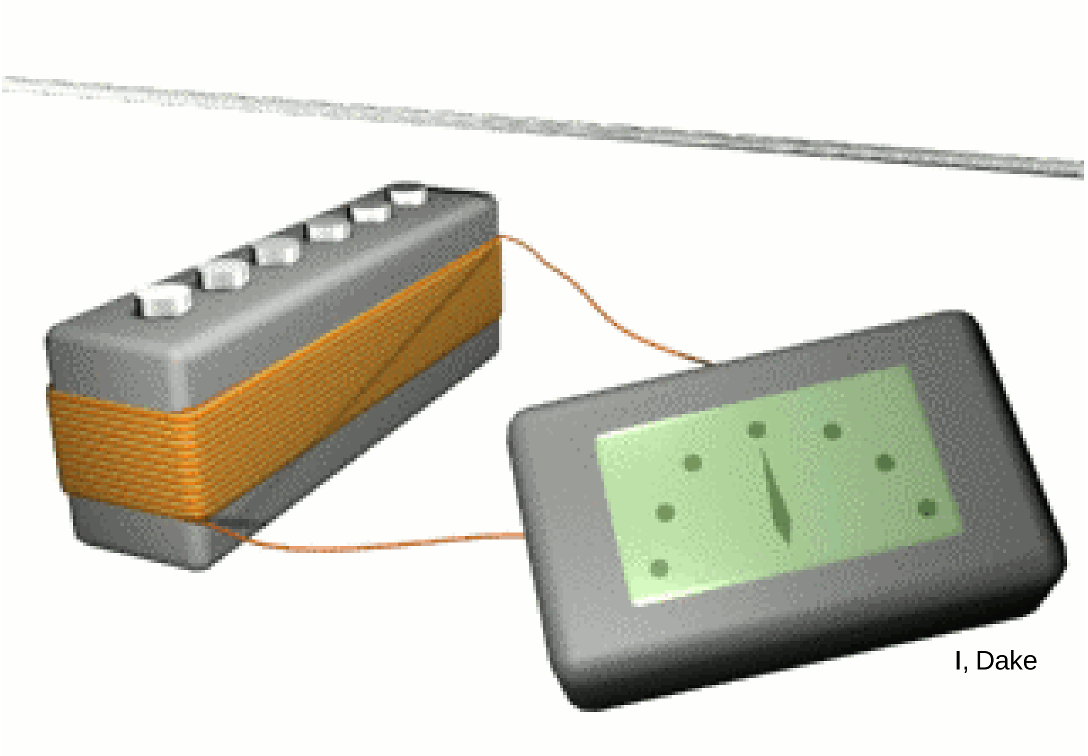
Alternating Current



The main advantage to AC is that the voltage can be changed. Because of this property, the current induced by **Power stations** is alternating current.

Electric Guitars

An electric guitar and electric bass uses a **single coil pickup** which is a type of magnetic pickup. The vibration of the strings is electromagnetically converted to an electric signal.

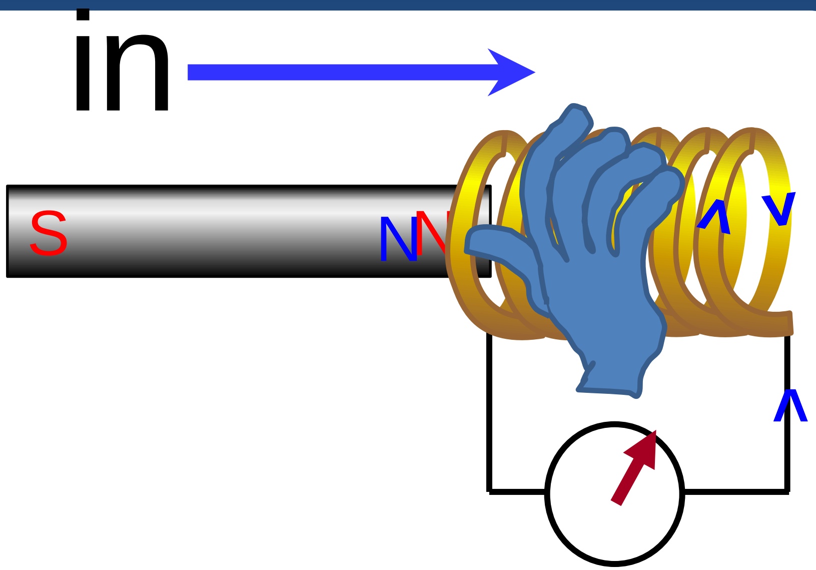


Note the alternating nature of the signal!

Class Exercise 1/1

Explain what happens when the magnet is pushed into the coil in terms of:

1. The magnetic field
2. Reaction of the coil
3. Current
4. Direction of current



1. The **magnetic flux linkage** to the coil **changes**.
2. The coil **induces a North pole** on the left hand side to oppose the incoming North pole.
3. A **current is induced** when the coil is connected to a closed circuit.
4. The direction of the current can be determined by the **variation of the Right Hand Rule**.

Class Exercise 1/2

2. Is the inducing of a current by a changing magnetic field principle to electric motors or electric generators? Explain.

   Electric generators, since it transforms mechanical energy (moving of magnet) into electrical energy (induced current).

3. Name two conditions for the inducing of a current.

- There must be a change in the flux linkage to the coil.
- The coil must be connected to a closed circuit.

4. Name three ways in which the induced emf (or current in a closed circuit) can be increased.

- Increase the speed of movement of the magnet
- Use a stronger magnet
- Increase the number of turns in the coil.

Class exercise 1/3

5. Which of the following statements describe an alternating current (AC)?

I It is produced by a battery

II Electrons change direction continuously.

III It is produced by a power plant.

IV Electrons move in the same direction.

A I and II B. II and III C. II and IV D. III and IV

6. In a coal-fired power plant, steam is used to turn turbine blades. The type of energy conversion which applies here is …

A mechanical energy to electrical energy

B chemical energy to electrical energy

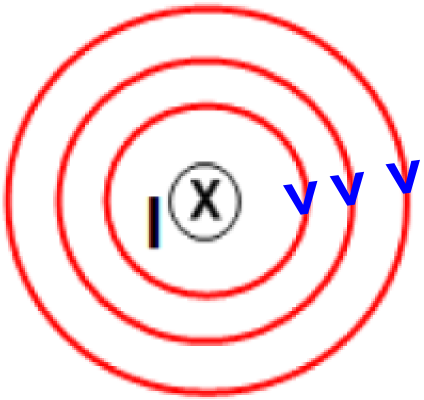
C electrical energy to chemical energy

D mechanical energy to chemical energy

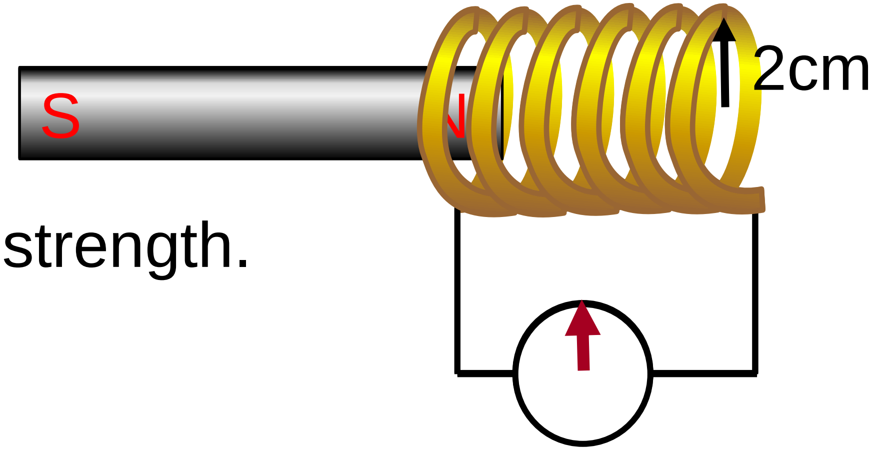
Class exercise 1/4

7. An electric current flows into the page. What is the direction of the magnetic field?

A to the bottom of the page
B to the top of the page
C clockwise
D counter-clockwise
E to the right



8. The magnetic flux in this situation is 0,02 Wb. Determine the magnetic field strength.



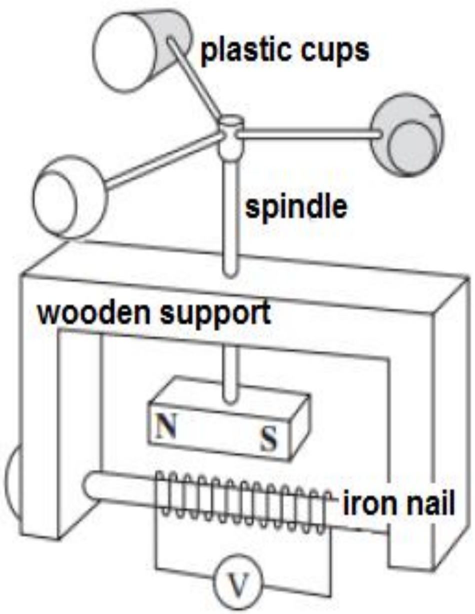
$\Phi = BA$

$B = \frac{0{,}02}{\pi(2\times10^{-2})^2}$

$= 15{,}92\ T$

Class exercise 1/5

(IEB St. Stithians Grade 12 Sept 2013)



9. The diagram shows a student's design for a simple wind speed gauge.

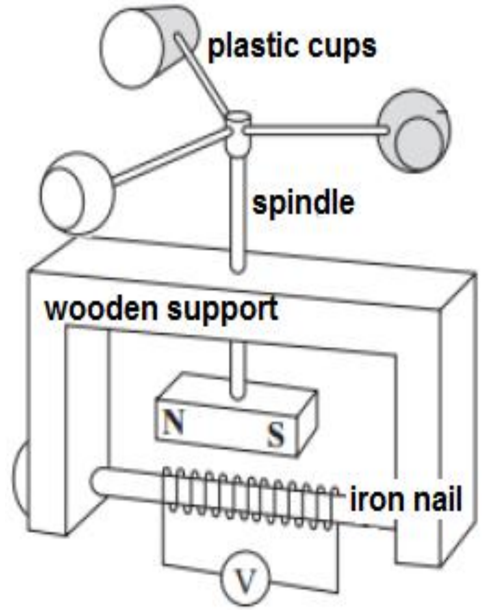
9.1. Explain how the wind will cause the voltmeter within the gauge to produce a reading.

The magnet is spun, producing changing magnetic flux through the coil. Potential difference is induced across the coil.

9.2. Name and state the law that will explain this effect

Faradays law of electromagnetic induction: The magnitude of the emf induced in a coil is proportional to the rate of change of magnetic flux.

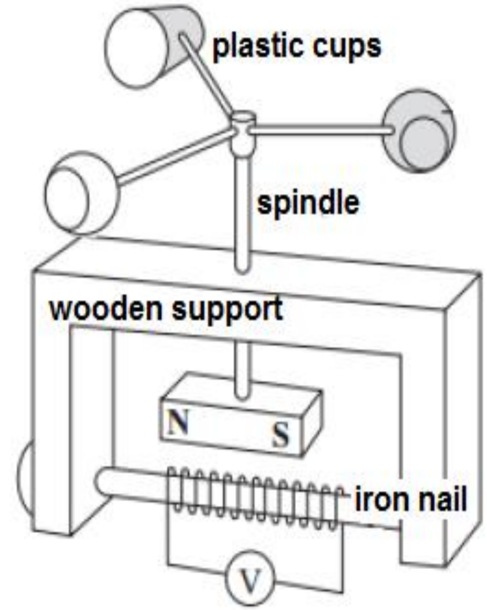
Class exercise 1/6



9.3. The gauge is not sensitive enough to measure light winds. Suggest THREE ways that the design can be modified to make the gauge more sensitive.

- more powerful / stronger / lighter magnet
- larger / more / bigger/ lighter cups / with a bigger surface area
- longer arms (increasing the torque – see lesson 4)
- lubricate the spindle
- add more turns to the coil / nail

Class exercise 1/7



9.4. The student decides to investigate the voltage produced in the wind gauge. He sets up the gauge as shown in the diagram but varies the size of the plastic cups that are used to catch the wind.

9.4.1. Suggest a possible hypothesis for his experiment.

As the cup size increases the voltage induced increases.

9.4.2. Identify the independent and dependant variables for this experiment?

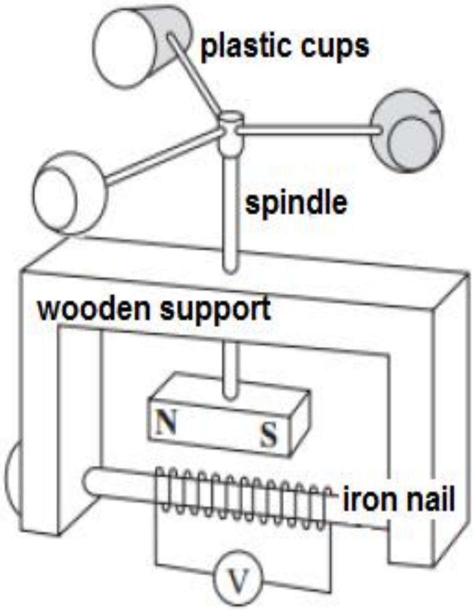
Independent: size of cups

Dependent: voltage generated

Class exercise 1/8

9.4. Name TWO variables will he need to control to ensure a fair test?

- Number of cups catching wind remains the same;
- Angle to the wind;
- Length of iron nail;
- Keep magnet strength the same;
- Keep number of turns on coil the same.



Key Concepts 1

- **Electric Motors** convert **electrical energy into mechanical energy** (e.g. an electric fan);
- **Electric Generators** convert **mechanical energy into electrical energy** (e.g. a bicycle lamp).

Both of these electrical machines function on the **Principle of change in magnetic flux.**

FARADAYS LAW OF ELECTROMAGNETIC INDUCTION:

The magnitude of the emf induced in a coil is proportional to the rate of change of magnetic flux.

ELECTROMAGNETIC INDUCTION is the process of **generating electricity** by changing the magnetic field acting on a conductor.

Key Concepts 2

The **maximum emf** is induced when the **area of the coil is perpendicular to the flux lines**.

The maximum emf induced can be increased by:

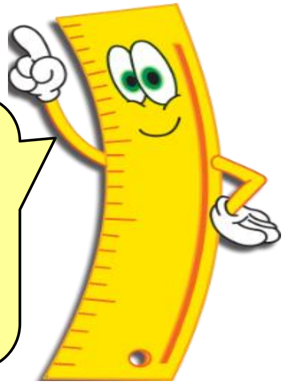
- Increasing the speed of movement of the magnet
- Using a stronger magnet
- Increasing the number of turns in the coil.

In **ALTERNATING CURRENT (AC),** the movement of electric charge periodically reverses direction.

In **DIRECT CURRENT (DC),** the flow of electric charge is only in one direction (e.g. where a battery supplies energy to the charges).

- **Memorise** the various definitions
- **Review** the exercises you had difficulty with …
- and do some **additional exercise** …
  - as given in your **workbooks** that accompany this video series or from your school textbook

Continue your learning by watching the
next video lesson in this series:
Lesson 2: AC Generators



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