Cape Town Science Centre

REVISION BOOKLET

Grade 11 • Physics

ELECTROMAGNETISM & ELECTRIC CIRCUITS

ELECTRICITY AND MAGNETISM

Term 3 - 2021

Western Cape Government
Education
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CTSC
CapeTownScienceCentre

Subject: Physical Science
Grade: 11
Content area: Electricity and Magnetism
Topic: Electromagnetism

In this unit we will focus on the following concepts and skills:

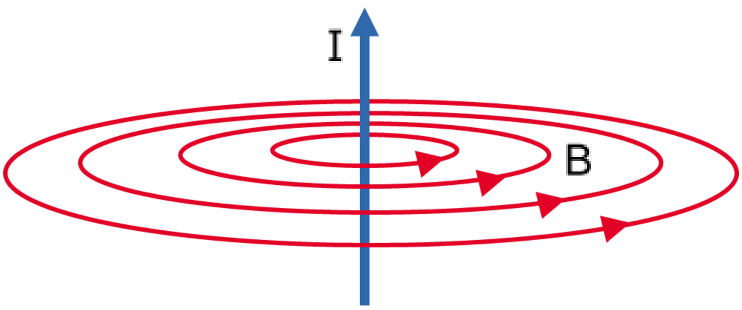
- **Magnetic Fields in current carrying wire**
- **The "Right Hand Rule"**
- **Sketching Magnetic fields.**

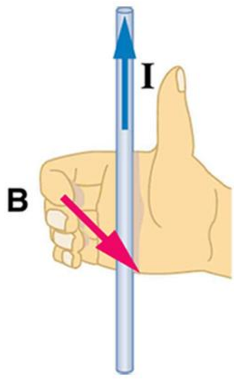
MAGNETIC FIELDS DUE TO A CURRENT

Electromagnetism is the study of the relationship between *electric* and *magnetic fields*. We've already seen that there are many similarities between the two.

In both electric and magnetic fields there is the concept of **like repels, and opposites attract**.

In fact, the two are very closely related. Whenever we have a wire which is carrying a current there will be a magnetic field. The direction of the magnetic field can be determined by the **RIGHT-HAND RULE**. If you stick your right thumb in the direction of the current, then your curling fingers should give you the direction of the magnetic field. In the example below the current is going up, so the magnetic field circles around it as shown.



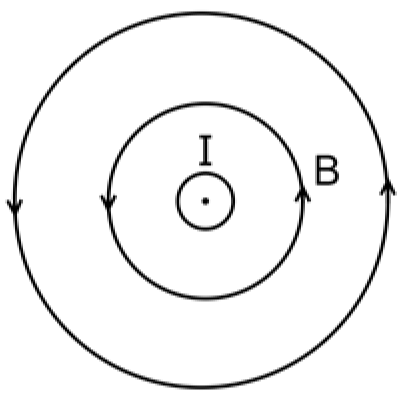


Right-Hand Rule

Notice that if you used your *left* hand then you would get the **wrong** direction.

If we were looking at this wire from directly above, we use a dot (⊙) to show that the current is coming "out" of the page. If the current were going "into" the page, then we use a cross (⊗).

An easy way to remember this is if you were looking at an arrow from the front, you'd see just a dot (⊙), but if you looked at the back, you'd see a cross (⊗).



I represents the current, and **B** represents the magnetic field.

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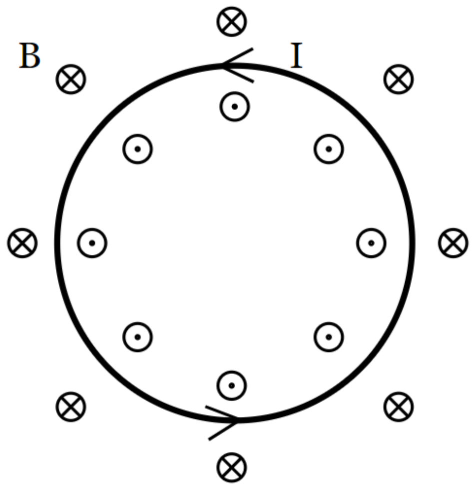
SKETCHING MAGNETIC FIELDS

Current Carrying Loop

Here we have a circular current (a loop), and using the Right-Hand Rule we can determine the direction of the magnetic field.

The arrows shows the current is flowing in the anti-clockwise direction around the loop

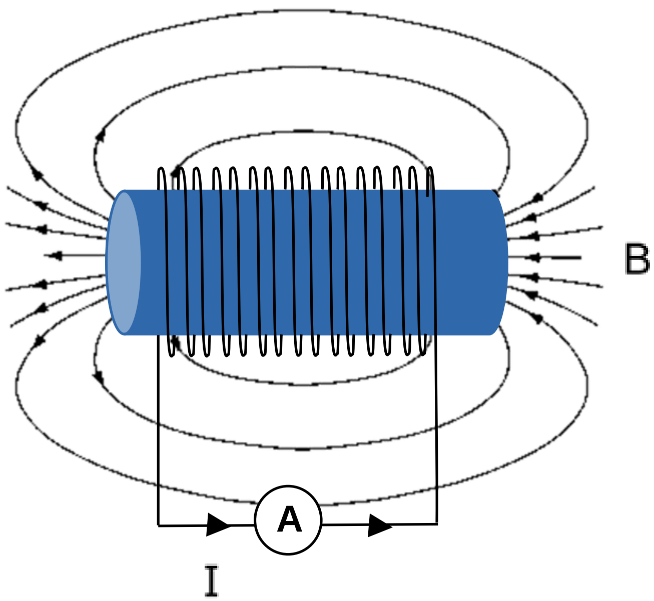
We can use the dots and crosses to show the direction of the magnetic field too.



Solenoid

Here we have a series of loops (a "solenoid").

Again, using the Right-Hand Rule we see that each loop creates a magnetic field within the loop going from left-to-right. Outside the loop the magnetic field will circle back around, right-to-left.



Subject: Physical Science
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Content area: Electricity and Magnetism
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In this unit we will focus on the following concepts and skills:

- **Environmental impact of overhead electrical cables**

ENVIRONMENTAL IMPACT

In South Africa we have many power lines, which carry electrical power all over the country. Unfortunately this can have a negative impact on the wildlife, particularly birds.

Birds may be physically harmed by power lines due to electrocution or physically colliding with the power lines. Large birds are especially at higher risk of colliding with the powerlines. Each year thousands of birds are killed from collisions.

The power lines also potentially interfere with nearby radio signals, as they can generate similar signals.

Subject: Physical Science
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In this unit we will focus on the following concepts and skills:
- **Magnetic Fields**
- **Faraday's law**

FARADAY'S LAW

Faraday's Law Faraday's law describes the relationship between the induced emf and the rate of change of magnetic flux. Michael Faraday discovered that when he moved a magnet near a wire a voltage was generated across it.

If the magnet was held stationary no voltage was generated, the voltage only existed while the magnet was moving. We call this voltage the **induced emf (E)**.

If the wire was set up in a closed circuit, and the magnet moved near it, then an ammeter connected to this circuit would register a current as the magnet was **moved**.

This current was called the **induced current**. This is a practical way to generate electricity.

Faraday's Law of Electromagnetic Induction

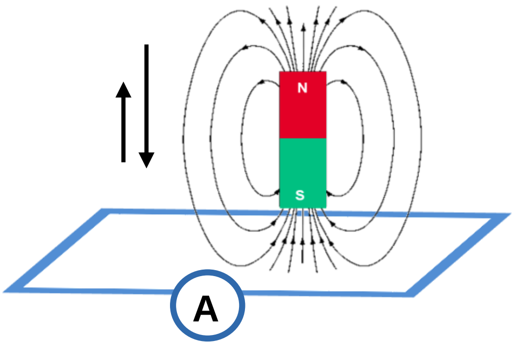
The emf, $\mathcal{E}$, produced around a loop of conductor is proportional to the rate of change of the magnetic flux, φ, through the area, A, of the loop

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

Where N is the number of circuit loops and $\phi = B.A$, B is the magnetic field strength

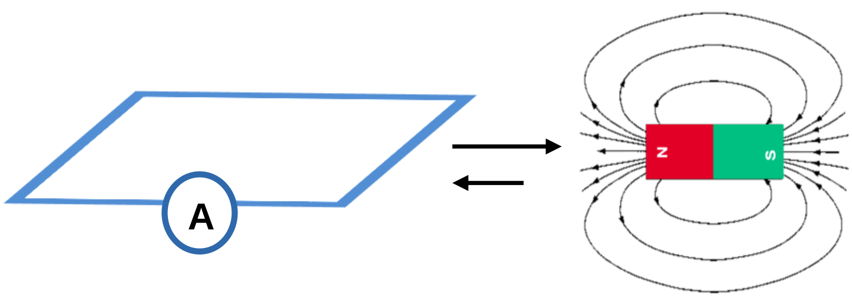
There must be a change in the magnetic flux (Φ) in order for an emf (ε) to be induced in the conductor.

Magnet moved PERPENDULAR to a Single Loop Conductor



Produce an induced current

Magnet moved PARALLEL to a Single Loop Conductor



NO induced current produced

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- **Faraday's law**

MAGNETIC FLUX

The magnetic flux (Φ) is a measure of the number of magnetic field lines passing through a surface perpendicular to it.

The magnetic flux of a constant magnetic field is given by:

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

Where:

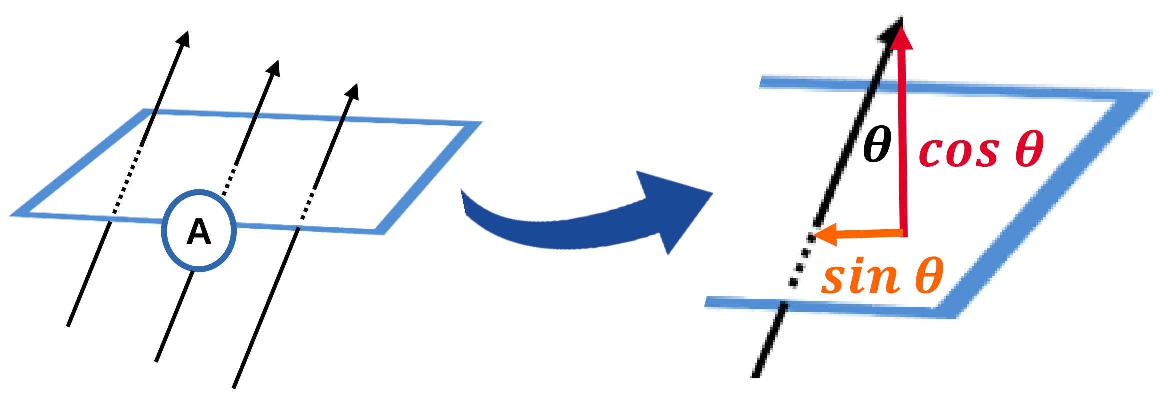
θ = the angle between magnetic field lines and the surface
A = the area of the loop
B = the magnetic field

The S.I. unit of magnetic flux is the weber (Wb)

Why the angle $\cos\theta$?

What happens when the magnetic field lines are not perpendicular or parallel to their surface but somewhere in-between? Then we can breakdown the angle (θ) into its perpendicular ($\cos\theta$) and parallel components ($\sin\theta$).

The parallel component does not contribute to the magnetic flux, only the perpendicular! The figure below shows how the angles affect the flux.



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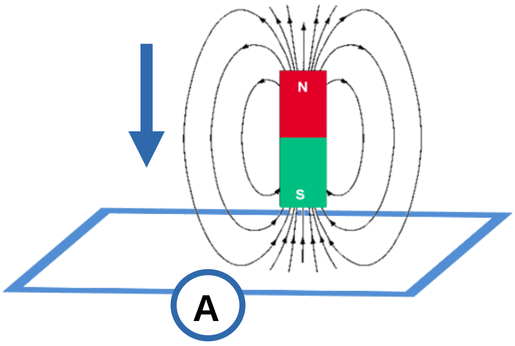
Direction of the Induced Current

The induced current OPPOSES whatever change is taking place!

An easy way to understand this is using the poles as examples

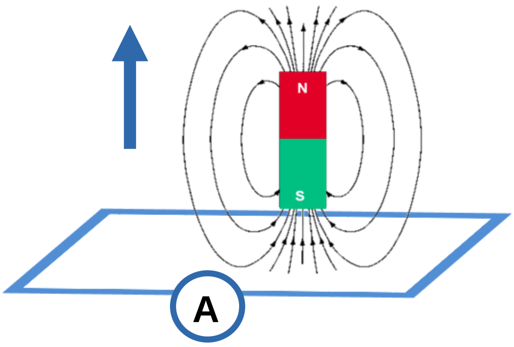
Think of it like this: When the magnetic pole is moving closer, the (opposing) response is to push it away. But when the magnetic pole is moving away, the (opposing) response is to pull it closer.



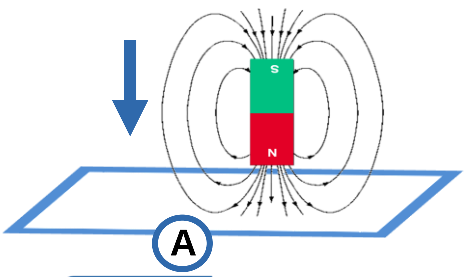
As the South Pole of the magnet moves closer to the coil, the magnetic field gets larger. The response is therefore to resist the field.

To resists means that a LIKE pole must be generated. Therefore the induced current generates an field that looks like another south pole. Remember like poles repel!

If the South Pole is moving away, then the magnetic field will be getting weaker. So the induced current will set up a north pole to attract the departing south pole.



Tip! You can use the a <u>variation</u> of the Right-Hand Rule where your finger point in the direction of the current and your thumb in the direction of field line (the north pole)



What is the direction of the induced current for this image?

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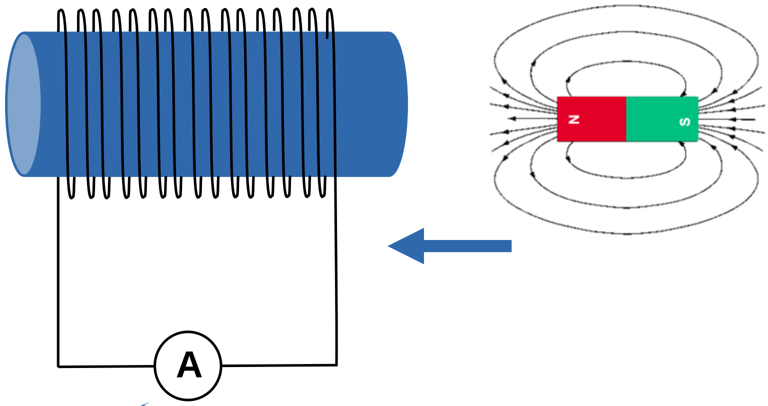
INDUCED CURRENT IN A SOLENOID

As before, the induced current OPPOSES whatever change is taking place!

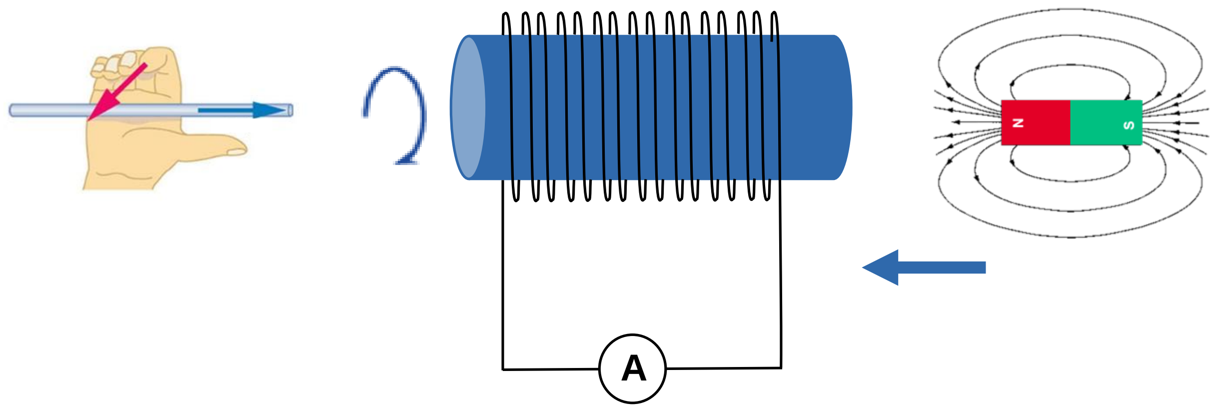


Since the **NORTH POLE** of the magnetic is moving **CLOSER**, the solenoid must generate an **OPPOSING NORTH POLE**.

Therefore the induced current will be counter clockwise.

Use the Right-Hand Rule verify

Remember! For the Right-Hand Rule, in a solenoid:
(i) Fingers points in the direction of the current and thumb in the direction of field lines (the north pole).



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In this unit we will focus on the following concepts and skills:
- **Ohm's law**
- **Power and Energy**

OHM'S LAW

Ohm's Law

For a resistor at a constant temperature, which is called an *Ohmic resistor*, the current (I) flowing through the resistor (R) is directly proportional to the voltage (V) across it.

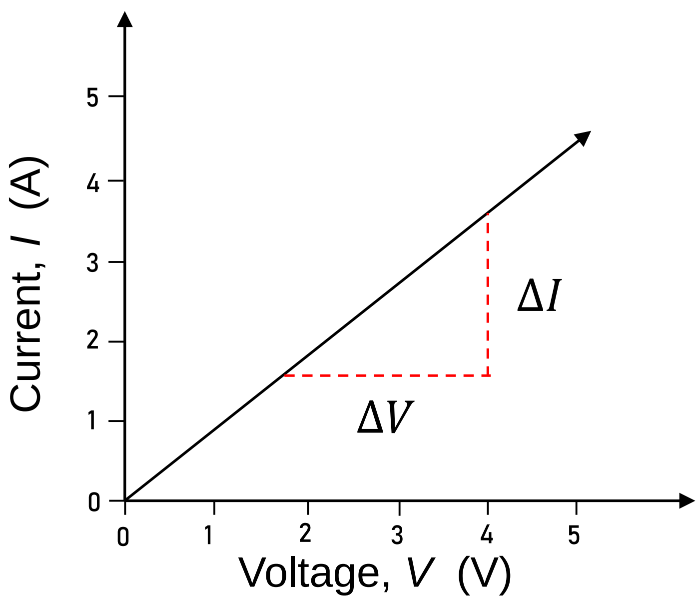
V = IR

REMEMBER:
- **Electrical current (I):** the rate of flow of charge through a circuit.
- **Potential difference or voltage (V):** the amount of energy per unit charge needed to move that charge between two points in a circuit.
- **Resistance (R):** a measure of how `hard' it is to push current through a circuit element.

The relationship between current (I) and voltage (V) can is graphically represented:

.

$$I = \frac{V}{R}$$



$$\frac{1}{R} = \frac{\Delta I}{\Delta V}$$

This can be rearranged in terms of the constant resistance as:

$$R = \frac{V}{I}$$

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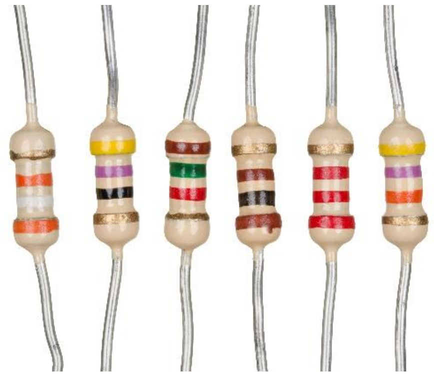
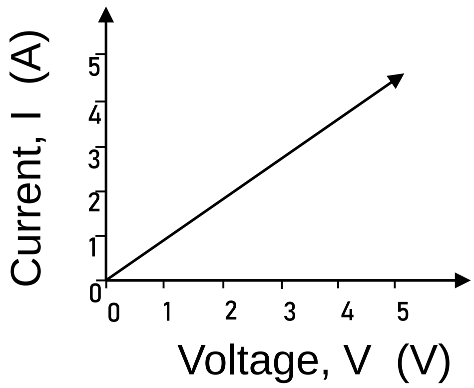
OHMIC AND NON-OHMIC CONDUCTORS

Ohmic Conductors
Conductors that have a constant resistance when the voltage is varied across them, or the current is increased through them, are known as ohmic conductors as they obey Ohm's law.

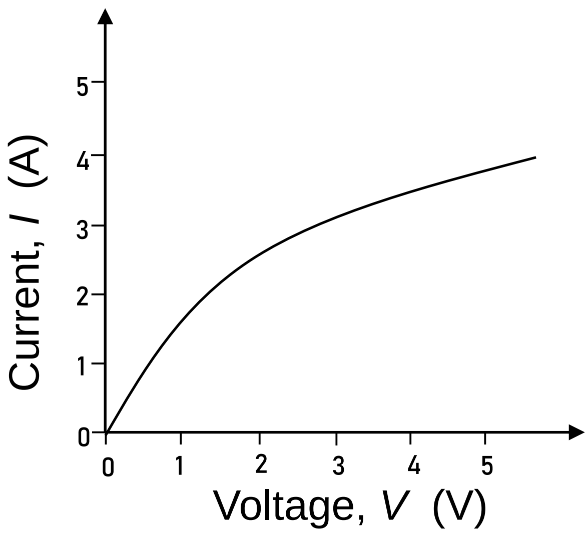


An example of ohmic resistors.



Non-Ohmic Conductors
A non-ohmic conductor is a conductor that does not obey Ohm's law. The resistance of the conductor will increase (when the temperature increases) due to an increase in the voltage and current through the conductor.

An example of a non-ohmic resistor is a lightbulb.



For non-ohmic conductors, a graph of voltage vs current will not produce straight-line trend which means resistance is not constant across all voltages and currents

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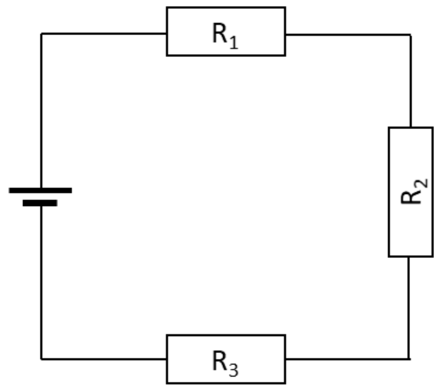
SERIES AND PARALLEL RESISTORS

Resistors Connected In Series

The resistance is ADDED, with the equivalent resistance for resistors in series (R_s) given as:

Resistance ADDS

$$R_s = R_1 + R_2 + R_3 + \dots$$



The total voltage (V_{total}) is split across the resistors:

Voltage SPLITS

$$V_{Total} = V_1 + V_2 + V_3 + \dots$$

The current is constant through all the resistors:

Current EQUAL (CONSTANT)

$$I_{Total} = I_1 = I_2 = I_3 = \dots$$

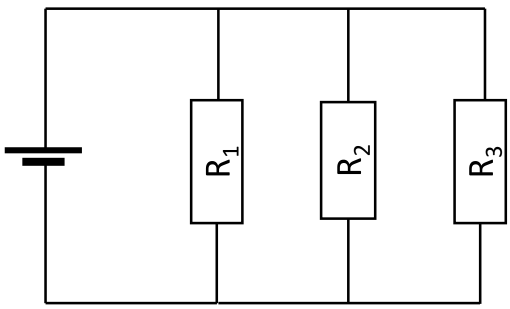
Resistors Connected in Parallel

When more than one resistor is connected in series in a branch, we can add the resistance and view it as a single resistor

Therefore the equivalent resistance for resistors in parallel (Rp) is given as:

Resistance ADDS INVERSELY across branches

$$\frac{1}{R_p} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \dots$$



The total voltage (V_{total}) is the same across each branch:

Voltage EQUAL (CONSTANT) across branches

$$V_{Total} = V_1 = V_2 = V_3 + \dots$$

Current SPLITS across branches

$$I_{Total} = I_1 + I_2 + I_3 + \dots$$

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Electrical Energy, Work and Power

Work (W) is done (energy transferred ΔE) when a charge Q moves across a potential difference ΔV

Recall that V = W/Q

$W = VQ$

Ohm's Law **$V = IR$**

Electric Charge **$Q = I\Delta t$**

$W = V(I\Delta t)$

$W = I^2R\Delta t$

$W = V^2\Delta t/R$

Electrical power (P) can be defined as the rate at which work done (W) is done or at which energy transferred (ΔE)

$$P = \frac{\Delta E}{\Delta t} = \frac{W}{\Delta t}$$

The unit of measurement for power is the watt (abbreviated W)

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Defining Power

We know that the work done (energy transfer) is equal to the unit charge moving across a potential difference W = VQ

Substituting this into our equation for power we get

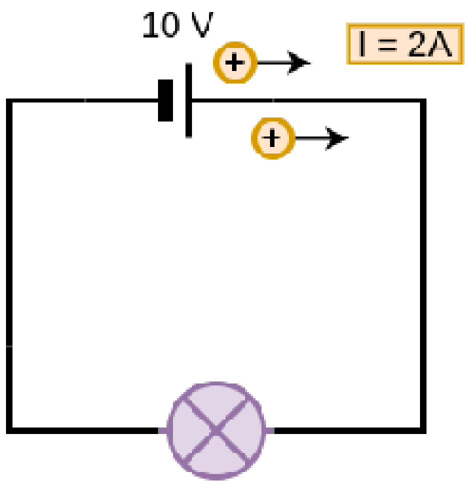
$$P = \frac{VQ}{\Delta t}$$

We know that current is defined as charge per unit second I = Q/Δt

Therefore, we can write our power equation as

$$P = IV$$

Electrical power (P) is the rate at which electrical energy is converted in an electric circuit.



Example: A simple circuit containing a lightbulb.

The light bulb will have a potential difference of 10V which means that when current passes through it, every charge (Q) exchanges 10 J of energy with the light bulb.

The current that passes through the light bulb is 2A, i.e. 2 charges are passing through it every second.

Therefore, every second, 2 charges (Q) are converting 10J of electrical energy to light energy

So the power supplied to this light bulb can be calculated

$$P = IV = 2A \cdot 10V = 2C/s \times 10J/C = 20J/s = 20\ W$$

One watt (W) is equal to one joule (J) of electric potential energy being used per second (s)

1 W = 1 J/s

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Defining Power

① P = IV

This equation can be further expanded using Ohm's Law

Ohm's Law

For a resistor at a constant temperature, which is called an *Ohmic resistor*, the current flowing through the resistor is directly proportional to the voltage across it.

V = IR

$$P = IV = I\,(I\,R)$$

② $P = I^2R$

$$P = IV = \left(\frac{V}{R}\right)V$$

③ $P = \frac{V^2}{R}$

ALL THREE EQUATIONS OF POWER ARE EQUIVALENT

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POWER AND ENERGY

The Cost Of Power Consumption

Electricity energy is sold as a measure of electrical power consumption in units called **kilowatt-hour (kW·h)**. This is known as one unit of electricity.

1 kilowatt = 1000 watts of power used in the span of 1 hour

Tariff is the amount of money (in cents or rands) per kW·h

The total cost of power consumption is the product of the power consumption and the tariff

Cost [cents] = Power consumption[kWh] x Tariff [cents/kWh]

or

Cost [rands] = Power consumption[kWh] x Tariff [rands/kWh]

What does it means we talk about a 60 W light bulb?

The 60 W, which is a measure of power, means t 60 Joules per second are consumed by the light bulb.

Let's calculate how much it would cost to have the light bulb on for a 150 min if the tariff was 164.29 c/kWh.

Assume that maximum power is used.

Power 60 W = 0.06 kW
Time duration = 150 min = 2.5 hours

Power consumption = Power x time = (0,06 kW)(2,5 h)

= (0,15 kWh)

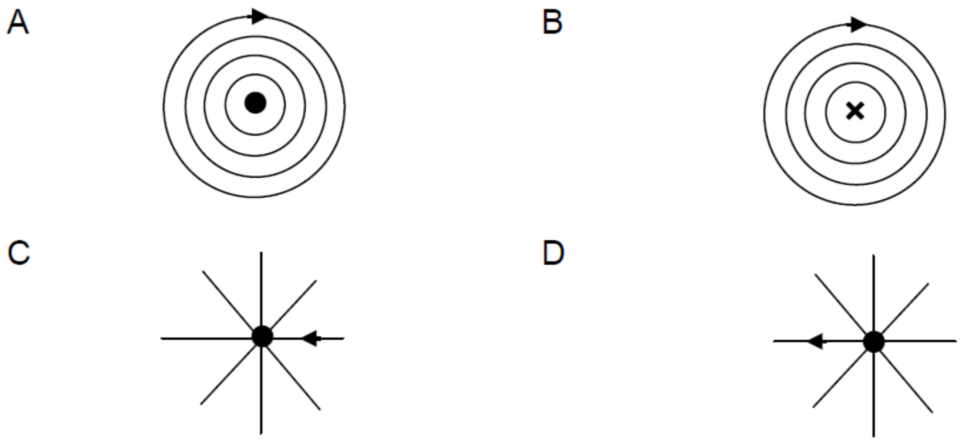
Cost = Power consumption x tariff

= (0,15 kWh)(164,29c/kWh)

= 24,64 c or R0,25

EXAM QUESTION | **MAGNETIC FIELDS** | **P1 NOV 2018 Q1**

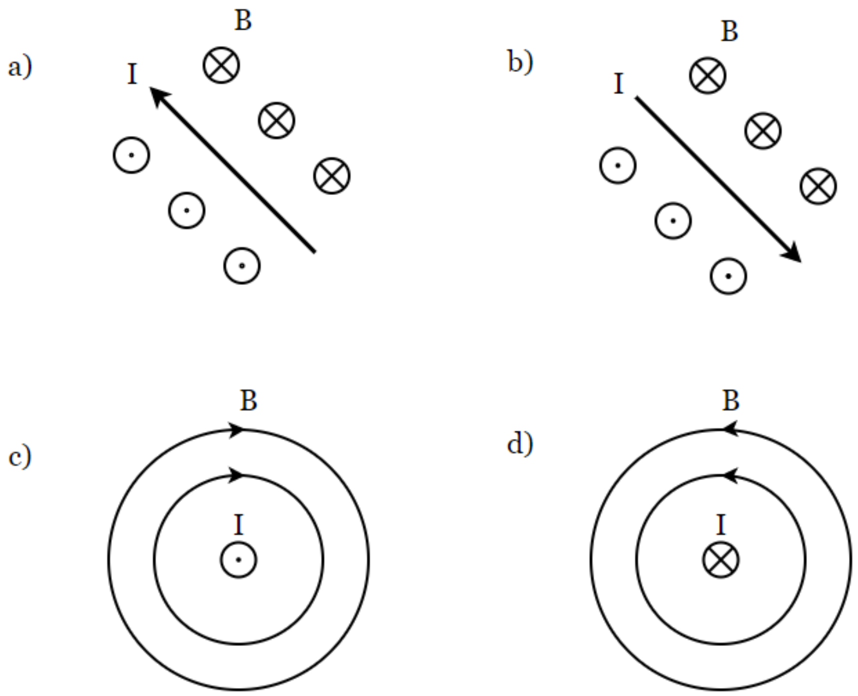
1.9 Which ONE of the sketches below represents the CORRECT magnetic field pattern around a straight current-carrying conductor?



(2)

The answer is **B**. This is the only option which follows the Right-Hand rule.

Which of the following represents a correct magnetic field for the given current carrying wire?



The answer is **A**. This is the only option which follows the Right-Hand rule.

EXAM QUESTION FARADAY'S LAW P1 NOV 2019 Q9

QUESTION 9

A coil with 200 windings and a surface area of 2,8 × 10-3 m is rotated at constant speed in a constant magnetic field of 2,5 T. An emf of 3,5 V is induced in the coil.

9.1) Consider the following statement: The magnitude of the induced emf across the ends of a conductor is directly proportional to the rate of change in the magnetic flux linkage with the conductor. Name the law represented by the above statement. (1)

Faraday's law of electromagnetic induction

9.2) Calculate the:
9.2.1) Change in magnetic flux if the angle of the coil relative to the magnetic field changes from 0° to 90° (3)

ΔΦ = ΔBAcos θ
= (2,8 x10-3)(2,5)(cos 90º - cos 0º)
= -0,007 Wb

9.2.2) Time it takes the coil to rotate from 0° to 90° (3)

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

$$3{,}5 = -\frac{200(-0{,}007)}{\Delta t}$$

$$\therefore \Delta t = 0{,}4s$$

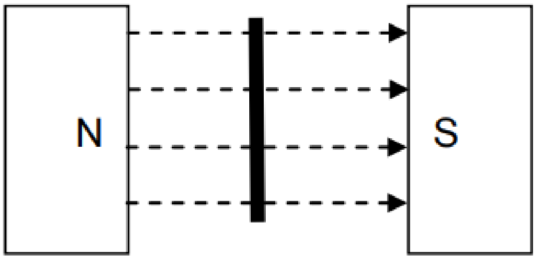
9.3) By what factor will the induced emf change if a coil with 100 windings is used under the same conditions? Give a reason for the answer. (2) [9]

Emf will be halve/two times smaller because Emf is directly proportional to number of coils

EXAM QUESTION **FARADAY'S LAW** **P1 NOV 2018 Q11**

QUESTION 11

A SQUARE induction coil with a side length 3 cm and 400 windings, is placed perpendicularly in a uniform magnetic field and then rotated through an angle of 45º in 0,08 s. An emf of 7 V is induced in the coil.



11.1) State Faraday's law of electromagnetic induction in words. (2)

11.2) Calculate the change in the magnetic flux. (3)

11.3) Calculate the magnitude of the magnetic field. (4)

The coil is now rotated through an angle of 45º in 0,05 s.

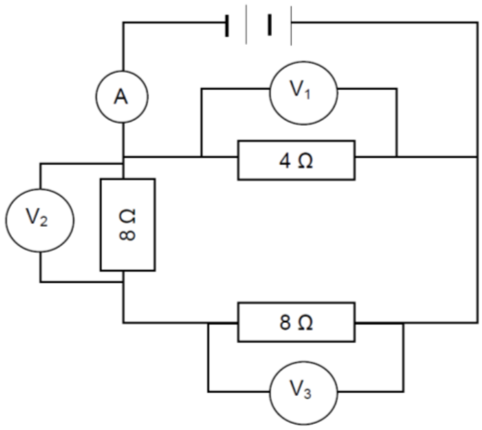
11.4) How will the induced emf be affected? Write only INCREASE, DECREASE or STAY THE SAME. (1)

11.5) Explain the answer to QUESTION 11.4. (1)

EXAM QUESTION	CIRCUITS	P1 NOV 2017-2019 Q1

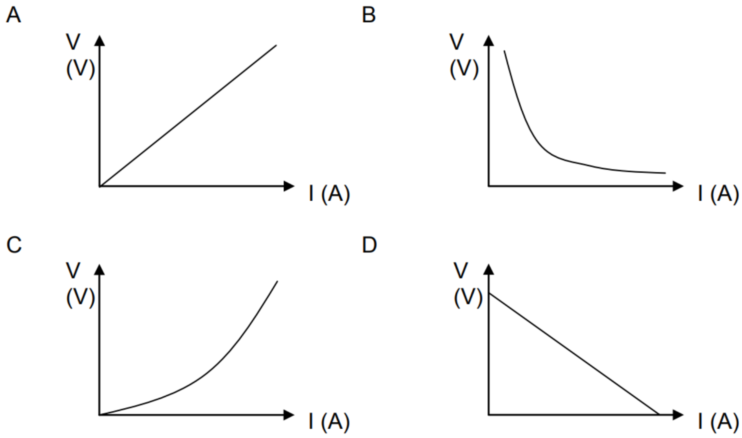
1.10 In the circuit diagram below, the battery has negligible internal resistance. The resistance of the ammeter and wires may also be ignored.

The reading on voltmeter V_3 will be equal to …

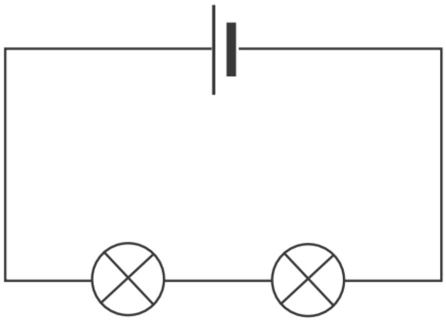


A V_1
B ½ V_1
C $V_1 + V_2$
D $V_2 - V_1$

1.10 Which ONE of the graphs below CORRECTLY represents the relationship between potential difference and current in a non-ohmic resistor?



1.10 The cell in the circuit below delivers a potential difference of 1,5V. The bulbs are identical and the current in the circuit is 0,2 A.

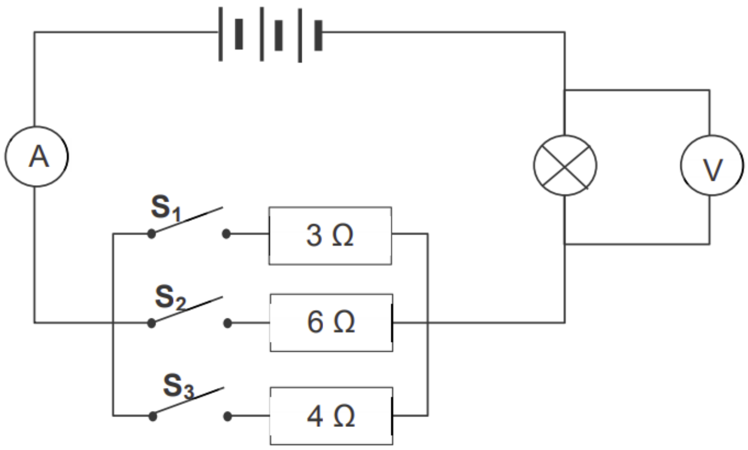


The energy, in joule, transferred by ONE of the bulbs in one minute is …

A $1,5 \times 0,2 \times 1$
B $1,5 \times 0,2 \times 60$
C $0,75 \times 0,2 \times 1$
D $0,75 \times 0,2 \times 60$

EXAM QUESTION	CIRCUITS	P1 NOV 2019 Q10

Three resistors, of resistances 3 Ω, 4 Ω and 6 Ω, and a bulb are connected in a circuit, as shown below. Initially all the switches, S1, S2 and S3, are open. The internal resistance of the battery and the resistance of the connecting wires may be ignored.



10.1 State Ohm's law in words. (2)

The potential difference across a conductor is directly proportional to the current in the conductor at constant temperature.

Switch S1 is now closed, and the voltmeter and ammeter readings are recorded. The voltmeter and ammeter readings, when both switch S1 and switch S2 are closed, are then recorded, as well as the readings when all three switches, S1, S2 and S3, are closed.

The results obtained are shown in the table below.

SWITCHES CLOSED	VOLTMETER READING (V)	AMMETER READING (A)
S_1	4,8	2,4
S_1 and S_2	6	3
S_1, S_2 and S_3	7,2	3,6

10.2 Explain the increase in the ammeter reading as more switches are closed. (2)

More resistors connected in parallel. Therefore, the effective resistance of the circuit decreases.

EXAM QUESTION	CIRCUITS	P1 NOV 2019 Q10

10.3 Calculate the:

10.3.1 Resistance of the bulb (3)

$$R = \frac{V}{I}$$

$$R = \frac{4.8}{2.4}$$

$$R = 2\Omega$$

10.3.2 Potential difference of the battery (4)

Switch 1 closed

$$R_{tot} = 3 + 2$$
$$R_{tot} = 5\Omega$$

$$V_{emf} = IR_{tot}$$
$$V_{emf} = (2.4)(5)$$
$$V_{emf} = 12\text{V}$$

Switch 1 & 2 closed

$$\frac{1}{R_p} = \frac{1}{R_1} + \frac{1}{R_2}$$
$$\frac{1}{R_p} = \frac{1}{3} + \frac{1}{6}$$
$$R_p = 2\Omega$$

$$R_{tot} = 2 + 2$$
$$R_{tot} = 4\Omega$$

$$V_{emf} = IR_{tot}$$
$$V_{emf} = (3)(4)$$
$$V_{emf} = 12\text{V}$$

Switch 1 & 2 & 3 closed

$$\frac{1}{R_p} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$
$$\frac{1}{R_p} = \frac{1}{3} + \frac{1}{6} + \frac{1}{4}$$
$$R_p = 1.33\Omega$$

$$R_{tot} = 1.33 + 2$$
$$R_{tot} = 3.33\Omega$$

$$V_{emf} = IR_{tot}$$
$$V_{emf} = (3.6)(3.33)$$
$$V_{emf} = 12\text{V}$$

EXAM QUESTION	CIRCUITS	P1 NOV 2019 Q10

10.4 Define the term power. (2)

Power is the rate at which work is done or energy is transferred.

10.5 Calculate the power dissipated in the 6 Ω resistor when ONLY SWITCHES S1 and S2 are closed. (4)

$V_{ll} = V_{emf} - V_{series} = 12 – 6 = 6$ V

$P = V^2_{ll} /R$

$P = (6\ V)^2/(6\ \Omega)$

$P = 36/6$

$P = 6$ W

10.6 How will the BRIGHTNESS of the bulb be affected as more switches in the circuit are closed? Write only INCREASES, DECREASES or REMAINS THE SAME. (1)

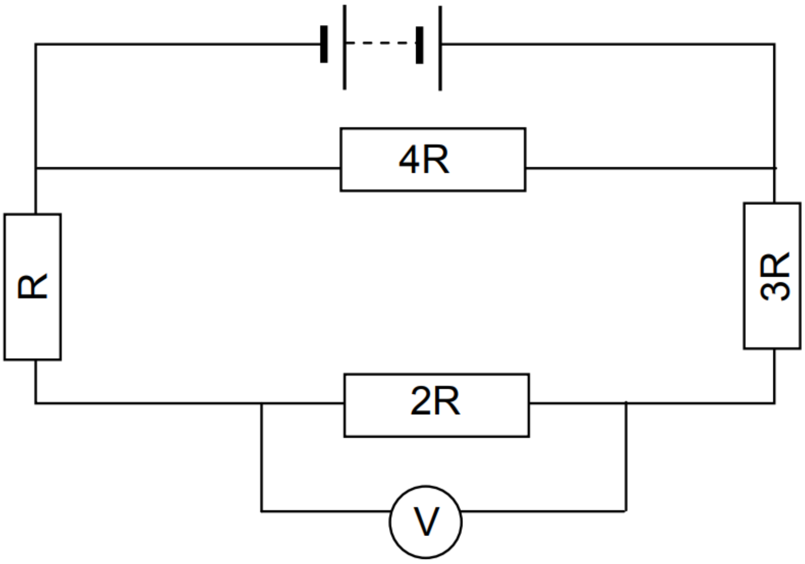
Increases

10.7 Explain the answer to QUESTION 10.6. (2)

(As more resistors are connected in parallel, the effective resistance decreases and the current increases.) From **$P = I^2 R$,** power is directly proportional to I^2 if R (of the bulb) stays constant. Increase in power increases brightness.

EXAM QUESTION	CIRCUITS	P1 NOV 2018 Q12

Consider the circuit diagram below. The internal resistance of the battery and any resistance in the wires can be ignored.



12.1 Calculate the value of resistor R if the total resistance of the circuit is 4,8 Ω. (3)

12.2 Calculate the reading on the voltmeter if the current through the 4R resistor is 1,8 A. (5)

12.3 Calculate the energy converted in resistor 4R in 2 minutes. (3)

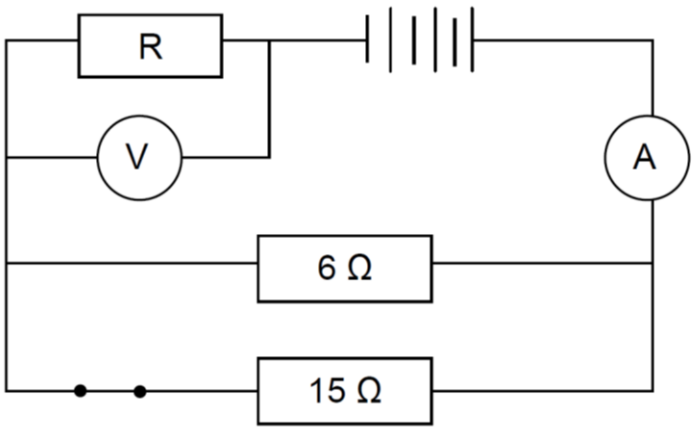
The 4R resistor is replaced with an ammeter.

12.4 How will the reading on the voltmeter be influenced? Write only INCREASE, DECREASE or STAY THE SAME. (1)

12.5 Explain the answer to QUESTION 12.4. (2)

EXAM QUESTION	CIRCUITS	P1 NOV 2017 Q10

10.1 The circuit below consists of a 6 Ω and 15 Ω resistor connected in parallel and an unknown resistor R, in series. An ammeter, a high-resistance voltmeter, a closed switch and battery are connected, as shown. The resistance of the battery and wires can be ignored.



The total power dissipated in the parallel part of the circuit is 50 W.

10.1.1 Define the term *power*. (2)

10.1.2 Calculate the effective resistance of the parallel combination. (2)

10.1.3 Calculate the potential difference across the resistors in parallel. (3)

10.1.4 Calculate the current through resistor R. (3)

The switch in the circuit is now OPENED.

10.1.5 How will the reading on the voltmeter (V) be influenced? Choose from INCREASE, DECREASE or REMAIN THE SAME. (1)

10.1.6 Explain the answer to QUESTION 10.1.5. (3)

10.2 A geyser, labelled 2 000 W, is used for an average of 5 hours per day. The cost of electricity is 80 cents per kWh.

10.2.1 Calculate the energy used by the geyser for 5 hours per day. (4)

10.2.2 Calculate the cost of electricity to operate the geyser for a month with 30 days. (2)