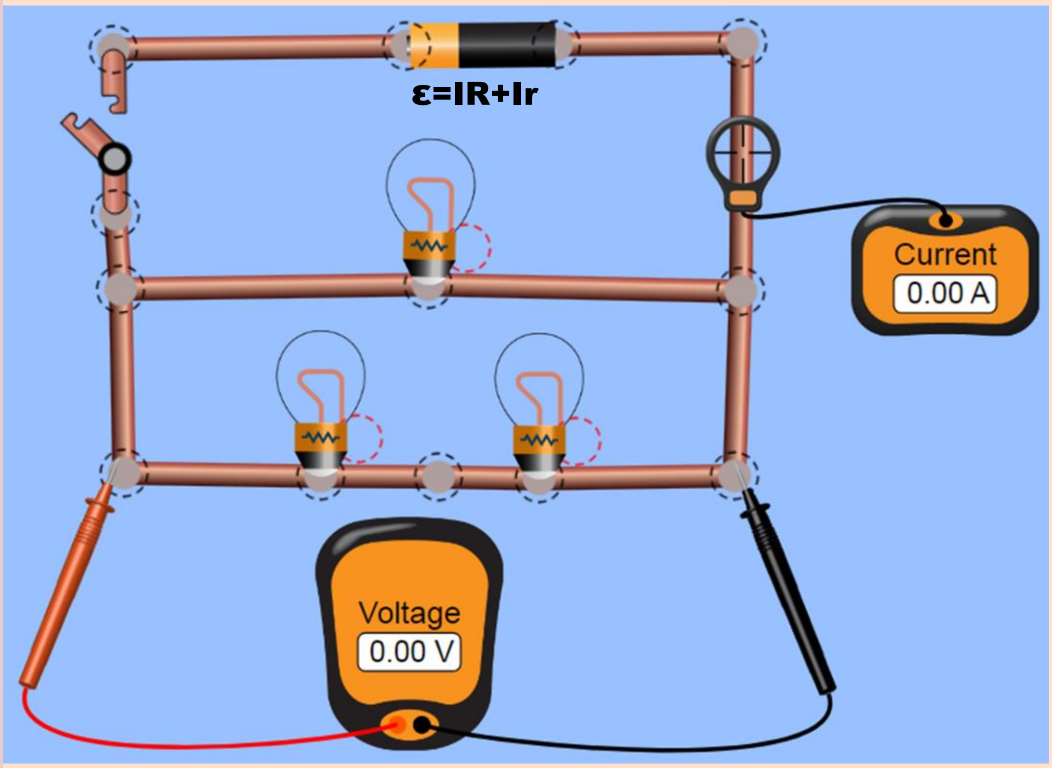
NORTHERN CAPE DEPARTMENT OF EDUCATION

PHYSICAL SCIENCES

GRADE 12

PHYSICS



TERM III

ELECTRIC CIRCUITS

THEORY, EXPERIMENTS

& EXERCISES

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Table of Contents

1 - ELECTRIC CIRCUITS: Ohm's law, electromotive force, internal resistance, electric power. 1

2 – SUMMARY ON ELECTRIC CIRCUITS 14

3 – REVISION EXERCISES 15

4 – REVISION EXERCISES 20

5 -SELF-ASSESSMENT 25

6 -MEMO FOR SELF-ASSESSMENT 30

1 - ELECTRIC CIRCUITS: Ohm's law, electromotive force, internal resistance, electric power.

Objective:

Learners must be able to:

- State **Ohm's law** in words.
- Determine the relationship between current, potential difference and resistance at constant temperature using a simple circuit.
- State the difference between *ohmic conductors* and *non-ohmic conductors* and give an example of each.
- Explain the term *internal resistance*.
- Define *power* as the rate at which work is done

Introduction:

In Grade 10 and Grade 11 we learned about **electric circuits** and we introduced three quantities which are fundamental to dealing with electric circuits. These quantities are closely related and are ***current***, ***voltage*** (potential difference) and ***resistance***. To recap:

1. Electrical current, I, is defined as the rate of flow of charge through a circuit. ($I = \frac{Q}{\Delta t}$)
2. Potential difference or voltage, V, is related to the energy gained or lost per unit charge moving between two points in a circuit. Charge moving through a battery gains energy which is then lost moving through the circuit. ($V = \frac{W}{Q}$)
3. Resistance, R, is an internal property of a circuit element that opposes the flow of charge and it is *the ratio of the voltage applied across a piece of material to the current that flows in that material*. Work must be done for a charge to move through a resistor.

Development:

Ohm's Law

The potential difference across a conductor is directly proportional to the current in the conductor at constant temperature. ($V \propto I$)

$$R=\frac{V}{I} \qquad \textbf{OR} \qquad V = IR$$

OR

The current in a conductor is directly proportional to the potential difference across the conductor at constant temperature. ($I \propto V$)

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

Where:

I is the current through the conductor
V is the voltage across the conductor
R is the resistance of the conductor.

In the Ohm's law relationship the proportionality constant is the resistance of the conductor and it is measured in ohms (Ω).

Experiment 1:

Aim: To determine the relationship between the current going through a resistor and the potential difference (voltage) across the same resistor.

Apparatus:

- 4 cells
- 4 resistors
- an ammeter
- a voltmeter
- connecting wires

Method:

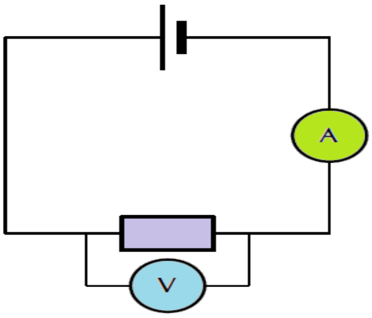
This experiment has two parts.

- In the first part we will vary the applied voltage across the resistor and measure the resulting current through the circuit.
- In the second part we will vary the current in the circuit and measure the resulting voltage across the resistor.

After obtaining both sets of measurements, we will examine the relationship between the current and the voltage across the resistor.

Part 1 (Varying the voltage):

Step 1: Set up the circuit according to the following circuit diagram.

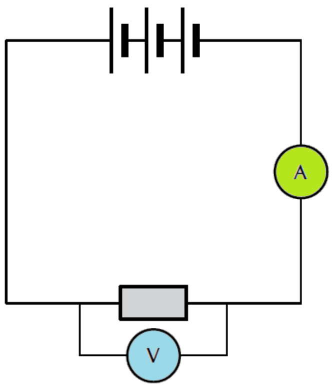


Step 2: Measure the voltage across the resistor using the voltmeter, and the current in the circuit using the ammeter.
Step 3: Add one more 1,5 V cell to the circuit and repeat your measurements.
Step 4: Repeat until you have four cells.
Step 5: Recall your result in the following table.

Number of cells	Voltage, V (V)	Current, I (A)
1		
2		
3		
4		

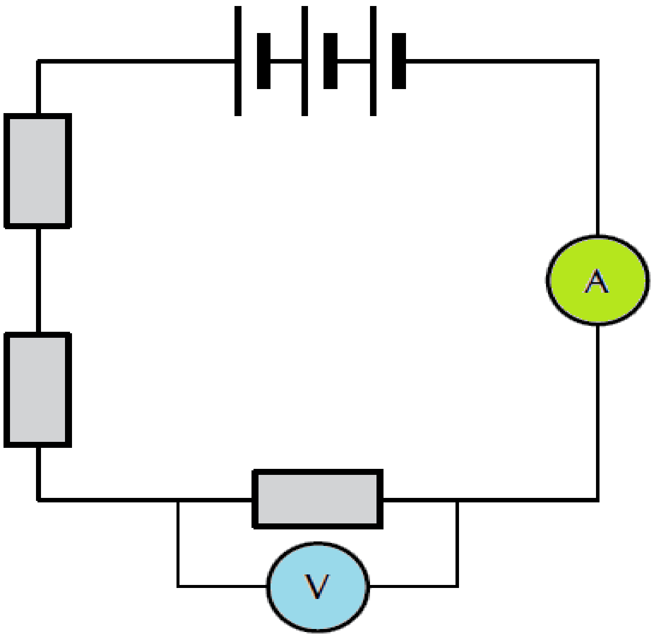
Part 2 (Varying the current):

Step 1: Set up the circuit according to the following circuit diagram.



Step 2: Measure the current and measure the voltage across the single resistor.

Step 3: Now add another resistor in series in the circuit and measure the current and the voltage across only the original resistor again. Continue adding resistors until you have four in series, but remember to only measure the voltage across the original resistor each time.



Step 4: Enter the values you measure into the following table.

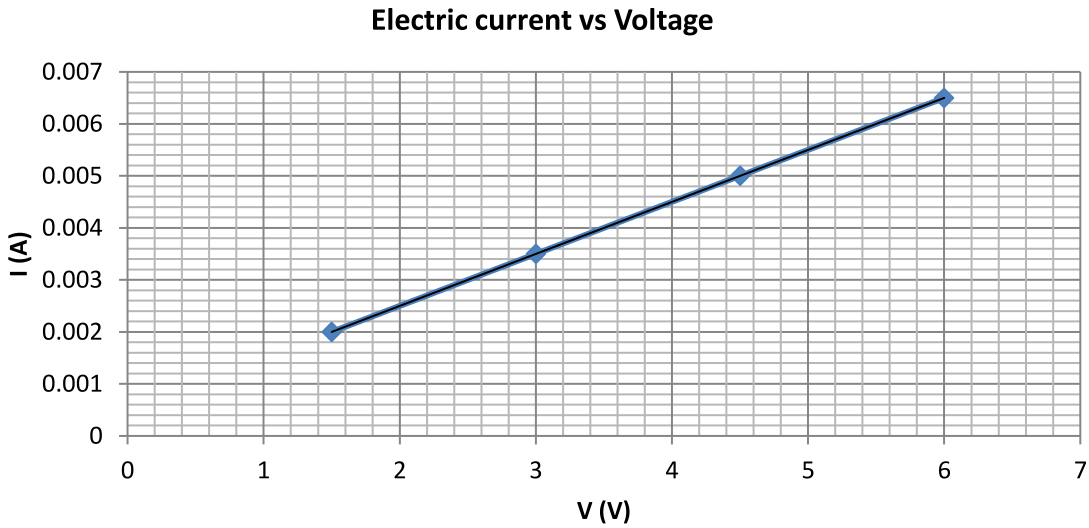
Number of resistors	Voltage, V (V)	Current, I (A)
1		
2		
3		
4		

Possible answers for table 1 and 2

Part 1 (Varying the voltage):

Number of cells	Voltage, V (V)	Current, I (A)
1	1,5	0,002
2	3	0,0035
3	4,5	0,005
4	6	0,0065

If we draw graph of current vs. voltage we will get:

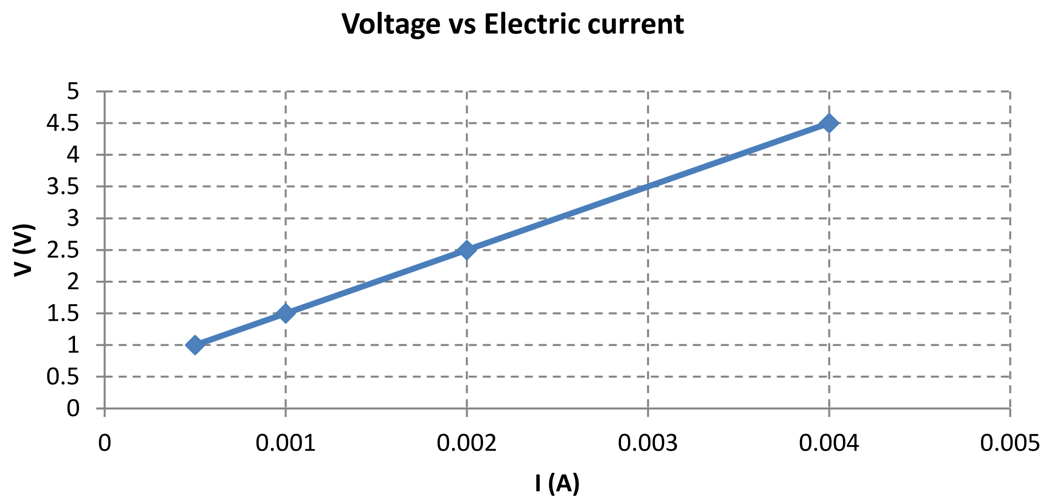


We can see that the graph is a straight line which shows that as the voltage (V) across a metal conductor (resistor) increases the current (I) also increases.

Part 2 (Varying the current):

Number of resistors	Voltage, V (V)	Current, I (A)
1	4,5	0,004
2	2,5	0,002
3	1,5	0,001
4	1,0	0,0005

If we draw a table of voltage vs. current we get:

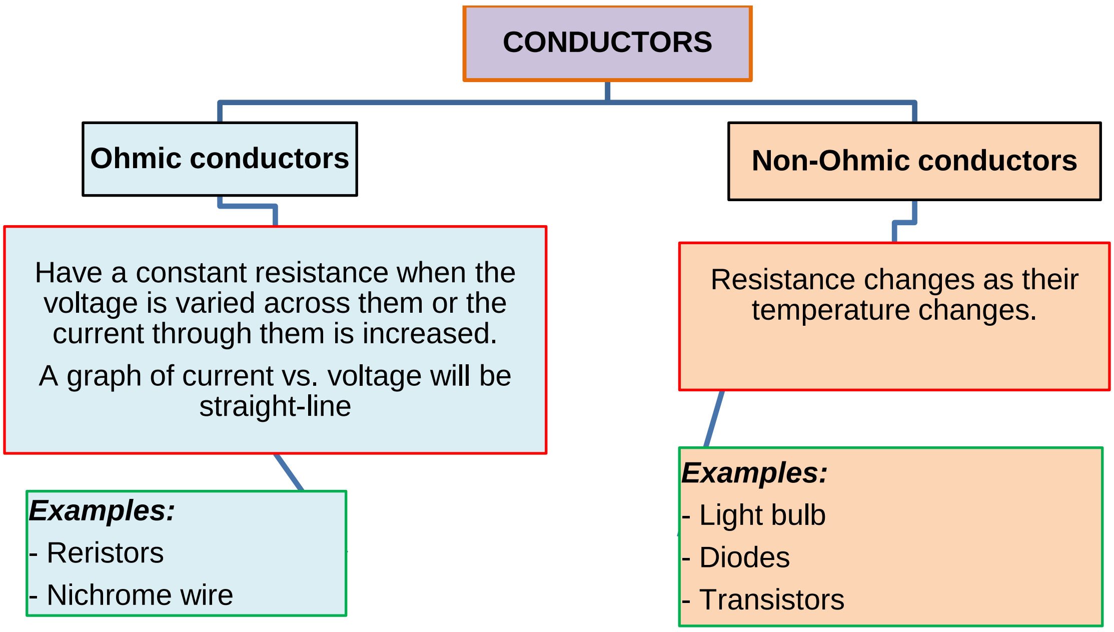


This graph is also a straight line which shows that as the current (I) increases in a metal conductor (resistor) the voltage increases too.

The results obtained verify Ohm's Law because **the current (I) through a metal conductor, at a constant temperature, in a circuit is proportional to the voltage (V) across the conductor** and the potential difference across a conductor is directly proportional to the current in the conductor at constant temperature.

Difference between ohmic conductors and non-ohmic conductors and give an example of each.

In <u>GRADE 11</u> we have learned that conductors can either be ohmic conductors or non-ohmic conductors.



Electromotive force

Emf is the work done (energy transferred) per unit charge to move the charge from the negative electrode to the positive electrode in the battery.

OR

The emf of an emf device is the work per unit charge that the device does in moving charge from its low-potential terminal to its high-potential terminal.

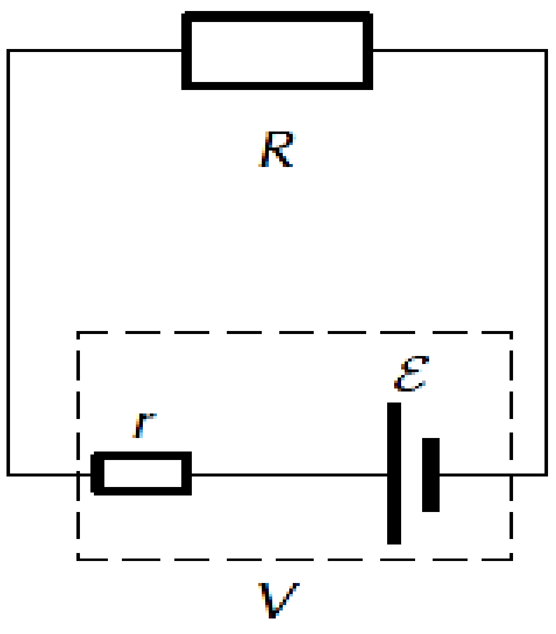
Up until now we have been dealing with ideal batteries in that they aren't affected by the circuit or current in any way and provide a precise voltage until they go flat.

If you measure the potential difference across the terminals of a battery on its own you will get a different value to what you measure when it is in a complete circuit. The value will be less when the battery is included in a complete circuit. Sometimes the difference is called the *lost volts*. Nothing has actually been lost but energy has been transferred.

*Youtube video (Electromotive force):*http://youtube.com/watch?v=cbSKkrzdXe4

Internal resistance

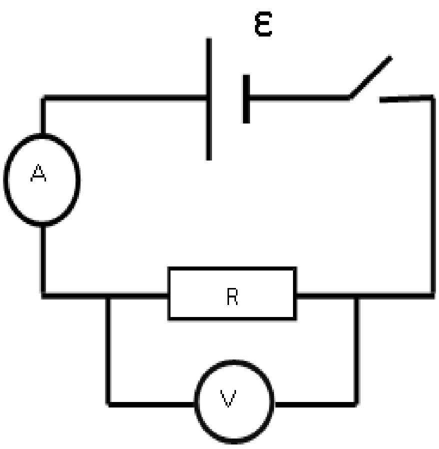
Real batteries are made from materials which have resistance. This means that real batteries are not just sources of potential difference (voltage), but they also possess ***internal resistance***. If the total potential difference source is referred to as the ***emf***, ε, then a real battery can be represented as an emf connected in series with a resistor ***r***. The internal resistance of the battery is represented by the symbol r.



Internal resistance is the resistance to current flow through a voltage source such as a battery which arises from the resistance of the materials from which the source is made.

In a battery the internal resistance is due to chemicals within the battery. In a generator, the internal resistance is the resistance of the wires and the other components within the generator.

The following circuit diagram shows a cell with an emf ε and its internal resistance **r**, an external resistance **R**, an ammeter and a voltmeter



In the circuit diagram the reading of the ammeter will be:

$$\boldsymbol{I = \frac{\varepsilon}{R + r}}$$

This is *Ohm's Law* for a whole circuit.

Now making ε the subject of the previous equation we have:

$$\varepsilon = I(R + r)$$

OR

$$\varepsilon = IR + Ir$$

IR = (V_{load}) - It is called terminal potential difference (potential difference V across the external circuit)

Ir – It is the drop of potential in the internal resistance ($V_{internal\ resistance}$)

$$IR = \varepsilon - Ir$$

Or

$V_{load} = \varepsilon - V_{int}$ OR $V_{ext} = \varepsilon - V_{int}$

Experiemnt 2: Internal resistance

Aim

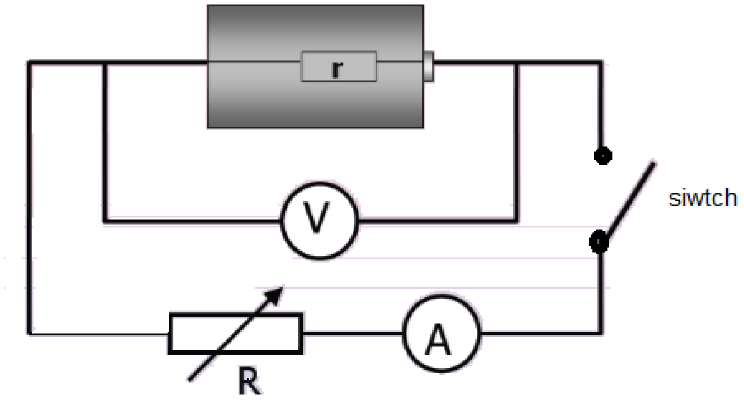
To determine experimentally the internal resistance of a battery

Materials

- 1.5 V AA Battery
- Battery holder
- Ammeter
- Voltmeter
- Switch
- Variable resistor/rheostat
- conductors

Method

1-Set up a circuit as shown below



2. With the circuit open measure the reading of voltmeter and the reading of the ammeter.

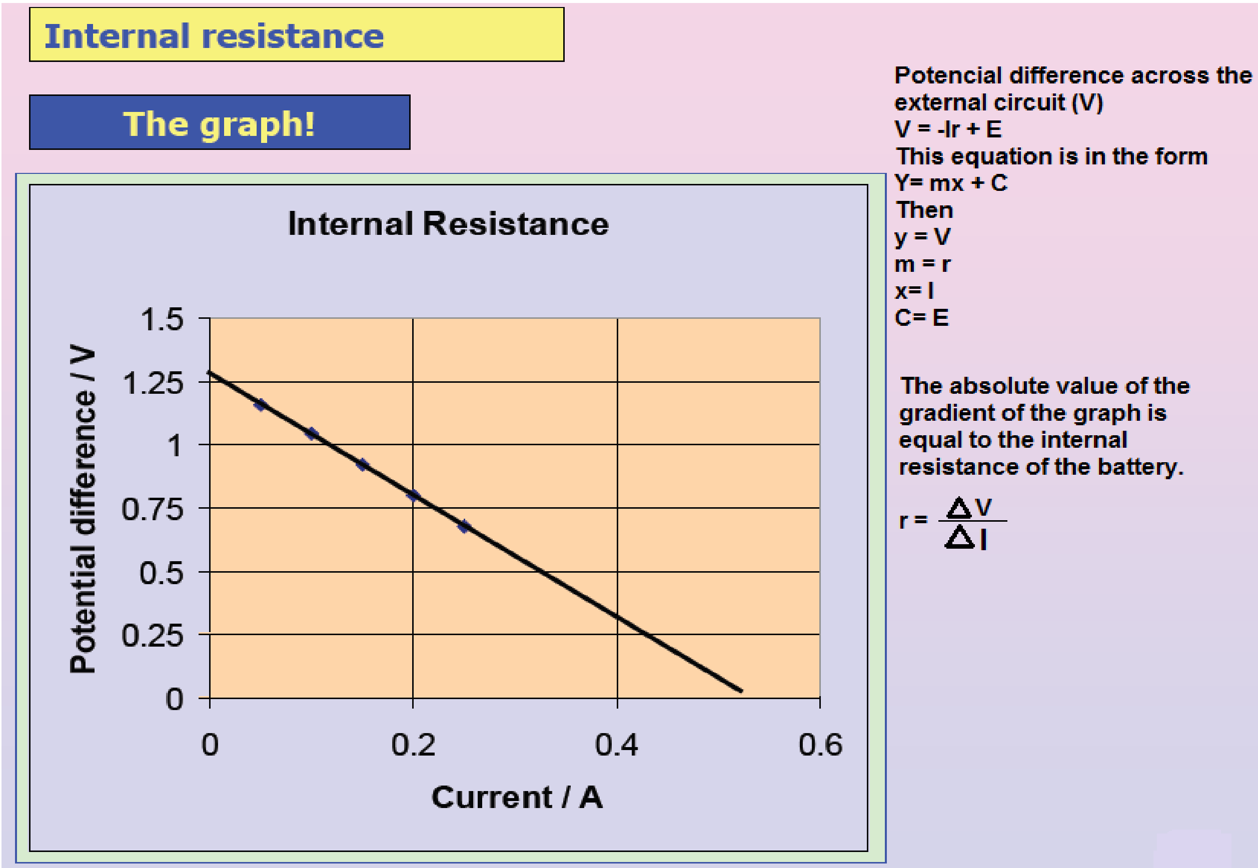
3. Close the circuit and measure the reading of the voltmeter for deferent values of the current. Record the reading in a table below.

Current (A)	Potential difference (V)

Possible results

Current (A)	Potential difference (V)
0.05	1.16
0.1	1.04
0.15	0.92
0.2	0.8
0.25	0.69

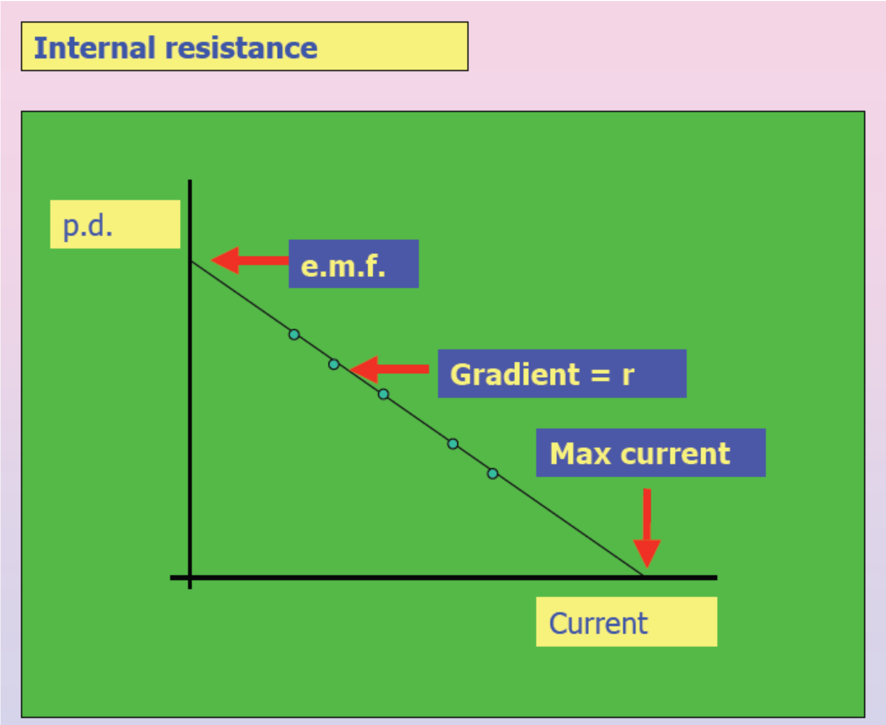
4. With the results recorded in the table above draw a graph of terminal potential difference (potential difference/drop of potential across the external circuit) and do the analysis and interpretation of the results.



5. Calculate internal resistance of the battery.

$$r = \frac{V_f - V_i}{I_f - I_i}$$

6. The graph below summarize the experiment done.



Conclusions

Potential difference decreases linearly as current increases where the internal resistance is the proportionality constant

Internal resistance of the battery is numerically equal to absolute value of the gradient of the graph of the potential difference versus current.

Power

Power of a device or appliance is the rate at which electrical energy is transformed or converted in an electrical circuit.

OR

Power **is the rate at which work is done.**

We can write this mathematically:

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

Where:

P is power measure in watts (W). An appliance use one watt of power when it converts one joule of energy in one second. ($1\ W = J/s$).

W is the work done and is measure in joules (J).

Δt is the interval of time measure in (s).

This expression of power can also be written as:

$$W = P\Delta t$$

In Grade 10 we learned that the potential difference is the work done per unit charge $V = \frac{W}{Q}$. If we rearrange the formula for calculate the work:

$$W = VQ$$

We can substitute in the equation to calculate power:

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

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

In grade 10 we also learned that current is the rate of flow of charge (charge per unit time):

$$I = \frac{Q}{\Delta t}$$

We can substitute in the equation of power:

$$P = \frac{W}{\Delta t} = \frac{V}{1} \times \frac{Q}{\Delta t} = VI$$

So in electric circuits, power is a function of both voltage and current and we talk about the power dissipated in a circuit element.

$$\mathrm{P} = \mathrm{VI}$$

This equation gives us the power converted by any device, where I is the current that passes through it and V is the potential difference across it.

We also substitute Ohm's Law in the equation to calculate power.

We know that $\mathrm{I} = \frac{\mathrm{V}}{\mathrm{R}}$ and so $\mathrm{V} = \mathrm{IR}$.

Now doing the substitution of $I = \frac{V}{R}$ in the formula to calculate power:

$$P = VI = \frac{VV}{R} = \frac{V^2}{R}$$

So we can calculate the power with the following formula:

$$\mathrm{P} = \frac{\mathrm{V}^2}{\mathrm{R}}$$

Now doing the substitution of $V = IR$ in the formula to calculate power:

$$P = IRI = I^2R$$

So we can calculate the power with the following formula:

$$P = I^2R$$

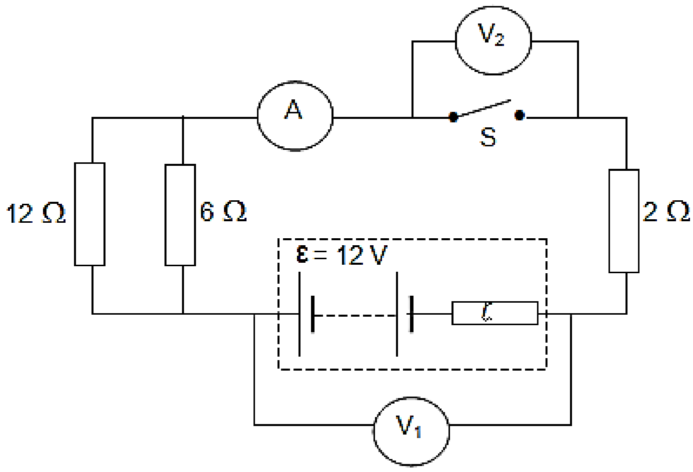
Any of these equation for power can be used to solve a problem, it depends on what is given and what is been asked.
We have the following equations for power:

$P = \frac{W}{\Delta t}$	$P = VI$		$P = \frac{V^2}{R}$	$P = I^2R$

EXAMPLE

QUESTION 1

The battery in the circuit diagram below has an ***emf*** of 12 V and an unknown internal resistance *r*. Voltmeter V_1 is connected across the battery and voltmeter V_2 is connected across the switch S. The resistance of the connecting wires and the ammeter is negligible.



1.1 Write down the respective readings on voltmeters V_1 and V_2 when switch S is open.

Switch S is now closed. The reading on voltmeter V_1 changes to 9 V.

1.2 What will the new reading on V_2 be?

1.3 Calculate the total external resistance of the circuit.

1.4 Calculate the internal resistance, *r*, of the battery.

1.5 Calculate the energy transferred in resistor 2 Ω in 10 minutes.

1.6 Calculate the power dissipated in resistor 2 Ω.

1.7 How much charge will pass through resistor 2 Ω within 5 minutes?

1.8 How many electrons pass through the resistor 2 Ω in 5 minutes?

Solution

QUESTION 1:

1.1 $V_1 = 12$ V
$V_2 = 12$ V

1.2 $V_2 = 0$ V

1.3 $R_T = R_s + R_P$

$$\frac{1}{R_p} = \frac{1}{R_1} + \frac{1}{R_2} \quad \therefore \quad \frac{1}{R_p} = \frac{1}{12} + \frac{1}{6} \quad \therefore R_p = 4\ \Omega$$

$R_T = R_s + R_P = 2 + 4 = 6\Omega$

1.4

Option 1	Option 2
$\varepsilon = IR + Ir$ We need to calculate I. $I = \frac{V}{R} = \frac{9}{6} = 1,5\ A$ So: $\varepsilon = IR + Ir$ $12 = (1,5)(6) + 1,5r$ $r = 2\Omega$	$V_{lost} = Ir$ $3 = 1,5r$ $r = 2\Omega$

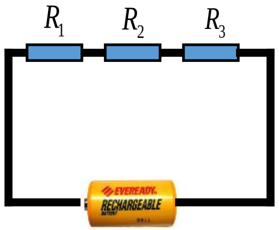
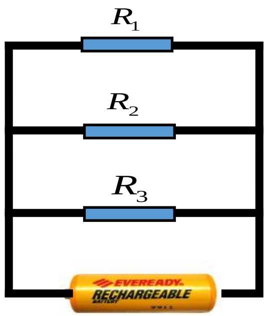
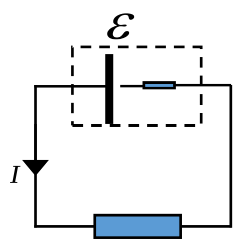
1.5 $W = VIt = I^2Rt = (1,5)^2(2)(60 \times 10) = 2700$ J

1.6 $P = I^2R = (1,5)^2(2) = 4,5$ W

1.7 $Q = It = (1,5)(5 \times 60) = 450$ C

1.8 $Q = nq_e$
$450 = n\,(1,6 \times 10^{-19})$
$n = 2,81 \times 10^{21}$ C

SUMMARY ON ELECTRIC CIRCUITS

CURRENT	*EMF &* POTENTIAL DIFFERENCE	Resistors in Series	Resistors in Parallel	Ohm's Law	Internal Resistance	Work (energy transferred)	Power
The total charge that passes through a conductor per unit of time. $I = \frac{Q}{\Delta t}$ Measured in amperes (A)	Emf is the work done (energy transferred) per unit charge to move the charge from the negative electrode to the positive electrode in the battery. $\varepsilon = \frac{W}{q}$ ***Potential defference*** is the work done per unit charge between two points in a circuit. $V = \frac{W}{Q}$ Measured in volts (V)	 $R_T = R_1 + R_2 + R_3$ $I_1 = I_2 = I_3$ $V_T = V_1 + V_2 + V_3$ (Resistors act as potential dividers.)	 $\frac{1}{R_E} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$ $V_1 = V_2 = V_3$ $I_T = I_1 + I_2 + I_3$ (Resistors act as current dividers.)	***Ohm's Law states that the potential difference across a conductor is directly proportional to the current in the conductor at constant temperature.*** $R = \frac{V}{I}$ ***Whole circuit:***  *A real battery has internal resistance.* $I = \frac{\varepsilon}{R + r}$	When current flows through a voltage source (battery/generator) a resistance to current flow arises due to the resistance of the materials (chemicals/conductors) from which the source is made. **Internal resistance is the resistance offered to the electron flow by the electrolyte/medium of the cell/generator** Measured in ohms (Ω)	General: $W = VIt$ Series: $W = I^2Rt$ Parallel: $W = \frac{V^2}{R}t$ **Whole circuit:** $W = \varepsilon It$ Measured in jouls (J)	**The rate at which electrical work is done or electrical energy is transferred.** $P = \frac{W}{\Delta t}$ $P = VI$ $P = \frac{V^2}{R}$ $P = I^2R$ Measured in watts (W)

2 – REVISION EXERCISES

Objective:

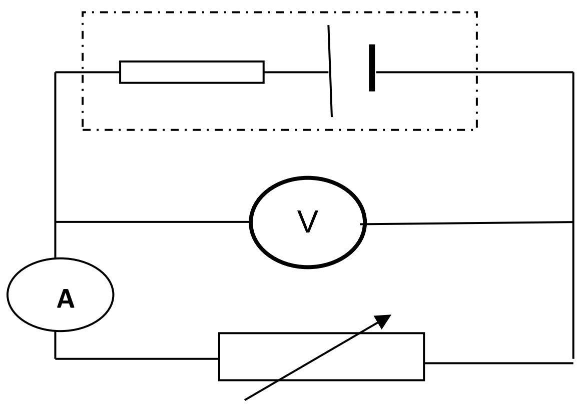
Learners must be able to:

- Solve problems using $R = \frac{V}{I}$ for series and parallel circuits (maximum four resistors).
- Solve problems involving current, voltage and resistance for circuits containing arrangements of resistors in series and in parallel (maximum four resistors).
- Solve circuit problems using $\varepsilon = V_{load} + V_{internal\,resistance}$ or $\varepsilon = IR + Ir$.
- Solve circuit problems, with internal resistance, involving series-parallel networks of resistors (maximum four resistors).

EXERCISES

QUESTION 1

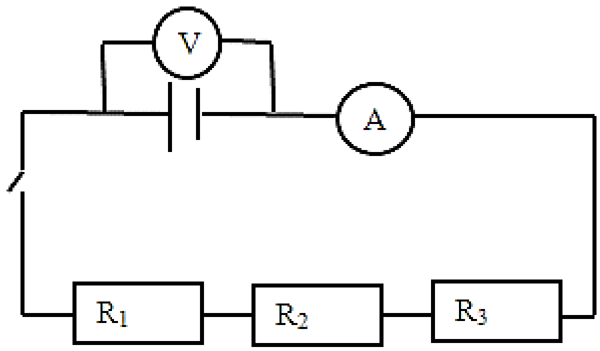
In the circuit represented below, the resistance of the variable resistor is decreased. How does this affect the reading of the ammeter and Voltmeter?



	Ammeter reading	Voltmeter reading
A	Unchanged	decreases
B	increases	decreases
C	decreases	decreases
D	decreases	increases

QUESTION 2

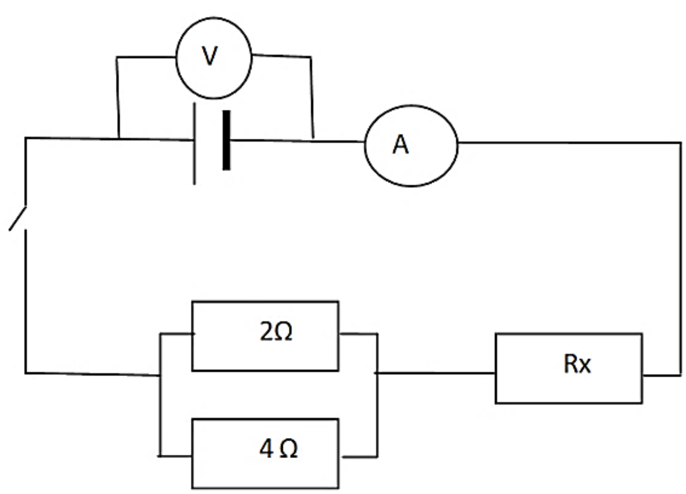
The following diagram shows three resistors $R_1 = 2\ \Omega$, $R_2 = 3\ \Omega$ and $R_3 = 4\ \Omega$, connected to a switch and a battery. When the switch is opened the voltmeter reads 12 V, but when the switch is closed the reading drops to 11 Ω.



2.1 What is the emf of the battery?
2.2 Calculate the equivalent external resistance.
2.3 Determine the reading of the ammeter.
2.4 Calculate the internal resistance of the battery.
2.5 How will the reading on the voltmeter and ammeter be affected if a resistor $R_4 = 4\ \Omega$ is connected in series with the rest of the resistors. Explain your answer.

QUESTION 3

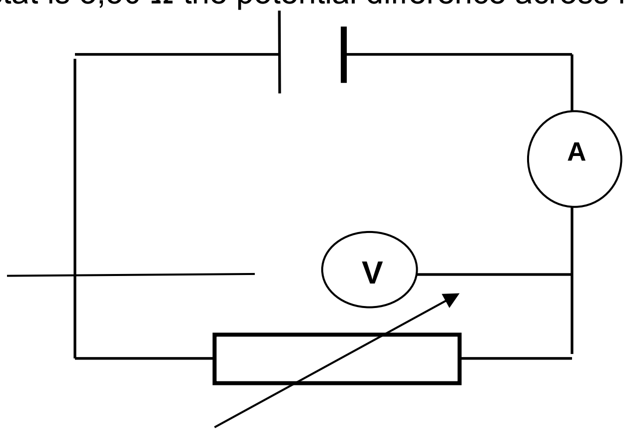
When the switch in the following circuit is open, the voltmeter reads 10 V. When the switch is closed the reading drops to 8 V and the ammeter reading is 1 A.



3.1 What is the value of the emf of the battery?
3.2 What is the reading of the ammeter when the switch is open?
3.3 Calculate the total external resistance.
3.4 Determine the resistance of the unknown resistor R_{x}.
3.5 Calculate the internal resistance of the battery.

QUESTION 4

An electric circuit consists of a battery and a rheostat as shown in diagram below. When the resistance of the rheostat is 1,65 Ω the potential difference across it is 3,30 V and when the resistance of the rheostat is 3,50 Ω the potential difference across it is 3,50 V.



4.1 Calculate the internal resistance of the battery.
4.2. Calculate the emf of the battery.
4.3. Calculate the power dissipated when the resistance of the rheostat is 3,50 Ω.
4.4 When the resistant of the rheostat is 4 Ω a resistor of 2 Ω is connected in parallel. Determine the reading of the ammeter.

SOLUTIONS

QUESTION 1:

B If the resistance decreases the current increases then the lost volts increases (V_{int} = Ir). Since the emf of the battery remains the same the V_{ext} decreases. V_{load} = ε – V_{int}.

QUESTION 2:

2.1 12 V

2.2 $R_s = R_1 + R_2 + R_3 = 2 + 3 + 4 = 9\,\Omega$

2.3 $I = \frac{V}{R_s} = \frac{11}{9} = 1{,}22\,A$

2.4 $V_{int} = Ir$

$1 = I(1{,}22)$

$r = 0{,}82\,\Omega$

2.5 The external resistance increases then the strength of the electric current decreases the reading of the ammeter decrease, as the current decreases the drop of potential in the internal resistance (lost volts) decreases that`s why the reading of the voltmeter increases because . V_{ext} = ε – V_{intt}.

QUESTION 3:

3.1 10 V.

3.2 Zero.

3.3 $R_{ext} = \frac{V}{I} = \frac{8}{1} = 8\,\Omega$

3.4 $R_{ext} = R_x + R_p$

$\frac{1}{R_p} = \frac{1}{R_1} + \frac{1}{R_2} = \frac{1}{2} + \frac{1}{4} = \frac{3}{4}$

$R_p = 1{,}33\,\Omega$

$8 = R_x + 1{,}33$

$R_x = 6{,}67\,\Omega$

3.5 $V_{int} = Ir$

$2 = 1r$

$r = 2\,\Omega$

QUESTION 4:

4.1

Option 1	**Option 2**
$\varepsilon = IR + Ir$ $\varepsilon = constant$ $I_1R_1 + I_1r = I_2R_2 + I_2r$ $I_1R_1 - I_2R_2 = (I_2 - I_1)r$ $I = \frac{V}{R}$ $\frac{V_1}{R_1}R_1 - \frac{V_2}{R_2}R_2 = \left(\frac{V_2}{R_2} - \frac{V_1}{R_1}\right)r$ $V_1 - V_2 = \left(\frac{V_2}{R_2} - \frac{V_1}{R_1}\right)r$ $3{,}30 - 3{,}50 = \left(\frac{3{,}50}{3{,}50} - \frac{3{,}30}{1{,}65}\right)r$ $r = 0{,}20\,\Omega$	$\varepsilon = IR + Ir$ $\varepsilon = constant$ $I_1R_1 + I_1r = I_2R_2 + I_2r$ $I_1R_1 - I_2R_2 = (I_2 - I_1)r$ $I = \frac{V}{R}$ $I_1 = \frac{3{,}30}{1{,}65} = 2\,A$ $I_2 = \frac{3{,}50}{3{,}50} = 1\,A$ $(2)(1{,}65) - (1)(3{,}50) = (1-2)r$ $r = 0{,}20\,\Omega$

4.2

Option 1	Option 2
$\varepsilon = I(R + r)$ $\varepsilon = 1(3{,}50 + 0{,}20)$ $\varepsilon = 3{,}70$ V	$\varepsilon = I(R + r)$ $\varepsilon = 2(1{,}65 + 0{,}20)$ $\varepsilon = 3{,}70$ V

4.3 $P = IV$

$V = V_R + V_{int} = \varepsilon$

$P = I\varepsilon$

$P = (1)(3{,}70)$

$P = 3{,}70$ W

4.4

$\varepsilon = I(R + r)$

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2}$$

$$\frac{1}{R} = \frac{1}{4} + \frac{1}{2}$$

$R = 1{,}33\ \Omega$

$3{,}70 = I(1{,}33 + 0{,}2)$

$I = 2{,}43$ A

3 – REVISON EXERCISES

Objective:

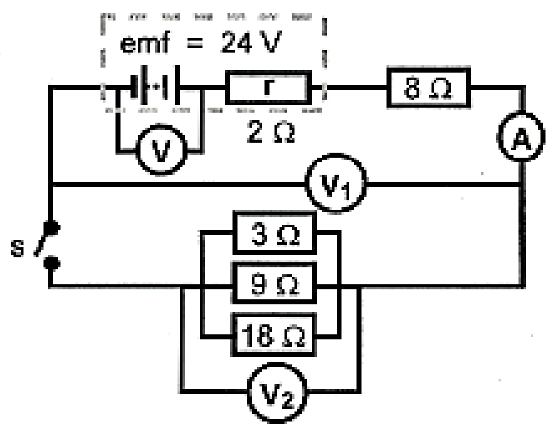
Learners must be able to:

- Solve problems using $R = \frac{V}{I}$ for series and parallel circuits (maximum four resistors).
- Solve problems involving current, voltage and resistance for circuits containing arrangements of resistors in series and in parallel (maximum four resistors).
- Solve circuit problems using $\varepsilon = V_{load} + V_{internal\ resistance}$ or $\varepsilon = IR + Ir$.
- Solve circuit problems, with internal resistance, involving series-parallel networks of resistors (maximum four resistors).
- Solve problems using $P = VI$, $P = I^2R$ or $P = \frac{V^2}{R}$.
- Solve circuit problems involving the concepts of power and electrical energy
- Deduce that the kilowatt hour (kWh) refers to the use of 1 kilowatt of electricity for 1 hour.
- Calculate the cost of electricity usage given the power specifications of the appliances used the duration and the cost of 1 kWh.

EXAMPLE

Consider the accompanying circuit diagram:

1.1 Give the definitions of:
  1.1.1 Current
  1.1.2 Potential difference
  1.1.3 Coulomb



The switch is open,

1.2 Determine the reading on V_1.

1.3 Determine the reading on V_2.

Now the switch S *is closed.*

1.4 Calculate the total resistance (R_T) of the circuit.

1.5 How much charge will move past a point in the 8 Ω resistor within 2 minutes?

Solution:

1.1.1 Electric current is the amount of charge that moves past a point in a conductor per second.

1.1.2 Potential difference between two points in an electric field is the work required to move a unit of charge (+1 C) from one point to another in the field.

1.1.3) A Coulomb is the amount of charge that moves past any point in a conductor in 1 second if the current in the conductor is 1 A. (1 Coulomb = 1 Ampere x 1 second)

1.2 $V_1 = 24$ V

1.3 $V_2 = 0$ V

1.4

$$R_T = R_{Ext} + r$$
$$R_{Ext} = R_s + R_P$$
$$\frac{1}{R_P} = \frac{1}{3} + \frac{1}{9} + \frac{1}{18} = \frac{9}{18}$$
$$R_P = 2\ \Omega$$
$$R_S = 8\ \Omega$$
$$R_{Ext} = R_s + R_P = 2 + 8 = 10\ \Omega$$
$$R_T = R_{Ext} + r = 10 + 2 = 12\ \Omega$$

1.5 ε = I (R + r)

24 = I (12)

I = 2 A

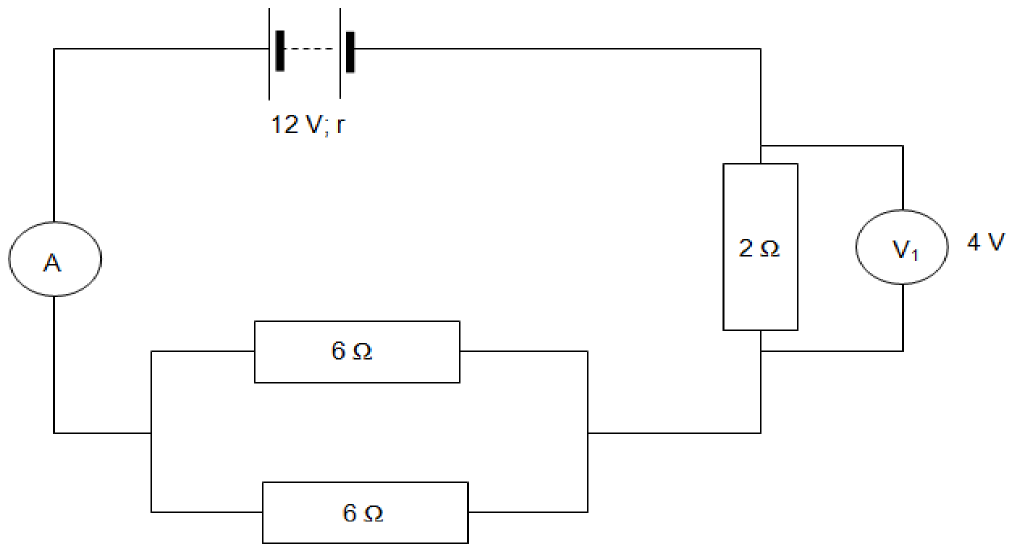
1.6 Q = IΔt

Q = (2)(2)(60) = 240 C

REVISION EXERCISES

QUESTION 1

In the circuit represented below, the battery has an internal resistance, r, and an **emf of 12 V**. Voltmeter V_1 has a reading of 4 V.



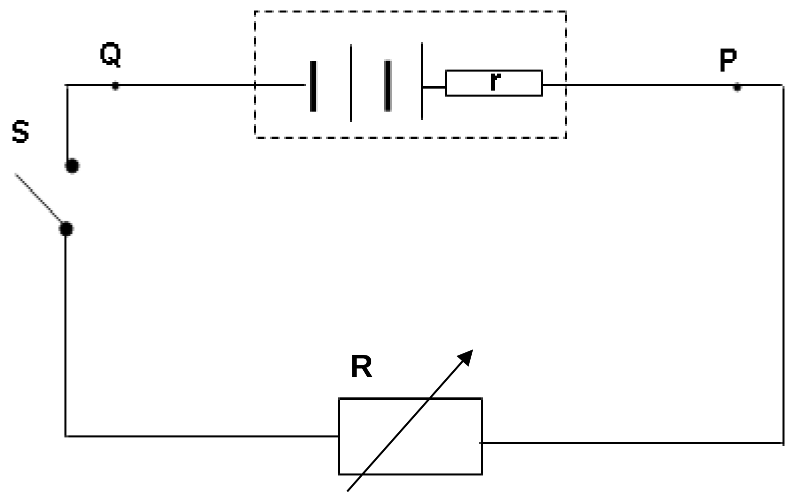
1.1 Calculate the resistance of the external circuit.
1.2 Calculate the reading on ammeter A.
1.3 Calculate the internal resistance of the battery.
1.4 Calculate the energy transfered in resistor 2 Ω in 2 minute.
1.5 Calculate the power dissipated in resistor 2 Ω.
1.6 How much charge will pass through resistor 2 Ω within 30 minutes?
1.7 How many electrons pass through the resistor 2 Ω in 30 minutes?

QUESTION 2

A 30 W light bulb is left on for 8 hours overnight, how much energy was wasted?

QUESTION 3

Grade 12 learners conduct an investigation to determine the emf (ε) and the internal resistance (r) of an unknown battery by using a rheostat. They use the circuit below and adjust the values of the rheostat and with a voltmeter and an ammeter connected in this circuit they measured the terminal potential and the current for each value of resistance.



With switch S closed, they obtained the following results:

Measurement	Voltmeter reading (V)	Ammeter reading (A)
1	1,16	0,05
2	1,04	0,1
3	0,92	0,15
4	0,8	0,2
5	0,68	0,25

3.1 Sketch this circuit in your answer book. Show in your sketch where the learners connected the ammeter and the voltmeter.

3.2 With the results recorded in the table above draw a graph of terminal potential difference versus current.

3.3 Calculate:

3.3.1 Internal resistance.

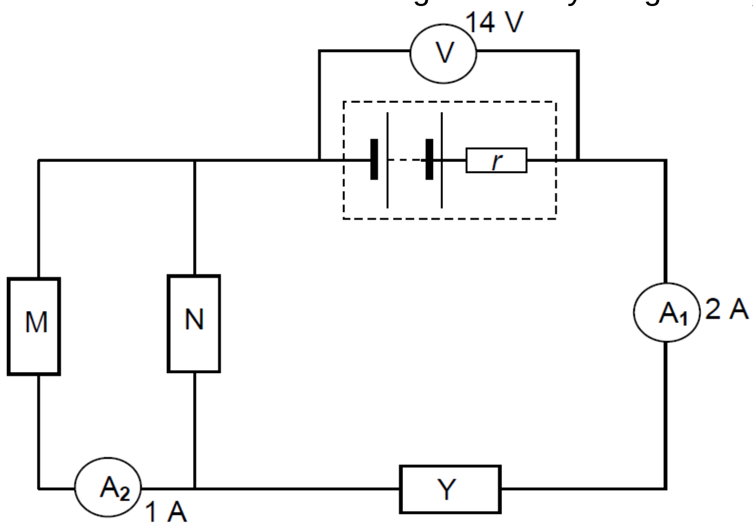
3.3.2 emf(ε) battery

3.4 Write down the equation of terminal potential difference versus current.

3.5 Calculate the value of the current for the terminal potential to be zero.

QUESTION 4 (Question 11 NSC question paper Feb – March 2010)

The circuit diagram below shows a battery, with an internal resistance r, connected to three resistors, M, N, and Y. The resistance of N is 2 Ω and the reading on voltmeter V is 14 V. The reading on ammeter A_1 is 2 A and the reading on ammeter A_2 is 1 A. (The resistance of the ammeters and the connecting wires may be ignored.)



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

4.2 How does the resistance of M compare with that of N? Explain how you arrived at the answer. (2)

4.3 If the emf of the battery is 17 V, calculate the internal resistance of the battery. (5)

4.4 Calculate the potential difference across resistor N. (3)

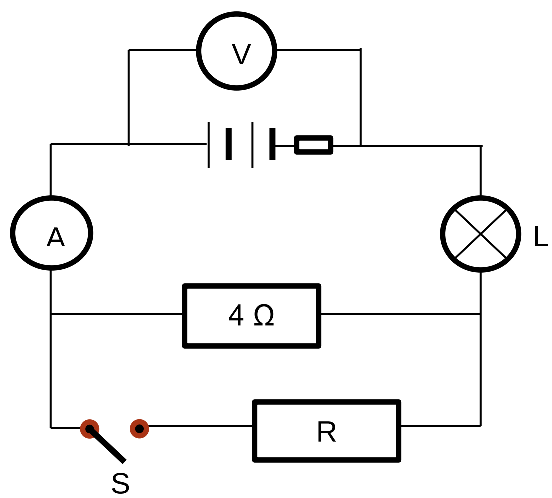
4.5 Calculate the resistance of Y. (4)

[16]

SEL-ASSESSMENT

QUESTION 1

In the circuit diagram represented below the battery has and *emf* of 18 V and an unknown resistance, *r*. The resistance of resistor R is also unknown. With switch S open the ammeter reading is 2 A.



1.1 State *Ohm's law* in words. (2)

1.2 Calculate the resistance of the bulb L if the power dissipated in it is 12 W. (3)

1.3 Calculate the internal resistance of the battery. (4)

1.4 The switch **S** is now closed. How will the reading on the ammeter be affected? Write down only INCREASE, DECREASE or REMAIN THE SAME.

(1)
[10]

SOLUTIONS

QUESTION 1:

1.1 $R_{Tot} = R_P + R_S$

$\frac{1}{R_P} = \frac{1}{R_1} + \frac{1}{R_2} = \frac{1}{6} + \frac{1}{6}$

$R_P = 3\ \Omega$

$R_S = 2\ \Omega$

$R_{Tot} = R_P + R_S = 3 + 2 = 5\ \Omega$

1.2 $I = \frac{V}{R} = \frac{4}{2} = 2\ A$

1.3 $\varepsilon = I(R + r)$

$12 = 2(5 + r)$

$r = 2\ \Omega$

1.4 W = VIt = I^2Rt = $(2)^2(2)(60)(2)$ = 960 J

1.5 P = I^2R = $(2)^2(2)$ = 8 W

1.6 Q= It = (2)(30)(60) = 3600 C

1.7 Q = n q_e

3600 = n(1,6 x 10^{-19})

n = 2,25 x 10^{22} electrons

QUESTION 2

We need to determine the total amount of electrical energy dissipated by the light bulb. We know the relationship between the power and energy and we are given the time. Time is not given in the correct units so we first need to convert to S.I. units:

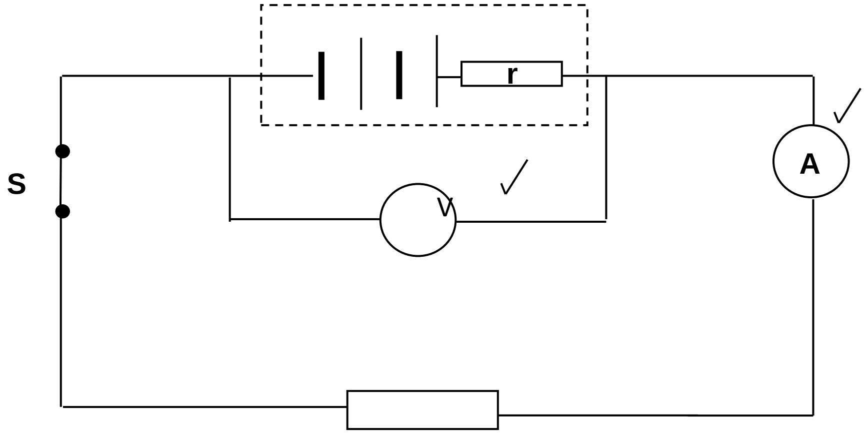
$t = (8)(3600) = 28\,800\ s$

Now we can calculate the energy.

E = *Pt*
E = (30)(28 800)
E = 864 000 J

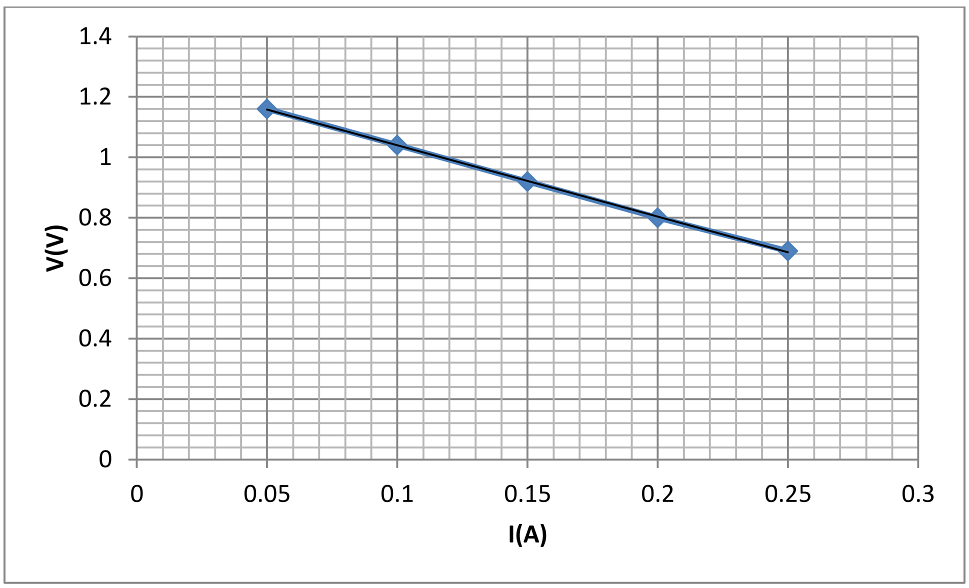
QUESTION 3

3.1



(2)

3.2



3.3 gradient=$r = \frac{\Delta V}{\Delta I}$

$$r = \frac{v_{f-V_i}}{I_f - I_i}$$

$$r = \frac{0{,}68 - 1{,}16}{0{,}25 - 0{,}05}$$

$$r = \frac{-0{,}48}{0{,}2}$$

$$r = 2{,}4\ \Omega$$

OR

$$= \frac{1{,}04 - 1{,}16}{0{,}1 - 0{,}05}$$

$$r = \frac{-0{,}12}{0{,}05}$$

$$r = 2{,}4\ \Omega$$

OR

$$\frac{0{,}92 - 1{,}16}{0{,}15 - 0{,}05}$$

$$r = \frac{-0{,}24}{0{,}1}$$

$$r = 2{,}4\ \Omega$$

Learners can use any value from the table or graph

Solve simultaneously for **ε** and **r** using any two sets of readings.

$$\left.\begin{aligned} \boldsymbol{\varepsilon} &= IR + Ir \\ \boldsymbol{\varepsilon} &= V + Ir \end{aligned}\right\}$$

$\boldsymbol{\varepsilon} = 1{,}16 + 0{,}05\ r$ … (I)

$\boldsymbol{\varepsilon} = 0{,}69 + 0{,}25\ r$ … (II)

(II) – (I): $1{,}16 + 0{,}05\ r = 0{,}68 + 0{,}25\ r$

$r = 2{,}4\ \Omega$

Substitute $r = 2{,}4\ \Omega$ into (II): [OR into equation (I)]

3.3.2 $\boldsymbol{\varepsilon} = IR + Ir$

$\boldsymbol{\varepsilon} = V_{load} + Ir$

$\boldsymbol{\varepsilon} = 1{,}16 + 0{,}05(2{,}4)$

$= 1{,}28\ V$

3.4 $V_{load} = 1{,}28 - 2{,}4I$ OR $V = 1{,}28 - 2.4I$

3.5 $0 = 1{,}28 - 2{,}4I$

$$I = \frac{-1{,}28}{-2.4} = 0{,}533\ A$$

QUESTION 4:

4.1 The current through a conductor is directly proportional to the potential difference across its ends at constant temperature. ✓✓ (2)

4.2 Equal ✓

2 A divides equally at T (and since $I_M = 1$ A it follows that $I_N = 1$ A) ✓

OR

$I \propto \frac{1}{R}$, $\therefore R_M = R_N$ (2)

4.3 emf = IR + Ir ✓ $\therefore$ 17 = 14 + Ir ✓ $\therefore$ Ir = 3 V

$r = \frac{V_{lost}}{I}$ ✓ $= \frac{3}{2}$ ✓ = 1,5 Ω ✓ (5)

4.4 $V_N = IR_N$ ✓ = (1)(2) ✓ = 2 V ✓ (3)

4.5 V_Y = 14 – 2 = 12 V ✓

$V_Y = IR_Y$ ✓ $\therefore$ 12 = (2)R_Y ✓

$\therefore R_Y$ = 6 Ω ✓ (4)

[16]

MEMO SEL-ASSESSMENT

QUESTION 1

1.1 The potential difference across a conductor is directly proportional to the current in the conductor at constant temperature.✓✓.
OR
The current in a conductor is directly proportional to the potential difference across the conductor at constant temperature. ✓✓
(2)

1.2
$P = I^2 R$✓
$12 = (2)^2 R$✓
$R = 3\ \Omega$✓ (3)

1.3 **OPSION 1**
$\varepsilon = I(R + r)$✓ OR $\varepsilon = IR + Ir$
$R_s = R_{bul} + R_{resistor}$
$R_s = 3 + 4$✓
$R_s = 7\ \Omega$
$\underline{18 = 2 \times 7 + 2r}$ ✓
$r = 2\ \Omega$✓
OPSION 2
$\varepsilon = I(R + r)$✓ OR $\varepsilon = IR + Ir$
18✓$= 2(3 + 4)$✓$+ 2r$
$r = 2\ \Omega$✓ (4)

1.4 INCREASES (1)
[10]