PhysBuddy

PHYSICAL SCIENCES

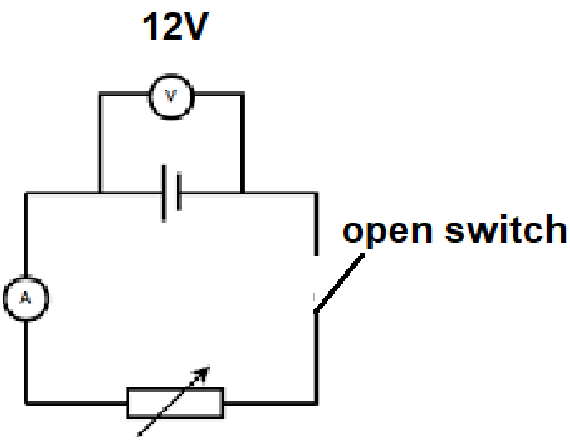
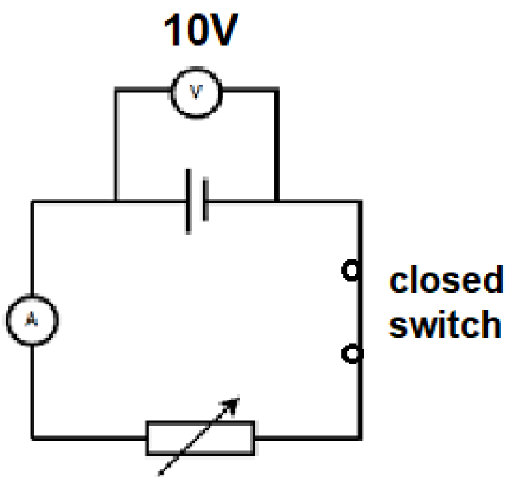
GRADE 11

ELECTRIC CIRCUITS P1

2024 ATP INCLUDES
INTERNAL RESISTANCE
CALCULATIONS
This is NEW for 2024 GR11

This document serves as a supplement to the 2024 PhysBuddy to ensure that the required content is covered as the 2024 PhysBuddy does not include this chapter -

EMF AND INTERNAL RESISTANCE

EMF	EXTERNAL VOLTAGE (Terminal Potential Difference)
- is measured with a voltmeter across the battery when **no current** flows through the battery. **Open switch**.	- Vext is measured with a voltmeter across the battery when the **switch is closed** - Vext is the sum of potential difference across resistors in a circuit
 EMF is the Maximum energy provided (work done) by a battery per coulomb/unit charge passing through it. $V = \frac{W}{Q}$ - Sources are labelled with their EMF. For example, a 12 V battery delivers 12 J of energy per coulomb of charge	 - When you connect a voltmeter across a12V battery, and close the switch, you find that the potential difference is less than 12V. - Some volts are 'lost' due to internal resistance of the battery

The difference between EMF and Vext is called V_{lost} or $V_{internal}$ and is due to the internal resistance of the battery itself (r)

$$\text{Vlost} = 12 - 10$$
$$= 2V$$

INTERNAL RESISTANCE (r) AND LOST VOLTS

- As current flows through a circuit, most of the energy is transferred to the resistors and other components in the external circuit, <u>but a small amount of energy is used up inside the cell or battery.</u>
- This energy is used to overcome the **internal resistance** of the cell. The volts used inside the cell are known as **'lost volts'**

To calculate 'lost volts'

$$\mathbf{V_{lost} = Ir}$$

Internal r

Total current

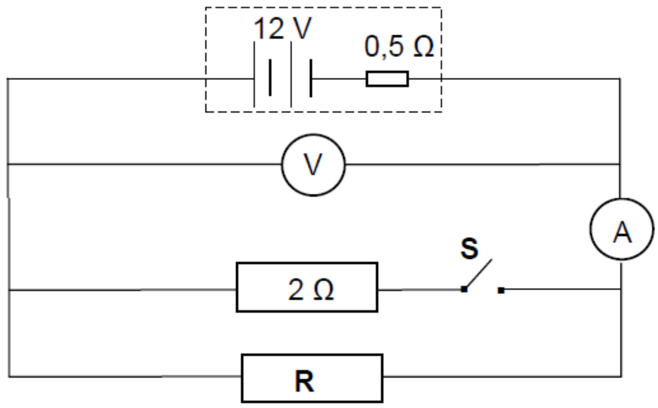
- The total EMF is made up of the lost volts + voltage of external circuit

$$\mathbf{EMF = V_{ext} + V_{lost}}$$
$$\mathbf{= IR + Ir}$$
$$\mathbf{\underline{E = I(R + r)}}$$

Data Sheet Equation

<u>Worked Example 2:</u>

NOV 2018



Switch **S** is now CLOSED.

8.3 How does this change affect the reading on the voltmeter? Choose from: INCREASES, DECREASES or REMAINS THE SAME. Explain the answer. (4)

$\mathbf{V_{ext}}$ is Voltmeter Reading which <u>DECREASES</u>

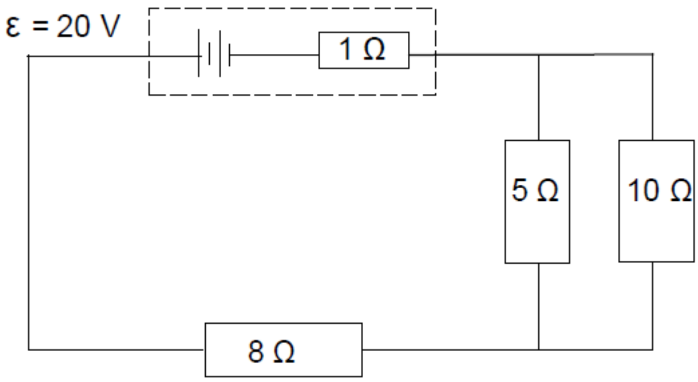
<u>Reason</u>

- By closing the switch, Total<u> Resistance Deceases</u> (Parallel Resistors)
- Therefore, <u>Total Current Increases</u>
- $\mathbf{V_{lost}}$ <u>increases</u> ($V_{lost} = Ir$) , because I increases and r constant
- From equation $\mathbf{EMF = V_{ext} + V_{lost}}$
- <u>Emf is constant</u>, so if $\mathbf{V_{lost}}$ increases then $\mathbf{V_{ext}}$ decreases

Worked Example 3:

FEB/MARCH 2017

8.2 A battery with an emf of 20 V and an internal resistance of 1 Ω is connected to three resistors, as shown in the circuit below.



3.1 Calculate the total external resistance.

Total external resistance is also called <u>'effective resistance'</u>

<u>Start by following the path of the current from positive terminal to the negative terminal (conventional current)</u>

- The total current flows from the battery (+ terminal) and flows through the 8Ω resistor.
- Thereafter the total current SPLITS. Some of the current flows to 5Ω and some flows to 10Ω indicating that 5Ω and 10Ω are connected in parallel
- The 8Ω resistor is in series with the parallel combination of the 5Ω and 10Ω

<u>Calculate Total Parallel Resistance</u>

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

$$\frac{1}{Rp} = \frac{1}{5} + \frac{1}{10}$$

$$\frac{1}{Rp} = \frac{3}{10}$$

$$Rp = \frac{10}{3}$$

$$\underline{= \mathbf{3,33\ \Omega}}$$

<u>Calculate The Total Resistance in The Circuit</u>

$$\mathbf{R_{TOTAL} = R_{SERIES} + R_{PARALLEL}}$$

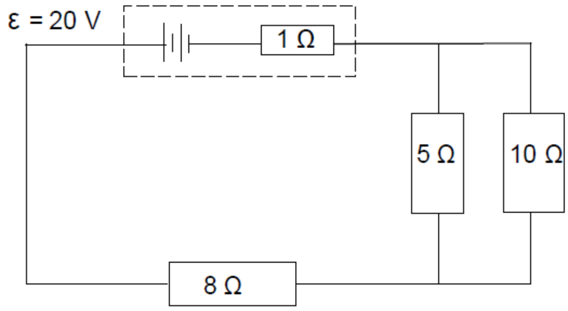
$$R_T = R_S + R_P$$

$$R_{TOTAL} = 8 + 3,33$$

$$\underline{= \mathbf{11,33\Omega}}$$

Useful equation to calculate <u>Total Resistance</u>

3.2 Calculate the current in the 8Ω resistor



By following the path of the current from positive terminal to the negative terminal (conventional current), we see that
The total current flows from the battery (+ terminal) and flows through the 8Ω resistor.

$$E = I(R + r)$$
$$20 = I(11{,}33 + 1)$$
$$\underline{\mathbf{= 1{,}62A}}$$

$\varepsilon = 20V$
$r = 1\Omega$
$R = 11{,}33$
(calculated above)

TIP!
List given values using symbols

3.3 Calculate the potential difference across the 5Ω resistor

- the 5Ω and 10Ω resistor are connected in parallel and thus have the same voltage (Voltage across parallel resistors is the same) We can call this Vp (parallel Voltage)
- we can call the voltage across the 8Ω resistor Vs (voltage in series)

$$Rext = \frac{Vext}{I}$$
$$11{,}33 = \frac{Vext}{1{,}62}$$
$$\underline{\mathbf{Vext = 18{,}35V}}$$

$$Rs = \frac{Vs}{I}$$
$$8 = \frac{Vs}{1{,}62}$$
$$\underline{\mathbf{Vs = 12{,}96V}}$$

$$Vext = V_{SERIES} + V_{PARALLEL}$$
$$Vext = V_S + V_P$$
$$18{,}35 = 12{,}96 + Vp$$
$$\underline{\mathbf{Vp = 5{,}39V}}$$

Depending on the method used you will get an answer in the range of 5,39V-5,41V
Accepted by official memo

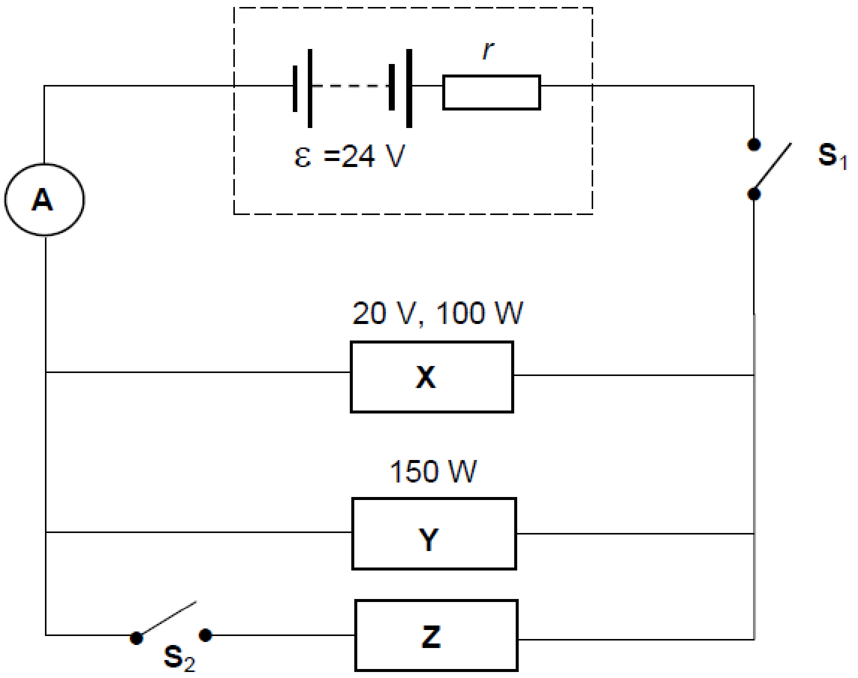
3.4 Calculate the total power supplied by the battery

$$P = I^2R$$
$$P = (1{,}62)^2(12.33)$$
$$\underline{\mathbf{P = 32{,}36W}}$$

The battery overcomes
$Rext + internal\ r$
$= 11{,}33 + 1$
$\underline{\mathbf{= 12{,}33\Omega}}$

The total current of 1,62A flows through the battery

8.2 Three electrical devices, **X**, **Y** and **Z**, are connected to a 24 V battery with internal resistance *r* as shown in the circuit diagram below. The power rating of each of the devices **X** and **Y** are indicated in the diagram.



With switch $\mathbf{S_1}$ closed and $\mathbf{S_2}$ open, the devices function as rated.

Calculate the:

8.2.1 Current in **X** (3)

8.2.2 Resistance of **Y** (3)

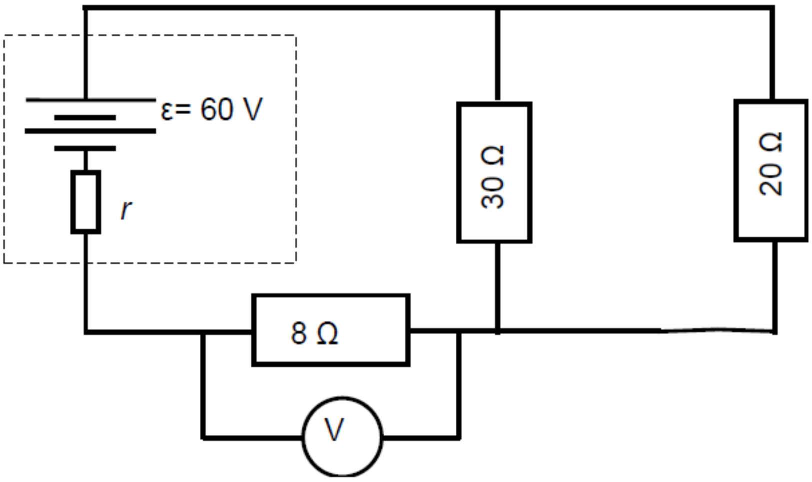
8.2.3 Internal resistance of the battery (5)

Now switch $\mathbf{S_2}$ is also closed.

8.2.4 Identify device **Z** which, when placed in the position shown, can still enable **X** and **Y** to operate as rated. Assume that the resistances of all the devices remain unchanged. (1)

8.2.5 Explain how you arrived at the answer to QUESTION 8.2.4. (2)
[22]

9.2 The circuit diagram below shows a battery with an emf (ε) of 60 V and an unknown internal resistance *r*, connected to three resistors.



A voltmeter connected across the 8 Ω resistor reads 21,84 V.

Calculate the:

9.2.1 Current in the 8 Ω resistor (3)

9.2.2 Equivalent resistance of the resistors in parallel (2)

9.2.3 Internal resistance *r* of the battery (4)

9.2.4 Heat dissipated in the external circuit in 0,2 seconds (3)
[20]

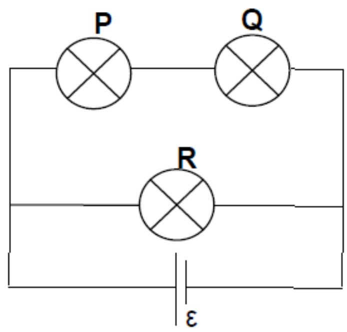
QUESTION 8 (Start on a new page). **FEB/MARCH 2017**

8.1 In Circuit 1 below three identical light bulbs, **P**, **Q** and **R**, with the same resistance, are connected to a battery with emf ε and negligible internal resistance.

8.1.1 How does the brightness of bulb **P** compare with that of bulb **Q**? Give a reason for the answer. (2)

8.1.2 How does the brightness of bulb **P** compare with that of bulb **R**? Give a reason for the answer. (2)

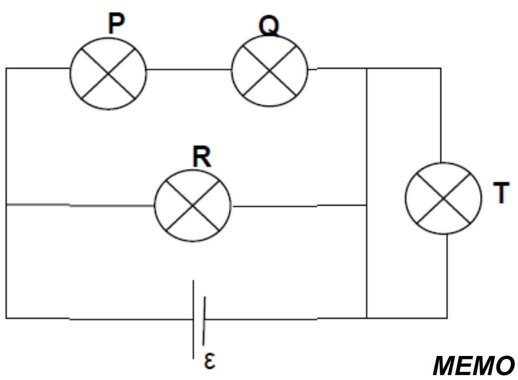
Circuit 1



A fourth, identical bulb **T**, with the same resistance as the other three, is connected to the circuit by means of an ordinary wire of negligible resistance, as shown in Circuit 2 below.

8.1.3 How does the brightness of bulb **T** compare with that of bulb **R**? Give a reason for the answer. (2)

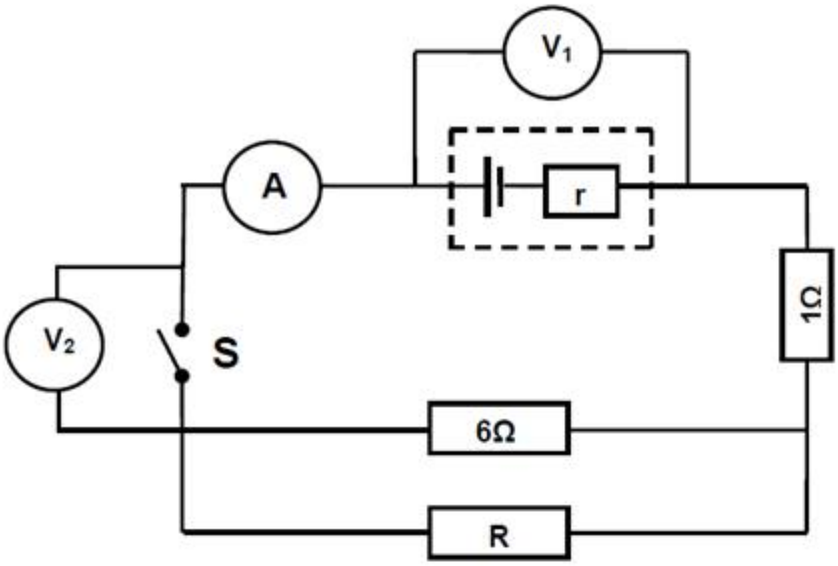
Circuit 2



MEMO PG 417

QUESTION 8 (Start on a new page)

In the circuit represented below, the battery has an emf of 10 V and an unknown internal resistance, **r**. Voltmeter V_1 is connected across the battery and voltmeter V_2 is connected across the open switch. Ignore the resistance of the ammeter and connecting wires.



8.1 Switch **S** is **open**. Will the readings on voltmeters V_1 and V_2 be the same? Provide a reason for your answer. (2)

8.2 When the switch **S** is closed the reading on voltmeter V_1 drops to 7,5 V.

8.2.1 What is the reading on voltmeter V_2? (1)

8.2.2 If the reading on the ammeter is 2,5 A, calculate the value of R. (7)

8.2.3 Define, in words, the term *internal resistance*. (2)

8.2.4 Calculate the internal resistance of the battery. (3)

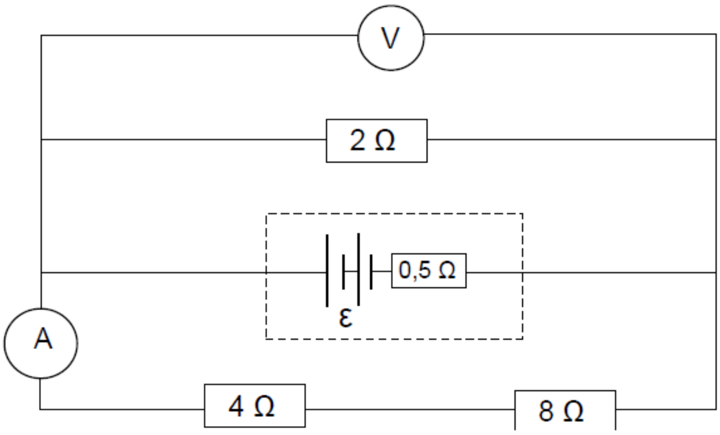
8.3 Does the reading on the ammeter **INCREASE**, **DECREASE** or **REMAIN THE SAME** when the resistor R is removed? (1)

[16]

MEMO PG 416

QUESTION 9 (Start on a new page.) **FEB/MARCH 2016**

A battery of an unknown emf and an internal resistance of 0,5 Ω is connected to three resistors, a high-resistance voltmeter and an ammeter of negligible resistance, as shown below.



The reading on the ammeter is 0,2 A.

9.1 Calculate the:

9.1.1 Reading on the voltmeter (3)

9.1.2 Total current supplied by the battery (4)

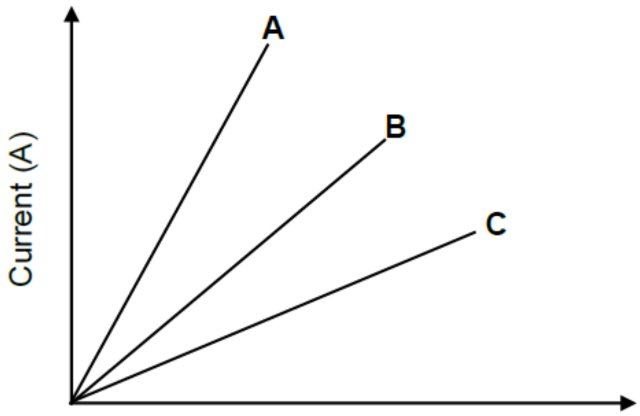
9.1.3 Emf of the battery (5)

9.2 How would the voltmeter reading change if the 2 Ω resistor is removed from the circuit? Write down INCREASE, DECREASE or REMAIN THE SAME. Explain the answer. (3) **[15]**

QUESTION 8 **EC SEPT 2021**

8.1 A group of Grade 12 learners want to determine an efficient conductor which can be used as the heating coil for a kettle that they are constructing for their Eskom Expo project.

They connected each of the three conductors (**A**, **B** and **C**) in a circuit and measured the current passing through the conductor and the potential difference across the conductors. Their results are as shown on the graph below.



8.1.1 Name any TWO variables that must be kept constant for a fair investigation. (2)

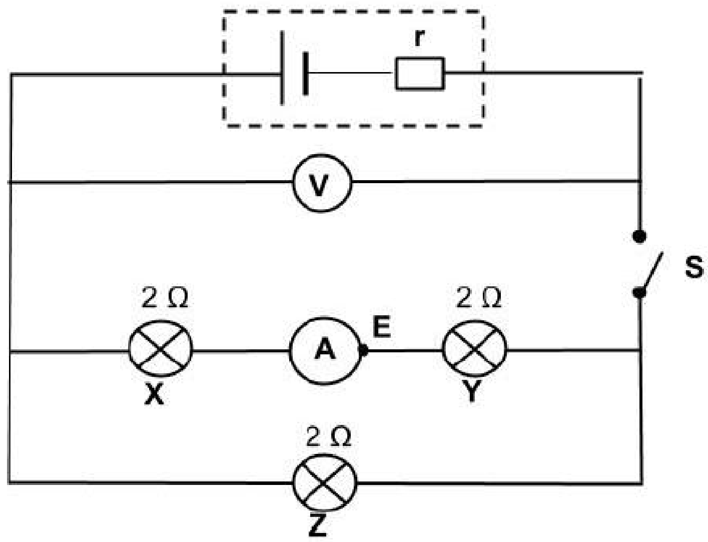
8.1.2 Write down the physical quantity represented by the gradient of each graph. (1)

8.1.3 Which ONE of the conductors is efficient enough to be used as a heating coil in a kettle? Give a reason for your answer. (2)

MEMO PG 418

QUESTION 8 [START ON A NEW PAGE] **CWED SEPTEMBER 2015**

A cell with unknown internal resistance, **r**, is connected to three identical light bulbs, each of resistance 2 Ω, a high resistance voltmeter **V**, a low resistance ammeter **A** and a switch **S** as shown below.



When switch **S** is open, the reading on the voltmeter is **6 V**. When switch **S** is closed, the reading on the voltmeter is **3,9 V**.

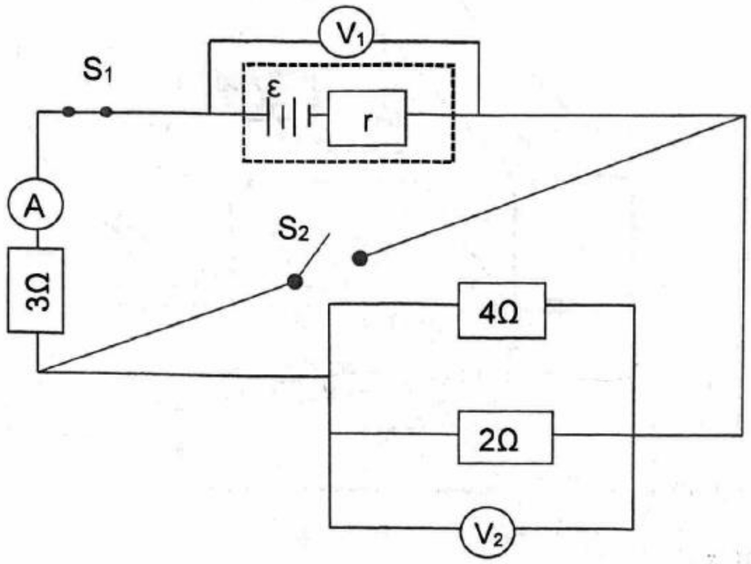
8.1	State Ohm's law in words.		(2)
8.2	Which terminal of the ammeter is represented by point **E**? Write down only POSITIVE or NEGATIVE		(1)
8.3	Calculate the total external resistance in the circuit.		(3)
8.4	Calculate the internal resistance, **r**, of the battery.		(6)
8.5	Calculate the reading on **A** when switch **S** is closed.		(2)
8.6	If light bulb **Z** burns out, how will this affect the following values? (Write down INCREASE, DECREASE or STAY THE SAME.)		
	8.6.1	The reading on voltmeter **V**.	(1)
	8.6.2	The total emf of the battery.	(1)
8.7	Calculate the new reading on ammeter **A**, after light bulb **Z** has burnt out.		(3)
			[19]

MEMO PG 420

QUESTION 8.

KZN SEPT 2023

A battery with an unknown emf (ε) and internal resistance (r) is connected in a circuit, as shown below. The ammeter and connecting wires have negligible resistance. V_1 and V_2 are high-resistance voltmeters



When switch S_1 is **closed** and switch S_2 is **open**, the ammeter reads 2,48 A.

8.1 Define the term *emf of a battery*. (2)

8.2 Calculate the:

8.2.1 reading on voltmeter V_2 (4)

8.2.2 energy transferred to the 3Ω resistor in 1,5 minutes (3)

With BOTH switches S_1 and S_2 **closed**, the ammeter reads 3,43 A.

8.3 How will the reading on the voltmeter, V_1, be affected? Choose from INCREASES, DECREASES or REMAINS THE SAME?
Explain the answer. (3)

8.4 Determine the emf of the battery. (5)

8.5 The battery is now replaced with another battery that has the SAME emf but a GREATER internal resistance. How will the reading on V_1 be affected when both switches are closed?
Choose from INCREASES, DECREASES or REMAINS THE SAME
Explain the answer. (3)

[20]

MEMO PG 425

NOV 2014

8.2.1 $P = VI$

$100 = 20I$

$I = 5A$

8.2.2 $P = \frac{V^2}{R}$

$150 = \frac{20^2}{R}$

$R = 2,67\Omega$

8.2.3

I in Y

$P = VI$

$150 = 20I$

$I = 7,5A$

$I_{Total} = I_y + I_x$

$= 7,5 + 5$

$= 12,5A$

$V_{lost} = Ir$

$24 - 20 = 12,5r$

$r = 0,32\Omega$

8.2.4 Z is a voltmeter

8.2.5 A voltmeter has a very high resistance and will draw very little current.

PhysBuddy

SCE 2017

9.2.1 $R = \frac{V}{I}$

$8 = \frac{21,84}{I}$

$I = 2,73A$

9.2.2 $\frac{1}{R_p} = \frac{1}{R_1} + \frac{1}{R_2}$

$\frac{1}{R_p} = \frac{1}{30} + \frac{1}{20}$

$R_p = 12\Omega$

9.2.3

$\mathcal{E} = I(R + r)$

$60 = 2,73(20 + r)$

$r = 1,98\Omega$

$R_T = R_s + R_p$

$= 8 + 12$

$= 20$

9.2.4

$W = I^2 R \Delta t$

$= (2,73)^2 (20)(0,2)$

$= 29,81 J$

PhysBuddy

Limpopo Sept 2015

8.1 Yes.
NO current flows in the circuit.
V_1 and V_2 give Emf

8.2.1 0V

8.2.2

$R_{ext} = \frac{V_{ext}}{I}$

$R_{ext} = \frac{7,5}{2,5}$

$= 3\Omega$

$R_{ext} = R_s + R_p$

$3 = 1 + R_p$

$R_p = 2$

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

$\frac{1}{2} = \frac{1}{6} + \frac{1}{R}$

$R = 3\Omega$

8.2.3 –

8.2.4 $\mathcal{E} = I(R+r)$

$10 = 2,5(3+r)$

$r = 1\Omega$

8.3 Decreases
Removing Resistor R
- R_{Total} increases
- I_{Total} decreases

Feb/March 2016

9.1.1 $I_{(4\Omega+8\Omega)} = 0,2A$

$R = 12\Omega$

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

$12 = \frac{V}{0,2}$

$V = 2,4V$

9.1.2 The 2Ω is in parallel with $(4\Omega+8\Omega)$
$\therefore$ V across $2\Omega = 2,4V$

2Ω: $R = \frac{V}{I}$

$2 = \frac{2,4}{I}$

$I = 1,2A$

$I_T = 0,2+1,2 = 1,4A$

9.1.3 $\mathcal{E} = I(R+r)$

$= 1,4(1,71+0,5)$

$= 3,1V$

$\frac{1}{R_p} = \frac{1}{(4+8)} + \frac{1}{2}$

$R_p = 1,71\Omega$

9.2. INCREASES

- R_{Total} Increases
- $\therefore I_{Total}$ decreases
- V_{lost} decreases ($V_{lost} = Ir$)

From $\mathcal{E} = V_{ext} + V_{lost}$
$\mathcal{E}$ constant, so if V_{lost} decreases V_{ext} must increase

CWED 2015

8.1 ~

8.2 Negative (connected to - Battery)

8.3 $\frac{1}{R_p} = \frac{1}{R_1} + \frac{1}{R_2}$

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

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

8.4

$\mathcal{E} = I(R+r)$

$6 = 2{,}93\ (1{,}33 + r)$

$r = 0{,}72\ \Omega$

$R_{ext} = \frac{V_{ext}}{I}$

$1{,}33 = \frac{3{,}9}{I}$

$I = 2{,}93A$

8.5 $R = \frac{V}{I}$

$4 = \frac{3{,}9}{I}$

$I = 0{,}98A$

8.6.1 INCREASES

R_T Increases

I_T decreases

V_{lost} decreases

From $\mathcal{E} = V_{ext} + V_{lost}$

if $V_{lost} \downarrow$ $V_{ext} \uparrow$

as $\mathcal{E}$ constant

8.6.2 STAYS THE SAME

8.7 $\mathcal{E} = I(R+r)$

$6 = I(4 + 0{,}72)$

$I = 1{,}27A$

KZN Sept 2023

8.1 -

8.2.1 $\frac{1}{R_p} = \frac{1}{R_1} + \frac{1}{R_2}$

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

$R_p = 1{,}33$

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

$1{,}33 = \frac{V}{2{,}48}$

$V_2 = 3{,}31V$

8.2.2 $W = I^2 R \Delta t$

$= (2{,}48)^2(3)(1{,}5 \times 60)$

$= 1660{,}61\ J$

8.3.1 DECREASES

current $\uparrow$, $V_{lost} \uparrow$, $V_{ext} \downarrow$

Emf constant ($\mathcal{E} = V_{ext} + V_{lost}$)

8.4

S_2 open	S_2 closed
$\mathcal{E} = I(R+r)$	
$\mathcal{E} = 2{,}48(4{,}33 + r)$	$\mathcal{E} = 3{,}43(3 + r)$

$2{,}48\ (4{,}33 + r) = 3{,}43\ (3 + r)$

$r = 0{,}472$

$\mathcal{E} = 2{,}48\ (4{,}33 + 0{,}472)$

$= 11{,}91V$

8.5 DECREASES

$r \uparrow$, $V_{lost} = Ir \uparrow$

$V_{lost} \uparrow$, $V_{ext} \downarrow$, E constant

$\mathcal{E} = V_{ext} + V_{lost}$