



eduresourceza.com



INTERNAL RESISTANCE

Developed by the
Cape Town Science Centre

In collaboration with the
Western Cape Education Department



Understanding Internal Resistance

When the **potential difference (voltage)** is measured across the terminals of a battery for an open circuit (no current flows), you are measuring the **electro-motive force (ϵ OR E), the emf**, of the battery.

The EMF (ϵ) is the maximum energy provided (work done) by a battery per coulomb charge passing through it.

It is the maximum potential difference a battery can supply, measured when there is no current.

When the circuit is closed (current is flowing), the potential difference measured across the terminal is less than the ϵ . This is called the **terminal potential difference (V_{external} OR V_{LOAD})**.

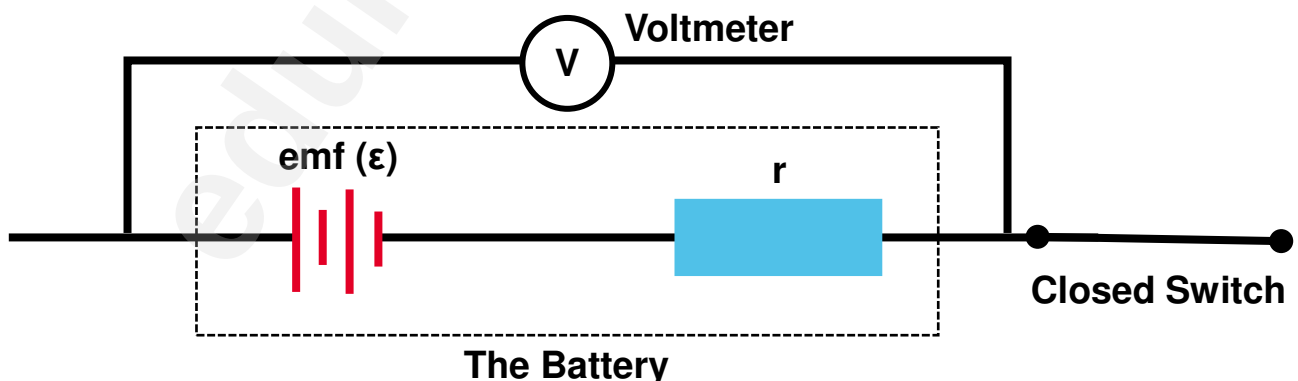
The EMF (ϵ) gains electrical energy whereas the terminal potential difference (V) loses electrical energy.

The drop in the potential difference measured across the terminal of a battery when the current is flowing is called lost volts (V).

It is caused by **internal resistance (r)** found within the battery.

Real batteries convert a small amount of the electrical energy it supplies into heat. This is because batteries are made of materials which have resistance.

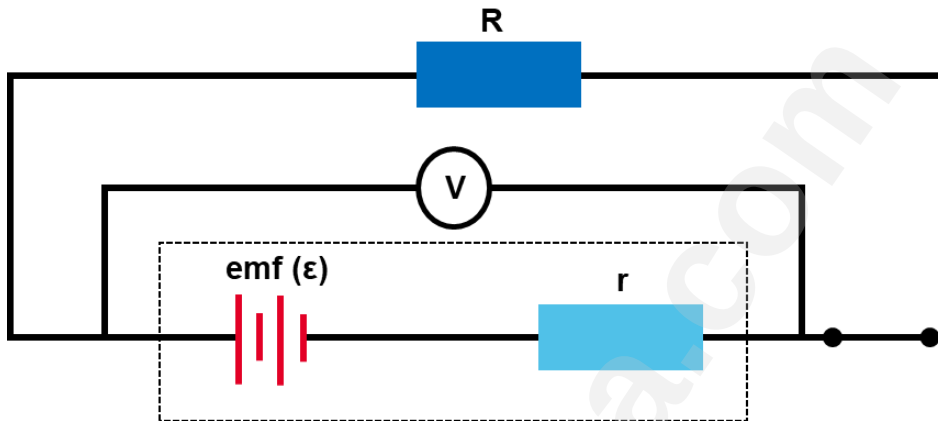
Therefore a real battery can be represented by an emf (ϵ) connected in series with a internal resistance (r).



Internal resistance (r) causes a decrease in the measured potential difference across the battery terminals when a current is flowing.

This terminal potential difference (V) is less than the EMF (ϵ)

Calculating the EMF



Consider a closed circuit which has a battery with internal resistance r and EMF ϵ . The “lost volts” due to the internal resistance (r) of the battery is given by

$$V_{\text{internal resistance}} = Ir$$

The circuit external to the battery has a resistance R . A voltmeter is placed parallel to the battery and an ammeter is connected in series within the circuit.

The voltmeter reads the terminal potential difference (V_{external}). This is potential difference across the external circuit.

$$V = V_{\text{external resistance}} = IR$$

The EMF (ϵ) is the sum of $V_{\text{internal resistance}}$ and V_{external}

$$\text{EMF} = V_{\text{external resistance}} + V_{\text{internal resistance}}$$

$$\text{EMF} = Ir + IR$$

$$\text{EMF} = I(r + R)$$

Changes to the external Resistance R

If the external resistance R in a circuit is decreased, the current I will increase (and vice versa).

Since $V_{\text{internal resistance}}$ is proportional to the current, $V_{\text{internal resistance}}$ increases. This means more volts will be lost.

Series and Parallel Resistors

Resistors Connected In Series

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

$$R_s = R_1 + R_2 + R_3 + \dots \quad \text{Resistance ADDS}$$

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

$$V_{\text{Total}} = V_1 + V_2 + V_3 + \dots \quad \text{Voltage SPLITS}$$

The current is constant through all the resistors:

$$I_{\text{Total}} = I_1 = I_2 = I_3 = \dots \quad \text{Current EQUAL}$$

Resistors Connected in Parallel

. The current is split into a number of branches, with each branch possibly containing a number of resistor in series. The biggest current will go through the smallest resistor and vice versa. (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 (R_p) is given as:

$$\frac{1}{R_p} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \dots \quad \text{Resistance ADDS INVERSELY across branches}$$

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

$$V_{\text{Total}} = V_1 = V_2 = V_3 = \dots \quad \text{Voltage EQUAL across branches}$$

$$I_{\text{Total}} = I_1 + I_2 + I_3 + \dots \quad \text{Current SPLITS across branches}$$

Power

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

It is describes mathematically as:

$$\textcircled{1} \quad P = IV$$

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.

$$V = IR$$

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

$$\textcircled{2} \quad P = I^2 R$$

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

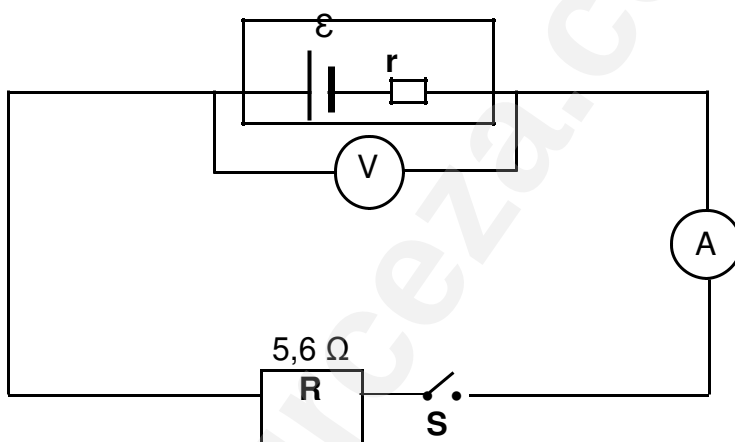
$$\textcircled{3} \quad P = \frac{V^2}{R}$$

**ALL THREE
EQUATIONS OF
POWER ARE
EQUIVALENT**

WORKED Exam Question**Paper 1, Oct/Nov 2019, Q.8**

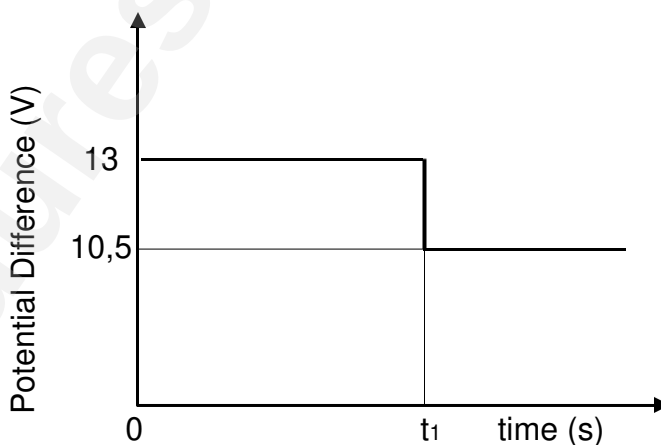
In the circuit diagram below, resistor **R**, with a resistance of $5,6\ \Omega$, is connected, together with a switch, an ammeter and a high-resistance voltmeter, to a battery with an unknown internal resistance, r .

The resistance of the connecting wires and the ammeter may be ignored.



The graph below shows the potential difference across the terminals of the battery as a function of time.

At time t_1 , switch **S** is closed.



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

Maximum energy provided (word done) by a battery per coulomb charge passing through it.

- 8.2 Write down the value of the emf of the battery. (1)

13 V

Continued...

Paper 1, Oct/Nov 2019, Q.8

8.3 When switch **S** is CLOSED, calculate the:

8.3.1 Current through resistor **R**

(3)

$$V = IR, \text{ therefore } I = \frac{V}{R} = \frac{10,5}{5,6} = 1,88 \text{ A}$$

8.3.2 Power dissipated in resistor **R**

(3)

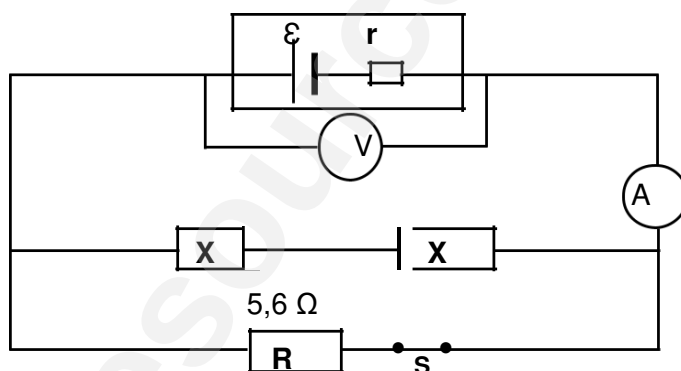
$$P = VI = 10,5 \times 1,88 = 19,74 \text{ W}$$

8.3.3 Internal resistance, **r**, of the battery

(3)

$$\mathcal{E} = I(R+r), \text{ therefore } r = \frac{\mathcal{E}}{I} - R = \frac{13}{1,88} - 5,6 = 1,31 \Omega$$

8.4 Two IDENTICAL resistors, each with resistance **X**, are now connected in the same circuit with switch **S** closed, as shown below.



The ammeter reading now increases to 4 A.

8.4.1 How would the voltmeter reading change? Choose from INCREASES, DECREASES or REMAINS THE SAME.

Give a reason for the answer by referring to $V_{\text{internal resistance}}$.

(2)

DECREASES

If the external resistance decreases, then current I increases.

$V_{\text{internal resistance}} = Ir$, where r is constant. Therefore $V_{\text{internal resistance}}$ increases

8.4.2 Calculate resistance **X**.

(5)

$$\mathcal{E} = I(R+r), \text{ therefore } R_{\text{ext}} = \frac{\mathcal{E}}{I} - r = \frac{13}{4} - 1,31 = 1,94 \Omega$$

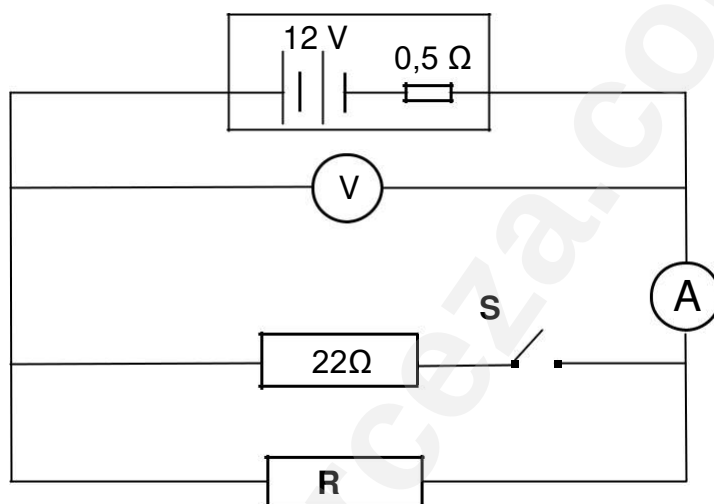
$$\frac{1}{R_p} = \frac{1}{R_{B1}} + \frac{1}{R_{B2}} = \frac{1}{5,6} + \frac{1}{2X}, \text{ therefore } 2X = 2,97 \Omega$$

$$X = \frac{1}{2}(2,97) = 1,49 \Omega$$

PREVIOUS Exam Question

Paper 1, Oct/Nov 2018, Q.8

The battery in the circuit diagram below has an emf of 12 V and an internal resistance of $0,5 \Omega$. Resistor **R** has an unknown resistance.



8.1 What is the meaning of the following statement?

The emf of the battery is 12 V.

(2)

The reading on the ammeter is 2 A when switch **S** is OPEN.

8.2 Calculate the:

8.2.1 Reading on the voltmeter

(3)

8.2.2 Resistance of resistor **R**

(2)

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.

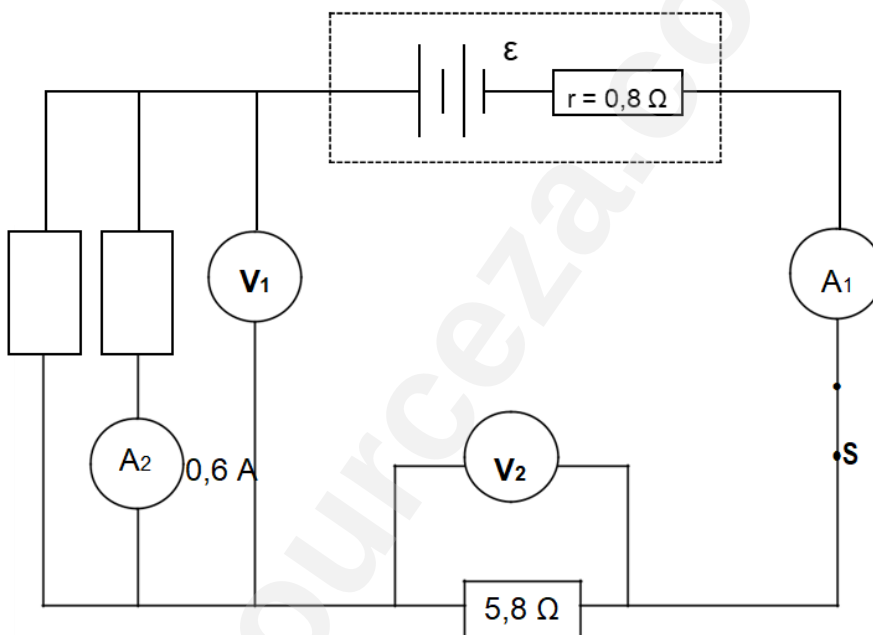
Explain the answer.

(4)

PREVIOUS Exam Question

Paper 1, May/June 2018, Q.9

- 9.1 In the circuit diagram below the battery has an unknown emf (ϵ) and an internal resistance (r) of $0,8 \Omega$.



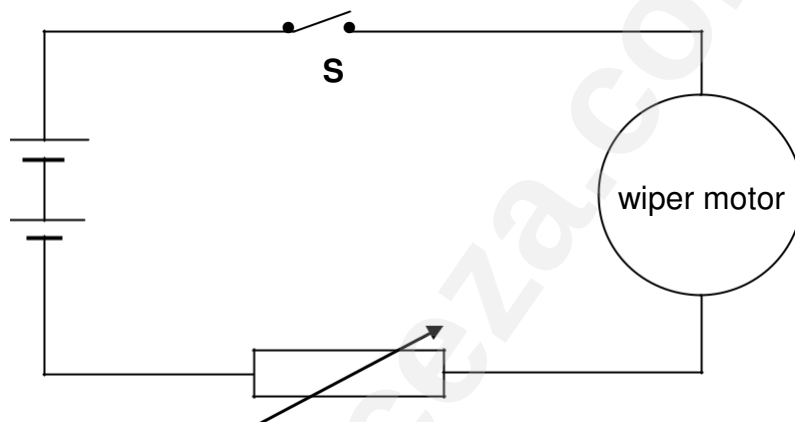
- 9.1.1 State Ohm's law in words. (2)

The reading on ammeter A_2 is $0,6 \text{ A}$ when switch **S** is closed.

Calculate the:

- 9.1.2 Reading on voltmeter V_1 (3)
- 9.1.3 Current through the 6Ω resistor (2)
- 9.1.4 Reading on voltmeter V_2 (2)
- 9.1.5 Emf (ϵ) of the battery (3)
- 9.1.6 Energy dissipated as heat inside the battery if the current flows in the circuit for 15 s (3)

- 9.2 A simplified circuit diagram for the windscreen wiper of a car consists of a variable resistor and a wiper motor connected to a 12 volt battery.



When switch **S** is closed, the potential difference across the variable resistor is 2,8 V and the current passing through it is 0,7 A.

- 9.2.1 Calculate the resistance of the variable resistor. (2)

The resistance of the variable resistor is now decreased.

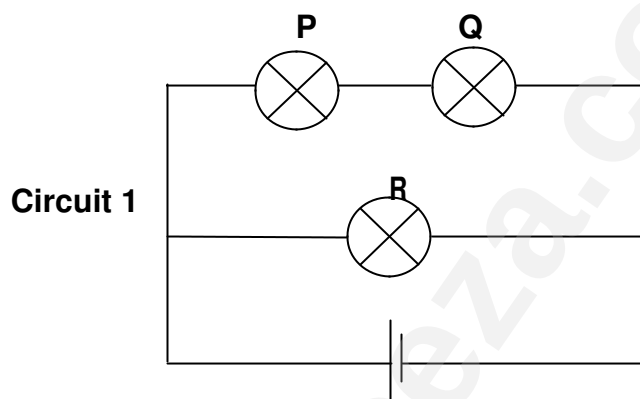
- 9.2.2 State whether the speed at which the wiper turns will INCREASE, DECREASE or REMAIN THE SAME.

Give a reason for the answer. (3)

PREVIOUS Exam Question

Paper 1, Feb/Mar 2017, Q.8

- 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.

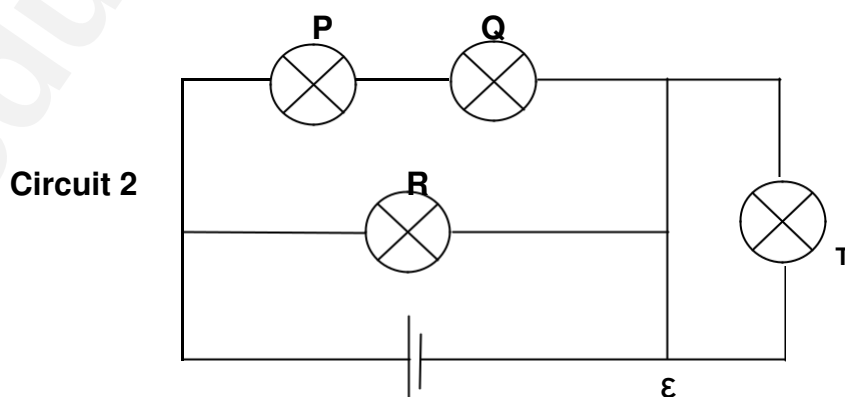
(2)

- 8.1.2 How does the brightness of bulb **P** compare with that of bulb **R**?

Give a reason for the answer.

(2)

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.

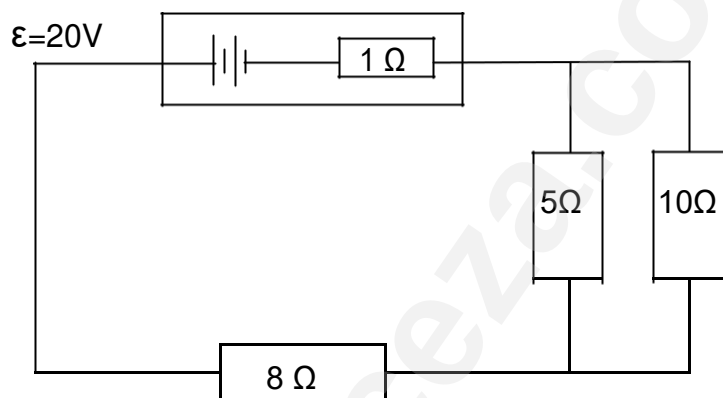


- 8.1.3 How does the brightness of bulb **T** compare with that of bulb **R**?

Give a reason for the answer.

(2)

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



Calculate the:

- | | | |
|-------|--|-----|
| 8.2.1 | Current in the $8\ \Omega$ resistor | (6) |
| 8.2.2 | Potential difference across the $5\ \Omega$ resistor | (4) |
| 8.2.3 | Total power supplied by the battery | (3) |