

Electric Circuits

Pg. 345

Current

- The amount of charge moving through a certain point in a circuit in 1 second.

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

- I = Current (A)
- Q = Charge (C)
- Δt = time (s)

Potential difference

- Indicates the work done by electrons to move 1 coulomb of charge from one point to another.

$$V = \frac{W}{Q}$$

- V = Potential difference
- W = Energy (J)
- Q = Charge (C)

Emf of a battery is the total energy that a battery can supply.

Resistance

- The opposition a conductor offers to a flow of charge.
- Resistance calculated as the ratio between potential difference across the conductor and the current flowing through it.

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

R = Ohm (Ω)

V = Potential difference (V)

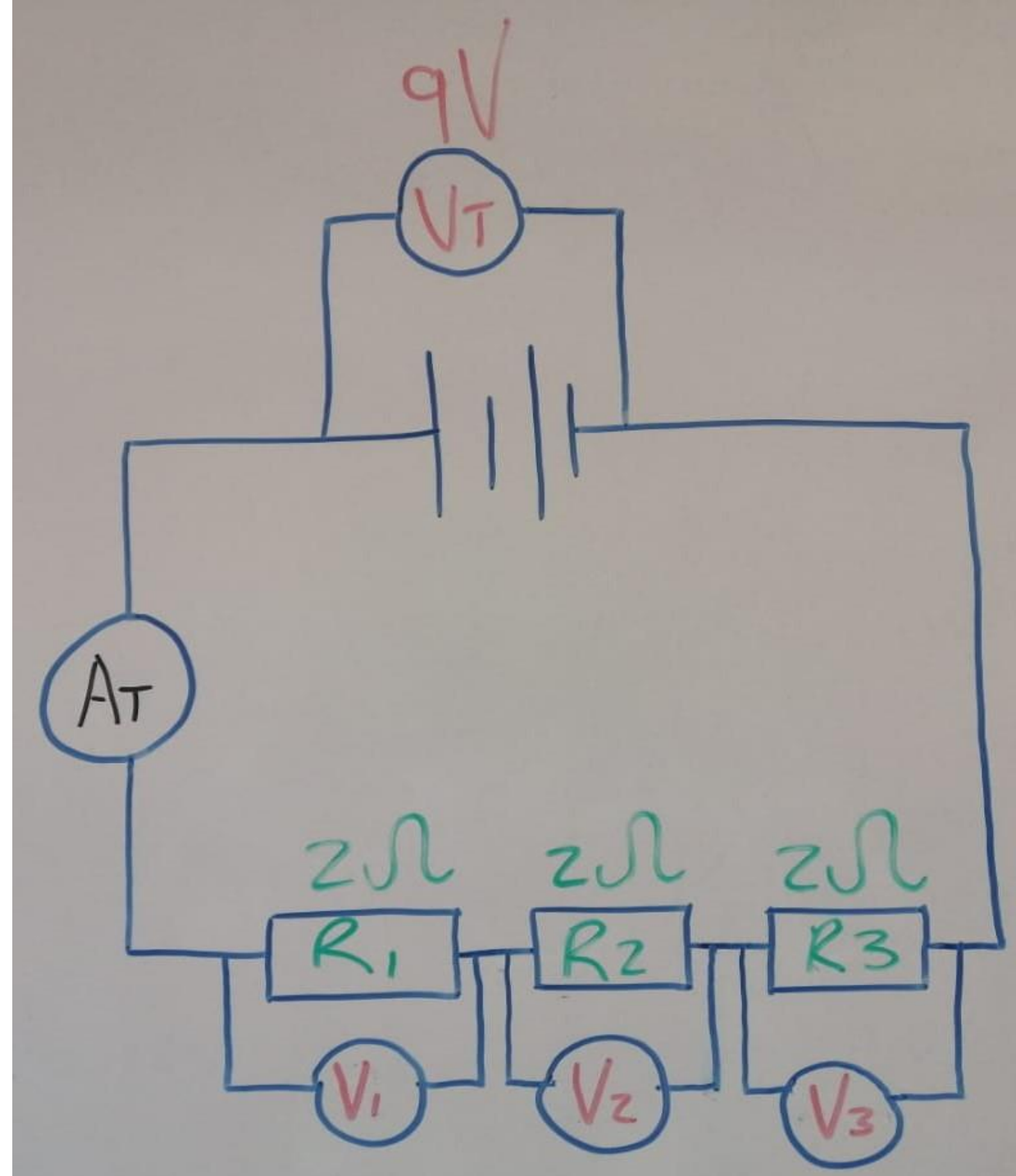
I = Current (A)

Ohm's law

- The current flowing through a resistor is directly proportional to the potential difference across the resistor, provided the temperature remains constant.

Series laws

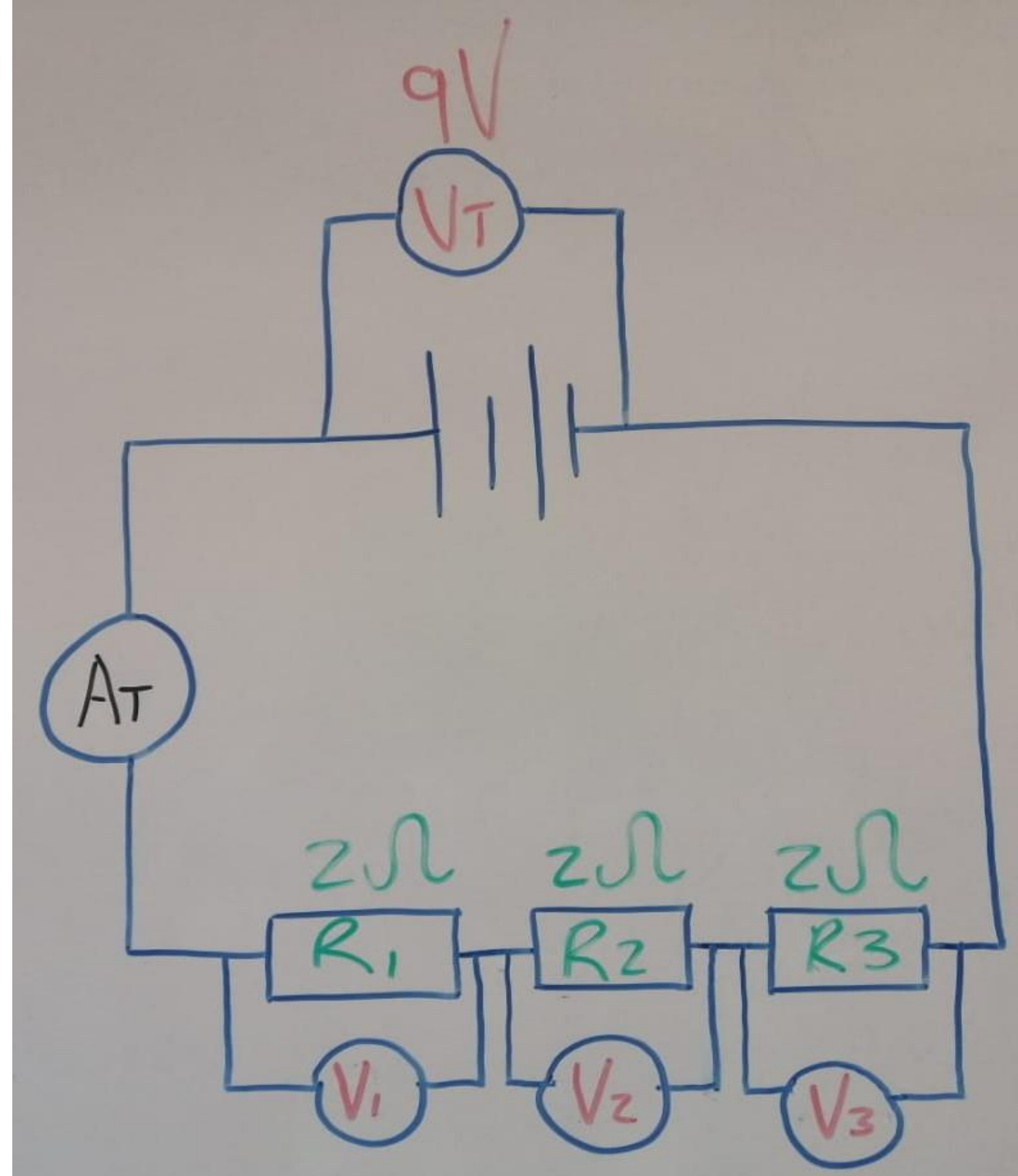
- $I_{Total} = I_1 = I_2 = I_3$
 - $V_{Total} = V_1 + V_2 + V_3$
 - $R_{Total} = R_1 + R_2 + R_3$
1. Calculate Total current.
 2. Calculate the potential difference over each resistor



Series laws

1. Calculate Total current.
2. Calculate the potential difference over each resistor.

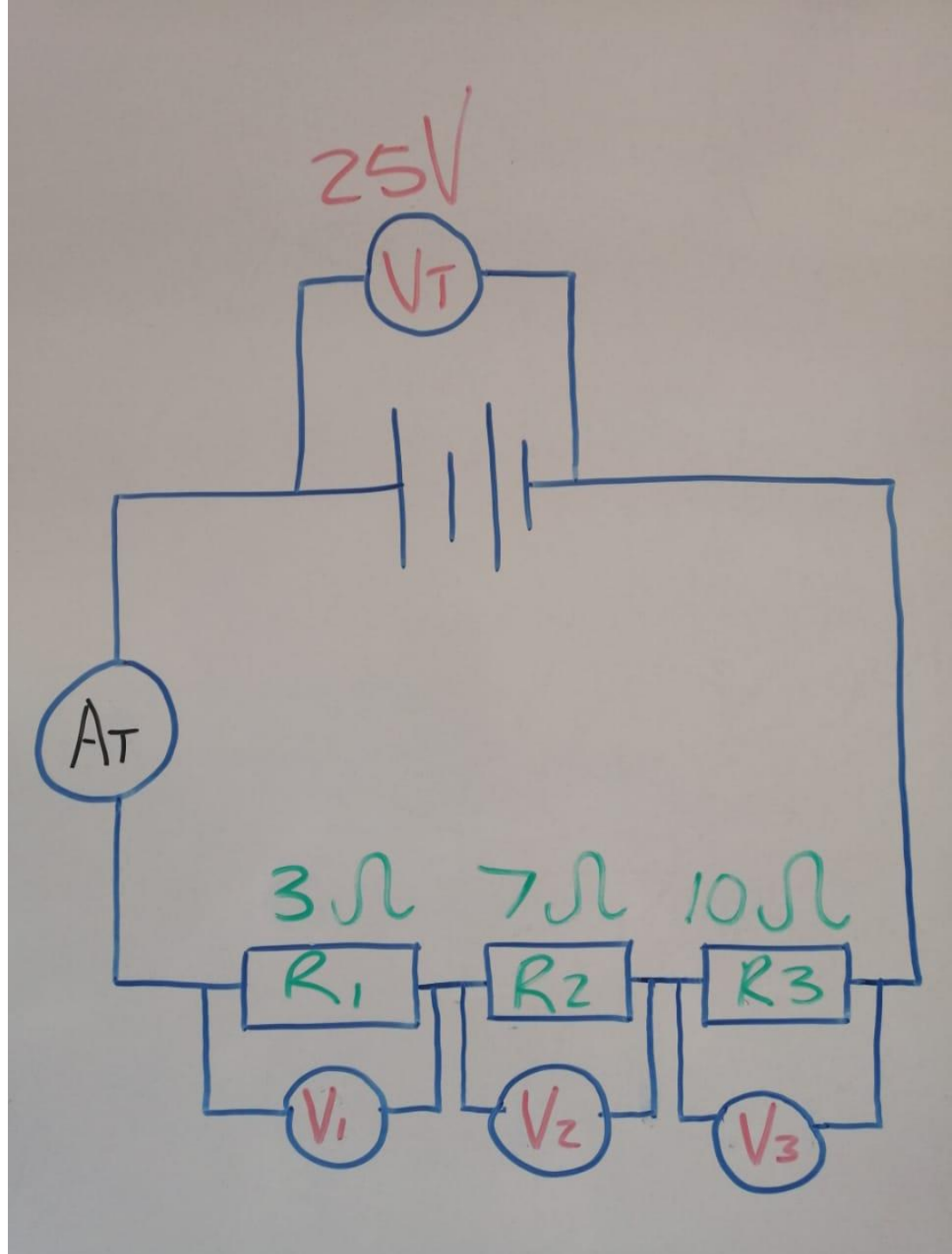
$$1. I_T = V_T \div R_T$$
$$2. V_1 = I_1 \times R_1$$



Calculating Voltage over resistors in series

When resistance have different values:

- Calculate total resistance.
 - Divide each resistor with total.
 - Multiply with total voltage.
-
1. Calculate total current.
 2. Calculate the voltage over each resistor.



Calculating Voltage over resistors in series

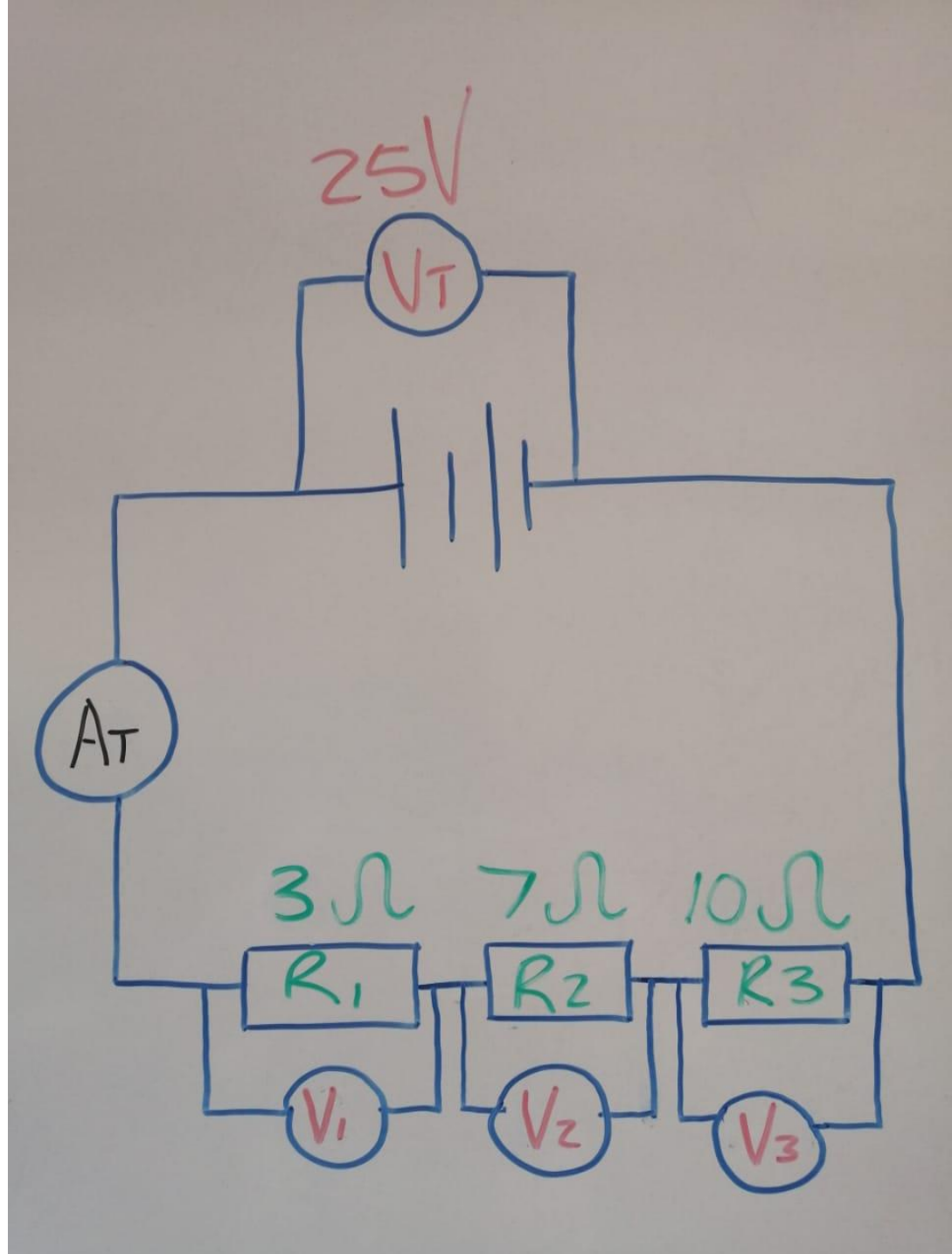
1. Calculate total current.
2. Calculate the voltage over each resistor.

$$1. I_T = V_T \div R_T$$

$$2. V_1 = A_1 \times R_1 \text{ or } V_1 = \frac{R_1}{R_T} \times V_T$$

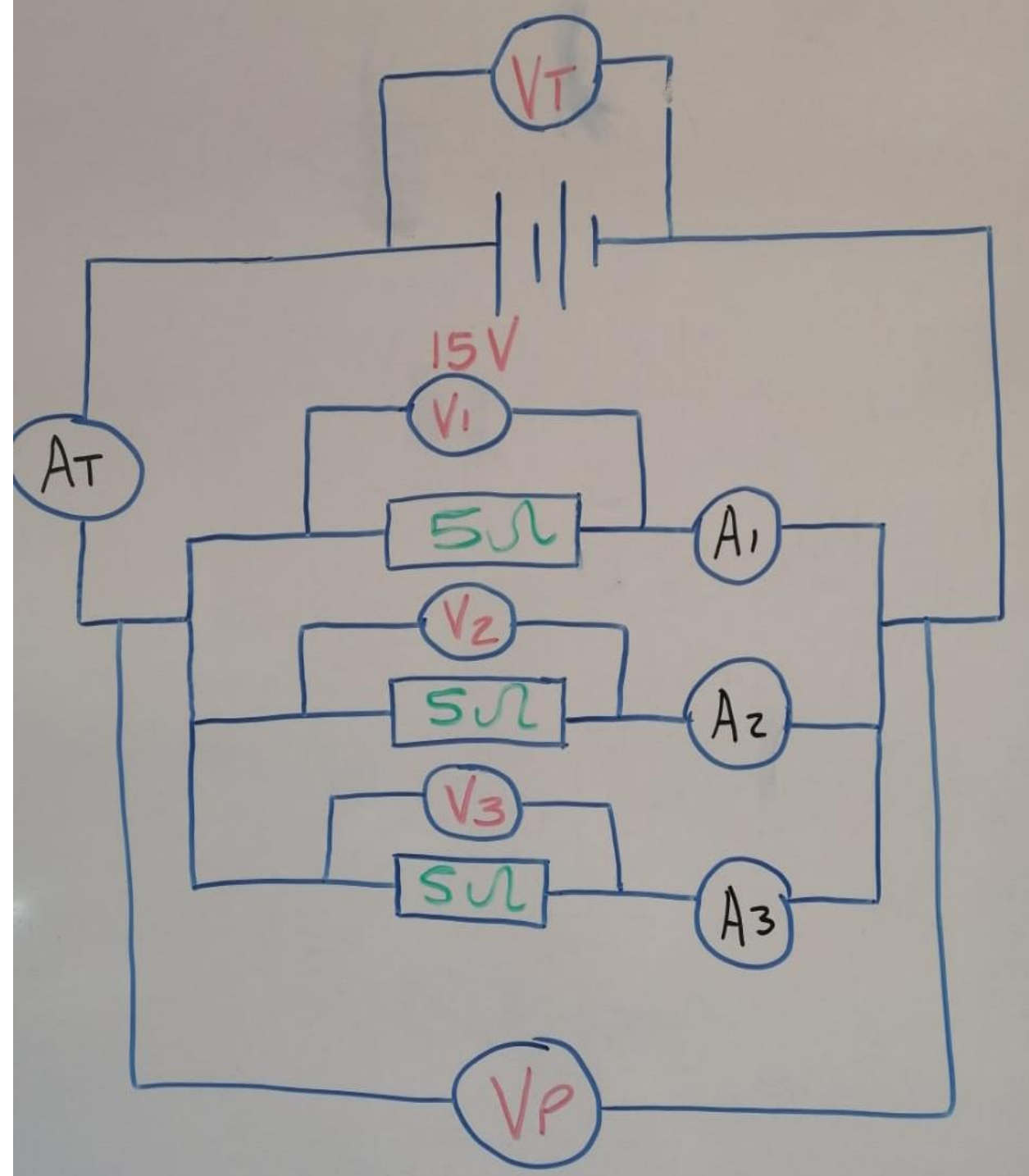
$$V_2 = A_2 \times R_2$$

$$V_3 = A_3 \times R_3$$



Parallel Laws

- $I_{Total} = I_1 + I_2 + I_3$
 - $V_{Total} = V_1 = V_2 = V_3 = V_p$
 - $\frac{1}{R_{parallel}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$
1. Calculate the parallel resistance.
 2. Calculate the total current.
 3. Calculate the current moving through each resistor.



Parallel Laws

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2. Calculate the total current.
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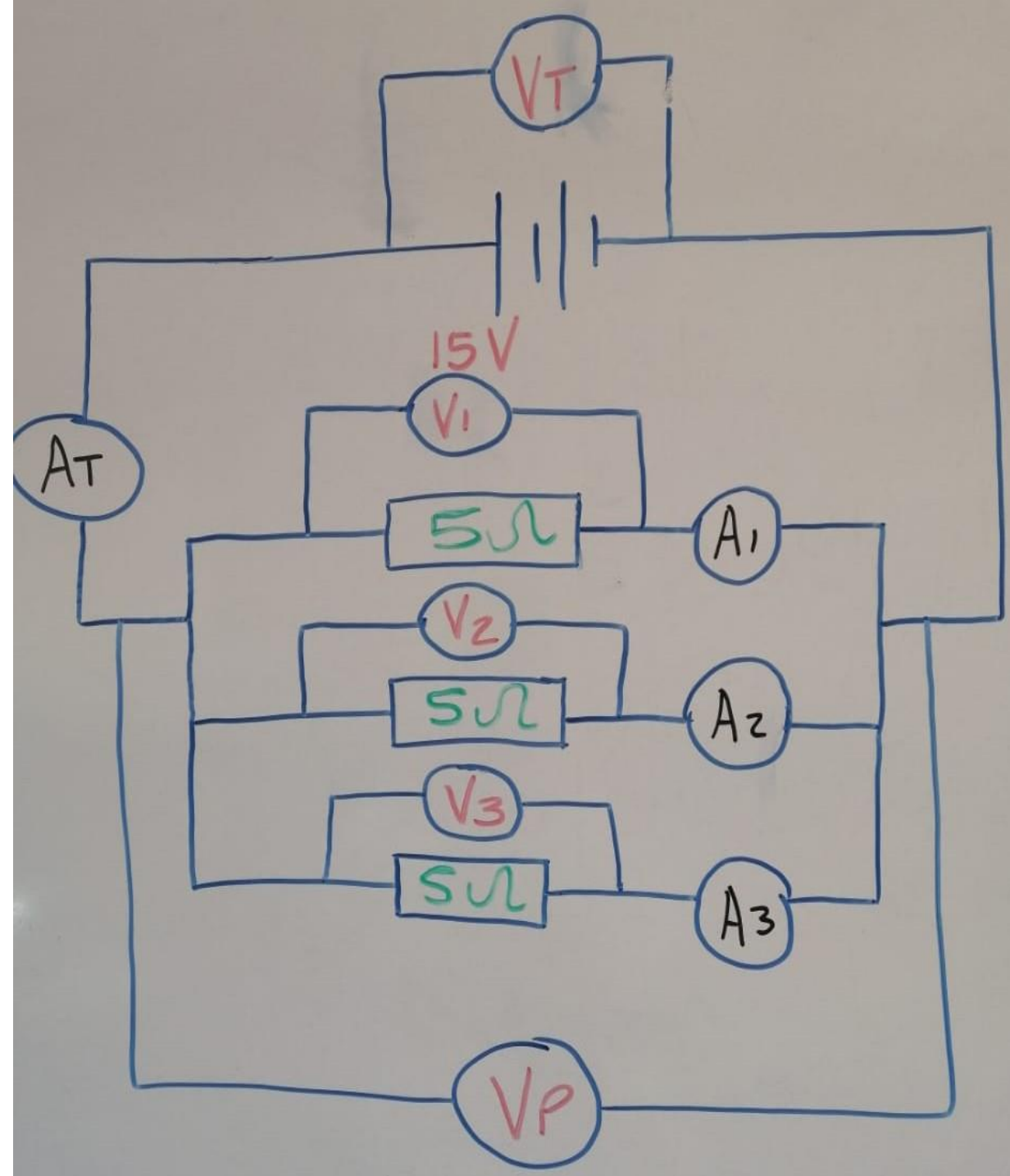
$$1. \frac{1}{R_{parallel}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

$$2. I_T = V_T \div R_T$$

$$3. I_1 = V_1 \div R_1 \text{ or } I_T \div 3$$

$$I_2 = V_2 \div R_2$$

$$I_3 = V_3 \div R_3$$

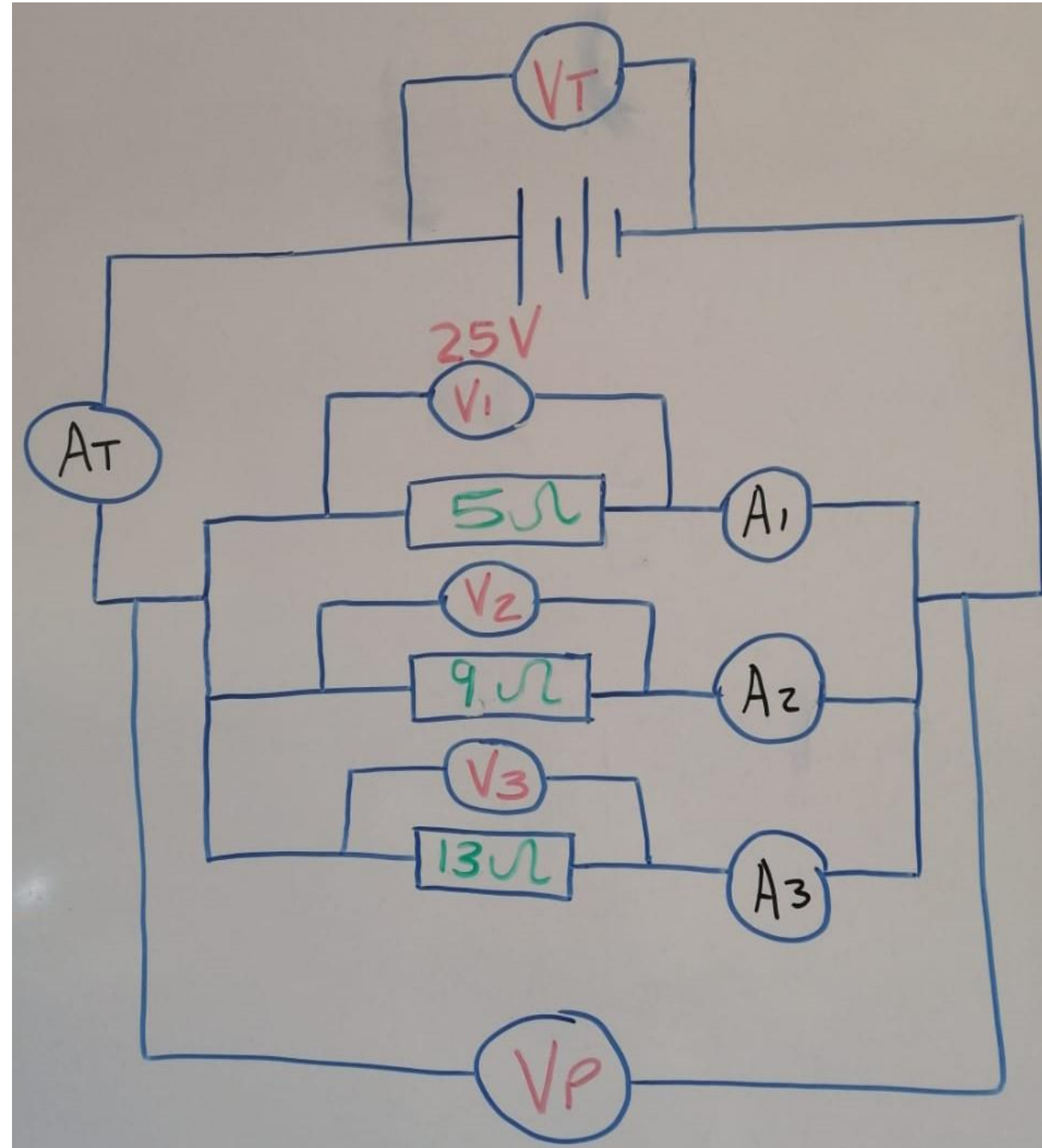


Calculating current in parallel

When resistance have different values:

- Calculate parallel resistance.
- Divide each resistor with total.
- Multiply with total current.

1. Calculate total current.
2. Calculate the current moving through each resistor.



Calculating current in parallel

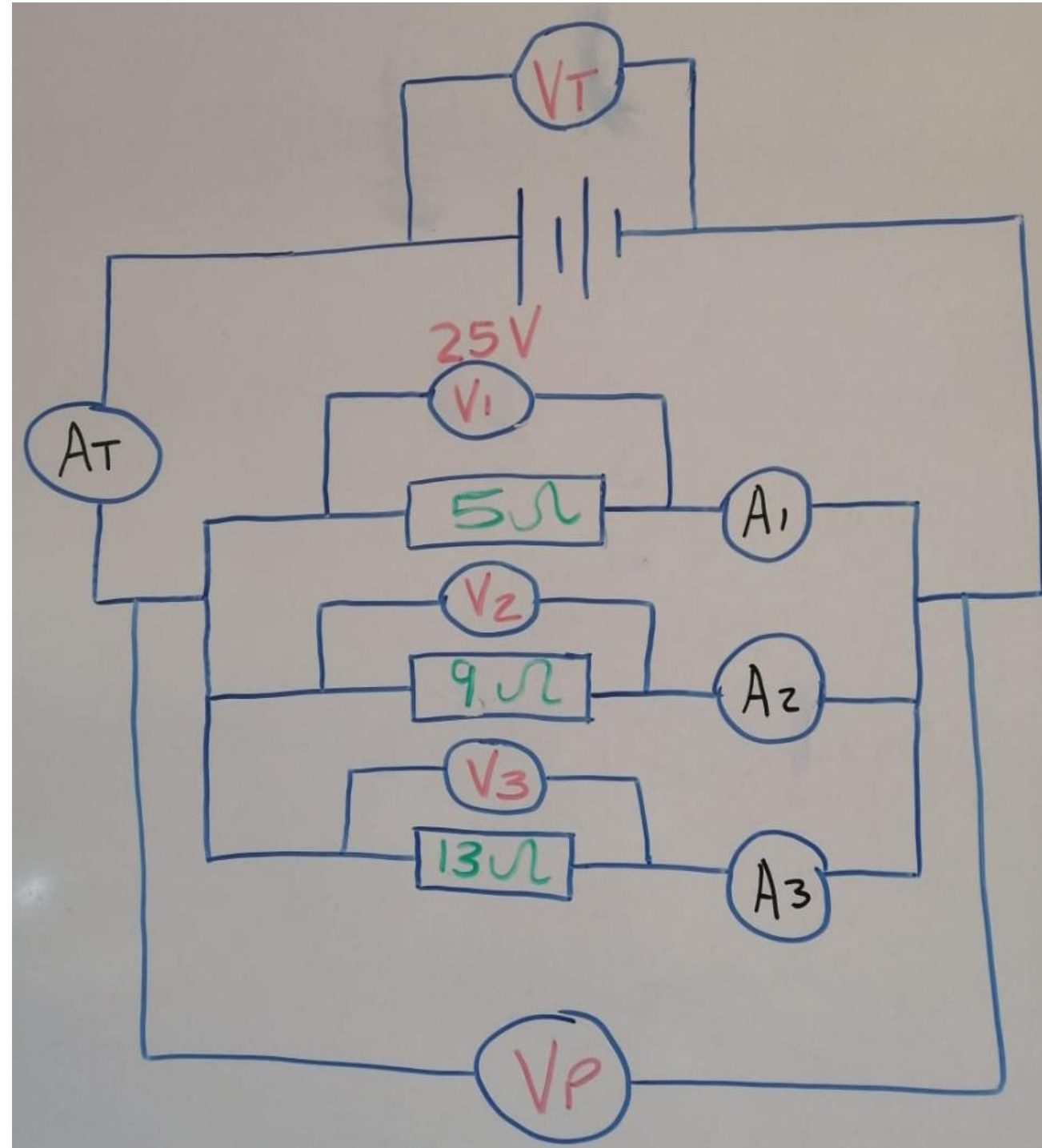
1. Calculate total current.
2. Calculate the current moving through each resistor.

$$1. I_T = V_T \div R_T$$

$$2. A_1 = V_1 \div R_1 \text{ or } A_1 = \frac{R_p}{R_1} \times I_T$$

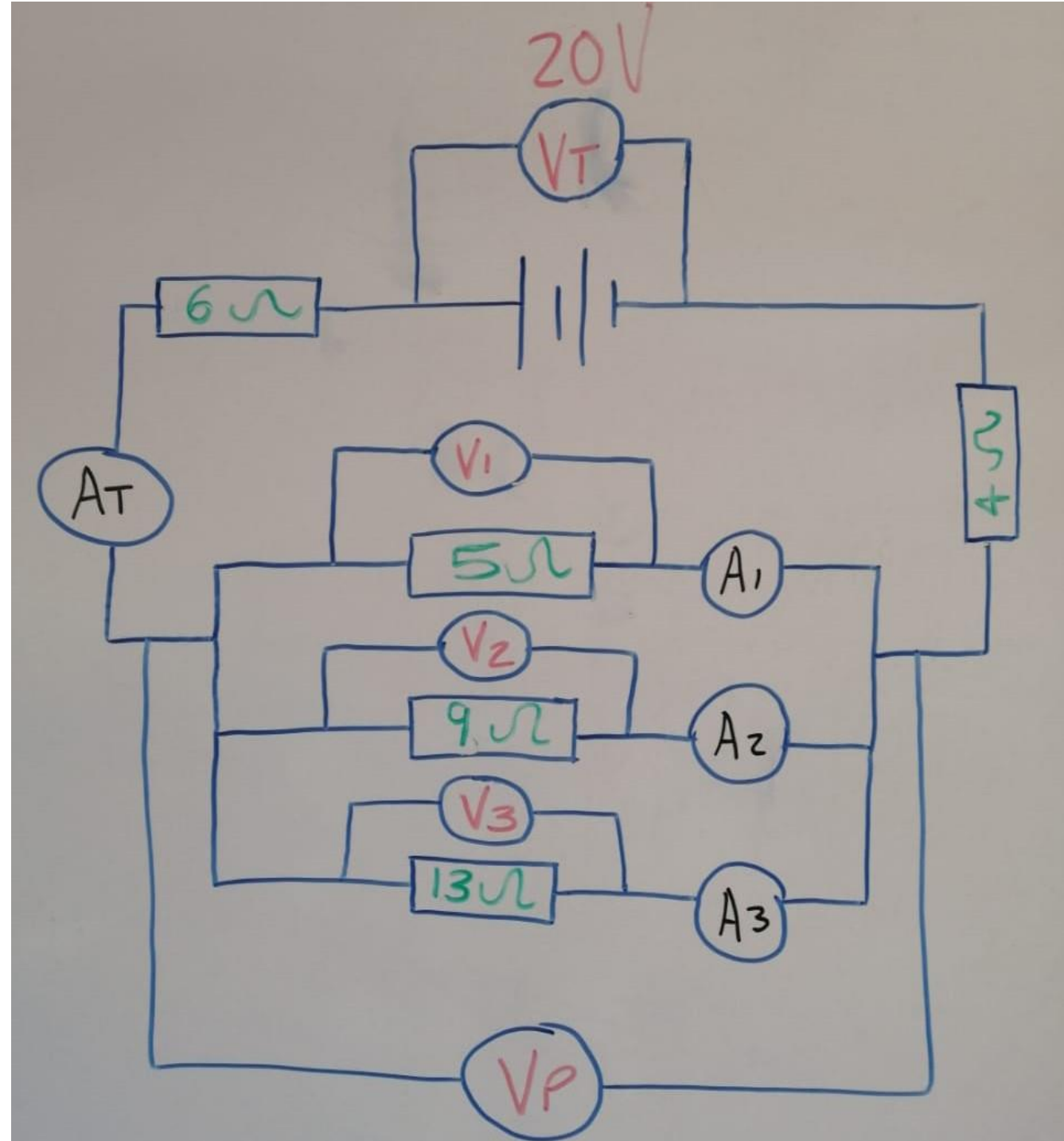
$$A_2 = V_2 \div R_2 \text{ or } A_2 = \frac{R_p}{R_2} \times I_T$$

$$A_3 = V_3 \div R_3 \text{ or } A_3 = \frac{R_p}{R_3} \times I_T$$



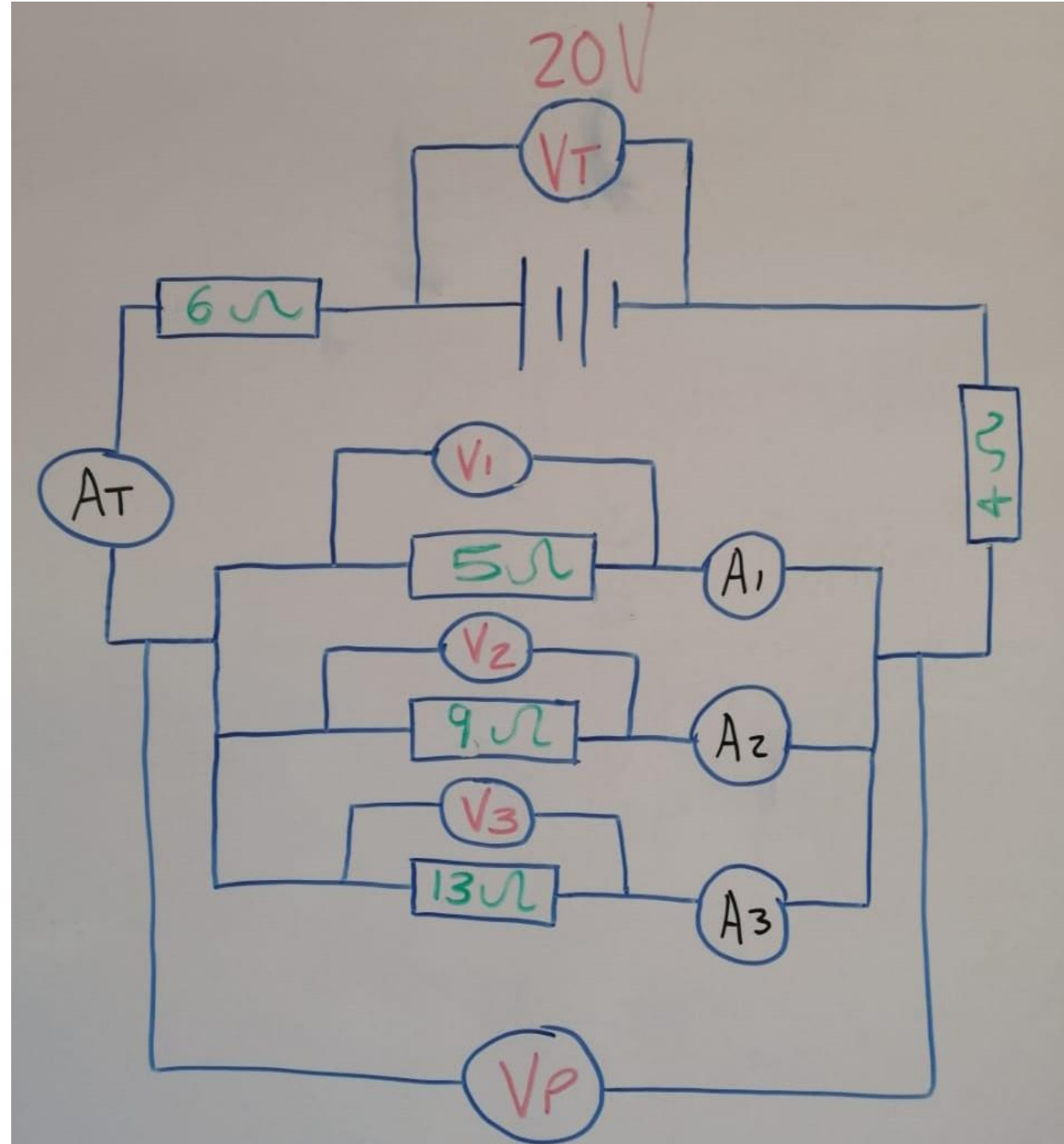
Series and Parallel combined

- Laws of series and parallel combined.
- $R_T = R_p + R_s$
- $V_T = V_p + V_s$
- $I_T = V_T \div R_T$



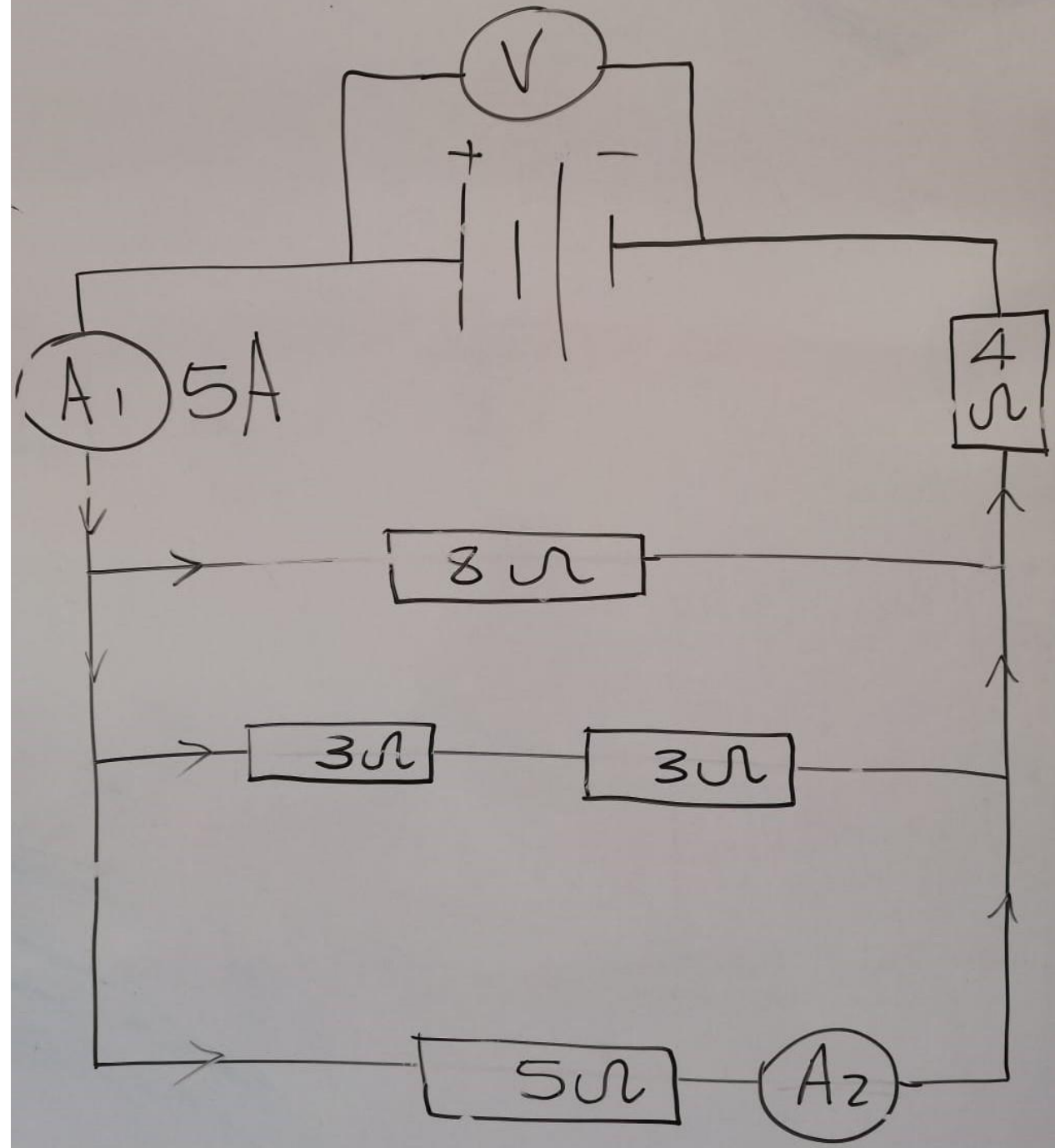
Series and Parallel combined

1. Calculate the resistance in the parallel component.
2. Calculate the total current in the circuit.
3. Calculate the Voltage in the parallel component.
4. Calculate the reading on A_2 .
5. Calculate the potential difference across the 6Ω resistor.



Example

1. Calculate total resistance
2. Calculate total potential difference
3. Calculate reading on A2.



Example

Each lightbulb has a resistance of 5Ω .

1. If switch S is closed, calculate:

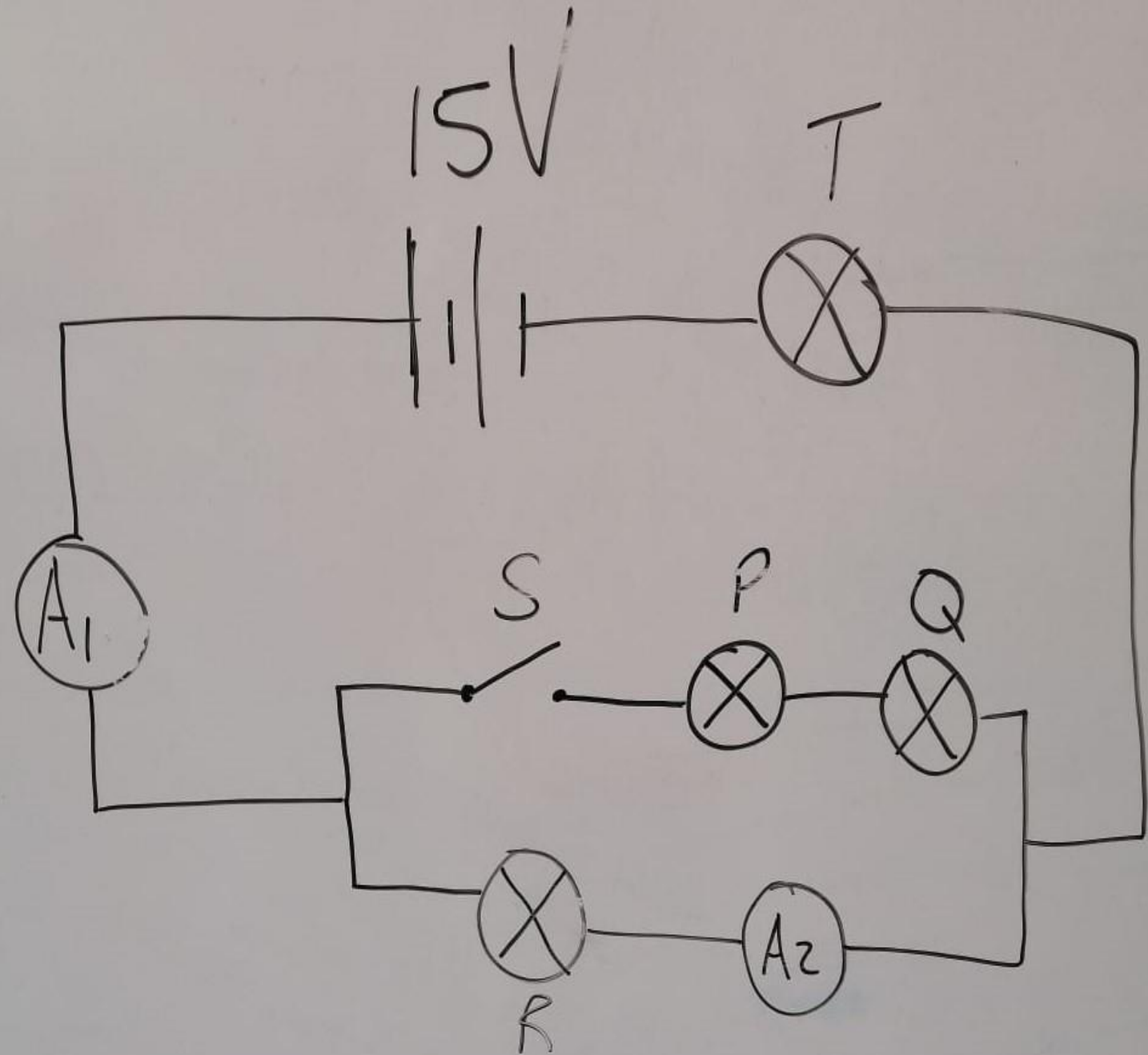
1.1 the readings on A1 and A2

1.2 the power of each lightbulb.

2. If switch S is open, calculate:

2.1 the readings on A1 and A2

2.2 The power of each lightbulb



Power

- The rate of electrical energy conversion in a circuit. (1 watt = 1 j/s)

$$P = V \times I$$

P - Power – watt (W)

V – Potential difference (V)

I – Current (A)

Power

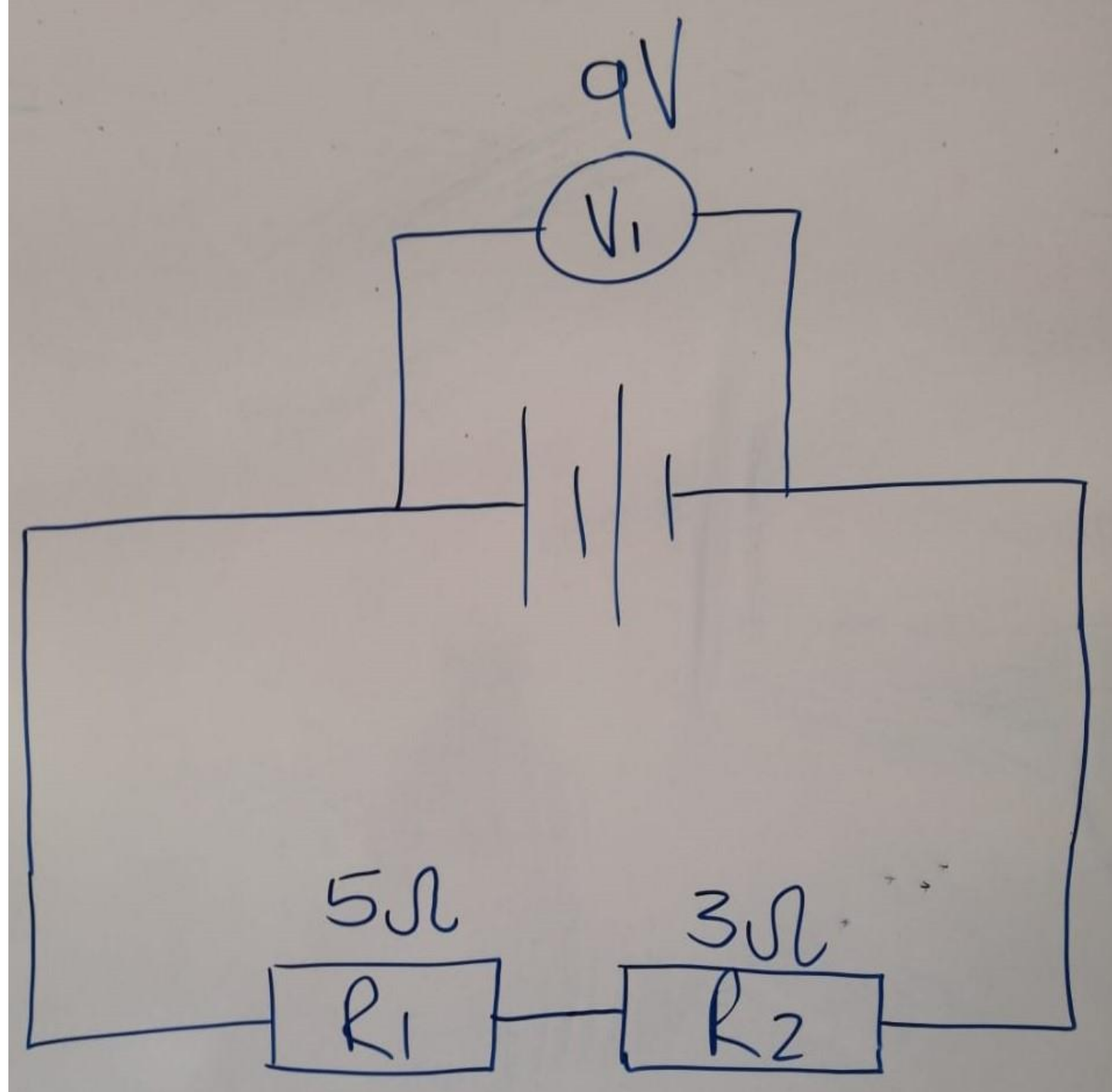
- Formula can be manipulated:
- $P = V \times I$
- $(V = I \times R) \dots P = I^2 \times R$

or

- $P = V \times I$
- $I = \frac{V}{R} \dots P = \frac{V^2}{R}$

Example

- Calculate the power output of each resistor in the circuit



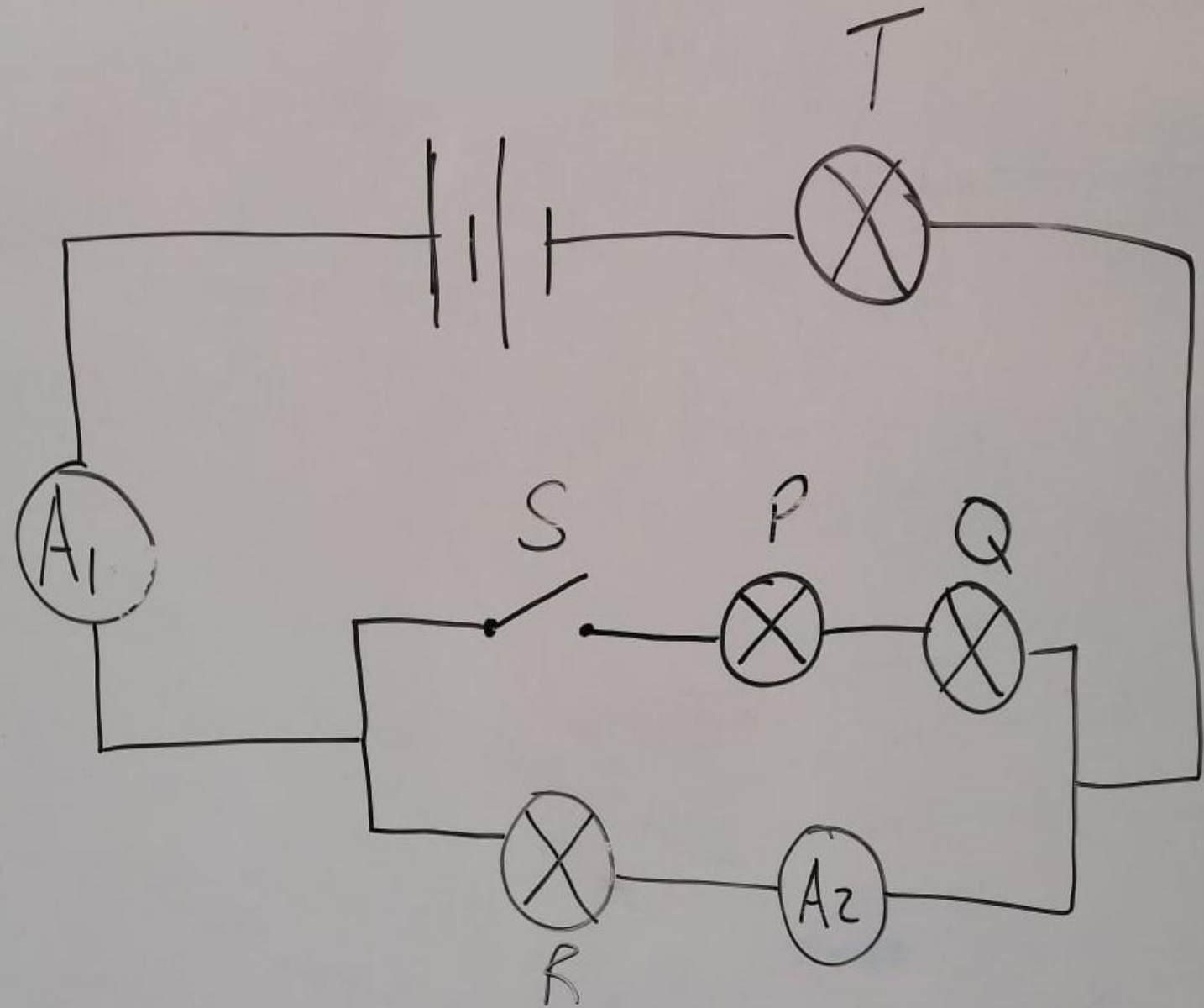
Example

Each lightbulb has a resistance of 8Ω . The parallel voltage is 15 V .

1. If switch S is closed, calculate:
 - 1.1 the readings on A_1 and A_2
 - 1.2 the power of each lightbulb.

2. If switch S is open the total voltage is 25V , calculate:

- 2.1 the readings on A_1 and A_2
- 2.2 The power of each lightbulb



Cost of electricity

- First calculate the transfer of energy (power)
- $P = V \times I$
- Convert power in watt to kilowatt (1000 W = 1kW)
- Multiply the power in kW with the amount of time it is in use (hour)
- Multiply with the cost per kWh.
- Cost of energy = kW x h x cost

Example

- Electricity is sold at 75c per kWh.
- A geyser is switched on for 6 hours and has a power of 2500W.
- Calculate the cost of energy, in R, of the geyser for that time period.

Example

- Stove plate – 2000 W.
- Frying pan – 4500 W.
- Cost per kWh 93c.
- Which appliance will be cheaper to cook the following:
- A lekker juicy steak, 40 min on stove or 25 min in frying pan.

Answer in Rand

Internal Resistance

- A battery converts chemical energy into electrical energy.
- Electrical energy is then converted by the external resistors into heat or light energy.
- The EMF of the battery is the TOTAL energy that is supplied to the circuit.
- The battery uses some of the EMF (internal Voltage) and the rest of the voltage is supplied to the external circuit.

Internal resistance

- $\mathcal{E} = V_T$
- $V_T = V_E + V_I$
- $V_E = V_S + V_P$
- $R_T = R_E + r$
- $R_E = R_S + R_P$
- $I_T = V_T / R_T$
- $I_E = V_E / R_E$
- $I_I = V_I / R_I$

Given formula:

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

EMF

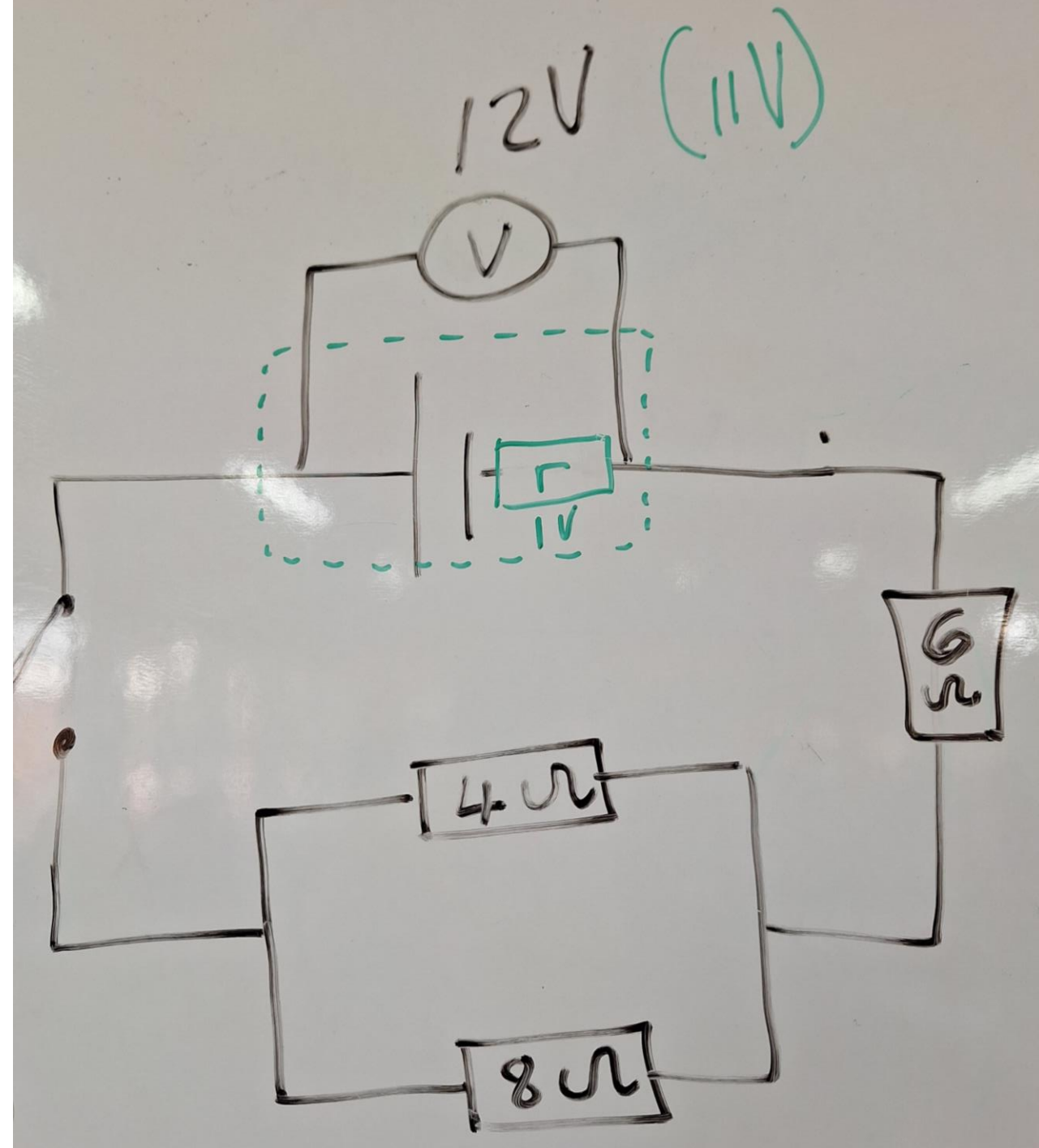
I_T

R_E

Internal resistance

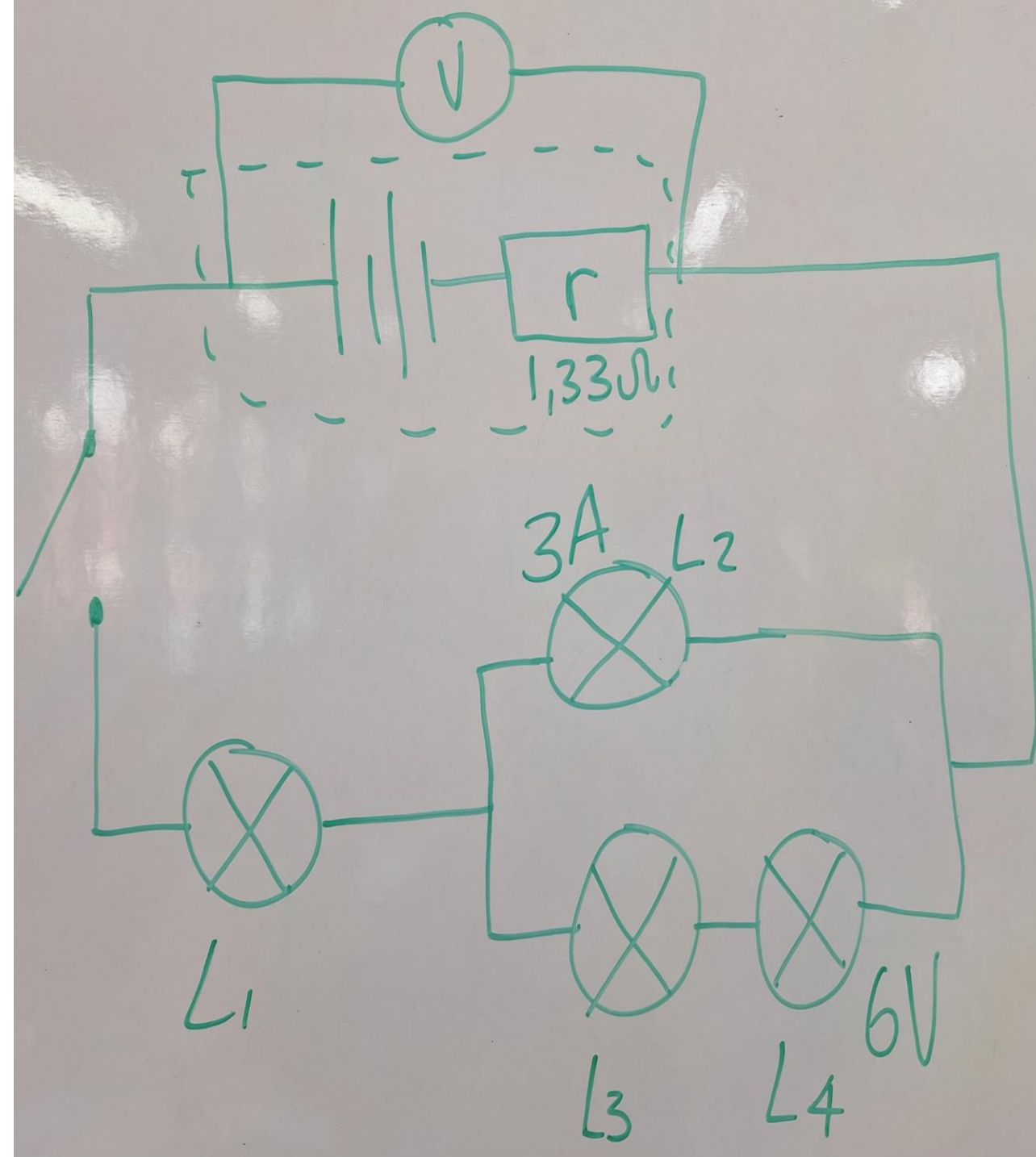
Example

1. When the switch is open the voltmeter has a reading of 12V. Calculate the maximum current the battery can produce.
2. When the switch is closed, the voltmeter has a reading of 11V. Calculate the actual current produced.
3. Calculate the internal resistance.



Lightbulbs L1, L2, L3 and L4 have the same resistance. When the switch is closed, L4 has a voltmeter reading of 6V and L2 has a current of 3A flowing through it.

1. Calculate the resistance of L4.
2. Calculate the EMF of the battery.

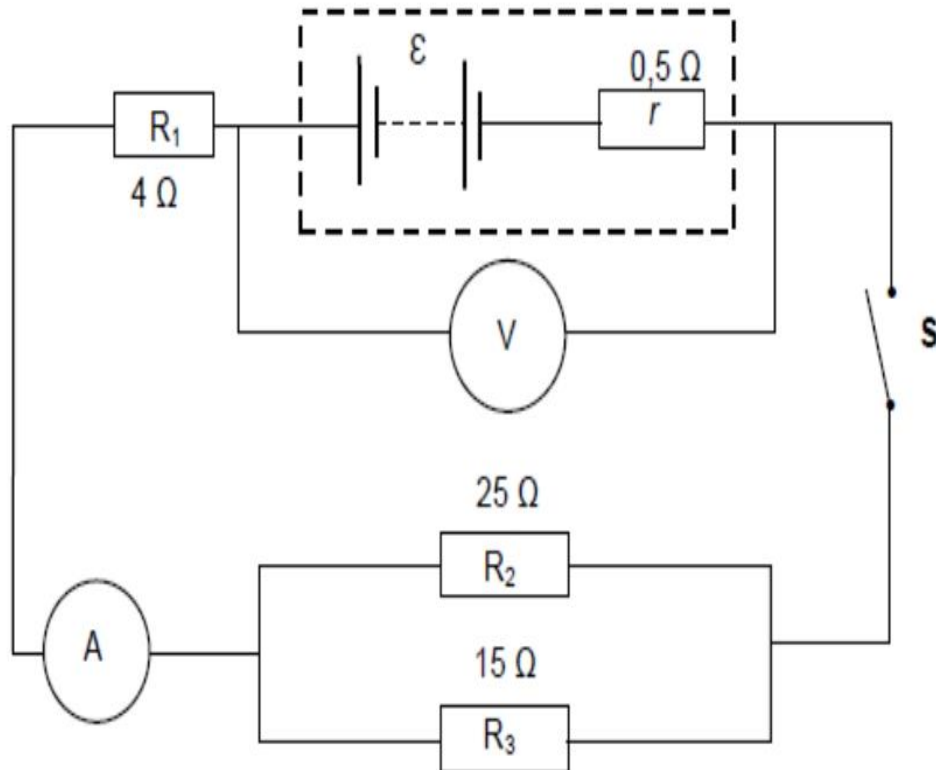


Extra Questions

QUESTION 8 (Start on a new page.)

A battery with an internal resistance of $0,5\ \Omega$ and an unknown emf (ϵ) is connected to three resistors, a high resistance voltmeter and an ammeter of negligible resistance, as shown in the circuit diagram below.

The resistance of the connecting wires must be ignored.



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

The reading on the voltmeter DECREASES by $1,5\ \text{V}$ when switch **S** is closed.

8.2 Give a reason why the voltmeter reading decreases. (2)

8.3 Calculate the following when switch **S** is closed:

8.3.1 Reading on the ammeter (3)

8.3.2 Total external resistance of the circuit (4)

8.3.3 Emf of the battery (3)

8.4 A learner makes the following statement:

The current through resistor R_3 is larger than the current through resistor R_2 .

Is this statement CORRECT? Choose from YES or NO. Explain the answer. (3)

8.5 The $4\ \Omega$ resistor is now removed from the circuit.

How will this affect the emf of the battery? Choose from INCREASES, DECREASES or REMAINS THE SAME. (1)

[18]

1. Total amount of Energy supplied per coulomb charge in a cell.

2. The battery converts chemical Energy into electrical energy, but the battery heats up and loses energy in the form of Heat.

3.1 $I_I = I_T = A.$

$$\begin{aligned} I_I &= V_I \div R_I \\ &= 1,5 \div 0,5 \\ &= 3A. \end{aligned}$$

3.2 $R_E = R_p + R_s$

$$\begin{aligned} 1/R_p &= 1/R_1 + 1/R_2 \\ &= 1/25 + 1/15 \end{aligned}$$

$$R_p = 9,38 \Omega$$

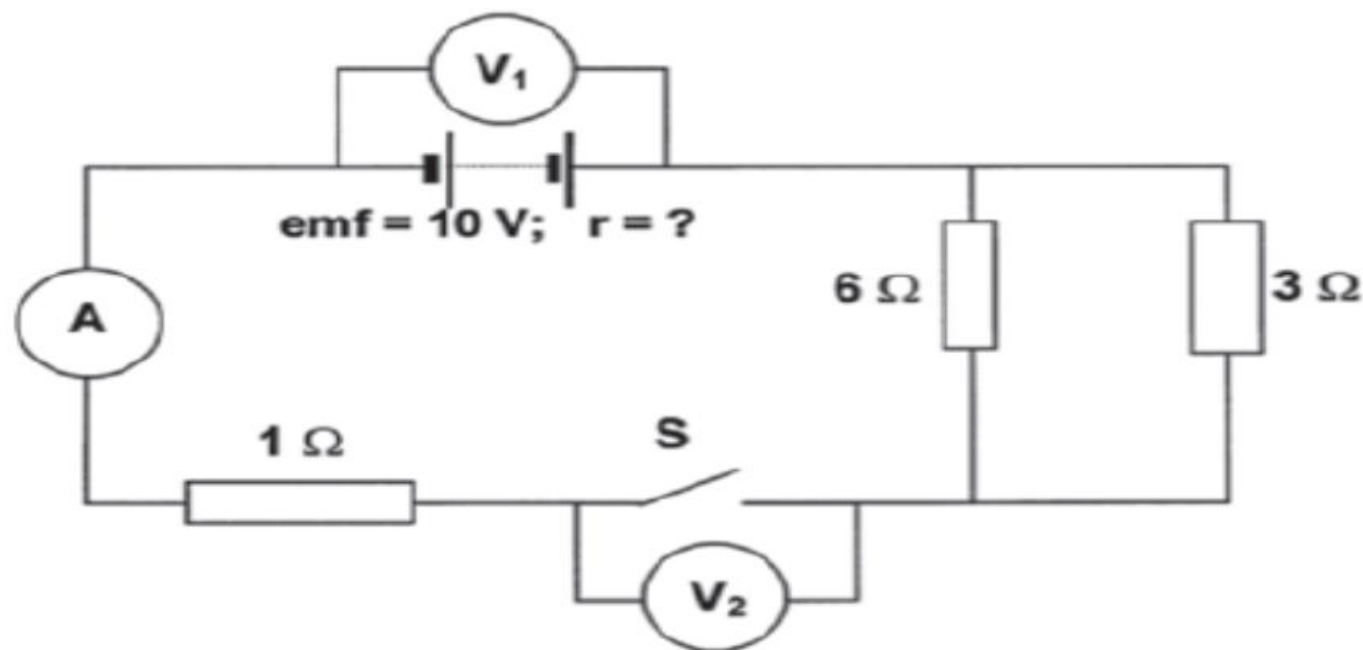
$$\begin{aligned} R_E &= 9,38 + 4 \\ &= 13,38 \Omega. \end{aligned}$$

3.3
$$\begin{aligned} \mathcal{E} &= I_T (R + r) \\ &= 3 (13,38 + 0,5) \\ &= 41,64 V. \end{aligned}$$

4. Yes, voltage is the same in parallel, therefore more current will flow in a pathway of smaller resistance.

5. Remains the same (EMF of Battery cannot change)
(NE can.)

In the circuit represented below, the battery has an emf of 10 V and an unknown internal resistance. Voltmeter V_1 is connected across the battery and voltmeter V_2 is connected across the open switch S . The resistance of the connecting wires and ammeter can be ignored.



Switch S is open

1. What is the reading on V_1 ? (2)
2. What is the reading on V_2 ? (2)

When Switch S is closed, the reading on V_1 drops to 7,5 V.

3. What is the reading on V_2 ? (2)
4. Calculate the reading on the ammeter. (8)
5. Calculate the internal resistance of the battery. (5)

[19]

1. $10V$

2. $0V$

3. $0V$

4. $V_T = 10V$

$$V_T = V_E + V_I$$

$$10 = 7,5 + V_I$$

$$2,5V = V_I$$

$$I_E = V_E \div R_E$$

$$= 7,5 \div 3$$

$$= 2,5A$$

$$R_E = R_S + R_P$$

$$= 1 + \left(\frac{1}{6} + \frac{1}{3}\right)$$

$$= 1 + 2$$

$$= 3\Omega$$

5. $r = V_I \div I_I$

$$= 2,5 \div 3$$

$$= 0,83\Omega$$

$$E = I_r (R + r)$$

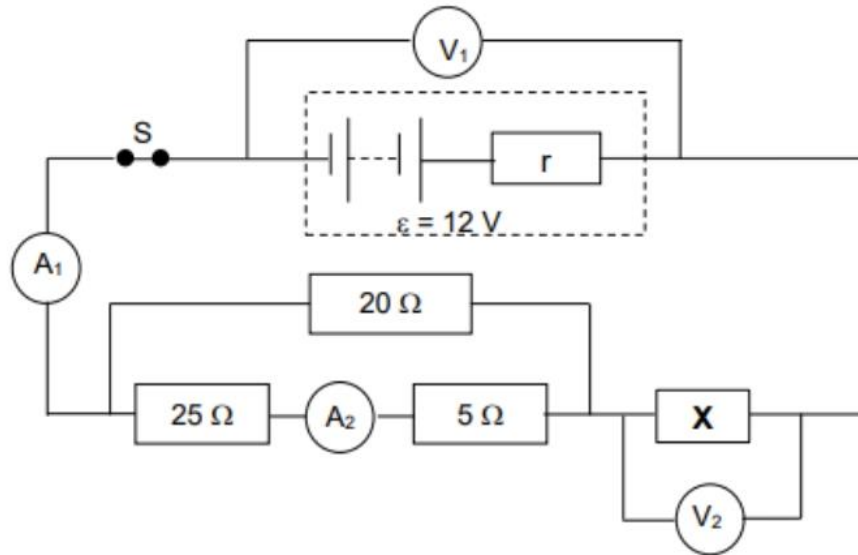
$$10 = 2,5(3 + r)$$

$$4 = 3 + r$$

$$1\Omega = r$$

QUESTION 8 (Start on a new page.)

The diagram below shows a circuit with a battery of emf 12 V and internal resistance r . The battery is connected to resistors of $25\ \Omega$, $20\ \Omega$, $5\ \Omega$ and resistor X of unknown resistance. The ammeters, switch and the conducting wires have negligible resistance, while the voltmeters have very high resistance.



8.1 Explain what is meant by an emf of 12 V. (2)

When switch S is closed, the reading on ammeter A_2 is 0,2 A and the reading on voltmeter V_2 is 5,5 V.

8.2 Calculate the:

8.2.1 Reading on ammeter A_1 (3)

8.2.2 Resistance of resistor X (3)

8.2.3 Total external resistance of the circuit (3)

8.2.4 Internal resistance (r) of the battery (3)

8.3 Resistor X is replaced by another ammeter.

Will the reading on voltmeter V_1 INCREASE, DECREASE or REMAIN THE SAME? Explain the answer.

(4)

[18]

$$\begin{aligned} 1. \quad I_2 &= V_2 \div R_{4\Omega} \\ &= 4 \div 4 \\ &= 1 \text{ A.} \end{aligned}$$

$$2. \quad A_1 = I_E = I_P.$$

$$\begin{aligned} V_P &= 8 \text{ V} \quad \therefore I_{16\Omega} = V_P \div R_{16\Omega} \\ &= 8 \div 16 \\ &= 0,5 \text{ A.} \end{aligned}$$

$$1 + 0,5 = 1,5 \text{ A}$$

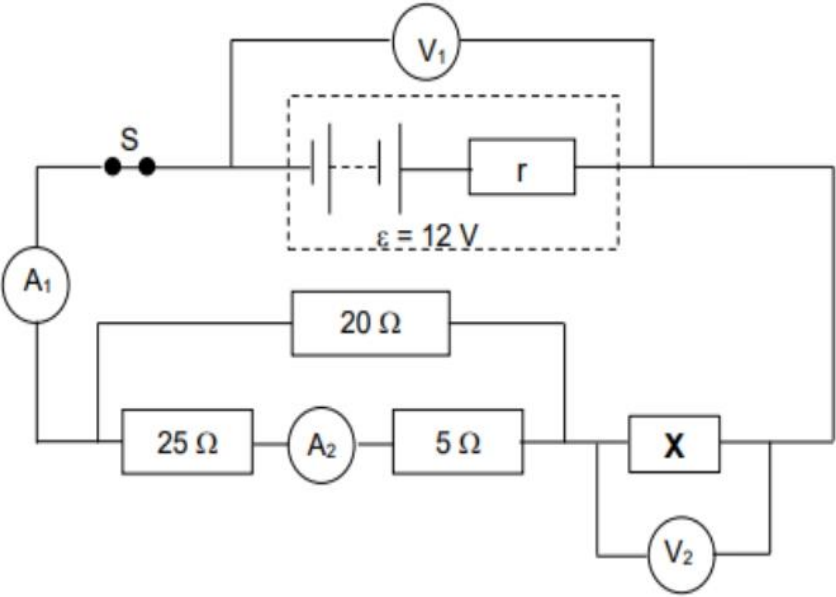
$$\begin{aligned} 3. \quad V_E &= \cancel{20} V_S + V_P & \therefore R_R &= V_R \div I_T \\ 20 &= V_S + \cancel{8} & &= 12 \div 1,5 \\ 12 \text{ V} &= V_S & &= 8 \Omega. \end{aligned}$$

$$\begin{aligned} 4. \quad r &= V_E \div I_E \\ &= 4 \div 1,5 \\ &= 2,67 \Omega. \end{aligned}$$

5. V_I Reads External voltage. When switch is open, circuit becomes Series. Resistance increase, therefore current will decrease. V_I will decrease, but V_E will increase to ensure EMF stay the same.

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8.2.4 Internal resistance (r) of the battery (3)

8.3 Resistor X is replaced by another ammeter.

Will the reading on voltmeter V_1 INCREASE, DECREASE or REMAIN THE SAME? Explain the answer. (4)

1. Total energy supplied by battery per coulomb charge in a cell.

$$2.1 \quad A_1 = I_E = I_p.$$

$$\begin{aligned} A_2: I_2 &= V_p \div R_{A_2} \\ 0,2 &= V_p \div 30. \\ 0,2 \times 30 &= V_p \\ 6V &= V_p. \end{aligned}$$

$$\begin{aligned} \text{Part 6} \quad I_{20\Omega} &= V_p \div R_{20\Omega} \\ &= 6 \div 20 \\ &= 0,3A. \end{aligned}$$

$$\begin{aligned} I_p &= I_1 + I_2 \\ &= 0,2 + 0,3 \\ &= 0,5A. \end{aligned}$$

$$\begin{aligned} \text{Q. 2.2) } R_x &= V_s \div I_s \\ &= 5,5 \div 0,5 \\ &= 11 \Omega. \end{aligned}$$

$$\begin{aligned} 2.3 \quad \frac{1}{R_p} &= \frac{1}{R_1} + \frac{1}{R_2} \\ &= \frac{1}{20} + \frac{1}{30} \\ &= \frac{1}{12} \Omega \end{aligned}$$

$$\begin{aligned} R_E &= R_p + R_s \\ &= 11 + 12 \\ &= 23 \Omega. \end{aligned}$$

$$\begin{aligned} 2.4 \quad \mathcal{E} &= I_T (R + r) \\ 12 &= 0,5 (23 + r) \\ 24 - 23 &= r \\ 1 \Omega &= r. \end{aligned}$$

3. V_E will $= V_i$ V_E will $\downarrow$, because Resistance (external) decrease, current will increase. For EMF to remain constant V_E must decrease. $\rightarrow V_E \uparrow$