1

Electrical Circuits – B McMULLEN

1) Cell
2) Battery
3) Lamp
4) Resistor
5) Variable Resistor
6) Diode
7) LED (Light emitting diode)
8) Photodiode
9) Capacitor
10) Fuse
11) Ammeter
12) Voltmeter
13) Ohmmeter
14) Electric Motor
15) DC Supply
16) AC Supply
17) LDR (Light dependant resistor)
18) Thermistor
19) Switch
20) Wire
21) Buzzer
22) npn transistor

Resistors

These are components which oppose the flow of current in an electrical circuit.

ie Resistance ↓ ∴ Current ↑ and

Resistance ↑ ∴ Current ↓

This can be described using the defence of a football team.

If a team has a good defence then they will not concede many goals

ie Resistance ↑ ∴ Current ↓

If a team has a very poor defence then they concede a lot of goals.

ie Resistance ↓ ∴ Current ↑

(Current is related to the number of goals scored here!!)

Resistance Networks.

Resistance is measured in the unit Ohms (Ω).

Resistors can be connected in:

- Series
- Parallel
- Combination of series and parallel.

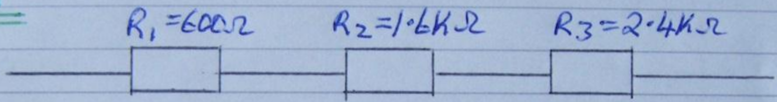
- <u>Resistors in series</u>

The resistors are connected in line with one another. This allows only one path for the current to take.

$$* \quad \boxed{R_S = R_1 + R_2 + R_3 + \ldots\ldots} \quad *$$

As more resistors are added in series the <u>total resistance in series</u> increases.

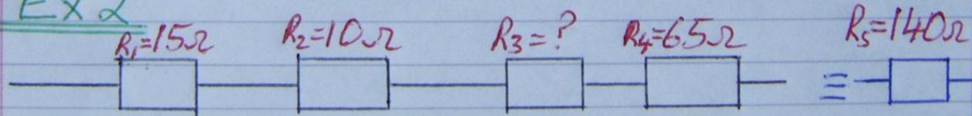
<u>Ex 1</u>



$$R_S = R_1 + R_2 + R_3 = 600 + 1600 + 2400$$

$\Rightarrow \underline{R_S = 4600\Omega}$ (All resistors are converted to Ω or $K\Omega$)

<u>Ex 2</u>



$$R_S = R_1 + R_2 + R_3 + R_4$$

$$\Rightarrow 140 = 15 + 10 + R_3 + 65$$

$$\Rightarrow 140 = 90 + R_3$$

$$\Rightarrow R_3 = 140 - 90 = \underline{50\Omega}$$

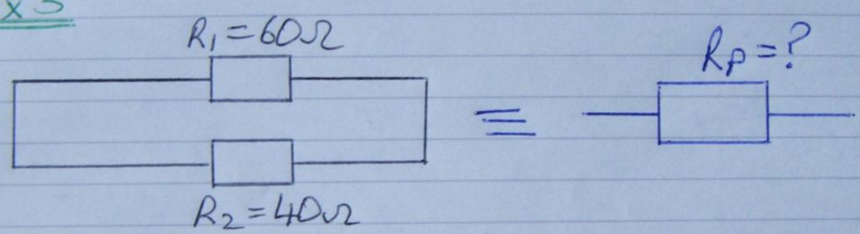
- Resistors in parallel

The resistors are connected across one another. This allows more than one path for the current to take.

$$\boxed{\frac{1}{R_P} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \ldots}$$

As more resistors are added in parallel then the total resistance in parallel decreases.

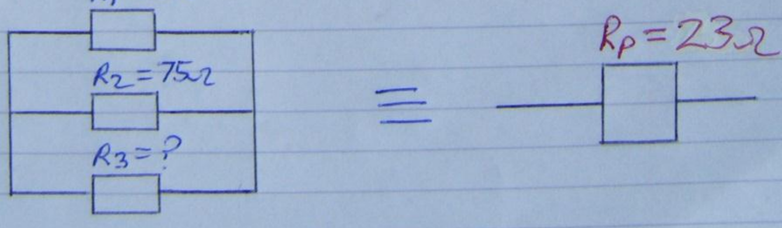
Ex 3



$$\frac{1}{R_P} = \frac{1}{R_1} + \frac{1}{R_2} \Rightarrow \frac{1}{R_P} = \frac{1}{60} + \frac{1}{40} = 60^{-1} + 40^{-1}$$

$$\Rightarrow \frac{1}{R_P} = \frac{1}{24} \Rightarrow \frac{R_P}{1} = \frac{24}{1} \Rightarrow R_P = 24\Omega$$

Ex 4



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

$$\Rightarrow \frac{1}{23} = \frac{1}{50} + \frac{1}{75} + \frac{1}{R_3} \Rightarrow \frac{1}{R_3} = \frac{1}{23} - \frac{1}{50} - \frac{1}{75}$$

$$\Rightarrow \frac{1}{R_3} = 23^{-1} - 50^{-1} - 75^{-1} = \frac{7}{690}$$

$$\Rightarrow \frac{R_3}{1} = \frac{690}{7} \Rightarrow \underline{\underline{R_3 = 98.6\,\Omega}}$$

* The total resistance in a parallel resistance network is smaller than the lowest resistance in parallel.

∴ Before attempting Ex3 which had a $60\,\Omega$ and $40\,\Omega$ resistors in parallel, we could conclude that the total resistance in parallel would be less than $40\,\Omega$. *

• Combination of Series + Parallel Resistors

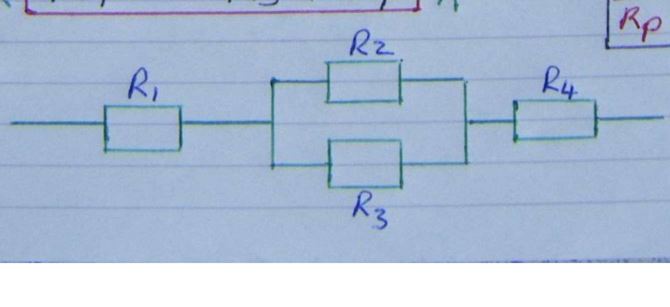
The total resistance in a network which involves resistors in series and parallel connected together would be:

$$\boxed{R_S = R_1 + R_4}$$

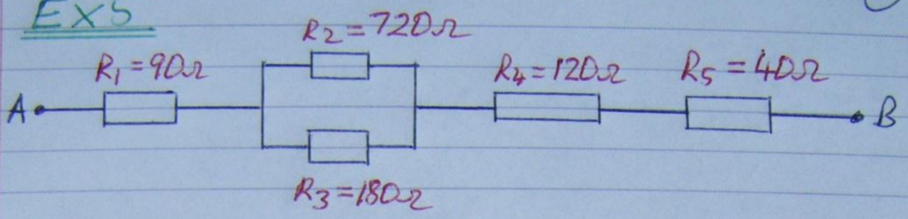
$$\boxed{\frac{1}{R_p} = \frac{1}{R_2} + \frac{1}{R_3}}$$

$$* \boxed{R_T = R_S + R_p} *$$

ie



Ex5



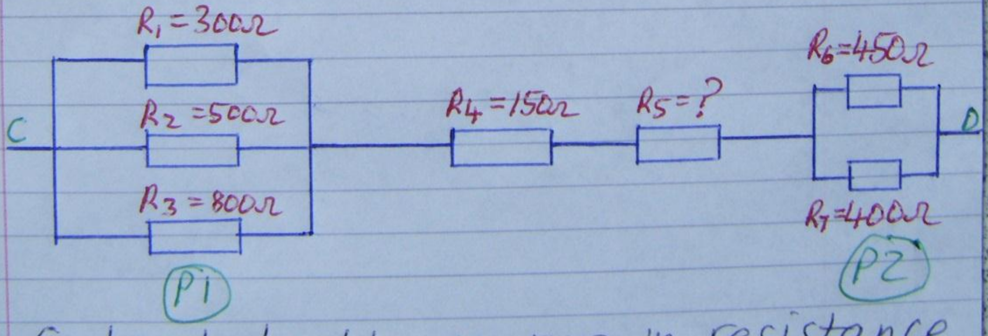
Calculate the total resistance between A and B.

- $R_S = R_1 + R_4 + R_5 = 90 + 120 + 40 = \underline{\underline{250\Omega}}$
- $\frac{1}{R_P} = \frac{1}{R_2} + \frac{1}{R_3} = \frac{1}{720} + \frac{1}{180} = 720^{-1} + 180^{-1}$

$\Rightarrow \frac{1}{R_P} = \frac{1}{144} \Rightarrow \frac{R_P}{1} = \frac{144}{1} \Rightarrow \underline{\underline{R_p = 144\Omega}}$

- $R_T = R_S + R_P = 250 + 144 = \underline{\underline{394\Omega}}$

Ex6



Calculate the unknown resistance R_5 if the total resistance in the network $R_T = 600\Omega$ between C and D.

• $R_S = R_4 + R_5 = \underline{\underline{(150 + R_5)\,\Omega}}$

• P1 $\dfrac{1}{R_P} = \dfrac{1}{R_1} + \dfrac{1}{R_2} + \dfrac{1}{R_3} = \dfrac{1}{300} + \dfrac{1}{500} + \dfrac{1}{800}$

$\Rightarrow \dfrac{1}{R_P} = 300^{-1} + 500^{-1} + 800^{-1} = \dfrac{79}{12000}$

$\Rightarrow \dfrac{R_P}{1} = \dfrac{12000}{79} \quad \Rightarrow \underline{\underline{R_P = 152\,\Omega}}$

• P2 $\dfrac{1}{R_P} = \dfrac{1}{R_1} + \dfrac{1}{R_2} = \dfrac{1}{450} + \dfrac{1}{400}$

$\Rightarrow \dfrac{1}{R_P} = 450^{-1} + 400^{-1} = \dfrac{17}{3600}$

$\Rightarrow \dfrac{R_P}{1} = \dfrac{3600}{17} \Rightarrow \underline{\underline{R_P = 212\,\Omega}}$

• $R_T = R_S + R_P = R_S +$ P1 $+$ P2

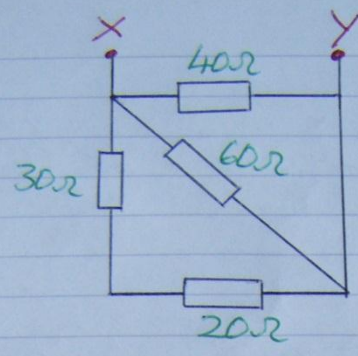
$\Rightarrow 600 = (150 + R_5) + 152 + 212$

$\Rightarrow 600 = 514 + R_5$

$\Rightarrow R_5 = 600 - 514 = 86$

$\Rightarrow \underline{\underline{R_5 = 86\,\Omega}}$

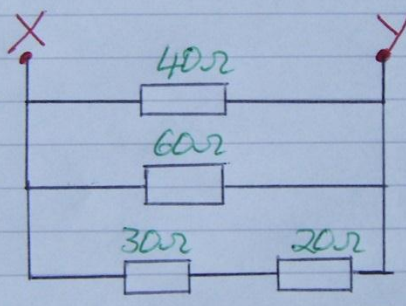
Ex7



Calculate the resistance between X and Y in the network.

• Redraw the diagram to make it easier to read. (Think of the possible paths that the current needs to take to go from X to Y.

≡



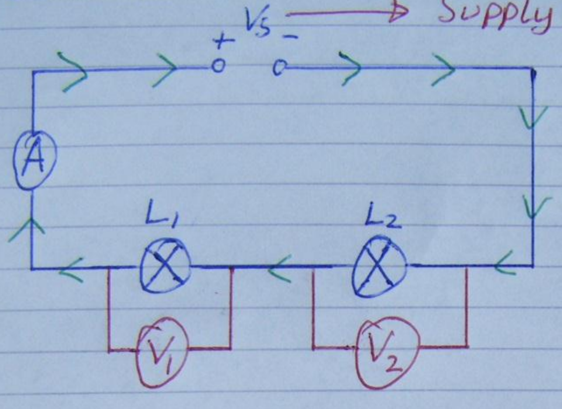
As the 30Ω and 20Ω resistors are in series with each other then this would add up to 50Ω in the third branch in parallel.

$$\frac{1}{R_p} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} = \frac{1}{40} + \frac{1}{60} + \frac{1}{50}$$

$$\Rightarrow \frac{1}{R_p} = 40^{-1} + 60^{-1} + 50^{-1} = \frac{37}{600}$$

$$\Rightarrow \frac{R_p}{1} = \frac{600}{37} \quad \Rightarrow \underline{\underline{R_p = R_{xy} = 16.2\,\Omega}}$$

Series Circuits



—(A)— ⇒ Ammeter
⇓
measures the current in a circuit in Amperes

—(V)— ⇒ Voltmeter
⇓
measures the voltage across a component in Volts.

- Ammeters are connected in a circuit in series.
- Voltmeters are connected in a circuit in parallel.

* Current passes through components in a circuit.

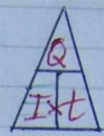
Voltage is dropped across components in a circuit. *

- In a series circuit the current is the same at any point in the circuit
- In a series circuit the supply voltage is split up between the components in the circuit. $\boxed{V_s = V_1 + V_2 + \ldots}$

* Definition of Current

The current is the number of coulombs of charge that passes a point per second.

$$\boxed{Q = It} \rightarrow \text{time (seconds)}$$



Q: Charge (Coulombs)
I: Current (Amperes)

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

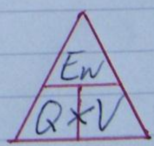
Q → Coulombs of charge
t → time in seconds

I: Current ⇒ Easiest way to remember the definition is from the equation!!

* Definition of Voltage (Potential Difference)

The Voltage (or potential difference) is the energy given to each coulomb of charge.

$$\boxed{E_W = QV} \rightarrow \text{Voltage (volts)}$$



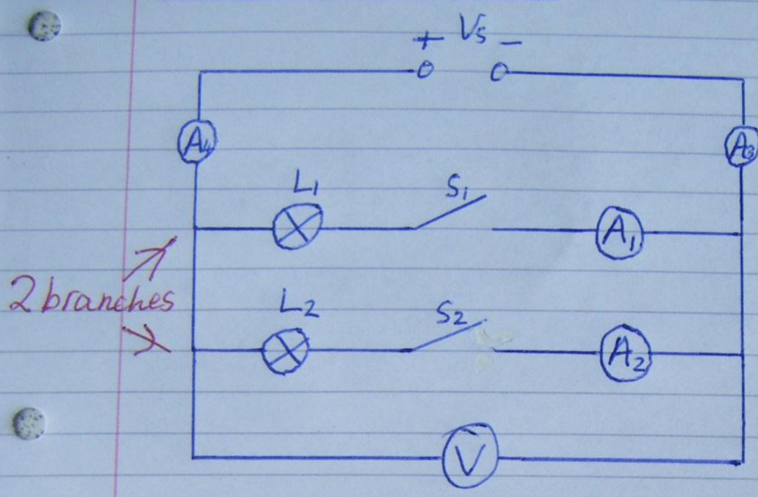
E_W: Work Done (Joules)
Q: Charge (Coulombs)

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

E_W → Electrical Work done in Joules
Q → Coulombs of charge

V: Voltage ⇒ Again the easiest way to remember the definition is through the equation!!

Parallel Circuits



If each of the switches are closed then:

- Current splits up in a parallel circuit between its branches.

ie A_3 or A_4 = $A_1 + A_2$

- Voltage dropped across each branch in a parallel circuit is the same.
- In a purely parallel circuit the voltage dropped across each component is the same as the supply voltage.

Ohms Law

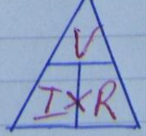
This links Voltage, Current and Resistance.

$$\boxed{V = I \times R}$$

V → Voltage (V)

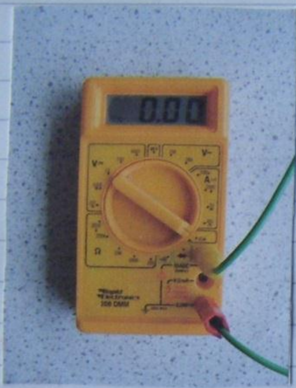
I → Current (A)

R → Resistance (Ω).



1. $V = IR$
2. $I = \frac{V}{R}$
3. $R = \frac{V}{I}$.

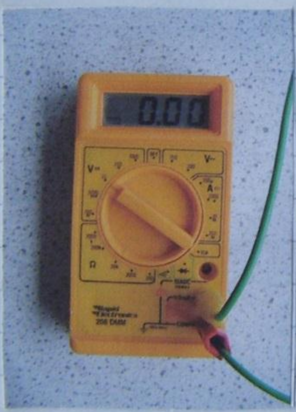
Using a multimeter to measure Current, Voltage and Resistance



DC CURRENT

TERMINALS
- COM
- 10A DC

RANGE SCALE
- 10A ===



DC VOLTAGE

TERMINALS
- COM
- VΩ mA

RANGE SCALE
- 20V ===

RESISTANCE

TERMINALS
- COM
- VΩ mA

RANGE SCALE
- 200Ω (OR HIGHER!!)

Voltage Dividers

In a series circuit we talked about the current being the same at any point in the circuit.

From Ohms Law $I = \frac{V}{R}$ then

$$I = \frac{V_1}{R_1} \quad \text{or} \quad I = \frac{V_2}{R_2}$$

ie The ratio of Voltage drop to resistance will be the same across any component.

$$\therefore \quad \boxed{\frac{V_1}{R_1} = \frac{V_2}{R_2}}$$

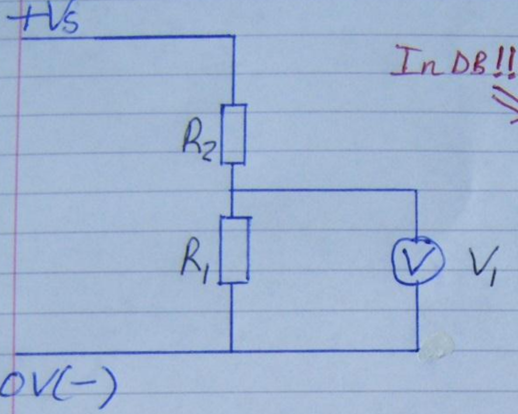
Compare Mr McMullen to a first year boy.
Mr McMullen is much bigger and uglier than the first year boy.
Mr McMullen will also eat far more than the first year boy.

Conclusion

- Resistance is linked with the size of the person
- Voltage is linked with how much food they eat.

This is discussed very loosely but I hope that it gets the point across.

Voltage Divider Circuits



Bear Equation

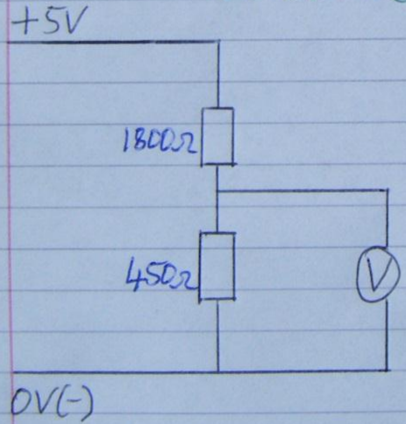
In DB!!!

$$\boxed{V_1 = \left(\frac{R_1}{R_1 + R_2}\right) \times V_s}$$

Also

$$\boxed{V_2 = \left(\frac{R_2}{R_1 + R_2}\right) \times V_s}$$

Ex8 Calculate the reading on the voltmeter –(V)–.



$$V_1 = \left(\frac{R_1}{R_1 + R_2}\right) \times V_s$$

$$\Rightarrow V_1 = \left(\frac{450}{450 + 1800}\right) \times 5V$$

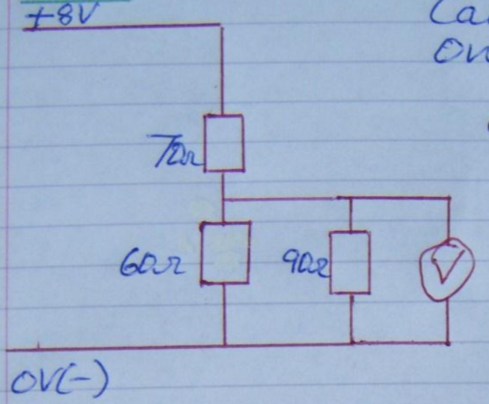
$$\Rightarrow V_1 = \frac{450}{2250} \times 5V$$

$$\Rightarrow V_1 = \frac{1}{5} \times 5V = \underline{\underline{1V}}$$

* ($\therefore V_{1800\Omega} = 5V - 1V = 4V$) *

* The resistance on the numerator of the 'Bear Equation' is the resistor that you are calculating the voltage dropped across it. *

Ex9

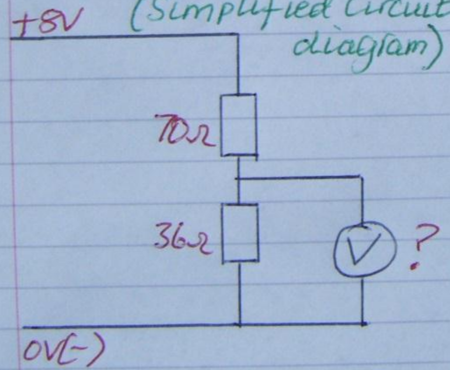


Calculate the reading on the voltmeter (V).

- Calculate the total resistance in parallel
- Then apply the 'Bear Equation'.

- $\frac{1}{R_p} = \frac{1}{R_1} + \frac{1}{R_2} = \frac{1}{60} + \frac{1}{90} = 60^{-1} + 90^{-1}$

$\Rightarrow \frac{1}{R_p} = \frac{1}{36} \Rightarrow \frac{R_p}{1} = \frac{36}{1} \Rightarrow R_p = 36\Omega$



(Simplified circuit diagram)

- 'Bear Equation'

$V_1 = \left(\frac{R_1}{R_1 + R_2}\right) \times V_S$

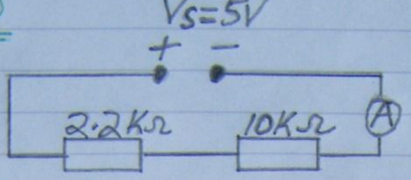
$\Rightarrow V_1 = \left(\frac{36}{36+70}\right) \times 8V$

$\Rightarrow V_1 = \frac{36}{106} \times 8V = 2.72V$

(The voltage across the 70Ω resistor would be $8V - 2.72V = 5.28V$)

CIRCUIT NETWORK PROBLEMS

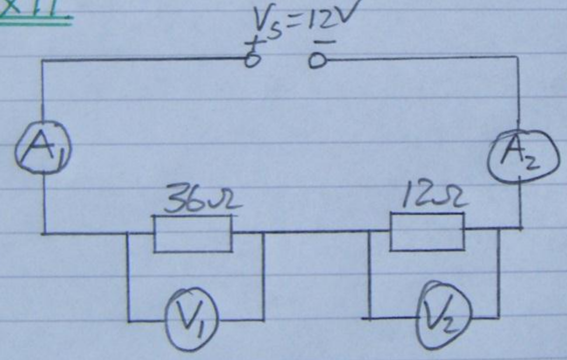
Ex10



Calculate the reading on the ammeter —Ⓐ— in mA.

- $R_S = R_1 + R_2 = 2200 + 10{,}000 = 12{,}200\,\Omega$
- $V = IR \Rightarrow I = \frac{V}{R} = \frac{5}{12200} = \underline{\underline{4{\cdot}1 \times 10^{-4} A}}$
- $4{\cdot}1 \times 10^{-4} A = 0{\cdot}41 \times 10^{-3} A = \underline{\underline{0{\cdot}41 mA}}$

Ex11



Calculate or find:

a) Readings on
  i) —A_1—
  ii) —A_2—

b) Readings on
  i) —V_1—
  ii) —V_2—

a) $R_S = R_1 + R_2 = 36 + 12 = \underline{\underline{48\,\Omega}}$

i) + ii) $I = \frac{V}{R} = \frac{12}{48} = \underline{\underline{0{\cdot}25 A}}$

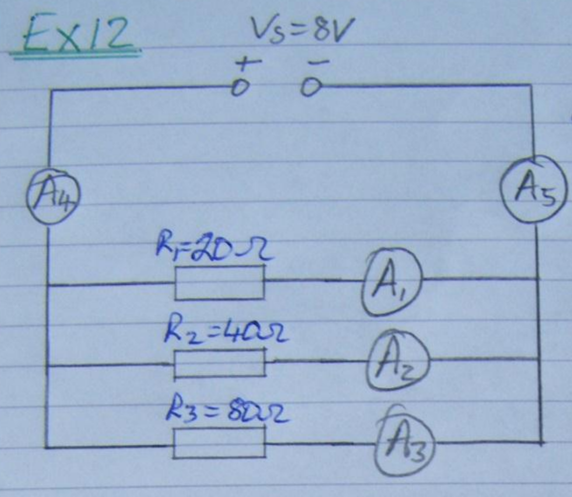
Series circuit ∴ Current is the same!!

b) i) $V_1 = IR_1 = 0{\cdot}25 \times 36 = \underline{\underline{9V}}$

ii) $V_2 = IR_2 = 0{\cdot}25 \times 12 = \underline{\underline{3V}}$ ✓

(Check $V_S = V_1 + V_2 \Rightarrow 12V = 9V + 3V$)

Ex12



Calculate or find:

a) Total resistance

b) Readings on

1) —(A4)— 11) —(A5)—

c) Readings on

1) —(A1)—

11) —(A2)—

111) —(A3)—

A

a) $\frac{1}{R_p} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} = \frac{1}{20} + \frac{1}{40} + \frac{1}{80}$

$\Rightarrow \frac{1}{R_p} = 20^{-1} + 40^{-1} + 80^{-1} \Rightarrow \frac{1}{R_p} = \frac{7}{80}$

$\Rightarrow \frac{R_p}{1} = \frac{80}{7} \Rightarrow R_p = 11.4\Omega$

b) —(A4)— and —(A5)— will be the same.

$I = \frac{V}{R} = \frac{8}{11.4} = 0.70A$

c) 1) $I_1 = \frac{V}{R_1} = \frac{8}{20} = 0.40A$

11) $I_2 = \frac{V}{R_2} = \frac{8}{40} = 0.20A$

111) $I_3 = \frac{V}{R_3} = \frac{8}{80} = 0.10A$

Check!!

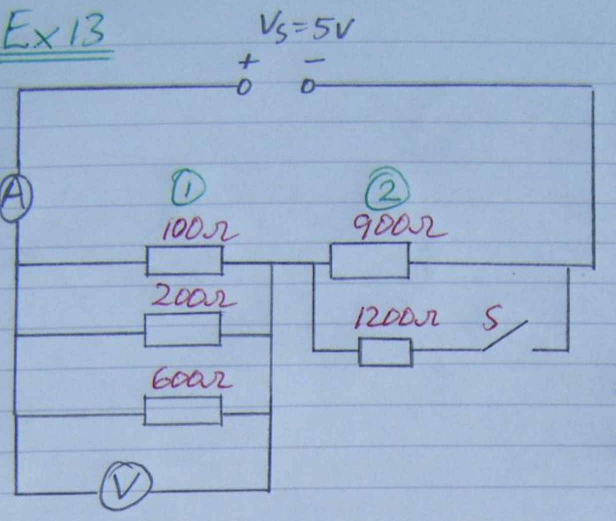
$I_T = I_1 + I_2 + I_3$

$\Rightarrow 0.70 = 0.40 + 0.20 + 0.10$

✓

Check!!

Ex 13



Calculate or find: The reading on

1) —Ⓐ—
11) —Ⓥ—

when

a) switch S is open
b) switch S is closed.

A// a) When S is open.

1) $\frac{1}{R_P} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} = \frac{1}{100} + \frac{1}{200} + \frac{1}{600}$

$\Rightarrow \frac{1}{R_P} = 100^{-1} + 200^{-1} + 600^{-1} = \frac{1}{60} \Rightarrow \frac{R_P}{1} = \frac{60}{1}$

$\Rightarrow R_P = 60\Omega$

$R_S = 900\Omega \quad \therefore R_T = R_S + R_P = 900 + 60 = 960\Omega$

$I = \frac{V_S}{R_T} = \frac{5}{960} = 5.21 \times 10^{-3} A$

11) $V = IR = 5.21 \times 10^{-3} \times 60 = 0.31V$

The voltmeter is placed across the parallel combination ≡ 60Ω in series.

b) When S is closed

1) • The 900Ω and 1200Ω resistors are now connected in parallel.

$$\frac{1}{R_P} = \frac{1}{R_1} + \frac{1}{R_2} = \frac{1}{900} + \frac{1}{1200} = 900^{-1} + 1200^{-1}$$

$$\Rightarrow \frac{1}{R_p} = \frac{7}{3600} \Rightarrow \frac{R_P}{1} = \frac{3600}{7} \Rightarrow R_P = 514\Omega$$

$$R_T = R_P① + R_P② = 60 + 514 = 574\Omega$$

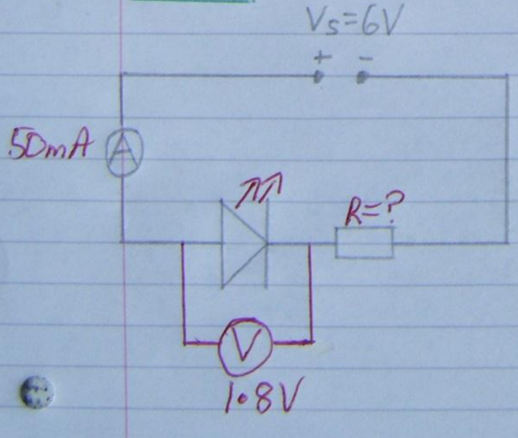
$$I = \frac{V_S}{R_T} = \frac{5}{574} = 8.71 \times 10^{-3} A$$

11) $V = IR = 8.71 \times 10^{-3} \times 60 = 0.52V$

Again the voltmeter is placed across the 100Ω, 200Ω and 600Ω parallel combination

$\equiv$ 60Ω in series.

Ex14



Calculate the unknown Resistance R.

• $V_R = 6V - 1.8V = 4.2V$

• $R = \frac{V_R}{I} = \frac{4.2}{50 \times 10^{-3}} = 84\Omega$

Electrical Power

Power is defined as the energy transformed per second.

$$\boxed{P = \frac{E}{t}}$$

Energy (Joules)

time (seconds)

Power (Watts)

$\boxed{1 \text{ Watt} = 1 \text{ Joule per second}}$

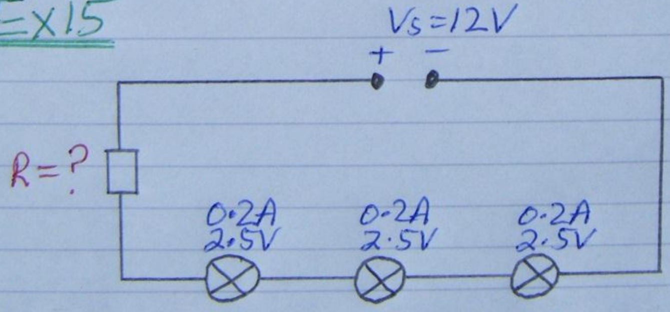
$* \; 1W = 1Js^{-1} \; *$

Electrical Energy Equations.

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

$V \rightarrow$ Voltage
$I \rightarrow$ Current
$R \rightarrow$ Resistance
$P \rightarrow$ Power.

Ex15



Calculate or find:

a) Power of the lamps

b) The unknown Resistance R.

a) $P=IV \Rightarrow P=0{\cdot}2 \times 2{\cdot}5$
$\Rightarrow P = 0{\cdot}5\,W$

b) $R = \frac{V_R}{I} = \frac{12-7{\cdot}5}{0{\cdot}2} = 22{\cdot}5\,\Omega$