CIRCUITS

VOLTAGE AND CURRENT

- VOLTAGE (POTENTIAL DIFFERENCE) IS THE CHANGE IN POTENTIAL ENERGY PER UNIT CHARGE.
- CURRENT IS THE RATE OF FLOW OF CHARGE THROUGH THE CROSS-SECTIONAL AREA OF A CONDUCTOR.

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

I: CURRENT (A)
Q: CHARGE (C)
t: TIME (s)

RESISTANCE AND OHM'S LAW

- OHM'S LAW: THE RATIO BETWEEN THE VOLTAGE AND THE CURRENT THROUGH A CONDUCTOR (LOAD, RESISTOR) IS A CONSTANT AND REPRESENTS THE RESISTANCE.

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

V: VOLTAGE (V)
I: CURRENT (A)
R: RESISTANCE (Ω) ← OHM

EXAMPLE

THE POTENTIAL DIFFERENCE ACROSS A $5.0\,\Omega$ RESISTOR IS 1.5 V. DETERMINE THE CURRENT ACROSS THE RESISTOR.

$$V = IR$$

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

$$= \frac{1.5}{5.0}$$

$$= 0.3\ A$$

- RESISTANCE DEPENDS ON RESISTIVITY (A PROPERTY OF THE MATERIAL) AND GEOMETRY.

$$R = \rho \frac{l}{A}$$

R: RESISTANCE (Ω)
ρ: RESISTIVITY (Ωm)
l: LENGTH (m)
A: CROSS-SECTIONAL AREA (m^2)

POWER

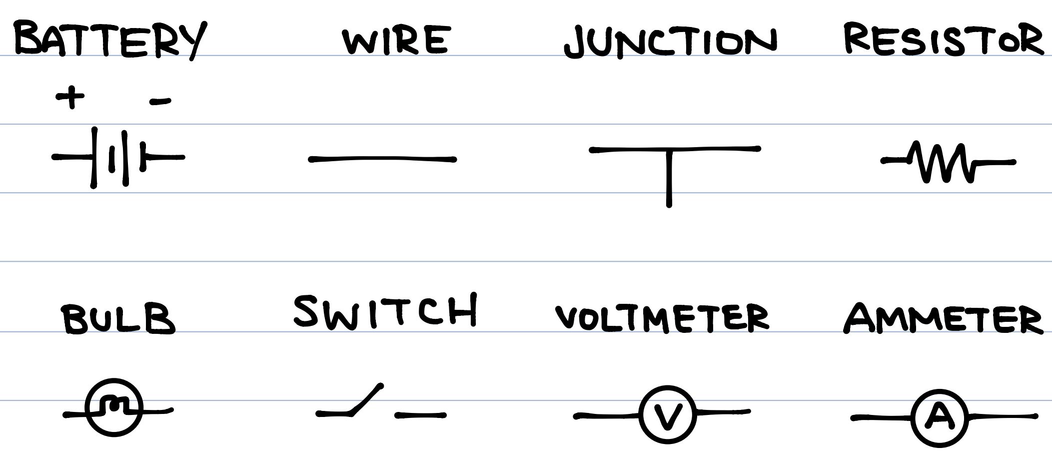
- ELECTRIC POWER IS THE RATE AT WHICH ENERGY IS TRANSFERRED.

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

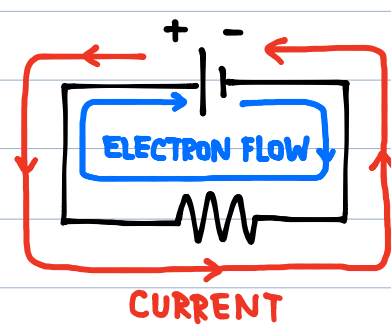
P: POWER (W)
I: CURRENT (A)
V: VOLTAGE (V)
R: RESISTANCE (Ω)

CIRCUITS

CIRCUIT SYMBOLS



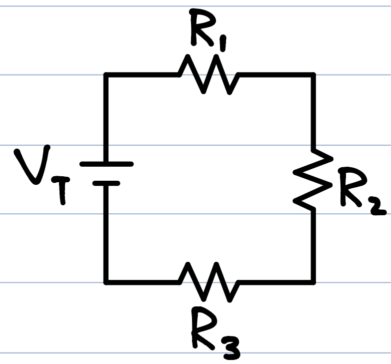
- THE DIRECTION OF CURRENT IS THE DIRECTION THAT A POSITIVE CHARGE CARRIER WOULD FLOW.



- CURRENT FLOWS IN DIRECTION OPPOSITE TO THE FLOW OF ELECTRONS.

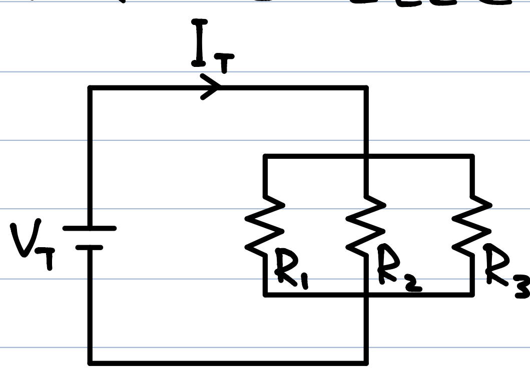
SERIES AND PARALLLEL CIRCUITS

- SERIES: ONE PATH FOR THE ELECTRONS



$$I_T = I_1 = I_2 = I_3$$
$$V_T = V_1 + V_2 + V_3$$
$$R_T = R_1 + R_2 + R_3$$

- PARALLEL: MORE THAN ONE PATH FOR THE ELECTRONS



$$I_T = I_1 + I_2 + I_3$$
$$V_T = V_1 = V_2 = V_3$$
$$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

ADDING MORE PATHS ALWAYS DECREASES TOTAL RESISTANCE AND INCREASES CURRENT.

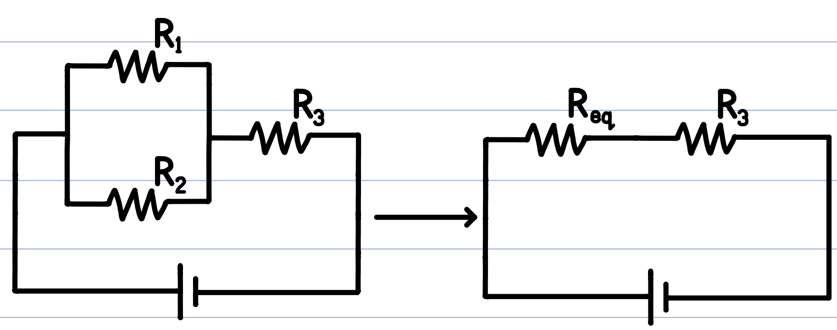
SOLVING CIRCUIT PROBLEMS

① DRAW A CIRCUIT DIAGRAM IF NOT PROVIDED.

② NEXT TO EACH RESISTOR, INDICATE V, I AND R.
NEXT TO THE BATTERY, INDICATE V_T, I_T AND R_T.

③ APPLY SERIES AND PARALLEL RULES APPROPRIATELY.
FOR EACH RESISTOR/BATTERY, WHEN TWO OF V, I AND R ARE KNOWN, USE OHM'S LAW TO DETERMINE THE THIRD.

FOR CIRCUITS WITH RESISTORS CONNECTED IN BOTH SERIES AND PARALLEL, YOU MAY NEED TO TRANSFORM THE COMBINATION CIRCUIT INTO A SERIES CIRCUIT BY DETERMINING THE EQUIVALENT RESISTANCE OF THE PARALLEL BRANCHES.



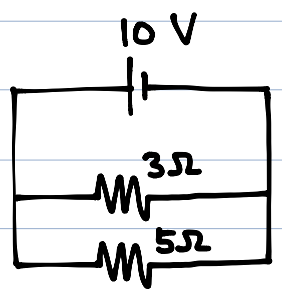
$$I_{eq} = I_1 + I_2$$

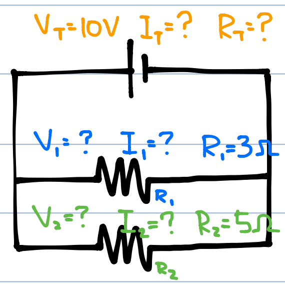
$$V_{eq} = V_1 = V_2$$

$$\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2}$$

EXAMPLE

DETERMINE THE CURRENT THROUGH THE 5Ω RESISTOR.





① $V_T = V_1 = V_2$

$V_2 = 10\text{ V}$

② $V_2 = I_2 R_2$

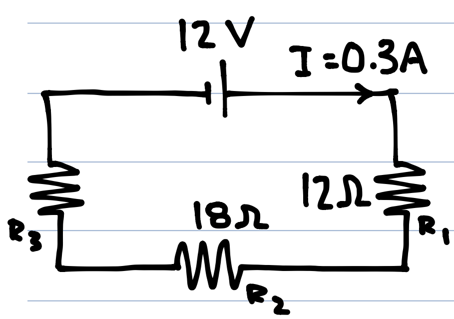
$I_2 = \frac{V_2}{R_2}$

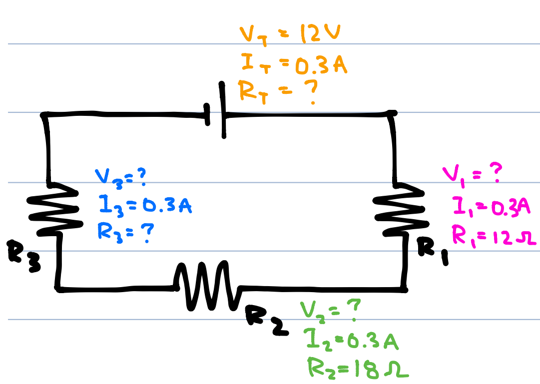
$= \frac{10}{5}$

$= 2\text{ A}$

EXAMPLE

DETEMINE THE RESISTANCE OF R_3





① $V_T = I_T R_T$

$R_T = \frac{V_T}{I_T}$

$= \frac{12}{0.3}$

$= 40\ \Omega$

② $R_T = R_1 + R_2 + R_3$

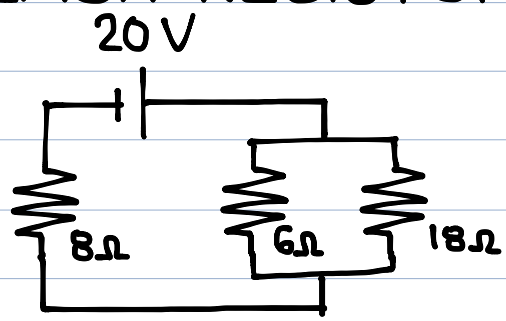
$R_3 = R_T - R_1 - R_2$

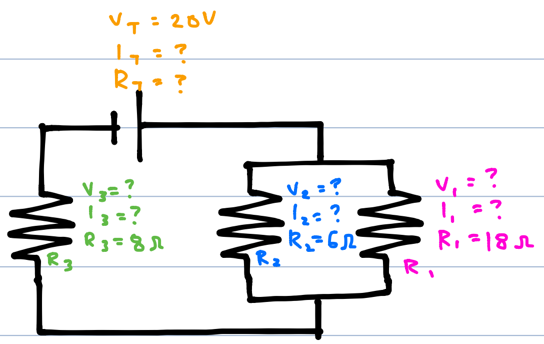
$= 40 - 12 - 18$

$= 10\ \Omega$

EXAMPLE

DETERMINE THE CURRENT THROUGH EACH RESISTOR.



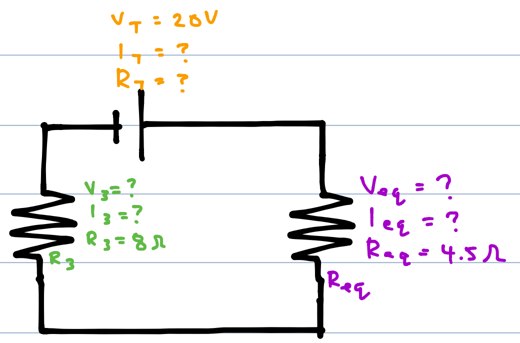


① $\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2}$

$= \frac{1}{18} + \frac{1}{6}$

$= \frac{2}{9}$

$R_{eq} = \frac{9}{2}\ \Omega = 4.5\ \Omega$



② $R_T = R_{eq} + R_3$

$= 4.5 + 8$

$= 12.5\ \Omega$

③ $V_T = I_T R_T$

$I_T = \frac{V_T}{R_T}$

$= \frac{20}{12.5}$

$= 1.6\text{A}$

④ $I_T = I_{eq} = I_3$

$I_{eq} = 1.6\text{A}$

$I_3 = 1.6\text{A}$

⑤ $V_{eq} = I_{eq} R_{eq}$

$= (1.6)(4.5)$

$= 7.2\text{V}$

⑥ $V_{eq} = V_1 = V_2$

$V_1 = 7.2V$

$V_2 = 7.2V$

⑦ $V_1 = I_1 R_1$

$I_1 = \frac{V_1}{R_1}$

$= \frac{7.2}{18}$

$= 0.4A$

⑧ $V_2 = I_2 R_2$

$I_2 = \frac{V_2}{R_2}$

$= \frac{7.2}{6}$

$= 1.2A$

$I_1 = 0.4A$ $I_2 = 1.2A$ $I_3 = 1.6A$

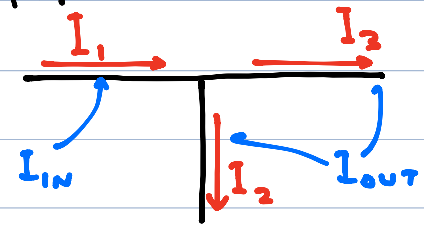
KIRCHHOFF'S LAWS

AKA JUNCTION RULE

- CURRENT LAW: THE SUM OF CURRENTS GOING INTO A JUNCTION IS EQUAL TO THE SUM OF CURRENTS LEAVING THE JUNCTION.

$$\Sigma I_{IN} = \Sigma I_{OUT}$$

CHARGE IS CONSERVED



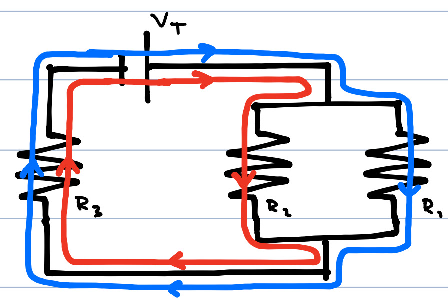
$I_1 = I_2 + I_3$

AKA LOOP RULE

- VOLTAGE LAW: FOR ANY CLOSED LOOP, THE SUM OF THE VOLTAGE GAINS IS EQUAL TO THE SUM OF THE POTENTIAL DROPS.

$$\Sigma V_{GAIN} = \Sigma V_{LOSS}$$

ENERGY IS CONSERVED



$V_T = V_1 + V_3$

$= I_1 R_1 + I_3 R_3$

$V_T = V_2 + V_3$

$= I_2 R_2 + I_3 R_3$

SOLVING CIRCUITS WITH KIRCHOFF'S LAWS

AN ALTERNATE METHOD, USEFUL FOR MORE COMPLICATED CIRCUITS.

① DRAW A CIRCUIT DIAGRAM IF NOT PROVIDED.

② NEXT TO EACH RESISTOR, INDICATE V, I AND R.
NEXT TO THE BATTERY, INDICATE V_T, I_T AND R_T.

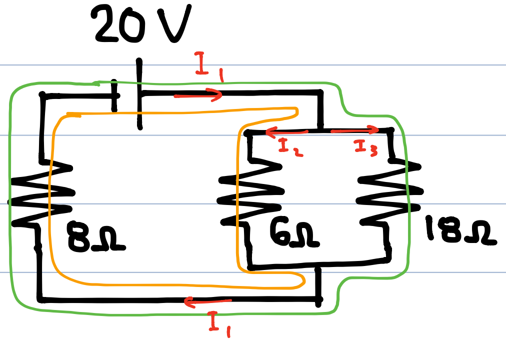
③ INDICATE THE DIRECTION OF THE CURRENT FOR EACH PART OF THE CIRCUIT.

④ APPLY THE CURRENT LAW TO WRITE AN EQUATION FOR EACH JUNCTION.
APPLY THE VOLTAGE LAW TO WRITE AN EQUATION FOR EACH LOOP.

⑤ SOLVE A SYSTEM OF EQUATIONS.

EXAMPLE

DETERMINE THE CURRENT THROUGH EACH RESISTOR.



CURRENT LAW:

① $I_1 = I_2 + I_3$

VOLTAGE LAW:

$20 = V_{6\Omega} + V_{8\Omega}$

② $20 = 6I_2 + 8I_1$

$20 = V_{18\Omega} + V_{8\Omega}$

③ $20 = 18I_3 + 8I_1$

3 EQUATIONS, 3 UNKNOWNS ⟶ SOLVE

(2) $20 = 6I_2 + 8I_1$

$6I_2 = 20 - 8I_1$

(4) $I_2 = \frac{10}{3} - \frac{4}{3} I_1$

(3) $20 = 18I_3 + 8I_1$

$18I_3 = 20 - 8I_1$

(5) $I_3 = \frac{10}{9} - \frac{4}{9} I_1$

(4) AND (5) INTO (1)

$I_1 = I_2 + I_3$

$I_1 = \left(\frac{10}{3} - \frac{4}{3} I_1\right) + \left(\frac{10}{9} - \frac{4}{9} I_1\right)$

$I_1 = \frac{40}{9} - \frac{16}{9} I_1$

$\frac{25}{9} I_1 = \frac{40}{9}$

(6) $I_1 = \frac{40}{25} \text{ A} = 1.6 \text{ A}$

(6) INTO (4)

$I_2 = \frac{10}{3} - \frac{4}{3} I_1$

$= \frac{10}{3} - \frac{4}{3}(1.6)$

$= 1.2 \text{ A}$

(6) INTO (5)

$I_3 = \frac{10}{9} - \frac{4}{9} I_1$

$= \frac{10}{9} - \frac{4}{9}(1.6)$

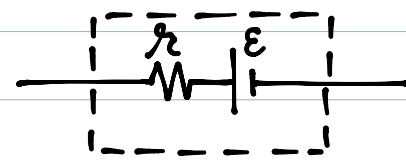
$= 0.4 \text{ A}$

$I_{8\Omega} = 1.6\text{A}$ $I_{6\Omega} = 1.2\text{A}$ $I_{18\Omega} = 0.4\text{A}$

TERMINAL VOLTAGE

- A BATTERY GETS HOT WHEN IN USE. WORK MUST BE DONE IN THE BATTERY MEANING THE BATTERY HAS INTERNAL RESISTANCE.
- A BATTERY PRODUCES MORE VOLTAGE THAN YOU GET AT THE TERMINAL. THIS VOLTAGE IS CALLED THE ELECTROMOTIVE FORCE (EMF).

NOT ACTUALLY A FORCE!



$$V_{TERMINAL} = \varepsilon - Ir$$

$V_{TERMINAL}$: TERMINAL VOLTAGE (V)

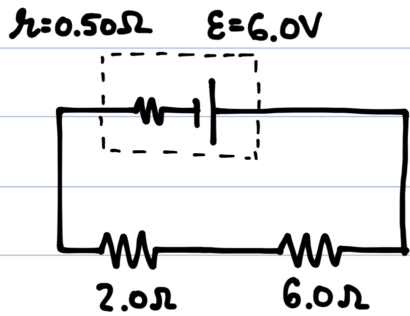
ε : ELECTROMOTIVE FORCE (V)

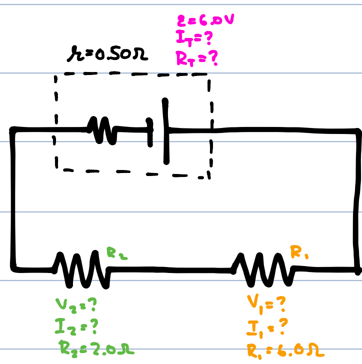
I : CURRENT THROUGH BATTERY (A)

r : INTERNAL RESISTANCE (Ω)

EXAMPLE

WHAT IS THE TERMINAL VOLTAGE OF THE BATTERY IN THIS CIRCUIT?





$$R_T = r + R_1 + R_2$$
$$= 0.50 + 6.0 + 2.0$$
$$= 8.5\,\Omega$$

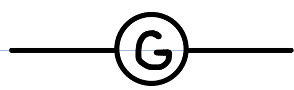
V_T

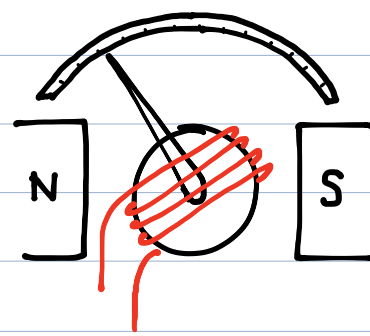
$$\varepsilon = I_T R_T$$
$$I_T = \frac{\varepsilon}{R_T}$$
$$= \frac{6.0}{8.5}$$
$$= 1.23\,A$$

$$V_{TERMINAL} = \varepsilon - I_T r$$
$$= 6.0 - (1.23)(0.50)$$
$$= 5.4\,V$$

INSTRUMENTS

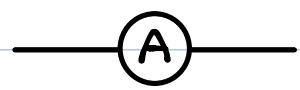
- GALVANOMETER: DETECTS <u>small</u> CURRENTS
  - CURRENT PASSES THROUGH A COIL WHICH BECOMES AN ELECTROMAGNET
  - COIL IS IN A MAGNETIC FIELD WITH WHICH IT INTERACTS
  - AN INDICATOR IS CONNECTED TO THE COIL WHICH MOVES ON A SCALE CALIBRATED TO SHOW AMPS (OR VOLTS.)

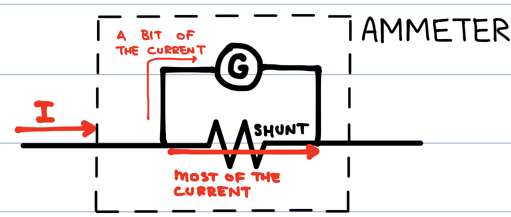




- AMMETER: MEASURES CURRENT
  - AN AMMETER IS CONNECTED IN SERIES (CURRENT IS SAME FOR ALL LOADS IN SERIES).
  - A VERY LOW RESISTANCE (SHUNT) IS CONNECTED IN PARALLEL WITH A GALVANOMETER.

- MOST OF THE CURRENT PASSES THROUGH THE SHUNT ALLOWING THE AMMETER TO MEASURE HEAVY CURRENTS WITHOUT THE INDICTOR BEING FULLY DEFLECTED.





- VOLTMETER: MEASURES POTENTIAL DIFFERENCE BETWEEN TWO POINTS
  - CONNECTED IN PARALLEL (VOLTAGE IS SAME FOR ALL LOADS IN PARALLEL).
  - A VERY HIGH RESISTANCE IS CONNECTED IN SERIES WITH A GALVANOMETER.
  - MOST OF THE CURRENT PASSES THROUGH THE CIRCUIT WITH ONLY A SMALL PERCENTAGE PASSING THROUGH THE VOLTMETER.