Electric Circuits Notes

1 – Introduction to Circuits Electricity

A) CHARGE [Mr.Cheung can I charge my phone?]

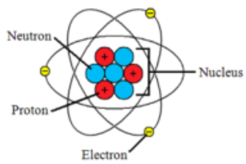


Figure 1: Charge!!!!

Fundamental particles like proton, neutron and electron make up in our universe. These particles have different properties like size, mass and charge.

Charge is a fundamental property of matter and it is measured in Coulomb (C). Name after French Physicists Charles-Augustin de Coulomb [1736-1806 Figure 2]

*Figure 2: Charles de Coulomb - Your old friend $F_f = \mu F_N$ was my work too. You are welcome ^__^*

Did you my name is craved into the Eiffel Tower? Ask Mr.Cheung to show you a picture~

Atlas: But… but…. daddy what is a charge?

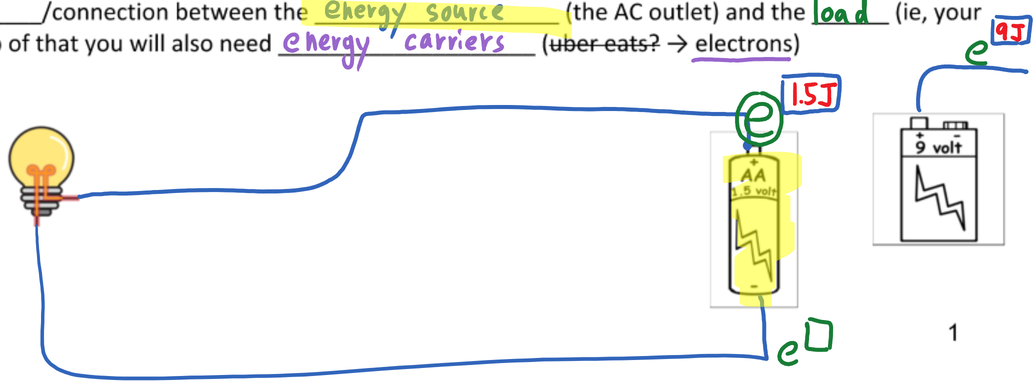
Mr. Cheung: No one can tell you what charge really is, the only rules scientists have discovered so far…..

1. There are two types of charges (+ positive and – negative) and…
2. Charges can interact with each other (via Electric Force)
   a. Opposite charges attract each other
   b. Like charges repel

Particle	Proton	Neutron	Electron
Symbol	p^+	n	e^-
Mass	1.67×10^{-27} kg	1.67×10^{-27} kg	9.11×10^{-31} kg
Charge	$+1.6 \times 10^{-19}$ C	$\emptyset$	-1.6×10^{-19} C

B) ELECTRONS AND ELECTRIC CIRCUIT

Have you ever wonder how energy is delivered to your electronic devices (ie. your TV set and cellphones etc.)? Energy can come from the AC outlet or it be stored in portable storage device like a battery, but nothing is going to happen if you hold up a battery in the air. For energy to flow into your devices, you must provide a pathway /connection between the energy source (the AC outlet) and the load (ie, your PS4); on top of that you will also need energy carriers (~~uber eats?~~ → electrons)



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C) Voltage, Current, resistance and Ohm's Law [let the great pizza analogy begin! Brought to you by Mr. Cheung]

Voltage (Potential Difference) is the change in potential energy per unit charge. It is the amount of energy carried by 1 Coulomb of electrons

* ex) 9 Volt = Every Coulomb of e^- carries 9J of Energy.

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

V: Voltage (V) Volt
E: Energy (J)
Q: Charge (C) Coulomb

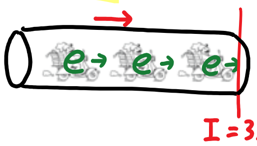
Current is the rate of flow of charge (electron) through the cross-sectional area of a conductor (wire).

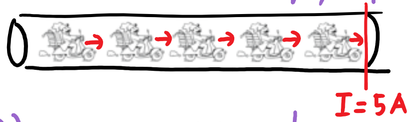
ex) 3Amps = 3 coulombs of e^- are passing by a point every sec.

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

I: current (A)
Q: Charge (C)
t: time (S)

unit: Ampere / Amps (A)





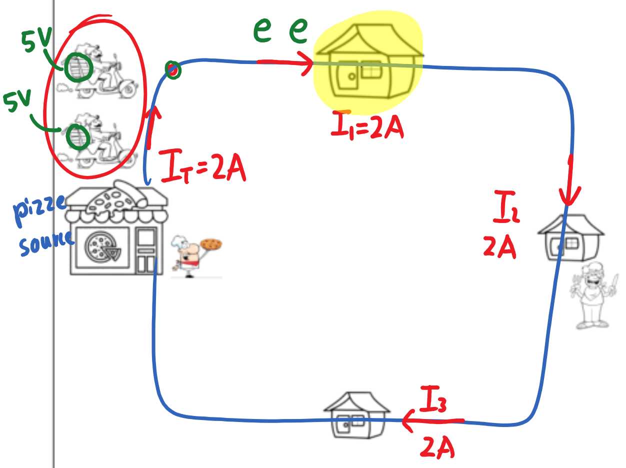
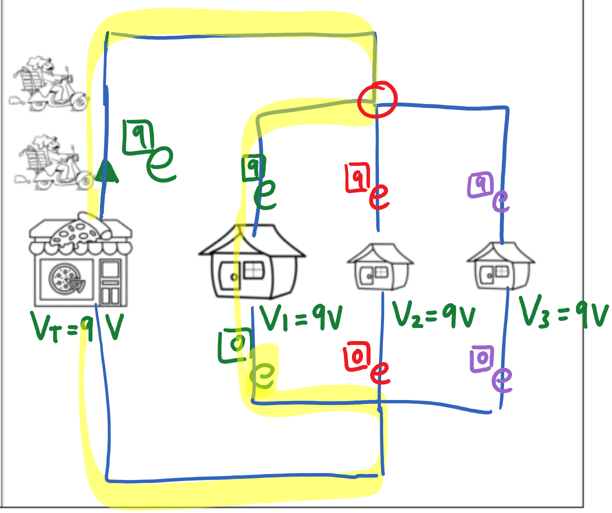
Resistance is a property of material and it is measured in Ohm (Ω). Some materials have low resistance and they are good conductor (ex, metals); they allow electrons to flow freely. Other materials (ex, wood/plastic/air) have high resistance value and they are bad conductor; electrons have a harder time (not impossible) traveling through them.

Ohm's Law: The ratio between the voltage and the current through a conductor (load, resistor) is a constant and represents the resistance of the material.

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

V: Voltage (V)
I: Current (A)
R: Resistance (Ω)

Mr.Cheung's Pizza model of Circuity

Series (basic)	Parallel (more complex)
	

$I = \frac{Q}{t}$ $V = \frac{E}{Q}$ $I \cdot V = \frac{Q}{t} \cdot \frac{E}{Q} = \frac{E}{t}$ same!!

D) POWER [Go Go Power Ranger~ sorry I had to... haha]

Recall that power is........ the rate of doing work $P = \frac{\Delta E}{t}$ (W)

Electric Power is the rate at which energy is transferred

From the definition of power and Ohm's Law we can derive some formulae to describe **electric power**

Ohm's Law: $V = IR$, $I = \frac{V}{R}$

$P = IV \Rightarrow P = \left(\frac{V}{R}\right) \cdot V \Rightarrow P = \frac{V^2}{R}$

$P = I \cdot (IR)$

$P = I^2 R$

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

Example: An electric fan has a resistance of 12 Ω and requires 0.75 A of current to function properly. What voltage is required to operate the fan?

$R = 12\,\Omega$ Ohm's Law $V = IR$

$I = 0.75\,A$ $V = (0.75)(12)$

$V = ?$ $V = 9\,V$

Example: An electric heater emits 100 W when connected to a 120 V power line. What is the resistance in the heater?

$P = 100\,W$ $P = \frac{V^2}{R}$ $R = \frac{120^2}{100}$

$V = 120\,V$ $100 = \frac{120^2}{R}$ $R = 144\,\Omega$

$R = ?$

Example: When a 12 V car battery powers a single 30 W headlight, how many electrons pass through it in one minute?

Current = I

① $P = IV$

$30 = I \cdot 12$

$I = 2.5$ Amps ↳ 2.5 Coulomb of e^-/sec

② In 1 mins

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

$2.5 = \frac{Q}{60\,\text{sec}}$

$Q = 150$ Coulombs in 1 min

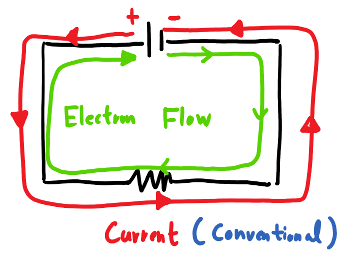
charge of 1 e = 1.6×10^{-19} C

# of electrons: $\frac{150\,C}{1.6 \times 10^{-19}\,C}$

of e^- = 9.375×10^{20}

E) DIRECTION OF CURRENT [what do you call a misunderstanding that is never fixed? A convention...]

The direction of current can be considered in two ways:



1) Electron Flow: The direction that the electrons actually move. The electrons go from the ___−___ to the ___+___ terminal.

2) Conventional Current: Flow of positive charge. Positive charges flow from the ___+___ to the ___−___ terminal.

Figure 3: I am on the US $100 Bill~~

In 1752, prior to electricity being identified with the electron, Ben Franklin chose a convention regarding the direction of current flow. Franklin assumed that __positive__ charge carriers flowed from positive to negative terminals. We now know this is incorrect. In metals, the charge carrier is the __electron__ whose charge is __negative__ by definition. As a result, most people still prefer using the direction of the conventional current.

In this class, unless otherwise stated, we will always use __conventional Current__!!!

F) CIRCUIT SYMBOLS (SCHEMATIC)

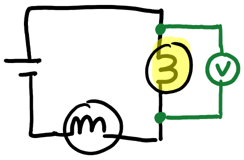
CELL	BATTERY	WIRE	JUNCTION	RESISTOR
+ −	+ −			

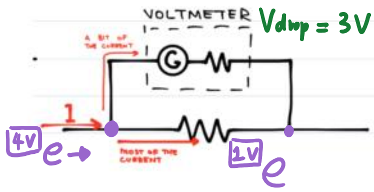
BULB	SWITCH (OPEN)	SWITCH (CLOSED)	VOLTMETER	AMMETER (measures current)
(m)			(V)	(A)

We can measure the voltage in a circuit using a __voltmeter__ and the current in a circuit using a __Ammeter__. But we need to connect these two devices in different ways.

Voltmeter:

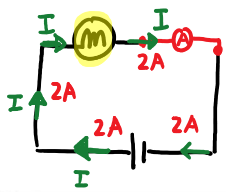
- must be connected in __parallel__. This is because a voltmeter measures the voltage drop __across__ a device and it has very high __resistance__.
- Most of the current passes through the __circuit__ with only a small percentage passing through the __voltmeter__ so we won't waste energy.
- "we are trying to measure the __Energy__ carried by the electrons __before__ and __after__ they go through a power source or a load."

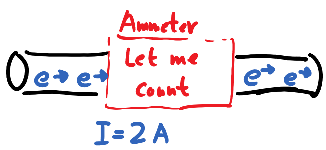




Ammeter:

- An ammeter must be connected in __Series__. This is because an ammeter measures the current __through__ a circuit and it has very low resistance.
- Ammeter is trying to count the __amount__ of electrons (in Coulombs) going through the conductor wire per second. You have to stand in the __path__ in order to count the people ^___^





Circuit Worksheet 5.1: Current/Voltage/Ohm's Law

1) A current of 3.60 A flows for 15.3 s through a conductor. Calculate the number of electrons that pass through a point in the conductor in this time.

(3.44×10^{20})

2) How long would it take 2.0×10^{20} electrons to pass through a point in a conductor if the current was 10.0 A?

(3.2 s)

3) Calculate the current if a charge of 5.60 C passes through a point in a conductor in 15.4 s.

(0.364 A)

4) What is the potential difference across a conductor to produce a current of 8.00 A if there is a resistance in the conductor of 12.0 Ω?

(96 V)

5) What is the heat produced in a conductor in 25.0 s if there is a current of 11.0 A and a resistance of 7.20 Ω?

(21800 J)

6) 150 J of heat are produced in a conductor in 5.50 s. If the current through the conductor is 10.0 A, what is the resistance of the conductor?

(0.273 Ω)

7) What is the current through a 400 W electric appliance when it is connected to a 120 V power line?

(3.33 A)

8) a. When an electric appliance is connected to a 120 V power line, there is a current through the appliance of 18.3 A. What is its resistance?

(6.56 Ω)

b. What is the average amount of energy given to each electron by the power line?

(1.92×10^{-17}J)

9) a. What potential difference is required across an electrical appliance to produce a current of 20.0 A when there is a resistance of 6.00 Ω?

(120 V)

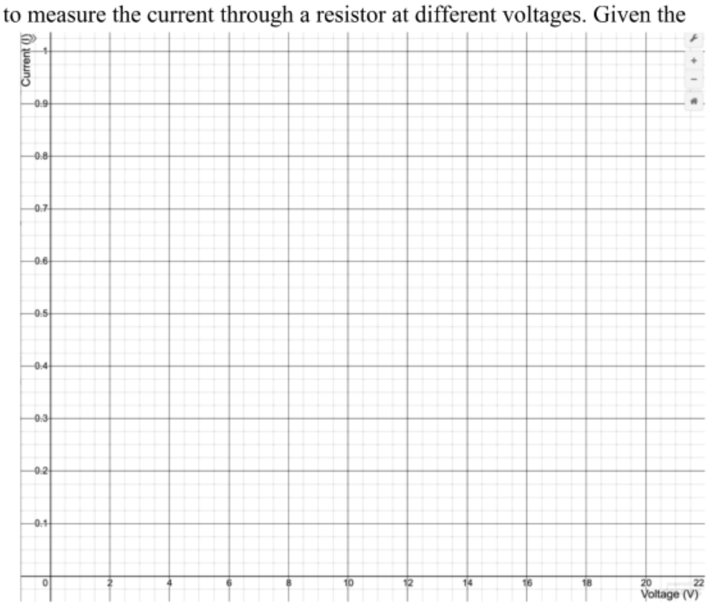
b. How many electrons pass through the appliance every minute?

(7.5×10^{21})

10) A student designed an experiment in order to measure the current through a resistor at different voltages. Given the following data:

Voltage (V)	Current (I)
3.0	0.15
6.0	0.30
9.0	0.45
12.0	0.50
15.0	0.75

a) Draw a graph showing the relationship between current and voltage (V vs. I)



b) Using the graph, what is the resistance of the resistor?

(20.0 +/- 0.5 Ω)

Electric Circuits Notes

2 – Basic Circuit

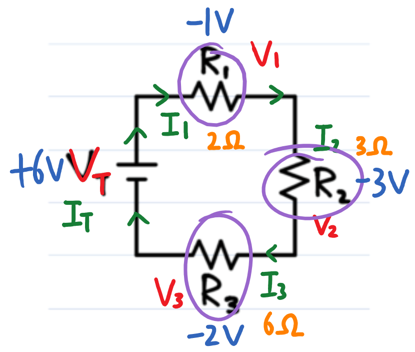
A) SERIES AND PARALLEL CIRCUIT

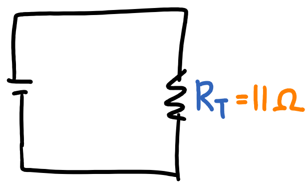
Series: one path for the electrons

$I_T = I_1 = I_2 = I_3$

$V_T = V_1 + V_2 + V_3$

$R_T = R_1 + R_2 + R_3$



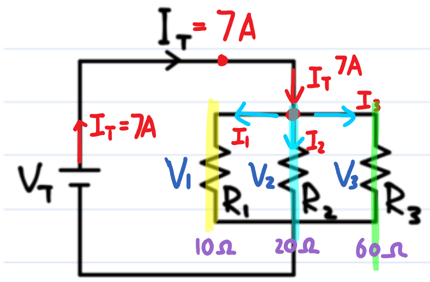


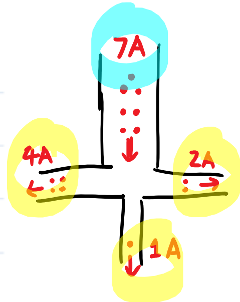
Parallel: more than one path for the electrons

$I_T = I_1 + I_2 + I_3$

$V_T = V_1 = V_2 = V_3$

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

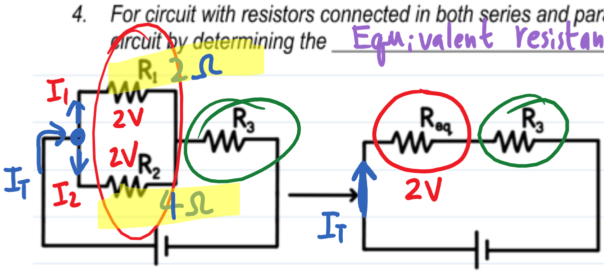




"Adding more paths always Decreases total resistance and increase current!!"

B) SOLVING BASIC 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* $V = IR$ $I = \frac{V}{R}$ $R = \frac{V}{I}$
4. *For circuit 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*



$I_{eq} = I_1 + I_2$

$V_{eq} = V_1 = V_2$

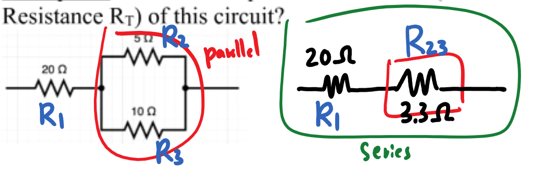
$$\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2}$$

$$\frac{1}{R_{eq}} = \frac{1}{2} + \frac{1}{4} \qquad \frac{1}{R_{eq}} = 0.75 \qquad \frac{1}{0.75} = R_{eq} \qquad R_{eq} = 1.\overline{3}\,\Omega$$

6

$k = \times 1000$

Example 1: What is the equivalent resistance (Total Resistance R_T) of this circuit?

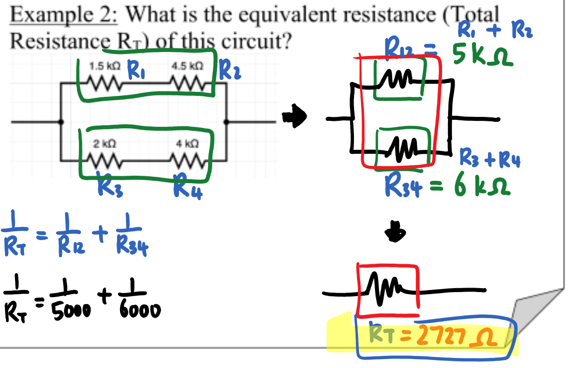


$$\frac{1}{R_{23}} = \frac{1}{5} + \frac{1}{10}$$

$R_{23} = 3.\overline{3}\,\Omega$

$R_T = R_1 + R_{23} = 23.\overline{3}\,\Omega$

Example 2: What is the equivalent resistance (Total Resistance R_T) of this circuit?

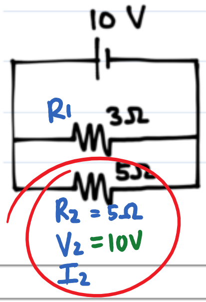


$$\frac{1}{R_T} = \frac{1}{R_{12}} + \frac{1}{R_{34}}$$

$$\frac{1}{R_T} = \frac{1}{5000} + \frac{1}{6000}$$

$R_T = 2727\,\Omega$

Example 3: Determine the current through the 5Ω Resistor



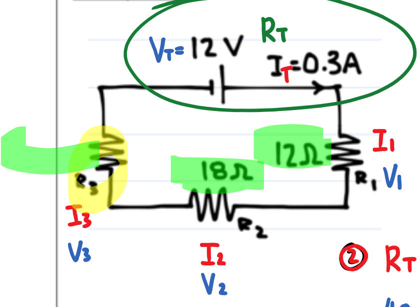
$V_T = V_1 = V_2$

$V_2 = I_2 R_2$

$10 = I_2 \cdot 5$

$I_2 = 2A$

Example 4: Determine the resistance of R_3



$I_T = I_1 = I_2 = I_3$

$V_T = I_T R_T$

$12V = 0.3A\,(R_T)$

$R_T = 40\,\Omega$

② $R_T = R_1 + R_2 + R_3$

$40 = 12 + 18 + R_3$

$R_3 = 10\,\Omega$

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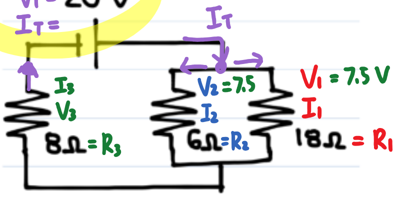
Example 5: Determine the current through each resistor.

$R_T = 12.5\Omega$
$V_T = 20\ V$
$I_T =$

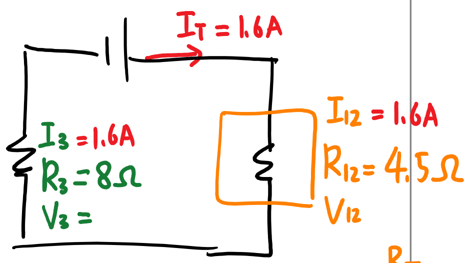


① $\frac{1}{R_{12}} = \frac{1}{R_1} + \frac{1}{R_2}$

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

$\frac{1}{R_{12}} = \frac{2}{9}$

$\therefore R_{12} = \frac{9}{2}\ \Omega$



② $R_T = R_3 + R_{12} = 12.5\ \Omega$ (R_T)

③ $V_T = I_T R_T$

$20 = I_T (12.5)$

$I_T = 1.6\ A$

④ $I_T = I_3$

$\therefore I_3 = 1.6A$

⑤ $R_{12} = 4.5\Omega$

$I_{12} = 1.6A$

$V_{12} = ?$

$V_{12} = I_{12} R_{12}$

$V_{12} = 1.6\ (4.5)$

$V_{12} = 7.5\ V$

⑥ $V_{12} = V_1 = V_2 = 7.5V$

⑦ $R_1 = 18\Omega$

$V_1 = 7.5V$

$I_1 =$

$V = IR$

$7.5 = I\ (18)$

$I_1 = 0.4\ A$

⑧ $R_2 = 6\Omega$

$V_2 = 7.5V$

$I_2 =$

$V_2 = I_2 R_2$

$7.5 = I_2 \cdot 6$

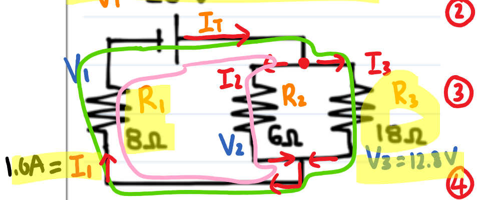
$I_2 = 1.2A$

$+$

$I_T = 1.6A$

Example 1 for Note Day 3: Kirchhoff's Law: Determine the current through each resistor

$V_T = 20\ V$ $\quad R_T = 12.5\Omega$



① $\frac{1}{R_{23}} = \frac{1}{6\Omega} + \frac{1}{18\Omega}$

$R_{23} = 4.5\ \Omega$

$R_T = R_1 + R_{23} = 12.5\Omega$
(8) (4.5)

② $V_T = I_T R_T$ (20) (12.5) $\quad I_T = 1.6A = I_1$

③ $V_1 = I_1 R_1$ 1.6 (8) $\quad V_1 = 7.2\ V$

④ Loop Rule. $V_T = V_3 + V_1$ (20) (7.2) $\quad V_3 = 12.8V = V_2$

⑤ $V_2 = I_2 R_2$ (12.8) (6Ω) $\quad I_2 = 1.2\ A$

$V_3 = I_3 R_3$ (12.8) (18Ω) $\quad I_3 = 0.4\ A$

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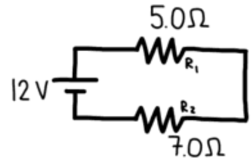
Circuit Worksheet 5.2 - Series and Parallel Circuits

For each circuit, determine the voltage, current and resistance through each resistor and the total voltage, current and resistance of the circuit.

1.



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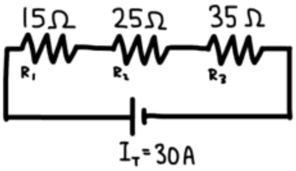

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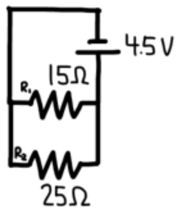

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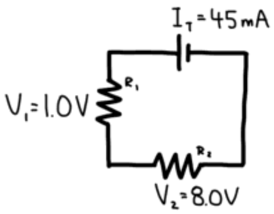

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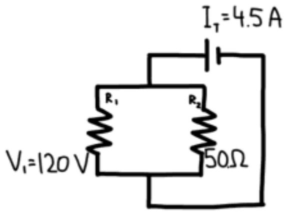

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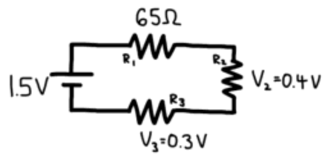

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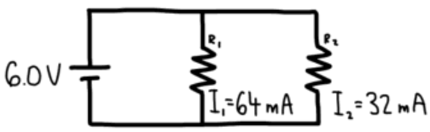

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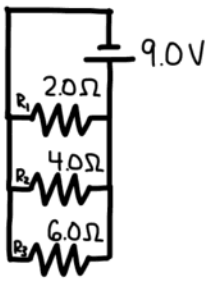


Answers:

Q1) $R_T = 12\ \Omega;\ I_T = I_1 = I_2 = 1.0\ A;\ V_1 = 5.0\ V;\ V_2 = 7.0\ V$

Q2) $R_T = 75\ \Omega;\ I_T = I_1 = I_2 = I_3 = 30\ A;\ V_T = 2250\ V; V_1 = 450\ V;\ V_2 = 750\ V;\ V_3 = 1050\ V$

Q3) $V_T = V_1 = V_2 = 4.5\ V;\ I_1 = 0.30\ A;\ I_2 = 0.18\ A;\ I_T = 0.48\ A;\ R_T = 9.375\ \Omega;$

Q4) $I_T = I_1 = I_2 = 45\ mA$ or $0.045\ A;\ R_1 = 22.2\ \Omega;\ R_2 = 177.8\ \Omega;\ V_T = 9.0\ V;\ R_T = 200\ \Omega$

Q5) $V_T = 120\ V;\ I_2 = 2.4\ A;\ I_1 = 2.1\ A;\ R_T = 26.7\ \Omega;\ R_1 = 57.1\ \Omega$

Q6) $V_1 = 0.8\ V;\ I_1 = 12.3\ mA$ or $0.0123\ A;\ R_T = 121.9\ \Omega;\ R_2 = 32.5\ \Omega;\ R_3 = 24.4\ \Omega$

Q7) $V_1 = V_2 = 6.0\ V;\ I_1 = 96\ mA$ or $0.096\ A;\ R_T = 62.5\ \Omega;\ R_1 = 93.75\ \Omega;\ R_2 = 187.5\ \Omega$

Q8) $V_T = V_1 = V_2 = V_3 = 9.0\ V;\ I_1 = 4.5\ A;\ I_2 = 2.25\ A;\ I_3 = 1.5\ A;\ I_T = 8.25\ A;\ R_T = 1.09\ \Omega$

Note 3

June 9, 2020 3:54 AM

Electric Circuits Notes

3 – Kirchhoff's Laws

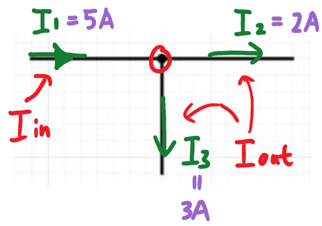
A) Kirchhoff's Current Law: AKA Junction Rule.

"The sum of current going into a junction is equal to the sum of currents leaving the junction."

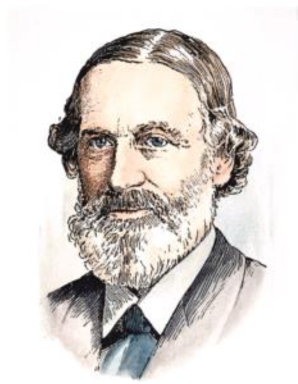
For any junctions:

$$\sum I_{in} = \sum I_{out}$$

Charge is conserved !!!



$$I_1 = I_2 + I_3$$



GUSTAV ROBERT KIRCHHOFF.

Cheung's Current Law: Enjoy your meal but don't eat the person who delivers the food!!

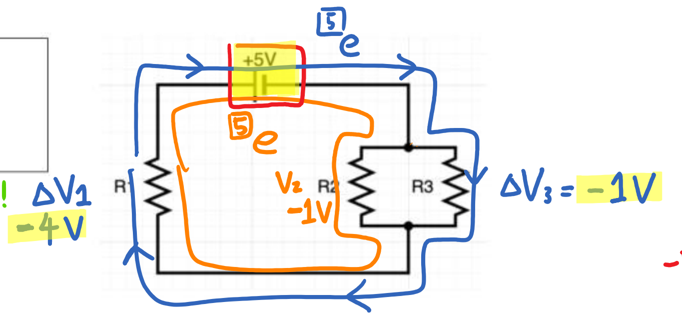
B) Kirchhoff's Voltage Law: AKA Loop Rule.

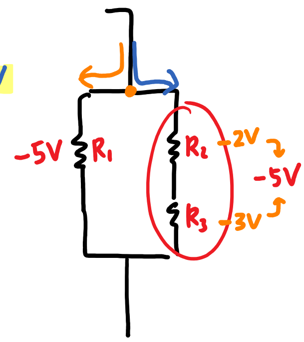
"For any closed loop, the sum of voltage gain is equal to the sum of voltage drops"

For any loops in the circuit:

$$\sum V_{Gain} = \sum V_{drop}$$

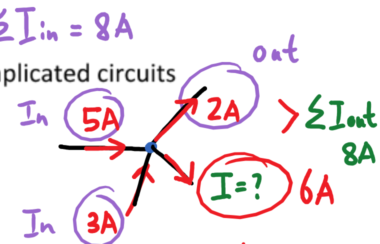
Energy is conserved !!

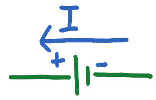




Cheung's Voltage Law: I give you 10 pizzas, you deliver 10 pizzas!!

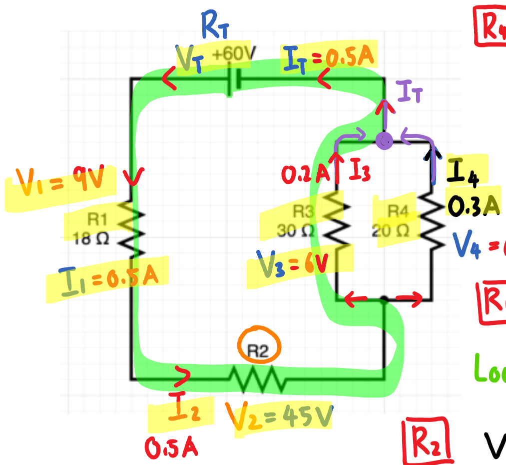
C) **Solving Circuits with Kirchhoff's Laws –** an alternate method, useful for more complicated circuits





1. Draw a circuit diagram if not provided
2. Next to each resistor, indicate V, I and R
3. Next to the battery, indicate V_T, I_T and R_T
4. Indicate the direction of current of each part of the circuit
5. Apply the Current Law to each Junction. Try to find a junction with only one unknown current.
6. Apply the Voltage Law to each Loop. Try to find a loop with only one unknown voltage.
7. You might need to calculate equivalent resistance of the parallel branches to simplify the question.
8. Use Ohm's Law $V = IR$ or Power formula $P = IV = I^2R = \frac{V^2}{R}$ to help you at any time ^____^

Example 2: What is the value of V_1, V_2 and R_2 in the circuit



$V_4 = I_4 R_4 = (20)(0.3) = 6V$

$V_3 = V_4 = 6V$

$V_3 = I_3 R_3 \quad I_3 = \frac{6V}{30\Omega} = 0.2A$

Junction Rule: $I_T = I_3 + I_4 = 0.5A$

$V_1 = I_1 R_1 = 0.5(18) = 9V$

Loop Rule: $V_T = V_1 + V_2 + V_3$ (60, 9, ?, 6) $V_2 = 45V$

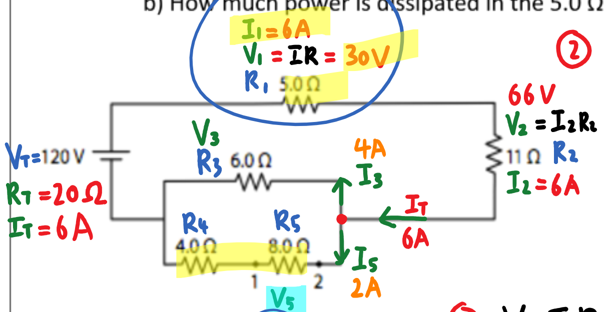
$V_2 = I_2 R_2$ (45, 0.5) $R_2 = 90\Omega$

V1 = 9V, V2 = 45V, R2 = 90 Ω

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

Example 3: a) What is the voltage across the 8.0 Ω resistor

b) How much power is dissipated in the 5.0 Ω resistor



① $R_{45} = R_4 + R_5 = 12\Omega$

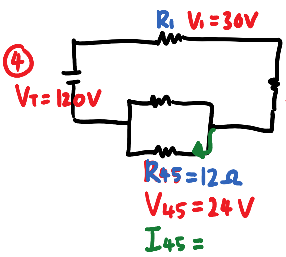
$\frac{1}{R_{345}} = \frac{1}{R_3} + \frac{1}{R_{45}} \quad R_{345} = 4\Omega$

$R_T = R_1 + R_2 + R_{345} = 20\Omega$ (5, 11, 4)

② $V_T = I_T R_T \quad 120 = I_T(20) \quad I_T = 6A$

③ $I_1 = I_2 = I_T = 6A$

④ Loop Rule: $V_T = V_1 + V_2 + V_{45}$ (120, 30, 66) $V_{45} = 24V$



⑤ $V_{45} = IR$ (24, 12) $I_{45} = 2A = I_4 = I_5$

⑥ $V_5 = I_5 R_5 = 16V$ (2 (8))

b) $P_1 = V_1 I_1 = 180W$ (30 (6))

a. 16 V b. 180 W

Note 4

July 29, 2020 8:53 AM

Electric Circuits Notes

4 – Electromotive Force / Terminal Voltage

We know that a battery is a source of potential difference (Voltage) or electric energy. When not connected to a circuit there is a potential difference between the terminals.

This voltage is also known as… Electro Motive Force = Emf = $\mathcal{E}$ ← Voltage

Despite the name, this is a Votage not a Force.
This dates back to a time when we thought that the two were equivalent.

For example a car battery has an EMF of 12V and lithium battery has an EMF of 1.5V.

However, as soon as a battery is connected to a circuit and current flows through it the potential difference across the terminals is always… less than Emf.

This is due to the fact that every battery has… internal resistance.

Because of this ______________ ______________ the terminal voltage is always ______________ than the EMF of the battery.

$$V_{terminal} = \mathcal{E} - I_T r$$

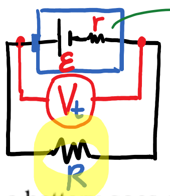
(V) (V) (A)(Ω)

Where: $\mathcal{E}$ = Emf.

Note: Ir = internal Voltage drop.

Note: If the battery is not connected to a circuit…
$I = \varnothing$ $V_{terminal} = \mathcal{E}$

Consider the following diagram showing a circuit with an external resistance, R, internal resistance r and EMF $\mathcal{E}$.



→ Internal Vdrop.

$V_{drop} = I_T \cdot r$

$\mathcal{E} = I_T R_T$

$R_T = R + r$

When a battery goes dead it is because… the internal resistance bulids up over time.

Example: If a 12.0 V battery has an internal resistance of 0.220 ohms, what is the terminal voltage of the battery when a current of 3.00 A flows through the battery?

($\mathcal{E}$ = 12.0 V, I_T = 3.00 A, V_t = terminal voltage)

$$V_t = \mathcal{E} - I_T r = 12 - 3(0.22)$$
$$= 12V - 0.66V$$
$$= 11.34V$$

When a rechargeable battery is being charged an external voltage is applied to the battery. In order to force electrons backwards into the battery the external voltage must be… Larger.

In fact the external voltage must be:

For charging

$$V_{terminal} = \mathcal{E} + I_T r$$

(battery) (e's payment)

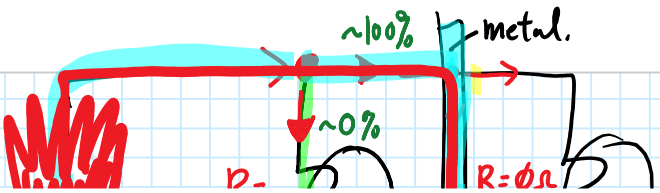
↑ Voltage needed to charge battery.

Example: A 12.0 V car battery is being charged by an alternator that can supply 15 V. If the internal resistance of the battery is 1.3 ohms, what is the current through the battery?

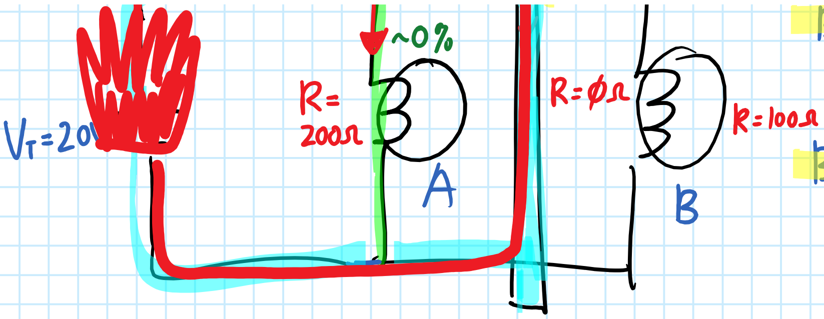
($\mathcal{E}$ = 12.0 V, $V_{terminal}$ = 15 V, r = 1.3 ohms)

$$V_t = \mathcal{E} + I_T r$$
$$15V = 12V + I_T(1.3\Omega)$$
$$I_T = 2.3A$$

WS 7.4



Bulb A off



Bulb A off

Bulb B off