DEVIL PHYSICS
THE BADDEST CLASS ON CAMPUS
IB PHYSICS

LSN 19-3: KIRCHOFF’S RULES

Reading Activity Questions?

Big Idea(s):

- Changes that occur as a result of interactions are constrained by conservation laws.

Enduring Understanding(s):

- The energy of a system is conserved.
- The electric charge of a system is conserved.

Essential Knowledge(s):

- Kirchhoff's loop rule describes conservation of energy in electrical circuits. The application of Kirchhoff's laws to circuits is introduced in Physics 1 and further developed in Physics 2 in the context of more complex circuits, including those with capacitors.
  - Energy changes in simple electrical circuits are conveniently represented in terms of energy change per charge moving through a battery and a resistor.
  - Since electric potential difference times charge is energy, and energy is conserved, the sum of the potential differences about any closed loop must add to zero.
  - The electric potential difference across a resistor is given by the product of the current and the resistance.
  - The rate at which energy is transferred from a resistor is equal to the product of the electric potential difference across the resistor and the current through the resistor.

Essential Knowledge(s):

- Kirchhoff's junction rule describes the conservation of electric charge in electrical circuits. Since charge is conserved, current must be conserved at each junction in the circuit. Examples should include circuits that combine resistors in series and parallel. [Physics 1: covers circuits with resistors in series, with at most one parallel branch, one battery only.]

Learning Objective(s):

- The student is able to construct or interpret a graph of the energy changes within an electrical circuit with only a single battery and resistors in series and/or in, at most, one parallel branch as an application of the conservation of energy (Kirchhoff's loop rule).
- The student is able to apply conservation of energy concepts to the design of an experiment that will demonstrate the validity of Kirchhoff's loop rule ($\Sigma \Delta V = 0$) in a circuit with only a battery and resistors either in series or in, at most, one pair of parallel branches.

Learning Objective(s):

- The student is able to apply conservation of energy (Kirchhoff's loop rule) in calculations involving the total electric potential difference for complete circuit loops with only a single battery and resistors in series and/or in, at most, one parallel branch.
- The student is able to apply conservation of electric charge (Kirchhoff's junction rule) to the comparison of electric current in various segments of an electrical circuit with a single battery and resistors in series and in, at most, one parallel branch and predict how those values would change if configurations of the circuit are changed.

Learning Objective(s):

- The student is able to design an investigation of an electrical circuit with one or more resistors in which evidence of conservation of electric charge can be collected and analyzed.
- The student is able to use a description or schematic diagram of an electrical circuit to calculate unknown values of current in various segments or branches of the circuit.

Series Circuits

- Circuits are said to be "in series" when the same current runs through them as if they were connected end to end
  - The potential drop across each resistor is, $V_1 = IR_1$, $V_2 = IR_2$, $V_3 = IR_3$

$$V = IR_1 + IR_2 + IR_3$$
$$V = I\left(R_1 + R_2 + R_3\right)$$
$$V = IR_{Total}$$
$$R_{Total} = R_1 + R_2 + R_3$$

Series Circuits

- **For resistors in series, it is the same as replacing all resistors with one that has the total value of all in series.**
- **<u>For resistors in series, the same current flows through all resistors and the potential drop across the resistors is equal to the drop across the series.</u>**

$$R_{Total} = R_1 + R_2 + R_3$$

Series Circuits

- <u>**EXAMPLE:**</u> **If resistors of 2Ω, 3 Ω, and 7 Ω are connected in series in a circuit with a current of 2.5 amps what will be the emf in a source with negligible resistance?**

$$R_{Total} = R_1 + R_2 + R_3$$

Series Circuits

- **<u>EXAMPLE:</u> If resistors of 2Ω, 3 Ω, and 7 Ω are connected in series in a circuit with a current of 2.5 amps what will be the emf in a source with negligible resistance?**

$$R_{Total} = R_1 + R_2 + R_3$$

$$R_{Total} = 3 + 2 + 7 = 12$$

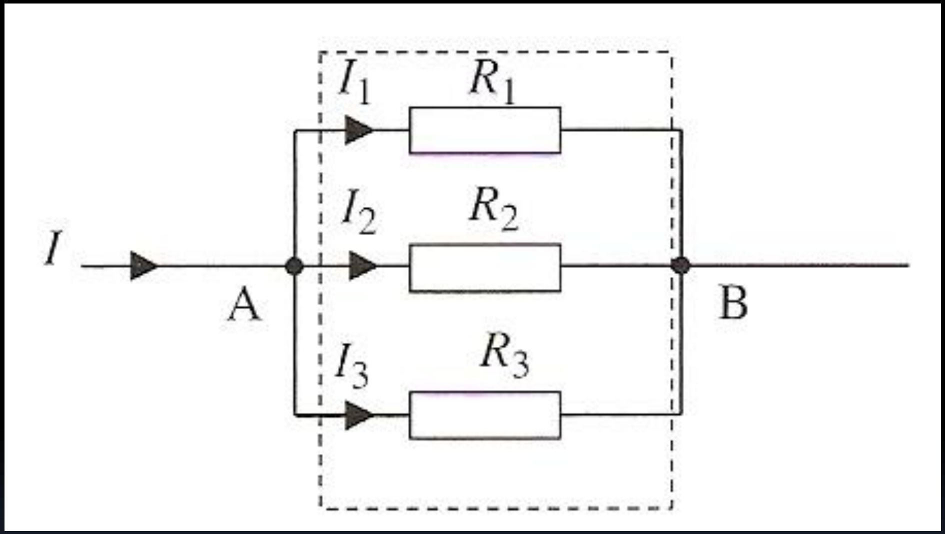
$$V = IR = 2.5x12 = 30V$$

Parallel Circuits

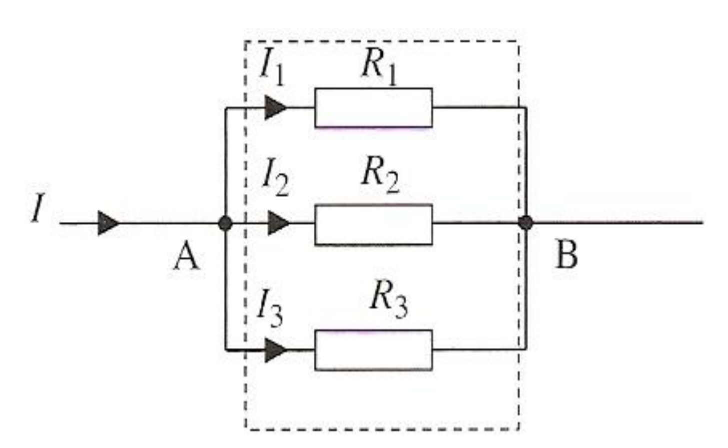
- In parallel circuits, the current splits and flows through two or more resistors
- The current that enters the split must equal the current that exits the split
- The sum of the split currents must equal the current in and out
- The same potential exists across each resistor that is connected in parallel
  - That is what determines the current

Parallel Circuits

- Consider the circuit below



Parallel Circuits



$$V = IR$$

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

$$I_{Total} = I_1 + I_2 + I_3$$

$$I_{Total} = \frac{V}{R_1} + \frac{V}{R_2} + \frac{V}{R_3}$$

$$I_{Total} = V\left(\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}\right)$$

$$\frac{I_{Total}}{V} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

$$R_{Total} = \frac{V}{I_{Total}}$$

$$\frac{1}{R_{Total}} = \frac{I_{Total}}{V} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

Series Circuits

$$R_{Total} = R_1 + R_2 + R_3 + \bullet\bullet\bullet$$

Parallel Circuits

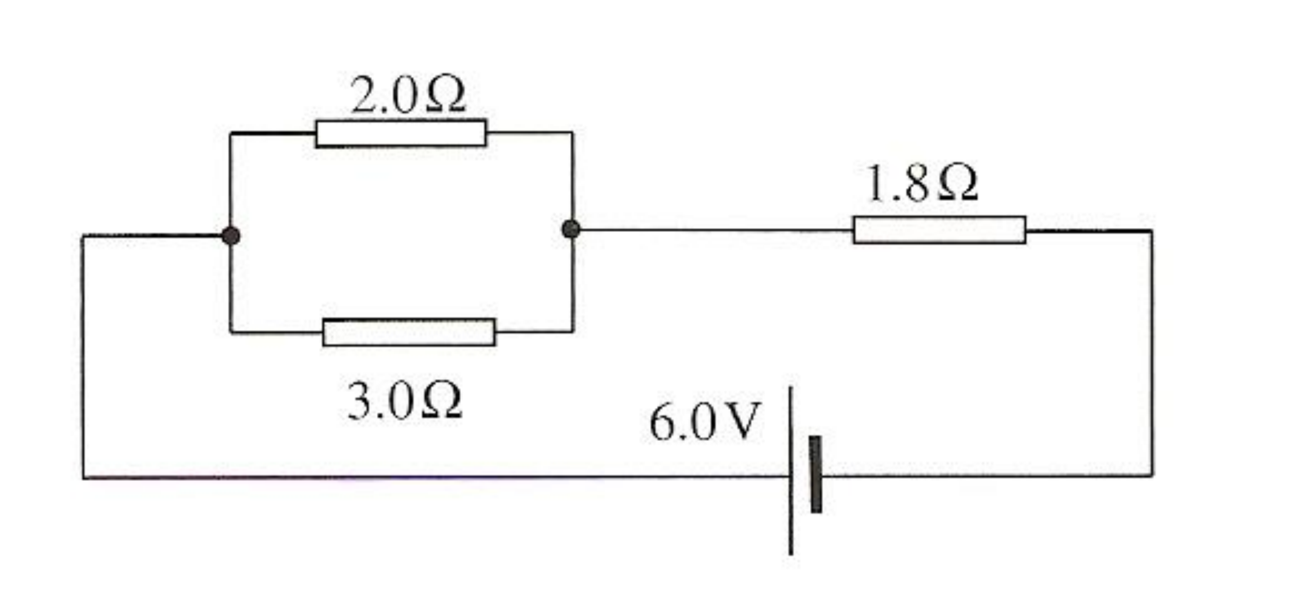
$$\frac{1}{R_{Total}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \bullet\bullet\bullet$$

Analyzing Circuits

- The reason we have learned how to combine resistors that are in series or in parallel is that it gives us a means for analyzing circuits

Analyzing Circuits

- **EXAMPLE: Find the current through each resistor and the potential difference across each resistor in the circuit below:**



- *In series resistors, the current through each resistor is the same and the potential difference (drop) is different.*

- *In parallel resistors, the potential difference (drop) is the same and the current through each resistor is different.*

Kirchhoff's Second Law

- AKA Voltage Law, AKA Loop Law
- The sum of the voltages around a circuit equal zero
  - Voltage across power sources are positive
  - Voltage drops across resisters are negative

$$\Sigma V = 0$$

Kirchhoff's Second Law

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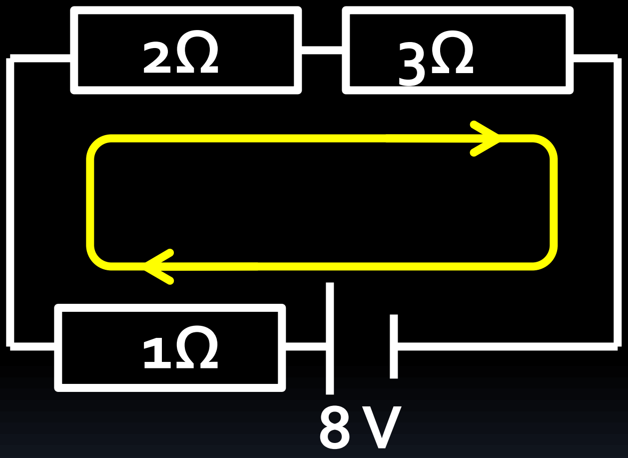
- The sum of the voltages around a circuit equal zero



$$\Sigma V = 0$$

$$V = IR$$

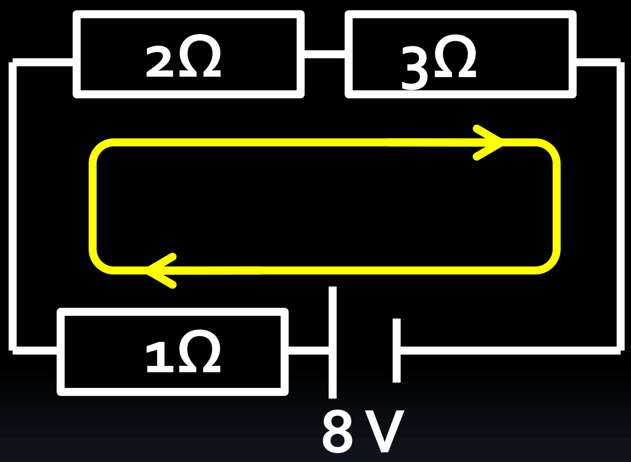
$$\Sigma V = +8 - 1I - 2I - 3I = 0$$

$$8 = 6I$$

$$1.3A = I$$

Kirchhoff's Second Law

- This example illustrates the fact that series resistors can be added.



$$\Sigma V = +8 - 1I - 2I - 3I = 0$$

$$8 = 6I$$

$$R_{total} = 1 + 2 + 3 = 6\Omega$$

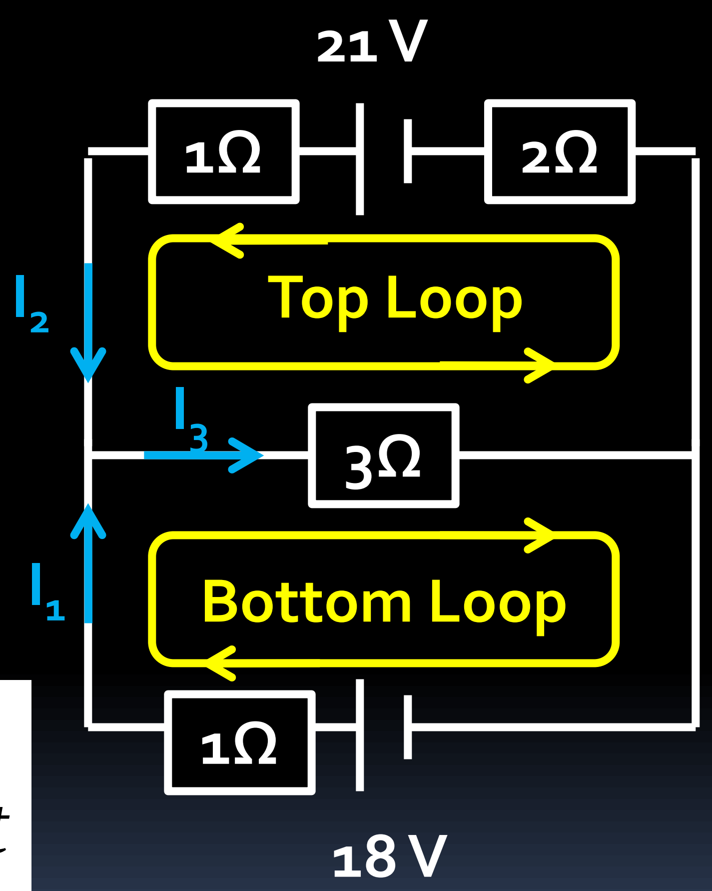
$$V = IR_{total}$$

$$8 = 6I$$

$$1.3 = I$$

Kirchhoff's First Law

- AKA Current Law, AKA Junction Law
- The sum of the currents going into a junction will equal the sum of the currents flowing out of a junction.



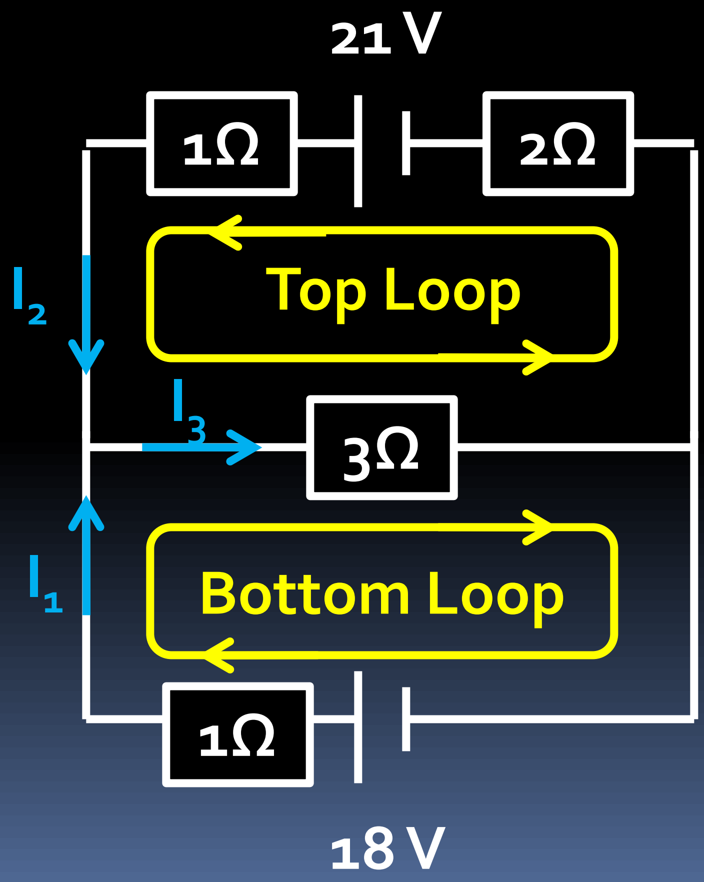
$$\Sigma I_{in} = \Sigma I_{out}$$

$$I_1 + I_2 = I_3$$

Kirchhoff's Laws In Action

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

$$\Sigma V = 0$$



$$I_1 + I_2 = I_3$$

$$21V = (2\Omega)I_2 + (1\Omega)I_2 + (3\Omega)I_3$$

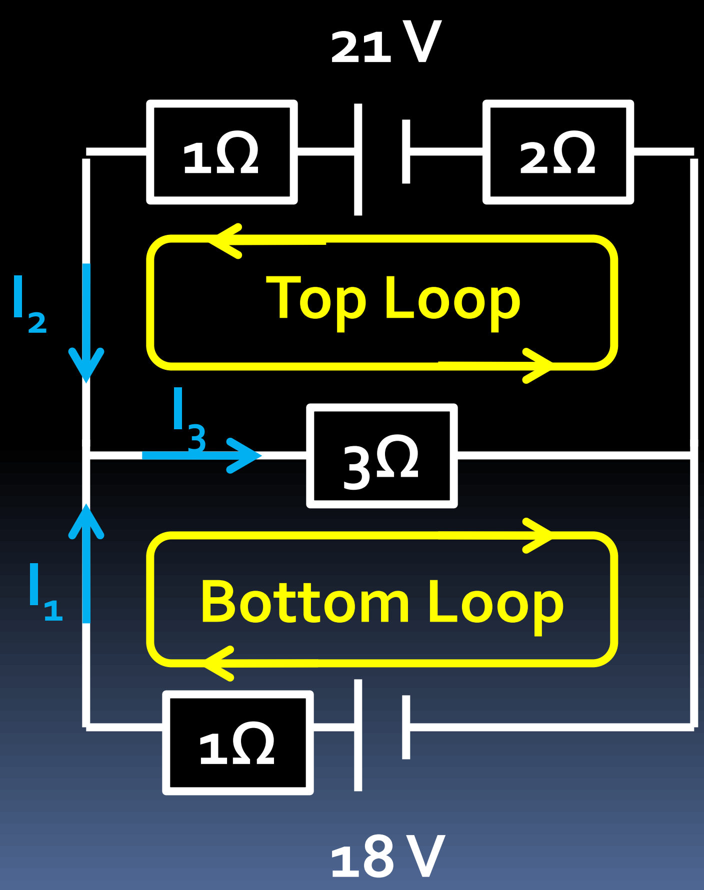
$$18V = (1\Omega)I_1 + (3\Omega)I_3$$

What's your strategy?

Kirchhoff's Laws In Action

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

$$\Sigma V = 0$$



$$I_1 + I_2 = I_3$$

$$21V = (3\Omega)I_2 + (3\Omega)I_3$$

$$18V = (1\Omega)I_1 + (3\Omega)I_3$$

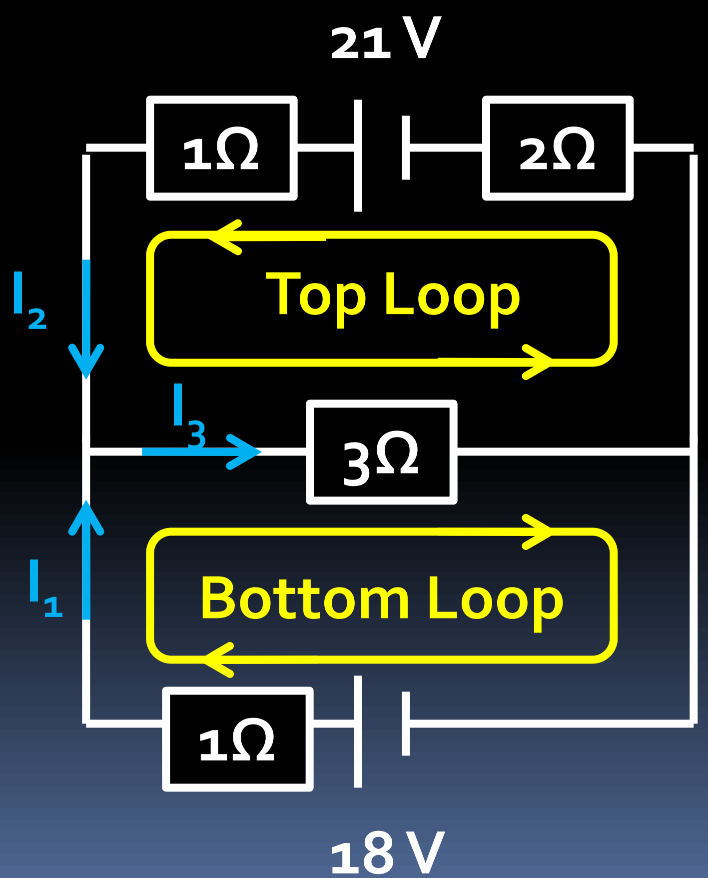
$$18V - (3\Omega)I_3 = (1\Omega)I_1$$

$$18A - 3I_3 = I_1$$

Kirchhoff's Laws In Action

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

$$\Sigma V = 0$$



$$I_1 + I_2 = I_3$$

$$18A - 3I_3 = I_1$$

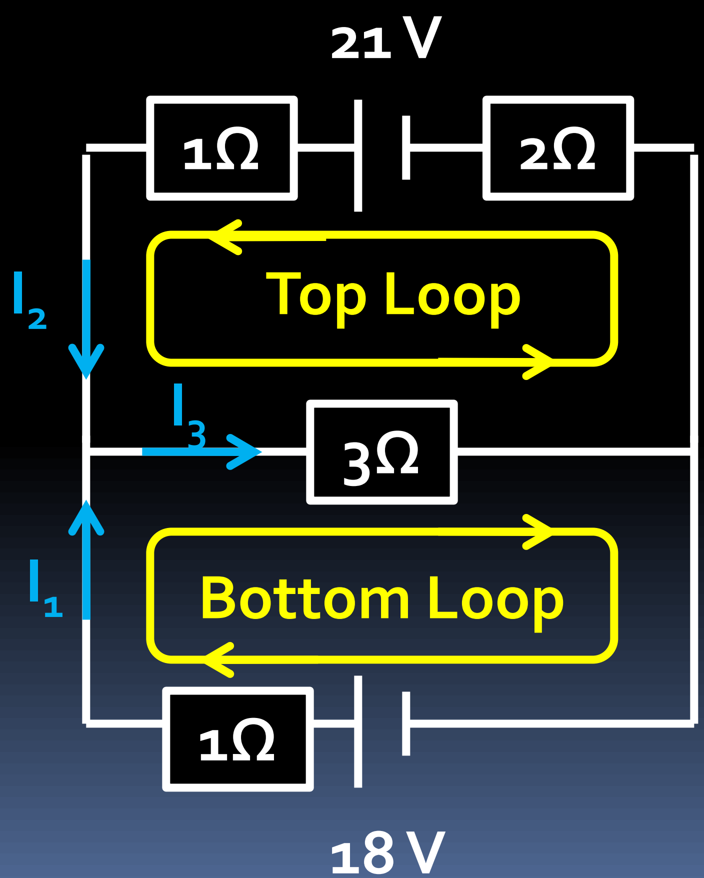
$$21V - (3\Omega)I_3 = (3\Omega)I_2$$

$$7A - I_3 = I_2$$

Kirchhoff's Laws In Action

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

$$\Sigma V = 0$$



$$I_1 + I_2 = I_3$$

$$18A - 3I_3 = I_1$$

$$7A - I_3 = I_2$$

$$(18A - 3I_3) + (7A - I_3) = I_3$$

$$25A - 4I_3 = I_3$$

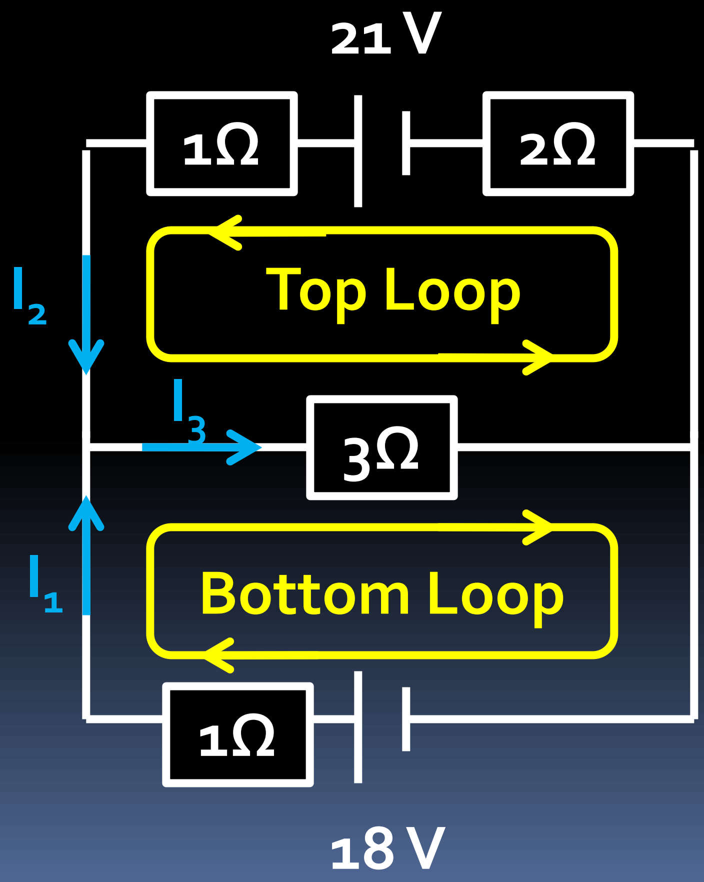
$$25A = 5I_3$$

$$5A = I_3$$

Kirchhoff's Laws In Action

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

$$\Sigma V = 0$$



$$I_1 + I_2 = I_3$$

$$18A - 3I_3 = I_1$$

$$5A = I_3$$

$$7A - I_3 = I_2$$

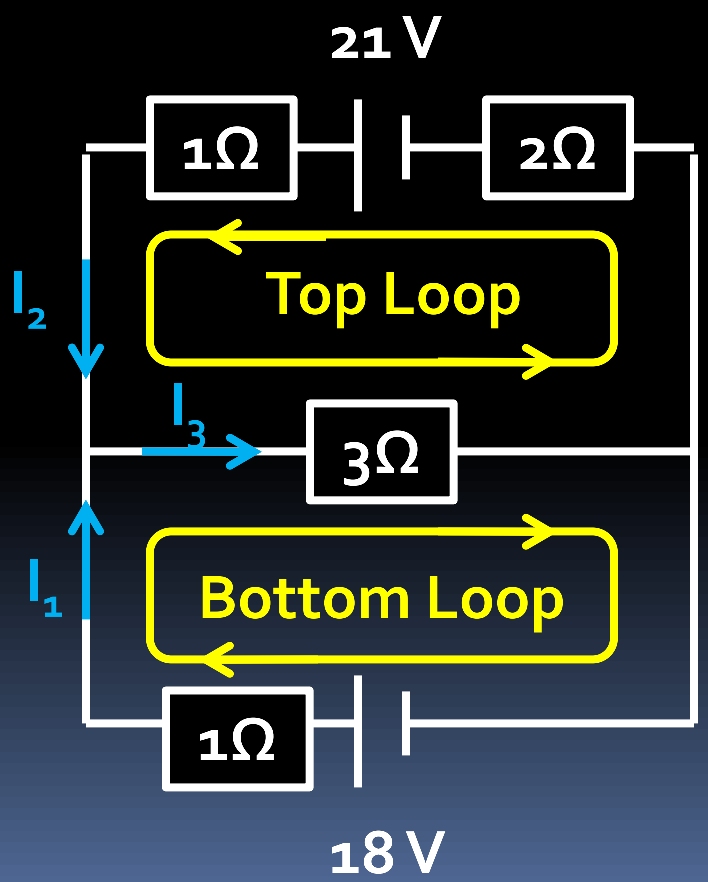
$$7A - 5A = I_2$$

$$2A = I_2$$

Kirchhoff's Laws In Action

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

$$\Sigma V = 0$$



$$I_1 + I_2 = I_3$$

$$18A - 3I_3 = I_1$$

$$5A = I_3$$

$$7A - I_3 = I_2$$

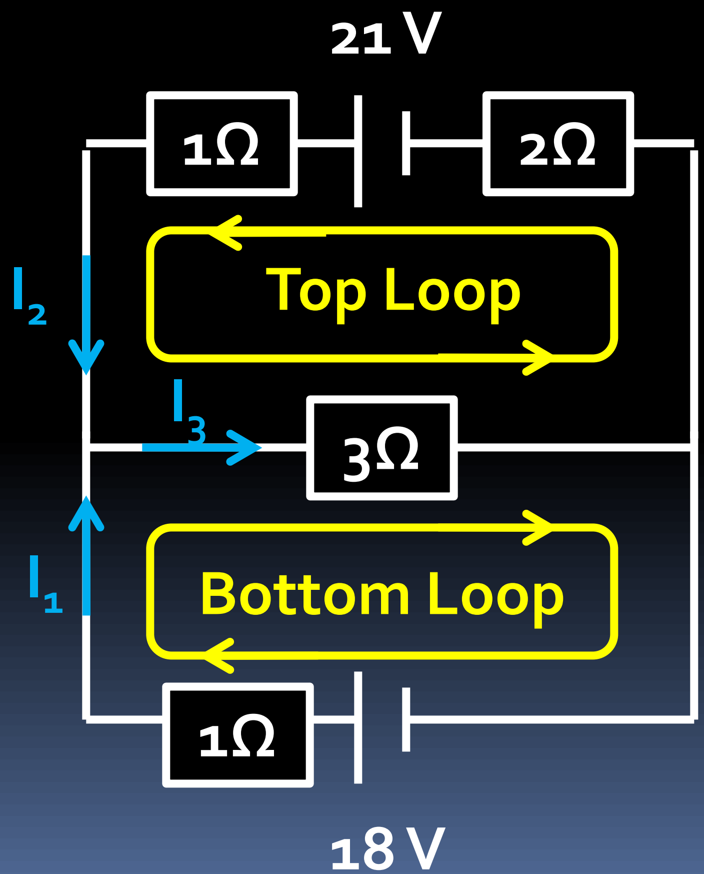
$$7A - 5A = I_2$$

$$2A = I_2$$

Kirchhoff's Laws In Action

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

$$\Sigma V = 0$$



$$I_1 + I_2 = I_3$$

$$5A = I_3$$

$$2A = I_2$$

$$18A - 3I_3 = I_1$$

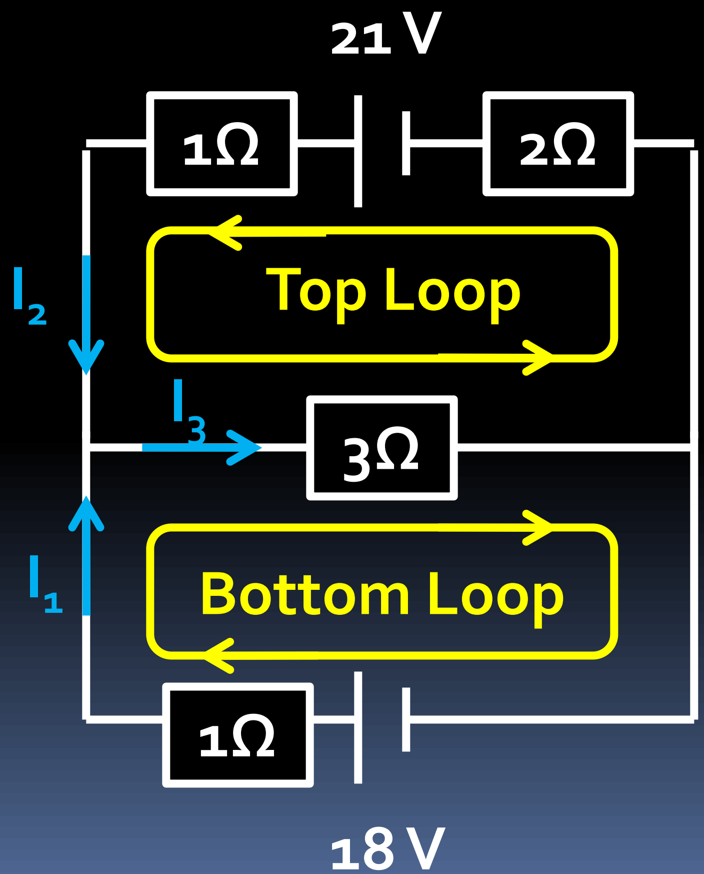
$$18A - 3(5A) = I_1$$

$$3A = I_1$$

Kirchhoff's Laws In Action

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

$$\Sigma V = 0$$



$$5A = I_3$$

$$2A = I_2$$

$$3A = I_1$$

Does it check?

$$I_1 + I_2 = I_3$$

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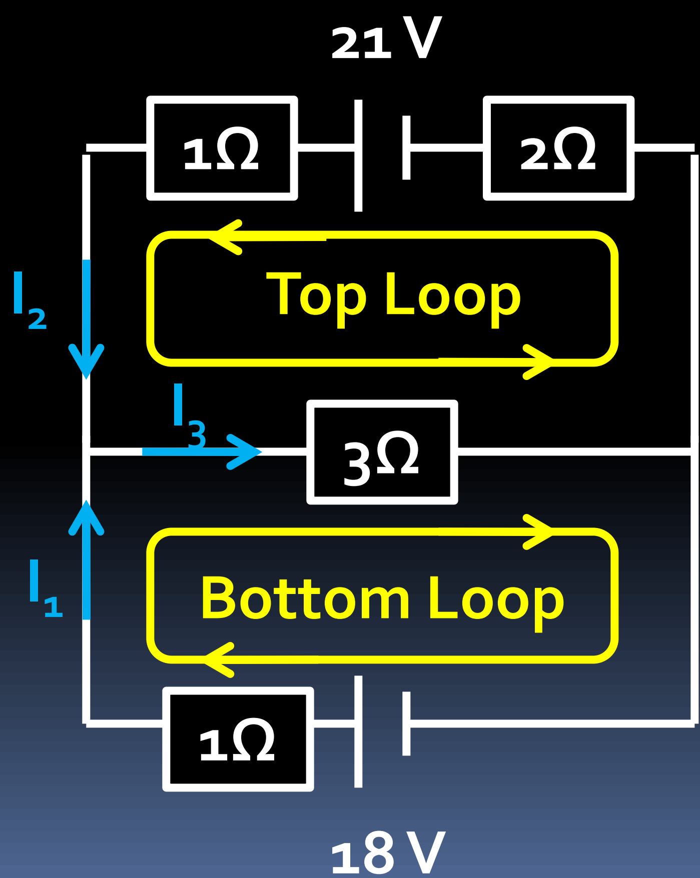

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Problem Solving Strategy

1. ***Label the currents and use direction arrows*** going into a junction. If you guess wrong on the direction, it will just come out negative indicating the opposite direction.
2. ***Identify and label the unknowns*** – this determines how many equations you need.
3. ***Apply Kirchhoff's junction rule*** for one or more junctions.
4. ***Apply Kirchhoff's loop rule*** for one or more loops.
5. ***Solve algebraically*** for the unknowns.

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Enduring Understanding(s):

- The energy of a system is conserved.
- The electric charge of a system is conserved.

Big Idea(s):

- Changes that occur as a result of interactions are constrained by conservation laws.

QUESTIONS?

Homework

#23-31

STOPPED HERE 4/21/15