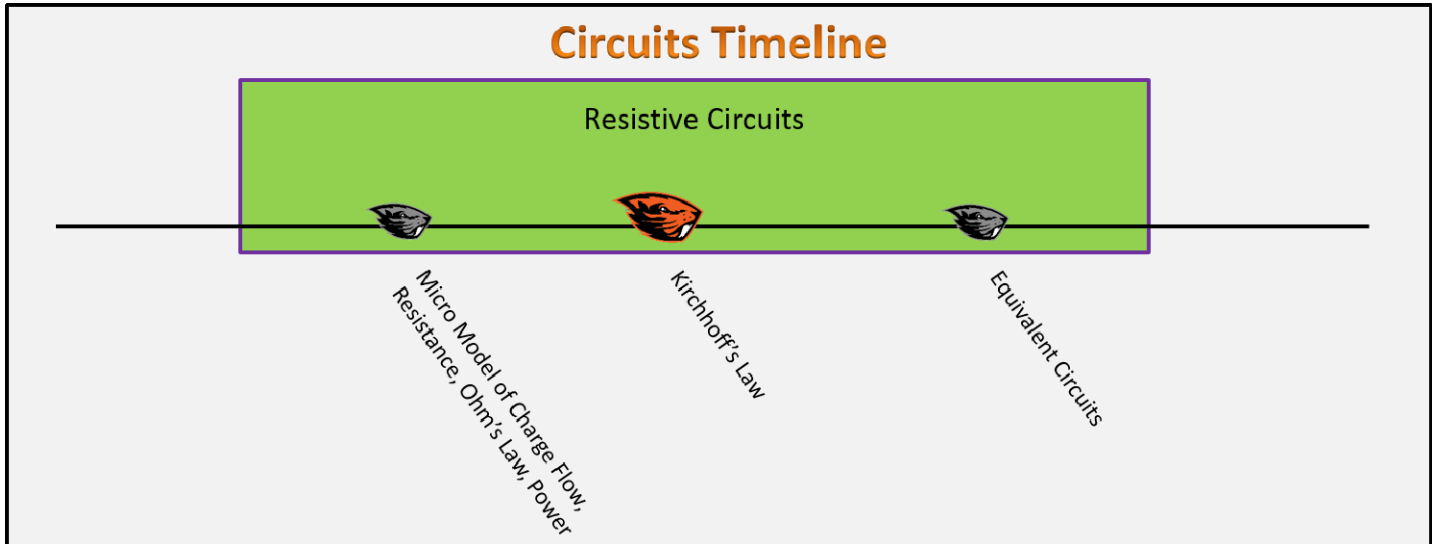


# Circuits

## Foundation Stage (RC.L2.2)

### Lecture 2 Kirchhoff's Laws



#### Textbook Chapters (\* Calculus version)

- **BoxSand** :: KC videos ( [Microscopic Charge Flow](#) )
- **Knight** (College Physics : A strategic approach 3<sup>rd</sup>) ::
- **\*Knight** (Physics for Scientists and Engineers 4<sup>th</sup>) ::
- **Giancoli** (Physics Principles with Applications 7<sup>th</sup>) ::

#### Warm up

**RC.L2.2-01:**

**Description:**

**Learning Objectives:** [?] - Can you identify the objectives from the previous lecture, and this lecture, that this question is relevant to?

**Problem Statement:**

## Selected Learning Objectives

1. Coming soon to a lecture template near you.

## Key Terms

- Electric Force
- Charge
- Coulombs
- Electron
- Proton
- Neutron
- Conductor
- Charge transfer

## Key Equations

$\Delta V = IR$	$I = \frac{\Delta q}{\Delta t}$
$0 = \sum_{loop} \Delta V$	

## Key Concepts

- Coming soon to a lecture template near you.

## Questions

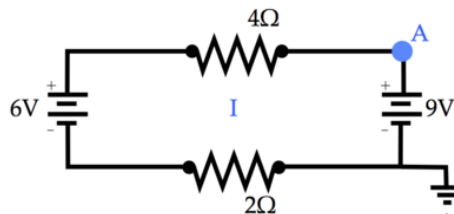
### Act I: Kirchhoff's Loop and Junction Rules

#### RC.L2.2-02:

Description: [?]

Learning Objectives: [?]

**Problem Statement:** What is the electrical potential at point A in the circuit?



- (1) +9 V
- (2) -9 V
- (3) +6 V

$V = 0$

- (1) +9 V
- (2) -9 V
- (3) +6 V
- (4) +3 V
- (5) 0 V
- (6) Can't determine with the information given.

$V = 0$   
"ground"

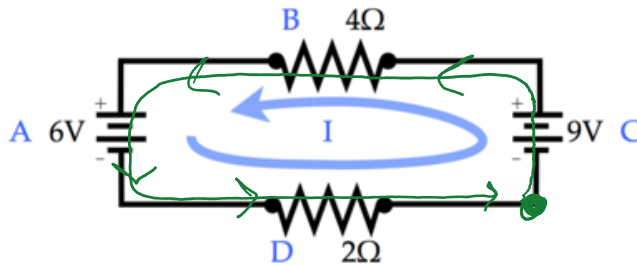
**RC.L2.2-03:**

**Description:** [?]

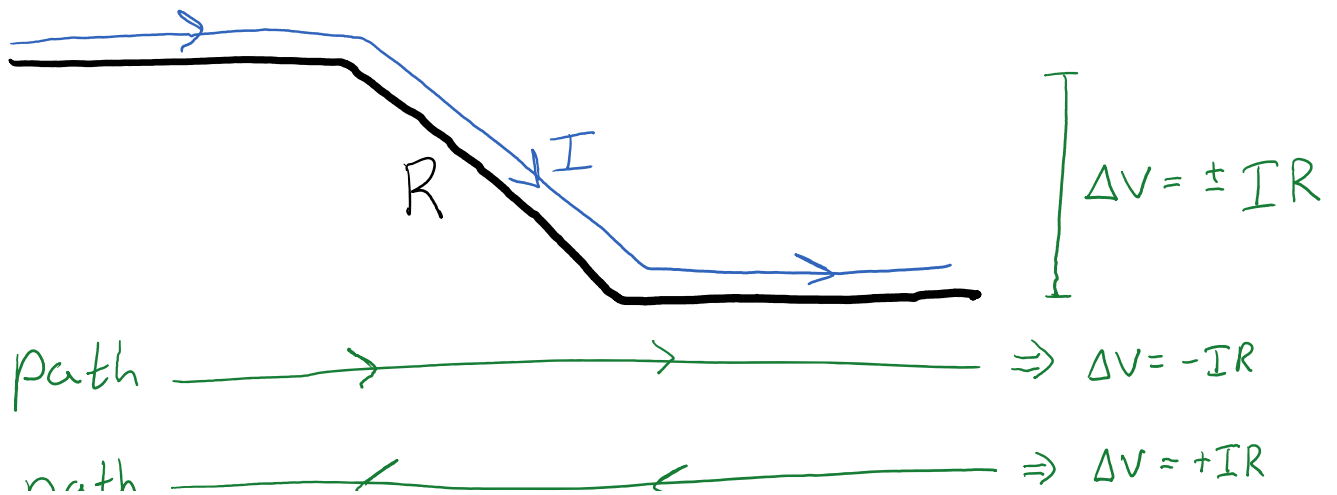
**Learning Objectives:** [?]

**Problem Statement:** Consider the following circuit. List the four potential voltage drops (and gains)  $\Delta V$  encountered going around the loop (don't include units).

Express your answer as a sum that should be zero according to Krichhoff's voltage rule: i.e. " $0 = 1 + 1I + -12I + -2I$ "



$$\sum \Delta V = 0 = +9V - I(4\Omega) - 6V - I(2\Omega)$$



I

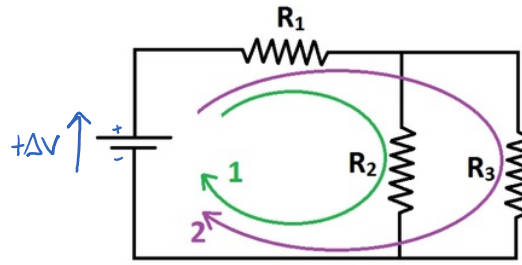
path  $\leftarrow \leftarrow \leftarrow \Rightarrow \Delta V = +IR$

**RC.L2.2-04:**

Description: [?]

Learning Objectives: [?]

**Problem Statement:** Consider the circuit in the figure below where  $I_1$  is the current that goes through  $R_1$ ,  $I_2$  goes through  $R_2$ , and  $I_3$  goes through  $R_3$ . What is the voltage drop across resistor  $R_1$ ?



- (1)  $\Delta V_1 = I_1 R_1$
- (2)  $\Delta V_1 = -I_1 R_1$
- (3)  $\Delta V_1 = -I_{total} R_1$

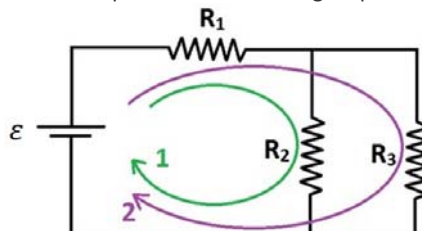
$I_1 = I_{total} = I_{battery}$

**RC.L2.2-05:**

Description: [?]

Learning Objectives: [?]

**Problem Statement:** Which equation satisfies Kirchoff's loop rule when following loop 1?



$$(1) + \mathcal{E} - I_1 R_1 + I_2 R_2 = 0$$

$$(2) + \mathcal{E} - I_2 R_1 - I_1 R_2 = 0$$

$$(3) + \mathcal{E} - I_1 R_1 - I_2 R_2 = 0$$

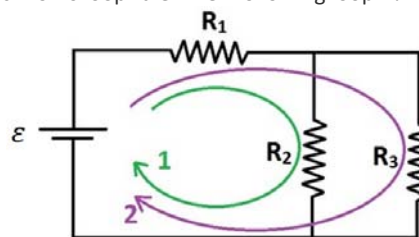
$$(4) + \mathcal{E} + I_1 R_1 + I_2 R_2 = 0$$

**RC.L2.2-06:**

Description: [?]

Learning Objectives: [?]

**Problem Statement:** Which equation satisfies Kirchoff's loop rule when following loop 2?



$$(1) + \mathcal{E} - I_1 R_1 + I_1 R_3 = 0$$

$$(2) + \mathcal{E} - I_1 R_1 - I_3 R_3 = 0$$

$$(3) + \mathcal{E} - I_1 R_1 - I_2 R_2 - I_3 R_3 = 0$$

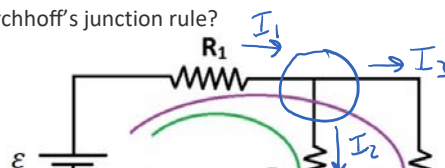
$$(4) + \mathcal{E} + I_1 R_1 + I_3 R_3 = 0$$

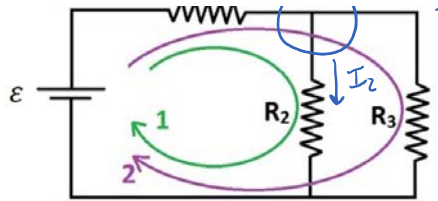
**RC.L2.2-07:**

Description: [?]

Learning Objectives: [?]

**Problem Statement:** Which equation satisfies Kirchoff's junction rule?





- (1)  $I_1 + I_3 = I_2$
- (1)  $I_1 - I_2 = I_3$
- (1)  $I_1 + I_2 = I_3$
- (1)  $I_2 + I_3 = I_1$
- (1)  $V_1 + V_3 = V_2$
- (1)  $V_1 + V_2 = V_3$

Current in = Current out

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

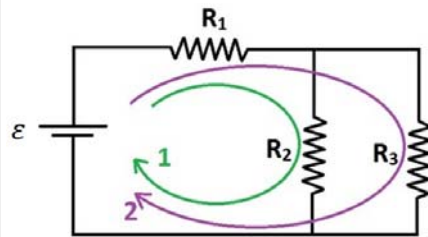
**RC.L2.2-08:**

Description: [?]

Learning Objectives: [?]

**Problem Statement:** With the given values of voltage and resistance, solve for the current in each segment of the circuit:

$\mathcal{E} = 11 \text{ V}$   
 $R_1 = 2 \Omega$   
 $R_2 = 4 \Omega$   
 $R_3 = 6 \Omega$



- (1)  $I_1 = 2.5 \text{ A}, \quad I_2 = 1.5 \text{ A}, \quad I_3 = 1.0 \text{ A}$
- (2)  $I_1 = \cancel{1.0} \text{ A}, \quad I_2 = 1.5 \text{ A}, \quad I_3 = 2.5 \text{ A}$
- (3)  $I_1 = 2.5 \text{ A}, \quad I_2 = \cancel{1.5} \text{ A}, \quad I_3 = 1.0 \text{ A}$
- (4)  $I_1 = 2.5 \text{ A}, \quad I_2 = 1.5 \text{ A}, \quad I_3 = \cancel{1.0} \text{ A}$

$$I_1 = 2.5 \text{ A}$$

$$I_2 = 1.5 \text{ A}$$

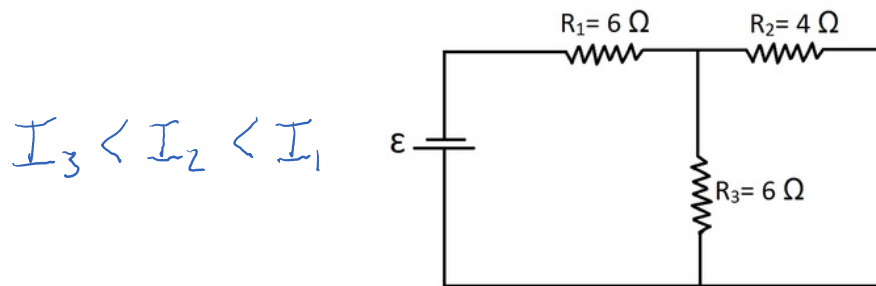
$$I_3 = 1 \text{ A}$$

**RC.L2.2-09:**

Description: [?]

Learning Objectives: [?]

**Problem Statement:** Let  $I_1$  be the current through  $R_1$ ,  $I_2$  be the current through  $R_2$ , and  $I_3$  be the current through  $R_3$ . Rank the current that goes through each resistor from least to greatest.



all current goes through  $R_1$

$R_2 < R_3 \Rightarrow$  more current through  $R_2$

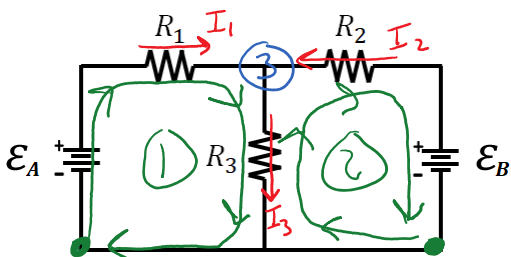
### Act II: Solving Circuits

#### RC.L2.2-10:

Description: [?]

Learning Objectives: [?]

**Problem Statement:** Consider the circuit here.



(a) If given values for the voltages and resistances, how many equations will you need in order to solve for the currents through each resistor?

- (1) 1
- (2) 2
- (3) 3
- (4) 4
- (5) 5

3 currents  $\Rightarrow$  3 unknowns  $\Rightarrow$  3 eqs

(b) Find the system of equations (of the appropriate number you found in the previous problem) that will let you solve for the currents.

(b) Find the system of equations (of the appropriate number you found in the previous problem) that will let you solve for the currents.

$$\begin{aligned} \textcircled{1} \quad \Delta V = 0 &= +\mathcal{E}_A - I_1 R_1 - I_3 R_3 \\ \textcircled{2} \quad \Delta V = 0 &= +I_3 R_3 + I_2 R_2 - \mathcal{E}_B \\ \textcircled{3} \quad I_1 + I_2 &= I_3 \end{aligned} \quad \left. \vphantom{\begin{aligned} \textcircled{1} \\ \textcircled{2} \\ \textcircled{3} \end{aligned}} \right\} \begin{array}{l} \text{direction of path/loop} \\ \text{can work either way!} \end{array}$$

(c) If  $\mathcal{E}_A = 6\text{ V}$ ,  $\mathcal{E}_B = 1\text{ V}$ ,  $R_1 = 2\ \Omega$ ,  $R_2 = 4\ \Omega$ , and  $R_3 = 3\ \Omega$  find the currents through each of the resistors.

$$\begin{aligned} \textcircled{1} \quad 0 &= 6\text{ V} - I_1(2\ \Omega) - I_3(3\ \Omega) \\ \textcircled{2} \quad 0 &= I_3(3\ \Omega) + I_2(4\ \Omega) - 1\text{ V} \\ \textcircled{3} \quad I_1 + I_2 &= I_3 \\ \textcircled{3} \Rightarrow I_1 &= I_3 - I_2 \\ \textcircled{3} \rightarrow \textcircled{1} \Rightarrow 0 &= 6\text{ V} - (I_3 - I_2)(2\ \Omega) - I_3(3\ \Omega) \\ \text{sloppy units} \Rightarrow 0 &= 6 - 2I_3 + 2I_2 - 3I_3 \\ 0 &= 6 - 5I_3 + 2I_2 \end{aligned}$$

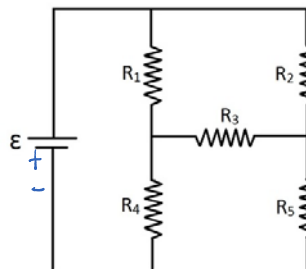
$$\begin{aligned} I_3 &= \frac{1}{5}(6 + 2I_2) \\ I_3 &= \frac{6}{5} + \frac{2}{5}I_2 \\ \textcircled{2} \Rightarrow 0 &= \frac{18}{5} + \frac{6}{5}I_2 + 4I_2 - 1 \\ 0 &= \frac{13}{5} + \frac{26}{5}I_2 \\ -\frac{13}{5} \frac{5}{26} &= I_2 = -\frac{1}{2}\text{ A} \\ \textcircled{2} \Rightarrow 0 &= 3I_3 + 4(-\frac{1}{2}) - 1 \\ \Rightarrow 1\text{ A} &= I_3 \\ \textcircled{3} \Rightarrow I_1 &= 1\text{ A} - (-\frac{1}{2}\text{ A}) = 1.5\text{ A} \\ I_1 &= 1.5\text{ A} \end{aligned}$$

### RC.I2.2-11:

Description: [?]

Learning Objectives: [?]

**Problem Statement:** If you want a challenge, consider the circuit below.



(a) What minimum number of loops can be used when applying Kirchhoff's loop rule to completely account for each element?

(a) What minimum number of loops can be used when applying Kirchhoff's loop rule to completely account for each element?

3

(b) Let  $I_1$  be the current through  $R_1$ ,  $I_2$  be the current through  $R_2$ ... How many values of  $I$  are present in this circuit?

6, each resistor + battery

(c) How many *unique* current junctions are there?

3

(d) Which set of equations is valid for this circuit?

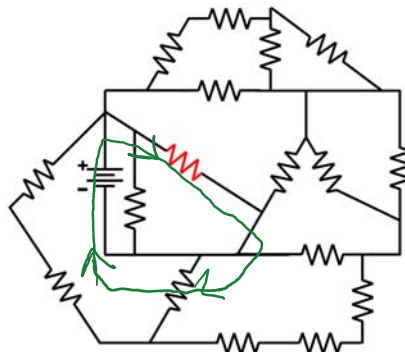
<p>(1)</p> <p><del><math>+\mathcal{E} - I_1R_1 - I_4R_4 = 0</math></del> <i>not consistent</i></p> <p><math>+\mathcal{E} - I_2R_2 - I_5R_5 = 0</math></p> <p><math>+I_2R_2 + I_3R_3 + I_1R_1 = 0</math></p> <p><math>+I_2R_2 + I_3R_3 + I_1R_1 = 0</math></p>	<p>(2)</p> <p><del><math>+\mathcal{E} - I_1R_1 - I_4R_4 = 0</math></del></p> <p><math>+\mathcal{E} - I_2R_2 - I_5R_5 = 0</math></p> <p><math>+\mathcal{E} - I_2R_2 + I_3R_3 + I_1R_1 = 0</math></p> <p><del><math>+\mathcal{E} - I_5R_5 + I_4R_4 - I_3R_3 = 0</math></del></p>	<p>(3)</p> <p><math>+\mathcal{E} - I_1R_1 - I_4R_4 = 0</math></p> <p><math>+\mathcal{E} - I_2R_2 - I_5R_5 = 0</math></p> <p><math>-I_2R_2 + I_3R_3 + I_1R_1 = 0</math></p> <p><math>-I_5R_5 + I_4R_4 - I_3R_3 = 0</math></p>
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### RC.L2.2-12:

Description: [?]

Learning Objectives: [?]

**Problem Statement:** Another challenge problem! (this one is easier!) Assume each resistor is  $1\ \Omega$ , and the battery is  $1\ \text{V}$ . Find the current through the red resistor.



$$0 = +\mathcal{E} - IR$$

$$\Rightarrow 0 = +1V - I(1\Omega)$$

$$\Rightarrow I = 1A$$

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### Conceptual questions for discussion

1. Coming soon to a lecture template near you.
- 

### Hints

RC.L1.2-01: No hints.

RC.L1.2-02: No hints.

RC.L1.2-03: No hints.

RC.L1.2-04: No hints.

RC.L1.2-05: No hints.

RC.L1.2-06: No hints.

RC.L1.2-07: No hints.

RC.L1.2-08: No hints.

RC.L1.2-09: No hints.

RC.L1.2-10: No hints.

RC.L1.2-11: No hints.

RC.L1.2-12: No hints.

RC.L1.2-13: No hints.

RC.L1.2-14: No hints.

RC.L1.2-15: No hints.

RC.L1.2-16: No hints.

RC.L1.2-17: No hints.