# *ECET 3000*

## *Electrical Principles*

## *Ground & Node Voltages*

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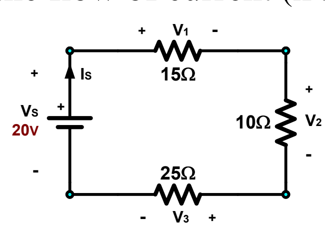
# Voltages in an Electric Circuit

In the circuit shown below, the **voltage** defined across each circuit element can be thought of as a measure of either:

- the **change in the potential energy** of charge as it flows through that element, or
- the **force developed by the circuit element** that tries to
  - · to induce the flow of current (if a source), or
  - · to prevent the flow of current (if a load).

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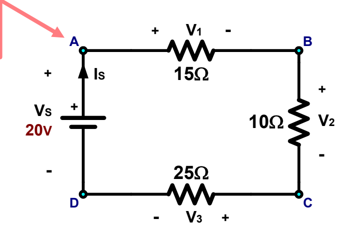
# Expressing Voltages in Terms of Nodes

Instead of expressing the voltages in terms of the circuit elements across which the potential differences exist, the voltages can also be expressed in terms of the **nodes** to which the circuit elements are connected.

**Remember that a "node" is a common point of connection between two or more elements within an electric circuit.**




**Each of the nodes in the circuit were assigned a name; either A, B, C, or D.**

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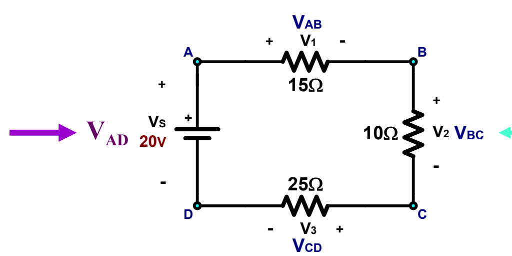
# Expressing Voltages in Terms of Nodes

In terms of nodes, the source is connected between nodes **A** and **D**, so the **source voltage**, $V_S$, can also be expressed as $\mathbf{V_{AD}}$ ($V_S \equiv V_{AD}$).

If considered a **potential difference** (**voltage**):

- $\mathbf{V_S}$ is the potential difference across the source, and
- $\mathbf{V_{AD}}$ is the potential difference between nodes **A** and **D**.

**Equivalent**




**Similarly, the voltage, $V_2$, across the 10Ω resistor can be expressed as $V_{BC}$. ($V_2 \equiv V_{BC}$)**

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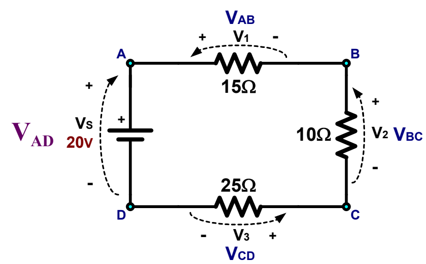
# Defining Voltages in Terms of Nodes

For example, the source is connected between nodes **A** and **D**, so the **source voltage**, $V_S$, can also be expressed as $\mathbf{V_{AD}}$ ($V_S \equiv V_{AD}$).

Or, if used to define a **voltage-rise** (**increase in potential**):

- $\mathbf{V_S}$ is the voltage-rise across the source from – → + , and
- $\mathbf{V_{AD}}$ is the voltage-rise from node **D** (–) → node **A** (+).

**When two subscripts are used to define a voltage-rise from one node to another, the voltage $V_{XY}$ is defined as the voltage-rise from node Y (–) to node X (+).**




**Thus, $V_{BC}$ is the voltage-rise from node C → B.**

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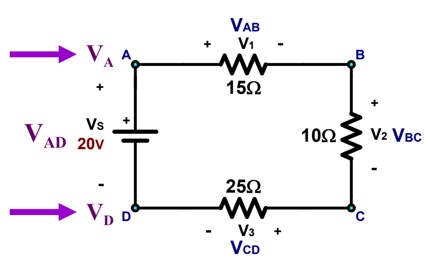
# Voltage Based on Node Potentials

If $\mathbf{V_{AD}}$ is the **potential difference** that exists between two nodes, doesn't that imply a <u>difference function</u> exists for $\mathbf{V_{AD}}$ such that:

$$V_{AD} = V_A - V_D$$

where: $\mathbf{V_A}$ would be the **potential** at node **A**, and
$\mathbf{V_D}$ would be the **potential** at node **D**?

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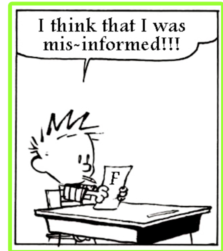
# Do Nodes Have Potential?

Yet, if **voltage** is the **potential difference** between two nodes in a circuit, and $\mathbf{V_{AD}}$ is defined by the difference function:

$$V_{AD} = V_A - V_D$$




then what exactly is **meant** by the statements:

- $\mathbf{V_A}$ is the **potential** at node **A**, or
- $\mathbf{V_D}$ is the **potential** at node **D**?

For the equation $V_{AD} = V_A - V_D$ to hold true, $\mathbf{V_{AD}}$, $\mathbf{V_A}$, and $\mathbf{V_D}$ must all have the same units (volts), which would lead us to believe that $\mathbf{V_{AD}}$ is the difference between the two **voltages** $\mathbf{V_A}$ and $\mathbf{V_D}$.

But if $\mathbf{V_A}$ is the **potential** at node A… and yet it's also a voltage, which is a **potential difference**, how can $\mathbf{V_A}$ be a "**potential**" and a "**potential difference**" at the same time???

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# The "Potential" at a Node

We originally defined **voltage** as the work per unit of charge required to move that charge from one location to another, such that:

$$V = \frac{W}{Q} \text{ (volts)},$$

and that a voltage of **1 volt** exists between points ***a*** and ***b*** if **1 joule** of energy is required to move **1 coulomb** of charge from $\boldsymbol{b} \rightarrow \boldsymbol{a}$.

But, based on the above equation, voltage could also be defined as the **amount of potential energy**, ***W***, contained within an amount of charge, ***Q***, when **at a specific location**.

**I.e. – the "potential" at a that location.**

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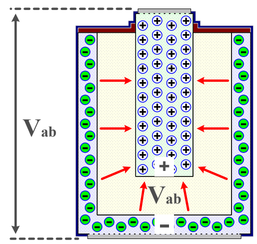
# The Potential Energy within Charge

When we discussed the operation of a **battery**, we stated that:

The battery develops a voltage across its terminals that equals the amount of energy required to move a coulomb of charge internally from the positive to the negative charged region, in opposition to the electrostatic force, such that the energy released by the chemical reaction is delivered to the charge as potential energy, thus **increasing the total potential (energy) of the charge**.

But, **we never considered** the potential of the charge (the exact amount of energy contained within the charge) before or after it was moved, or whether it even had a potential to begin with;




We only considered the "**change in potential**".

**I.e. – the "potential difference".**

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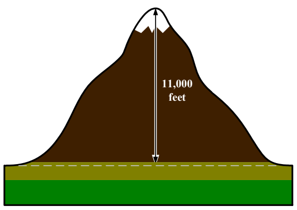
# The Importance of a Reference Value

Similar to the "height of an object", the "**potential of charge**" holds **no practical relevance** unless compared to the charge's potential at an **arbitrary reference** point.

**If a plane is currently flying at a height of 12,000 feet and maintains level flight (neither ascending or descending), will it safely pass over a mountain if that mountain is 11,000 feet tall from base to peak?**

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# The Importance of a Reference Value

Similar to the "height of an object", the "**potential of charge**" holds **no practical relevance** <u>unless</u> compared to the charge's potential at an **arbitrary reference** point.

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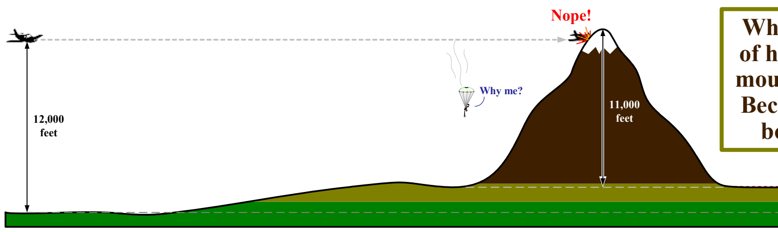


**Why do pilots use <u>altitude</u> instead of height, and why do they classify mountain peaks by their <u>elevation</u>? Because altitude and elevation are both <u>referenced</u> to "sea level".**

**The values 11,000 and 12,000 were referenced to two different surfaces.**

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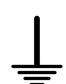
# "Ground"

In electric circuits, **ground** provides an arbitrary **zero-volt reference** to which the potential at any node in a circuit can be compared.

**Thus, when one node is selected as the ground-node, the concept of defining a voltage potential (with respect to ground) for a different node is similar to defining an elevation (with respect to sea level) for a specific location on the earth.**

The two **symbols** that are most commonly used to denote **ground** in an electric circuit are:

 and 

but these symbols actually represent different things.

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# Common (Signal) Ground

In circuit analysis, a **common ground** may simply be thought of as the **zero-volt reference** point to which the voltage potential present at any node in the circuit can be compared.

**Common Ground**

In electronic circuits, common ground is also called **signal ground**, because it provides a common return path for any currents that relate to the signals (voltages) that are present in the circuit.

The are many important aspects of ground relating to circuit design, but since our focus at this time is circuit analysis, and not design, we will only consider "**common ground**" as defined above.

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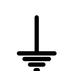
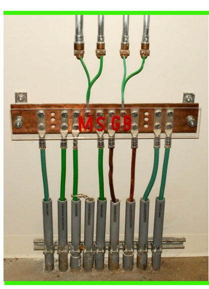
# Earth Ground

**Earth ground** refers to a point in a circuit at which the electric potential is held equal to the potential that exists within the earth (i.e. – the actual ground) at that location.



**Earth Ground**



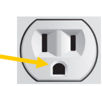
**Q-building Main Switchboard Ground Bus**

In building wiring systems, **earth ground** may be composed of a set of grounding conductors that are connected to one or more conductive rods that, in-turn, are driven deep into the physical ground.

Note that the **earth ground** for a building's wiring system is required for **safety reasons** that are beyond the scope of this presentation.

**Grounding Electrode at My House**

**Note that, if supplied using the voltage available from a wall outlet, the "common ground" of an electric circuit is often connected to the "earth ground" via the outlet's 3rd terminal.**



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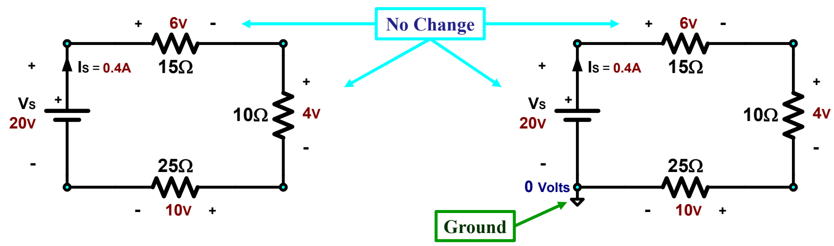
# Ground Location and Circuit Operation

The choice of an arbitrary **ground node** within a circuit is denoted by connecting the ground symbol to that node.




When a **single node** is chosen as the location for common ground, the **normal operation** of the circuit **remains unchanged**.

**Note – placing a ground symbol at more than one node implies that all of those nodes are actually connected together by an ideal wire. (I.e. – a "common" ground)**

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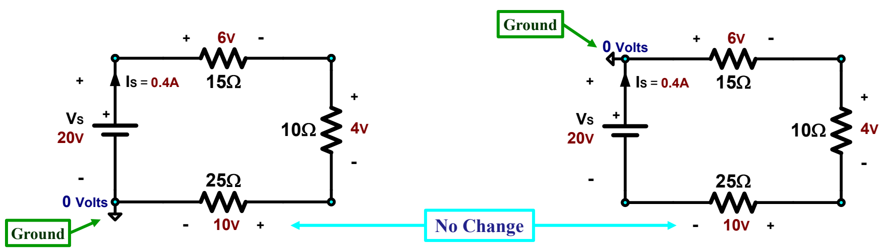
# Ground Location and Circuit Operation

Since the addition of a ground connection to a single node within a circuit does not affect the circuit's operation*, the specific choice of the **ground location** also has no effect on its operation*.

* – For example, whether the positive or negative terminal of a battery is selected as ground, a circuit's operation will remain unchanged such that **the voltages across each element** and **the current through each element** will be the same in either case.

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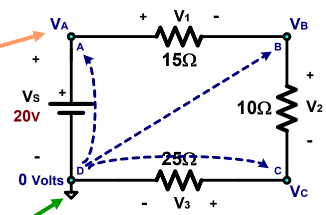
# Node Voltages

Once a ground node (zero-volt reference) is chosen for a circuit, then a set of node voltages can be defined, such that the **node voltage** of a specific node is the **potential difference** (voltage-rise) that exists **from ground to that specific node**.

**Node voltage $V_A$ is defined as the voltage potential at node A compared to ground, or simply as the voltage-rise from ground → node A.**




**Node D ≡ Ground (zero-volt reference)**

**Nodes A, B, and C have been assigned variables $V_A$, $V_B$, and $V_C$ to represent their node voltages.**

**Note that node D has not been assigned a variable because that node was connected to ground, thus constraining its voltage to the 0-volt reference value.**

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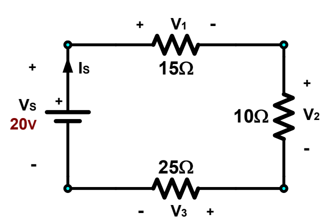
# Determining the Node Voltages

There is a simple*, indirect method that can be applied in order to determine the **node voltages** that exist within a circuit, provided that the you are able analyze the circuit's normal operation.

*** – The method for solving the node voltages is simple.**

**On the other hand, the difficulty of the analysis that must be performed in order to determine the circuit's normal operation will vary depending on the complexity of the circuit.**




**There is a direct method, called "Nodal Analysis", that can be utilized in order to solve each of the node voltages in a circuit without first determining the circuit's normal operation.**

**But, that method is more complex because it requires solving a set of simultaneous equations, and thus we will not cover Nodal Analysis during this course.**

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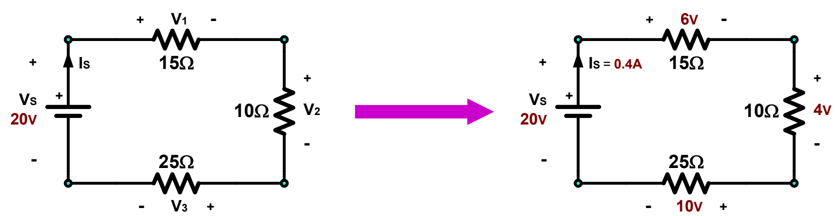
## Determining the Node Voltages

But as stated, before you can determine the values of the various **node voltages** in a circuit, you must first:

- **Analyze the circuit** (as discussed in the DC Electric Circuits lectures) in order to solve for the **voltage across each circuit element**.




**Since this is a simple circuit that contains only series-connected resistors, the steps required to solve the current and the various voltages in the circuit will not be shown in this presentation.**

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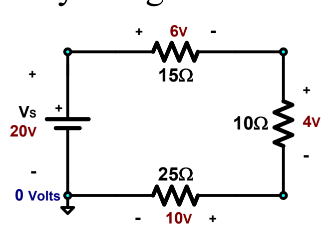
## Determining the Node Voltages

Once the circuit has been fully analyzed and all of the element voltages are known, the next step is to **choose the ground node**, unless it was already specified for you (as will occur on an exam).

In this example, the battery's negative terminal will be "**grounded**".




**Grounding the negative terminal of a battery is common practice in the United States.**
**For example, the metal frame of almost every US-manufactured vehicle is connected to the negative terminal of the vehicle's battery in order to provide a common ground for all of the vehicle's electrical systems.**
**Note that this practice may differ for older US vehicles and in other countries.**

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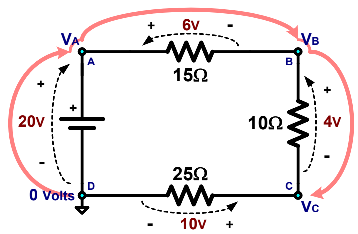
# Determining the Node Voltages

Once the circuit element voltages are all known, and the ground node has been set, the **node voltages** can be determined by:

- Beginning at a node whose voltage is "**known**" (i.e. – ground), step through the circuit, node-by-node, determining the voltage of each **adjacent node** based on the voltage of the previous node and the potential difference across the interconnecting element.

**Each unknown node voltage is equal to the known voltage at the adjacent node plus the potential difference, defined in the direction from: known → unknown node, across the element that connects the two nodes.**




**The process is repeated until the voltage at every node has been defined.**

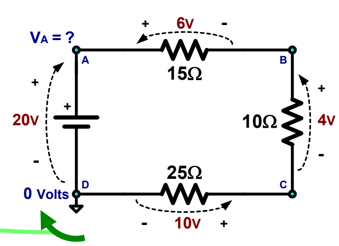


# Node Voltage Example

Determine the **node voltages** in the following circuit:

**1)** Beginning at ground, **solve** for the **voltage** at an **adjacent node**, in this case node **A**, based on the **potential difference** across the element that connects the adjacent node to ground.

**In this example, we'll travel clockwise around the circuit from ground, node-by-node to each adjacent node, until all of the unknown node voltages are defined.**

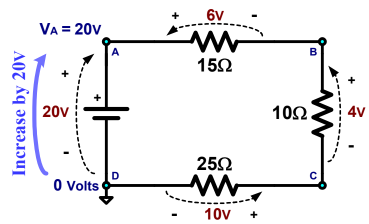


## Node Voltage Example

Determine the **node voltages** in the following circuit:

**1)** Beginning at ground, **solve** for the **voltage** at an **adjacent node**, in this case <u>node **A**</u>, based on the **potential difference** across the element that connects the adjacent node to ground.

$$V_A = 0 + 20\text{V} = 20\text{V}$$




**Since we are traveling upwards across the source from ground to adjacent <u>node A</u>, the voltage at node A, $V_A$, is equal to the voltage at ground (0 volts) <u>plus</u> the increase in potential that occurs when traveling upwards across the source (20 volts).**

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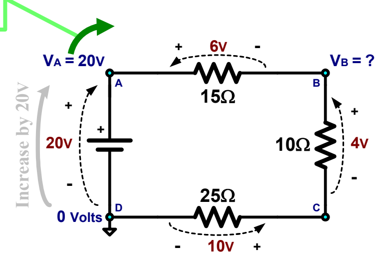
## Node Voltage Example

Determine the **node voltages** in the following circuit:

**2)** Now that $\mathbf{V_A}$ is known, repeat the process in order to solve for the voltage at <u>node **B**</u> based on $\mathbf{V_A}$ and the **potential difference** across the element that connects nodes **A** and **B**.

**Continuing <u>clockwise</u> travel from node A → B:**

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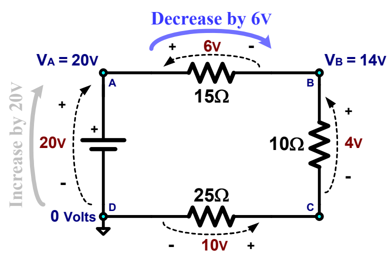
# Node Voltage Example

Determine the **node voltages** in the following circuit:

**2)** Now that $\mathbf{V_A}$ is known, repeat the process in order to solve for the voltage at <u>node **B**</u> based on $\mathbf{V_A}$ and the **potential difference** across the element that connects nodes **A** and **B**.

$$V_B = V_A - 6\text{V} = 14\text{V}$$




**We are traveling from node A, left-to-right across the 15Ω resistor, to adjacent <u>node B</u>, but the voltage-rise across the resistor is defined in the opposite direction.**
**Thus, the node B voltage, $V_B$, is equal to the voltage at node A (20 volts) <u>minus</u> the decrease in potential that occurs when traveling left-to-right across the resistor (6 volts).**

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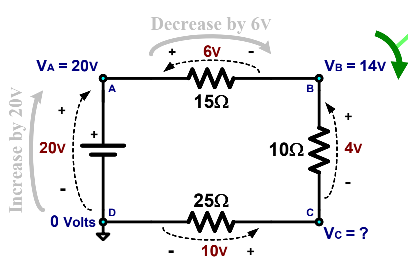
# Node Voltage Example

Determine the **node voltages** in the following circuit:

**3)** And then, now that $\mathbf{V_B}$ is known, repeat the process to solve for the voltage at <u>node **C**</u> based on $\mathbf{V_B}$ and the **potential difference** across the element that connects nodes **B** and **C**.

**Continuing <u>clockwise</u> travel from node B → C:**

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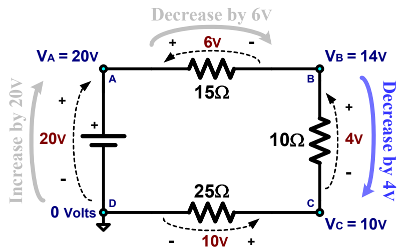
# Node Voltage Example

Determine the **node voltages** in the following circuit:

**3)** And then, now that $\mathbf{V_B}$ is known, repeat the process to solve for the voltage at <u>node **C**</u> based on $\mathbf{V_B}$ and the **potential difference** across the element that connects nodes **B** and **C**.

$$V_C = V_B - 4\text{V} = 10\text{V}$$

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# Node Voltage Example

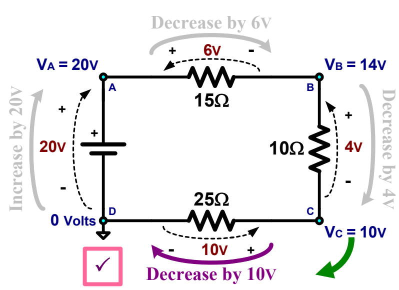
Determine the **node voltages** in the following circuit:

**4) Check your results**?

**You can check the results by returning back to the ground node.**

$\mathbf{V_D = V_C - 10V = 0V}$ ✓

**Continuing <u>clockwise</u> travel from node C → ground:**

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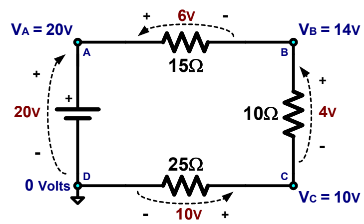
# Node Voltage Example

Thus, the **node voltages** in the circuit are:

$$V_A = 20\text{V}$$
$$V_B = 14\text{V}$$
$$V_C = 10\text{V}$$
$$V_D = \ \ 0\text{V}$$

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# Node Voltage Example (CCW)

Note that the **same results** would be obtained if traveling **CCW**:

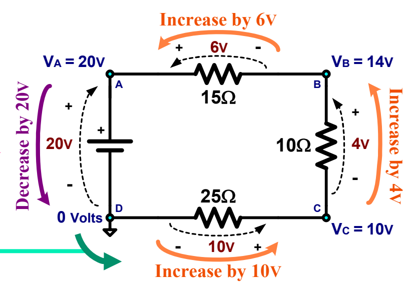
$$V_C = 0 - 10\text{V} = 10\text{V}$$
$$V_B = V_C + 4\text{V} = 14\text{V}$$
$$V_A = V_B + 6\text{V} = 20\text{V}$$

**CW Results:**

$$V_A = 20\text{V}$$
$$V_B = 14\text{V}$$
$$V_C = 10\text{V}$$

**Checking the results:**
$V_D = V_A - 20\text{V} = 0\text{V}$ ✓

**Traveling counter-clockwise: from ground.**

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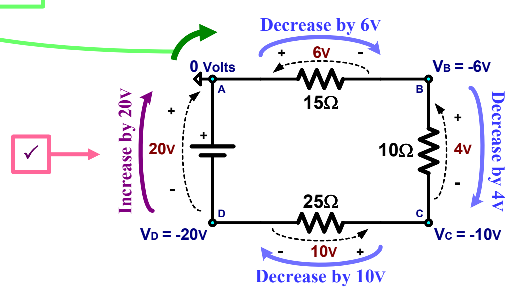
# Node Voltage Example (Positive Ground)

But, what if the **positive terminal** of the source was **grounded** <u>instead</u> of the negative terminal?

**Following the same procedure as before, but this time traveling clockwise from the <u>new</u> ground node.**

$$V_B = 0 - 6\text{V} \quad = -6\text{V}$$
$$V_C = V_B - 4\text{V} \quad = -10\text{V}$$
$$V_D = V_C - 10\text{V} = -20\text{V}$$




**Checking the results:**
**$V_A = V_D + 20\text{V} = 0\text{V}$ ✓**

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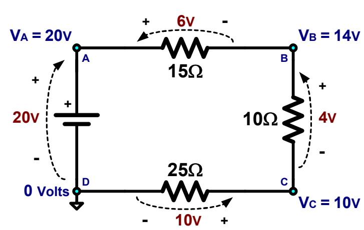
# Comparison (Negative vs. Positive Ground)

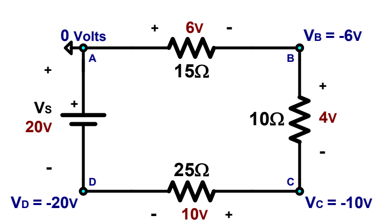
The **voltages across the circuit elements*** <u>are the same in both cases</u>.

*** – The same is true about potential differences between any two specific nodes.**

But, <u>when ground was moved</u> from the negative terminal to the positive terminal, **the node voltages all decreased by 20 V**.



Negative Ground



Positive Ground

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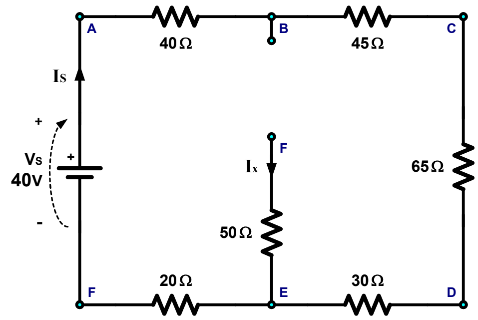
# Node Voltage Example II

Given the following circuit, determine:

- All of the **resistor voltages** and **currents**.
- All of the **node voltages** if node **F** is grounded. (negative ground)
- The **voltage**, $V_{BF}$, across (the open circuited) nodes **B** and **F**.

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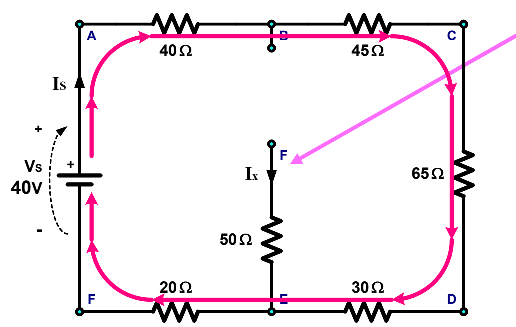
# Example II – Resistor Voltages/Currents

**1)** Determine all of the **resistor voltages** and **currents**:

$$R_{eq} = 40 + 45 + 65 + 30 + 20 = 200\Omega$$




No current can flow down through the center branch due to the "open-circuit" between nodes B and F. Thus, all of the source current must flow around the outer loop.

Because of this, the resistors around the outer loop of the circuit are operationally connected in series with each other.

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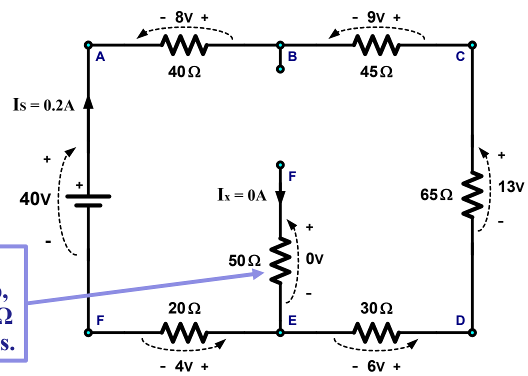
# Example II – Resistor Voltages/Currents

**1)** Determine all of the **resistor voltages** and **currents**:

$$R_{eq} = 40 + 45 + 65 + 30 + 20 = 200\Omega$$

**The calculations used to determine each of the individual resistor voltages will <u>not</u> be shown here.**




**Since the current, $I_x$, in the center branch is zero, the voltage across the 50Ω resistor must be zero volts.**

$$I_S = \frac{V_S}{R_{eq}} = \frac{40\text{V}}{200\Omega} = 0.2\text{A}$$

$$V_{Rx} = I_{Rx} \cdot R_X$$

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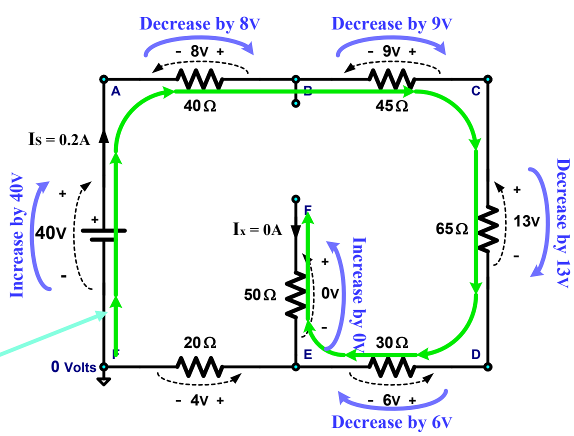
# Example II – Node Voltages

**2)** Determine the **node voltages** if node **F** is grounded **(negative ground)**.

(negative ground ≡ the negative terminal of the source is grounded)

**To determine the node voltages, begin at ground (a "known" voltage) and step through the circuit, determining each adjacent node's voltage based on a "known" voltage and the potential difference across the connecting element.**




**We will follow this path through the circuit, step-by-step, in order to determine each of the node voltages.**

**To facilitate this process, the changes in potential experienced while traveling along the path due to each of the circuit elements have been added to the figure.**

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# Example II – Node Voltages

**2)** Determine the **node voltages** if node **F** is grounded **(negative ground).**

(negative ground ≡ the negative terminal of the source is grounded)

**Beginning At Ground**

$V_A = 0 + 40\text{V} \;= 40\text{V}$

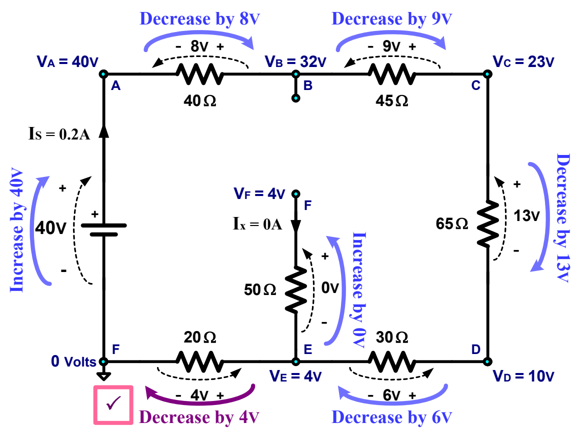
$V_B = V_A - 8\text{V} \;= 32\text{V}$

$V_C = V_B - 9\text{V} \;= 23\text{V}$

$V_D = V_C - 13\text{V} = 10\text{V}$

$V_E = V_D - 6\text{V} \;= 4\text{V}$

$V_F = V_E + 0\text{V} \;= 4\text{V}$




**Checking Work**

$V_F = V_E - 4\text{V} = 0\text{V}$

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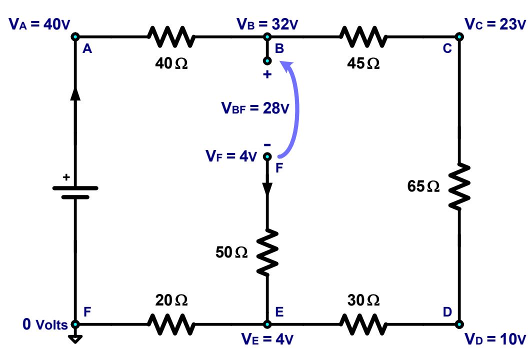
# Example II – Voltage $V_{BF}$

**3)** Determine the **voltage**, $\mathbf{V_{BF}}$, across (open circuited) nodes **B** and **F**.

**You can determine the voltage by utilizing the definition of $V_{BF}$.**

$$V_{BF} = V_B - V_F$$




$$\begin{aligned} V_{BF} &= V_B - V_F \\ &= 32\text{V} - 4\text{V} \\ &= 28\text{V} \end{aligned}$$

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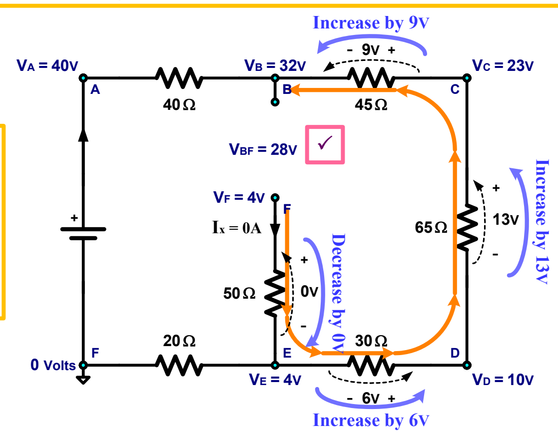
# Example II – Voltage $V_{BF}$

**3)** Determine the **voltage**, $\mathbf{V_{BF}}$, across (open circuited) nodes **B** and **F**.

**Kirchhoff's Voltage Law can be extended to state that:**
**"The potential difference (voltage) between any two nodes in a circuit is path independent."**

**Thus, the voltage-rise from node F → B can be determined by summing the potential differences experienced while traveling along any path from node F to node B.**




**Checking Work**

$$V_{BF} = 0\text{V} + 6\text{V} + 13\text{V} + 9\text{V}$$
$$= 28\text{V} \checkmark$$

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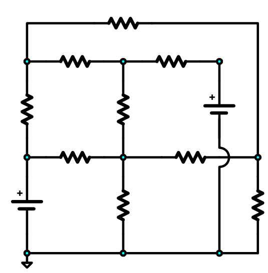
# "Common Ground"

Within a complex circuit, there may be many devices (circuit elements) that are all connected to the ground node.

But, drawing wires from the ground node to each of those devices may increase the complexity of the drawing, in-turn making it difficult to read, especially when wires must cross over each other.



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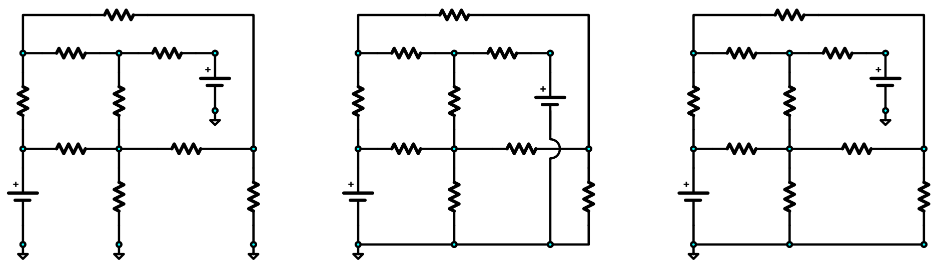
# Ground Shown in Multiple Locations

An alternative method for showing some or all of these ground connections, in lieu of drawing every wire, is to draw a ground symbol at the appropriate terminals of those devices.

If you see this in a circuit drawing, you can assume that wires **are** actually connecting all of the ground terminals.



All of these circuits are electrically equivalent.

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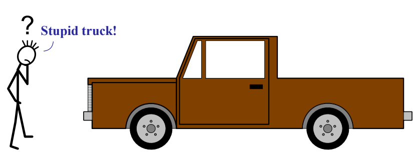
# Negative Ground vs. Positive Ground

**If the operation of the circuit is the same** in either case, such that the voltages across the circuit elements and the currents through the elements are unaffected by the location of the ground node, then **does it really matter which terminal is grounded**?

For an isolated circuit, **probably not**… (btw – that's not a definite "no")

But, when different circuits are connected together, then the location of the ground might be **critically important**!




**For example, have you even left your headlights on, only to return and find that your battery was "dead"?**

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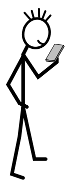
# Case Study

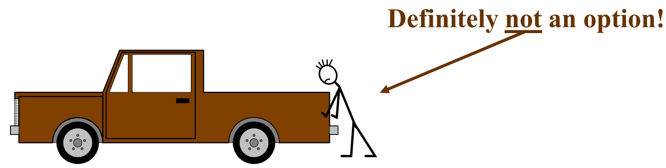
**Scenario**: while borrowing your uncle's old truck, you left the lights on and the battery is dead. You called a friend for help, and he's on the way with his car. There's also jumper cables behind the seat in the truck, but you've never used them before.



So, you do what anyone would when in this situation, you get on your phone, pull up Google, and search:

"**how do I connect jumper cables**"…

and you get 100's of hits!

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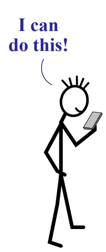
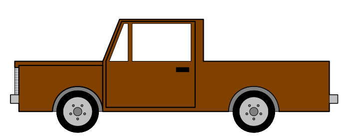
# Case Study

**Scenario**: (continued)…

The instructions are so simple that you don't even feel the need to watch a tutorial video on YouTube: all you have to do is:

- **Get out your jumper cables and connect one of the red clamps to the positive (+) post of the dead battery. Clamp the matching end of the same cable to the positive (+) post on the working battery.**
- **Connect one of the black clamps to the negative (-) post of the good battery. But instead of connecting the other end of the cable to the negative post of the dead battery, clamp it to a bare, metal surface on the engine of the dead car.**



**Copied from a Google search.**

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# Case Study

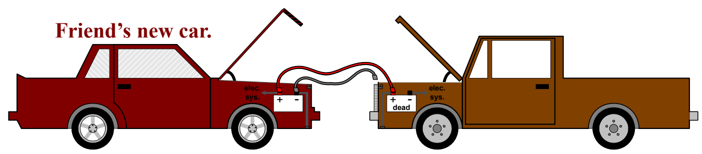
**Scenario**: (continued)…

Your friend arrives, and so you begin…

1) Connect one of the red clamps to the positive (+) post of the dead battery. ✓
2) Clamp the matching end of the same cable to the positive (+) post on the working battery. ✓
3) Connect one of the black clamps to the negative (-) post of the good battery. ✓
4)

But…

**Remember I mentioned:**
**…the metal frame of <u>almost</u> every US vehicle is connected to the negative terminal…**

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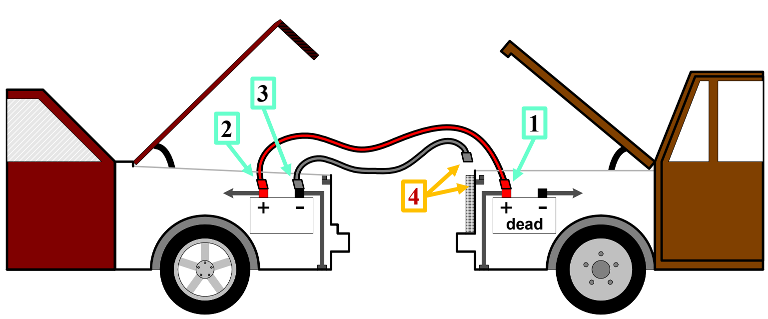
# Case Study

**Scenario**: (continued)…

You don't realize is that your uncle's old truck has a **positive ground**!

1) Connect one of the red clamps to the positive (+) post of the dead battery.
2) Clamp the matching end of the same cable to the positive (+) post on the working battery.
3) Connect one of the black clamps to the negative (-) post of the good battery.
4) Clamp the other end of the cable to a bare, metal surface on the engine of the dead car.

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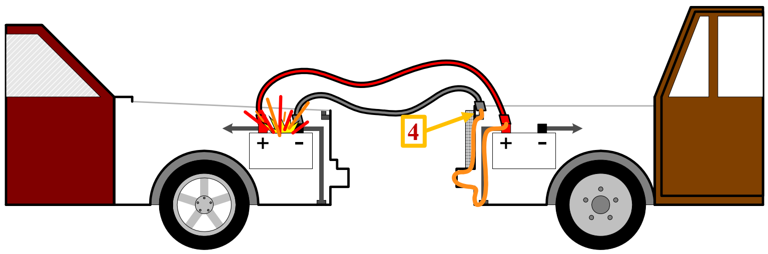
## Case Study

**Scenario**: (continued)…

Because the truck has a **positive ground**, and if you follow the instructions and make that last connection:

**4) Clamp the other end of the cable to a bare, metal surface on the engine of the dead car.**

you will "**short-circuit**" your friend's battery through the frame of the truck, damaging both his car and your friendship!

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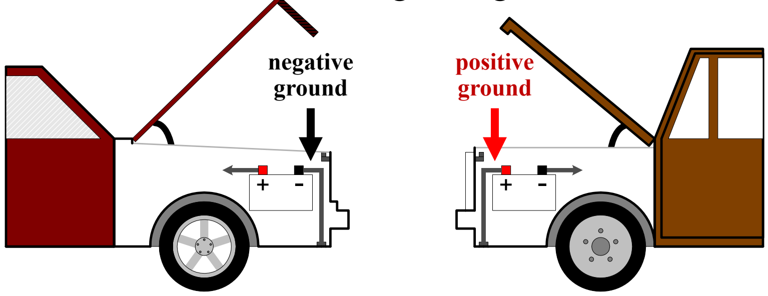
## Case Study

**Scenario**: (continued)…

It's uncommon, but there are vehicles that utilize a positive ground.

Yet, after checking over a dozen links from that search, not once was the possibility even mentioned. **Every** set of instructions **assumed** both vehicles were "negative grounded".

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