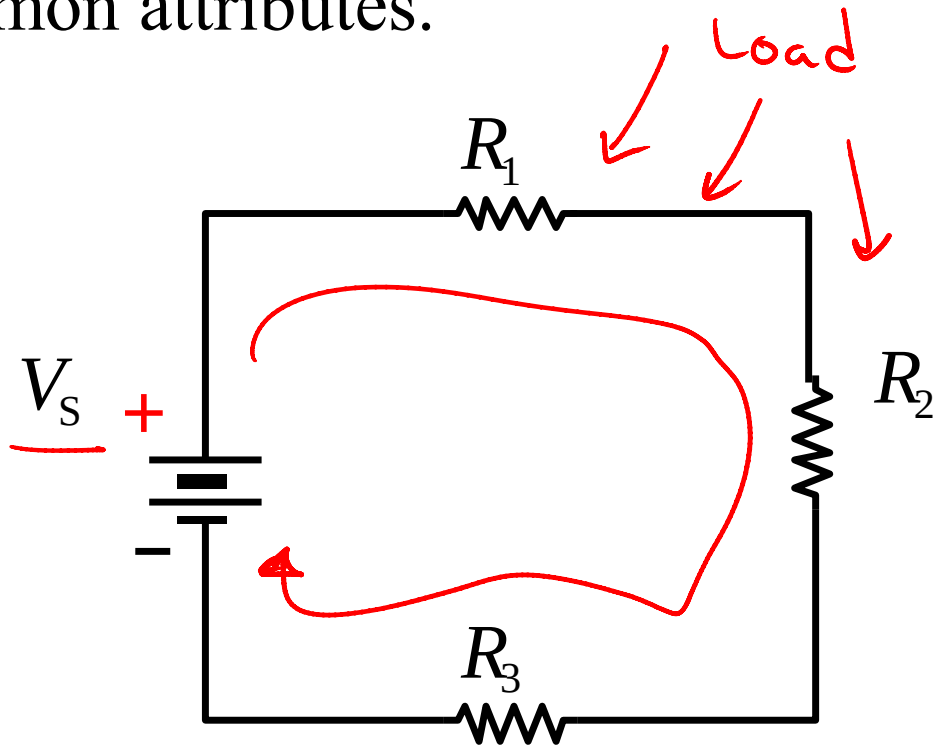
ENGR12

Chapter 2.4 – 2.6
Series Resistors and Voltage Dividers

Series circuits

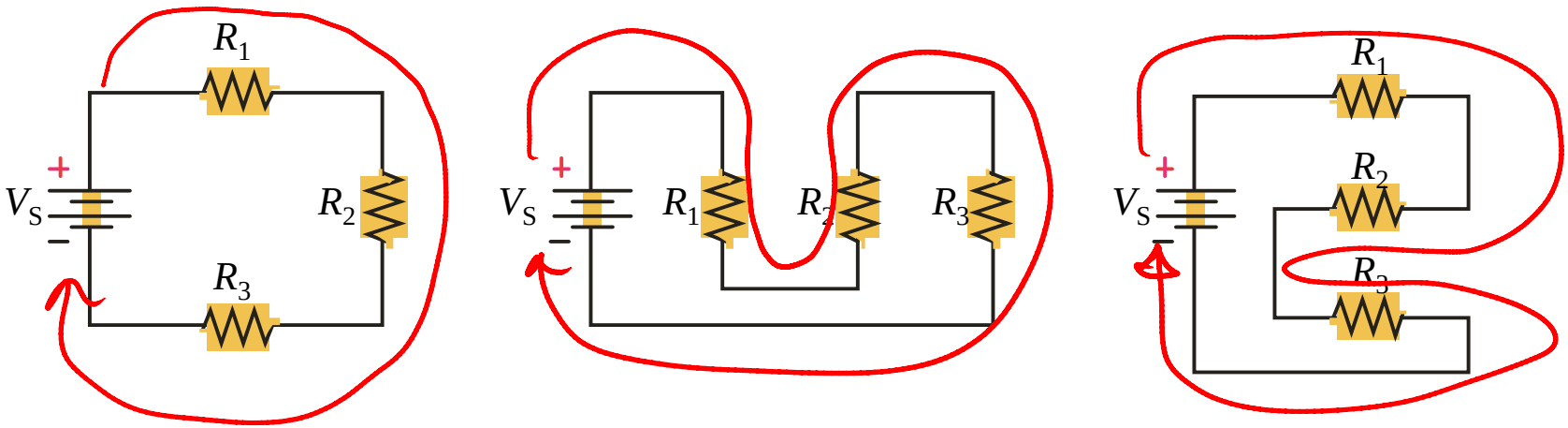
All circuits have three common attributes. These are:

1. A source of voltage.
2. A load.
3. A complete path.



Series circuits

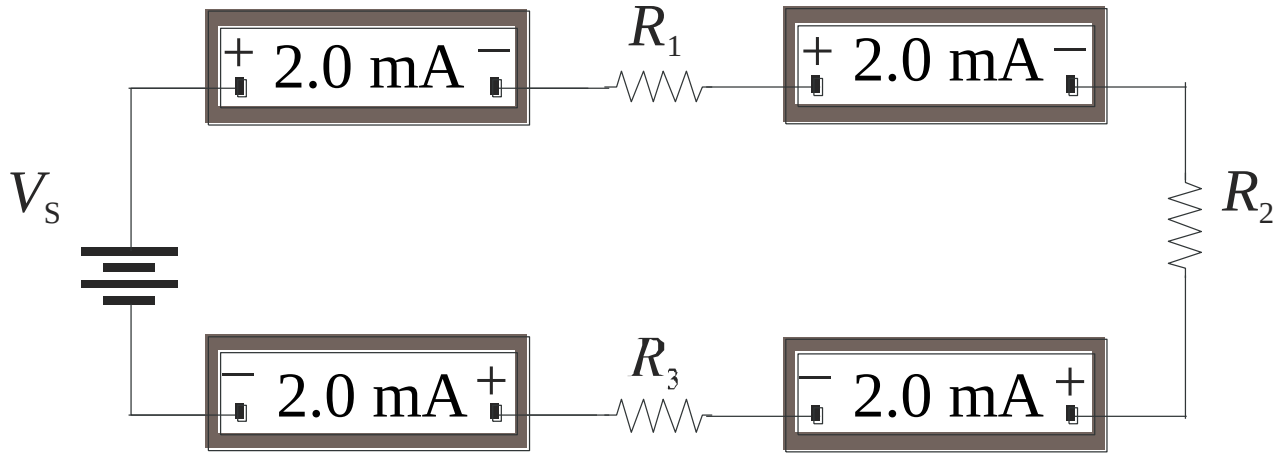
A ***series circuit*** is one that has only one current path.



Series circuit rule for current:

Because there is only one path, the current everywhere is the same.

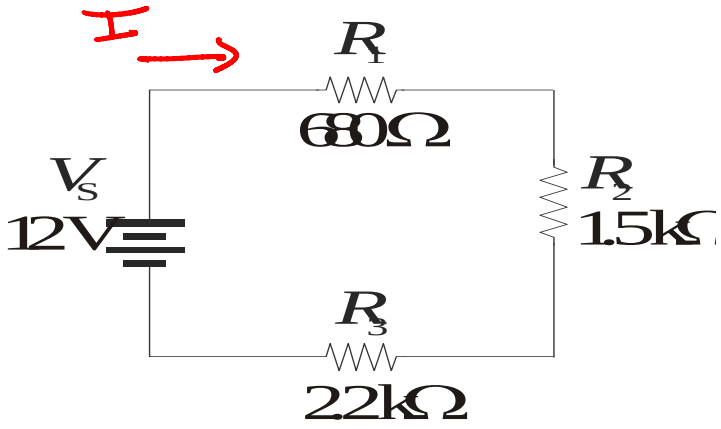
For example, the reading on the first ammeter is 2.0 mA, What do the other meters read?



Series circuits

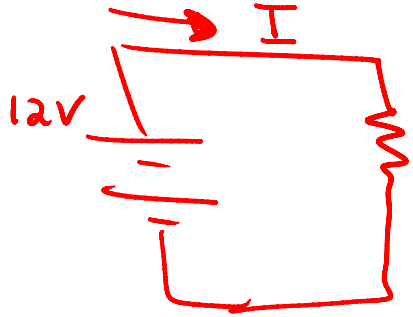
The total resistance of resistors in series is the sum of the individual resistors.

For example, the resistors in a series circuit are 680 Ω, 1.5 kΩ, and 2.2 kΩ. What is the total resistance?



$R_T = 680 + 1500 + 2200$

$= 4380\ \Omega = 4.38\ k\Omega$

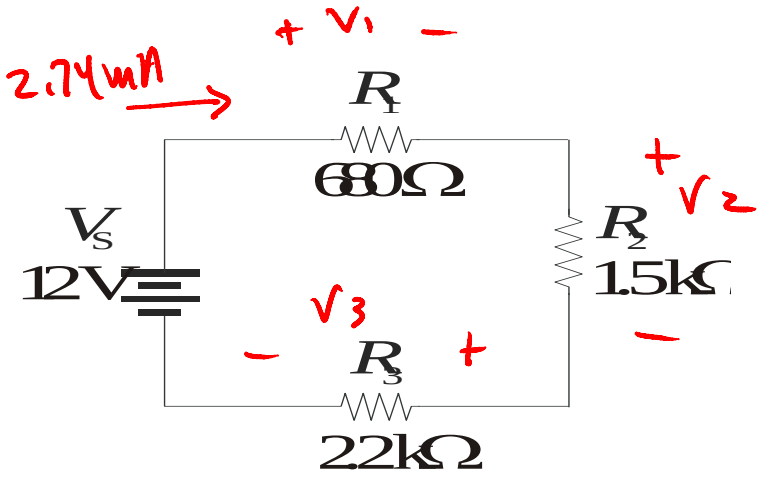


$R_T = 4.38\ k\Omega$

current $I = \frac{12V}{4.38\ k\Omega} = 2.74\ mA$

= same in both ccts. R_T is same load as series R_1, R_2, R_3

$V_i = I R_i = (2.74)(R_i)$



Series circuit

Tabulating current, resistance, voltage and power is a useful way to summarize parameters in a series circuit. Continuing with the previous example, complete the parameters listed in the Table.

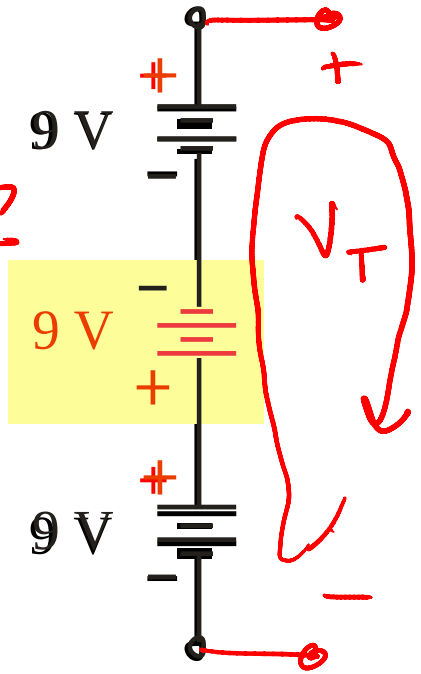
I_1= 2.74 mA	R_1= 0.68 kΩ	V_1= 1.86 V	P_1= 5.1 mW
I_2= 2.74 mA	R_2= 1.50 kΩ	V_2= 4.11 V	P_2= 11.3 mW
I_3= 2.74 mA	R_3= 2.20 kΩ	V_3= 6.03 V	P_3= 16.5 mW
I_T= 2.74 mA	R_T= 4.38 kΩ	V_S= 12 V	P_T= 32.9 mW

adds up to

adds up to 12 V!

Voltage sources in series

Voltage sources in series add algebraically. For example, the total voltage of the sources shown is 27 V KVL: $-9-9-9+V_T=0$, $V_T=27$



Question:

What is the total voltage if one battery is accidentally reversed? 9 V

KVL $-9+9-9+V_T=0$

$V_T = 9$ V

Kirchhoff's voltage law

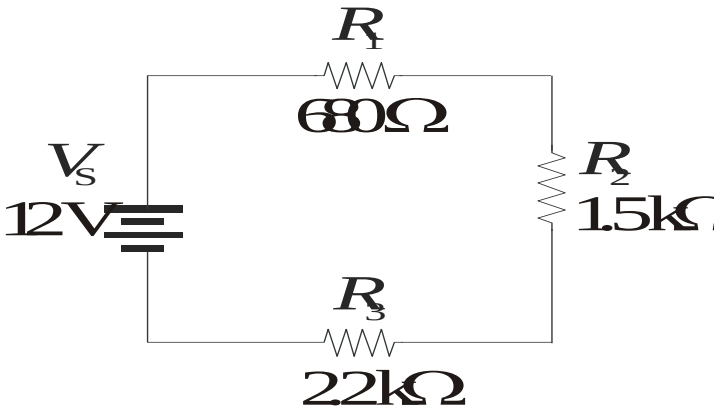
Kirchhoff's voltage law (KVL) is generally stated as:

The sum of all the voltage drops around a single closed path in a circuit is equal to the total source voltage in that closed path.

KVL applies to all circuits, but you must apply it to only one closed path. In a series circuit, this is (of course) the entire circuit.

A mathematical shorthand way of writing KVL is $\sum_{i=1}^{n} V_i = 0$

Kirchhoff's voltage law



Notice in the series example given earlier that the sum of the resistor voltages is equal to the source voltage.

I_1= 2.74 mA	R_1= 0.68 kΩ	V_1= 1.86 V	P_1= 5.1 mW
I_2= 2.74 mA	R_2= 1.50 kΩ	V_2= 4.11 V	P_2= 11.3 mW
I_3= 2.74 mA	R_3= 2.20 kΩ	V_3= 6.03 V	P_3= 16.5 mW
I_T= 2.74 mA	R_T= 4.38 kΩ	V_S= 12 V	P_T= 32.9 mW

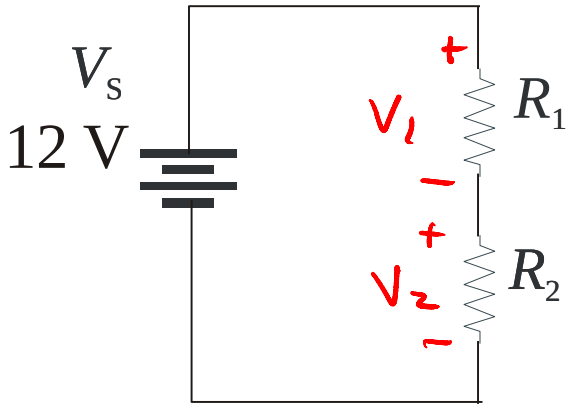
Voltage divider rule

$$V_j = V_s \left(\frac{R_j}{\sum R_i} \right)$$

The voltage drop across any given resistor in a series circuit is equal to the ratio of that resistor to the total resistance, multiplied by source voltage.

Question:

Assume R_1 is twice the size of R_2. What is the voltage across R_1?

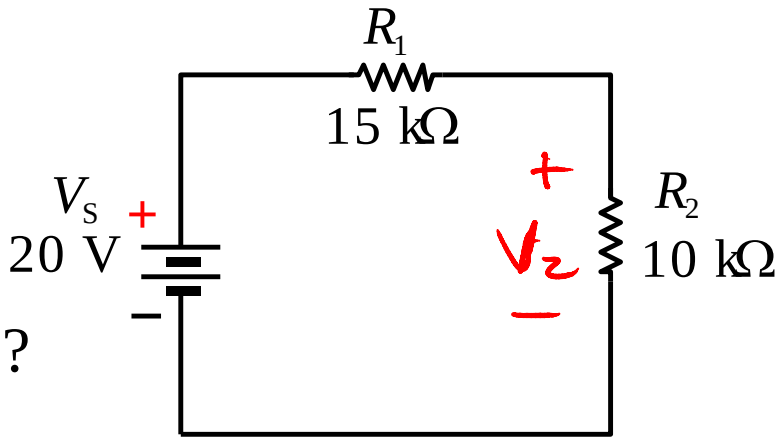


$R_1 = 2R_2$

$$V_1 = V_s \left(\frac{R_1}{R_1 + R_2} \right)$$

$$= 12 \left(\frac{2R_2}{2R_2 + R_2} \right) = 12 \left(\frac{2}{3} \right) = 8\,V$$

Voltage divider



Example:

What is the voltage across R_2?

Solution:

The total resistance is 25 kΩ. $= R_1 + R_2$

Applying the voltage divider formula:

$$V_2 = V_S\left(\frac{R_2}{R_1+R_2}\right)$$

$$= 20\left(\frac{10}{10+15}\right) = 8\text{ V}$$

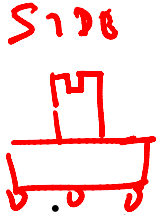
Notice that 40% of the source voltage is across R_2, which represents 40% of the total resistance. →

proportional

$V_2 \propto R_2$

Voltage divider

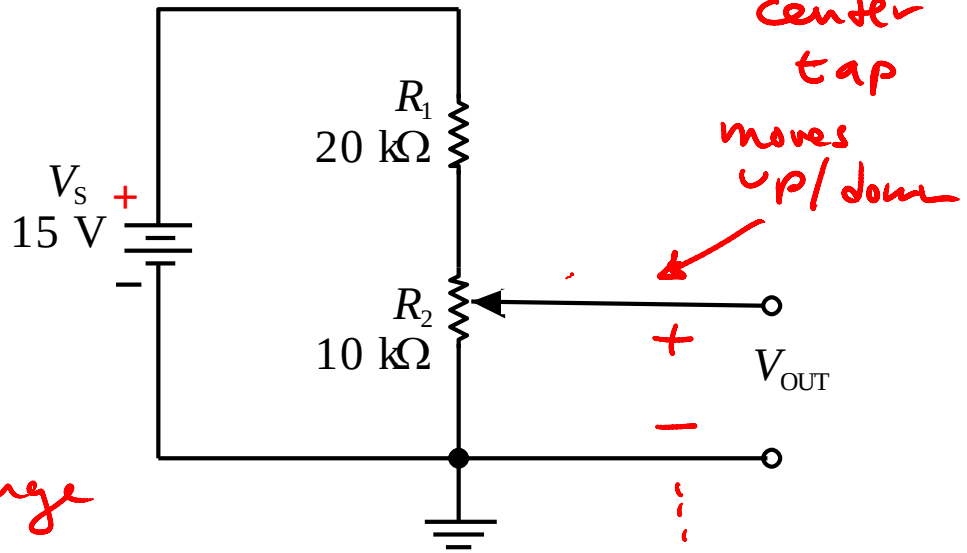
Potentiometer



Voltage dividers can be set up for a variable output using a potentiometer. In the circuit shown, the output voltage is variable.

center tap

moves up/down



Question:

What is the largest output voltage available? 5V

A: When Rout is as large as possible (10k)

$$V_{out} = V_S\left(\frac{R_{out}}{R_{out}+(R_2-R_{out})+R_1}\right)$$

$$= 15\left(\frac{10}{R_2+R_1}\right) = 15\left(\frac{10}{30}\right) = 5V$$

R_2 splits into two R's

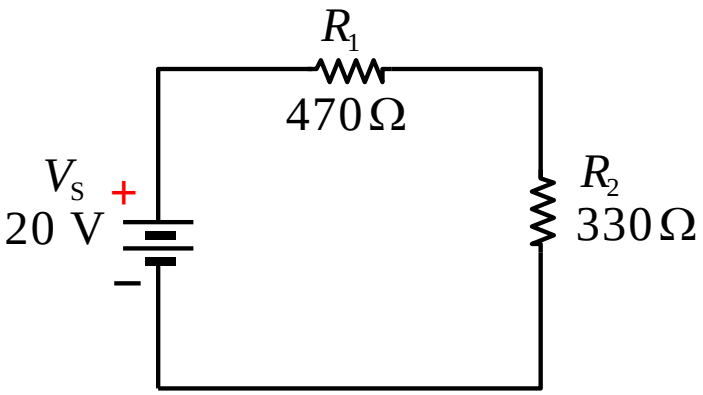
$R_2 - R_{out}$

R_{out}

Power in Series Circuits

Example:

Use the voltage divider rule to find V_1 and V_2. Then find the power in R_1 and R_2 and P_T.



Solution:

Applying the voltage divider rule:

$$V_1 = 20V\left(\frac{470}{470+330}\right) = 11.75V$$

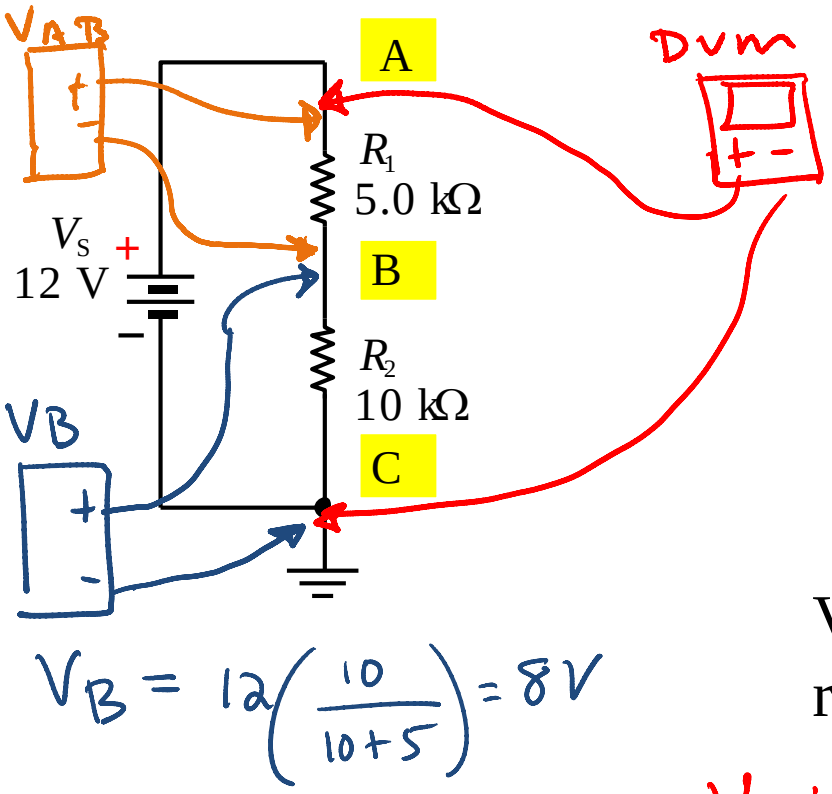
$$V_2 = 20V\left(\frac{330}{470+330}\right) = 8.25V$$

The power dissipated by each resistor is: $P_i = V_i^2 / R_i$

$$P_1 = \frac{11.75^2}{470\Omega} = .29\,W$$

$$P_2 = \frac{8.25^2}{330\Omega} = .21\,W$$

$$P_T = \frac{20^2}{800} = 0.5\,W$$



Voltage measurements

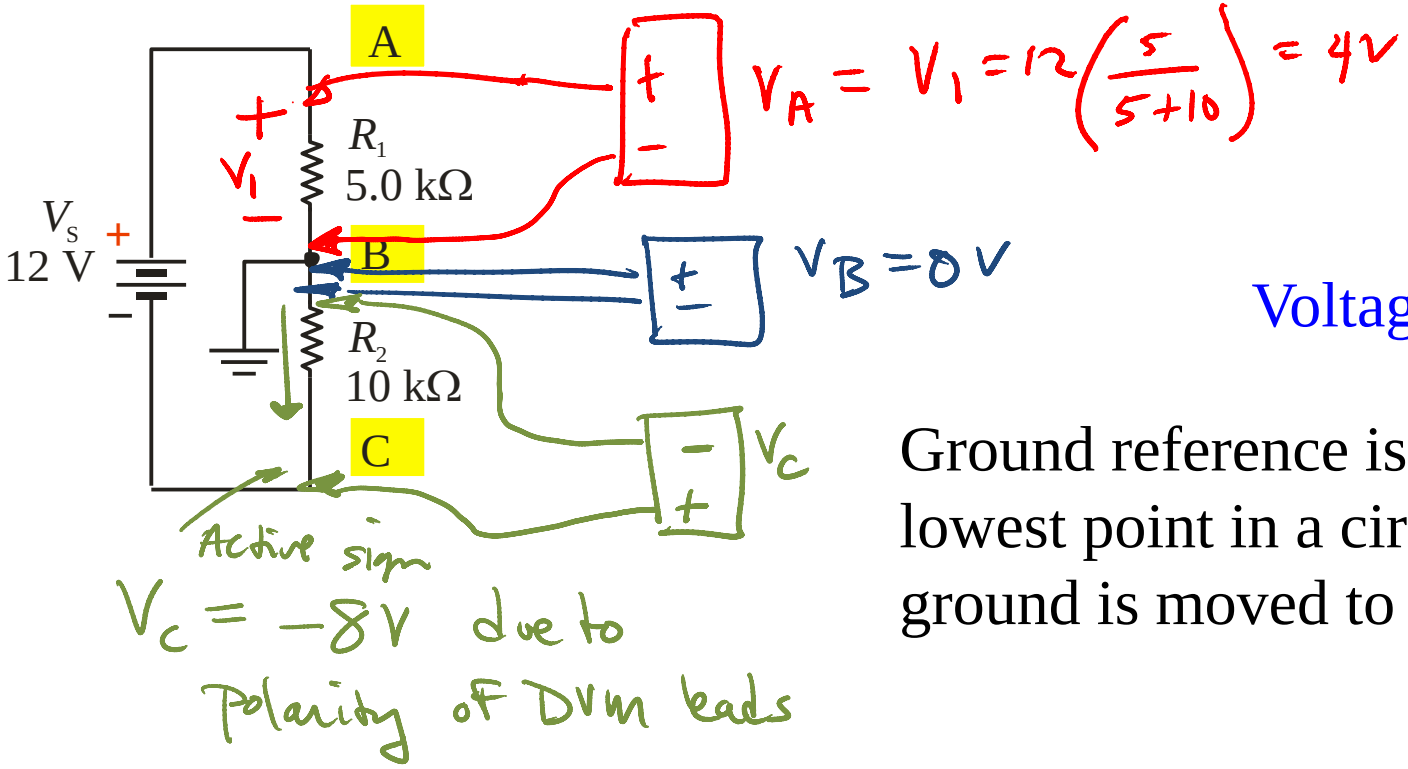
Voltage is relative and is measured with respect to another point in the circuit.

V_A: Voltage of node A with respect to Gnd

V_B: " " B " "

V_{AB}: $V_A - V_B = 12 - 8 = 4V$

Question: What are V_A, V_B, and V_{AB}?



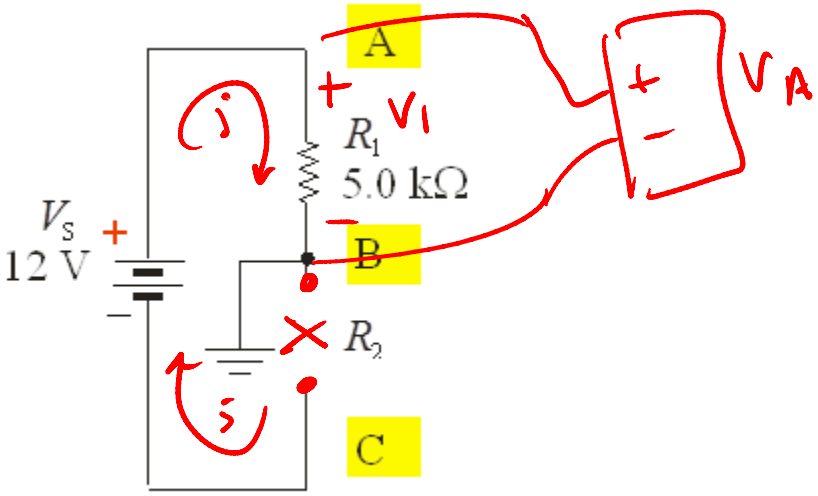
Voltage measurements

Ground reference is not always at the lowest point in a circuit. Assume the ground is moved to B as shown.

Question: What are V_A, V_B, and V_C for the circuit?

Has V_{AB} changed from the previous circuit?

No



Voltage measurements

Question:

Assume that R_2 is open. For this case, what are V_A, V_B, and V_C for the circuit?

open at $R_2 \rightarrow i = 0$

$i = 0 \rightarrow V_1 = i R_1 = 0$, $V_A = 0V$

Answer:

$V_B = 0$ (ground)

$V_C = V_A - 12 = -12V$

Selected Key Terms

Series	In an electric circuit, a relationship of components in which the components are connected such that they provide a single path between two points.
Kirchhoff's voltage law	A law stating that (1) the sum of the voltage drops around a closed loop equals the source voltage in that loop or (2) the algebraic sum of all of the voltages (drops and source) is zero.
Voltage divider	A circuit consisting of series resistors across which one or more output voltages are taken.

Selected Key Terms

Reference ground	The metal chassis that houses the assembly or a large conductive area on a printed circuit board is used as a common or reference point; also called common.
Open	A circuit condition in which the current path is broken.
Short	A circuit condition in which there is zero or an abnormally low resistance between two points; usually an inadvertent condition.

Quiz

1. In a series circuit with more than one resistor, the current is

a. larger in larger resistors

b. smaller in larger resistors

c. always the same in all resistors

d. there is not enough information to say

Quiz

2. In a series circuit with more than one resistor, the voltage is

a. larger across larger resistors

b. smaller across larger resistors

c. always the same across all resistors

d. there is not enough information to say

Quiz

3. If three equal resistors are in series, the total resistance is

a. one third the value of one resistor

b. the same as one resistor

c. three times the value of one resistor

d. there is not enough information to say

Quiz

4. A series circuit cannot have

   a. more than two resistors

   b. more than one voltage source

   c. more than one path

   d. all of the above

Quiz

5. In a closed loop, the algebraic sum of all voltages (both sources and drops)

a. is zero

b. is equal to the smallest voltage in the loop

c. is equal to the largest voltage in the loop

d. depends on the source voltage

Quiz

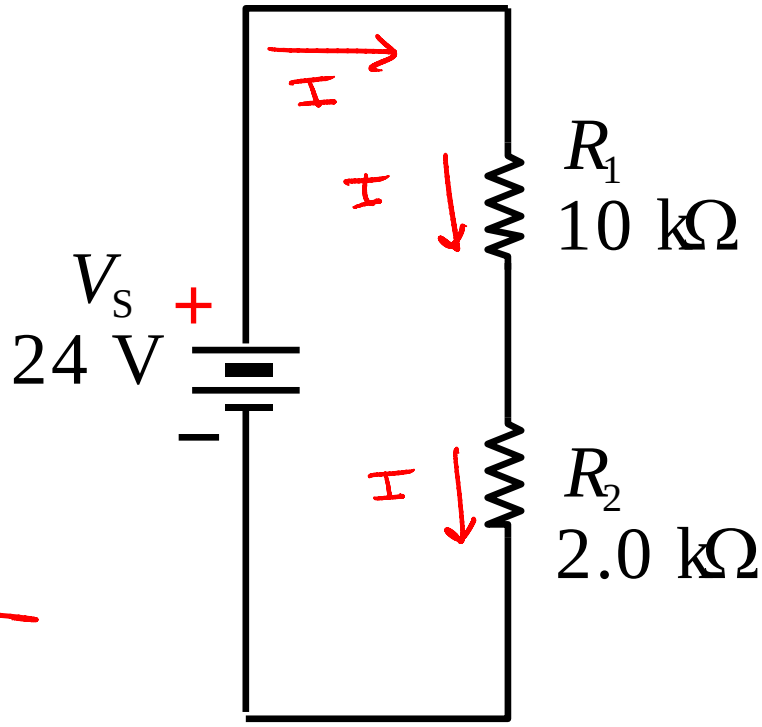
6. The current in the 10 kΩ resistor is

a. 0.5 mA

b. 2.0 mA

c. 2.4 mA

d. 10 mA



$$I = \frac{24\text{V}}{R_1 + R_2} = \frac{24}{12} = 2\text{ mA}$$

Quiz

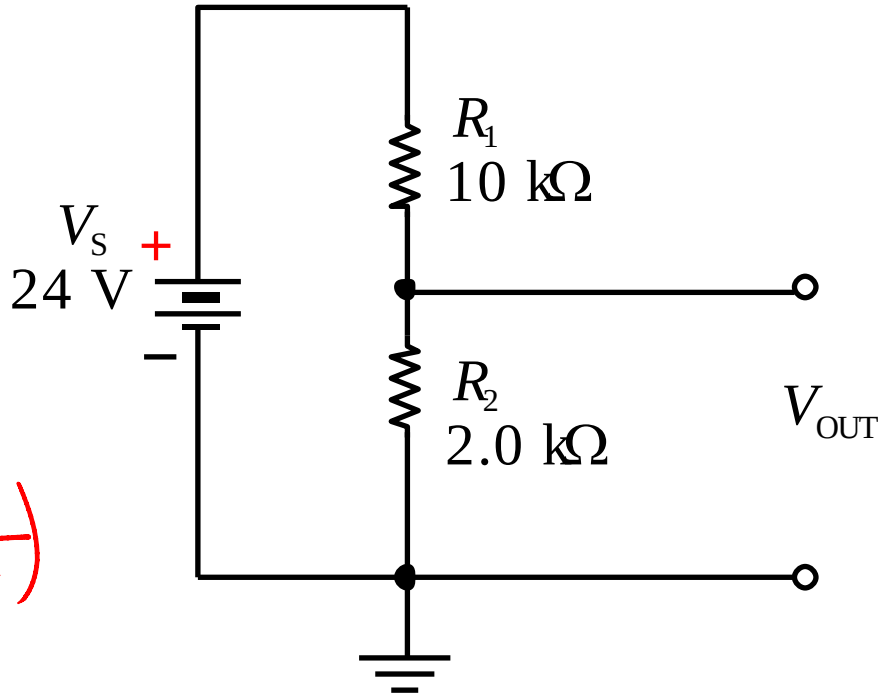
7. The output voltage from the voltage divider is

a. 2.0 V

b. 4.0 V

c. 12 V

d. 20 V



$$V_{out} = V_s\left(\frac{R_2}{R_1+R_2}\right) = 24\left(\frac{2}{12}\right)$$

$$= 4\,V$$

Quiz

8. The smallest output voltage available from the voltage divider is

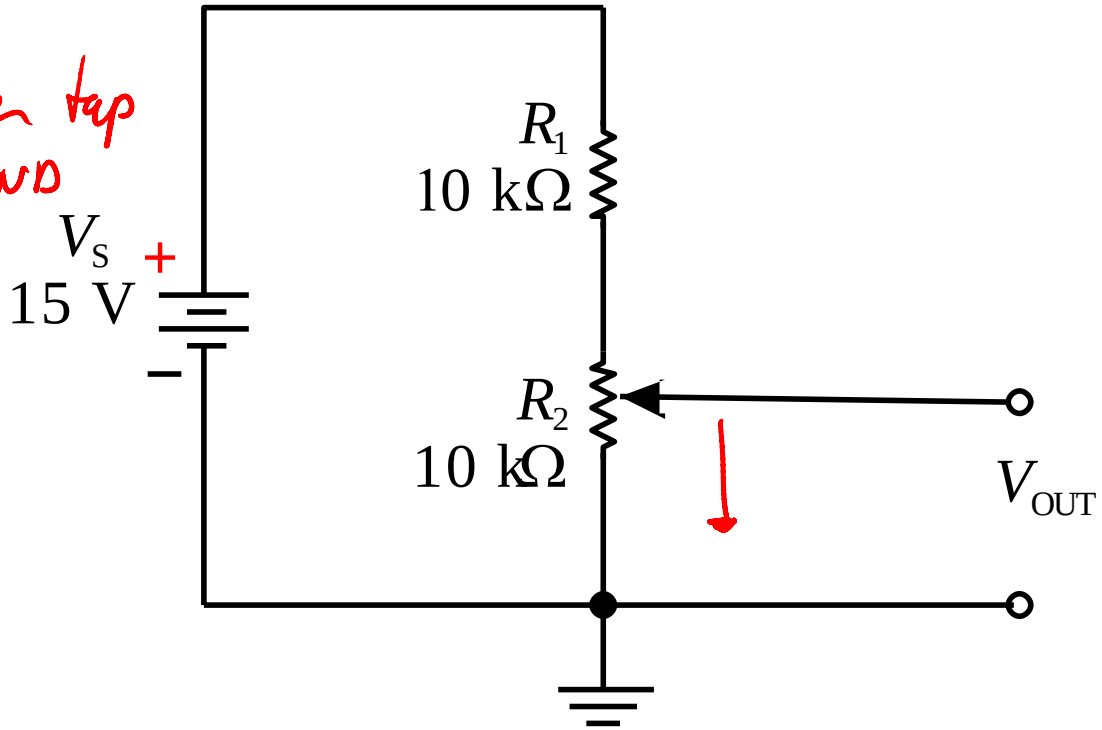
a. 0 V

b. 1.5 V

c. 5.0 V

d. 7.5 V

When center tap drops to GND



Quiz

9. The total power dissipated in a series circuit is equal to the

a. power in the largest resistor

b. power in the smallest resistor

c. average of the power in all resistors

d. sum of the power in all resistors

Quiz

10. The meaning of the voltage V_{AB} is the voltage at

a. Point A with respect to ground

b. Point B with respect to ground

c. The average voltage between points A and B.

d. The voltage difference between points A and B.

Quiz

Answers:

1. c
2. a
3. c
4. c
5. a
6. b
7. b
8. a
9. d
10. d

Handouts

Quiz

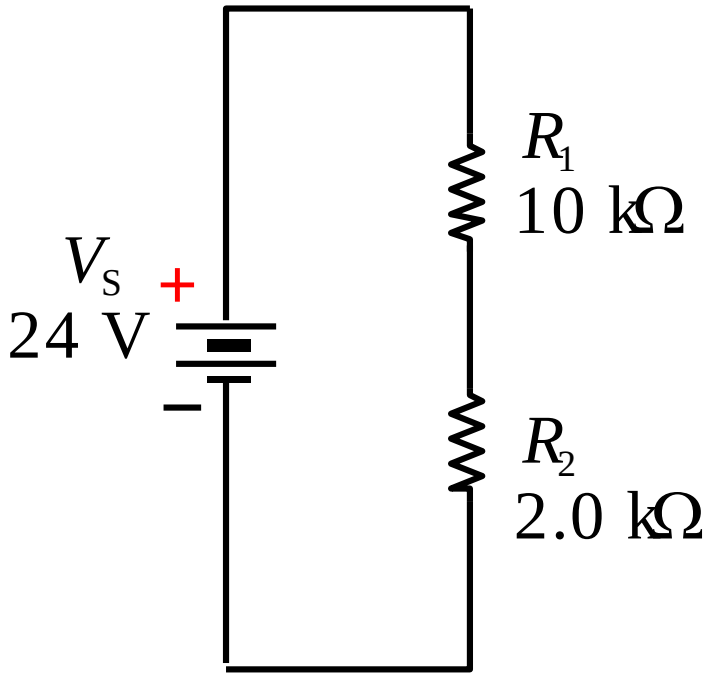
6. The current in the 10 kΩ resistor is

a. 0.5 mA

b. 2.0 mA

c. 2.4 mA

d. 10 mA



Quiz

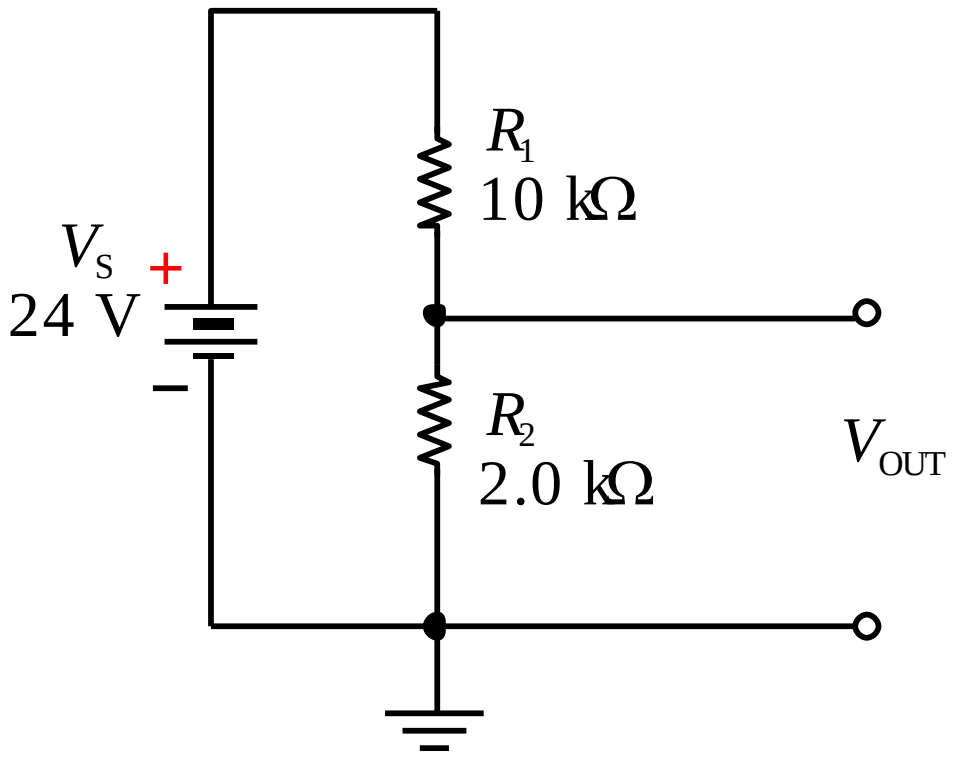
7. The output voltage from the voltage divider is

a. 2.0 V

b. 4.0 V

c. 12 V

d. 20 V



Quiz

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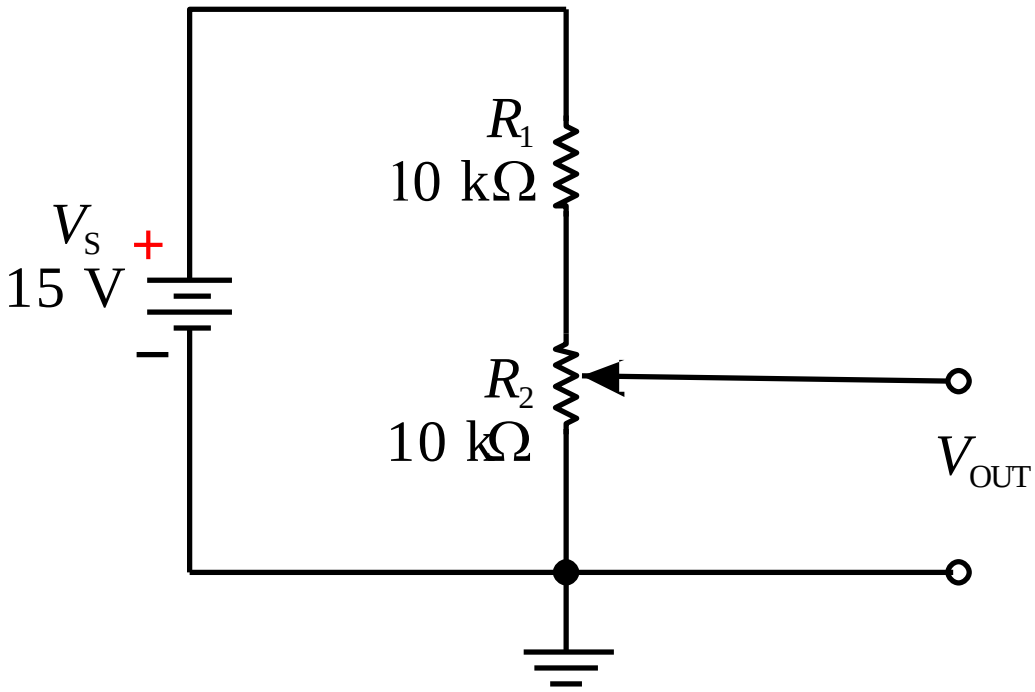

What is v?