

Your comments

We have a midterm and we're learning new material? Ain't nobody got time fo dat.

Feels good to be an ECE major right about now. I finally know what the MechE's felt like during 211.

Couple logistical things: 1. No lab today? 2. Where can we find the video of you solving the old midterms?

I am stressing out for this exam! What concepts should I focus most of my time on?

I just wanted to thank you for making the second deadline 100% because I have four midterms this week and I am on the brink of quitting school and working as a roadkillpickerupper.

I'm really nervous about the exam. In terms of difficulty level how hard is it? Also one of my professors told me that if the lecture before an exam isn't review then the professor must give the next lecture off. Apparently it's university policy. As much as i love this class, how come this isn't true for physics 212?

What does EMF stand for? **ElectroMotiveForce**

I couldn't help but notice that the constant/equation sheet that we are supplied with in our discussion book is pretty weak. Is that completely identical to the one we will Wednesday for our midterm? The 211 sheet was pretty solid, this one just feels it's lacking.

I accept that wires with a larger cross sectional area have less resistance, but why isn't surface area taken into account instead considering charges only move 'on the surfaces' of conductors? Does this have to do with scattering from electron-electron interactions?

If we all get A's on the exam can we have a pizza party instead of a lecture this Thursday?

Electric Current

Physics 212 *Lecture 9*

Today's Concept:

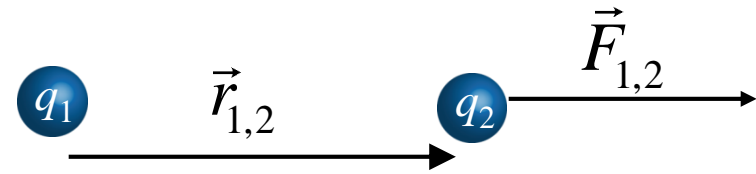
Ohm's Law, Resistors in circuits

A Big Idea Review

Coulomb's Law

Force law between point charges

$$\vec{F}_{1,2} = \frac{kq_1q_2}{r_{1,2}^2} \hat{r}_{1,2}$$



Electric Field

Force per unit charge

$$\vec{E} \equiv \frac{\vec{F}}{q}$$

Electric Field

Property of Space
Created by Charges
Superposition

Gauss' Law

Flux through closed surface is always proportional to charge enclosed

$$\int \vec{E} \cdot d\vec{A} = \frac{Q_{enc}}{\epsilon_0}$$

Gauss' Law

Can be used to determine E field



Spheres
Cylinders
Infinite Planes

Electric Potential

Potential energy per unit charge

$$\Delta V_{a \rightarrow b} \equiv \frac{\Delta U_{a \rightarrow b}}{q} = -\int_a^b \vec{E} \cdot d\vec{l}$$

Capacitance

Relates charge and potential for two conductor system

$$C \equiv \frac{Q}{V}$$

Electric Potential

Scalar Function that can be used to determine E

$$\vec{E} = -\nabla V$$

Applications of Big Ideas

Conductors
Charges free to move



What Determines
How They Move?

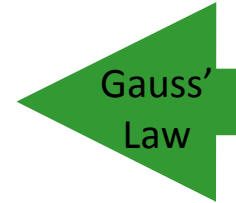


They move until
 $E = 0!$

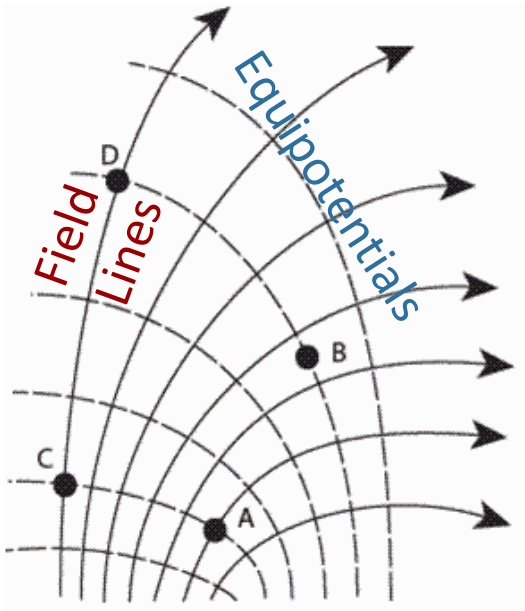


$E = 0$ in conductor
determines charge
densities on surfaces

Spheres
Cylinders
Infinite Planes



Field Lines &
Equipotentials



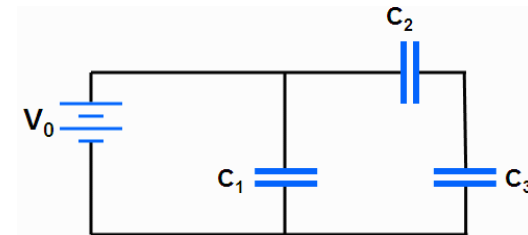
Work Done By E Field

$$W_{a \rightarrow b} = \int_a^b \vec{F} \cdot d\vec{l} = \int_a^b q\vec{E} \cdot d\vec{l}$$

Change in Potential Energy

$$\Delta U_{a \rightarrow b} = -W_{a \rightarrow b} = -\int_a^b q\vec{E} \cdot d\vec{l}$$

Capacitor Networks



Series:

$$(1/C_{23}) = (1/C_2) + (1/C_3)$$

Parallel

$$C_{123} = C_1 + C_{23}$$

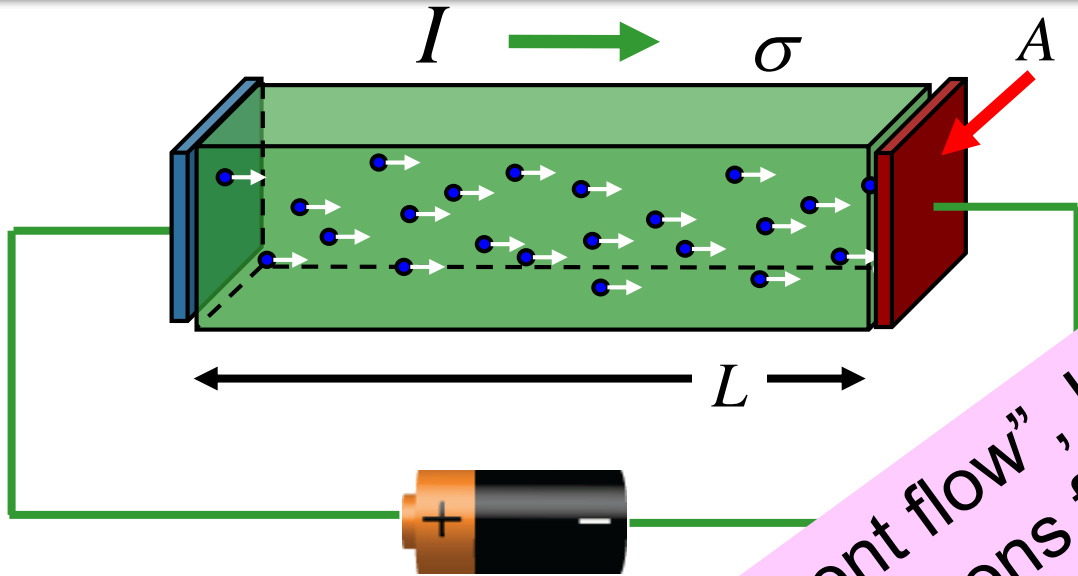
Current and Resistance

Key Concepts:

- 1) How resistance depends on A , L , σ , r
- 2) How to combine resistors in series and parallel
- 3) Understanding resistors in circuits

Today's Plan:

- 1) Review of resistance & preflights
- 2) Work out a circuit problem in detail



conductivity – high for good conductors.

V Ohm's Law $= \sigma E$

Observables:

$V = EL$

$I = JA$

$J = \sigma E = \sigma V/L$

$I = V/(L/\sigma A)$

Note: "Conventional current flow", I , is opposite to direction electrons flow

resistance

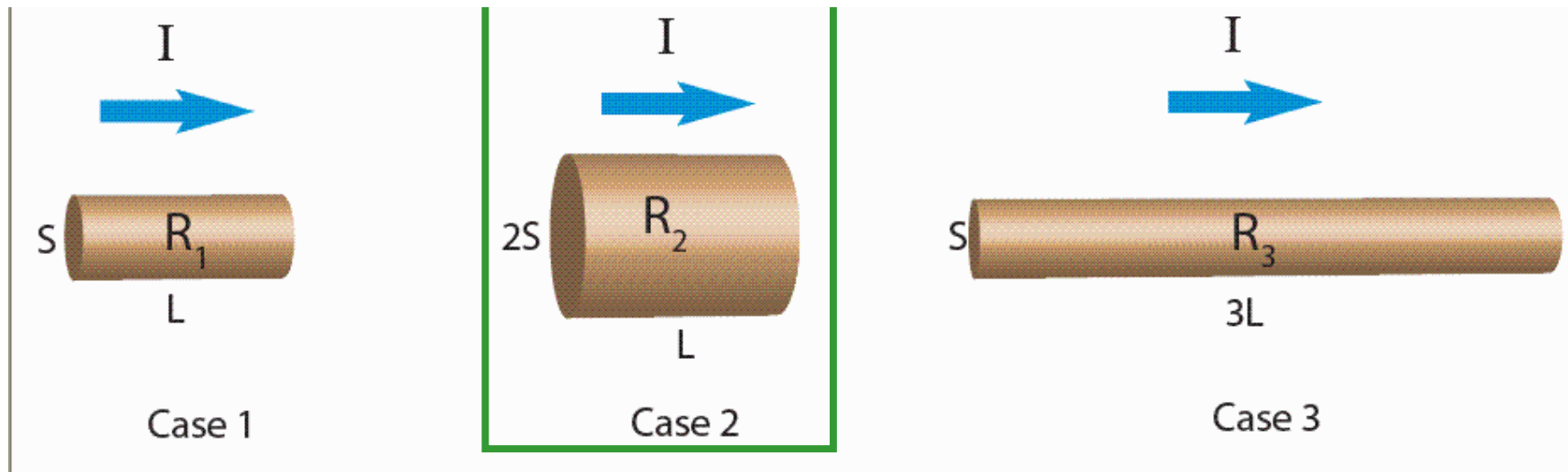
$R = 1/\sigma$

$I = V/R$

$R = \frac{L}{\sigma A}$

Checkpoint 3

The SAME amount of current I passes through three different resistors. R_2 has twice the cross-sectional area and the same length as R_1 , and R_3 is three times as long as R_1 but has the same cross-sectional area as R_1 .



In which case is the CURRENT DENSITY through the resistor the smallest?

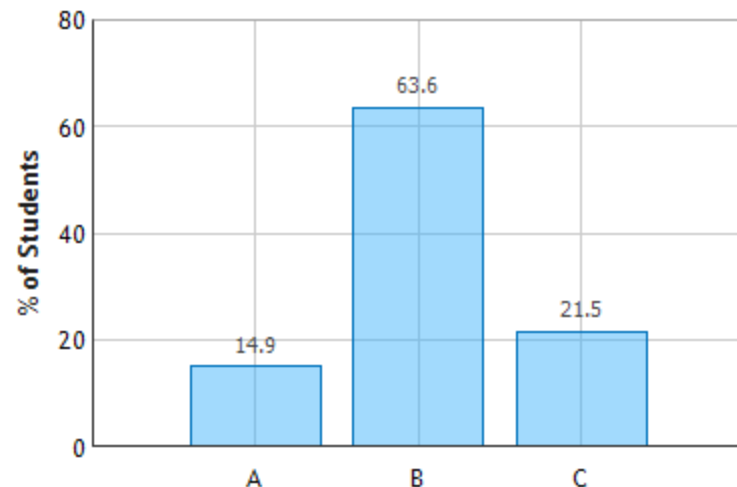
A. Case 1

B. Case 2

C. Case 3

$$J \equiv \frac{I}{A} \quad \longrightarrow \quad J_1 = J_3 = 2J_2$$

Same Current $\longrightarrow J \propto \frac{1}{A}$



This is just like Plumbing!

I is like flow rate of water

V is like pressure

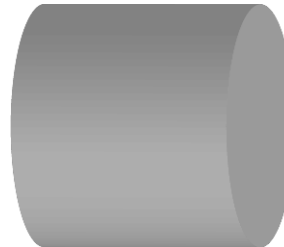
R is how hard it is for water to flow in a pipe

$$R = \frac{L}{\sigma A}$$

To make R big, make L long or A small

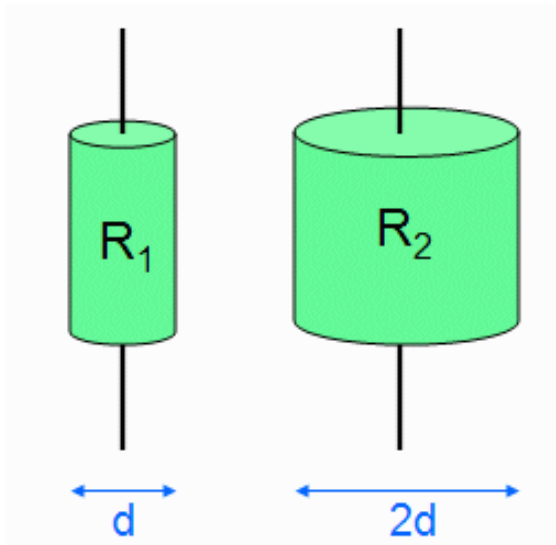


To make R small, make L short or A big



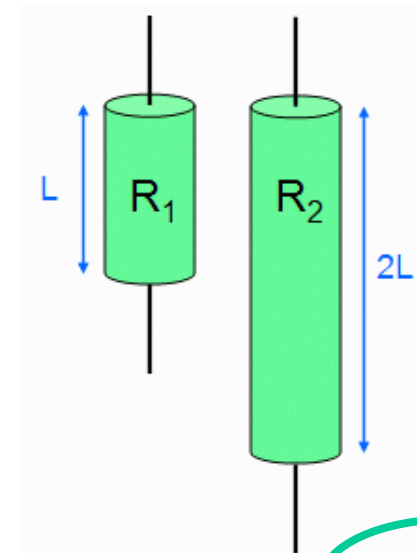
CheckPoint 1a

CheckPoint 1b



Same current through both resistors

Compare voltages across resistors

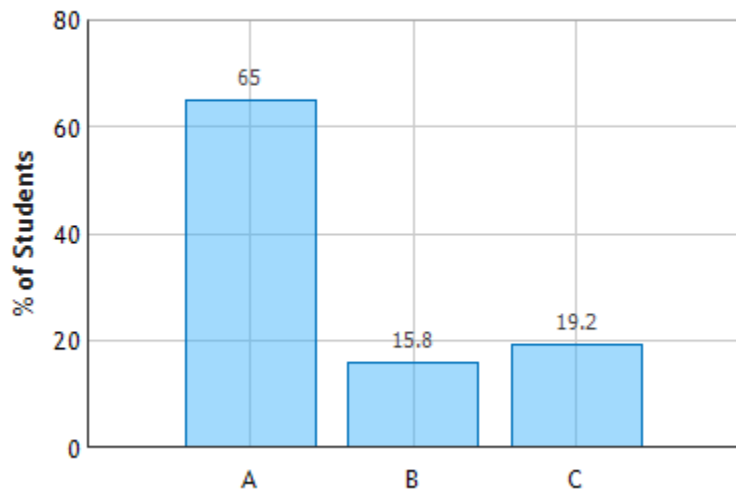


- $V_1 > V_2$
 $V_1 = V_2$
 $V_1 < V_2$

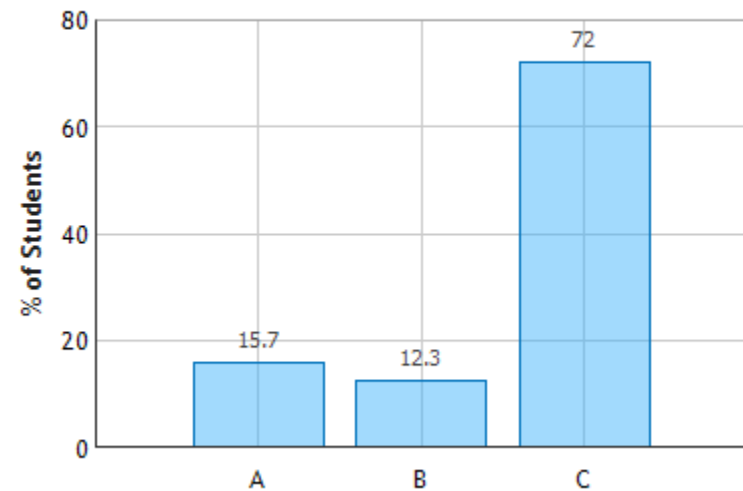
$$R \propto \frac{L}{A}$$

$$V = IR \propto \frac{L}{A}$$

Two Resistors: Question 1 (N = 785)



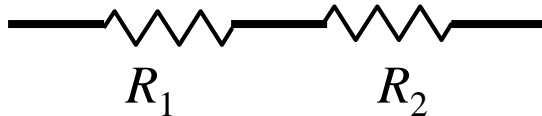
Two Resistors: Question 3 (N = 783)



Resistor Summary

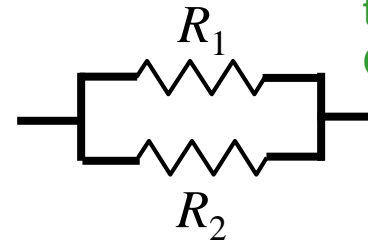
Series

Every loop with R_1 also has R_2



Parallel

There is a loop that contains ONLY R_1 and R_2



Wiring

Each resistor on the same wire.

Each resistor on a different wire.

Voltage

Different for each resistor.

$$V_{total} = V_1 + V_2$$

Same for each resistor.

$$V_{total} = V_1 = V_2$$

Current

Same for each resistor

$$I_{total} = I_1 = I_2$$

Different for each resistor

$$I_{total} = I_1 + I_2$$

Resistance

Increases

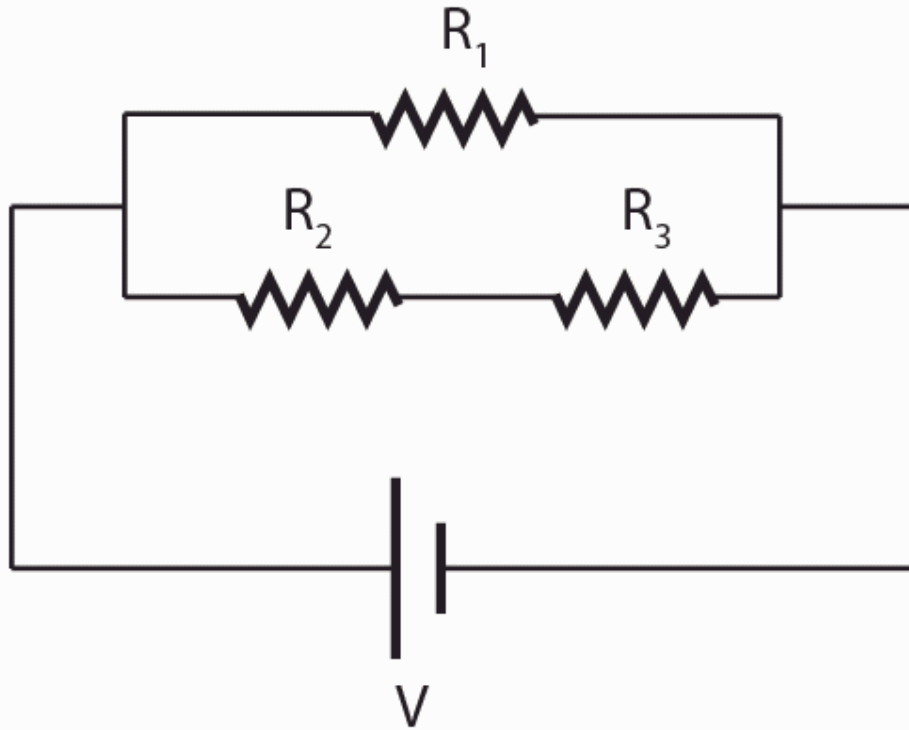
$$R_{eq} = R_1 + R_2$$

Decreases

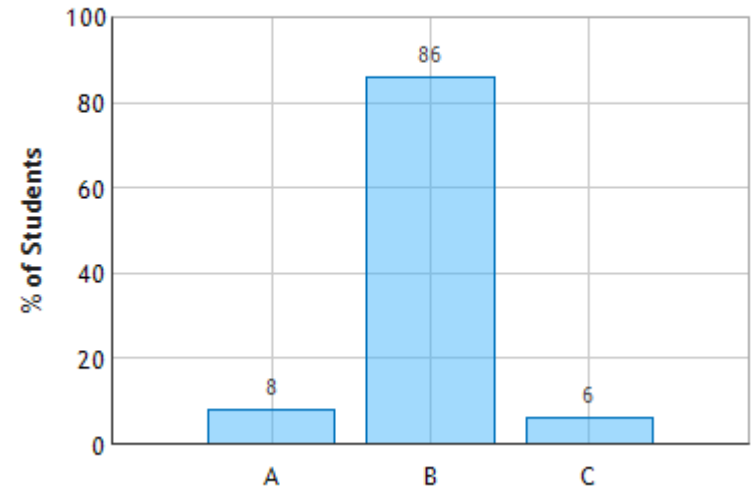
$$1/R_{eq} = 1/R_1 + 1/R_2$$

CheckPoint 2a

Three resistors are connected to a battery with emf V as shown. The resistances of the resistors are all the same, i.e. $R_1 = R_2 = R_3 = R$.



Resistor Network: Question 1 (N = 784)



Compare the current through R_2 with the current through R_3 :

A. $I_2 > I_3$

B. $I_2 = I_3$

C. $I_2 < I_3$

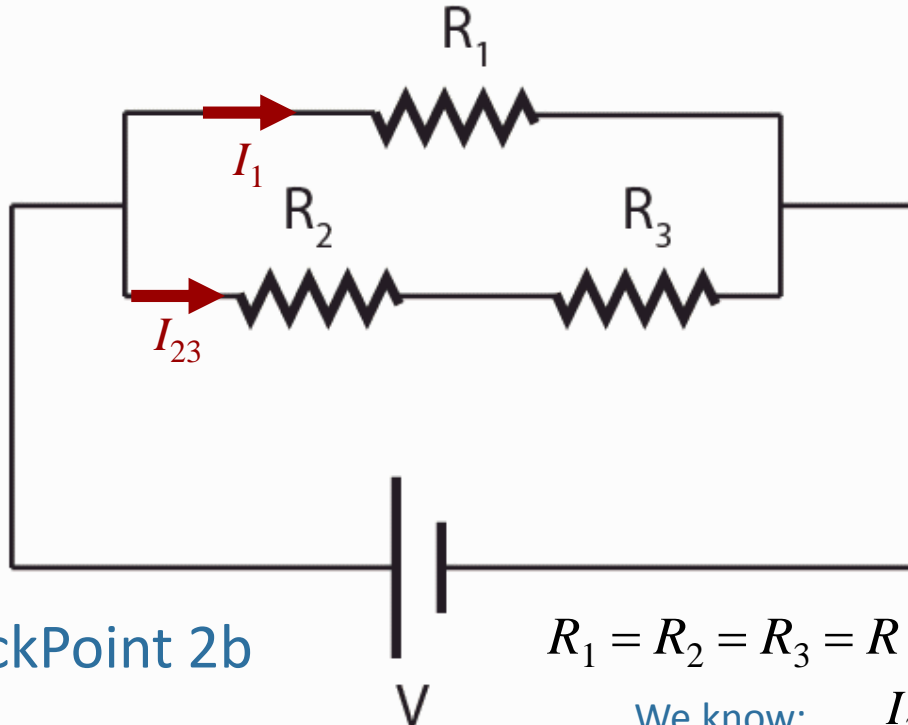
R_2 in series with R_3



Current through R_2 and R_3 is the same

$$I_{23} = \frac{V}{R_2 + R_3}$$

Checkpoint 2b



CheckPoint 2b

Compare the current through R_1 with the current through R_2

- A $I_1/I_2 = 1/2$
- B $I_1/I_2 = 1/3$
- C $I_1/I_2 = 1$
- D $I_1/I_2 = 2$**
- E $I_1/I_2 = 3$

$$R_1 = R_2 = R_3 = R$$

We know:

$$I_{23} = \frac{V}{R_2 + R_3}$$

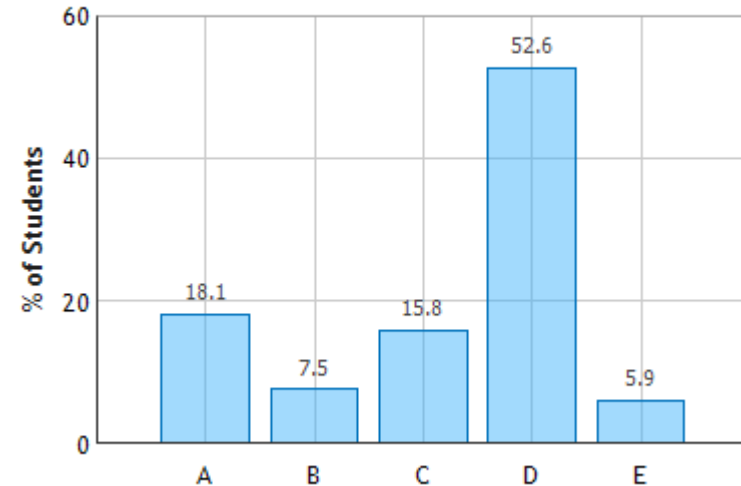
Similarly:

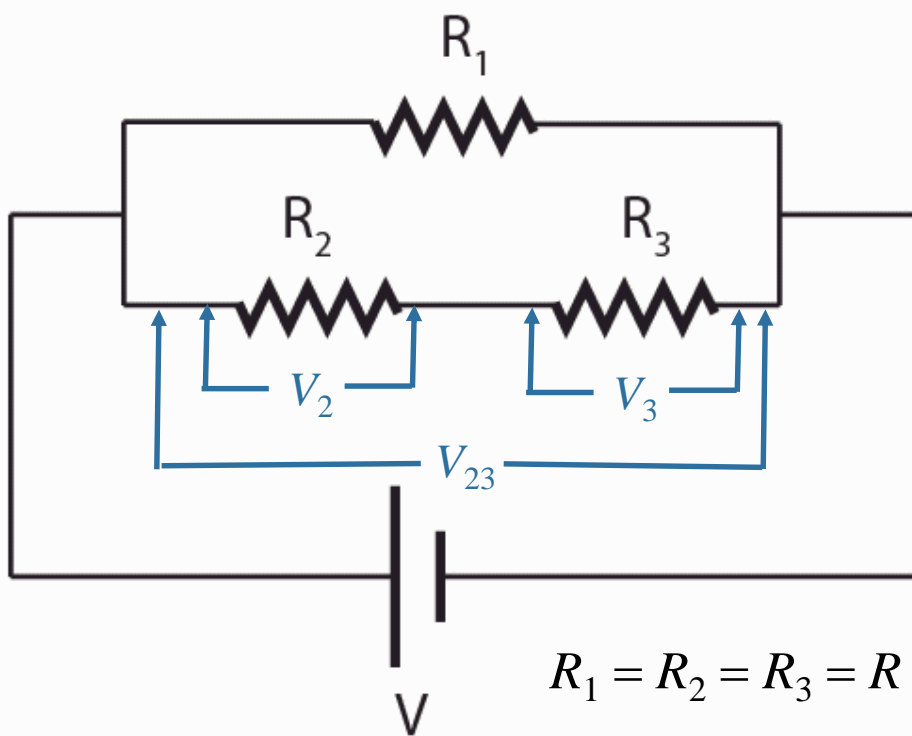
$$I_1 = \frac{V}{R_1}$$

$$\longrightarrow I_1 = I_{23} \frac{R_2 + R_3}{R_1}$$

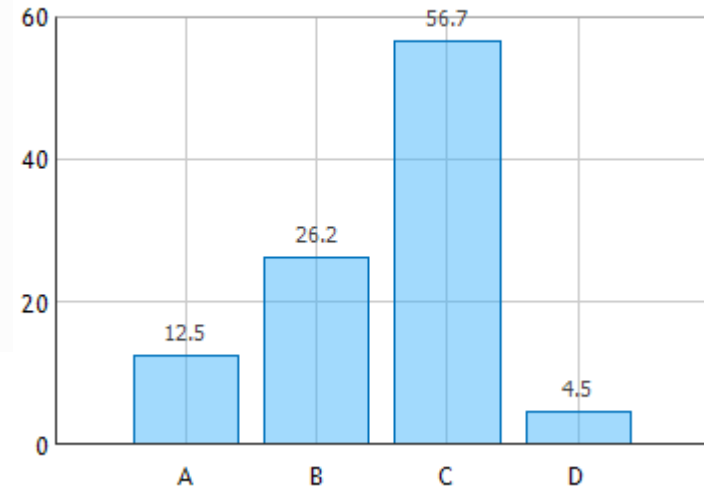
$$\frac{I_1}{I_{23}} = \frac{R_2 + R_3}{R_1} = 2$$

Resistor Network: Question 2 (N = 783)





Resistor Network: Question 4 (N = 781)



CheckPoint 2c

Compare the voltage across R_2 with the voltage across R_3

A $V_2 > V_3$

B $V_2 = V_3 = V$

C $V_2 = V_3 < V$

D $V_2 < V_3$

$$V_2 = I_2 R_2$$

$$V_3 = I_3 R_3$$

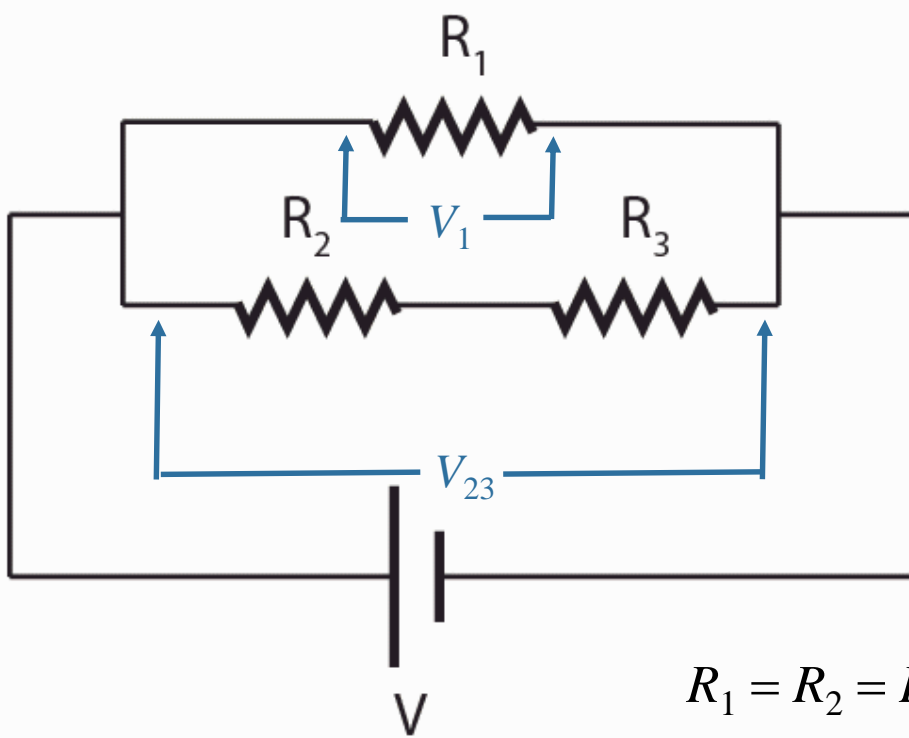
$I_2 = I_3$ (Series)
 $R_2 = R_3$ (Problem statement)

$$V_2 = V_3$$

$$V_{23} = V$$

$$V_{23} = V_2 + V_3$$

$$V_2 = V_3 = \frac{V}{2}$$



$$R_1 = R_2 = R_3 = R$$

CheckPoint 2d

Compare the voltage across R_1 with the voltage across R_2

- A $V_1 = V_2 = V$
- B $V_1 = \frac{1}{2} V_2 = V$
- C $V_1 = 2V_2 = V$**
- D $V_1 = \frac{1}{2} V_2 = \frac{1}{5} V$
- E $V_1 = \frac{1}{2} V_2 = \frac{1}{2} V$

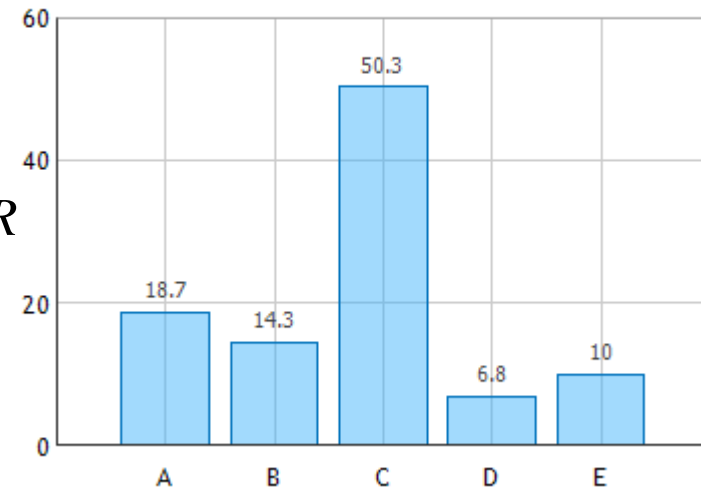
R_1 in parallel with series combination of R_2 and R_3

$$V_1 = V_{23}$$

$$R_2 = R_3 \Rightarrow V_2 = V_3$$

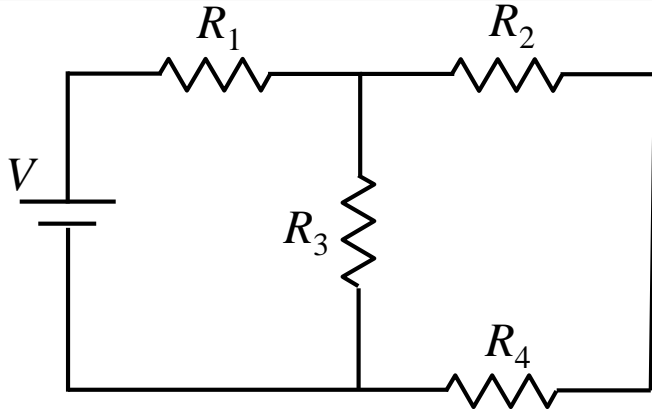
$$V_{23} = V_2 + V_3 = 2V_2$$

Resistor Network: Question 5 (N = 782)



→ $V_1 = 2V_2 = V$

Calculation



In the circuit shown: $V = 18V$,
 $R_1 = 1\Omega$, $R_2 = 2\Omega$, $R_3 = 3\Omega$, and $R_4 = 4\Omega$.

What is V_2 , the voltage across R_2 ?

Conceptual Analysis:

Ohm's Law: when current I flows through resistance R , the potential drop V is given by:
 $V = IR$.

Resistances are combined in series and parallel combinations

$$R_{series} = R_a + R_b$$

$$(1/R_{parallel}) = (1/R_a) + (1/R_b)$$

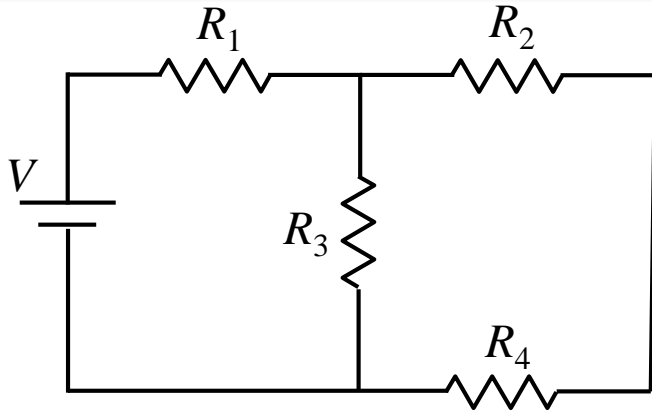
Strategic Analysis:

Combine resistances to form equivalent resistances

Evaluate voltages or currents from Ohm's Law

Expand circuit back using knowledge of voltages and currents

Calculation



In the circuit shown: $V = 18V$,
 $R_1 = 1\Omega$, $R_2 = 2\Omega$, $R_3 = 3\Omega$, and $R_4 = 4\Omega$.

What is V_2 , the voltage across R_2 ?

Combine Resistances:

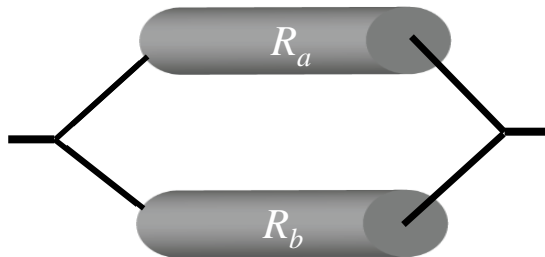
R_1 and R_2 are connected:

A) in series

B) in parallel

C) neither in series nor in parallel

Parallel Combination



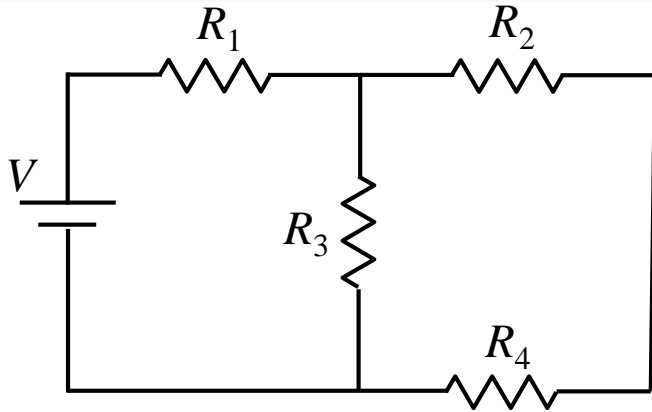
Parallel: Can make a loop that contains only those two resistors

Series Combination



Series : Every loop with resistor 1 also has resistor 2.

Calculation



In the circuit shown: $V = 18V$,
 $R_1 = 1\Omega$, $R_2 = 2\Omega$, $R_3 = 3\Omega$, and $R_4 = 4\Omega$.

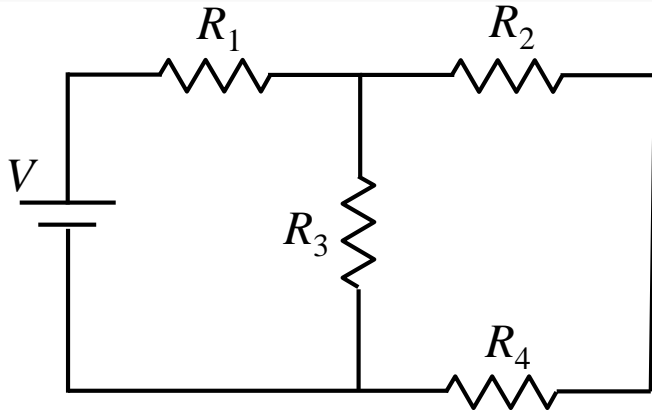
What is V_2 , the voltage across R_2 ?

We first will combine resistances R_2 , R_3 , R_4 :

Which of the following is true?

- A) R_2 , R_3 and R_4 are connected in series
- B) R_2 , R_3 , and R_4 are connected in parallel
- C) R_3 and R_4 are connected in series (R_{34}) which is connected in parallel with R_2
- D) R_2 and R_4 are connected in series (R_{24}) which is connected in parallel with R_3
- E) R_2 and R_4 are connected in parallel (R_{24}) which is connected in parallel with R_3

Calculation

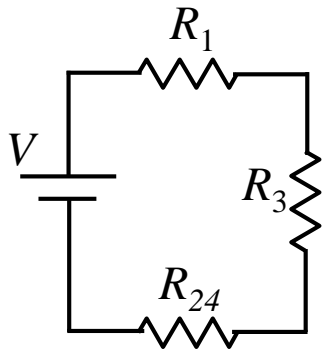


In the circuit shown: $V = 18V$,
 $R_1 = 1\Omega$, $R_2 = 2\Omega$, $R_3 = 3\Omega$, and $R_4 = 4\Omega$.

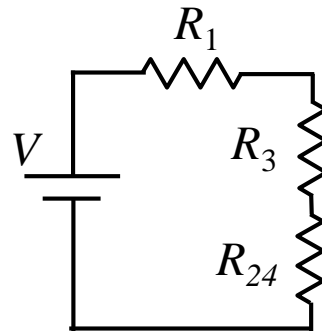
What is V_2 , the voltage across R_2 ?

R_2 and R_4 are connected in series (R_{24}) which is connected in parallel with R_3

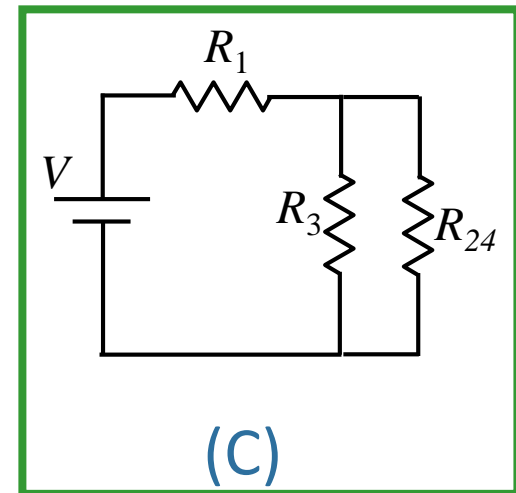
Redraw the circuit using the equivalent resistor $R_{24} =$ series combination of R_2 and R_4 .



(A)

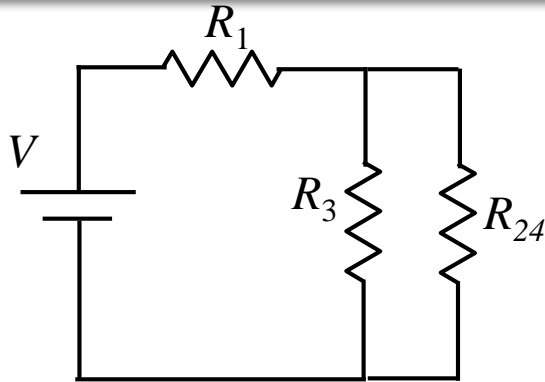


(B)



(C)

Calculation



In the circuit shown: $V = 18V$,
 $R_1 = 1\Omega$, $R_2 = 2\Omega$, $R_3 = 3\Omega$, and $R_4 = 4\Omega$.

What is V_2 , the voltage across R_2 ?

Combine Resistances:

R_2 and R_4 are connected in series = R_{24}
 R_3 and R_{24} are connected in parallel = R_{234}

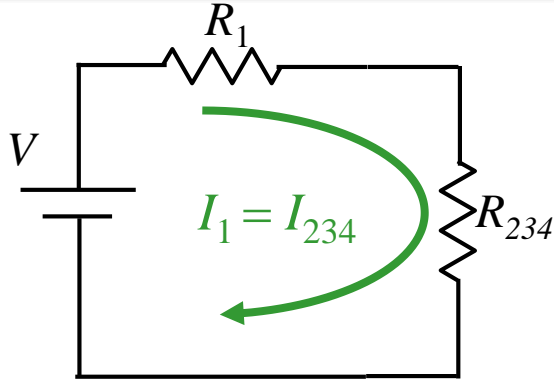
What is the value of R_{234} ?

A) $R_{234} = 1 \Omega$ B) $R_{234} = 2 \Omega$ C) $R_{234} = 4 \Omega$ D) $R_{234} = 6 \Omega$

R_2 and R_4 in series \rightarrow $R_{24} = R_2 + R_4 = 2\Omega + 4\Omega = 6\Omega$

$(1/R_{parallel}) = (1/R_a) + (1/R_b)$ \rightarrow $1/R_{234} = (1/3) + (1/6) = (3/6) \Omega^{-1}$ \rightarrow $R_{234} = 2 \Omega$

Calculation



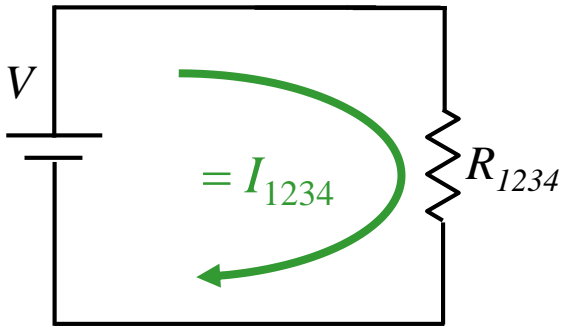
In the circuit shown: $V = 18V$,
 $R_1 = 1\Omega$, $R_2 = 2\Omega$, $R_3 = 3\Omega$, and $R_4 = 4\Omega$.

$$R_{24} = 6\Omega \quad R_{234} = 2\Omega$$

What is V_2 , the voltage across R_2 ?

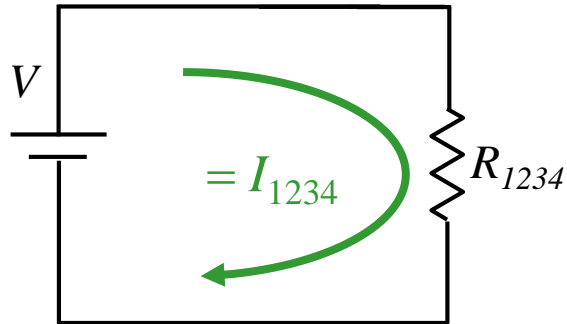
R_1 and R_{234} are in series. $R_{1234} = 1 + 2 = 3\Omega$

Our next task is to calculate the total current in the circuit



Ohm's Law tells us: $I_{1234} = V/R_{1234}$
 $= 18 / 3$
 $= 6 \text{ Amps}$

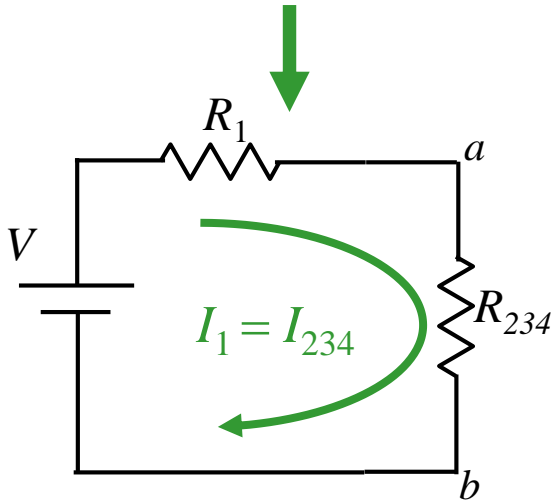
Calculation



In the circuit shown: $V = 18V$,
 $R_1 = 1\Omega$, $R_2 = 2\Omega$, $R_3 = 3\Omega$, and $R_4 = 4\Omega$.

$$R_{24} = 6\Omega \quad R_{234} = 2\Omega \quad I_{1234} = 6A$$

What is V_2 , the voltage across R_2 ?



$$I_{234} = I_{1234} \quad \text{Since } R_1 \text{ in series with } R_{234}$$

$$\begin{aligned} V_{234} &= I_{234} R_{234} \\ &= 6 \times 2 \\ &= 12 \text{ Volts} \end{aligned}$$

What is V_{ab} , the voltage across R_{234} ?

A) $V_{ab} = 1V$

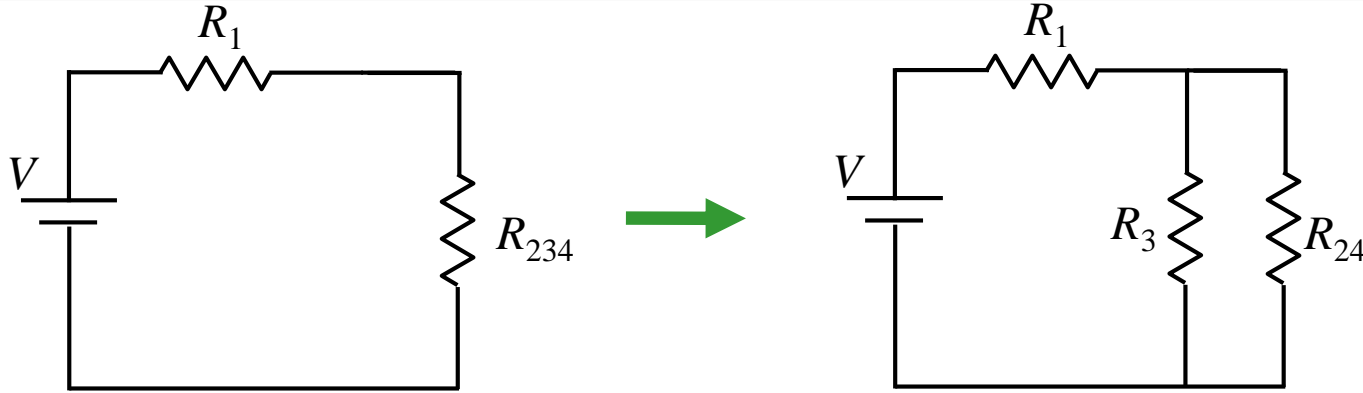
B) $V_{ab} = 2V$

C) $V_{ab} = 9V$

D) $V_{ab} = 12V$

E) $V_{ab} = 16V$

Calculation



$V = 18V$
 $R_1 = 1\Omega$
 $R_2 = 2\Omega$
 $R_3 = 3\Omega$
 $R_4 = 4\Omega$
 $R_{24} = 6\Omega$
 $R_{234} = 2\Omega$
 $I_{1234} = 6 \text{ Amps}$
 $I_{234} = 6 \text{ Amps}$
 $V_{234} = 12V$
What is V_2 ?

Which of the following are true?

A) $V_{234} = V_{24}$

B) $I_{234} = I_{24}$

C) Both A+B

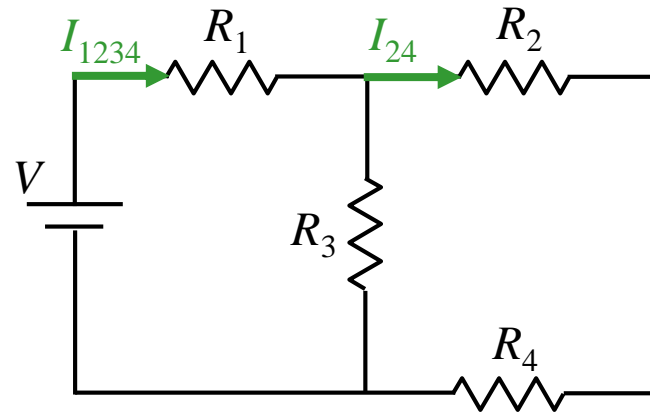
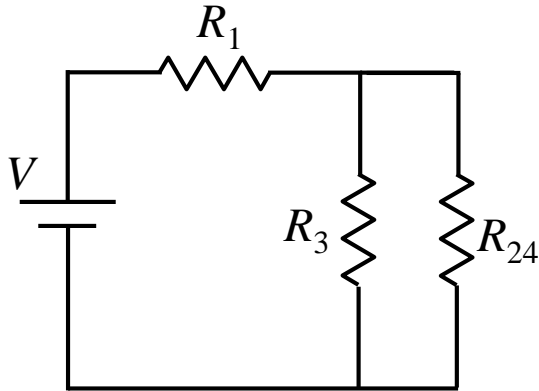
D) None

R_3 and R_{24} were combined in parallel to get R_{234} → Voltages are same!

Ohm's Law

$$\begin{aligned} I_{24} &= V_{24} / R_{24} \\ &= 12 / 6 \\ &= 2 \text{ Amps} \end{aligned}$$

Calculation



$V = 18V$
 $R_1 = 1\Omega$
 $R_2 = 2\Omega$
 $R_3 = 3\Omega$
 $R_4 = 4\Omega$
 $R_{24} = 6\Omega$
 $R_{234} = 2\Omega$
 $I_{1234} = 6 \text{ Amps}$
 $I_{234} = 6 \text{ Amps}$
 $V_{234} = 12V$
 $V_{24} = 12V$
 $I_{24} = 2 \text{ Amps}$
What is V_2 ?

Which of the following are true?

- A) $V_{24} = V_2$ **B) $I_{24} = I_2$** C) Both A+B D) None

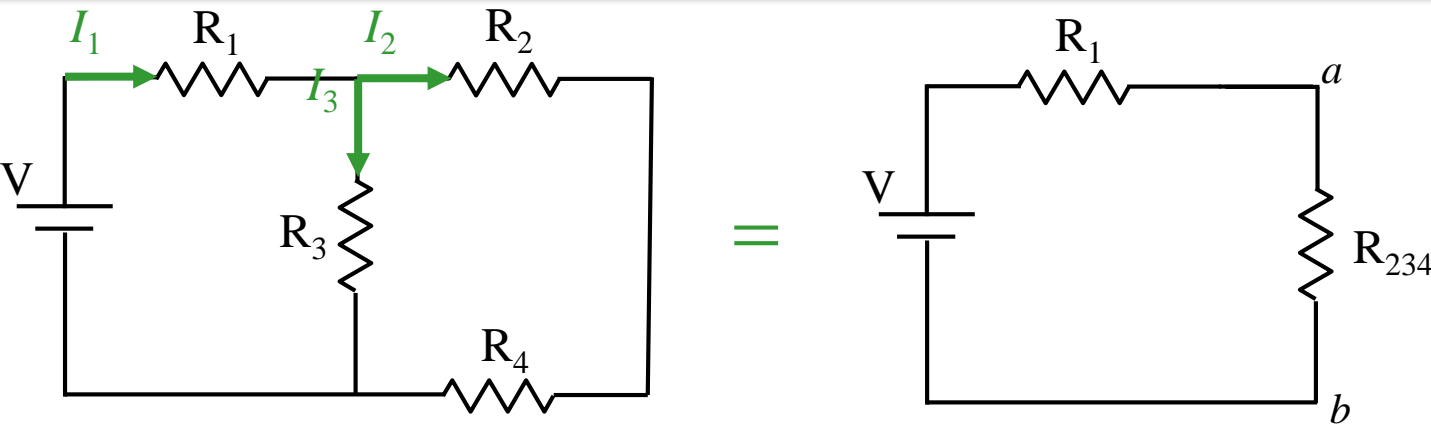
R_2 and R_4 where combined in series to get R_{24} → Currents are same!

Ohm's Law

$$\begin{aligned} V_2 &= I_2 R_2 \\ &= 2 \times 2 \\ &= 4 \text{ Volts!} \end{aligned}$$

The Problem Can Now Be Solved!

Quick Follow-Ups



- $V = 18V$
- $R_1 = 1\Omega$
- $R_2 = 2\Omega$
- $R_3 = 3\Omega$
- $R_4 = 4\Omega$
- $R_{24} = 6\Omega$
- $R_{234} = 2\Omega$
- $V_{234} = 12V$
- $V_2 = 4V$
- $I_{1234} = 6 \text{ Amps}$

What is I_3 ?

- A) $I_3 = 2 A$
- B) $I_3 = 3 A$
- C) $I_3 = 4 A$**

$V_3 = V_{234} = 12V \rightarrow I_3 = V_3/R_3 = 12V/3\Omega = 4A$

What is I_1 ?

We know $I_1 = I_{1234} = 6 A$

NOTE: $I_2 = V_2/R_2 = 4/2 = 2 A \rightarrow I_1 = I_2 + I_3$ **Make Sense?**