Physics 1022

Fall 2011, Ch 31, 32

Chapter 31. Current and Resistance

Topics:

- Conductivity and Resistivity
- Resistance and Ohm's Law

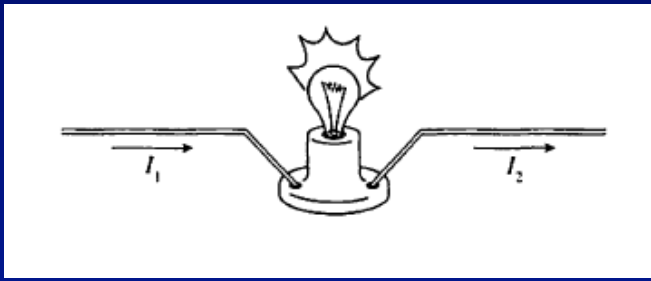
Chapter 32. Simple circuits

- Capacitors in series and parallel
- Resistors in series and parallel
- Kirchhoff's Rules

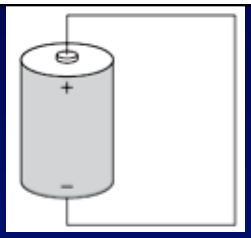
ConcepTest 1 Electric Current

Compare the currents I_1 and I_2.

1. $I_1 > I_2$
2. $I_1 = I_2$
3. $I_1 < I_2$



Consider a battery with a wire connecting its terminals.



(a) In which direction (CW or CCW) does an electron travel through the wire?

(b) In which direction (CW or CCW) does an electron travel through the wire?

(c) How does an electron's potential energy change as it moves through the wire?

(d) What happened to that energy? Where did it come from, or where did it go?

Resistance and Resistivity

New Topic

Resistivity

- The electric field is directly proportional to the current density in the wire.

$$\vec{E} = \rho \vec{J}$$

- ρ is called resistivity, R is the resistance
  - a measure of how hard a charge can move in a material

$$V = RI$$

- SI unit: V.m / A = Ω. m

Table 25.1 Resistivities at Room Temperature (20°C)

	Substance	$\rho(\Omega \cdot m)$	Substance	$\rho(\Omega \cdot m)$
Conductors	*Semiconductors*			
Metals:	Silver	1.47×10^{-8}	Pure carbon (graphite)	3.5×10^{-5}
	Copper	1.72×10^{-8}	Pure germanium	0.60
	Gold	2.44×10^{-8}	Pure silicon	2300
	Aluminum	2.75×10^{-8}	*Insulators*	
	Tungsten	5.25×10^{-8}	Amber	5×10^{14}
	Steel	20×10^{-8}	Glass	10^{10}–10^{14}
	Lead	22×10^{-8}	Lucite	$>10^{13}$
	Mercury	95×10^{-8}	Mica	10^{11}–10^{15}
Alloys:	Manganin (Cu 84%, Mn 12%, Ni 4%)	44×10^{-8}	Quartz (fused)	75×10^{16}
	Constantan (Cu 60%, Ni 40%)	49×10^{-8}	Sulfur	10^{15}
	Nichrome	100×10^{-8}	Teflon	$>10^{13}$
			Wood	10^{8}–10^{11}

- A perfect conductor has zero resistivity. A perfect insulator has infinite resistivity
  - The reciprocal of resistivity (1/ρ) is called conductivi

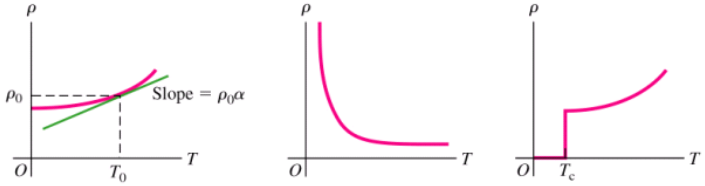
$$\sigma \vec{E} = \vec{J}$$

Temperature dependence of Resistivity

- The resistivity of a material depends on *temperature.*
  Metal near room temperature: $\rho(T) = \rho_0[1 + \alpha(T - T_0)]$

Table 25.2 Temperature Coefficients of Resistivity (Approximate Values Near Room Temperature)

Material	$\alpha\,[(°C)^{-1}]$	Material	$\alpha\,[(°C)^{-1}]$
Aluminum	0.0039	Lead	0.0043
Brass	0.0020	Manganin	0.00000
Carbon (graphite)	−0.0005	Mercury	0.00088
Constantan	0.00001	Nichrome	0.0004
Copper	0.00393	Silver	0.0038
Iron	0.0050	Tungsten	0.0045



(a) Metal: ρ increases with increasing T

(b) Semiconductor: ρ decreases with increasing T

(c) Superconductor: $\rho = 0$ for $T < T_c$

ConcepTest 3 Conductivity

If a metal is heated, what happens to its conductivity?

1. increases
2. does not change
3. decreases

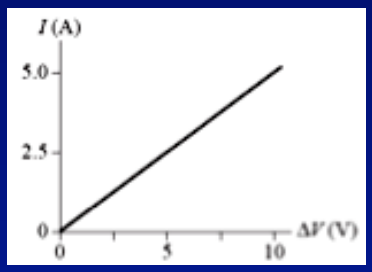
- Are collisions with positive ions more frequent?
- How does that affect the drift speed?
- Does this make a better or worse conductor?

ConcepTest 2 (Post) Ohm's Law

What is the value of R?

Draw the graph for the case where the length of the resistor is doubled.

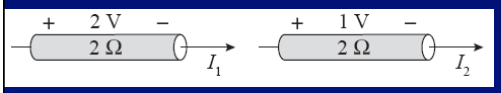
1. 0.25 Ω
2. 0.5 Ω
3. 1.0 Ω
4. 2.0 Ω
5. 4.0 Ω

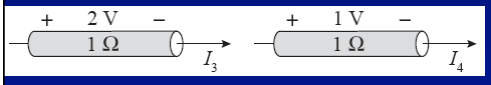


ConcepTest 3 (Post) Ohm's Law

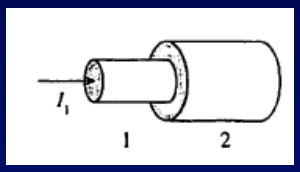
Rank the currents in the resistors shown below.

1. $I_3 > (I_1 = I_4) > I_2$
2. $(I_1 = I_3) > (I_2 = I_4)$
3. $(I_1 = I_2) > (I_3 = I_4)$
4. $I_1 > (I_2 = I_3) > I_4$
5. $I_3 > I_1 > (I_2 = I_4)$





A wire consists of two segments of different diameters of the same material.



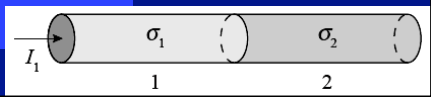
(a) Compare the currents I_1 and I_2.

(b) Compare the current densities J_1 and J_2.

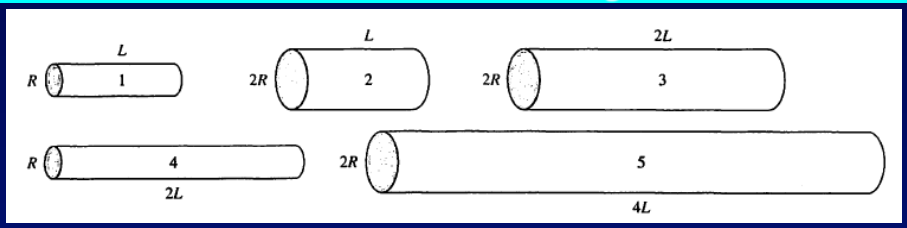
(c) Compare the electric field strengths E_1 and E_2.

(d) Compare the electron drift speeds v_1 and v_2.

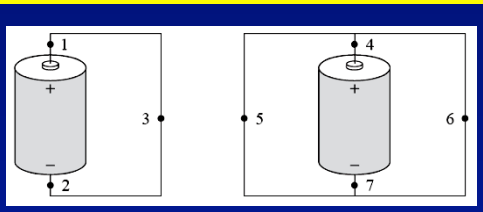
A wire consists of two segments with equal diameters, but their conductivities and electron densities differ ($\sigma_2 > \sigma_1$ and $n_2 > n_1$).



Rank these resistances, from largest to smallest.



Rank the currents at 1-7, from largest to smallest. Both batteries are identical.



Chapter 31. Current and Resistance

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Chapter 32. Simple circuits

- Capacitors in series and parallel
- Resistors in series and parallel
- Kirchhoff's Rules

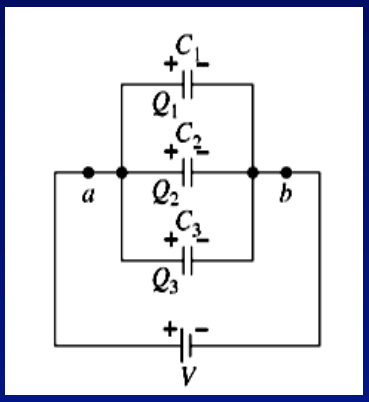
Combinations of Capacitors

New Topic

Capacitors in parallel

- Potential difference between points *a* and *b* is the *same* for all 3 capacitors
  - $V_1 = V_2 = V_3 = V$
- However, charges add:
  - $Q_1 + Q_2 + Q_3 = Q$
- Since $Q = C V$, we have
  - $C_1V + C_2V + C_3V = CV$

$$C = C_1 + C_2 + C_3$$

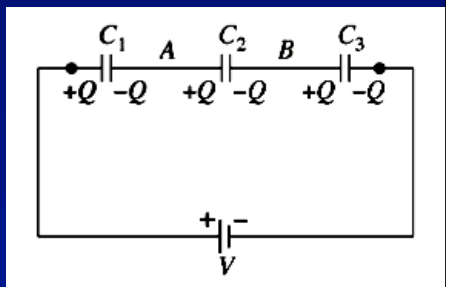


C is called an equivalent capacitor.

Capacitors in series

- Each capacitor has to hold the *same charge:*
  - $Q_1 = Q_2 = Q_3 = Q$
- However, voltages add:
  - $V_1 + V_2 + V_3 = V$
- Since $V = Q/C$, we have
  - $Q/C_1 + Q/C_2 + Q/C_3 = Q/C$

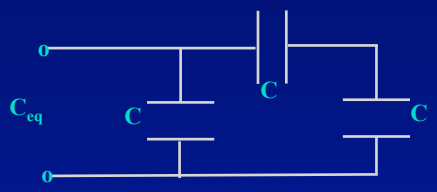
$$\frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}$$



ConcepTest 4 capacitors

What is the equivalent capacitance of the combination shown ?

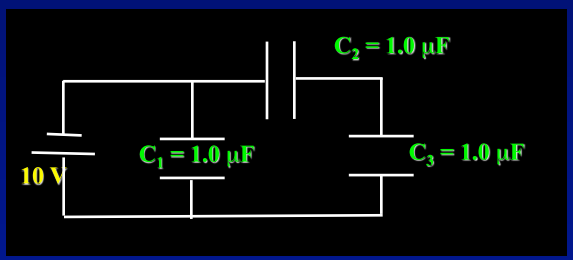
1) 3C/2
2) 2C/3
3) 3C
4) 2C
5) C/2



ConcepTest 5 capacitors

How does the voltage V_1 across the C_1 compare to the voltage V_2 across C_2?

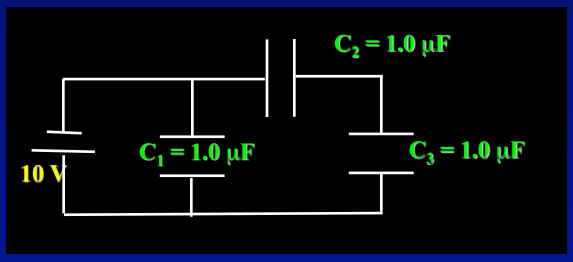
1) V1 = V2
2) V1 > V2
3) V1 < V2
4) all voltages are zero



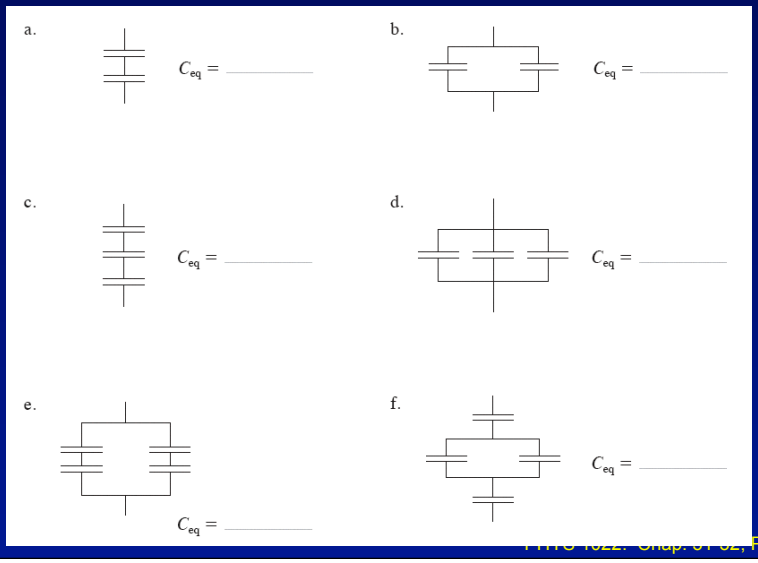
ConcepTest 6 capacitors

How does the charge Q_1 across C_1 compare to the charge Q_2 across C_2?

1) $Q_1 = Q_2$
2) $Q_1 < Q_2$
3) $Q_1 > Q_2$
4) all charges are zero

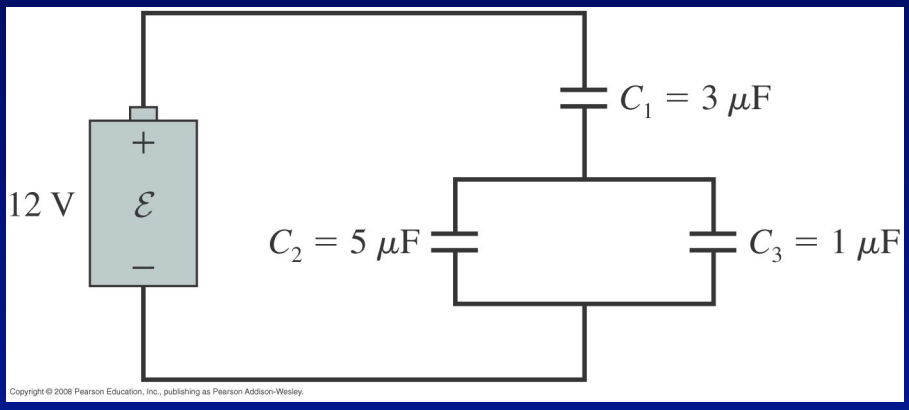


Each capacitor in the circuits below has capacitance C. What is the equivalent capacitance of the group of capacitors?



Capacitor calculations

- Find the charge, potential difference, and energy stored in each capacitor.



Combination of Resistors

New Topic

Resistors in series

- Same charge has to flow through all the resistors

  same current: $I_1 = I_2 = I_3 = I$

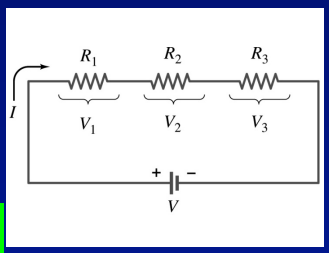
- Total work done by battery must equal sum of energy lost as charge moves through resistors

  voltages add: $V = V_1 + V_2 + V_3$

- Ohm's Law, V = I R, gives:

$$IR_{eq} = IR_1 + IR_2 + IR_3$$

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



Resistors in parallel

- **Current splits up into several branches. However, total current must be conserved!**

  ➢currents add: $I = I_1 + I_2 + I_3$

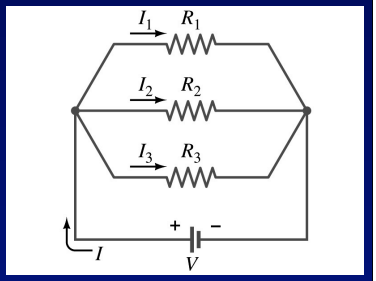
- But the voltage is the same across each resistor

  ⧫ $V = V_1 = V_2 = V_3$

- From Ohm's Law, V = I R, we find:

$$\frac{V}{R_{eq}} = \frac{V}{R_1} + \frac{V}{R_2} + \frac{V}{R_3}$$

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



R_{eq} is the reciprocal of the sum of the reciprocals.

Kirchhoff's Rules

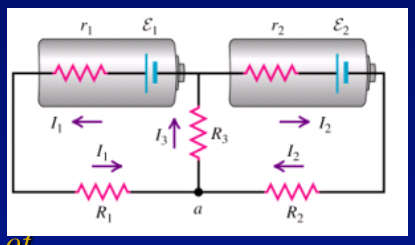
New Topic

Kirchhoff's Junction Rule

- **At any junction point, the sum of all currents entering the junction must equal the sum of all currents leaving.**

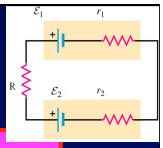
(or: what goes in has to come out!)

$$I_3 = I_1 + I_2$$



This rule follows from *conservation of charge* !

Kirchhoff's Loop Rule



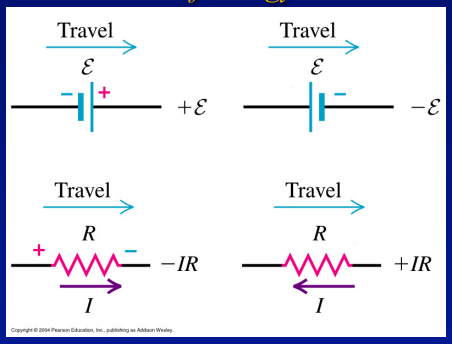
- "The sum of voltage drops and gains around any closed circuit loop must be zero"

$$\Delta V_1 + \Delta V_2 + \Delta V_3 + \Delta V_4 + \ldots = 0$$

- This rule follows from *conservation of energy*

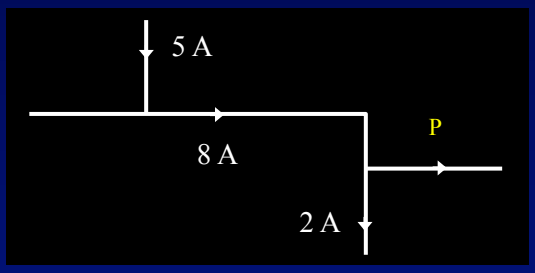
Sign convention:
– sign for voltage drop and + sign voltage gain.

It depends on several factors:
1. emf or resistor
2. direction of current
3. direction of loop travel



ConcepTest 7 Junction Rule

What is the current at point P?

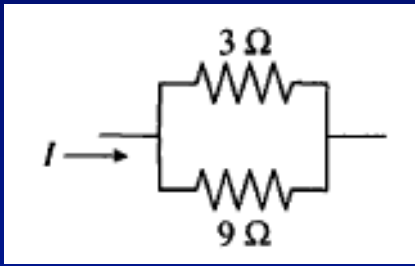


1) 2 A
2) 5 A
3) 6 A
4) 10 A

ConcepTest 8 (Post) Parallel Resistors

What fraction of the current goes through the 3 Ω resistor?

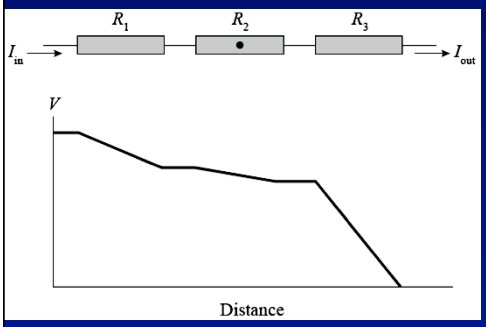
1. 100% (all of it)
2. 75%
3. 50%
4. 33%
5. 0%



ConcepTest 9 (Post) Kirchhoff's Laws

Rank the resistors in the part of the circuit below.

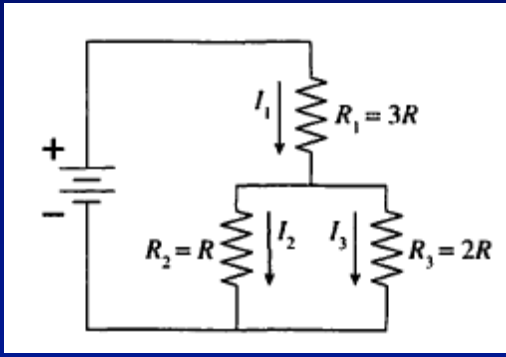
1. $R_1 > R_2 > R_3$
2. $R_2 > R_1 > R_3$
3. $R_3 > (R_2 = R_1)$
4. $R_3 > R_1 > R_2$
5. $R_1 = R_2 = R_3$



ConcepTest 10 (Post) Kirchhoff's Laws

Rank the currents shown in the circuit below.

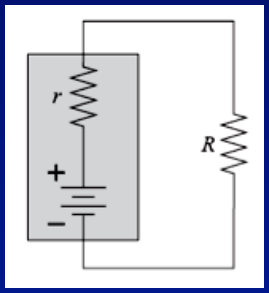
1. $I_3 > I_2 > I_1$
2. $I_2 > I_1 > I_3$
3. $I_1 > (I_2 = I_3)$
4. $I_1 > I_3 > I_2$
5. $I_1 > I_2 > I_3$



ConcepTest 11 (Post) Real Batteries

If the resistor R increases, what happens to the terminal voltage ΔV_{bat} of the battery?

1. increases
2. decreases
3. stays the same
4. goes to zero

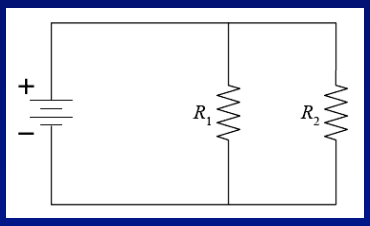


ConcepTest 12 (Post) Parallel Resistors

Which resistor dissipates the greater power, if $R_1 > R_2$?

$P = V^2/R$

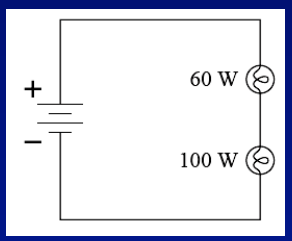
1. $P_1 > P_2$
2. $P_2 > P_1$
3. both the same



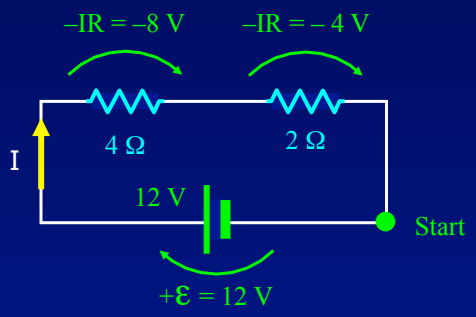
ConcepTest 13 (Post) Light Bulbs

Which bulb glows brighter? For a 100W bulb, $P = V^2/R$, where V = 110V.

1. 60 W is brighter
2. 100 W is brighter
3. both equally bright



Loop Rule Example
(with numbers)



Current in each resistor?

Total resistance = 6 Ω

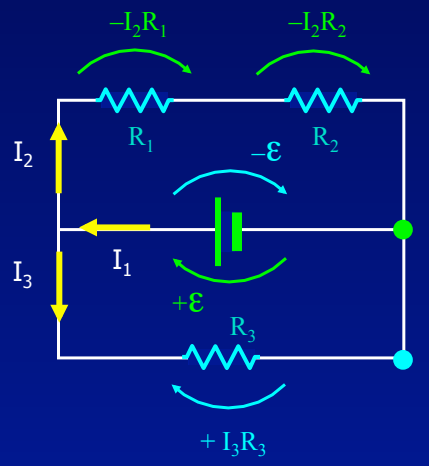
Ohm's Law: I = V / R
= 12 V / 6 Ω
= 2 A

Voltage drop across resistor?

V = I R

$\Delta V = +12\text{ V} - 8\text{ V} - 4\text{ V} = 0$ ✓

Loop Rule Example
(without numbers)



The first thing we have to do is?
Define currents!

Next: Define travel direction:
top loop (CW)
bottom loop (CW)

Now apply Loop rule to each loop

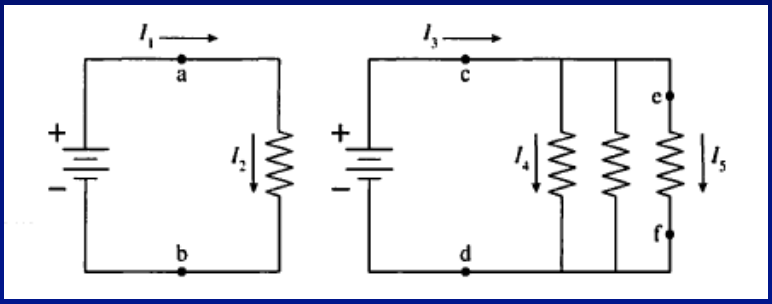
$\Delta V = +\mathcal{E} - I_2R_1 - I_2R_2 = 0$

$\Delta V = +I_3R_3 - \mathcal{E} = 0$

In the circuits below, the two batteries are identical and all of the resistors have the same value.

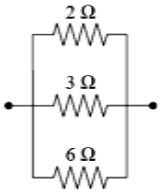
(a) Compare ΔV_{ab} and ΔV_{cd}.

(b) Rank the currents (from high to low).

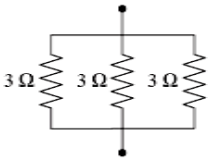


Find the equivalent resistance of each resistor network.

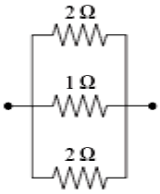
a.



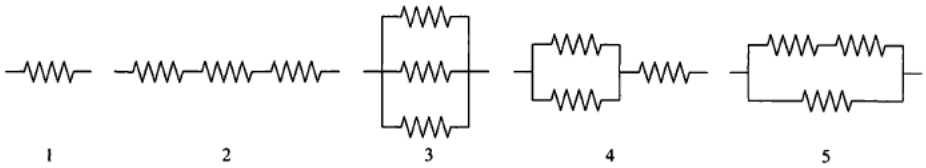
b.



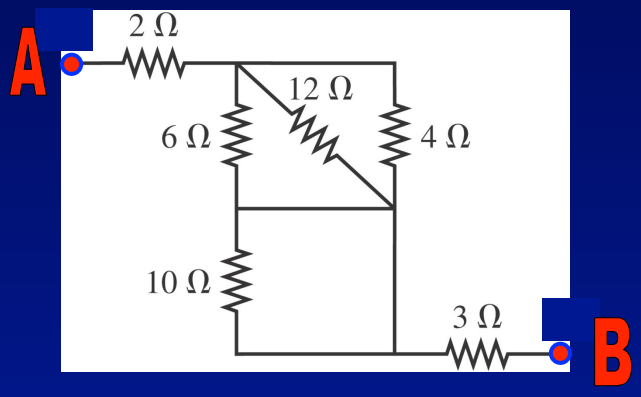
c.



Rank the equivalent resistances (large to small).

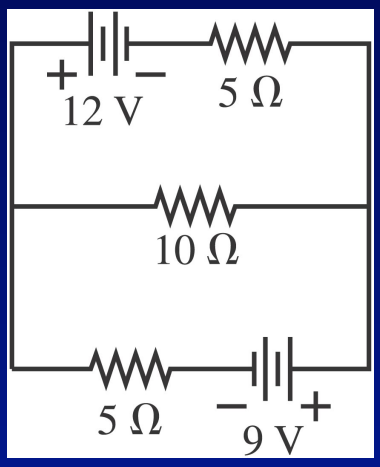


What is the equivalent resistance between points A and B in the network below?



3+2:5

Find the current through each resistor in the circuit.



3+2:5