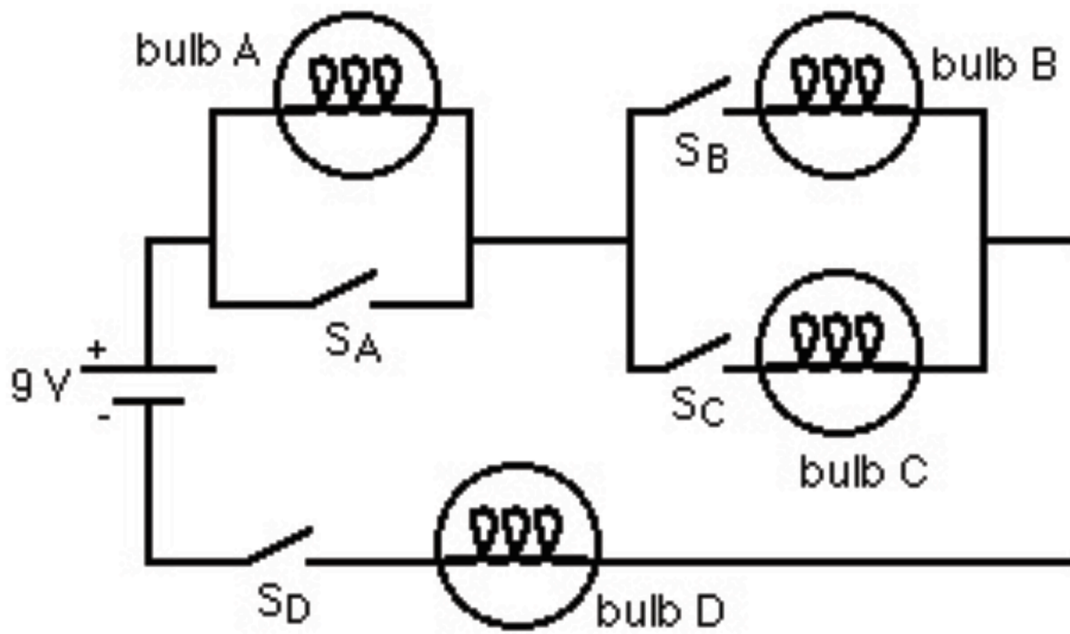
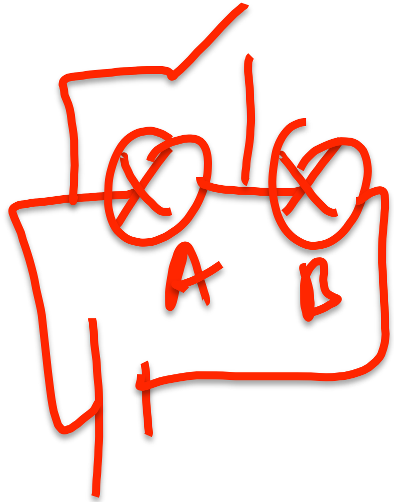
Bulbs and switches

What is the minimum number of switches that must be closed for at least one light bulb to come on?

1. 1
2. 2
3. 3
4. 4
5. 0





[illegible]

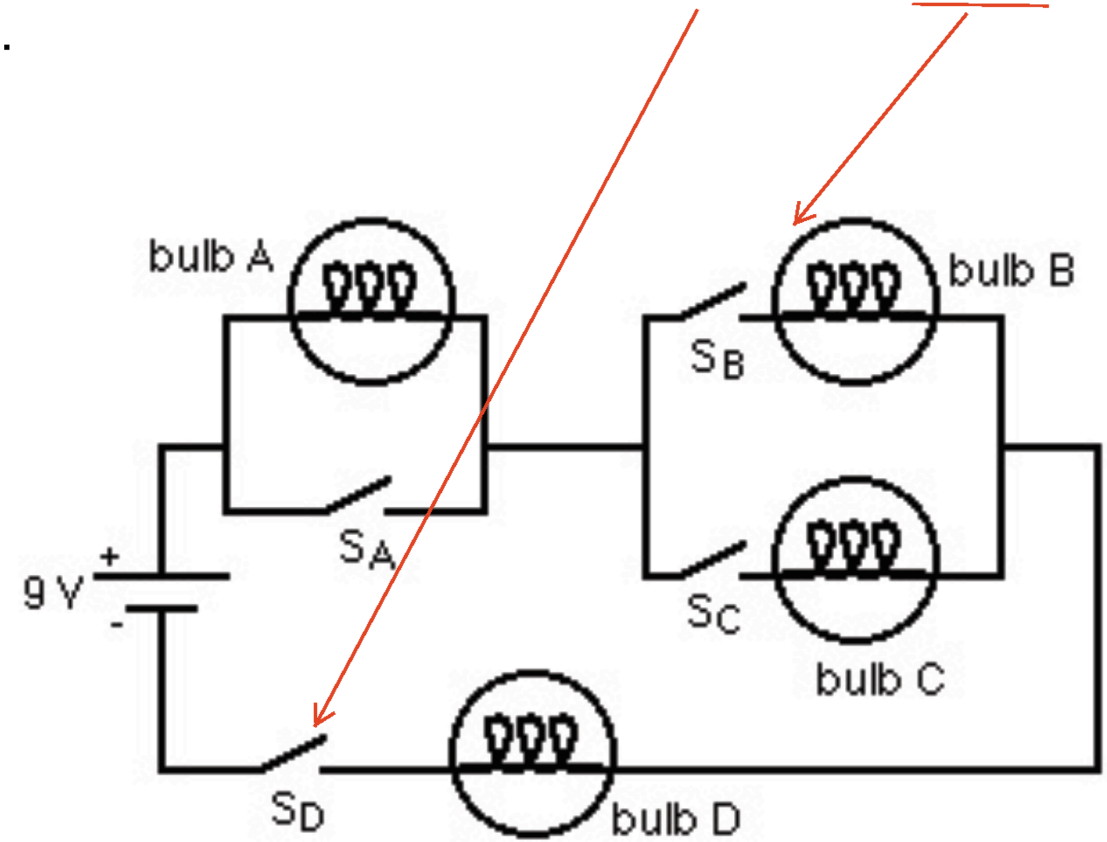
1、=

2、↗

3 ↙

Bulbs and switches

To complete the circuit, we need to close switch D, and either switch B or switch C.



Electric Power

The work done by the current on a device is equal to the energy spent to carry the charge through the device.

$$W = U = Q * \Delta V = I * \Delta V * \Delta t$$

By a definition: Power = work/time

$$P = \frac{W}{\Delta t} = \frac{I \cdot \Delta V \cdot \Delta t}{\Delta t} = I \cdot \Delta V$$

If we use the Ohm's Law ($\Delta V = I * R$), we can get other expressions:

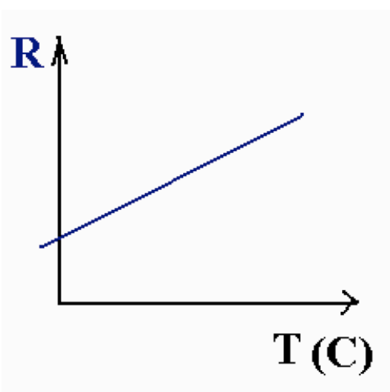
$$P = I \cdot \Delta V = I^2 \cdot R = \frac{(\Delta V)^2}{R}$$

The unit for power is Amp*V = W (Watt)

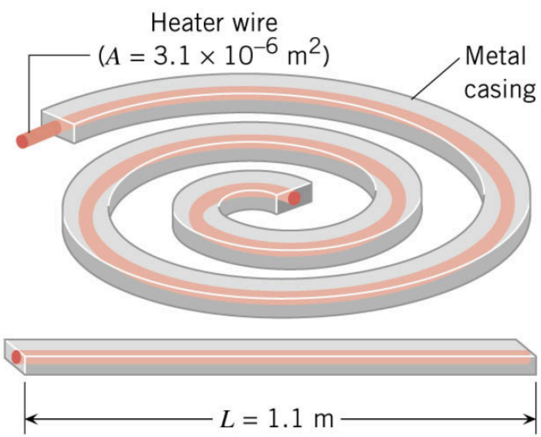
$$\rho = \rho_o\left[1 + \alpha\left(T - T_o\right)\right]$$

temperature coefficient of resistivity

$$R = R_o\left[1 + \alpha\left(T - T_o\right)\right]$$

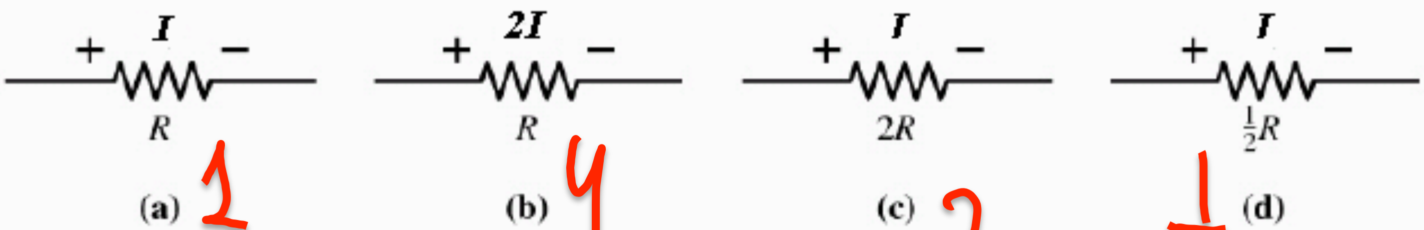


(a)



(b)

Rank in order, from largest to smallest, the powers P_a to P_d dissipated in resistors a to d.

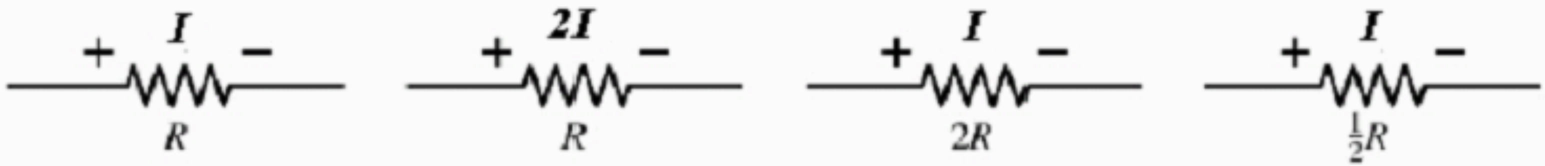


1. $P_b > P_a = P_c = P_d$
2. $P_b = P_c > P_a > P_c$
3. $P_b = P_d > P_a > P_c$
4. $P_b > P_c > P_a > P_d$
5. $P_b > P_d > P_a > P_c$

$$P = I \cdot \Delta V = I^2 \cdot R = \frac{(\Delta V)^2}{R}$$

Rank in order, from largest to smallest, the powers P_a to P_d dissipated in resistors a to d.

$$P = I^2 * R$$



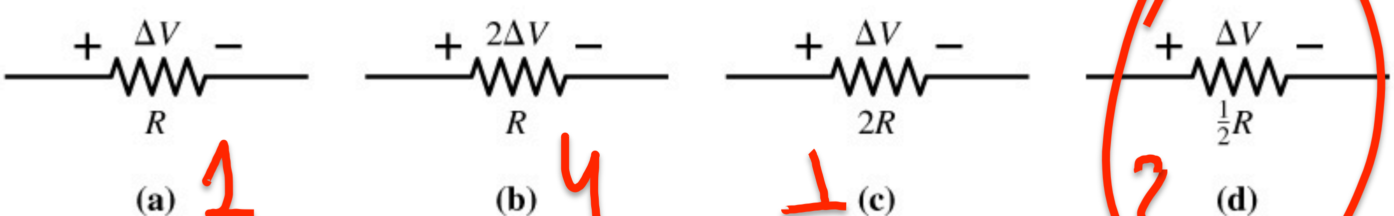
(a) (b) (c) (d)

(a)	(b)	(c)	(d)
1	$(2)^2 = 4$	2	$\frac{1}{2}$

✓ 4. $P_b > P_c > P_a > P_d$

A different problem!

Rank in order, from largest to smallest, the powers P_a to P_d dissipated in resistors a to d.

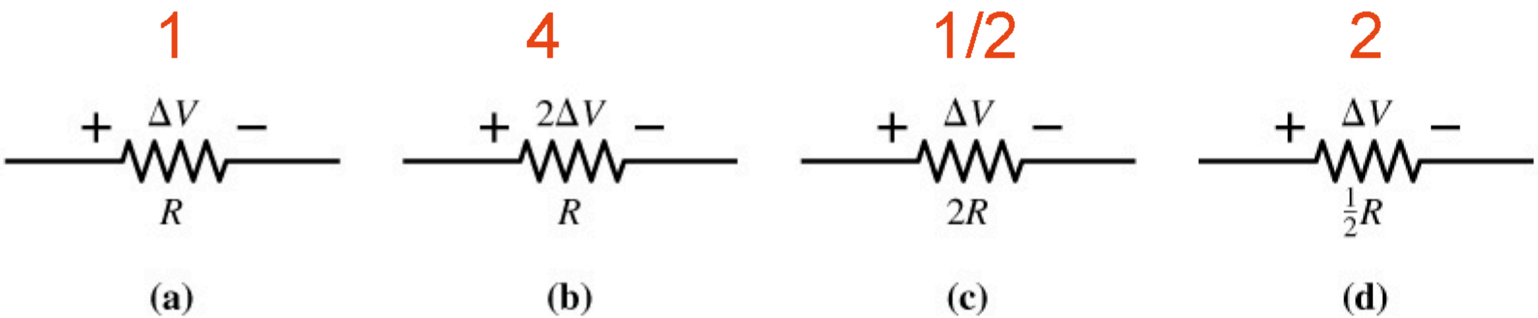


1. $P_b > P_a = P_c = P_d$
2. $P_b = P_c > P_a > P_c$
3. $P_b = P_d > P_a > P_c$
4. $P_b > P_c > P_a > P_d$
5. $P_b > P_d > P_a > P_c$

$$P = I \cdot \Delta V = I^2 \cdot R = \frac{(\Delta V)^2}{R}$$

Rank in order, from largest to smallest, the powers P_a to P_d dissipated in resistors a to d.

$P = V^2/R$



1. $P_b > P_a = P_c = P_d$
2. $P_b = P_c > P_a > P_c$
3. $P_b = P_d > P_a > P_c$
4. $P_b > P_c > P_a > P_d$
5. **$P_b > P_d > P_a > P_c$**

The cost of watching TV

The average household in the U.S. has a television on for about 3 hours every day. About how much does this cost every day?

1. 0.2 cents
2. 2 cents
3. 20 cents
4. $2

Understanding your electric bill

The electric company bills you for the amount of energy you use each month.

They measure this in units of kilowatt-hours (kW h).

How much does 1 of these units cost?

Approximately 10 cents.

How many joules is 1 kW h?

$$1 \text{ kW h} = (1000 \text{ W}) \times (1 \text{ h}) = (1000 \text{ J/s}) \times (3600 \text{ s}) = 3.6 \text{ million joules}$$

The cost of watching TV

Looked up on a TV – power rating of 75 W = 0.075 kW

Cost = (Power rating in kW) x (number of hours it's running) x (cost per kW-h)

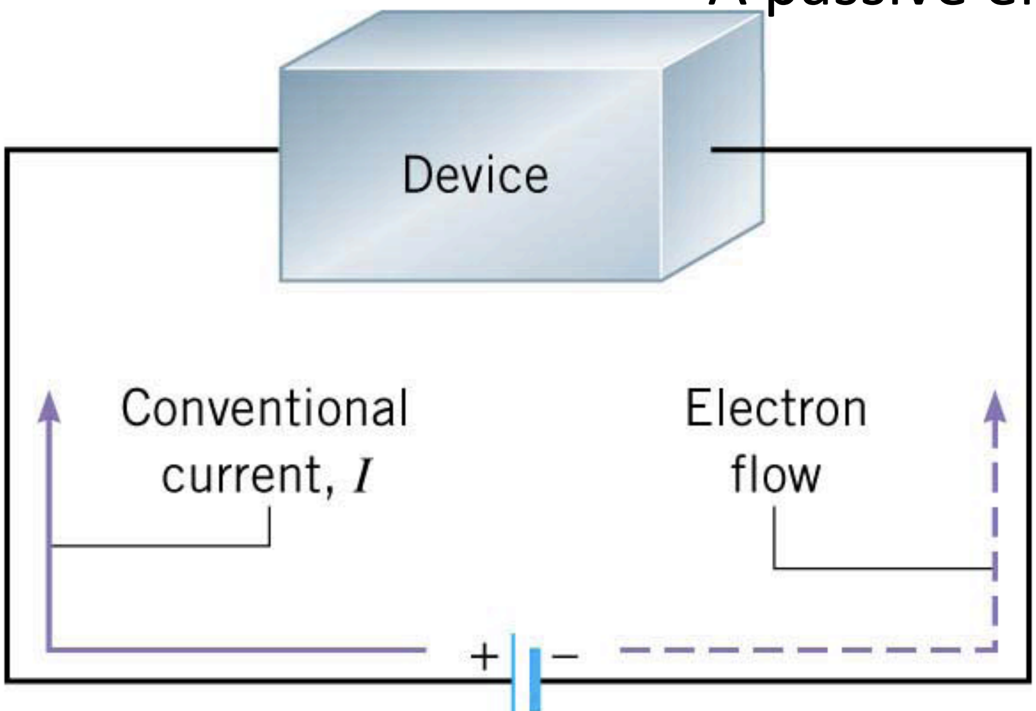
Cost = 0.075 kW x 3 h x 10 cents/(kW h) = 2 cents (or so).

Compare this to the $$$$ it costs to go to the movie theater.

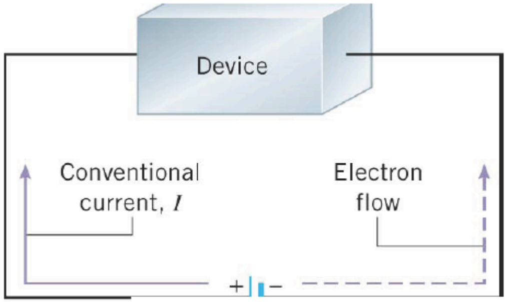
Electromotive Force and Current

Conventional current is the hypothetical flow of positive charges that would have the same effect in the circuit as the movement of negative charges that actually does occur.

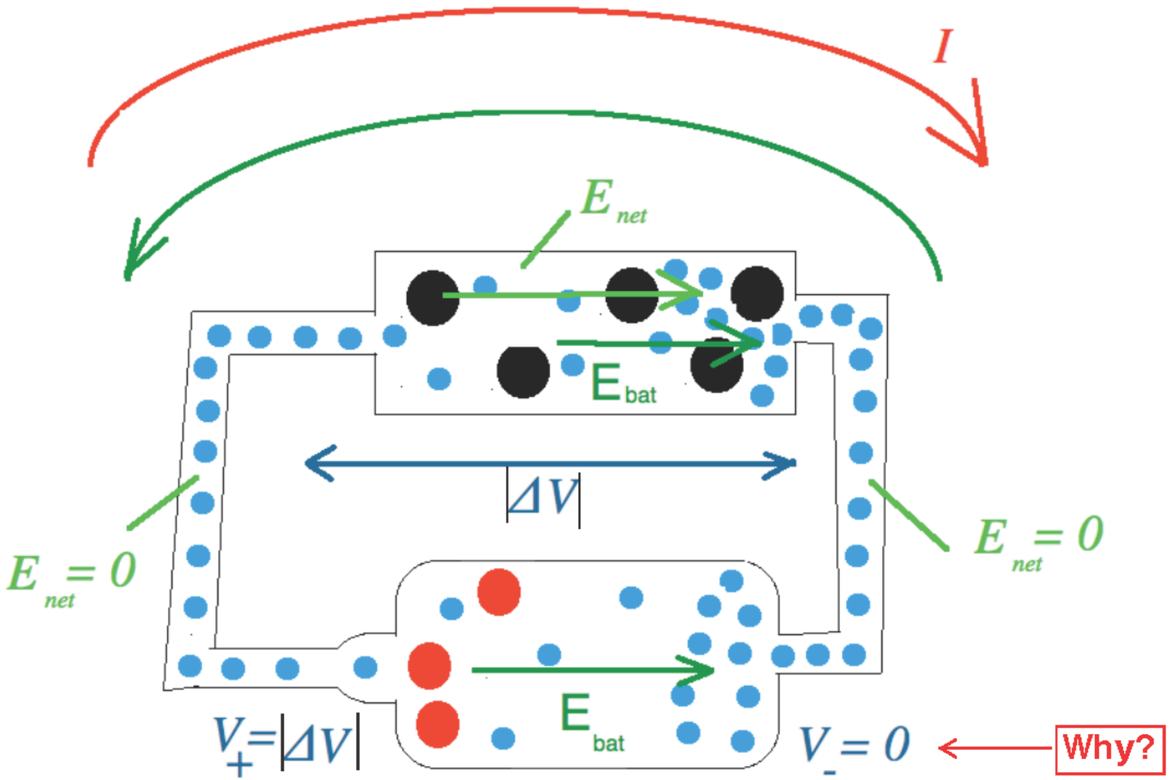
A passive element (a load)



An active element (a battery)



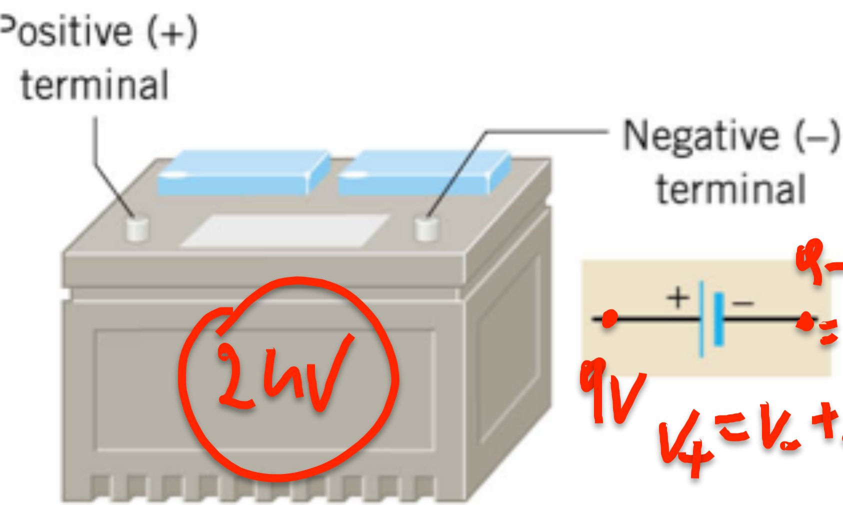
Ideal wires, ideal battery, dynamic equilibrium (=> current does not change over time, i.e. constant)

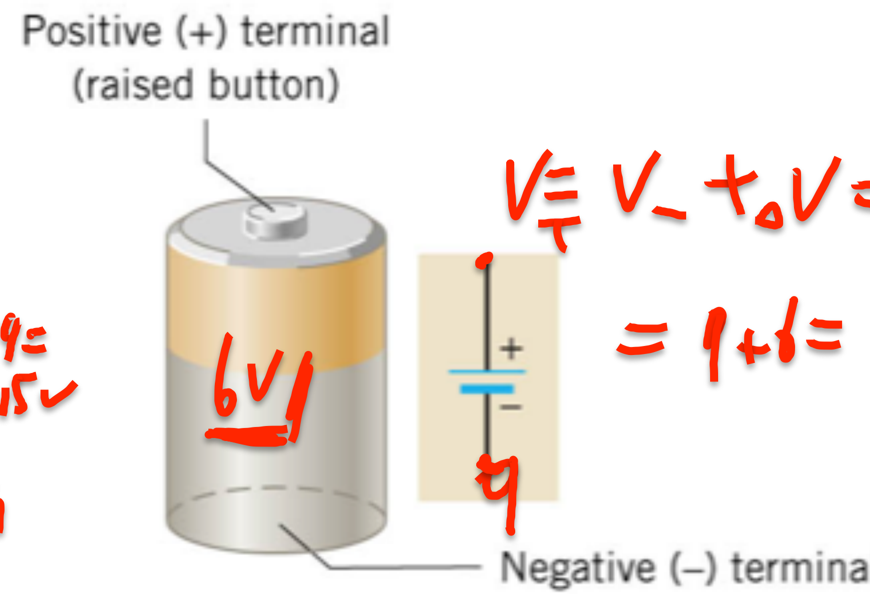


Electromotive Force and Current

Within a battery, a chemical reaction occurs that transfers electrons from one terminal to another terminal.

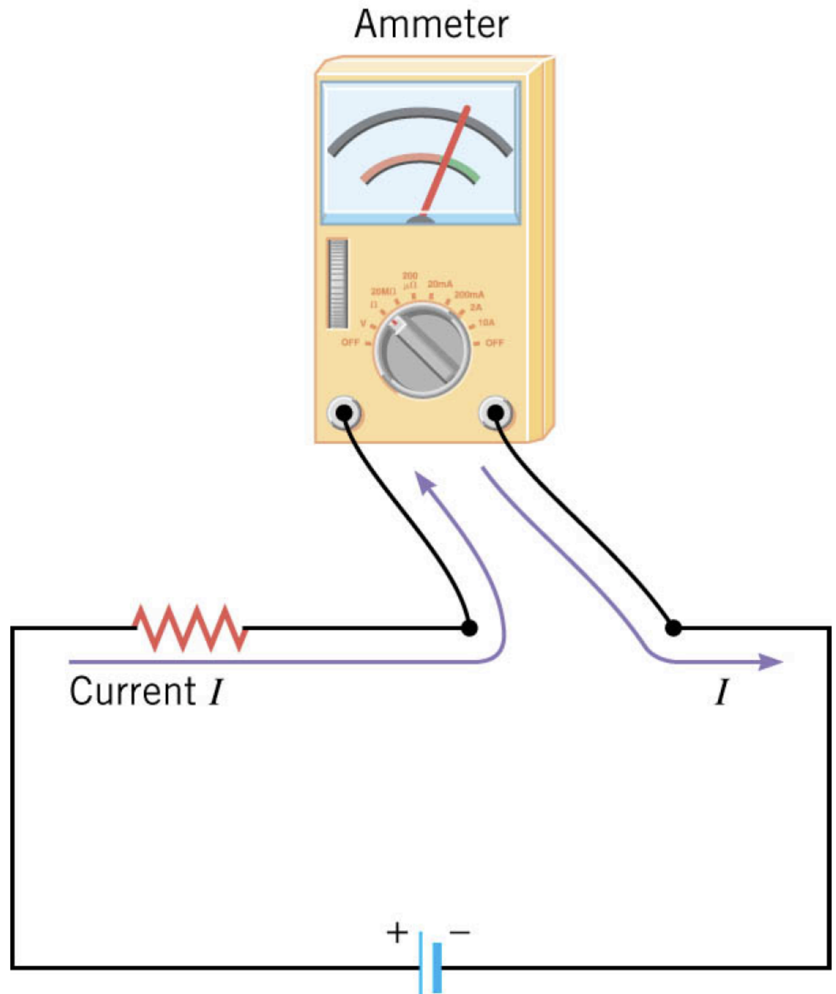
The maximum potential difference across the terminals is called the ***electromotive force (emf)***.



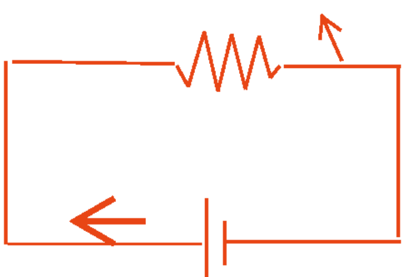


The Measurement of Current and Voltage

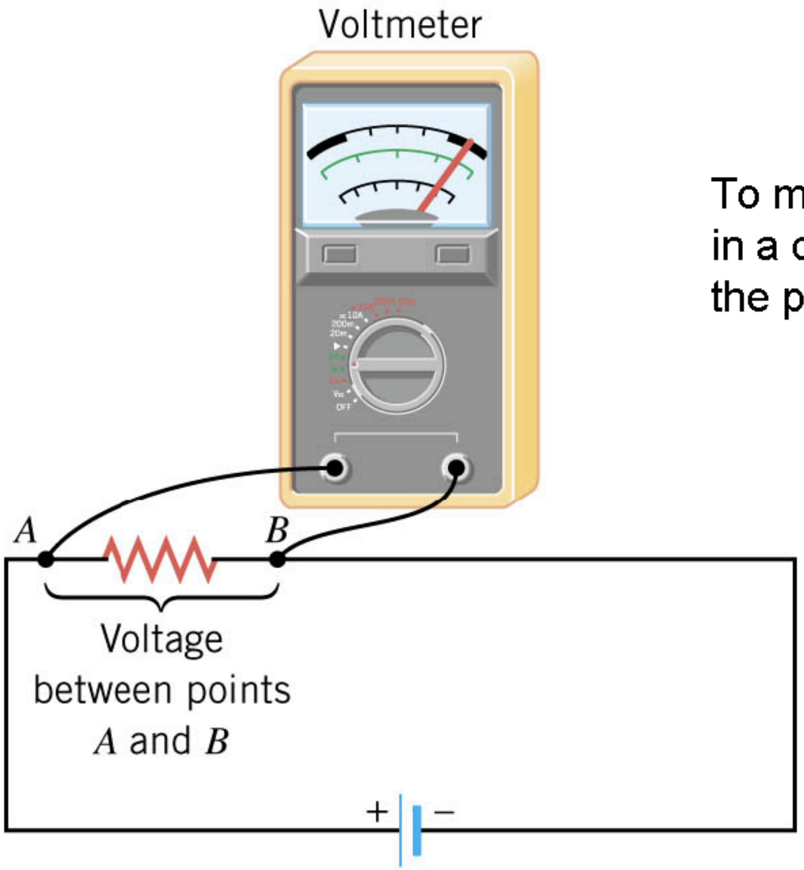
An ammeter must be inserted into a circuit so that the current passes directly through it.



brake the circuit;
insert an ammeter



The Measurement of Current and Voltage



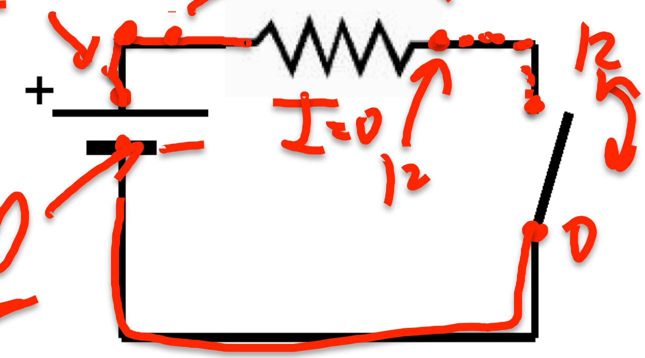
To measure the voltage between two points in a circuit, a voltmeter is connected between the points.

Voltage Across an Open Switch

A simple circuit consists of a battery that supplies a potential difference of 12 V, a 6 Ω resistor, and an open switch.

What is the potential difference across the open switch?

1) 0 Volts
2) 2 Volts
3) 6 Volts
4) 12 Volts

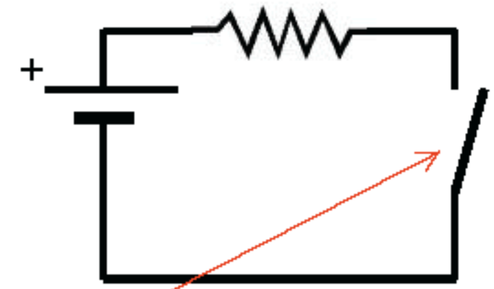


Voltage Across an Open Switch

A simple circuit consists of a battery that supplies a potential difference of 12 V, a 6 Ω resistor, and an open switch.

What is the potential difference across the open switch?

1) 0 Volts
2) 2 Volts
3) 6 Volts
4) 12 Volts



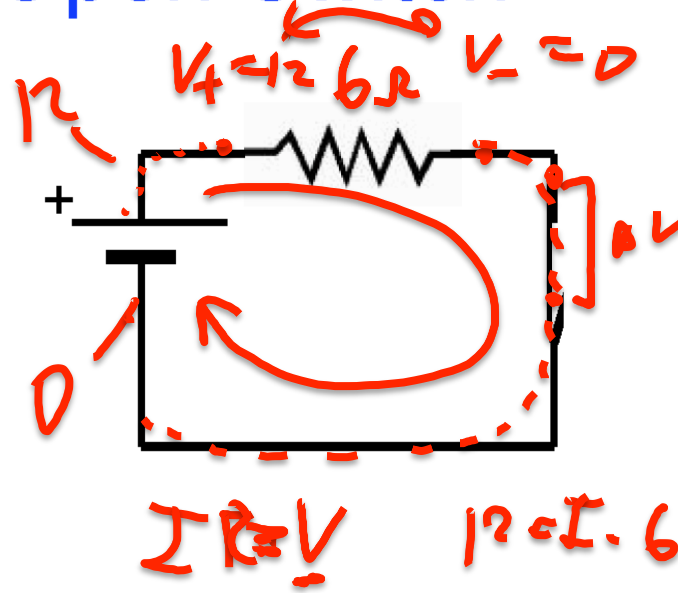
The switch has infinite resistance and does not allow any current to flow.

Therefore the voltage across the resistor is zero, and the full 12 V of the battery is applied across the switch.

When the switch is open, what is the voltage across the *resistor*? (choose on e of the answer above)

no current => no E => V = const!

Voltage Across an Open Switch



A simple circuit consists of a battery that supplies a potential difference of 12 V, a 6 Ω resistor, and an open switch.

What is the potential difference across the closed switch?

1) 0 Volts
2) 2 Volts
3) 6 Volts
4) 12 Volts

When the switch is closed, the voltage across the resistor is

Flipping a switch

When a light switch on a wall is turned on, how long (on average) does it take an electron in the wire right next to the switch to reach the filament in the light bulb?

Is it almost instantaneous, or could it be a minute or even more?

1) Almost instantaneous
2) Perhaps a minute or so
3) Weeks
4) Thousands of years

Flipping a switch

The drift velocities of electrons in wires are "typically 1 mm/s or less". Since a wall switch is usually a meter or more from the light bulb, the time for an average electron to drift from the switch to the bulb can be

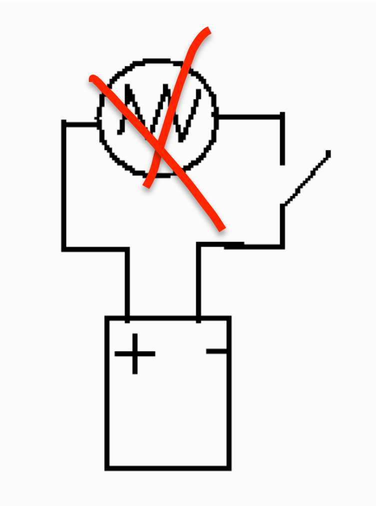
hundreds of seconds = a few minutes.

So why does the bulb come on almost instantaneously?

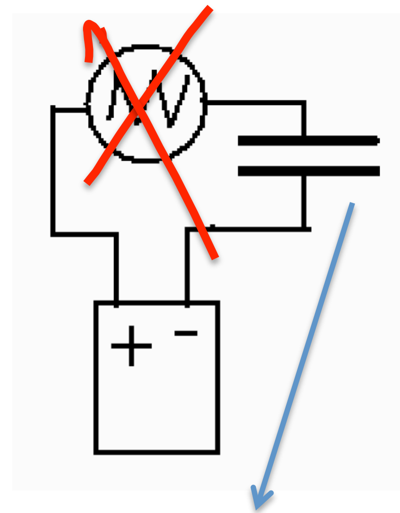
The potential source connected by the switch sets up an electric field inside the wire and the filament of the bulb. This change of electric field travels at around 10^8 m/s, so it is set up in the conductor almost instantaneously. The field is largest in the resistor (filament).

The conduction electrons throughout the circuit each acquire a drift velocity from the field. The ones in the bulb have the largest drift velocity, and transfer the most energy to vibrating atoms. The filament gets HOT.

A capacitor in a circuit



Two identical bulbs
are connected to two
identical batteries;
one through the open switch;
another through a capacitor.



Which of the bulbs is shining?

1 both

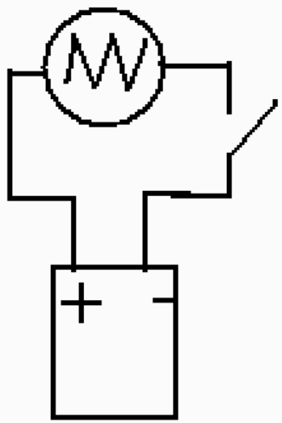
2 nether

3 Only the connected through the switch

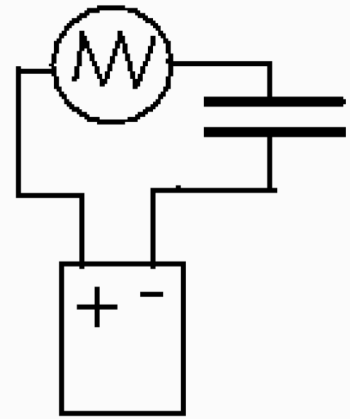
4 Only the connected through the capacitor

Has been connected ≠
Is getting connected

A capacitor in a circuit



Two identical bulbs
are connected to two
identical batteries;
one through the open switch;
another through a capacitor.



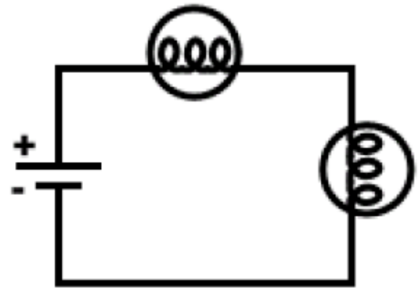
Which of the bulbs is shining?

B. nether

A switch as well as a capacitor represents a brake in a circuit (electrons cannot jump over the switch or from one plate onto another!). There is no current through a switch or a capacitor when a device is a connected to a battery.

Least current

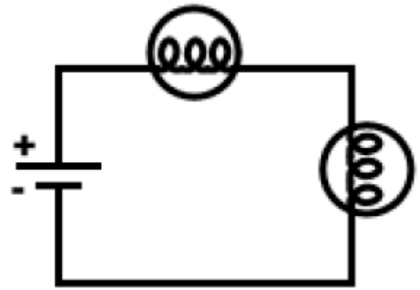
In the electrical circuit shown, at what point is the current the least?



1. Nowhere - the current is the same everywhere
2. The current is least near the positive terminal of the battery
3. The current is least between the lightbulbs
4. The current is least after the second lightbulb
5. The current is least near the negative terminal of the battery

Least current

In the electrical circuit shown, at what point is the current the least?



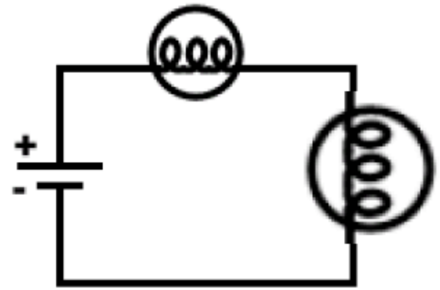
1. **Nowhere - the current is the same everywhere**

What about now?

One bulb has a resistance twice another one.

Least current

In the electrical circuit shown, at what point is the current the least?

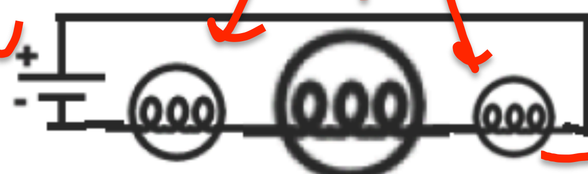


1. Nowhere - the current is the same everywhere
2. The current is least near the positive terminal of the battery
3. The current is least between the lightbulbs
4. The current is least after the second lightbulb
5. The current is least near the negative terminal of the battery

$$I = \frac{\Delta Q}{\Delta T} \Leftrightarrow Nv$$

Current = how fast ***charge*** is traveling (= Charge Flow Rate)

Current ≠ how fast ***electrons*** are traveling



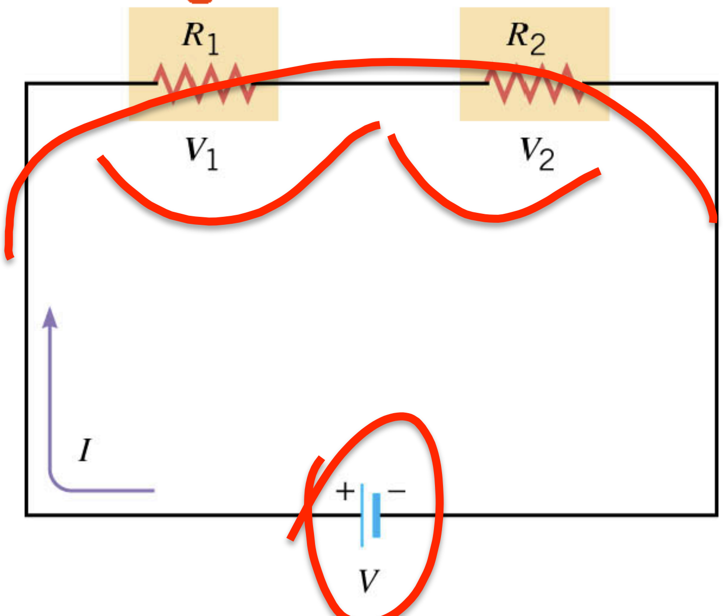
$$N_1 v_1 = N_2 v_2 = N_3 v_3 \quad => \quad I_1 = I_2 = I_3 = I$$

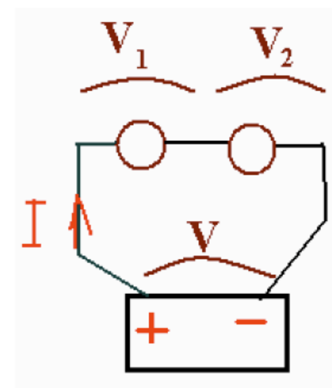
(When dynamic equilibrium is reached Charge Flow Rate remains constant)

Series Wiring

Two devices connected in series: is there anything the same for both?

1. resistance of each one
2. current through each one
3. voltage across each one

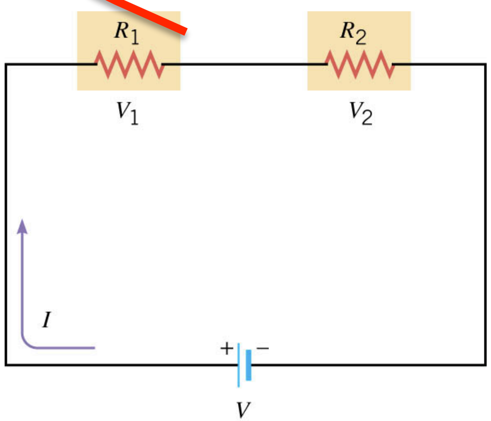


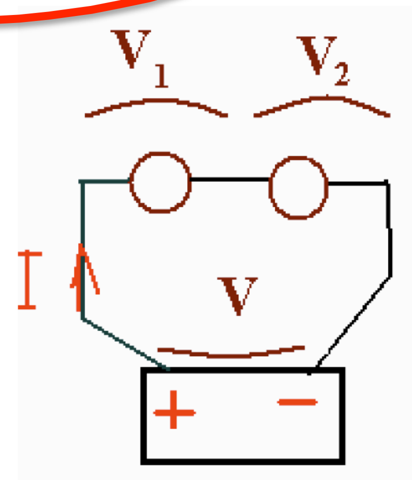


$V = V_1 + V_2$

Current I is the same!

$$V = V_1 + V_2 = IR_1 + IR_2 = I(R_1 + R_2) = IR_S$$



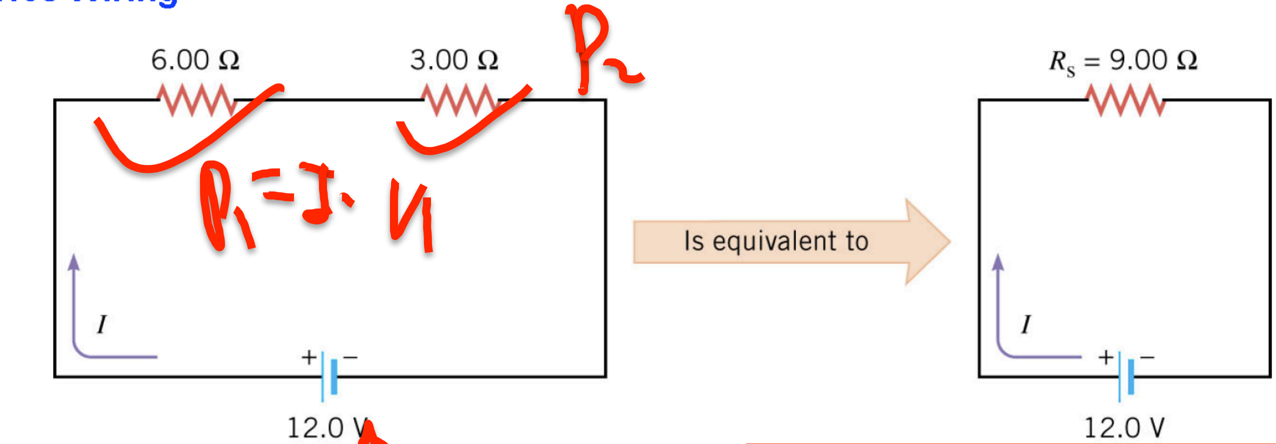


Series resistors

$$R_S = R_1 + R_2 + R_3 + \cdots$$

R_s is equivalent resistance

Series Wiring



I = V/R = 12/9 = 4/3 amp

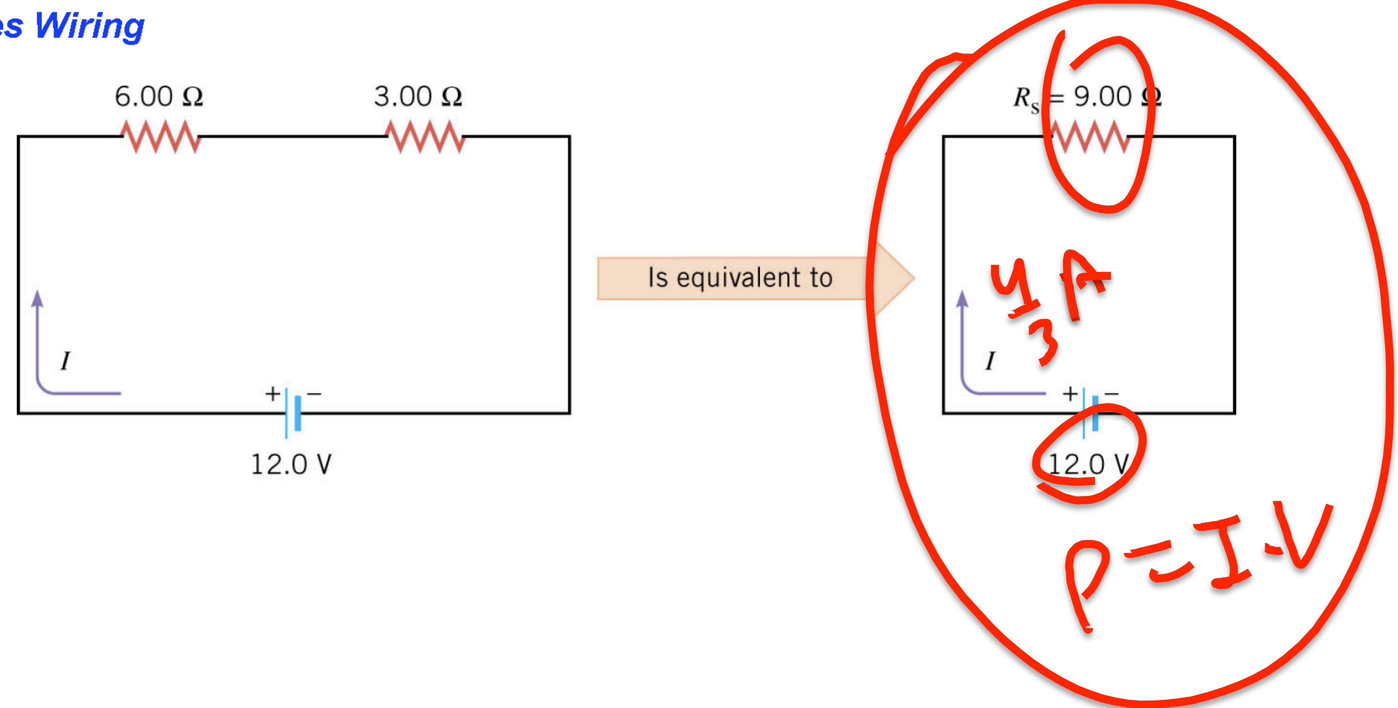
V1 = I*R1 = (4/3)*6 = 8 V

V2 = I*R2 = (4/3)*3 = 4 V

Example

A 6.00 Ω resistor and a 3.00 Ω resistor are connected in series with a 12.0 V battery. Assuming the battery contributes no resistance to the circuit, find (a) the current,

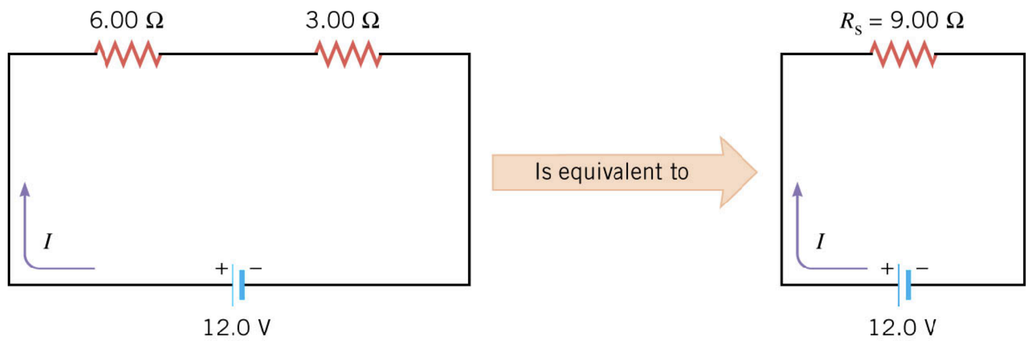
Series Wiring



Example

A 6.00 Ω resistor and a 3.00 Ω resistor are connected in series with a 12.0 V battery. Assuming the battery contributes no resistance to the circuit, find (b) the power dissipated in each resistor, and (c) the total power delivered to the resistors by the battery.

In addition to the Ohm's Law we need to use the expression for the power.



(a) $$R_S = 6.00\,\Omega + 3.00\,\Omega = 9.00\,\Omega \qquad I = \frac{V}{R_S} = \frac{12.0\text{ V}}{9.00\,\Omega} = 1.33\text{ A}$$

(b) $$P_6 = I^2R = (1.33\text{ A})^2(6.00\,\Omega) = 10.6\text{ W}$$

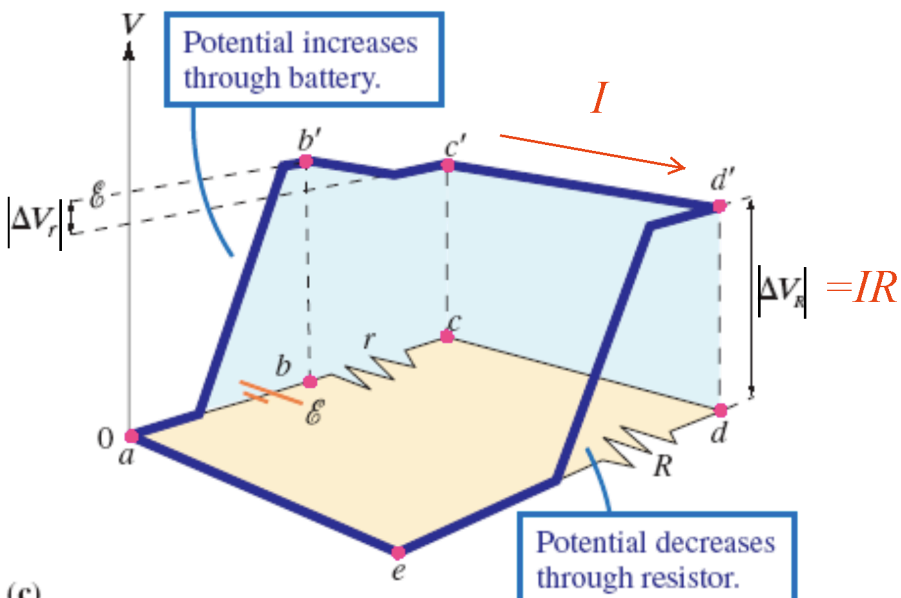
$$P_3 = I^2R = (1.33\text{ A})^2(3.00\,\Omega) = 5.31\text{ W}$$

(c) $$P_{total} = 10.6\text{ W} + 5.31\text{ W} = 15.9\text{ W}$$

This calculation accumulated roundoff error. How do I know?
Because: (12 V)(1.333 A) = 16 W is the power out of the battery!

r = 10 Ohm, R = 20 Ohm, I = 0.1 A.
Let's find all the potentials.

Basic single-loop circuit:



The sum of all the potential differences around a closed loop equals zero.

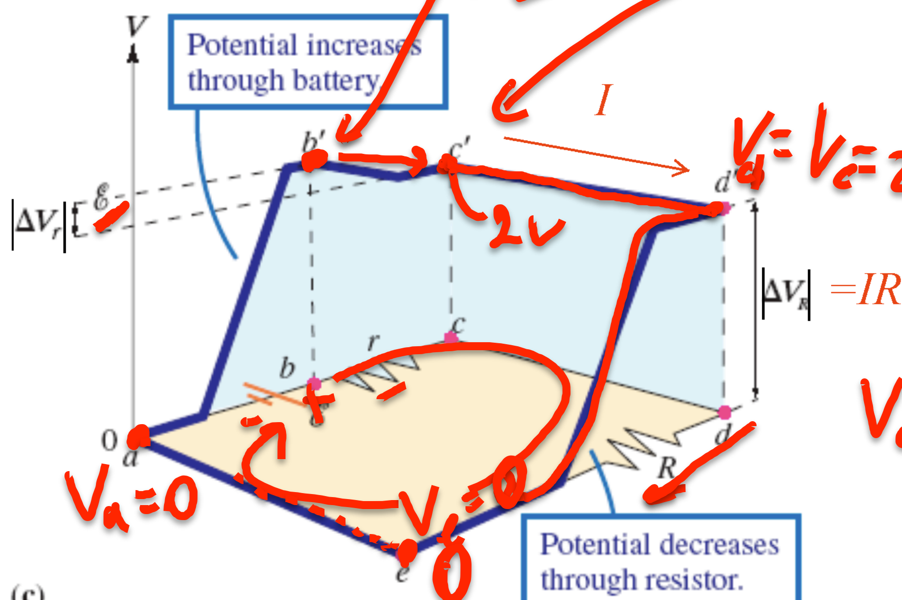
$$\sum \Delta V = 0 \quad \text{for a complete loop}$$

Loop Rule

r = 10 Ohm, R = 20 Ohm, I = 0.1 A.

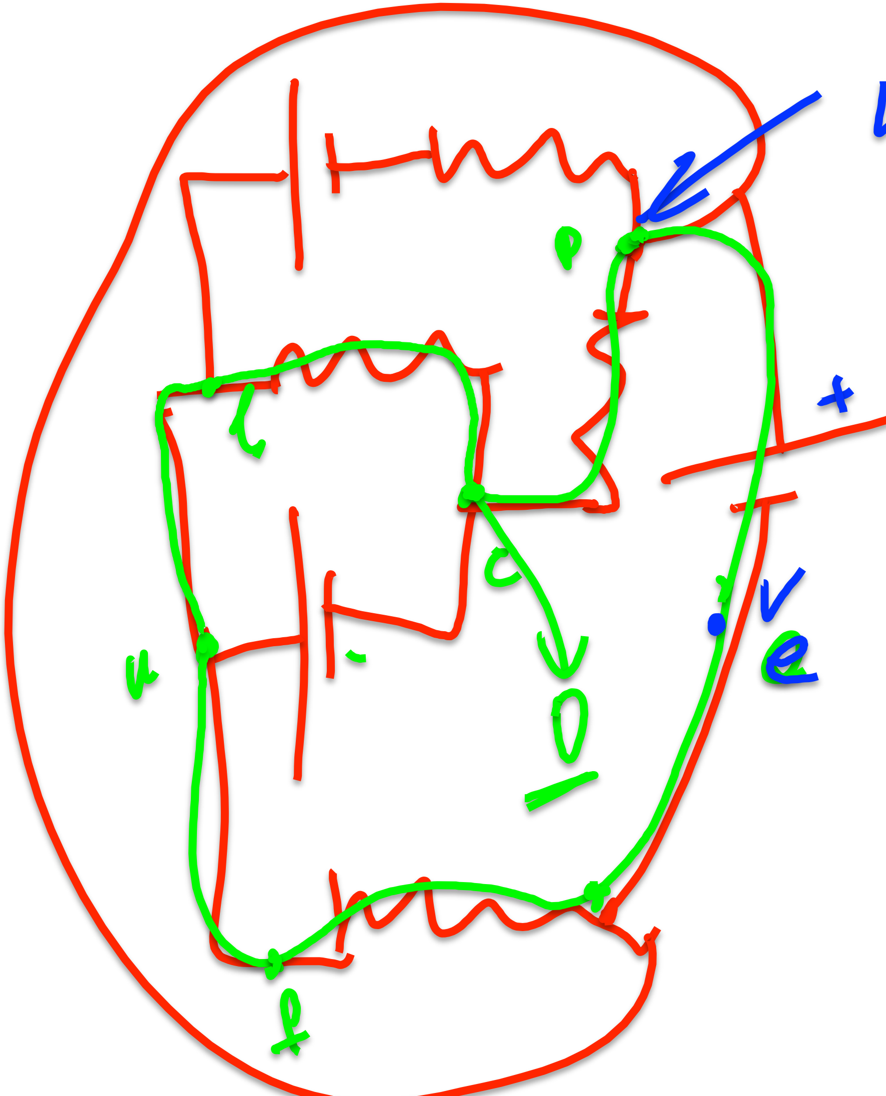
Let's find all the potentials.

Basic single-loop circuit:



$V_b - V_c = I \cdot r = 0.1 \cdot 10 = 1V$

$V_c - 0 = I \cdot R = 0.1 \cdot 20 = 2V$



$V_D = 10\ V$

$\xi = 24\ V$

$V_D - V_e = 24$

The sum of all the potential differences around a closed loop equals zero.

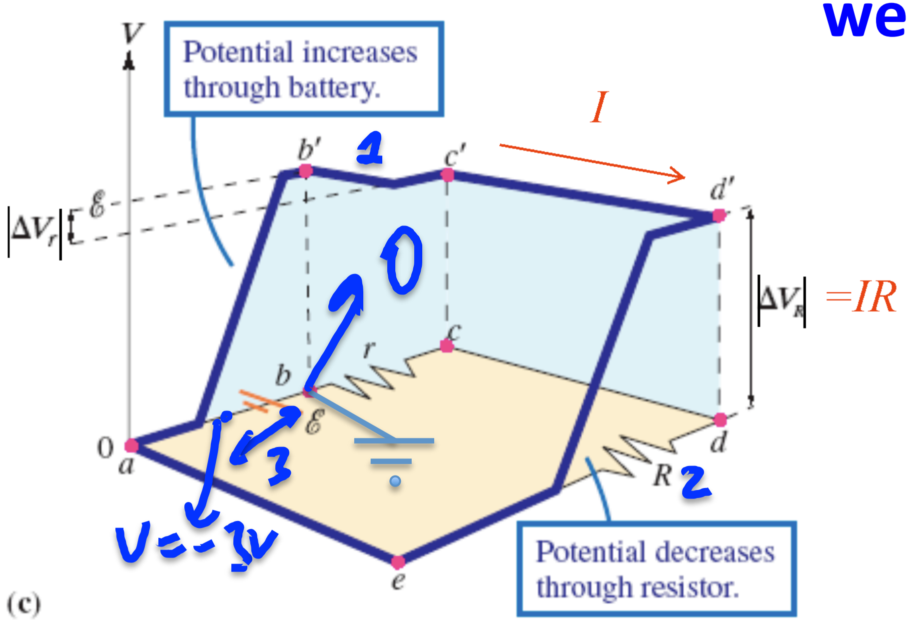
$$\sum \Delta V = 0 \quad \text{for a complete loop}$$

Loop Rule

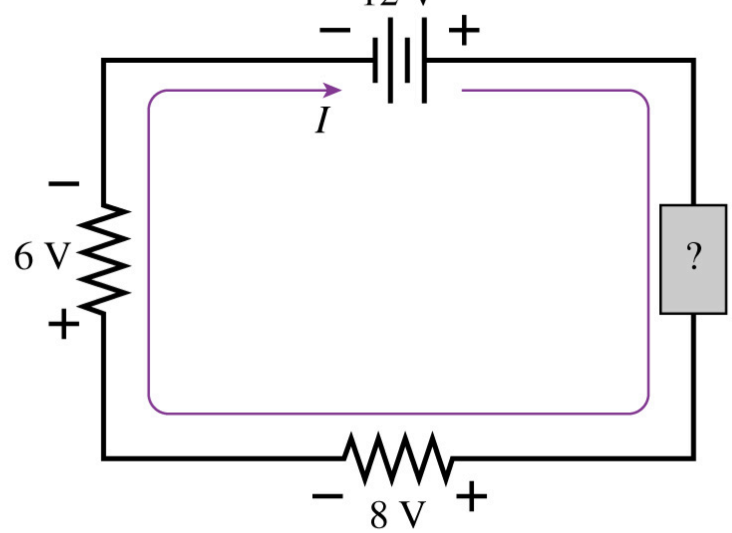
r = 10 Ohm, R = 20 Ohm, I = 0.1 A.
Let's find all the potentials.

Basic single-loop circuit:

What changes if we ground point *b*?!

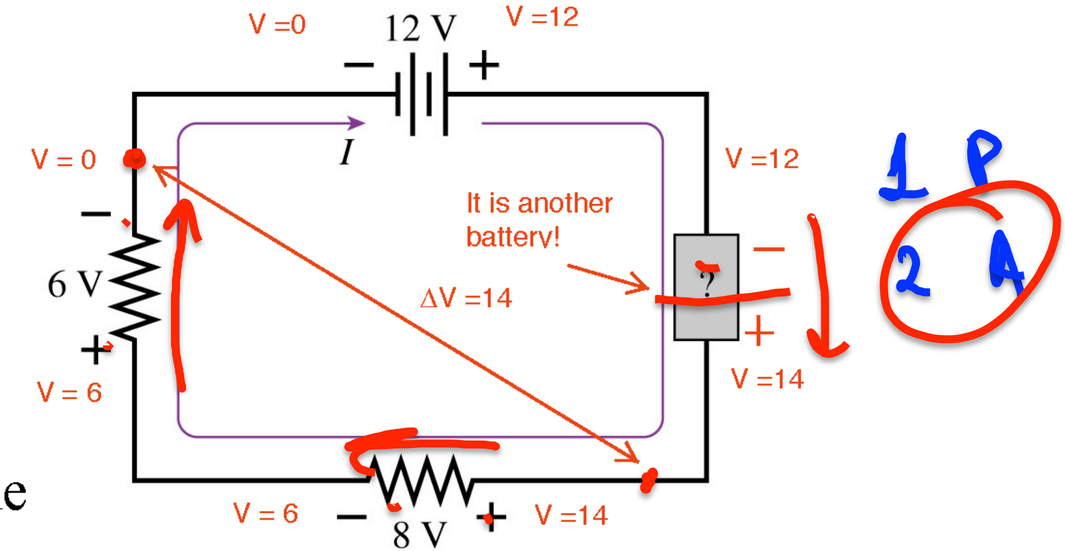


What is $|\Delta V|$ across the unspecified circuit element? Does the potential increase or decrease when traveling through this element in the direction assigned to I?



1. V increases by 2 V in the direction of I.
2. V decreases by 2 V in the direction of I.
3. V increases by 10 V in the direction of I.
4. V decreases by 10 V in the direction of I.
5. V increases by 26 V in the direction of I.

What is $|\Delta V|$ across the unspecified circuit element? Does the potential increase or decrease when traveling through this element in the direction assigned to I?

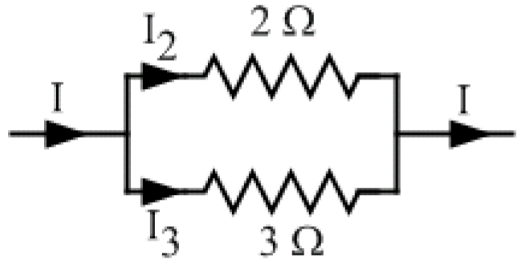


1. V increases by 2 V in the direction of I.
2. V decreases by 2 V in the direction of I.
3. V increases by 10 V in the direction of I.
4. V decreases by 10 V in the direction of I.
5. V increases by 26 V in the direction of I.

The junction rule

A junction is a place where three or more current paths meet.

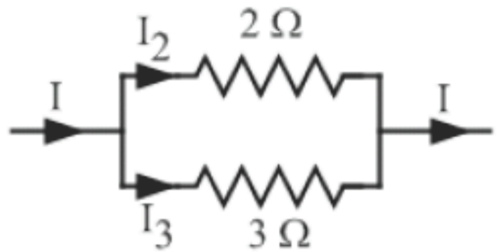
The junction rule: The total current coming into a junction equals the total current going out from a junction.



In the picture, a 2 Ω resistor is in parallel with a 3 Ω resistor. A current I comes into the junction before the resistors, splitting into two currents I_2 through the 2 Ω resistor and I_3 through the 3 Ω resistor.

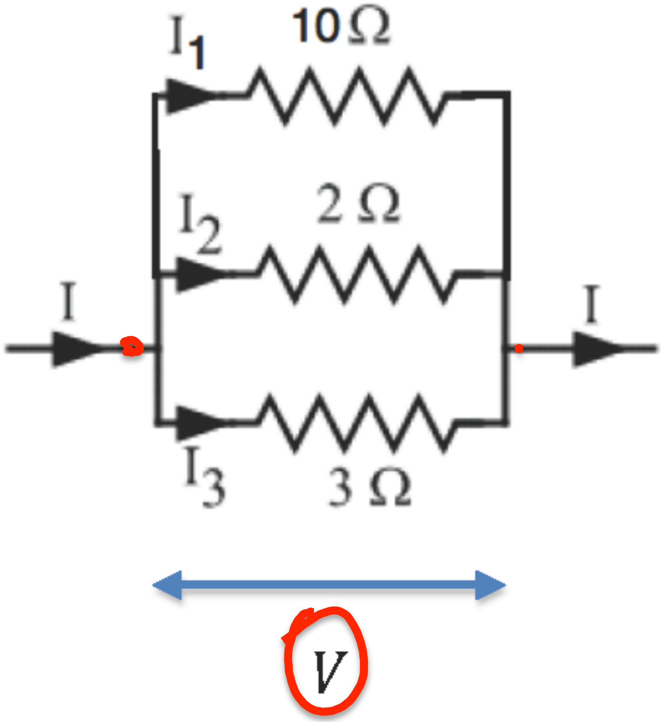
The junction rule tells us that $I = I_2 + I_3$

Practice Exercise



What fraction of the current, *I*, passes through the 2 Ω resistor?

Whenever we need to compare something, the first thing to do is to state what is the same!



$$V_1 = V_2 = V_3 = V$$

$$I_1 R_1 = I_2 R_2 = I_3 R_3$$

$$I = I_1 + I_2 + I_3$$

The highest current is ...

Etc. (more elements => more terms)

The junction rule

The correct answer is 3/5, which we can prove. Let's make our method more general by calling the two resistors R_2 and R_3. Resistors in parallel have the same potential difference across them, so:

$$|\Delta V| = I_2 R_2 = I_3 R_3$$

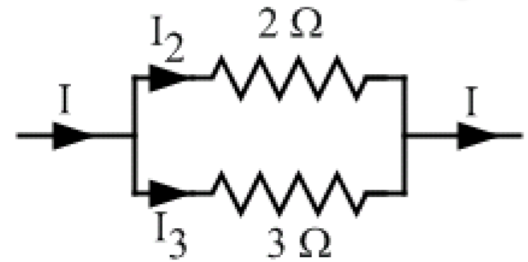
Ohm's Law

Combine this with the junction equation: $I = I_2 + I_3$.

Therefore: $I_3 = I - I_2$.

$I_3 = I - I_2$

Substitute this into the first expression:



$$I_2 R_2 = (I - I_2) R_3$$

$$I_2 (R_2 + R_3) = I R_3$$

$$I_2 = \frac{R_3}{R_2 + R_3} I \quad \text{and} \quad I_3 = \frac{R_2}{R_2 + R_3} I$$

$$\frac{I_2}{I_3} = \frac{R_3}{R_2}$$

$R\downarrow \Rightarrow I\uparrow$