

You can easily show that the units of electric field can be written as N/C (Newtons per Coulomb) or V/m (volts per meter).

$$V = \frac{J}{C} = \frac{Nm}{C}$$

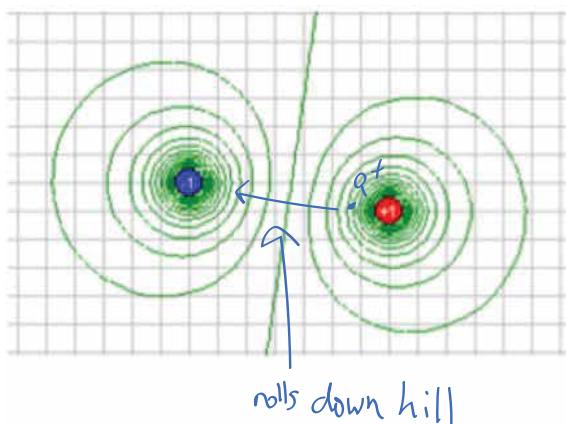
$$\frac{V}{m} = \frac{J}{m} = \frac{Nm}{Cm} = \frac{V}{m}$$

If E is uniform between two points along an E field line:

$$\Delta KE = Q\vec{E} \cdot \vec{d} \\ = \vec{F} \cdot \vec{d} = \Delta PE_v$$

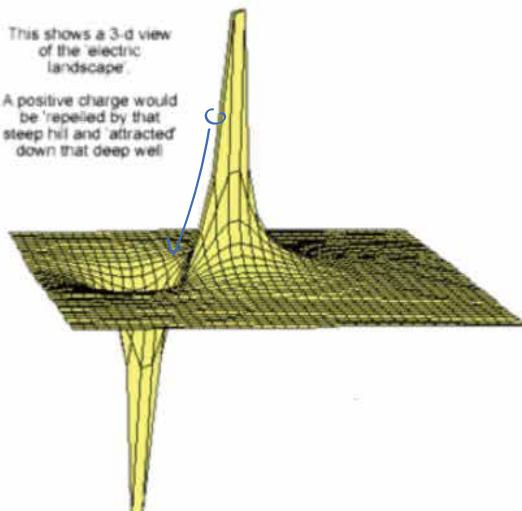
You have probably seen this before as: Change in potential energy equals force multiplied by distance, if force is constant, and distance is measured in the direction of the force.

$$\Delta KE = \vec{F} \cdot \vec{d}$$

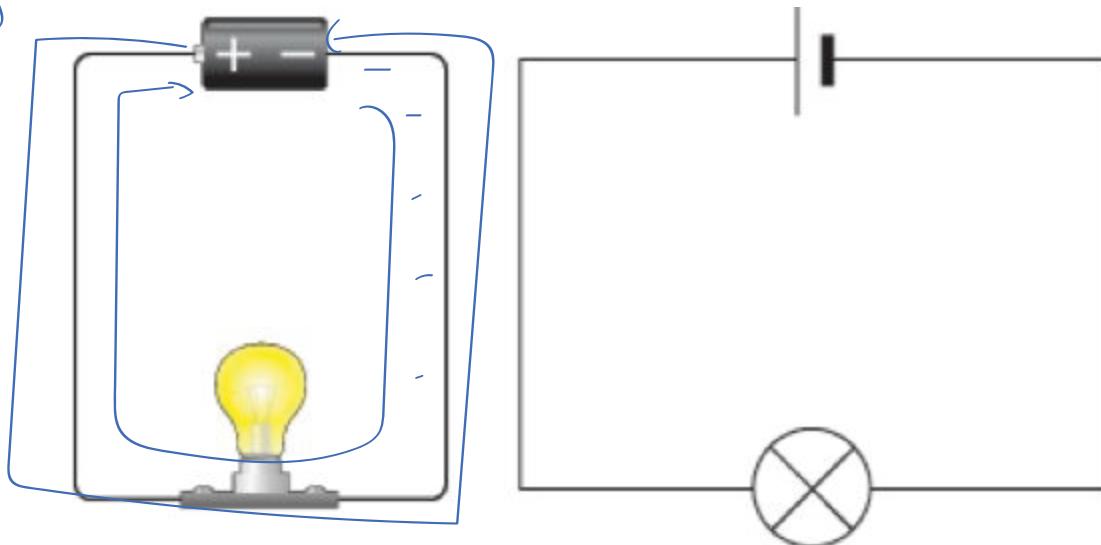


This shows a 3-d view of the electric landscape

A positive charge would be 'repelled' by that steep hill and 'attracted' down that deep well



convention: show positive flow
The voltage difference between, for example, two ends of a battery, can cause charges to flow. In the picture below, in which direction are charged things moving?



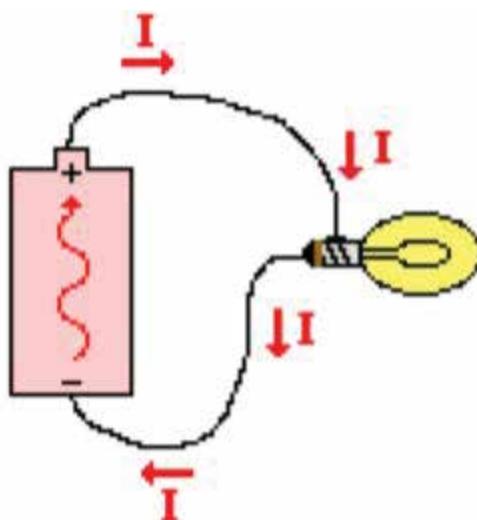
By convention, we take current to be the movement of positive charges.

One Ampere or Amp of current = 1 Coulomb / Second

$$uni + = A$$

Current is usually represented with the variable I .

Current in the external circuit goes from the positive to the negative terminal of the battery.



How much current flows?

The amount of current flowing through a circuit element depends on the difference in voltage across the item, and the item's resistance.

$$I = \frac{\Delta V}{R} \quad \text{or}$$

Ohm's Law

$$\Delta V = IR$$

Resistance is measured in units of Ohms using the symbol Ω .

Resistance depends on
 Material
 L Length
 A Cross-sectional area

$$R = \frac{L\rho}{A} ?$$

$$l = 0.0663 \text{ m}$$

$$A = 0.25 \pi \text{ cm}^2$$

$$l = 1.3 \text{ m} = 0.03302 \text{ m}$$

$$\rho = 3.5 \times 10^{-5}$$

$$R = 0.029 \Omega$$

Material	Resistivity* ($\Omega \cdot \text{m}$)	Temperature Coefficient ^b $\alpha [(\text{ }^\circ\text{C})^{-1}]$	
		$\rho \leftarrow \text{greek letter rho}$	
Silver	1.59×10^{-8}	3.8×10^{-3}	
Copper	1.7×10^{-8}	3.9×10^{-3}	
Gold	2.44×10^{-8}	3.4×10^{-3}	
Aluminum	2.82×10^{-8}	3.9×10^{-3}	
Tungsten	5.6×10^{-8}	4.5×10^{-3}	
Iron	10×10^{-8}	5.0×10^{-3}	
Platinum	11×10^{-8}	3.92×10^{-3}	
Lead	22×10^{-8}	3.9×10^{-3}	
Nichrome ^c	1.00×10^{-6}	0.4×10^{-3}	
Carbon	3.5×10^{-5}	-0.5×10^{-3}	
Germanium	0.46	-48×10^{-3}	
Silicon ^d	2.3×10^3	-75×10^{-3}	
Glass	$10^{10} \text{ to } 10^{14}$		
Hard rubber	$\sim 10^{13}$		
Sulfur	10^{15}		
Quartz (fused)	75×10^{16}		

^a All values at 20°C. All elements in this table are assumed to be free of impurities.

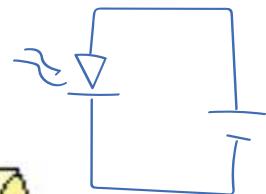
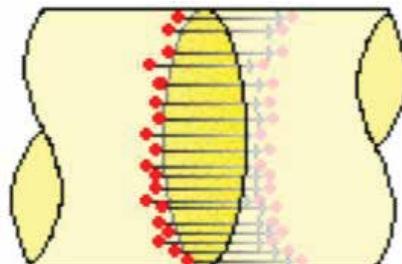
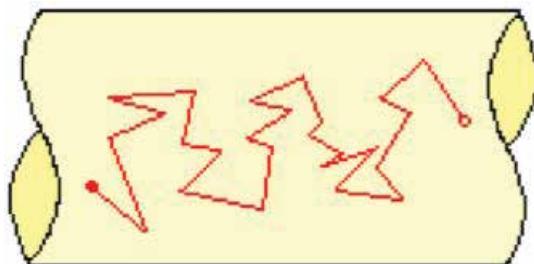
^b See Section 27.4.

^c A nickel-chromium alloy commonly used in heating elements. The resistivity of Nichrome varies with composition and ranges between 1.00×10^{-6} and $1.50 \times 10^{-6} \Omega \cdot \text{m}$.

^d The resistivity of silicon is very sensitive to purity. The value can be changed by several orders of magnitude when it is doped with other atoms.

Dispelling a Common Misconception: Although the electric field in a circuit is set up at the speed of light, current itself flows slowly, and individual electrons move slowly.

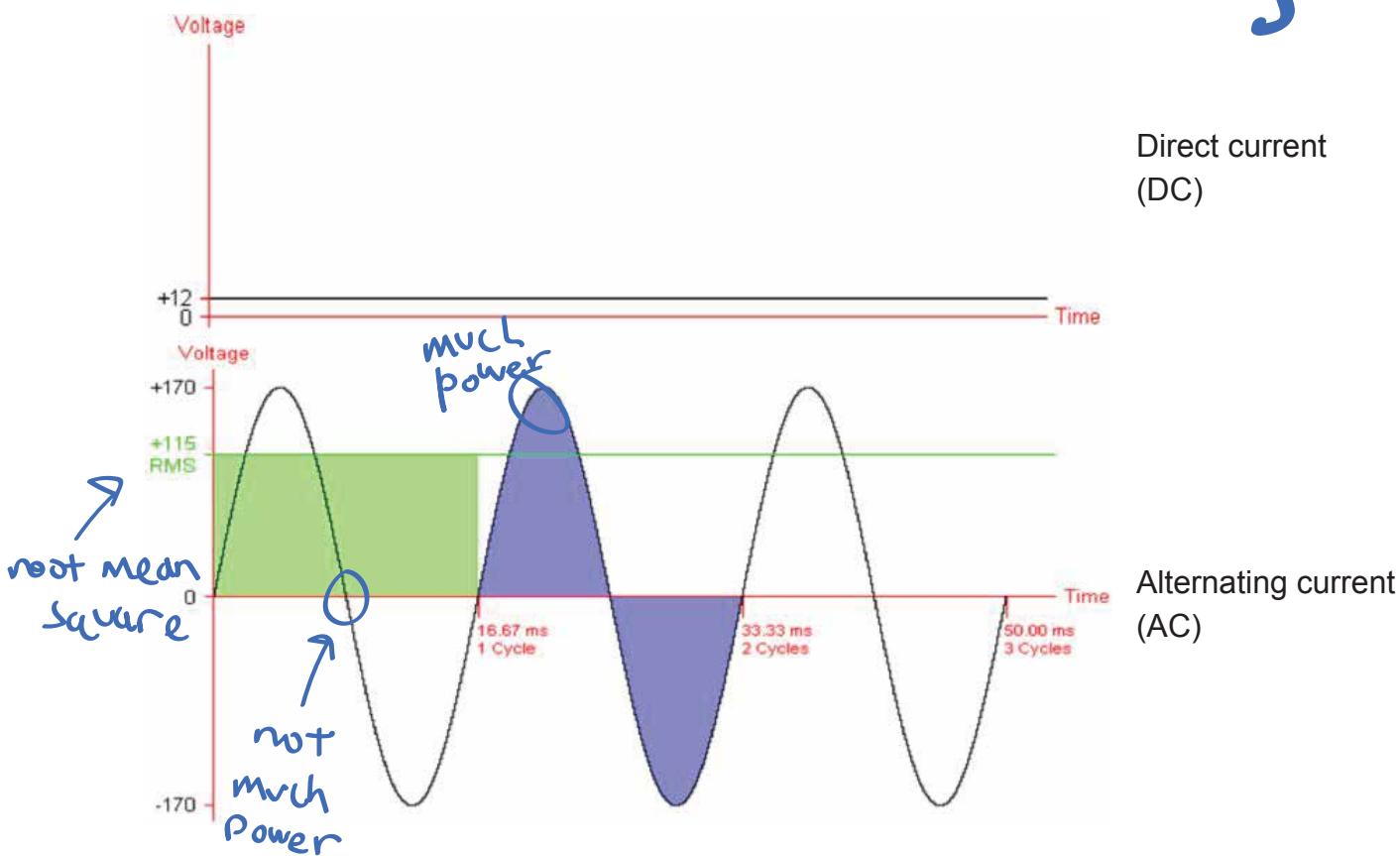
Typical path of an Electron



**Electrons slow,
but field is Speed of light**

AC/DC

A high current results from
many charge carriers passing
through a cross section of
wire in a circuit.



Kirchoff's Laws

1. The sum of all voltage changes around a closed loop in a circuit must equal zero.

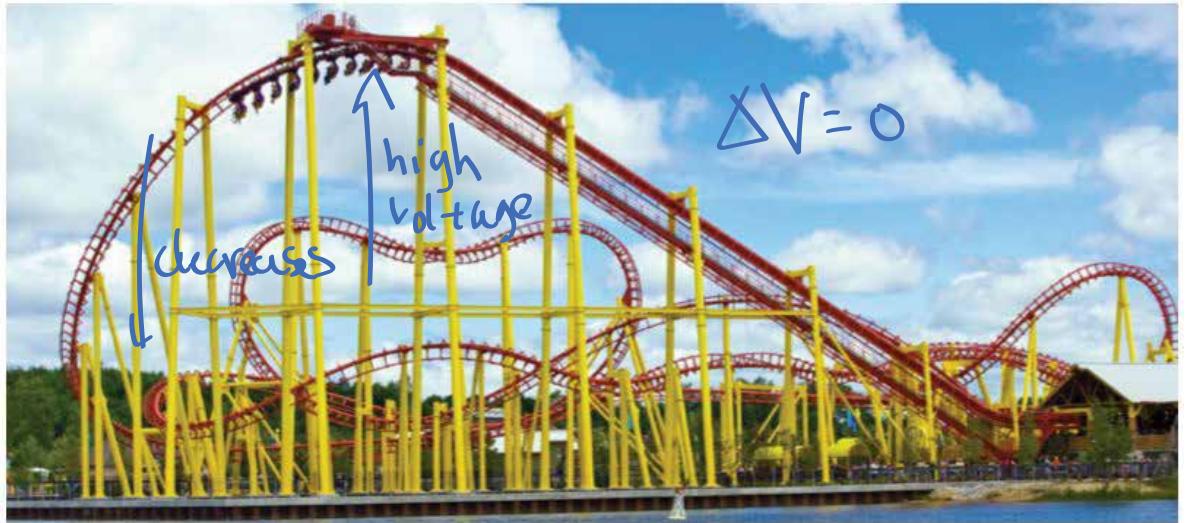
KVL

2. The sum of all currents entering a point on the circuit (a *node*) equals the sum of all currents leaving the node.

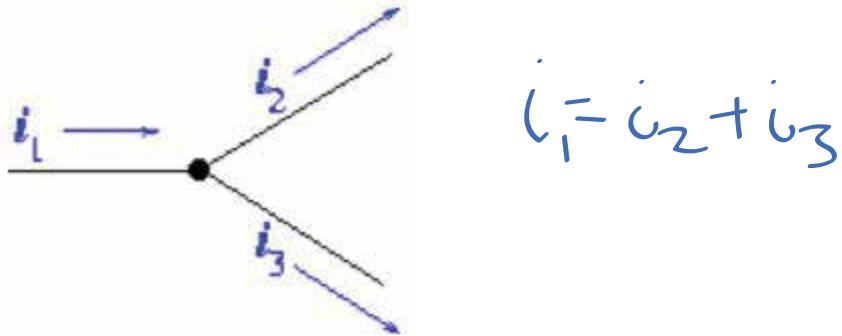
k CL

$$\sum I_{\text{node}} = 0$$

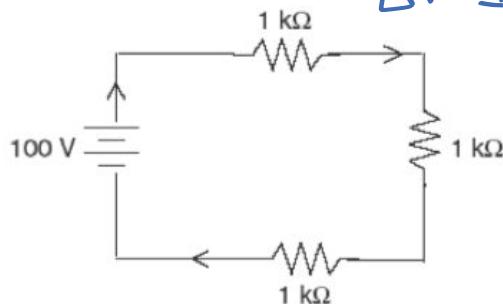
1.



2.



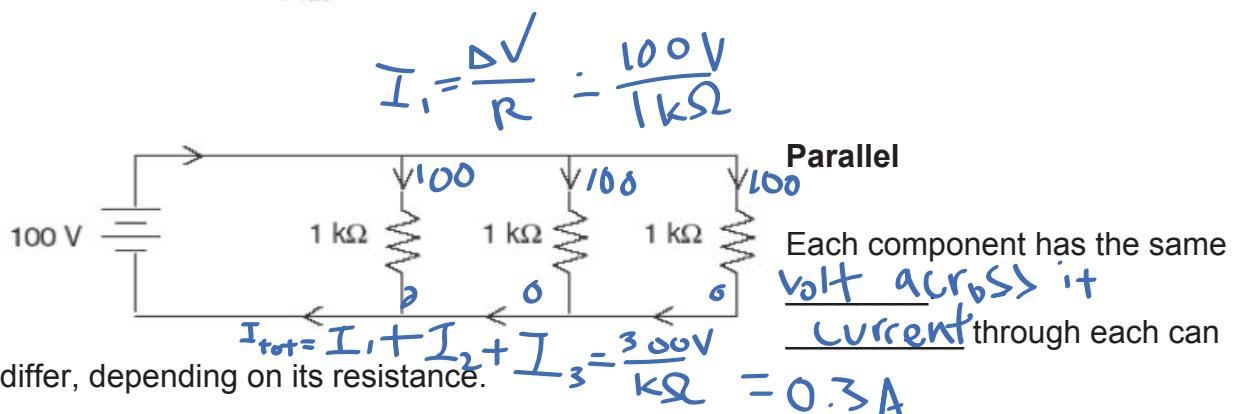
Two Ways of Arranging Circuit Components: Series and Parallel



$$\Delta V = IR \quad I = \frac{\Delta V}{R} = \frac{100V}{3k\Omega} \text{ Perfect wires}$$

Series

Each component has the same current.
voltage across each can differ, depending on its resistance.



$$I_1 = \frac{\Delta V}{R} = \frac{100V}{1k\Omega}$$

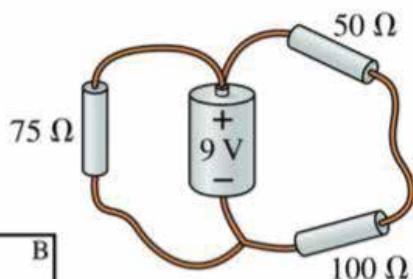
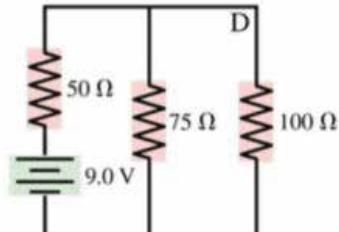
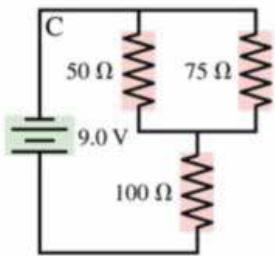
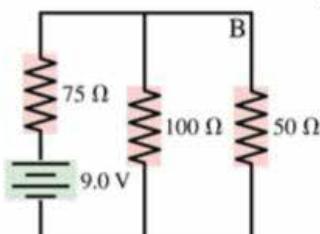
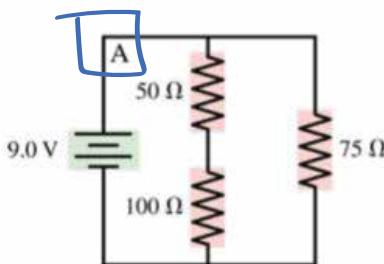
Parallel

Each component has the same volt across it
current through each can

$$I_{\text{tot}} = I_1 + I_2 + I_3 = \frac{300V}{k\Omega} = 0.3A$$

QuickCheck 23.5

- Which is the correct circuit diagram for the circuit shown?



Parallel resistors

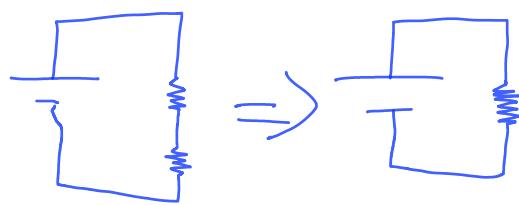
Series Resistors
 $R_{eq} = R_1 + R_2$

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

Name Albert
Block _____
Date 14 Sep 2020

Applying Kirchoff's Laws

1. What single resistor would offer the same resistance as R_1 and R_2 in series?



$$I_1 = I_2 = I_{eq} \quad (\text{KCL})$$

$$\Delta V_1 + \Delta V_2 = V_{bat} = \Delta V_{eq}$$

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

2. What single resistor would offer the same resistance as R_1 and R_2 in parallel?

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

The diagram shows a circuit with two resistors, res_1 and res_2 , connected in parallel. An arrow points from this parallel combination to a single resistor labeled res_{eq} .

$$\Delta V_1 = \Delta V_2 = \Delta V_{eq} = V_{bat}$$

$$I_1 R_1 = I_2 R_2 = I_{eq} R_{eq} = (I_1 + I_2) R_{eq}$$

$$R_{eq} = \frac{V_{bat}}{I_1 + I_2}$$

$$\frac{1}{R_{eq}} = \frac{I_1 + I_2}{V_{bat}} = \frac{I_1}{\Delta V} + \frac{I_2}{\Delta V} =$$

$$= \frac{1}{R_1} + \frac{1}{R_2}$$

3. One resistor in series w/ two parallel resistors

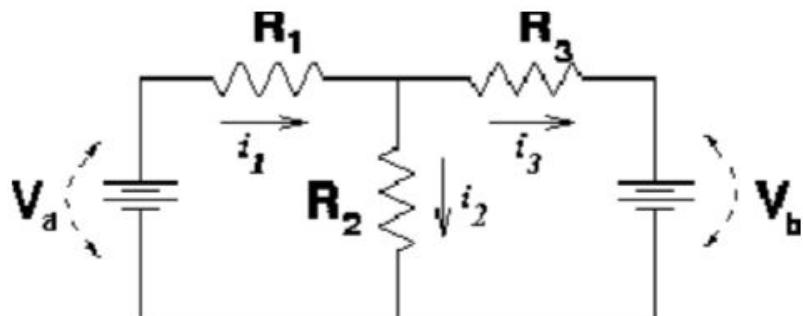
$$\Delta V_2 = \Delta V_3 \quad \Delta V_1 + \Delta V_2 = \Delta V_{eq} = V_{bat}$$

The diagram shows a circuit with three resistors. A resistor is in series with a parallel combination of two resistors. An arrow labeled "2.5" points to the parallel combination.

$$R_{2S} = \frac{R_2 R_3}{R_2 + R_3}$$

$$R_{eq} = R_1 + R_{2S} = R_1 + \frac{R_2 R_3}{R_2 + R_3}$$

4. A more complicated circuit: $V_a = 9V$, $V_b = 3V$, $R_1 = 10\Omega$, $R_2 = 20\Omega$, $R_3 = 50\Omega$



Frequently-Used Equations in Analyzing Circuits

$$I = \frac{\Delta V}{R} \quad \Delta V = IR$$

Resistors in series

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

Resistors in parallel

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

For two parallel resistors, this simplifies to

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