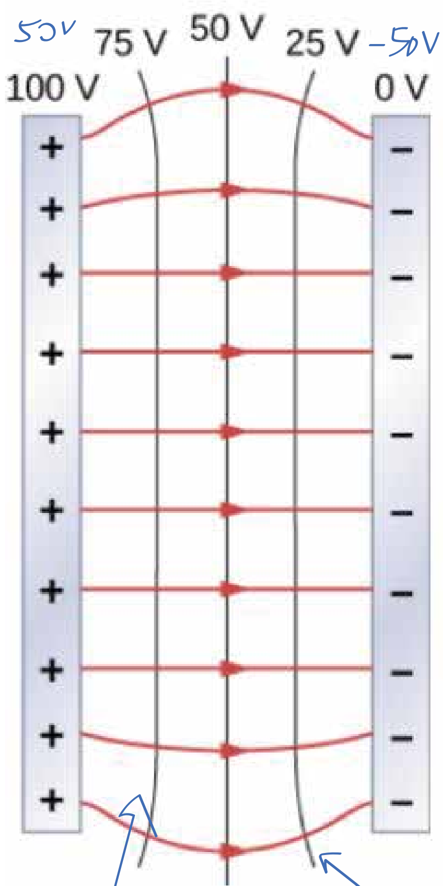
Modern Physics
Fall 2020

Name ______________________
Block ______________________
Date 10 Sep 2020

one plate

Relationship Between Voltage and Electric Field

0 V



equipot lines

uniform

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).

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

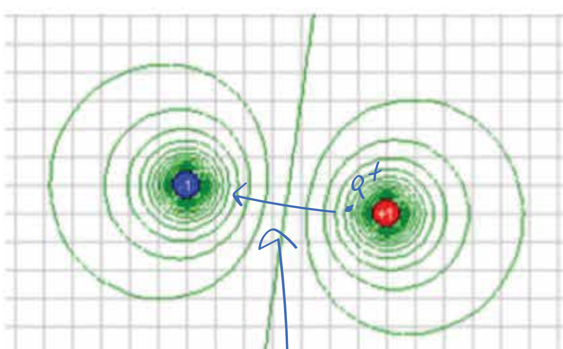
$$\frac{V}{m} = \frac{J}{C\,m} = \boxed{\frac{N\cancel{m}}{C\,\cancel{m}} = \frac{V}{m}}$$

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

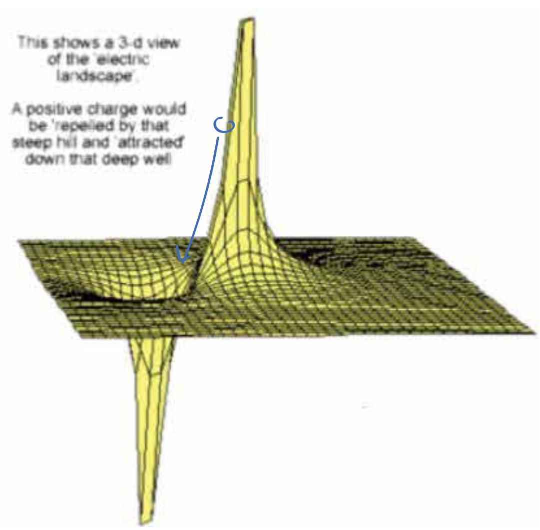
$$\Delta KE = Q\vec{E}\cdot\vec{d}$$
$$= \vec{F}\cdot\vec{d} = \Delta PE_v$$

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.

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



rolls down hill



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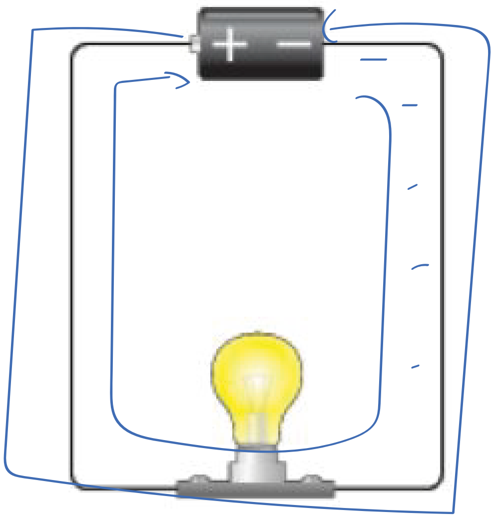
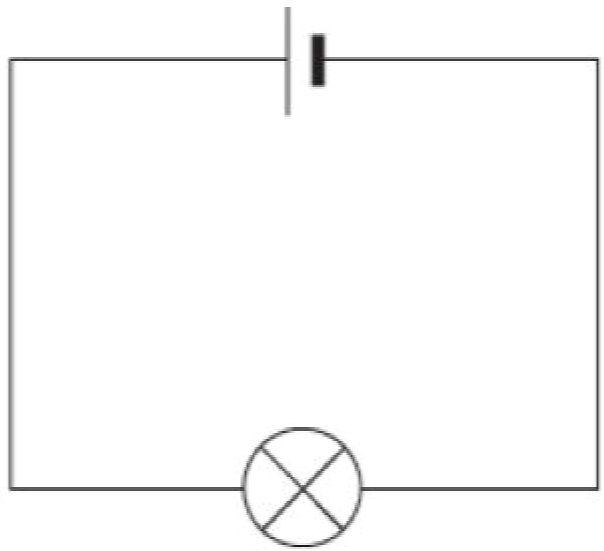
convention: show positive flow

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?





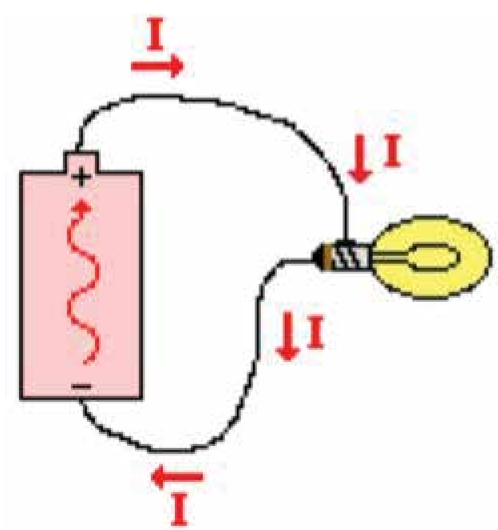
By convention, we take current to be the movement of positive charges.

One Ampere or Amp of current = 1 Coulomb / Second

unit = 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.



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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.

OHM's LAW

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

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

Resistance depends on
Material
L Length
A Cross-sectional area

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

0.0663 m

$A = 0.25^2 \pi$

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

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

$R = 0.029\ \Omega$

31:22

Resistivities and Temperature Coefficients of Resistivity for Various Materials

ρ ← greek letter "row"

Material	Resistivity[a] (Ω · m)	Temperature Coefficient[b] α[(°C)⁻¹]
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} to 10^{14}	
Hard rubber	$\sim 10^{13}$	
Sulfur	10^{15}	
Quartz (fused)	75×10^{16}	

Semi conductor

[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 1.50×10^{-6} Ω · 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.

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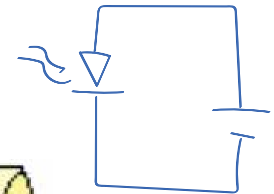
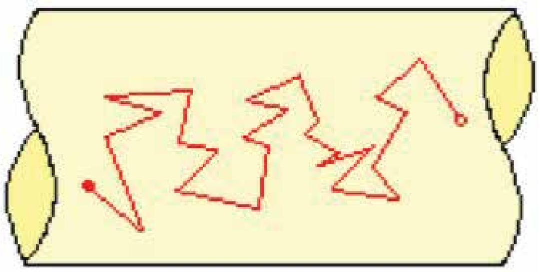
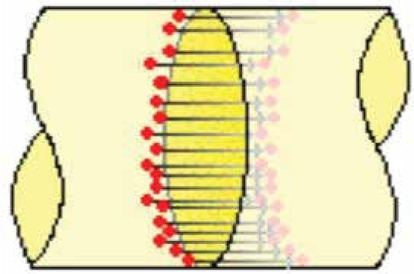
Dispelling a Common Misconception: Although the electric field in a circuit is set up at the speed of light, current itself flows slowly, and individual electrons move slowly.



Typical path of an Electron



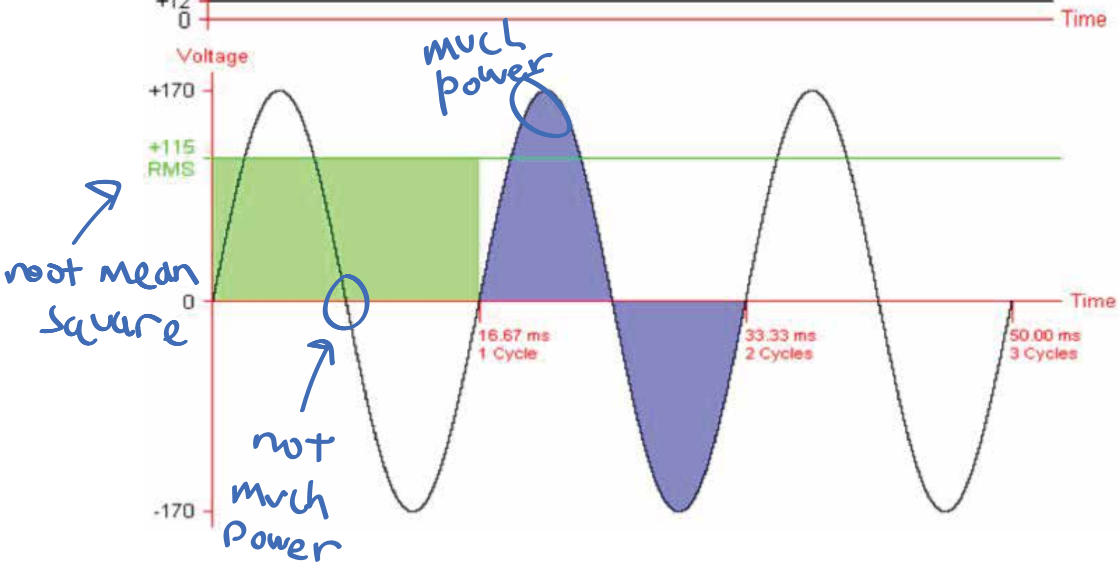


A high current results from many charge carriers passing through a cross section of wire in a circuit.

Electrons slow, but field is speed of light

AC/DC

Direct current (DC)



Alternating current (AC)

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Kirchoff's Laws

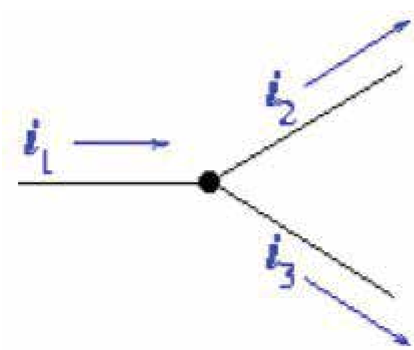
1. The sum of all voltage changes around a closed loop in a circuit must equal zero. KVL

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

$\Sigma I_{node} = 0$

1.

2.



$i_1 = i_2 + i_3$

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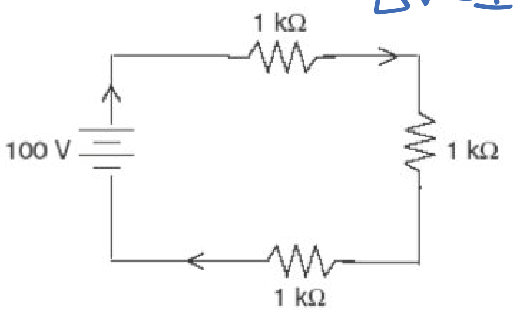
Two Ways of Arranging Circuit Components: Series and Parallel

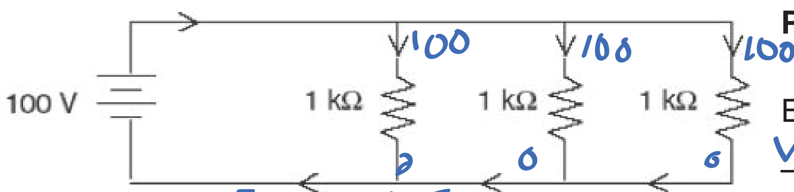
$\Delta V = IR \qquad I = \frac{\Delta V}{R} = \frac{100V}{3k\Omega}$ Perfect wires



Series

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

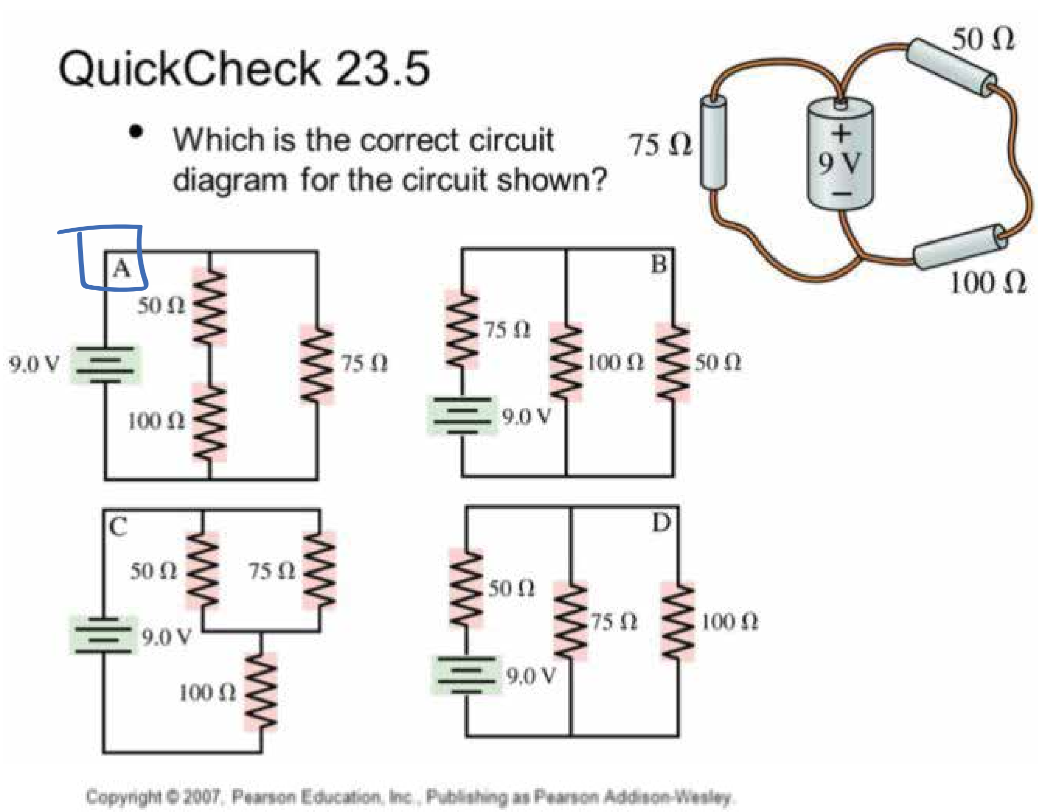
$I_1 = \frac{\Delta V}{R} = \frac{100V}{1k\Omega}$



Parallel

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

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



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Parallel resistors

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

Series Resistors

$R_{eq} = R_1 + R_2$

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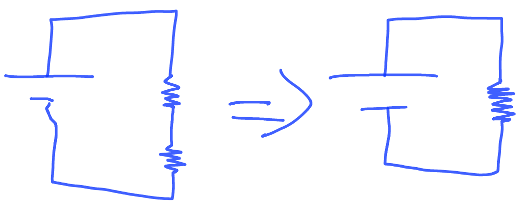
Applying Kirchoff's Laws

1. What single resistor would offer the same resistance as R1 and R2 in series?



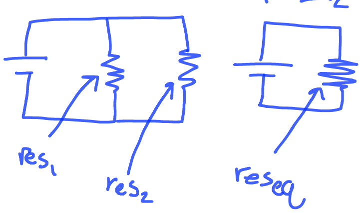
$I_1 = I_2 = I_{eq}$ (KCL)

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

$\therefore \cancel{I}R_1 + \cancel{I}R_2 = \cancel{I}R_{eq} \Rightarrow R_{eq} = R_1 + R_2$

2. What single resistor would offer the same resistance as R1 and R2 in parallel?

$I_1 + I_2 = I_{eq}$



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

$I_1R_1 = I_2R_2 = I_{eq}R_{eq} = (I_1 + I_2)R_{eq}$

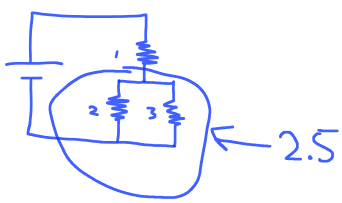
$R_{eq} = \frac{V_{bat}}{I_1 + I_2}$

$\Delta V = IR$

$\frac{1}{R_{eq}} = \frac{I_1 + I_2}{V_{bat}} = \frac{I_1}{\Delta V} + \frac{I_2}{\Delta V} = \frac{1}{R_1} + \frac{1}{R_2}$

3. One resistor in series w/ two parallel resistors

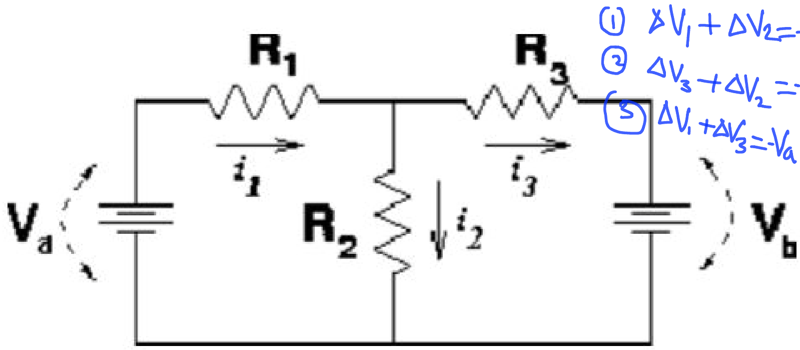
$\Delta V_2 = \Delta V_3$ $\quad \Delta V_1 + \Delta V_2 = \Delta V_{eq} = V_{bat}$



$R_{2.5} = \frac{R_2 R_3}{R_2 + R_3}$

$R_{eq} = R_1 + R_{2.5} = \boxed{R_1 + \frac{R_2 R_3}{R_2 + R_3}}$

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



① $\Delta V_1 + \Delta V_2 = -V_a$

② $\Delta V_3 + \Delta V_2 = -V_b$

③ $\Delta V_1 + \Delta V_3 = -V_a - V_b$

④ $\Delta V_1 - \Delta V_3 = V_b - V_a$

③+④ $\Rightarrow 2\Delta V_1 = -2V_a$

④-③ $\Rightarrow -2\Delta V_3 = 2V_b$

$\Delta V_1 = -V_a = I_1R_1$

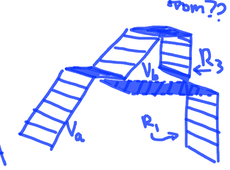
$\Delta V_3 = -V_b = I_3R_3$

$\Delta V_2 = I_2R_2 = 0$?? where did this come from??

$I_1 = \frac{-V_a}{R_1} = 0.9$ A

$I_2 = 0$ A

$I_3 = \frac{-V_b}{R_3} = 0.06$ A



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Frequently-Used Equations in Analyzing Circuits

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

Resistors in series

$$R_{eq} = R_1 + R_2 + \ldots.$$

Resistors in parallel

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

For two parallel resistors, this simplifies to

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