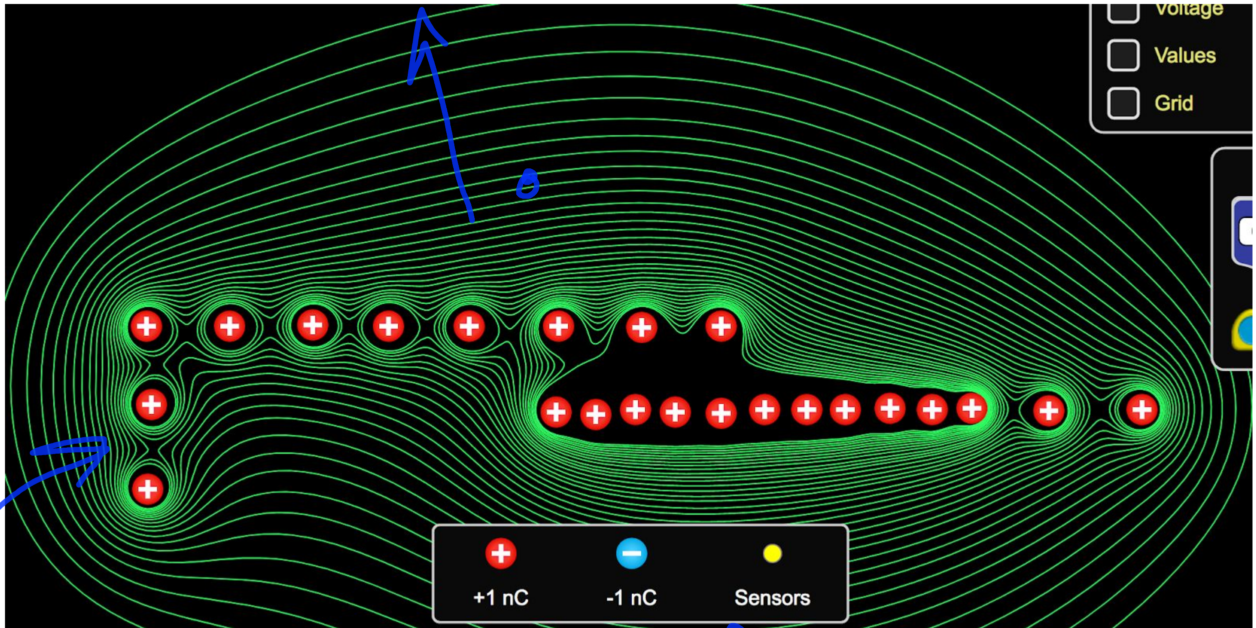
Modern Physics
Fall 2020

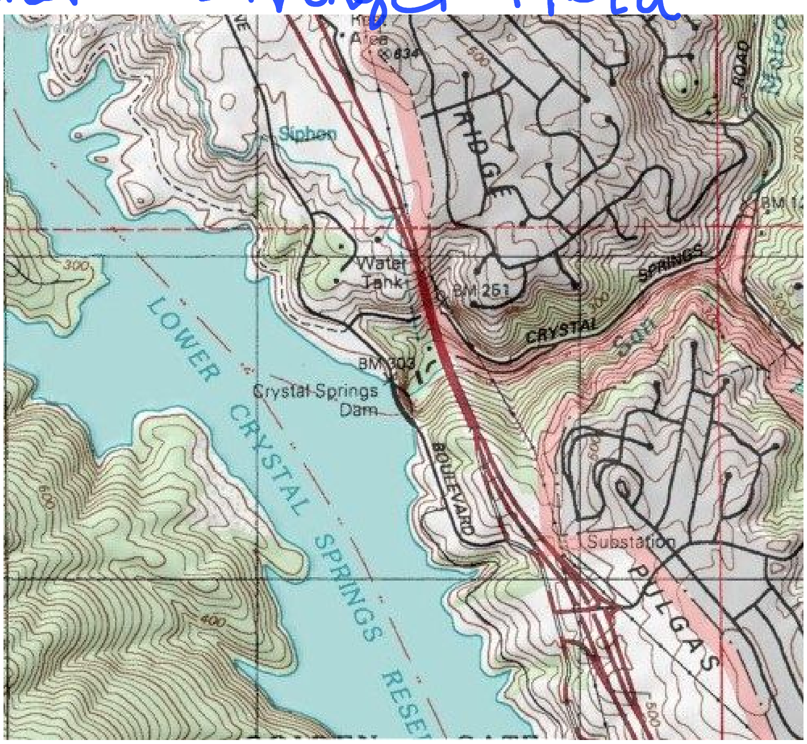
Name Albert
Block 3
Date 9 sep 2020

Introduction to Voltage and Current
Using Gravity as an Analogy



closer together = stronger field

analogous to topo-map



closer lines means steeper

lines of altitude aka grav pot energy

steepest path = perpendicular

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Two objects are at the same height.
Object at left has a mass of 1 kg.
Object at right has a mass of 6 kg.

1. What is the gravitational potential energy (PE_g) of the 1 kg object?

$PE_g = mgh$ (intro phys) assuming rel to floor

2. If our system consists of the 6 kg object and earth, what is the *difference* or *change* in the PE_g if the mass moves a distance h farther from the earth?

$\Delta PE_g = \Delta(mgh) = mg\,\Delta h$ $\quad \frac{kg\,m^2}{s^2} = \text{Joules}$

PE_g does not reside within a single mass. PE_g changes when the configuration of two or more masses changes.

Differences in PE_g are physically important. But for most purposes we are free to declare that potential energy is "zero," or any other value, in any configuration we want. For example, it is sometimes convenient to say that a system's PE_g is zero if an object is sitting on Earth's surface, or on a table, or at the top of a cliff, or at the center of the Earth, but that is entirely arbitrary.

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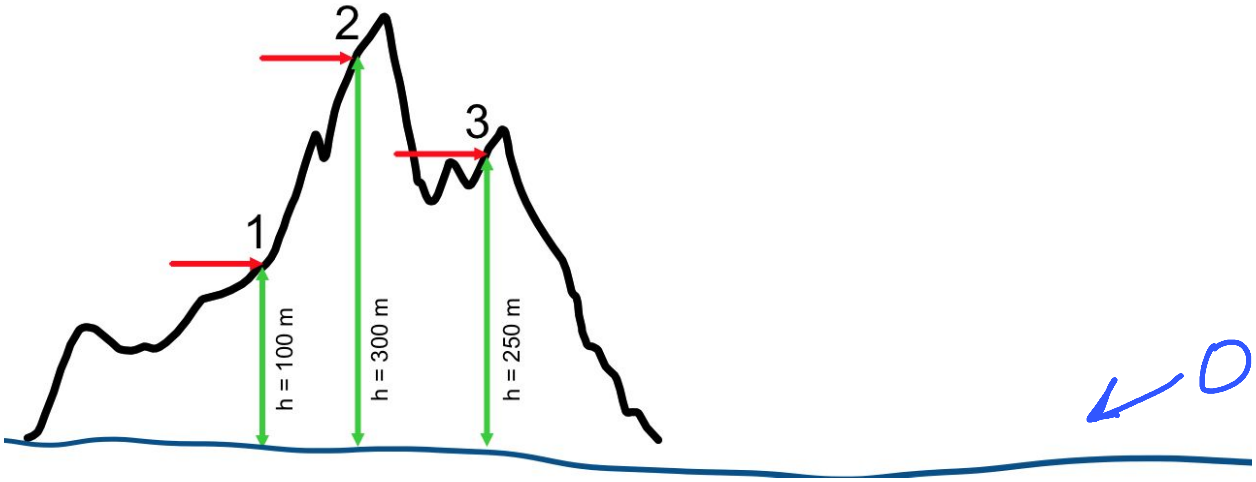
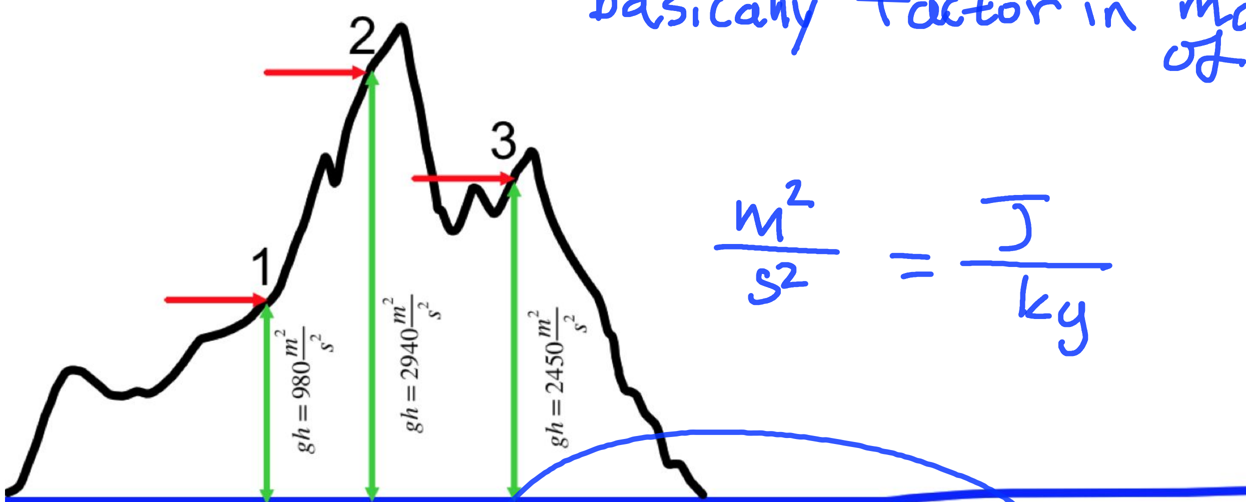


To make it easier to calculate changes in PE_g as masses move, we could label each point not with its height (relative to the ground) in meters, but with its $\boxed{g*h}$ (relative to ground).

Using the g*h values, what is the change in PE_g if 1 kg moves from Location 2 to Location 1?

basically factor in mass of planet



$$\frac{m^2}{s^2} = \frac{J}{kg}$$

$$PE_{g_1} = mgh_1$$

$$PE_{g_2} = mgh_2$$

$$\Delta gh = g\Delta h$$

$$\Delta PE_g = PE_{g_2} - PE_{g_1} = mgh_2 - mgh_1 = mg(h_2 - h_1)$$

$$= mg\Delta h = 1(2940 - 980) = 1960$$

Joules

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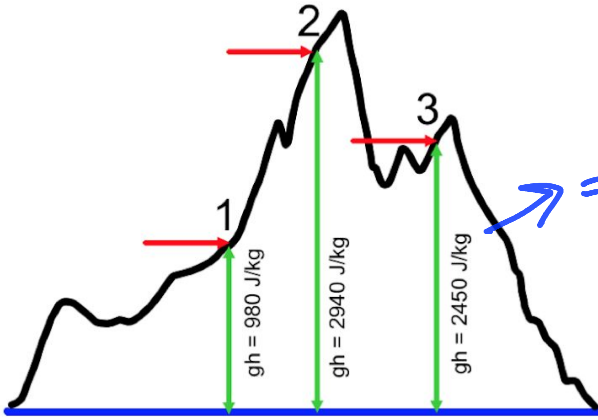

$= \frac{J}{kg} =$ "gravitational potential"

A change in g*h does not represent a change in PE_g. It represents how much the PE_g would change per kg of mass that moves, and its units can be written as Joules / kg.

We call g*h the "gravitational potential" (not potential energy!) of different points on the mountain, relative to the ground.

$Q \approx m$

Electrical Potential

1 Volt - 1 Joule / Coulomb

The "electrical potential" is completely analogous to gravitational potential gh. It represents how much the electric potential energy would change per Coulomb of charge that moves

$\Delta PE_V = \Delta V Q$



Volta = Joule / Coulomb

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How much is one Coulomb of charge?

alot

One electron has a charge of -1.6×10^{-19} C

a static $\approx 0.1 \mu C$

One proton has a charge of 1.6×10^{-19} C

$\approx 10^{-7} C$

Test your Understanding:

How much energy is required to move 3 C of charge from the negative to the positive end of a 1.5 V battery?

$$1.5V = \frac{x J}{3C} \qquad xJ = (1.5V)(3C) = \boxed{4.5 J}$$

How many protons would be needed to create 3 C of charge?

like 4

Barak, it's too late for this... my brain doesn't function

$$1 \text{ proton} = 1.6 \times 10^{-19} C$$
$$x = x(1.6 \times 10^{-19})$$
$$x \text{ proton} = 3C$$
$$x = \frac{3}{1.6 \times 10^{-19}} = 1.875 \times 10^{19}$$

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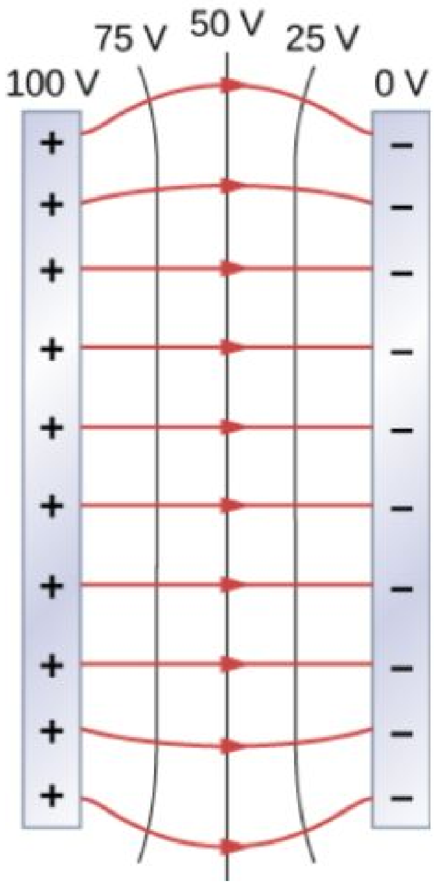
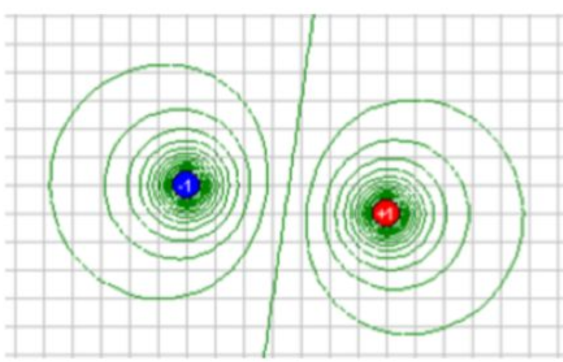
Relationship Between Voltage and Electric Field

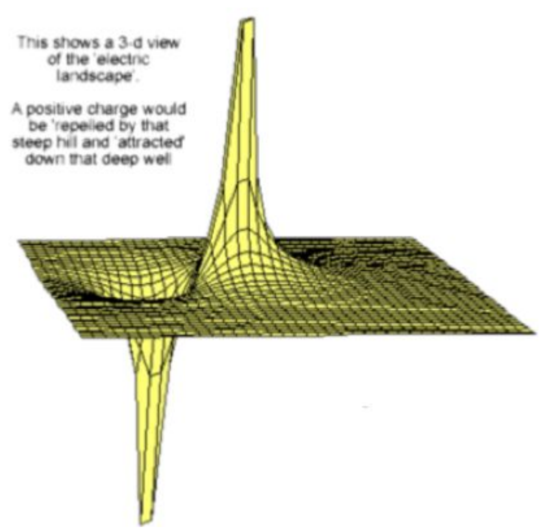


You can easily show that the units of electric field can be written as N/C (Newtons per Coulomb) or V/m (volts per meter).

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

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.





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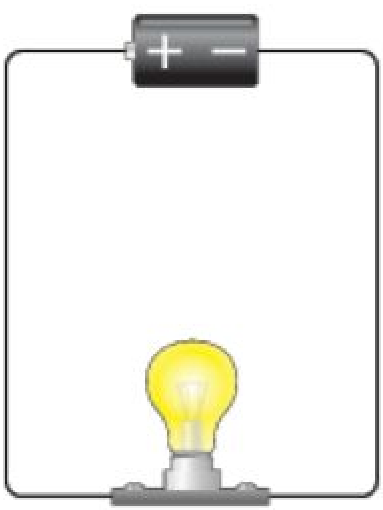
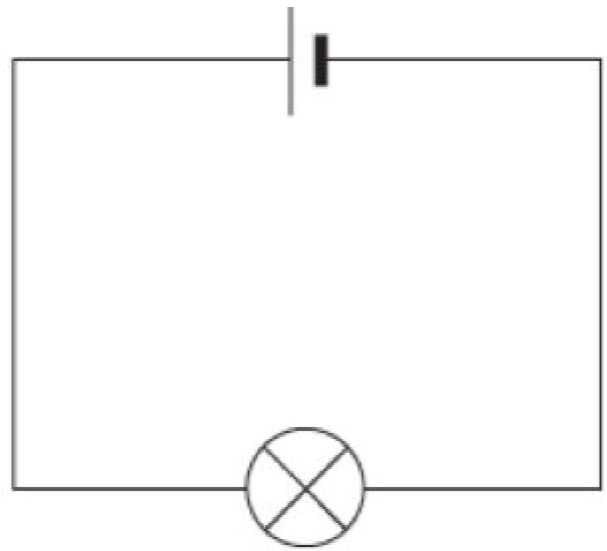
The voltage difference between, for example, two ends of a battery, can cause charges to flow. In the picture below, in which direction are charged things moving?



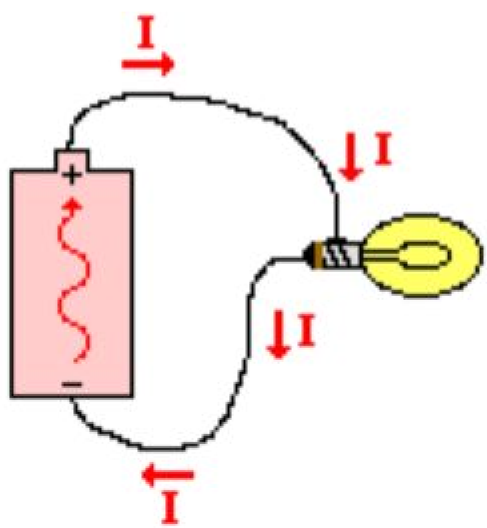


By convention, we take current to be the movement of positive charges.

One Ampere or Amp of current = 1 Coulomb / Second

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.

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

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

Resistance depends on
- Material
- Length
- Cross-sectional area

Resistivities and Temperature Coefficients of Resistivity for Various Materials

Material	Resistivity[a] ($\Omega \cdot m$)	Temperature Coefficient[b] $\alpha[(^\circ C)^{-1}]$
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}	

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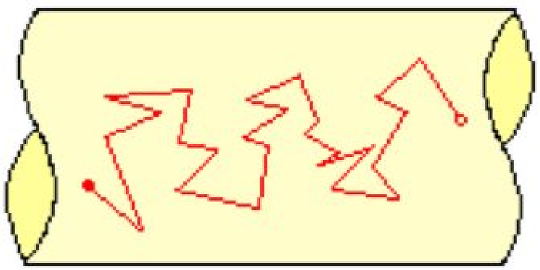
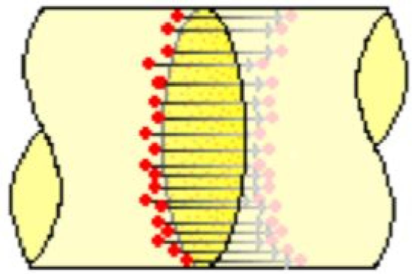
Dispelling a Common Misconception: Although the electric field in a circuit is set up at the speed of light, current itself flows slowly, and individual electrons move slowly.

Typical path of an Electron

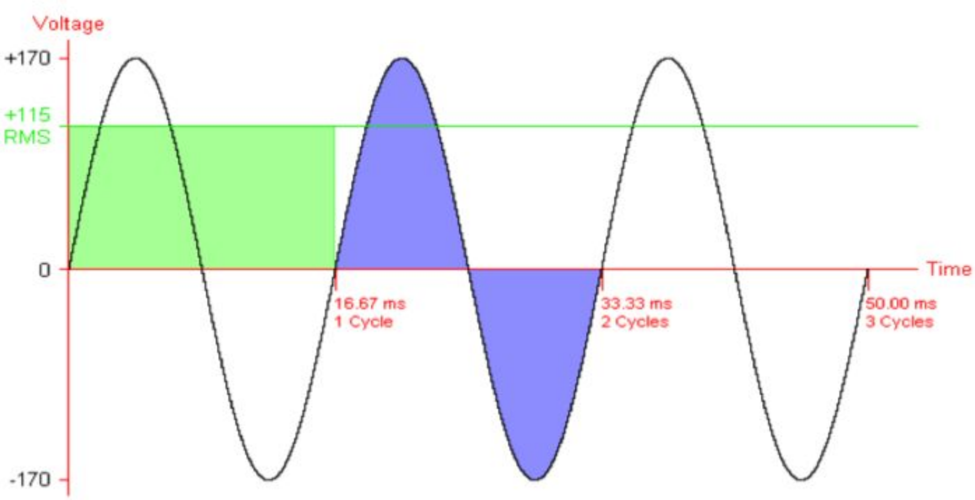




A high current results from many charge carriers passing through a cross section of wire in a circuit.

AC/DC

Direct current (DC)



Alternating current (AC)

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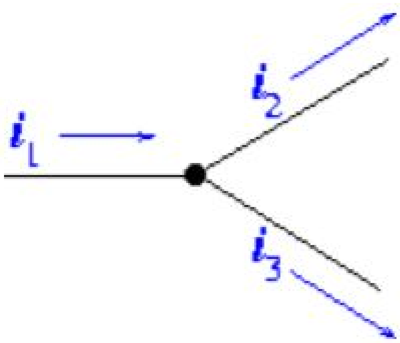
Kirchoff's Laws

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

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

1.

2.



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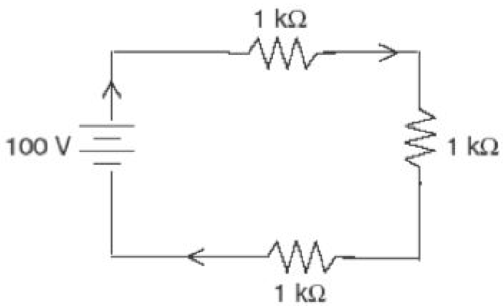
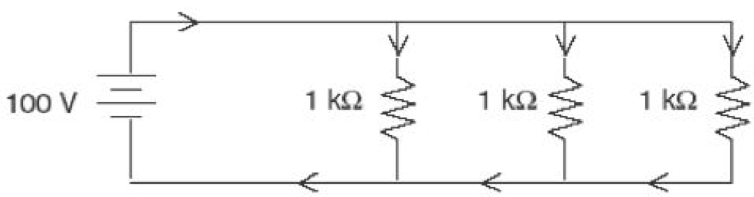
Two Ways of Arranging Circuit Components: Series and Parallel



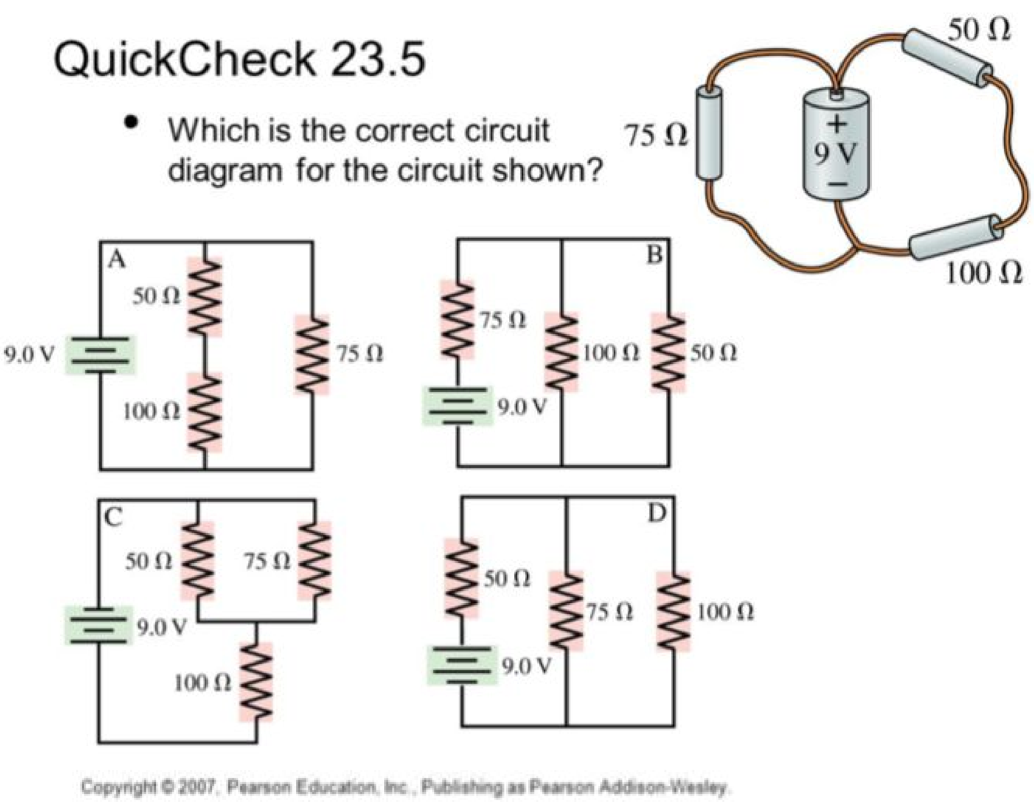
Series

Each component has the same ____________. ______________ across each can differ, depending on its resistance.



Parallel

Each component has the same ________. __________ through each can differ, depending on its resistance.



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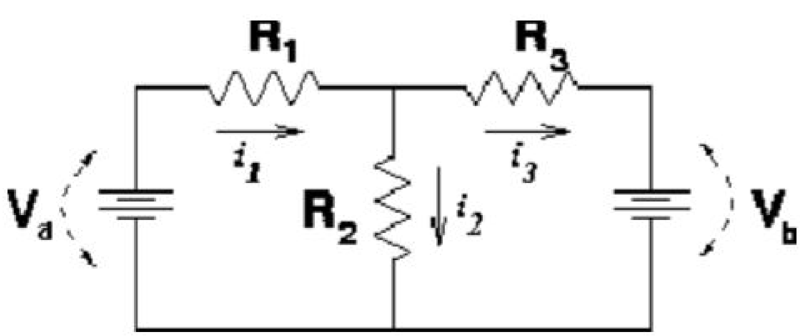
Applying Kirchoff's Laws

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

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

3. One resistor in series w/ two parallel resistors

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



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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

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