Electrostatics: Not moving. Deals a lot with point charges, small ***q***. Can calculate the force between two point charges and the strength of the electric field created by point charges. If there are a number of charges you simply do the calculations for each charge separately and then add the results, the principle of superposition. However, never plug in minus charges for ***q***. Always plug in the positive magnitude for the charge whether positive or negative. Use the signs on the charges to tell you if they are moving right (positive) or left (negative). Assign each completed calculation of ***F*** or ***E*** the appropriate sign and then add the ***F's*** for the total force or add the ***E's*** for the total electric field strength.

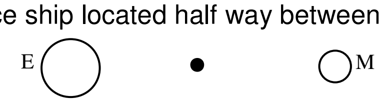
$$F_E = k\frac{q_1 q_2}{r^2} \qquad E = \frac{F_E}{q} \qquad E = k\frac{q}{r^2}$$

Remember small ***q*** is for a point charge, like a small group of electrons or protons, or even an oil drop.
Large ***Q*** (similar to heat energy, so watch out) is for lots and lots of charge, like that stored on charged plates.

Gravitational Fields	***Electric Fields***
* $F_g = G\frac{m_1 m_2}{r^2}$	* $F_E = k\frac{q_1 q_2}{r^2}$
$F_g = mg$	* $E = \frac{F_E}{q}$ $\quad F_E = qE$
Combine the above equation to create an new equation $mg = G\frac{m_1 m_2}{r^2}$	
Simplify $g = G\frac{m}{r^2}$	**Simplify** $E = k\frac{q}{r^2}$
• $\boldsymbol{F_g}$, Force of gravity is felt in a gravitational field. • ***m***, mass causes gravitational fields • ***g*** is a way to assess the strength of the gravity field. • Double mass: $\boldsymbol{F_g}$ (force) and ***g*** (field strength) double. • Distance follows the inverse square law. Double ***r***: $\boldsymbol{F_g}$ (force) and ***g*** (field strength) are 1/4. Halve ***r***: $\boldsymbol{F_g}$ (force) and ***g*** (field strength) are quadrupled.	• $\boldsymbol{F_E}$, Force of electrostatics, is felt in an electric field. • ***q***, charge, causes electric fields. • ***E*** is a way to assess the strength of the electric field. • Double charge: $\boldsymbol{F_E}$ (force) and ***E*** (field strength) double. • Distance follows the inverse square law. Double ***r***: $\boldsymbol{F_E}$ (force) and ***E*** (field strength) are 1/4. Halve ***r***: $\boldsymbol{F_E}$ (force) and ***E*** (field strength) are quadrupled.

Superposition

What is (a) the force of gravity and (b) the acceleration of gravity on a 1000 *kg* space ship located half way between the earth and the moon?



Both are pulling on it so find each ***F*** and ***g*** separately.

(a) $F_g = G\frac{m_1 m_2}{r^2}$

$$F_g earth = 6.67\times10^{-11}\frac{(5.98\times10^{24})(1000)}{\left[1/2(3.84\times10^8)\right]^2} = 10.2N$$

$$F_g moon = 6.67\times10^{-11}\frac{(7.4\times10^{22})(1000)}{\left[1/2(3.84\times10^8)\right]^2} = 0.13N$$

As drawn: earth pulls left, negative
moon pulls right, positive.
Add $-10.2N + 0.13N = -10.07N$ **left, so toward earth.**

(b) $g = G\frac{m}{r^2}$

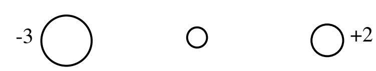
$$g_{earth} = 6.67\times10^{-11}\frac{(5.98\times10^{24})}{\left[1/2(3.84\times10^8)\right]^2} = 0.0102\,m/s^2$$

$$g_{moon} = 6.67\times10^{-11}\frac{(7.4\times10^{22})}{\left[1/2(3.84\times10^8)\right]^2} = 0.00013\,m/s^2$$

As drawn: earth pulls left, negative
moon pulls right, positive.
Add $-0.0102 + 0.00013 = -0.01007\,m/s^2$ **left, so toward earth.**

Superposition

What is (a) the force of electricity on a +1 *C* charge located half way between a –3 *C* charge and a +2 *C* charge separated by 2 *m*? (b) What is the electric field strength at this location due to the – 3 and +2 C charges only?



Both are pulling on it so find each ***F*** and ***g*** separately.

(a) $F_E = k\frac{q_1 q_2}{r^2}$

$$F_E = 9\times10^9\frac{(3C)(1C)}{\left[1/2(2m)\right]^2} = 27\times10^9 N$$

$$F_E = 9\times10^9\frac{(2C)(1C)}{\left[1/2(2m)\right]^2} = 18\times10^9 N$$

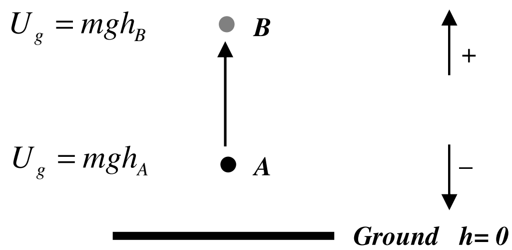
As drawn: –3 charge attracts +1 charge to left, negative.
+2 charge repels +1 charge to left, negative.
Add $-27\times10^9 N + -18\times10^9 N = -45\times10^9 N$ **left toward –3.**

(b) $E = k\frac{q}{r^2}$

$$E_{from-3} = 9\times10^9\frac{(3C)}{\left[1/2(2m)\right]^2} = 27\times10^9\,N/C$$

$$E_{from+2} = 9\times10^9\frac{(2C)}{\left[1/2(2m)\right]^2} = 18\times10^9\,N/C$$

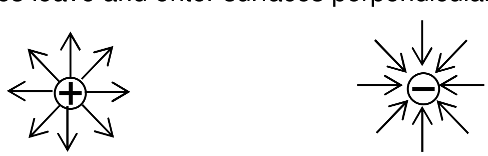
As drawn: –3 attracts positive test charge left, negative.
+2 repels positive test charge left, negative.
Add $-27\times10^9 + -18\times10^9 = -45\times10^9\,N/C$ **left toward –3.**

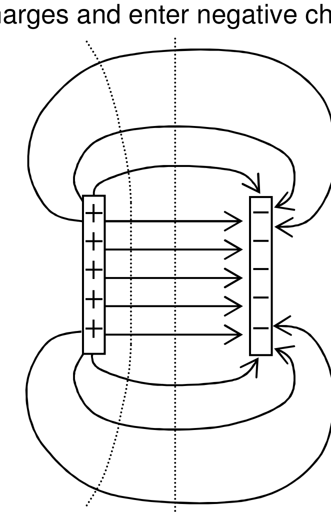
 	
• Gravitational Field acts downward. • ***<u>Gravity Field forces masses to move.</u>*** • Point ***A*** has less potential energy than point ***B***. • To lift it from ***A*** to ***B*** you must increase energy, add energy. You must do ***+ W*** • Work energy theorem says that ***W = Δ Energy***. • Moving from ***A*** to ***B*** increases ***U***. • The increase (change) in ***U*** equals the work. • ***U*** = 0 at the ground, the lowest point. Release the mass at ***B***. Mass accelerates toward ground. The velocity increases so, ***K*** increases while ***U*** decreases. The mass can do work on the way down.	**Electric Field is based on a positive test charge** • Electric Field acts away from positive & toward negative.

Voltage: It is a way to express the difference (change) between potential energies of two charged plates or two parts of an electrical circuit.

Electric Field Lines

An <u>imaginary</u> way to view the electric field, similar to the elevation lines on a map. On maps, steep slopes are indicated by lines close together. In a similar fashion a concentration of electric field lines indicates higher field strength. The lines are based on the direction a positive test charge will go, so field lines leave positive charges and enter negative charges. Field lines leave and enter surfaces perpendicular to the surface.





On the figure at the right the electric field lines are closest between the two plates. They are also virtually parallel in the center of the diagram.

Equipotential Lines: Lines of equal electric potential energy, ***U***. If a charge is moved along an equipotential line it does not change its potential energy. If you hike in the mountains along the contour lines you always stay at the same height above sea level, so you don't change your gravitational potential energy. The equipotential lines are perpendicular to the field lines. The two dotted lines in the diagram are two examples of the many possible equipotential lines.

Current: The flow of electricity. Current, ***I***, is assumed to be positive due to an old convention (Thanks a heap Ben!). We now know that the electrons actually flow, but we still refer to current as positive. So if we want to talk about actual electron flow we must say electron current or negative current, etc. The word current by itself implies positive current flow. Positive current flow follows the direction of the electric field, so this negative flow is counter to the electric field.

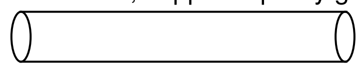
$I = \frac{\Delta Q}{\Delta t}$ It's a rate (divided by time). But, it is unlike velocity where we measure the distance the car went. Instead we stand still and count how many charges, ***Q*** (charge represents an amount of charged particles), go by. Big ***Q*** since we're counting lots-o-charge.

Resistance: When current flows the wires have internal properties that slow the current. When water flows down a stream it runs into rocks, sand, salmon on their way to their grave, etc. These act like friction slowing the water down. Resistance is like friction countering the forward progress of the electrons. Conductors slow the current very little, while insulators have a lot of resistance and slow it drastically. In addition to the wires, all appliances, and even the sources of electricity have resistance. There are also actual resistors built into circuits to help control the amount of electrical flow to exact quantities in various parts of the circuit.

$R = \dfrac{\rho \ell}{Area}$ Resistance is a function of resistivity, ρ, wire length, ℓ, and cross sectional area.

Resistivity, ρ, is like the coefficient of friction. It is given since it is derived by experimentation. Different materials have different natural resistances. Gold has very low resistance, copper is pretty good, and plastic is not so hot.

So let's worry about length and cross section of wire.



What kind of water pipe would provide the least friction, allowing water to pass through more easily?
a. long and narrow b. long and wide c. short and narrow d. short and wide

Look at the equation above. Try to make ***R*** as small as possible, by changing ℓ and Area. Make length small and area big, so the answer is d. The longer the wire the more resistance it has. And resistance is like friction. What type of energy does some of the KE turn into when an object is slowed by friction? Heat. What kind of energy is produced when charges are slowed down by resistance? Heat. What do you feel when you touch an electrical component, like a stereo? It gets hot. Heat loss is disadvantageous. You're losing valuable energy, wasting money on you electrical bill, and increasing entropy. So minimizing resistance is usually a good thing. But, sometimes you need to create resistance if you have components that can only handle certain amounts of power, energy, voltage, etc. In addition the wires themselves act like resistors. One goal in circuit design is to shorten the wires between components to minimize power loss and heat. How much energy is lost to heat in the high tension wires from Hoover Dam to California?

Two important equations for circuits, and two equations (not given) but that can be derived from these.

$V = IR$ $P = IV$ $P = I^2R$ $P = \dfrac{V^2}{R}$

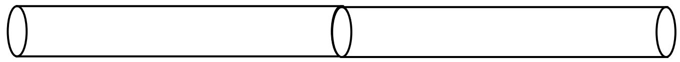
DC Circuits: Direct Current, meaning it travels in one direction only following the electric field lines. The battery or power supply pumps charges creating a potential difference (voltage) between the ends of the circuit. You have a positive terminal (positive plate) which is a region of high potential energy. At the other end of the circuit (wires and components) is a negative terminal (negative plate) which is a region of low potential energy. Positive current (positive charges) want to fall toward the ground through the potential difference toward the negative plate. This is the direction of the electric field. So the potential difference between the positive and negative plates creates the electric field that guides the charges through the circuit. (Just remember the electrons really flow, so its all backwards. But, mathematically you get the same numbers).

Water Analogy: A pump (battery or generator) pumps water (charge) from the ground (negative plate) up to the top of the water theme park (positive plate) The water (charge) wants to follow the gravitational field (electric field) back to the ground. But we've constructed a series of tubes (wires) for the water (charge) to pass through on the way to the ground. Because the water (charge) is losing potential energy as it falls, and because energy must be conserved, the potential energy must be turning into another form of energy. It is turning into the kinetic energy of the water (charge). If the water (charge) is run through a paddle wheel (appliance, light bulb, etc.) it can turn the wheel thus doing useful work (browning toast, lighting up you desk lamp). Unfortunately, some of the water is slowed going through the wheel (appliance, lamp, etc.) and this friction (resistance) creates heat. Also our contractor who built the park used inferior materials that impede (high resistivity) the flow of water (current). So the water (charge) is slowed in the tubes (wires) as well. Fortunately the contractor did note that the paddle wheel (appliance, lamp, etc.) was very small and fragile. And while the plan placed the paddle wheel (appliance, lamp, etc.) in a very steep section of pipe (high potential difference) where the flow of water (current) was very high the contractor installed a metal grating (resistor) in front of the paddle wheel (appliance, lamp, etc.) to slow the amount of water flow (current) to a level that the paddle wheel (appliance, lamp, etc.) could handle.

Circuits Containing Resistors

Series: All resistors are in line. Resistors are like sections of wire, designed to slow current. Let's examine the resistivity of two sections of wire placed in series, or end to end.

$$R = \frac{\rho \ell}{Area}$$

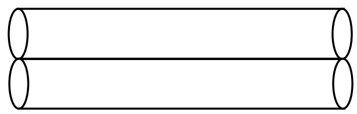


ℓ is doubled, but cross sectional area stayed the same. So ***R*** doubles. If there were three wires ***R*** would triple. This makes sense. Lets pretend they make your commute on the freeway longer, but they didn't build more lanes to widen the road. So you experience the same traffic (resistance) for two or three times as long.

So in series Resistance adds $R_s = \sum_i R_i$ or $R_s = R_1 + R_2 + R_3 + ...$

Now let's examine the resistivity of two sections of wire placed in parallel, or next to each other.

$$R = \frac{\rho \ell}{Area}$$



ℓ stays the same, but cross sectional area doubles. It's more complicated than above. Area is in the denominator. If area doubles ***R*** is cut in half. If there were three wires ***R*** would be cut in third. This makes sense since the current and a bigger pipe to flow through. Its like they expanded the freeway from four lanes to 8 or even 12. You travel the same distance as before but now have less traffic congestion.

So in parallel $\frac{1}{R_p} = \sum_i \frac{1}{R_i}$ or $\frac{1}{R_p} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + ...$

Please don't solve for 1/R. Remember to invert you final answer.

Current and Voltage in Circuits: Think of current as traffic and resistors as less lanes

Series Current stays the same (resistors in line slow traffic in the whole circuit) $I_S = I_1 = I_2 = I_3 = ...$

Voltage adds $V_S = V_1 + V_2 + V_3 + ...$ (cars are all pushed down a single path)

Parallel Current adds $I_S = I_1 + I_2 + I_3 + ...$ (current can choose paths, but the total must split between paths available)

Voltage stays the same $V_S = V_1 = V_2 = V_3 = ...$ (cars have an equal pressure down any path)