Unit 10: Electricity and Magnetism – Electrostatics

OBJECTIVES

Big Idea 1: Objects and systems have properties such as mass and charge. Systems may have internal structure.

Enduring Understanding 1.B: Electric charge is a property of an object or system that affects its interactions with other objects or systems containing charge.

Essential Knowledge 1.B.1: Electric charge is conserved. The net charge of a system is equal to the sum of the charges of all the objects in the system.

a. An electrical current is a movement of charge through a conductor.

b. A circuit is a closed loop of electrical current.

Learning Objective 1.B.1.1: The student is able to make claims about natural phenomena based on conservation of electric charge.

Learning Objective 1.B.1.2: The student is able to make predictions, using the conservation of electric charge, about the sign and relative quantity of net charge of objects or systems after various charging processes, including conservation of charge in simple circuits.

Essential Knowledge 1.B.2: There are only two kinds of electric charge. Neutral objects or systems contain equal quantities of positive and negative charge, with the exception of some fundamental particles that have no electric charge.

a. Like-charged objects and systems repel, and unlike-charged objects and systems attract.

b. Charged objects or systems may attract neutral systems by changing the distribution of charge in the neutral system.

Learning Objective 1.B.2.1: The student is able to construct an explanation of the two-charge model of electric charge based on evidence produced through scientific practices.

Learning Objective 1.B.2.2: The student is able to make qualitative predictions about the distribution of positive and negative electric charges within neutral systems as they undergo various processes.

Learning Objective 1.B.2.3: The student is able to challenge claims that polarization of electric charge or separation of charge must result in a net charge on the object.

Essential Knowledge 1.B.3: The smallest observed unit of charge that can be isolated is the electron charge, also known as the elementary charge.

a. The magnitude of the elementary charge is equal to 1.6×10^{-19} coulombs.

b. Electrons have a negative elementary charge; protons have a positive elementary charge of equal magnitude, although the mass of a proton is much larger than the mass of an electron.

Learning Objective 1.B.3.1: The student is able to challenge the claim that an electric charge smaller than the elementary charge has been isolated.

Enduring Understanding 1.E: Materials have many macroscopic properties that result from the arrangement and interactions of the atoms and molecules that make up the material.

Essential Knowledge 1.E.4: Matter has a property called electric permittivity.

a. Free space has a constant value of the permittivity that appears in physical relationships.

b. The permittivity of matter has a value different from that of free space.

Big Idea 2: Fields existing in space can be used to explain interactions.

Enduring Understanding 2.A: A field associates a value of some physical quantity with every point in space. Field models are useful for describing interactions that occur at a distance (long-range forces) as well as a variety of other physical phenomena.

Essential Knowledge 2.A.1: A vector field gives, as a function of position (and perhaps time), the value of a physical quantity that is described by a vector.

a. Vector fields are represented by field vectors indicating direction and magnitude.

b. When more than one source object with mass *or electric charge* is present, the field value can be determined by vector addition.

c. Conversely, a known vector field can be used to make inferences about the number, relative size, and location of sources.

Essential Knowledge 2.A.2: A scalar field gives, as a function of position (and perhaps time), the value of a physical quantity that is described by a scalar. *This should include electric potential.*

a. Scalar fields are represented by field values.

b. When more than one source object with mass *or charge* is present, the scalar field value can   be determined by scalar addition.

c. Conversely, a known scalar field can be used to make inferences about the number, relative size, and location of sources.

Enduring Understanding 2.C: An electric field is caused by an object with electric charge.

Essential Knowledge 2.C.1: The magnitude of the electric force F exerted on an object with electric charge q by an electric field is $\vec{F} = q\vec{E}$. The direction of the force is determined by the direction of the field and the sign of the charge, with positively charged objects accelerating in the direction of the field and negatively charged objects accelerating in the direction opposite the field. This should include a vector field map for positive point charges, negative point charges, spherically symmetric charge distributions, and uniformly charged parallel plates.

Learning Objective 2.C.1.1: The student is able to predict the direction and the magnitude of the force exerted on an object with an electric charge q placed in an electric field E using the mathematical model of the relation between an electric force and an electric field: $\vec{F} = q\vec{E}$; a vector relation.

Learning Objective 2.C.1.2: The student is able to calculate any one of the variables — electric force, electric charge, and electric field — at a point given the values and sign or direction of the other two quantities.

Essential Knowledge 2.C.2: The magnitude of the electric field vector is proportional to the net electric charge of the object(s) creating that field. This includes positive point charges, negative point charges, spherically symmetric charge distributions, and uniformly charged parallel plates.

Learning Objective 2.C.2.1: The student is able to qualitatively and semiquantitatively apply the vector relationship between the electric field and the net electric charge creating that field.

Essential Knowledge 2.C.3: The electric field outside a spherically symmetric charged object is radial and its magnitude varies as the inverse square of the radial distance from the center of that

object. Electric field lines are not in the curriculum. Students will be expected to rely only on the rough intuitive sense underlying field lines, wherein the field is viewed as analogous to something emanating uniformly from a source.

a. The inverse square relation known as Coulomb's law gives the magnitude of the electric field at a distance r from the center of a source object of electric charge Q as $|E| = \frac{1}{4\pi\varepsilon_0} \frac{|Q|}{r^2}$.

b. This relation is based on a model of the space surrounding a charged source object by considering the radial dependence of the area of the surface of a sphere centered on the source object.

> Learning Objective 2.C.3.1: The student is able to explain the inverse square dependence of the electric field surrounding a spherically symmetric electrically charged object.

Essential Knowledge 2.C.4: The electric field around dipoles and other systems of electrically charged objects (that can be modeled as point objects) is found by vector addition of the field of each individual object. Electric dipoles are treated qualitatively in this course as a teaching analogy to facilitate student understanding of magnetic dipoles.

a. When an object is small compared to the distances involved in the problem, or when a larger object is being modeled as a large number of very small constituent particles, these can be modeled as charged objects of negligible size, or "point charges."

b. The expression for the electric field due to a point charge can be used to determine the electric field, either qualitatively or quantitatively, around a simple, highly symmetric distribution of point charges.

> Learning Objective 2.C.4.1: The student is able to distinguish the characteristics that differ between monopole fields (gravitational field of spherical mass and electrical field due to single point charge) and dipole fields (electric dipole field and magnetic field) and make claims about the spatial behavior of the fields using qualitative or semiquantitative arguments based on vector addition of fields due to each point source, including identifying the locations and signs of sources from a vector diagram of the field.

> Learning Objective 2.C.4.2: The student is able to apply mathematical routines to determine the magnitude and direction of the electric field at specified points in the vicinity of a small set (2-4) of point charges, and express the results in terms of magnitude and direction of the field in a visual representation by drawing field vectors of appropriate length and direction at the specified points

Essential Knowledge 2.C.5: Between two oppositely charged parallel plates with uniformly distributed electric charge, at points far from the edges of the plates, the electric field is perpendicular to the plates and is constant in both magnitude and direction.

> Learning Objective 2.C.5.1: The student is able to create representations of the magnitude and direction of the electric field at various distances (small compared to plate size) from two electrically charged plates of equal magnitude and opposite signs and is able to recognize that the assumption of uniform field is not appropriate near edges of plates.

> Learning Objective 2.C.5.2: The student is able to calculate the magnitude and determine the direction of the electric field between two electrically charged parallel plates, given the charge of each plate, or the electric potential difference and plate separation.

       <u>Learning Objective 2.C.5.3</u>: The student is able to represent the motion of an electrically charged particle in the uniform field between two oppositely charged plates and express the connection of this motion to projectile motion of an object with mass in the Earth's gravitational field.

<u>Enduring Understanding 2.E</u>: Physicists often construct a map of isolines connecting points of equal value for some quantity related to a field and use these maps to help visualize the field.

    <u>Essential Knowledge 2.E.1</u>: Isolines on a topographic (elevation) map describe lines of approximately equal gravitational potential energy per unit mass (gravitational equipotential). As the distance between two different isolines decreases, the steepness of the surface increases. [Contour lines on topographic maps are useful teaching tools for introducing the concept of equipotential lines. Students are encouraged to use the analogy in their answers when explaining gravitational and electrical potential and potential differences.]

       <u>Learning Objective 2.E.1.1</u>: The student is able to construct or interpret visual representations of the isolines of equal gravitational potential energy per unit mass and refer to each line as a gravitational equipotential.

    <u>Essential Knowledge 2.E.2</u>: Isolines in a region where an electric field exists represent lines of equal electric potential referred to as equipotential lines.

a. An isoline map of electric potential can be constructed from an electric field vector map, using the fact that the isolines are perpendicular to the electric field vectors.

b. Since the electric potential has the same value along an isoline, there can be no component of the electric field along the isoline.

       <u>Learning Objective 2.E.2.1</u>: The student is able to determine the structure of isolines of electric potential by constructing them in a given electric field.

       <u>Learning Objective 2.E.2.2</u>: The student is able to predict the structure of isolines of electric potential by constructing them in a given electric field and make connections between these isolines and those found in a gravitational field.

       <u>Learning Objective 2.E.2.3</u>: The student is able to qualitatively use the concept of isolines to construct isolines of electric potential in an electric field and determine the effect of that field on electrically charged objects.

    <u>Essential Knowledge 2.E.3</u>: The average value of the electric field in a region equals the change in electric potential across that region divided by the change in position (displacement) in the relevant direction.

       <u>Learning Objective 2.E.3.1</u>: The student is able to apply mathematical routines to calculate the average value of the magnitude of the electric field in a region from a description of the electric potential in that region using the displacement along the line on which the difference in potential is evaluated.

       <u>Learning Objective 2.E.3.2</u>: The student is able to apply the concept of the isoline representation of electric potential for a given electric charge distribution to predict the average value of the electric field in the region.

Enduring Understanding 3.C: At the macroscopic level, forces can be categorized as either long-range (action-at-a-distance) forces or contact forces.

Essential Knowledge 3.C.2: Electric force results from the interaction of one object that has an electric charge with another object that has an electric charge.

a. Electric forces dominate the properties of the objects in our everyday experiences. However, the large number of particle interactions that occur make it more convenient to treat everyday forces in terms of nonfundamental forces called contact forces, such as normal force, friction, and tension.

b. Electric forces may be attractive or repulsive, depending upon the charges on the objects involved.

Learning Objective 3.C.2.1: The student is able to use Coulomb's law qualitatively and quantitatively to make predictions about the interaction between two electric point charges (interactions between collections of electric point charges are not covered in Physics 1 and instead are restricted to Physics 2).

Learning Objective 3.C.2.2: The student is able to connect the concepts of gravitational force and electric force to compare similarities and differences between the forces.

Learning Objective 3.C.2.3: The student is able to use mathematics to describe the electric force that results from the interaction of several separated point charges (generally 2 to 4 point charges, though more are permitted in situations of high symmetry).

Enduring Understanding 3.G: Certain types of forces are considered fundamental.

Essential Knowledge 3.G.2: Electromagnetic forces are exerted at all scales and can dominate at the human scale.

Learning Objective 3.G.2.1: The student is able to connect the strength of electromagnetic forces with the spatial scale of the situation, the magnitude of the electric charges, and the motion of the electrically charged objects involved.

Enduring Understanding 4.E: The electric and magnetic properties of a system can change in response to the presence of, or changes in, other objects or systems.

Essential Knowledge 4.E.3: The charge distribution in a system can be altered by the effects of electric forces produced by a charged object.

a. Charging can take place by friction or by contact.

b. An induced charge separation can cause a neutral object to become polarized.

c. Charging by induction can occur when a polarizing conducting object is touched by another.

d. In solid conductors, some electrons are mobile. When no current flows, mobile charges are in static equilibrium, excess charge resides at the surface, and the interior field is zero. In solid insulators, excess (fixed) charge may reside in the interior as well as at the surface.

Learning Objective 4.E.3.1: The student is able to make predictions about the redistribution of charge during charging by friction, conduction, and induction.

Learning Objective 4.E.3.2: The student is able to make predictions about the redistribution of charge caused by the electric field due to other systems, resulting in charged or polarized objects.

Learning Objective 4.E.3.3: The student is able to construct a representation of the distribution of fixed and mobile charge in insulators and conductors.

Learning Objective 4.E.3.4: The student is able to construct a representation of the distribution of fixed and mobile charge in insulators and conductors that predicts charge distribution in processes involving induction or conduction.

Learning Objective 4.E.3.5: The student is able to explain and/or analyze the results of experiments in which electric charge rearrangement occurs by electrostatic induction, or is able to refine a scientific question relating to such an experiment by identifying anomalies in a data set or procedure.

Essential Knowledge 4.E.4: The resistance of a resistor and the capacitance of a capacitor can be understood from the basic properties of electric fields and forces as well as the properties of materials and their geometry.

a. The resistance of a resistor is proportional to its length and inversely proportional to its cross-sectional area. The constant of proportionality is the resistivity of the material.

b. The capacitance of a parallel plate capacitor is proportional to the area of one of its plates and inversely proportional to the separation between its plates. The constant of proportionality is the product of the dielectric constant, κ of the material between the plates and the electric permittivity, ε_0 .

c. The current through a resistor is equal to the potential difference across the resistor divided by its resistance.

d. The magnitude of charge of one of the plates of a parallel plate capacitor is directly proportional to the product of the potential difference across the capacitor and the capacitance. The plates have equal amounts of charge of opposite sign.

Learning Objective 4.E.4.1: The student is able to make predictions about the properties of resistors and/or capacitors when placed in a simple circuit based on the geometry of the circuit element and supported by scientific theories and mathematical relationships.

Learning Objective 4.E.4.2: The student is able to design a plan for the collection of data to determine the effect of changing the geometry and/or materials on the resistance or capacitance of a circuit element and relate results to the basic properties of resistors and capacitors.

Learning Objective 4.E.4.3: The student is able to analyze data to determine the effect of changing the geometry and/or materials on the resistance or capacitance of a circuit element and relate results to the basic properties of resistors and capacitors.

Big Idea 5: Changes that occur as a result of interactions are constrained by conservation laws.
Enduring Understanding 5.B: The energy of a system is conserved.

Essential Knowledge 5.B.3: A system with internal structure can have potential energy. Potential energy exists within a system if the objects within that system interact with conservative forces.
a. The work done by a conservative force is independent of the path taken. The work description is used for forces external to the system. Potential energy is used when the forces are internal interactions between parts of the system.
b. Changes in the internal structure can result in changes in potential energy. Examples should include mass-spring oscillators and objects falling in a gravitational field.
c. The change in electric potential in a circuit is the change in potential energy per unit charge.

Learning Objective 5.B.3.1: The student is able to describe and make qualitative and/or quantitative predictions about everyday examples of systems with internal potential energy.
Learning Objective 5.B.3.2: The student is able to make quantitative calculations of the internal potential energy of a system from a description or diagram of that system.
Learning Objective 5.B.3.3: The student is able to apply mathematical reasoning to create a description of the internal potential energy of a system from a description or diagram of the objects and interactions in that system.

Enduring Understanding 5.C: The electric charge of a system is conserved.

Essential Knowledge 5.C.2: The exchange of electric charges among a set of objects in a system conserves electric charge.
a. Charging by conduction between objects in a system conserves the electric charge of the entire system.
b. Charge separation in a neutral system can be induced by an external charged object placed close to the neutral system.
c. Grounding involves the transfer of excess charge to another larger system (e.g., the Earth).

Learning Objective 5.C.2.1: The student is able to predict electric charges on objects within a system by application of the principle of charge conservation within a system.
Learning Objective 5.C.2.2: The student is able to design a plan to collect data on the electrical charging of objects and electric charge induction on neutral objects and qualitatively analyze that data.
Learning Objective 5.C.2.3: The student is able to justify the selection of data relevant to an investigation of the electrical charging of objects and electric charge induction on neutral objects.

NOTES:

I. Charge and Coulomb's Law

    A. _____

        1. Charge is a _____that _____

        _____ of other charged particles.

          a. Symbol:

          b. Unit:

        2. There are _____ of charged particles:

          a.) Electrons: negative

              • $q = $ _____   (e will be defined shortly.)

              •   mass = _____

          b.) Protons: positive

              • $q = $ _____

              •   mass = _____

          c.) Neutrons are _____ with a _____ (essentially) _____ mass.[1]

        3. _____, and _____ is the _____.

          a.) The _____that can be isolated is the

          _____, also known as the _____.

          b.) The _____ of elementary charge is _____ (An electron's

          charge is the negative of this magnitude, and a proton the positive.)

          c.) _____: No object can have a fraction of an electron or proton,

          so all charged objects are whole-number multiples of e. That means charge is quantized,

          and all objects have a charge equal to $N e$ where N is an integer.

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[1] A neutron contains a proton and an electron as part of its makeup. The electron adds *barely* any mass, but the neutron is slightly heavier than a single proton.

4. Charged objects have either an excess or a deficit of electrons.

    a.) Protons do not transfer. Only electrons are free to transfer.

    b.) Therefore…

        1.) _____-charged objects have a _____ because at some point they lost electrons. Therefore they have more protons than electrons.

        2.) _____-charged objects have an _____ because at some point they gained electrons.

        3.) Neutral objects have an equal balance of protons and electrons.

5. _____: Like charges repel, opposite charges attract.

- AND _____ by _____ in the neutral system. (See induction and polarization, below.)

Big Idea 5: Changes that occur as a result of interactions are constrained by conservation laws.

Enduring Understanding 5.C: The electric charge of a system is conserved.

B. _____: Charge can neither be created nor destroyed such that the total charge of a system is conserved. The exchange of electric charges among a set of objects within a system conserves electric charge.

    1. Charging by _____

        a. _____from one object to another either through contact or through a medium.

        b. One object gains the exact amount of charge the other object loses, and charge in the system is conserved.
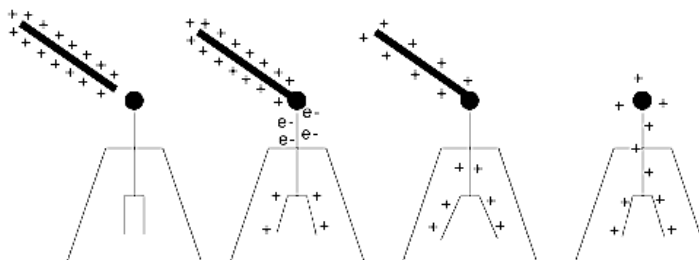
c. _____ is a special type of conduction: Grounding involves the transfer of excess charge to another larger system (e.g., the Earth).
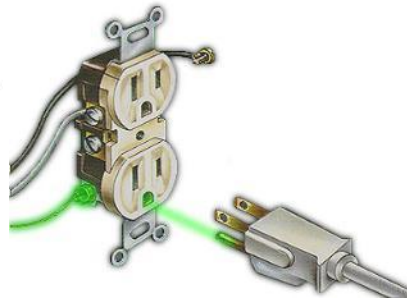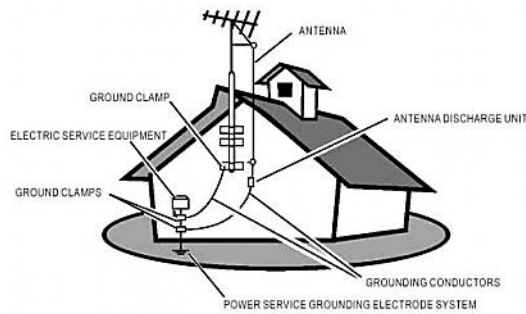
2. Charging by _____

a. _____ can be induced by an external charged object placed close to the neutral system: A neutral conductor has the ability to transfer charge from one side of itself to the other when exposed to but not touched by a charged object. (The charged object is then attracted to the induced object.)

b. No charge transfers, so the total charge of the system is conserved.

c. HOWEVER, if the induced object is grounded, charge exits the system. The object is no longer neutral.
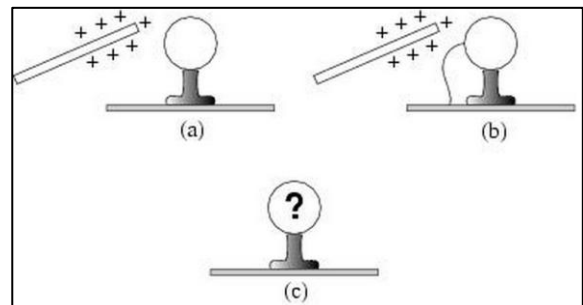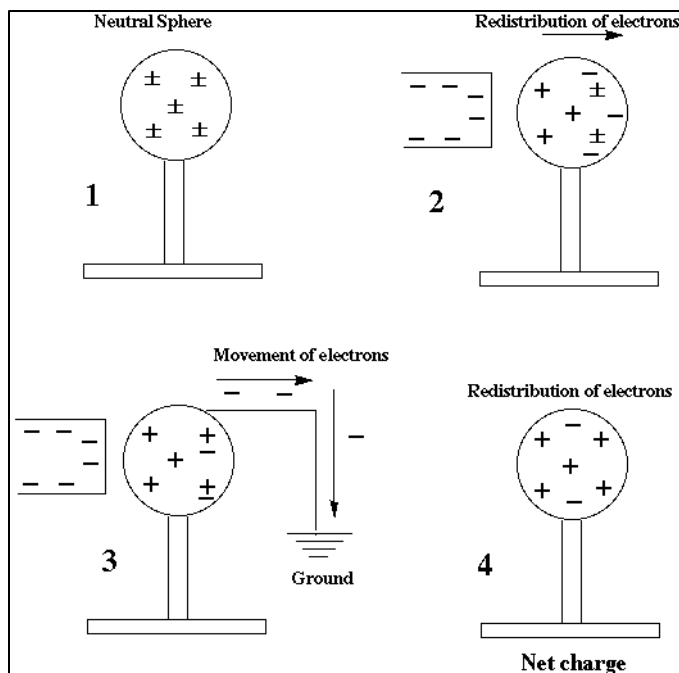
3. Charging by _____

    a. _____ has the ability to _____

    _____ but not throughout the entire

    object when exposed to but not touched by a charged object. The charged object is then

    attracted to the polarized object.

    b. No charge transfers, so the total charge of the system is conserved.

    c. Because the object is an insulator, it cannot readily be grounded. Charge will not leave the

    system.

(a)

(b)
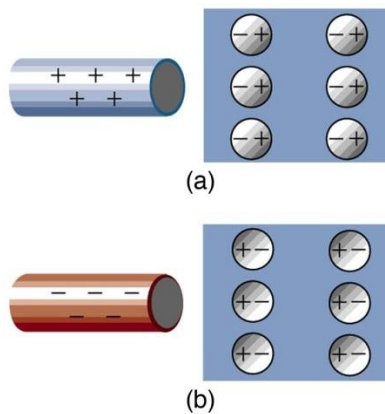
4. Examples:

    a. Example 1: Water molecules are polar and can help carry excess charge from a system,

    but in the winter there is not enough humidity to do this very well. A person walks across a

    rug in the wintertime when the air is really dry and exchanges charge with the rug. (a)

    Describe the system and the method of charging. (b) If a human body is more likely to grab

    electrons than a rug is likely to hold on to them, which object becomes positive, and which

    object becomes negative? (c) Generate an example in SI units of a possible charge on the

    person and the rug following the walk.

b. <u>Example 2</u>: The person then comes to a door and brings her hand near a metal doorknob without touching it. (a) If no charge transfers, what happens to the charges in the doorknob? (b) Does this happen to all of the charges in the doorknob? (c) What method of charging is this? (d) Define the system and relate this scenario to conservation of charge. (e) Describe a scenario in which the charge of the system would not be conserved. (f) In your own words, compare and contrast this situation with one in which the person's hand came near an insulating material, such as the drywall on the wall next to the door.

C. _____ describes the _____two or more _____

1. Electric force results from the interaction of one object that has an electric charge with another object that has an electric charge.

a. *Review*: Electric forces dominate the properties of the objects in our everyday experiences. However, the large number of particle interactions that occur make it more convenient to treat everyday forces in terms of nonfundamental forces called contact forces, such as normal force, friction, and tension.

b. Electric forces may be attractive or repulsive, depending upon the charges on the objects involved.

2. _____

    a. Based on the arrangement and interactions of the atoms and molecules that make up a

    material, _____

    _____.

    b. _____and _____

    for electric permittivity. The value for electric permittivity in a vacuum (free space) is called

    _____, and its value

    _____:

    c. The _____has a value _____ from that of

    free space. All matter has a permittivity that is actually _____

    _____.[2]

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[2] Electric permittivity is actually a measure of the *resistance* to the establishment of an electric field. Permittivity is a misnomer. Therefore as permittivity goes up, the material is *less* "permissive" to the establishment of a field.

3. _____formula:

(This is the formula on the AP Physics 2 equation sheet.)

where

- ε_0 is the constant vacuum permittivity (a.k.a. electric permittivity)[3]

- q_1 and q_2 are the *magnitudes of* the two charges

- r is the distance between the charges

Coulomb's Law variant:

(This is the formula on the AP Physics 1 equation sheet.)

where

- k is _____ (which *is* on your formula sheet.)

  - $k = \dfrac{1}{4\pi\varepsilon_0} = 9.0 \times 10^9 \text{ N} \bullet \text{m}^2/\text{C}^2$

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[3] ALERT: On your formula sheet in the column where the variables are defined, you will see ε defined as emf (electromotive force.) This is DIFFERENT from ε_0, which is vacuum permittivity and is defined on the front of the AP Physics 2 equation sheet. (Yes, ugh!)

4. <u>Example 3</u>: The image below shows the charge distribution in a medium with three point charges[4] fixed in place. The focus of your attention will be on charge q_3. (a) Create a vector model to represent the forces acting on charge q_3. (b) Find the net electrostatic force on q_3.

$q_3 = 25 \ \mu C$

57.7 cm

32 cm

$q_1 = 65 \ \mu C$

48 cm

$q_2 = -85 \mu C$

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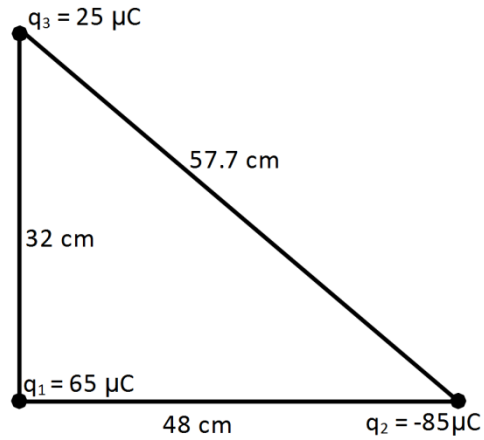
[4] When an object is small compared to the distances involved in the problem, or when a larger object is being modeled as a large number of very small constituent particles, these can be modeled as charged objects of negligible size, or "point charges."

Break time!

Generate a graphic organizer comparing and contrasting gravitational force with electric force.

(This is important and is in the curriculum.)

Big Idea 2: Fields existing in space can be used to explain interactions.

II. _____

    A. An electric field is _____.

- The _____for electric field is _____. Conceptually this means that we're examining how many Newtons of force act on a Coulomb of charge at a particular location in the field.

B. _____: Electric fields are _____ that

have direction. The direction of the force is determined by the direction of the field and the sign of

the charge. The convention is to consider _____

accelerating _____and _____

accelerating in the _____.

- Sketch which way you think the vector field points in all regions around each of the

  following charged objects. Each rectangle represents a separate question.[5]
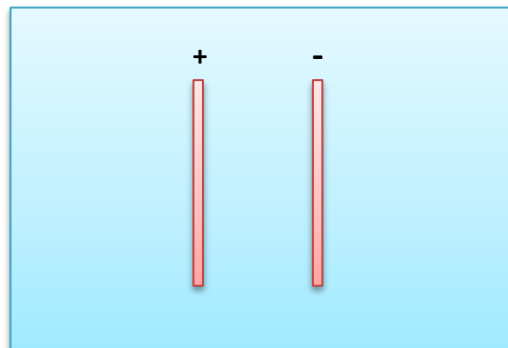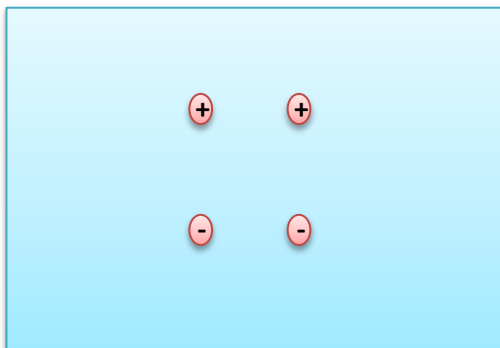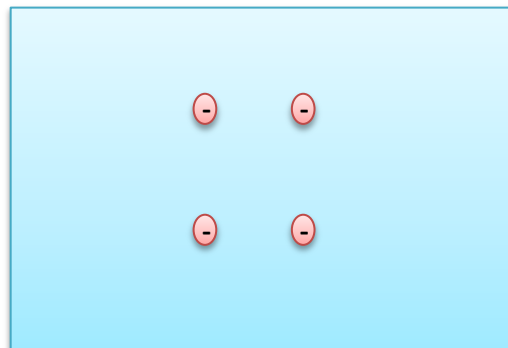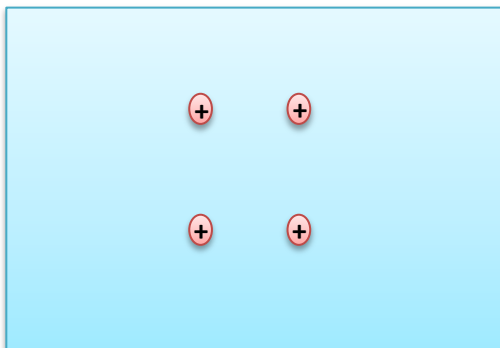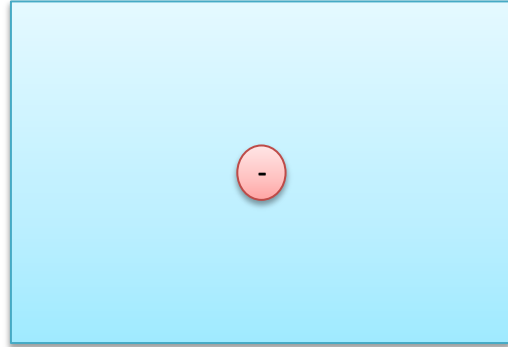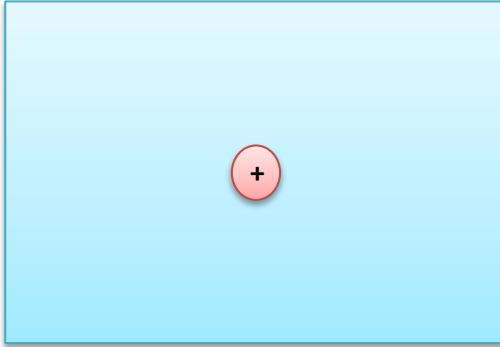
- In the vector field of an electric field, we can construct _____. Isolines in a region where an electric field exists represent lines of _____ [6] referred to as _____.

  o An isoline map of electric potential can be constructed from an electric field vector map, using the fact that the isolines are perpendicular to the electric field vectors.

  o Since the electric potential has the same value along an isoline, there can be no component of the electric field along the isoline.

  o As the distance between two different equipotential lines decreases, the intensity of the change increases.

  o Compare these conceptually to gravitational isolines. [7]

  o Sketch isolines on each of your six vector fields.

C. _____: There are two ways we can look at the magnitude of electric fields: From the perspective of the charge *creating* the field and from the perspective of a small point charge *experiencing* the field.

   1. The electric field outside a spherically symmetric charged object is _____ and its _____as _____ from the center of that object.
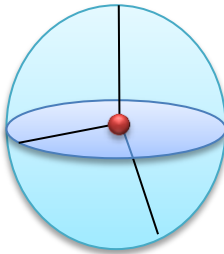
   The inverse square relation gives the magnitude of the electric field at a distance r from the center of a source object of electric charge q as

   (The right side is not on the formula sheets.)

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[6] We will define electric potential in depth later.
[7] Essential Knowledge 2.E.1: Isolines on a topographic (elevation) map describe lines of approximately equal gravitational potential energy per unit mass (gravitational equipotential). As the distance between two different isolines decreases, the steepness of the surface increases.

2. We can also examine the field in relation to its effect on a point _____

_____.

3. Note the similarities to the behavior of gravitational force and gravitational fields.

Gravitational force	Electric force
$F_g = G\dfrac{m_1 m_2}{r^2}$	$F_E = \dfrac{1}{4\pi\varepsilon_0}\dfrac{q_1 q_2}{r^2}$
Gravitational field created BY the object	**Electric field created BY the object**
$g = G\dfrac{M}{r^2}$	$E = \dfrac{1}{4\pi\varepsilon_0}\dfrac{q}{r^2}$
Gravitational field acting ON an object in the field	**Electric field acting ON an object in the field**
$g = \dfrac{F_g}{m}$	$E = \dfrac{F_E}{q}$

- What's the big, glaring difference between electric force and fields compared to gravitational force and fields?

D. Examples

1. <u>Example 4</u>: Two spherically symmetrical charged objects create the vector field shown below. (a) Identify which lines (solid or dashed) are the vector field lines and which are the equipotential lines. (Ignore the triangle for now.) (b) Why can there be no component of the electric field directed along an equipotential line (isoline)? (c) Charge 1 is on the left and has a charge of 6.4 E-18 C, and charge 2 is on the right and has a charge of -3.2 E-18 C. At the point marked by the star, what is the net field? This point is 1.9 E-3m from the negative charge at an angle of 64° above horizontal, and it is 3.7 E-3 m from the positive charge at an angle of 28° above horizontal as shown in the triangle, below. (d) OK, that was complicated! Now write instructions for how to solve this type of problem.
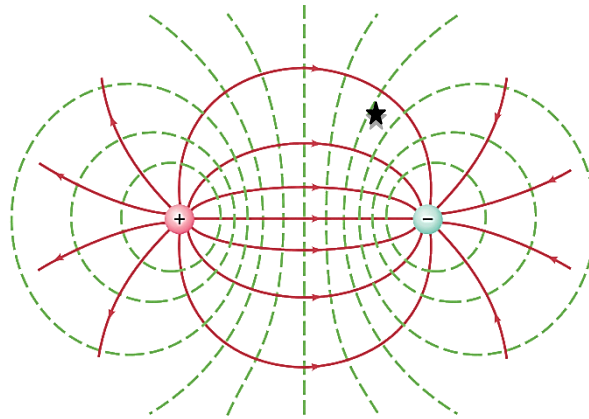
More space is on the next pge.

2. <u>Example 5</u>: Now that you know the field strength and direction, predict qualitatively and quantitatively what an electron would experience if it were placed at the location specified in example 4. Note the direction and magnitude of the force it experiences as well as the electron's acceleration.

3. <u>Example 6</u>: Below are isolines for three charges, Q_1 (negative,) Q_2 (negative,) and Q_3 (positive.) Each line represents a difference of 1 Volt. (We will get to Volts soon. For now consider it to be a reflection of field strength.) (a) Sketch vector field lines on the diagram. (b) Identify where the field is the strongest. (c) Which is the strongest charge?
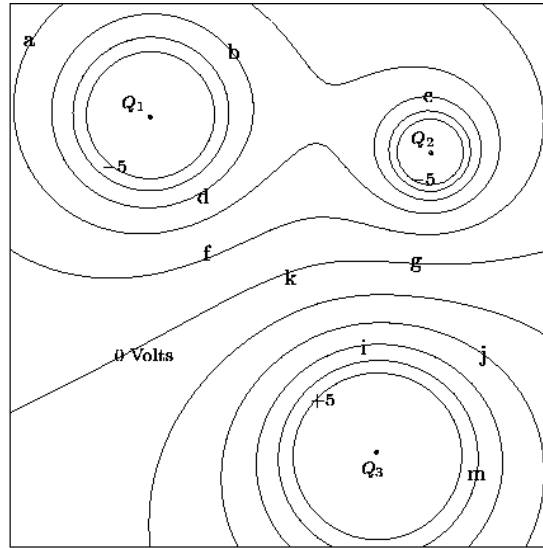

4. <u>Example 7</u>: (From your textbook, page 553) A positive point charge is fixed in position at the center of a square ABCD. The net electric field at corner A is zero. (a) At which corner is the second charge located? (b) Is the second charge positive or negative? (c) Does the second charge have a greater, a smaller, or the same magnitude as the charge at the center?

E. Special cases: Electric dipoles, shielding, and parallel plates

1. _____are _____with

the _____but _____that

are separated by a distance.

- Determine the signs and relative magnitudes of the charges creating the electric

    fields below. Are they true dipoles?
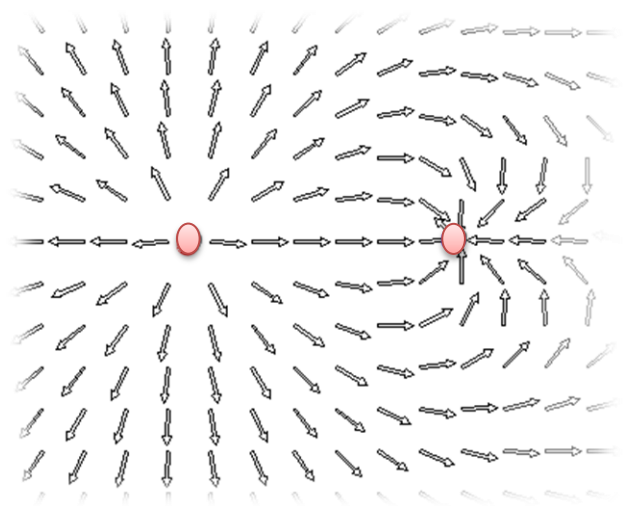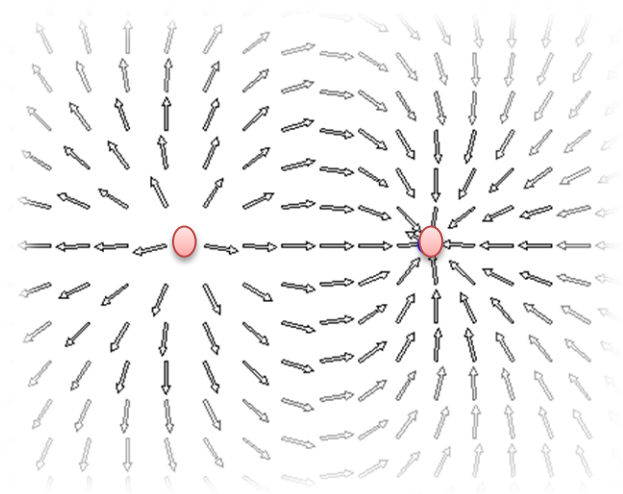
2. _____:

    a. In solid conductors, some electrons are mobile. When no current flows, mobile charges are in static equilibrium, excess charge resides at the surface, and the interior field is zero.

    b. In solid insulators, excess (fixed) charge may reside in the interior as well as at the surface.

    c. This can result when the system is inside a stable external field or when the external field is uniformly neutral.
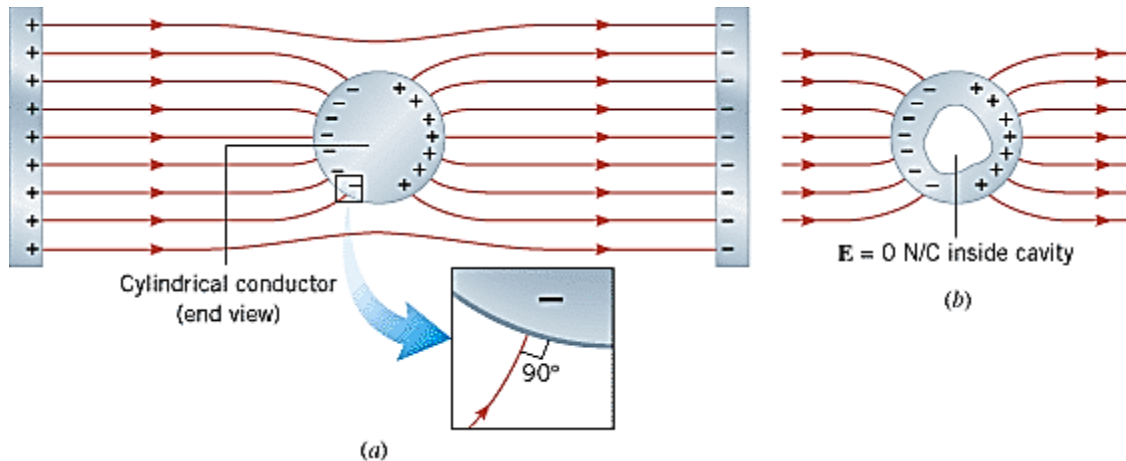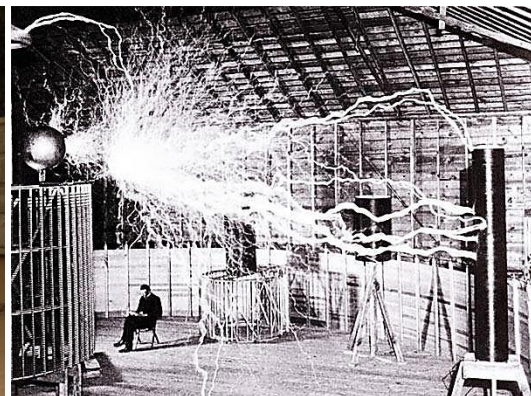

Cylindrical conductor
(end view)

90°

(a)

$E = 0$ N/C inside cavity

(b)

Image from a guy's survivalist blog   Michael Faraday testing his cage

Decent animation: https://www.youtube.com/watch?v=yHfgqDcEqfA

Benjamin Franklin in a tinsel skirt: https://www.youtube.com/watch?v=WqvImbn9GG4

3. Between two oppositely charged _____with uniformly distributed electric charge, at points far from the edges of the plates, the electric field is perpendicular to the plates and is constant in both magnitude and direction.

    a. The assumption of a uniform field is not appropriate near edges of the plates.

    b. We can calculate the magnitude of the field in between the plates by

where
- Q is the charge on each plate.
- A is the area of each plate.
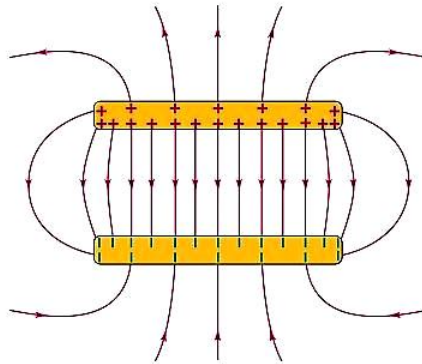
    c. <u>Example 8</u>: (a) What is the charge on two parallel plates with surface area 0.02 m^2 if the electric field between them is 3.6 E5 N/C? (b) Sketch the plates and the field. (c) A small magnitude positive point charge (called a "test charge") is shot into the region between the plates. On your sketch from part b, draw the path the test charge will take. (d) Describe its acceleration in both dimensions.

III. Electric Potential Energy & Electric Potential

    A. _____:

        1. _____ of a system, _____

        _____. As with gravitational potential energy,

        particles with electric potential energy have the potential to move.

        2. Formula:

- U_E is the electric potential energy in the charge
- q is the _____.
- V is the electric potential (next topic…)

    B. Work, the conservation of energy, and an obnoxious convention:

        1. As with gravitational potential energy, electric potential energy exists due to the

        configuration of the system. If positive external _____,

        the electric potential energy of the system can increase.

        2. If the configuration changes such that _____of a

        point charge _____, the point charge _____its _____.

        3. Direction of motion:

- A _____from a region of _____ potential _____ potential.
- A _____from a region of _____ potential _____ potential.
- By historical _____, when we examine _____
  in _____, we consider current to consist of _____ charges _____ .[8]

C. _____ (also called _____ and, as a shorter nickname, simply

_____)

    1. Electric potential is the _____

    that a _____ at a particular _____.

    It is a _____ value.

- Conceptually it is almost the same as electric potential energy except that it is a ratio.

    2. <u>Formula relating electric potential to charge and distance</u> from the field source:

(The right side is not on the formula sheet.)

    where…

- q is the _____.
- V is the electric potential.
- r is the distance from the source of the electric field.

    3. _____ is the _____

    within an electric field.

- Formula:

- ΔV is the potential difference.
- $\vec{E}$ is the average electric field strength over the region.
- Δr is the displacement from one end of the region to the other.

      ○ In a battery, we look at positive charges having a potential to move toward the negative terminal. The potential difference between the positive end and the negative end is 1.5 Volts.


    4. Units: Volts (V) where 1V = 1 J/C

- Special perspective: The _____
  - An electron volt is the amount the electric potential energy of one electron changes when moving through a potential difference of one volt.
  - 1 eV = 1.60 x 10^{-19} J

5. Electric potential (and, therefore, potential difference) is a _____.

6. _____ (a.k.a. isolines) are useful in examining electric fields and electric potential. Revisit our earlier notes on equipotential lines.

D. Examples

1. Example 9: Analyze the equipotential lines below. (a) Sketch the charge configuration and the electric field that would create these equipotential lines. Be specific about relative strengths of the charges creating the field. (b) Describe the motion of a positive point charge located initially at the top right corner on the -2V equipotential line. Refer to average electric field, electric potential energy, electric potential, potential difference, and kinetic energy in your answer. (c) Compare these values to the values of another equal positive point charge placed top and center on the -2V isoline.
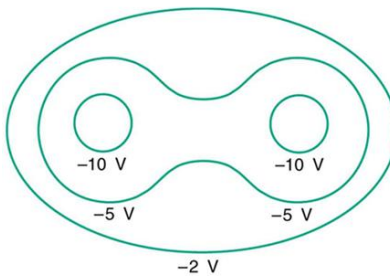
2. <u>Example 10</u>: Analyze the equipotential lines below noting that each line is $|\Delta V|$ = 50V from the adjacent lines. (a) Sketch the charge configuration and the electric field that would create these equipotential lines. Be specific about relative strengths of the charges creating the field. (b) How is it possible that there is a potential of 0V in the middle? What does this mean? (c) What is the average electric field between points a & b (taking the separation to be about 1.0 m)? b & c (taking the separation to be about 0.75m)?
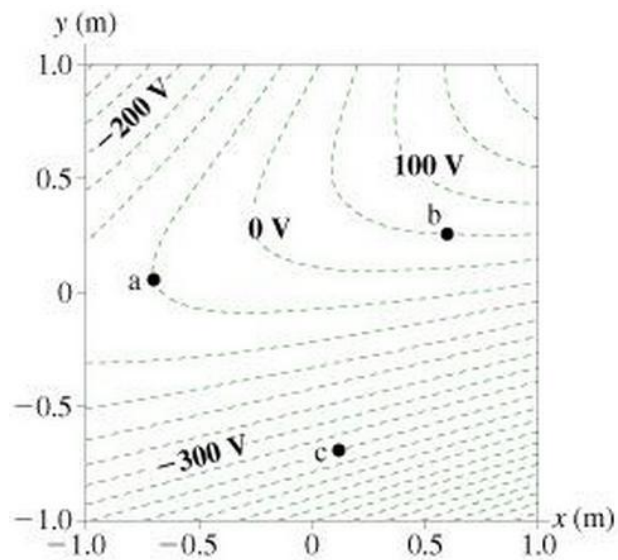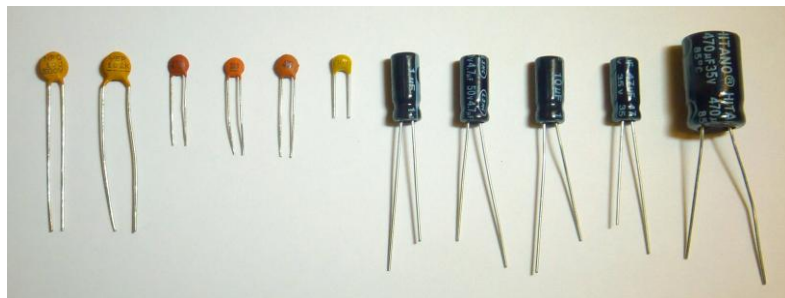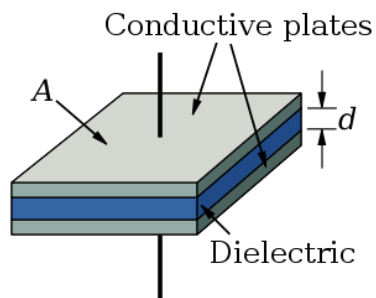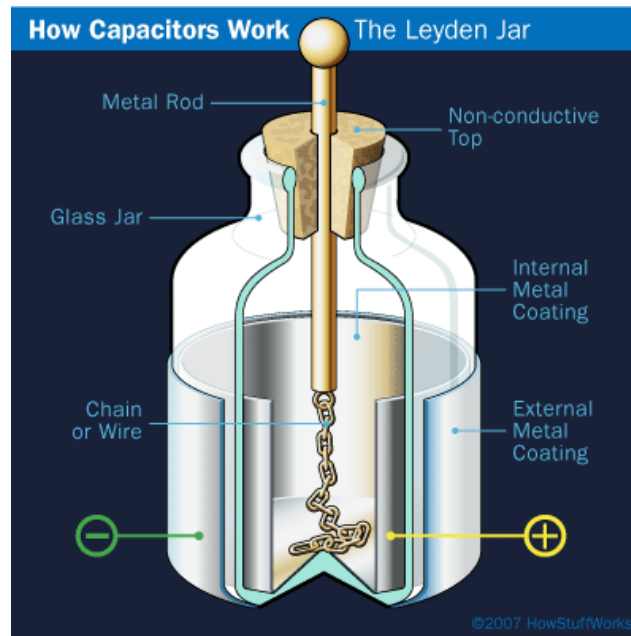
IV. _____

    A. Capacitors are devices that _____

    due to their _____.

- _____, one positively charged and one negatively charged, are placed near each other but are _____ an _____called a _____. The two conductors have an equal magnitude of charge.

B. _____

    1. _____in a capacitor, _____ must be done. Typically

this work comes from _____ the capacitor to an _____

_____.

    2. _____ is a _____the _____ of a capacitor to

_____the capacitor is _____

an _____, _____ an _____

within the capacitor.

    3. Details:

        a. Symbol:

        b. SI Unit:

            (usually between pico (10^{-12}) and micro (10^{-6}))

    4. Formula after formula after formula after formula…

        a. The magnitude of charge of one of the plates of a parallel plate capacitor is directly

proportional to the product of the potential difference across the capacitor and the

capacitance such that[9]

        where

- Q is the magnitude of the charge on either of the plates.
- ΔV is the potential difference between the plates.

        b. The capacitance of a parallel plate capacitor is proportional to the area of one of its

plates and inversely proportional to the separation between its plates. The qualities of

the dielectric also play a role.

        where

- κ (kappa) is the dielectric constant for the material between the plates.
- A is the surface area of each conductor
- d is the distance between the conductors

---

[9] This formula sometimes confuses people, but consider that to achieve a particular voltage, if the capacitance is large, the capacitor will store a lot of charge. If the capacitance is small, the capacitor won't store as much charge to create that voltage.

      c. The _____can be found by

      d. The _____can be found by

5. Examples:

    a. <u>Example 11</u>: A set of oppositely-charged parallel plates are separated by a distance of 1.2 E-3m creating a capacitor of capacitance 2200µF. Between the plates is a glass dielectric with a dielectric constant of 2.1. A potential difference of 1.5 V exists between them where the field is uniform. (a) What is the magnitude of the average electric field between the plates? (b) What must be the charge on each plate? (c) Sketch the plates leaving space between them so that you can also draw the field and three evenly-spaced equipotential lines. (d) Quantify the voltage on each plate and each of the equipotential lines.

b. Example 12: A particular capacitor stores energy in a 140μF capacitor at 200V. (a) How much charge is stored on each plate? (b) If the area of each plate is 1cm^2, what is the electric field between them?(c) How much electric energy can be stored? (d) What is the power output if the capacitor releases the energy in 0.001 seconds?

c. Example 13: (This problem is from a great website, http://www.learnapphysics.com.)
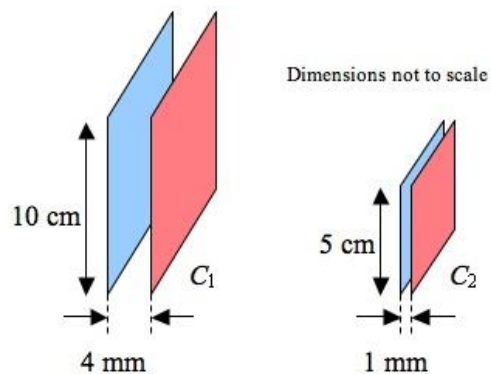
Capacitor C_1 consists of square parallel plates 10cm on a side and separated by a distance of 4mm. Capacitor C_2 has square parallel plates 5cm on a side and separated by a distance of 1mm. What is the ratio between the capacitances of the two parallel-plate systems?