AP Physics C: E&M
Unit 1 Practice Exercises

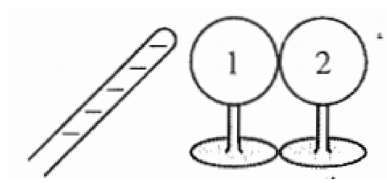
Directions: Show the steps required to arrive at the answer (if applicable). Work the problems on separate page.

1.1 – Electric Charge

1. How does the attraction of electrons to the atomic nucleus differ in a conductor vs. an insulator? How does this allow conductors to better allow the flow of charge? Answer in a complete sentence.

2. A glass object receives a positive charge by rubbing it with a silk cloth. In the rubbing process, have protons been added to the object or have electrons been removed from it?

3. Two initially uncharged conductors, 1 and 2, are mounted on insulating stands and are in contact as shown on the right. A negatively charged rod is brought near but does not touch them. With the rod held in place, conductor 2 is moved to the right by pushing its stand, so that the conductors are separated. What is the charge on conductor 2? Justify your answer.

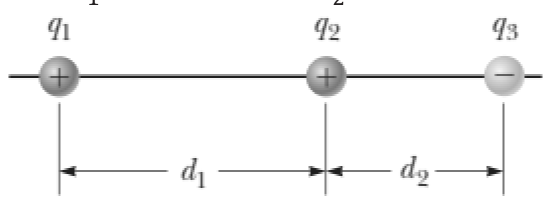


4. An uncharged electroscope's knob is touched by a positively charged rod and then the rod is removed.
   a) What is the type of charge on the knob of the electroscope after the rod is removed?
   b) What is the type of charge on the leaves of the electroscope after the rod is removed?
   c) What is the net charge on the electroscope after the rod is removed?
   d) By which process was the scope charged by?
   e) Are the leaves diverged or collapsed after the rod is removed?

1.2 – Coulomb's Law

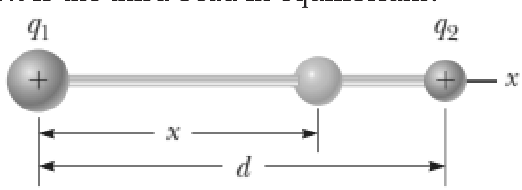
1. Two protons in a molecule are 3.8×10^{-10} m apart.
   a) Find the magnitude of the electric force exerted by one proton on the other.
   b) State how the magnitude of this force compares with the magnitude of the gravitational force exerted by one proton on the other

2. Three point charges lie along a straight line as shown below, where $q_1 = 6.00\ \mu C$, $q_2 = 1.50\ \mu C$ and $q_3 = -2.00\ \mu C$. The separation distances are $d_1 = 3.00\ cm$ and $d_2 = 2.00\ cm$.



Calculate the magnitude and direction of the net electric charge on q_1, q_2, and q_3.

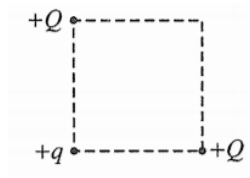
3. Two small beads having positive charges $q_1 = 3q$ and $q_2 = q$ are fixed at the opposite ends of a horizontal insulating rod of length *d* = 1.50 m. The bead with charge q_1 is at the origin. A third small, charged bead is free to slide on the rod. At what position *x* is the third bead in equilibrium?



4. Two particles, each of particle +Q, are fixed at opposite corners of a square that lies in the plane of this page. A positive charge +q is placed at a third corner.

a) What is the direction of the force on the test charge due to the other charges?

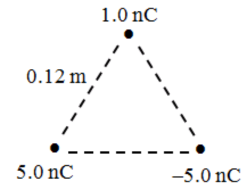
b) If F is the magnitude of the force on the test charge due to only one of the other charges, what is the magnitude of the net force acting on the charge due to both of these charges?



5. As shown in the figure, three charges are at the vertices of an equilateral triangle.

a) What is the direction of net electrical force on the 1.0 nC charge due to the other two charges.

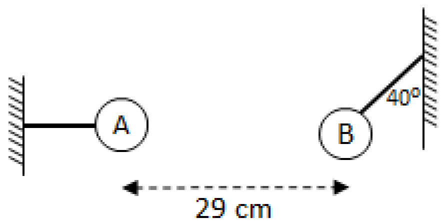
b) What is the magnitude of the net electrical force on the 1.0 nC charge due to the other two charges.



6. Two charged objects are connected to fixed walls, as shown. The charge on sphere A is 6.8×10^{-5} C and the charge of sphere B is -7.9×10^{-5} C. Calculate:

a) the mass of sphere B and

b) the tension in the rope attached to sphere B.

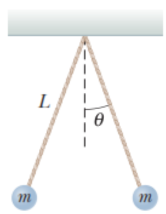


7. The charge on a proton is $1.6\text{x}10^{-19}$ C. A hydrogen atom contains an electron and a proton separated by a $5.0\text{x}10^{-11}$ m. The mass of an electron is $9.11\text{x}10^{-31}$ kg. If the electron orbited the proton in a circular orbit:

a) Calculate the orbital speed.

b) Calculate the period of the orbit.

8. Two small metallic spheres, each of mass m =0.200 g, are suspended as pendulums by light strings of length L as shown. The spheres are given the same electric charge of 7.2 nC, and they come to equilibrium when each string is at an angle of $\boldsymbol{\theta = 5.00°}$ with the vertical. How long are the strings?



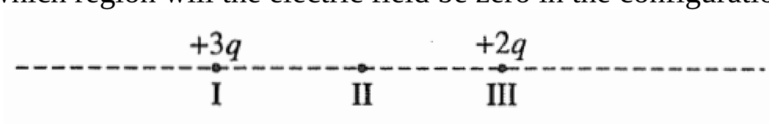
1.3 – <u>Electric Field</u>

1. A 26 μC charge experiences a force of 8.9 N in an electric field.

a) What is the electric field at the point where the charge is located?

b) What force would a 34 μC charge experience in the same field?

2. Other than infinity, in which region will the electric field be zero in the configuration shown below?

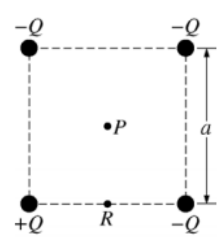


3. The square of side a shown contains a positive test charge $+Q$ fixed at the lower corner and negative point charges $-Q$ fixed at the other three corners of the square. Point P is located at the center of the square.

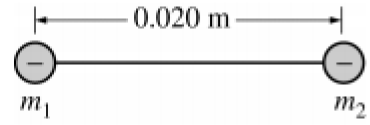
a) Indicate the direction of the net electric field at point P.

b) Derive an expression for the magnitude of the electric field at point P.

c) Describe one way to replace a single charge in this configuration that would make the electric field at the center of the square equal to zero. Justify your answer.



4. Two small objects, each with a charge of -4.0 nC, are held together by a 0.020 m length of insulating string as shown in the diagram above. The objects are initially at rest on a horizontal, nonconducting frictionless surface. The effect of gravity on each object due to the other is negligible.’



a) Calculate the tension in the string.

b) Illustrate the electric field by drawing electric field lines for the two objects.

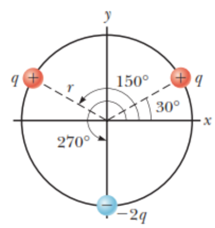
The masses of the objects are m1 = 0.030 kg and m2 = 0.060 kg. The string is now cut.

c) Calculate the magnitude of the initial acceleration of each object.

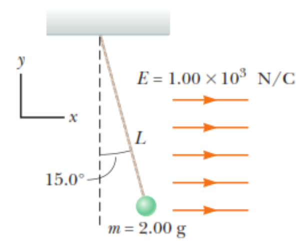
d) Qualitatively sketch a graph of the acceleration a of the object of mass m2 versus the distance d between the objects after the string has been cut.

e) Describe qualitatively what happens to the speeds of the objects as time increases, assuming that the objects remain on the horizontal, nonconducting frictionless surface.

5. Three point charges lie along a circle of radius *r* at angles of 30º, 150º, and 270^0 as shown. Find a symbolic expression for the resultant electric field at the center of the circle.

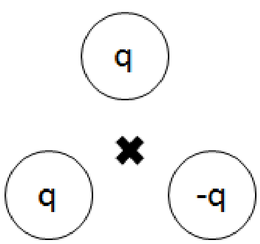


6. A small, 2.00-g plastic ball is suspended by a 20.0-cmlong string in a uniform electric field as shown. If the ball is in equilibrium when the string makes a 15.0° angle with the vertical, what is the net charge on the ball?

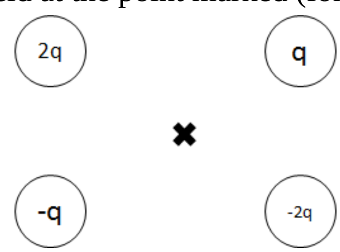


7. Draw a vector representing the direction of the electric field at the point marked (for a positive test charge).

a)



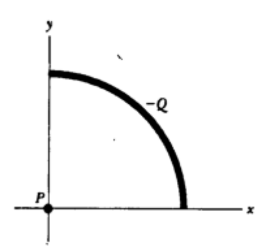
b)



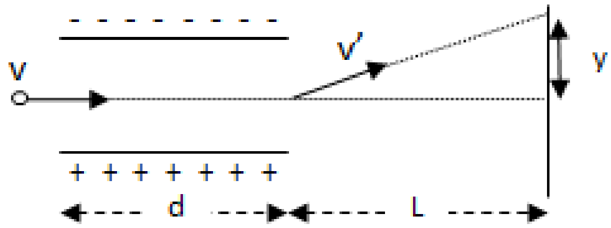
8. A thin insulating semicircle of total charge Q with radius R is center around a point, P. Determine the electric field at point P due to the semicircle of charge.

9. A uniform charge of σ C/m extends from (-L,0) to (0,0). Find the magnitude of the electric field due to this charge distribution at point (a,0).

10. Negative electric charge is distributed uniformly around a quarter of a circle of radius a, with total charge -Q. What are the x and y components of the resultant at the center of curvature (point P)?



11. A particle of mass m and charge q enters an electric field with velocity v, parallel to two oppositely charged plates as shown below. The particle travels a distance d between the plates and L after the plates. The electric field between the plates is E. What is the deflection y, in terms of given variables?



1.4 – Gauss's Law

1. A cubical surface surrounds a point charge *q*. Describe what happens to the total f lux through the surface if

   a) the charge is doubled
   b) the volume of the cube is doubled
   c) the surface is changed to a sphere
   d) the charge is moved to another location inside the surface
   e) the charge is moved outside the surface.

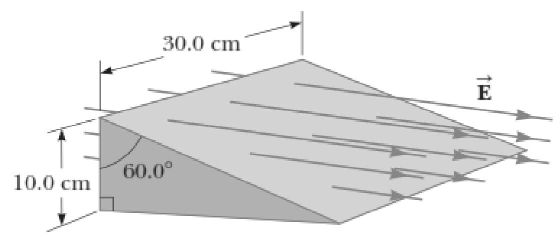
2. A uniform electric field exists in a region of space containing no charges. What can you conclude about the net electric flux through a gaussian surface placed in this region of space?

3. If more electric field lines leave a gaussian surface than enter it, what can you conclude about the net charge enclosed by that surface?

4. A vertical electric field of magnitude 2.00 x 10^4 N/C exists above the Earth's surface on a day when a thunderstorm is brewing. A car with a rectangular size of 6.00 m by 3.00 m is traveling along a dry gravel roadway sloping downward at 10.0°. Determine the electric flux through the bottom of the car.

5. Consider a closed triangular box resting within a horizontal electric field of magnitude E = 7.80x10^4 N/C as shown. Calculate the electric flux through

   a) the vertical rectangular surface
   b) the slanted surface
   c) the entire surface of the box.



6. The electric field everywhere on the surface of a thin, spherical shell of radius 0.750 m is of magnitude 890 N/C and points radially toward the center of the sphere.

   a) What is the net charge within the sphere's surface?
   b) What is the distribution of the charge inside the spherical shell?

7. In the air over a particular region at an altitude of 500 m above the ground, the electric field is 120 N/C directed downward. At 600 m above the ground, the electric field is 100 N/C downward. What is the average volume charge density in the layer of air between these two elevations?

8. A particle with charge of 12.0 mC is placed at the center of a spherical shell of radius 22.0 cm. What is the total electric flux through

   a) the surface of the shell and
   b) any hemispherical surface of the shell?

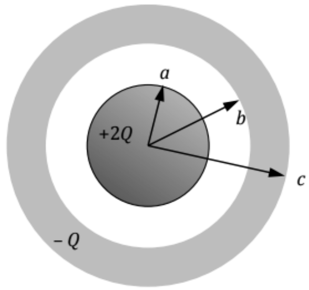
1.5 – Applications of Gauss's Law

1. A 10.0-g piece of Styrofoam carries a net charge of -700 μC and is suspended in equilibrium above the center of a large, horizontal sheet of plastic that has a uniform charge density on its surface. What is the charge per unit area on the plastic sheet?

2. Consider a thin, spherical shell of radius 14.0 cm with a total charge of 32.0 μC distributed uniformly on its surface. Find the electric field a) 10.0 cm and b) 20.0 cm from the center of the charge distribution.

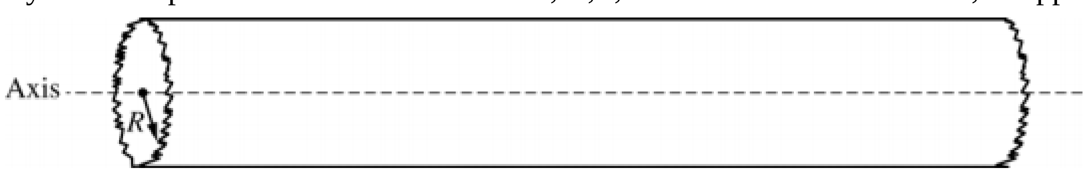
3. The charge per unit length on a long, straight filament is 290.0 mC/m. Find the electric field a) 10.0 cm and b) 100 cm from the filament, where distances are measured perpendicular to the length of the filament.

3. A solid, non-conducting sphere of radius a has a charge of +2Q distributed uniformly throughout its volume. A conducting shell with an inner radius of b and an outer radius of c is located concentrically around the solid sphere, and has a net charge of –Q. Express all answers in terms of the given values and fundamental constants.



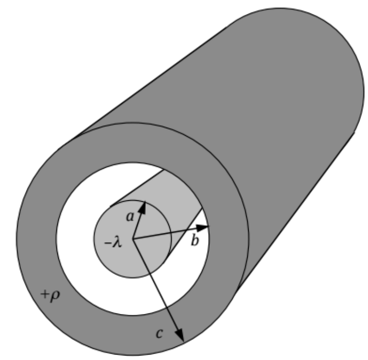
a) Use Gauss's Law to determine the magnitude and direction of the electric field E at a point located r away from the center of the spheres, where r > c.
b) Use Gauss's Law to determine the magnitude and direction of the electric field E at a point located r away from the center of the spheres, where b > r > a.
c) Identify the total amount of charge induced on the inner surface of the conducting shell, at radius b.
d) Identify the total amount of charge induced on the outer surface of the conducting shell, at radius c.
e) Use Gauss's Law to determine the magnitude and direction of the electric field E as a function of r, where r < a.
f) Sketch a graph of electric field E as a function of radius r, from r = 0 to 2c, with radii a, b, and c clearly identified.

4. A very long, solid, nonconducting cylinder of radius R has a positive charge of uniform volume density r . A section of the cylinder far from its ends is shown in the diagram above. Let r represent the radial distance from the axis of the cylinder. Express all answers in terms of r, R, r, and fundamental constants, as appropriate.



a) Using Gauss's law, derive an expression for the magnitude of the electric field at a radius r < R. Draw an appropriate Gaussian surface on the diagram.
b) Using Gauss's law, derive an expression for the magnitude of the electric field at a radius r > R.
c) Sketch the graph of electric field E as a function of radial distance r for r = 0 to r = 2R. Explicitly label any intercepts, asymptotes, maxima, or minima with numerical values or algebraic expressions, as appropriate.
d) Derive an expression for the magnitude of the potential difference between r = 0 and r = R .
e) The nonconducting cylinder is replaced with a conducting cylinder of the same shape and same linear charge density. Sketch the electric field E as a function of r for r = 0 to r = 2R. Explicitly label any intercepts, asymptotes, maxima, or minima with numerical values or algebraic expressions, as appropriate.

5. An infinitely long cylindrical conductor has a radius a and a linear charge density of $-\lambda$ as shown above. The conductor is surrounded by a cylindrical shell made of a nonconducting material of inner radius b, outer radius c, and with a constant volume charge density of $+\rho$. The conductor and nonductor are located concentrically about a common axis.



a) Determine the net electric flux per unit length passing through a cylindrically symmetric Gaussian surface located just outside the surface of the conductor.

b) Use Gauss's Law to determine the magnitude of the electric field E as a function of radius r, where:

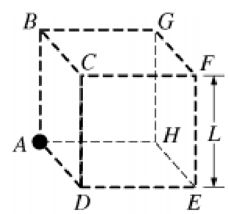
i. $r < a$ ii. $a < r < b$ iii. $r > c$

6. A nonconducting, thin, spherical shell has a uniform surface charge density σ on its outside surface and no charge anywhere else inside.

a) Use Gauss's law to prove that the electric field inside the shell is zero everywhere. Describe the Gaussian surface that you use.

b) The charges are now redistributed so that the surface charge density is no longer uniform. Is the electric field still zero everywhere inside the shell. Justify your answer.

Now consider a small conducting sphere with charge +Q whose center is at corner A of a cubical surface, as shown below.



c) For which faces of the surface, if any, is the electric flux through that face equal to zero? Explain your reasoning.

d) At which corner(s) of the surface does the electric field have the least magnitude?

e) Determine the electric field strength at the position(s) you have indicated in part (d).

f) Given that one-eighth of the sphere at point A is inside the surface, calculate the electric flux through face CDEF.

7. A scientist describes an electrically neutral atom with a model that consists of a nucleus that is a point particle with positive charge +Q at the center of the atom and an electron volume charge density of the form:

$$\rho(r) = \begin{cases} -\frac{\beta}{r^2} e^{-\frac{r}{\alpha}} & r < a \\ 0 & r > a \end{cases}$$

where α and β are positive constants and r is the distance from the center of the atom.

a) Sketch the graph for each of the following enclosed by a Gaussian sphere of radius r as a function of r.

i. The nuclear charge only.

ii. The electron charge only.

b) Use Gauss's Law to derive an expression for the electric field strength due to the neutral atom for the following positions:

i. $r > a$

ii. $r < a$

c) Based on the model, what is the physical meaning of the constant α?