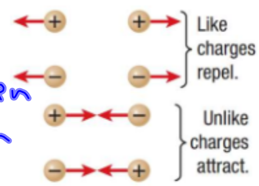
SPH4U 7.1 Properties of Electric Charge

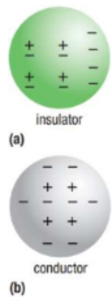
1. Electric charge

Law of electric charges:	opposites attract, likes repel
Law of conservation of charge:	charge can be transferred between objects, but the total charge in a closed system is constant.
coulomb C	electron: $-e = -1.60 \times 10^{-19}$ C proton: $+e = +1.60 \times 10^{-19}$ C.



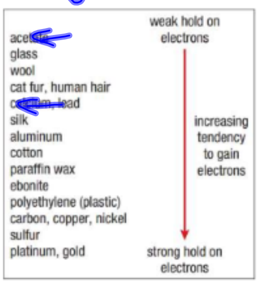
2. Conductors and insulators

Conductor:	substance where electrons move freely
Insulator:	substance where electrons don't move freely.
liquids and gases	substances can dissolve into separate ions.
charging an insulator	electrons stay on surface.
charging a conductor	electrons distribute evenly.

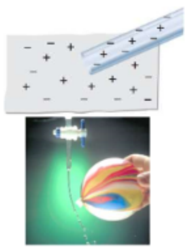


3. Charging objects

① By friction:	electrons transfer from one material to another because they hold their electrons with different strengths.
electrostatic series	shows the relative strength (hold on electrons) of different materials.



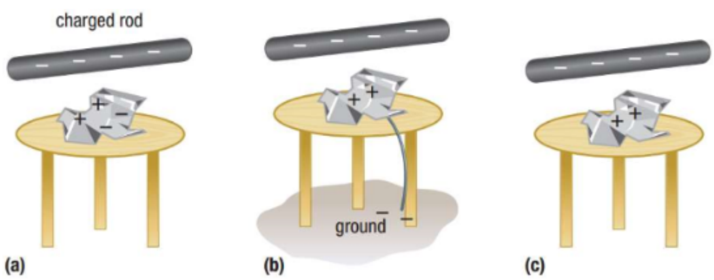
② By induced charge separation:	bring a negative rod near neutral paper. the electrons in the paper move away, creating a positive region attracted to the rod.



4. Grounding

Grounding:	Connect an object to the Earth. Earth is so large that it can absorb or supply enough charge to make any object neutral.
3 Charging by contact:	When two objects touch, the charge on both objects will (mostly) balance.

4 Charging by induction:	Combines induced charge separation and grounding. Bring a negative rod near a metal, then ground the metal. Electrons flee into ground. Then, unground - metal is now positive.

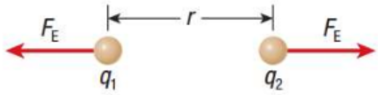


Homework: page 326: #1, 4, 7-9

SPH4U 7.2 Coulomb's Law

1. Electric force

Electric force:	F_E, force between two charged particles.
Coulomb's law:	$F_E = k\frac{q_1 q_2}{r^2}$ → always use $\lvert q_1 \rvert$, $\lvert q_2 \rvert$ (always + values).
Coulomb's constant	$k = 8.99\times10^9\ Nm^2/C^2$ (not spring constant).
direction	along the line connecting the two charges. opposite: towards each other; like: away.



Superposition principal:	the resultant (net) vector at any point equals the sum of all individual vectors at that point.

An early model of the hydrogen atom had the electron revolving around the proton, like the Earth revolves around the Sun.

a. The distance between the electron and the proton in a hydrogen atom is 5.3 x 10^{-11} m, the charge of each is 1.6 x 10^{-19} C, the mass of the electron is 9.11 x 10^{-31} kg, and the mass of the proton is 1.67 x 10^{-27} kg. Calculate the ratio of the electric force F_E to the gravitational force F_g.

$$F_E = \frac{k q_e q_p}{r^2} = \frac{(8.99\times10^9)(1.6\times10^{-19})^2}{(5.3\times10^{-11})^2} = \underline{8.193\times10^{-8}\ N.}$$

$$F_g = \frac{G m_e m_p}{r^2} = \frac{(6.67\times10^{-11})(9.11\times10^{-31})(1.67\times10^{-27})}{(5.3\times10^{-11})^2} = \underline{3.613\times10^{-47}\ N.}$$

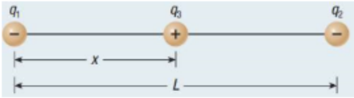
$$\frac{F_E}{F_g} = \frac{8.193\times10^{-8}}{3.613\times10^{-47}} = \underline{2.3\times10^{39}}$$

b. Determine the accelerations of the electron caused by both the electric force and the gravitational force.

$$a_E = \frac{F_E}{m_e} = \frac{8.193\times10^{-8}}{9.11\times10^{-31}} = \underline{9.0\times10^{22}\ m/s^2}$$

$$a_g = \frac{F_g}{m_e} = \frac{3.613\times10^{-47}}{9.11\times10^{-31}} = \underline{4.0\times10^{-17}\ m/s^2}$$

Two charges, $q_1 = -2.00 \times 10^{-6}$ C and $q_2 = -1.80 \times 10^{-5}$ C are separated by a distance, L, of 4.00 m. A third charge, $q_3 = +1.50 \times 10^{-6}$ C, is placed somewhere between q_1 and q_2. The net force exerted on q_3 by the other two charges is zero. Determine the location of q_3.



$F_{E1} = F_{E2}$.

$\frac{kq_1q_3}{x^2} = \frac{kq_2q_3}{(L-x)^2}$ $\quad \frac{q_1}{x^2} = \frac{q_2}{(L-x)^2}$

$q_1(L^2 - 2Lx + x^2) = q_2x^2$

$q_1x^2 - q_2x^2 - 2q_1Lx + q_1L^2 = 0$

$(q_1 - q_2)x^2 - 2q_1Lx + q_1L^2 = 0.$

$\frac{q_1 - q_2}{q_1}x^2 - 2Lx + L^2 = 0.$

$\frac{2\times10^{-6} - 1.8\times10^{-5}}{2\times10^{-6}}x^2 - 2(4) + 4^2 = 0$

$-\frac{1.6\times10^{-5}}{2\times10^{-6}}x^2 - 8x + 16 = 0$

$-8x^2 - 8x + 16 = 0$

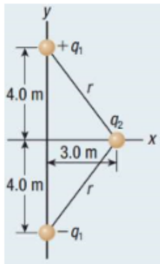
$x^2 + x - 2 = 0$

$(x-1)(x+2) = 0$

$x = 1, -2.$

$\therefore x = 1.$

Two point particles have equal but opposite charges of $+q_1$ and $-q_1$. The particles are arranged as shown. Suppose a charge q_2 is placed on the x-axis as shown. $q_1 = 5.0 \times 10^{-6}$ C, $q_2 = 1.0 \times 10^{-6}$ C, and the distance between $+q_1$ and $-q_1$ is 8.0 m measured vertically along the y-axis. Calculate the magnitude and the direction of the net electric force on q_2.



$r = \sqrt{4^2 + 3^2} = 5.0\text{ m}.$

$F_{E1} = \frac{kq_1q_2}{r^2} = \frac{(8.99\times10^9)(5\times10^{-6})(1\times10^{-6})}{5^2} = 1.798\times10^{-3}\text{ N}.$

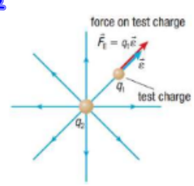
$F_{E2} = F_{E1} = 1.798\times10^{-3}\text{ N}.$

Homework: pg. 333 #1, 5-7, 9b, 10

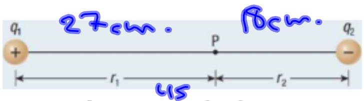
SPH4U 7.3 Electric Fields

1. Electric fields

Electric field:	$\vec{\varepsilon}$ the electric force per unit positive charge in a region
equation	$\vec{F_E} = q\vec{\varepsilon}$ $\quad \vec{\varepsilon}$ has units N/C. $\vec{\varepsilon} = \frac{kq_2}{r^2}$
test charge	always a single positive charge



Two point charges are 45 cm apart. The charge on q₁ is 3.3 x 10^{-9} C, and the charge on q_2 is -1.00 x 10^{-8} C.



a. Calculate the net electric field at point P, 27 cm from the positive charge, on the line connecting the charges.

$$\varepsilon_1 = \frac{kq_1}{r_1^2} = \frac{(8.99\times10^9)(3.3\times10^{-9})}{(0.27)^2} = 4.070\times10^2 \text{ N/C [right]}$$

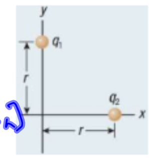
$$\varepsilon_2 = \frac{kq_2}{r_2^2} = \frac{(8.99\times10^9)(-1.00\times10^{-8})}{(0.18)^2} = 2.775\times10^3 \text{ N/C [right]}.$$

$$\boxed{\varepsilon_{Net} = \varepsilon_1 + \varepsilon_2 = 3.2\times10^3 \text{ N/C [right]}}$$

b. A new charge of +2.0 x 10^{-12} C is placed at P. Determine the electric force on this new charge.

$$\vec{F}_{E\,net} = q\vec{\varepsilon}_{Net} = (2.0\times10^{-12})(3.182\times10^3) = \underline{6.4\times10^{-9} \text{ N [right]}}.$$

Two point charges are arranged as shown. $q_1 = 4.0 \times 10^{-6}$ C, $q_2 = -2.0 \times 10^{-6}$ C, and r = 3.0 cm. Calculate the magnitude of the electric field at the origin.



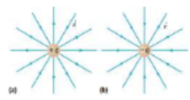
$$\varepsilon_1 = \frac{kq_1}{r^2} = \frac{(8.99\times10^9)(4.0\times10^{-6})}{0.03^2} = 3.996\times10^7 \text{ N/C [down]}$$

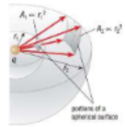
$$\varepsilon_2 = \frac{kq_2}{r^2} = \frac{(8.99\times10^9)(-2\times10^{-6})}{0.03^2} = 1.998\times10^7 \text{ N/C [right]}.$$

$$\varepsilon = \sqrt{(3.996\times10^7)^2 + (1.998\times10^7)^2} = \underline{4.5\times10^7 \text{ N/C}}.$$

2. Electric field lines

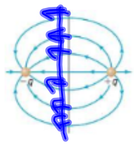
Electric field lines:	continuous lines of force that show the direction of electric force in a field.
direction	direction a positive charge moves.
inverse square law	field strength is spread across the area of a sphere.

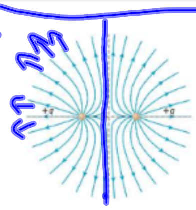


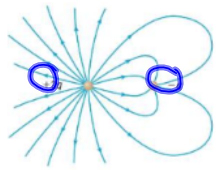


3. Electric dipoles

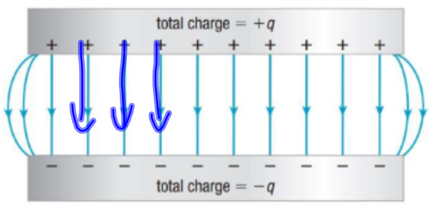
Electric dipole:	a pair of equal and opposite electric charges separated by a small distance.
field lines	point from + to −. Look like a magnet. Parallel at the midway point between charges.
Two +q charges:	center line with 0 electric field.
+2q and −q:	+2q has twice the lines as −q.







Uniform electric field:	field lines are parallel. created by placing two plates near each other with opposite charges.

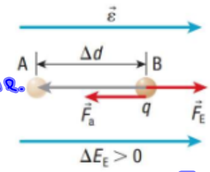


Homework: pg. 345 #2-6

SPH4U 7.4 Potential Difference and Electric Potential

1. Electric potential energy

Electric potential energy:	energy stored in an electric field that can do work on a positive particle.
equation	$\Delta E_E = -W = -F_E \Delta d \rightarrow \Delta E_E = -q\varepsilon\Delta d.$
direction	ΔE_E is positive (energy is stored) when you oppose F_E.



↳ + charge moving against ε, − particle with ε.

A charged particle moves from rest in a uniform electric field.

a. For a proton, calculate the change in electric potential energy when the magnitude of the electric field is 250 N/C, the starting position is 2.4 m from the origin, and the final position is 3.9 m from the origin.

$$\Delta E_E = -q\varepsilon\Delta d = -(1.6\times10^{-19})(250)(3.9-2.4)$$
$$= \underline{-6.0\times10^{-17}\text{ J}.}$$

b. Calculate the change in electric potential energy for an electron in the same field and with the same displacement.

$$\Delta E_E = -q\varepsilon\Delta d = -(-1.6\times10^{-19})(250)(3.9-2.4)$$
$$= \underline{+6.0\times10^{-17}\text{ J}.}$$

c. Using the law of conservation of energy, calculate the final speed of the proton in part (a), assuming that the proton starts from rest.

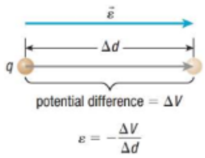
$$\Delta E_E + \Delta E_K = 0 \qquad -q\varepsilon\Delta d + \tfrac{1}{2}mv^2 = 0.$$
$$\tfrac{1}{2}mv^2 = q\varepsilon\Delta d \qquad v = \sqrt{\frac{2q\varepsilon\Delta d}{m}} = \sqrt{\frac{2(1.6\times10^{-19})(250)(1.5)}{1.67\times10^{-27}}}$$
$$= \underline{2.7\times10^{5}\text{ m/s}.}$$

d. Determine the initial speed of the electron in part (b), assuming its final speed has decreased to half of its initial speed.

$$\tfrac{1}{2}m(v_f^2 - v_i^2) = q\varepsilon\Delta d \qquad v_f = \tfrac{1}{2}v_i.$$
$$\tfrac{1}{2}m\left(\left(\tfrac{1}{2}v_i\right)^2 - v_i^2\right) = \tfrac{1}{2}mv_i^2\left(\tfrac{1}{4}-1\right) = -\tfrac{3}{8}mv_i^2$$
$$-\tfrac{3}{8}mv_i^2 = q\varepsilon\Delta d \qquad v_i = \sqrt{-\frac{8}{3}\frac{q\varepsilon\Delta d}{m}} = \underline{1.3\times10^{7}\text{ m/s}.}$$

2. Electric potential

Electric potential:	the potential energy per unit positive charge for a point in an electric field.
equation	$V = \frac{E_E}{q}$ Units: V (Volts)
Electric potential difference:	the work required per unit charge to move a positive charge in an electric field.
equation	$\Delta V = \frac{\Delta E_E}{q}$.
uniform electric field	$\Delta V = \frac{-W}{q} = \frac{-q\varepsilon\Delta d}{q} = \underline{-\varepsilon\Delta d}$ $\quad \varepsilon = -\frac{\Delta V}{\Delta d}$.



The cathode-ray tubes in old televisions use a uniform electric field to accelerate particles.

a. An electron leaves the negative plate of a cathode-ray tube (CRT) toward the positive plate. The electric potential difference between the plates is 1.5 x 10⁴ V. Using conservation of energy, calculate the final speed of the electron, assuming that it is initially at rest. The mass of an electron is 9.11 x 10⁻³¹ kg.

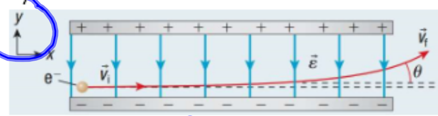
$\Delta V = \frac{\Delta E_E}{q}$. $\quad \Delta E_E = q\Delta V \quad \Delta E_E + \Delta E_k = 0$.

$q\Delta V = -\frac{1}{2}mv^2 \quad v = \sqrt{\frac{-2q\Delta V}{m}} = \sqrt{\frac{-2(-1.6\times10^{-19})(1.5\times10^4)}{9.11\times10^{-31}}} = \underline{7.3\times10^7 \text{ m/s}}.$

b. The two plates are 15 cm apart. Calculate the magnitude of the electric field.

$\varepsilon = -\frac{\Delta V}{\Delta d} = -\frac{1.5\times10^4}{0.15} = \underline{-1.0\times10^5 \text{ V/m}}.$ (or N/C).

An electron moves horizontally with a speed of 1.6 x 10⁶ m/s between two horizontal parallel plates. The plates have a length of 12.5 cm. The electric field within the plates is 150 N/C. Calculate the final velocity of an electron as it leaves the plates.



$a_y = \frac{F_{net}}{m} = \frac{F_E}{m} = \frac{q\varepsilon}{m} = \frac{(-1.6\times10^{-19})(-150)}{9.11\times10^{-31}}$

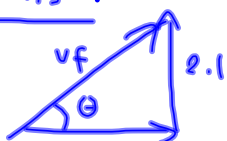
$= \underline{2.634\times10^{13} \text{ m/s}^2}.$

$v_x = \frac{L}{\Delta t} \quad \Delta t = \frac{L}{v_x} = \frac{0.125}{1.6\times10^6} = \underline{7.812\times10^{-8} \text{ s}}.$

$v_{fy} = a_y\Delta t = (2.634\times10^{13})(7.812\times10^{-8}) = \underline{2.058\times10^6 \text{ m/s}}.$

$v_f = \sqrt{(1.6\times10^6)^2 + (2.058\times10^6)^2} = \underline{2.6\times10^6 \text{ m/s}}.$

$\therefore \vec{v}_f = 2.6\times10^6 \text{ m/s [E 52° N]}.$



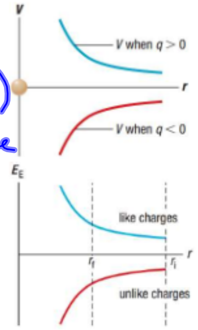
$\theta = \tan^{-1}\left(\frac{2.058}{1.6}\right) = \underline{52°}.$

Homework: pg. 354 #1-5, 7

SPH4U 7.5 Electric Potential Due to Point Charges

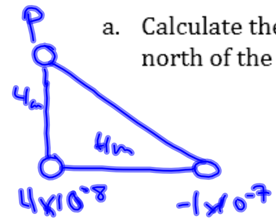
1. Electric potential due to a point charge

Electric field:	$\varepsilon = \frac{kq}{r^2}$
Electric potential due to a point charge:	$\Delta V = -\varepsilon\Delta d \quad V = \frac{kq\Delta d}{r^2} = \frac{kq}{r} \quad (\Delta d = r)$
sign	V has the same sign as q, the source charge
E_E of two point charges:	$E_E = F_E\Delta d = \frac{kq_1q_2\Delta d}{r^2} = \frac{kq_1q_2}{r} \quad (\Delta d = r).$
change in E_E	$\Delta E_E = \frac{kq_1q_2}{r_f} - \frac{kq_1q_2}{r_i} = kq_1q_2\left(\frac{1}{r_f} - \frac{1}{r_i}\right).$



A point charge with a charge of 4.00 x 10^{-8} C is 4.00 m due west from a second point charge with a charge of −1.00 x 10^{-7} C.

a. Calculate the total electric potential due to these charges at a point P, 4.00 m due north of the first charge.



$V_T = V_1 + V_2$

$V_1 = \frac{kq_1}{r_{1P}} = \frac{(8.99\times10^9)(4.00\times10^{-8})}{4} = 8.99\times10^1 \text{ J/C}.$

$\times10^2$

$V_2 = \frac{kq_2}{r_{2P}} = \frac{(8.99\times10^9)(-1.00\times10^{-7})}{5.6569} = -1.5892 \times10^2 \text{ J/C}.$

$r_{2P} = \sqrt{4^2+4^2}$
$= 5.6569\text{m}.$

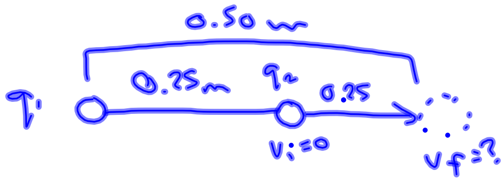
$V_T = V_1 + V_2 = (8.99\times10^1 - 1.5892\times10^2)$
$= -69.02 \text{ J/C}$

b. Calculate the work required to bring a third point charge with a charge of 2.0 x 10^{-9} C from infinity to point P.

$W = -\Delta E = -q\Delta V = q(V_\infty - V_T) = q(0 - V_T) = -qV_T.$

$W = -(2.0\times10^{-9})(-69.02)$
$= 1.4\times10^{-7} \text{ J}$

A point charge q_1 with charge 2.0×10^{-6} C is initially at rest at a distance of 0.25 m from a second charge q_2 with charge 8.0×10^{-6} C and mass 4.0×10^{-9} kg. Charge q_1 remains fixed at the origin, whereas q_2 travels to the right upon release. Determine the speed of charge q_2 when it reaches a distance of 0.50 m from q_1.



$E_E \rightarrow E_K \qquad \Delta E_K = -\Delta E_E$.

$E_{Kf} = E_{Ei} - E_{Ef}$

$\frac{1}{2}mv^2 = \frac{kq_1q_2}{r_1} - \frac{kq_1q_2}{r_2} = kq_1q_2\left(\frac{1}{r_1} - \frac{1}{r_2}\right)$

$= kq_1q_2\left(\frac{1}{0.25} - \frac{1}{0.5}\right) = kq_1q_2(2)$.

$v = \sqrt{\frac{4kq_1q_2}{m}}$

$= \sqrt{\frac{4(8.99\times10^{9})(2\times10^{-6})(8\times10^{-6})}{4\times10^{-9}}}$

$= \underline{1.2\times10^{4} \text{ m/s}}$.

2. Head-on "collision"

Two particles, a proton with charge 1.60×10^{-19} C and mass 1.67×10^{-27} kg and an alpha particle (He-4 nucleus) with charge 3.20×10^{-19} C and mass 6.64×10^{-27} kg, are separated by an extremely large distance. They approach each other along a straight line with initial speeds of 3.00×10^6 m/s each. Calculate the separation between the particles when they are closest to each other.

$E_K \rightarrow E_E \qquad \Delta E_E = -\Delta E_K$.

$E_{Ef} = E_K$:

$\frac{kq_1q_2}{r} = \frac{1}{2}(m_1+m_2)v^2 \qquad 2kq_1q_2 = r(m_1+m_2)v^2$

$r = \frac{2kq_1q_2}{(m_1+m_2)v^2} = \frac{2(8.99\times10^{9})(1.6\times10^{-19})(3.2\times10^{-19})}{(6.64\times10^{-27}+1.67\times10^{-27})(3\times10^{6})^2}$

$= \underline{1.23\times10^{-14} \text{ m}}$

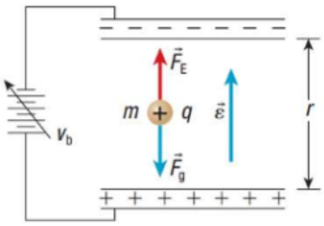
Homework: pg. 361 #1-4, 6, 8

SPH4U 7.6 The Millikan Oil Drop Experiment

1. Millikan's experiment

Fundamental physical constants:	measurable values that are constant and can be found experimentally.
Elementary charge:	Millikan believed in an elementary charge, e, that is the smallest unit of charge (electron)
Millikan's experiment	He sprayed oil drops between 2 electric plates using an atomizer, which ionized the drops. He then adjusted the voltage in the plates so $F_E = F_g$, suspending a drop in the air. He could use F_E to find q.

If q is always a multiple of some minimum, then that value is e! And he would be right.



To find q: $\vec{F_E} = q\vec{\varepsilon}$

when suspended, $F_E = F_g$

$$q\varepsilon = mg$$

$$q = \frac{mg}{\varepsilon}$$

$\because \varepsilon = \frac{\Delta V}{\Delta d}$, $q = \frac{mg\Delta d}{\Delta V_b}$, where ΔV_b is the potential difference when the drop is balanced.

→ he got m by releasing the drop, measuring v_f, finding a to get F_g and F_{air}.

Elementary

Electric charge:	$e = 1.602\times10^{-19}$ C (proton)
excess protons	$q = Ne$, when an object has N more p^+ than e^-

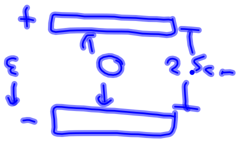
Calculate the charge on a small sphere with an excess of 3.2 x 10[14] electrons.

$q = Ne = (3.2\times10^{14})(-1.602\times10^{-19})$

$= -5.1\times10^{5}$ C.

In a Millikan-type experiment, two horizontal plates maintained at a potential difference of 360 V are separated by 2.5 cm. A latex sphere with a mass of 1.41 x 10^{-15} kg hangs between the plates, the upper plate of which is positive.

a. Is the sphere negatively or positively charged?



$F_g = F_E$.

$\vec{\varepsilon}$ points down.

$\vec{F_E}$ points up.

$\therefore$ q is negative.

b. Calculate the magnitude of the charge on the latex sphere.

$$q = \frac{mg\Delta d}{\Delta V_b} = \frac{(1.41\times10^{-15})(9.8)(2.5\times10^{-2})}{360}$$

$$= \underline{-9.596\times10^{-19}\,C}$$

c. Determine the number of excess ~~of~~ or deficit particles on the sphere.

$q = Ne$

$$N = \frac{q}{e} = \frac{-9.596\times10^{-19}}{-1.602\times10^{-19}} = \underline{\underline{6}}.$$

Quarks:	fundamental particles with charge $\frac{1}{3}e$ or $\frac{2}{3}e$.
subatomic particles	all have a whole-number multiple of e for charge, even though they're made up of quarks.

Homework: pg. 365 #1-3, 5-7