 Name Hayden Fuller Section 6

21A – Charge and Polarization

Reading: Lecture Notes 1. Young and Freedman Section 21.02.
Recommended Viewing: https://www.khanacademy.org/science/physics/electric-charge-electric-force-and-voltage (Click on "Conductors and Insulators")

Basic facts:

- All materials have a nearly equal balance between positive (proton) and negative (electron) charge. Protons and electrons have equal and opposite charge. The electron has a charge of $-1.6\text{x}10^{-19}$ Coulombs. A typical solid has about 10^{28} electrons and protons per cubic meter.
- Charge can move rapidly (< microseconds) over large distances (meters) in a conductor. Charge cannot move rapidly over large distances in insulators. Typical motion in insulators is just over atomic scale distances.
- Coulomb's Law applies. ($F = kqQ/r^2$)
- When you "ground" an object you are connecting it to a pipe in the ground via a conducting wire. Charge can flow to and from "ground".
- When two dissimilar materials are rubbed against one another, charge is exchanged and usually one material becomes positive and the other becomes negative.
  (When a glass rod is rubbed with silk, the rod becomes positive.)

Thinking and calculating:

1. If two excess electrons are placed on a long straight copper wire, where are they most likely to be found?

(Anywhere? On one end? On opposite ends?) Explain your answer.

This is why most charge flows on the surface of a wire

Ans. Opposite ends because like charges repel.

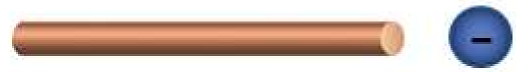
2. If 10^6 electrons are placed on a long straight copper wire, how will they be distributed?

(Anywhere? On one end? On opposite ends? Evenly throughout the volume? Over the outside surface?) Explain your answer.

Ans. Over the outside surface

Again, like charges repel, so the surface is the best way to maximize distance

3. The conducting rod to the right has no net charge. A negatively charged object is brought near the right end of the rod. What happens to electrons in the conducting rod?



The electrons shift to the left to maximize the distance from the negatively charged object

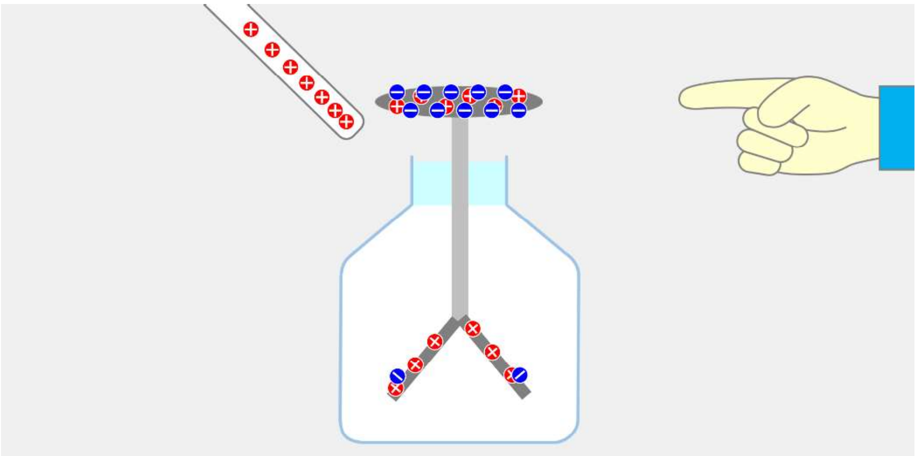
4. Would the charged object exert a force on the neutral rod? Ans. (Yes/No): Yes

If yes, in what direction is the force on the rod? (Attract or Repel?) Ans. (Attract/Repel) Attract

Explain. They attract because though the negative end of the rod mostly cancels out the positive end, the negative end is further away and therefore has a smaller effect, resulting in a net attractive force.

Doing Science – Simulation:

An electroscope has thin conducting foil leaves hung from a conducting rod. If the leaves are similarly charged they repel one another, indicating the presence of net charge on the leaves.



You will explore the behavior of an electroscope using the simulation:
https://javalab.org/en/electroscope_en/

The conceptual focus is on how charge moves on a conductor when charge is brought near it.
In this simulation the hand acts as a grounded conductor. Charge can flow from the hand to and from ground. The rod can be charged with positive or negative charge.

5. Perform the operations in the table below in the sequence instructed and record i) the number of positive and negative charges and the net charge on the knob of the electroscope; ii) the number of positive and negative charges and the net charge on the leaves of the electroscope; iii) the net charge on the whole electroscope; iv) whether the leaves are separated or together.

   Initial situation: Start with the rod positively charged and far from the electroscope. Touch the hand to the electroscope. Move the hand back away from the electroscope.

	+	-	net
knob:	6	6	0
leaf:	6	6	0
total:	12	12	0

position: together

Situation	Observations **i) Charges and net charge on knob** **ii) Charges and net charge on leaves** **iii) Net charge on whole electroscope.** **iv) Position of leaves.**
Example: (not correct) Initial condition with rod and hand far from knob.	i) 100 positive, 100 negative; net charge=0 ii) 200 positive, 200 negative; net charge=0 iii) net charge=0 iv) leaves together
a) Rod positive; Rod near; Hand far away.	+ - net knob: 6 10 -4 leaf: 6 2 4 total: 12 12 0 position: apart
b) Rod positive; Rod far; Hand touching.	+ - net knob: 6 6 0 leaf: 6 6 0 total: 12 12 0 position: together
c) Rod positive; Rod near; Hand touching.	+ - net knob: 6 13 -7 leaf: 6 6 0 total: 12 19 -7 position: together
d) Rod positive; Rod near; Hand moved away.	+ - net knob: 6 13 -7 leaf: 6 6 0 total: 12 19 -7 position: together
e) Rod positive; Rod far; Hand moved away.	+ - net knob: 6 9 -3 leaf: 6 10 -4 total: 12 19 -7 position: apart
f) Rod positive; Rod far; Hand touching	+ - net knob: 6 6 0 leaf: 6 6 0 total: 12 12 0 position: together
g) Rod positive; Rod far; Hand moved away.	+ - net knob: 6 6 0 leaf: 6 6 0 total: 12 12 0 position: together
h) Rod positive Rod near; Hand far.	+ - net knob: 6 10 -4 leaf: 6 2 +4 total: 12 12 0 position: apart

i) Explain your observations for situation "h" in the table above using the concepts of charge carriers in conductors, the sequence of situations, and Coulomb's Law as discussed in Chapter 21.02 of your textbook.

In previous steps, the device was grounded while the rod was far, resulting in a net 0 charge in the system, and the system is closed because the hand isn't touching.When the positive rod is moved close, it attracts electrons, pulling them up from the leafs. This leaves the leafs with a positive charge, making them repel eachother.

Doing Science – Hands-on Experiment

6. Place a metal beverage container, on its side, on the tabletop. Charge one of the insulating rods by rubbing it. Bring the rod near the can. Is the can attracted to, repelled by, or unmoved by, the charged rod? Repeat the experiment with other different rod materials and other cloth types. Write down your observations.

Rod Material	Rubbing Material	Attraction/Repulsion/No Force
a) PVC	Fur (or your hair, or a piece of paper…)	Attraction
b) PVC	Rayon (or whatever the pastel green fabric is in the lab)	Attraction

c) Explain your observations above using the concepts of charge carriers in conductors and Coulomb's Law. (A free-body sketch would be great!)

The rod and fur/rayon exchanged electrons when rubbed together. Because the rod had a net charge, we saw the same effect as part 4, and they were attracted.

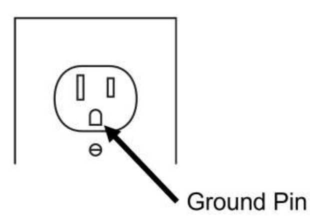
-----------can----------- ---rod---

- - - - - - + + + + + + - - - - - -

<---- -------> <---

(or vice versa, it doesn't matter and
I don't know what charge the rod has)

7. **Optional**: Get an electroscope from the cart at the front of your lab classroom; it is like the one used in the simulation in part 5 above, although instead of a round knob at the top it has a flat conducting plate. Use the rayon fabric (or, pieces of paper) to charge the PVC rod, like you did in part 6 above. To ground the electroscope, instead of using your hand (as in the simulation), use one of the wires stored at the front of your lab room and connect it to the grounding pin of a power outlet at your lab station (see the figure at right); touching the grounding wire to any metal part of the electroscope will provide a path for charge to ground. Write your observations of the behavior of the electroscope needle/leaves in the right column for each situation. Note that each item is a part of a sequence – that is, for example, (d) follows after having done (c), which comes after (b), etc.



a) Rod charged & near; Grounding wire far away.	
b) Rod charged & far away; Grounding wire touching.	
c) Rod charged & near; Grounding wire touching.	
d) Rod near; Grounding wire now moved away.	
e) Rod moved far away; Grounding wire far away.	
f) Rod near; Grounding wire far; then move rod away	
g) Rod far; Grounding wire now touching	
h) Rod far; Grounding wire moved away.	
i) Rod near; Grounding wire far.	
j) Rod touching upper plate; Grounding wire far away.	
k) Rod moved far away; Grounding wire still far away.	

21B – Quantitative Practice Applying Coulomb's Law

Reference and Reading: Young and Freedman Chapter Section 21.03

Coulomb's Law describes the force between charged particles. In symbolic form the force exerted on particle 0 by particle 1 is given by

$$\vec{\boldsymbol{F}}_{1\ on\ 0} = k\frac{q_0 q_1}{r_{10}^2}\frac{\vec{\boldsymbol{r}}_{10}}{|\vec{\boldsymbol{r}}_{10}|} \qquad \textbf{Equation 21a}.$$

where $\vec{\boldsymbol{r}}_{10}$ is the vector pointing from particle 1 to particle 0, q_0 and q_1 are the charge values for the two charges (including sign), and k is a constant.

1. Complete the sketch below of the physical situation represented by equation 21a when both charges are positive. Draw a Free Body Diagram for particle 0 (which we will designate as the left hand particle). Add and label the vector $\vec{r}_{10}$ to your sketch.

2. What is the relationship between k and the electric permittivity in the front of your textbook? What is the numerical value of k and its units in the SI system?

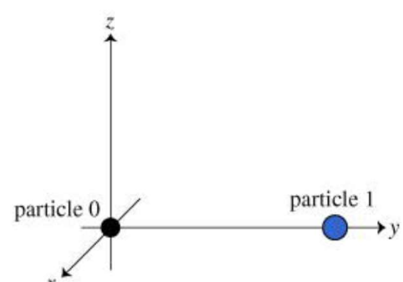
   9.0x10^9 N*m^2/C^2
   k is the ratio of electric permitivity, how much charge can be stored

3. How does equation 21a change if you want to find the force exerted on particle 1 by particle 0? (Rewrite it and explain the change.)

   F01=-F10=-k(q0q1)/(r10^2)*(r10)/(|r10|)

   It's just negated

4. In the figure to the right, particle 1 has a negative charge q_1 = -9.00 nC and lies at the position P(0, 10.00, 0) with units in meters. Particle 0 has charge magnitude $|q_0|$ = 4.00 nC, but the sign is unknown. The direction of the force on particle 1 is to the left.



   a) What is the sign of charge q_0? Explain.

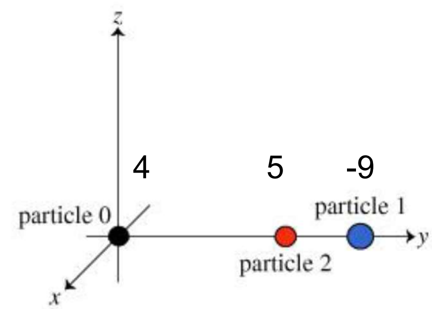
   Positive. Since p1 is experiencing a leftward foece, they must be attracted, and they must have opposite charges.

b) Rewrite equation 21a, putting numbers in the place of variables and including sign and vector direction for the force on particle 0.

F10=9x10^9N*m^2/C^2*(4nC*-9nC)/(((10j)m)^2)
=9x10^9*(4x10^-9*-9x10^-9)/100j N
=0i+(-3.24x10^-9)j+0k

c) What is the magnitude of the force on charge 0? F= 3.24x10^-9N

5. Consider the same case, but with the addition of particle 2 at some point $P(0, y', 0)$ between particles 0 and 1. Particle 0 experiences an attraction from particle 1 and a repulsion to particle 2. Particle 2 has charge $|q_2| = 5.00$ nC.



a) What is the sign of charge q_2?

Positive

b) For what value of y' does particle 0 experience a net force of zero?
k(4nC*9nC)/(10^2)=k(4nC*5nC)/(r^2)
9/100=5/r^2
9r^2=500
r^2=500/9
r=sqrt(500/9)
r=7.454

7.454m

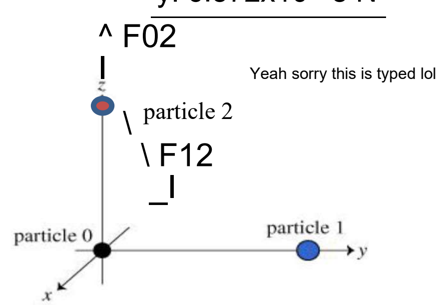
c) For this position, find the x and y components of the total force on particle 2.

F=9x10^9*(4x10^-9*5x10^-9)/(7.454^2j)-9x10^9*(5x10^-9*-9x10^-9)/(2.546^2j)

F=(0i+6.572x10^-8j+0k)N

x: 0 y: 6.572x10^-8 N

Consider the case when the charged particle 2 from question 5 is now located at point $P(0, 0, 1.80)$ on the z-axis.



a) Draw two vectors representing the forces on particle 2 due to each of the two charges 0 and 1.

b) What is the magnitude of F_{0on2}?

F02=9x10^9*(4x10^-9*5x10^-9)/(1.8^2) N
=5.56x10^-8 N

F = 5.56x10^-8 N

c) What is the magnitude of F_{1on2}?

r12=sqrt(10^2+1.8^2)=10.161m
F12=9x10^9*(5x10^-9*-9x10^-9)/(10.161^2) N
=3.923x10^-9 N

F = 3.923x10^-9 N

d) What angle θ does $\vec{F}_{1on2}$ make with the +y-axis?

theta=arctan(1.8/10)=.178 rad(=10.2 deg)

θ = .178 rad