Electrostatics and Coulomb's Law

Outcomes and Summary Notes

Explain the behavior of electric charges, using the laws that govern electrical interactions.

- *Explain electrical interactions in terms of the law of conservation of charge*
- *Explain electrical interactions in terms of the repulsion and attraction of charges*
- *Compare the methods of transferring charge (friction, induction, conduction)*
- *Explain , qualitatively, the distribution of charge on the surfaces of conductors and insulators.*
- *Explain, qualitatively, the principles pertinent to the Coulomb torsion balance experiment.*
- *Apply Coulomb's law, quantitatively, the magnitude and direction of the electric force on a point charge due to 2 or more point charges in a plane.*
- *Apply Coulomb's, quantitatively, to analyze the interaction of 2 point charges.*
- *Compare, qualitatively and quantitatively, the inverse square relationship as it is expressed by Coulomb's law and by Newton's law of gravity.*

Summary Notes:

Electric Theory of Matter

Matter is made up of two types of charges: positive and negative. An electron carries a negative charge, and a proton carries a positive charge. Both types of charge have the same magnitude (1.60×10^{-19} C). For all interactions involving electric charges, the net charge of the system must remain the same (conservation of charge).

Neutral matter contains equal numbers of positive and negative charges. In solids, only the negative charges (electrons) can move. The positive charges (protons) are fixed in the nucleus. In electrical interactions within a closed system, the appearance of a + charge (loss of electrons) is matched by the appearance of a negative charge (gain of electrons).

Behavior of Charges in Matter

Like charges (eg + and +) exert repulsive forces on each other. Unlike charges (+ and -) exert attractive forces on each other. Electrons move easily through conductors and with difficulty (or not at all) through insulators.

Electric Charge is measured in Coulombs

In most lab work you would do at school, or even just in everyday life, charges are usually in this range of about 10^{-6}C (1 μC).

- Only really special cases have charge of 1 C or 2 C... things like a lightning bolt!
- Common subatomic particles can have a charge, as shown in the following table.

Particle	*Charge*
Electron (e_-)	- 1.60e-19 C
Proton (p_+)	+1.60e-19 C
Neutron (n_0)	0 C

Particle Charge

- A charge of 1.60e-19 is so important, that it is called an **elementary charge**, and its symbol is just the letter "**e**".
  - This is not "e" for electron, since there is no negative sign on the symbol.
  - If it was written as e- with the little minus sign on it, then it would refer to an electron.
  - You will find the value of the elementary charge on your data sheet.
- That means that if something has a charge of -1 C, it has a LOT of electrons...

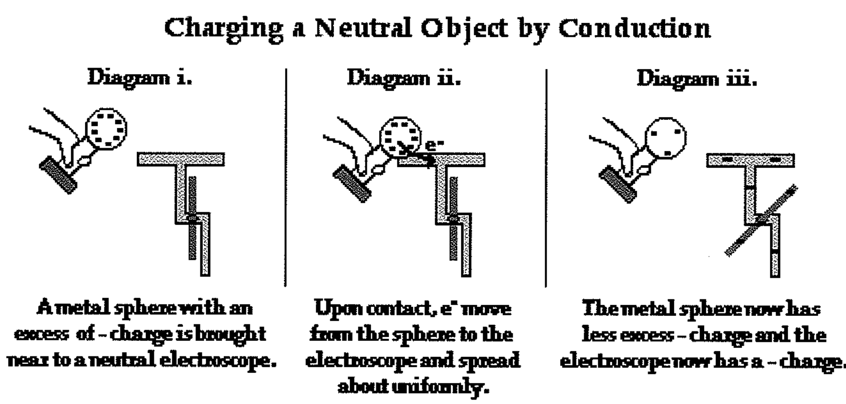
1*C x* 1*electron*
1.60e-19*C* =6.25e18 *electrons*

- Although day to day objects can have this (or more!) electrons, keep in mind that they will often have an equal number of protons to cancel out the charges, for a net charge of zero.

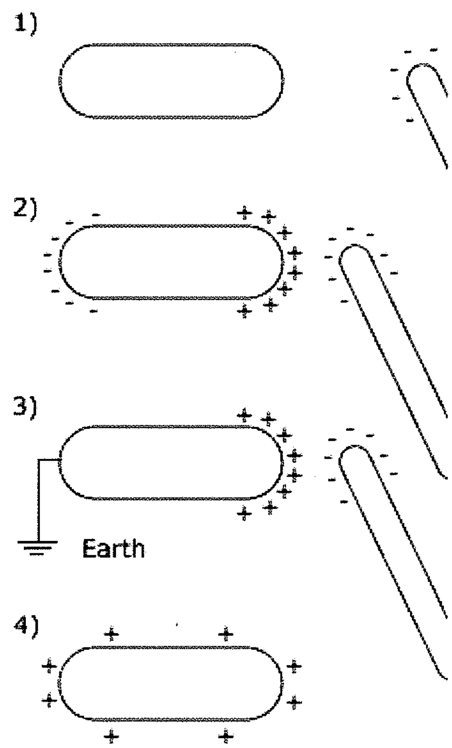
Methods for Transferring Charge

Sometimes when different materials are rubbed together, the electrons from one material may move to the other. One material is then + charged and the other is – charged. For example, when ebonite, a black plastic, is rubbed with fur, the ebonite becomes – charged and the fur becomes + charged. This is called **charging by friction.**

When a charged object touches a neutral one, charge transfers to the neutral one until both objects are charged with the same amount of charge. This is called **charging by conduction. Conduction produces identically charged objects.**



The presence of a charged object held near a neutral object causes a rearrangement or polarization of charge on the neutral object.. This is called **charging by induction.** This is shown in diagrams 1 and 2 below.

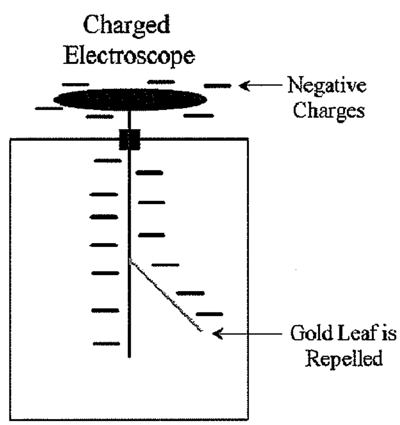


A neutral object that is connected to the Earth's surface is grounded. If a charged object is placed near a grounded object and the ground is removed while the object is still near, the neutral object becomes charged opposite to the charged object. This is called **charging by induction with a ground.** This is shown in steps 3 and 4 above. **Chargin by inductin with a ground produces oppositely charged objects.**

Distribution of Charge on Conductors and Insulators:

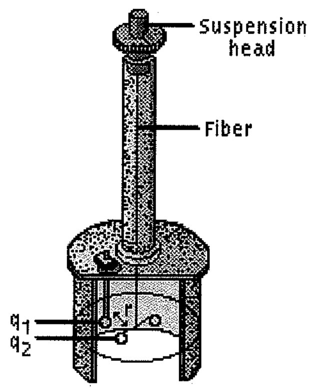
Any charge placed on an insulator will stay where it is since electrons cannot flow through the insulator. Charges placed on a conductor can move, and they will distribute themselves as far from each other as they can, since they repel one another. As a result, the excess charge is found on the outside surface of a conductor. The pointier the surface is, the more charge that collects there (pointy surfaces have a large surface area).

An electroscope is a device that detects excess charge. Electroscopes have moving leaves that open when they are charged.



Coulomb's Law

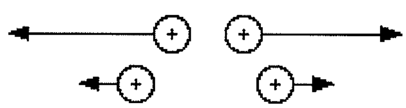
Charles Coulomb applied a charge to one end of a torsion balance. He then placed a second charge q_2 near q_1. The repulsion or attraction between the charges caused the torsion balance to twist (a torque is a twisting force).



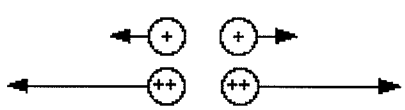
By measuring the angle of twist, Coulomb determined the force of repulsion or attraction between the charges. He also found a relation between the force, distance between the 2 charges and magnitude of the charges resulting in the following equation:

$$F_{el} = k\,(q_1 \times q_2) / R^2$$

where Fel is the electric force, q_1 and q_2 are the charges, and R is the distance between the charges. k is the proportionality constant (in your data book), and depends on the material separating the charges.



double the distance, force drops to 1/4



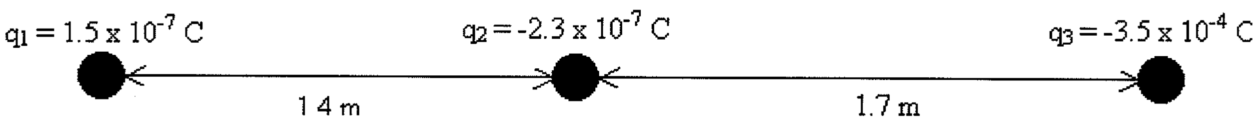
double the charge,
force increases by factor of 4

Electric Force due to more than Two Charges

Coulomb's law can be presented in scalar form as well as in vector form. Coulomb's law addresses the force between only TWO charges, so the force is either attractive or repulsive depending on the sign of the charges. The force will always act in the direction of the line connecting the two charges. Coulomb's law is used to calculate the MAGNITUDE of the electric force.

Force however is a vector quantity, so the direction is important. The direction is determined by analyzing the signs of the charges (+ or -) and the positions of the charges.

See examples below (Example 1: 1 dimensional)



The following three charges are arranged as shown. **Determine** the net force acting on the charge on the far right (q3).

Calculate the force between one pair of charges, then the next pair of charges, and so on until you have calculated all the possible combinations for that particular question. Remember, if you've calculated the force of q1 on q2, then you also know the force of q2 on q1 ... they're the same!

Step 1: Calculate the force that charge 1 exerts on charge 3...

It does **NOT** matter that there is another charge in between these two... ignore it! It will not effect the calculations that we are doing for these two. Notice that the **total** distance between q1 and q3 is 3.1 m , since we need to add 1.4 m and 1.7 m .

Fe= *k q*1 *q*3

r 2 =8.99e9 *x* 1.5e-7 *x* 3.5e-4

3.1^2 =4.9e-2 *N*

Since q1 is positive and q3 is negative, there will be a force of attraction between them. We know that q1 is pulling charge q3 left, while charge q3 is pulling q1 to the right. Since all I care about is what is happening to q3 , all I really need to know from this is that q3 feels a pull towards the left of 4.9e-2 N.

Step 2: Calculate the force that charge 2 exerts on charge 3...
Same thing as above, only now we are dealing with two negative charges, so the force will be repulsive.

Fe=k q2 q3
r 2 =8.99e9 *x* 2.3e-7 *x* 3.5e-4
1.72 =2.5e-1 *N*
Since we know that the force is repulsive between these two charges, q2 is pushing q3 to the right with a force of 2.5e-1 N. Again, we only care about what is happening to q3.

Step 3: Add you values to find the net force.
- We now need to add the two values from above, being careful about directions. Everything has to be based on the directions of the forces acting on q3... we don't care about the other charges anymore.
  - The 4.9e-2 N force is pulling q3 to the left, which is the direction we usually call negative, so we'll put the negative sign on it. **Fe = -4.9e-2 N.**
  - We also have a 2.5e-1 N force pushing to the right. We usually call a vector pointing right positive, so we'll do that here also. **Fe = +2.5e-1 N**

FNET = -4.9e-2 N + 2.5e-1 N = 2.0e-1 N
- Since the answer is positive, we know that the net force acting on q3 is **2.0e-1 N [right]**.

Multiple Charges in 2 Dimensions
Doing questions with charges in multiple dimensions are the same as the question you did above. You just need to be careful about directions and use vectors to figure out the problem.
- Figure out all the individual forces between pairs of charges (just like in the 1-D problem).
- Then pay attention to the directions of the forces and calculate the net force as you would any vector problem. This will usually (but not necessarily always) involve a triangle vector diagram. See # 19 page 94 of your workbook for an example.

Comparing Coulomb's Law to Newton's Law of Gravity:

It is interesting to note the similarities between the forces that act between masses and those that act between charges. In both cases the equations are of the same form.

$$F_g = \frac{Gm_1m_2}{R^2}$$

Newton's law of gravity

$$F_e = \frac{kq_1q_2}{R^2}$$

Coulomb's electric force law

While the causes of both forces differ, there is an obvious similarity in the relationships between the magnitudes of the forces and distances separating the objects producing those forces. In both cases, the force diminishes as the distance between the objects increases. In other words, the forces are inversely proportional to the square of the distance between the objects.

$F \infty 1 / R^2$

Compare the magnitudes of the two constants k and G. the ratio of k/G shows approximately how much larger electrical forces are compared to gravitational forces.

k/G $8.99 \times 10^9 / 6.67 \times 10^{-11} = 1.35 \times 10^{20}$

This is an enormous difference. You can see this in action by used a statically charged comb to pick up bits of paper. The electrical force is much stronger than the gravity force.