22 Electric Charges and Forces

22.1 The Charge Model

Note: Your answers in Section 22.1 should make *no* mention of electrons or protons.

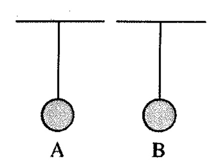
1. Can an insulator be charged? If so, how would you charge an insulator? If not, why not?

An insulator can be charged. Plastic is an insulator.
A plastic rod can be charged by rubbing it with wool.

2. Can a conductor be charged? If so, how would you charge a conductor? If not, why not?

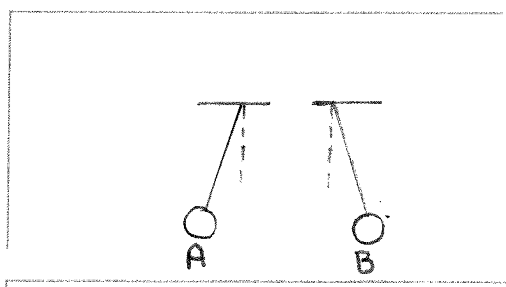
A conductor can be charged. A conductor can be charged by touching it with another charged object.

3. Lightweight balls A and B hang straight down when both are neutral. They are close enough together to interact, but not close enough to touch. Draw pictures showing how the balls hang if:



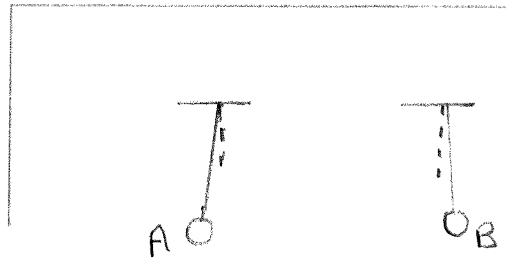
a. Both are touched with a plastic rod that was rubbed with wool.

A and B move away from each other. Angles from vertical are the same if masses are equal.

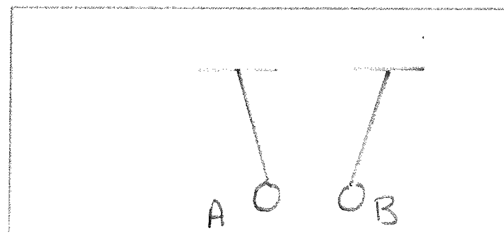


b. The two charged balls of part a are moved farther apart.

A and B move away from each other. Angles from vertical are smaller now.

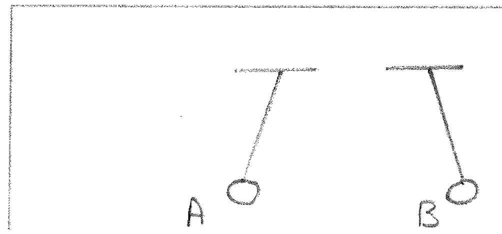


c. Ball A is touched by a plastic rod that was rubbed with wool and ball B is touched by a glass rod that was rubbed with silk.



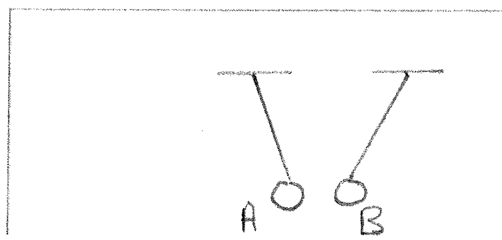
d. Both are charged by a plastic rod, but ball A is charged more than ball B.

Angles from verticals are the same if masses are the same. (Equal and opposite forces.)

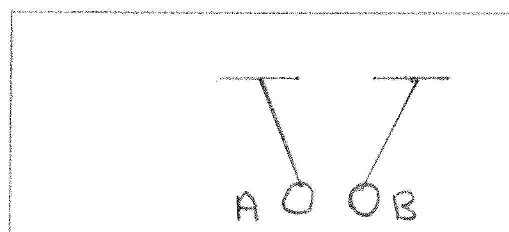


e. Ball A is charged by a plastic rod. Ball B is neutral.

Angles from verticals are the same if masses are the same.



f. Ball A is charged by a glass rod. Ball B is neutral.



4. Four lightweight balls A, B, C, and D are suspended by threads. Ball A has been touched by a plastic rod that was rubbed with wool. When the balls are brought close together, without touching, the following observations are made:

- Balls B, C, and D are attracted to ball A.
- Balls B and D have no effect on each other.
- Ball B is attracted to ball C.

What are the charge states (glass, plastic, or neutral) of balls A, B, C, and D? Explain.

Ball A picked up "plastic charge" by contact.
Ball B and D are both neutral since they neither attract nor repel each other.
Ball C must have "glass charge" since it is attracted to both Ball A ("plastic charge") and a neutral object.

5. Charged plastic and glass rods hang by threads.

   a. An object repels the plastic rod. Can you predict what it will do to the glass rod? If so, what? If not, why not? Explain.

   Two like charges repel each other, so the object must also have "plastic charge". The glass rod ("glass charge") will be attracted to the object.

   b. A different object attracts the plastic rod. Can you predict what it will do to the glass rod? If so, what? If not, why not? Explain.

   You cannot predict what will happen. The object could be either neutral or have "glass charge". If neutral, the object will attract the glass rod, but if charged, the object will repel the glass rod.

6. After combing your hair briskly, the comb will pick up small pieces of paper.

   a. Is the comb charged? Explain.

   Yes. A neutral comb would have no effect on the pieces of paper that are not charged.

   b. How can you be sure that it isn't the paper that is charged? Propose an experiment to test this.

   Place a neutral object (such as a comb that has never been used) near the pieces of paper. If the paper is attracted to the object, then the paper is charged.

   c. Is your hair charged after being combed? What evidence do you have for your answer?

   Yes, some strands of hair will be charged, and you will observe these hairs "fly away" (repel each other).

7. When you take clothes out of the drier right after it stops, the clothes often stick to your hands and arms. Is your body charged? If so, how did it acquire a charge? If not, why does this happen?

Your body is initially neutral, but the charged clothes are attracted to your body. Your body may become charged when the clothes make contact.

8. You've been given a piece of material. Propose an experiment or a series of experiments to determine if the material is a conductor or an insulator. State clearly what the outcome of each experiment will be if the material is a conductor and if it is an insulator.

Place two metal spheres close together and use the unknown material to connect them together. Charge a plastic rod by rubbing and then touch it to one of the spheres. Afterwards, if the other sphere can pick up small pieces of neutral paper, then the material is a conductor. If not, then the material is an insulator.

9. Suppose there exists a third type of charge in addition to the two types we've called glass and plastic. Call this third type X charge. What experiment or series of experiments would you use to test whether an object has X charge? State clearly how each possible outcome of the experiments is to be interpreted.

An object has X charge if <u>both</u> of these observations occur:

① The object attracts both a charged plastic rod and a charged glass rod.

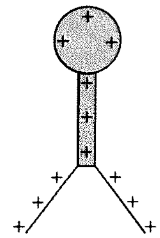
② Any two pieces of the object that satisfy ① must repel each other.

Note, observation ② is needed to rule out the possibility that the object is neutral.

22.2 Charge

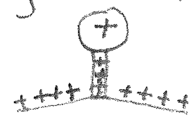
22.3 Insulators and Conductors

10. A positively charged electroscope has separated leaves.



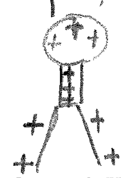
a. Suppose you bring a positively charged rod close to the top of the electroscope, but not touching. How will the leaves respond? Use both charge diagrams and words to explain.

The positively charged rod will attract negative charges on the electroscope pulling more negative charge up from the leaves.
The leaves will separate more.



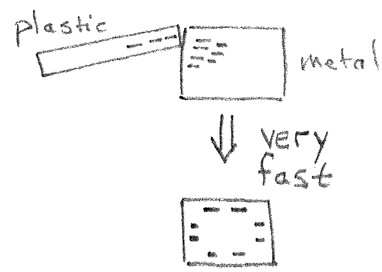
b. How will the leaves respond if you bring a negatively charged rod close to the top of the electroscope, but not touching? Use both charge diagrams and words to explain.

The negatively charged rod will repel negative charges to the bottom of the electroscope, making the leaves less positively charged.
The leaves will move closer together.



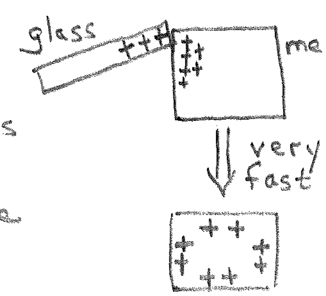
11. a. A negatively charged plastic rod touches a neutral piece of metal. What is the final charge state (positive, negative, or neutral) of the metal? Use both charge diagrams and words to explain how this charge state is achieved.

The metal is negatively charged by contact. This excess charge quickly spreads out over the surface of the metal.

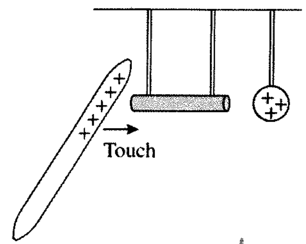


b. A positively charged glass rod touches a neutral piece of metal. What is the final charge state of the metal? Use both charge diagrams and words to explain how this charge state is achieved.

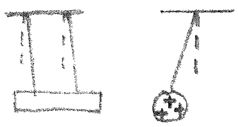
The metal is positively charged by contact as electrons flow from the metal on to the glass. Electrons move quickly such that excess positive charge spreads out over the surface of the metal.



12. A lightweight, positively charged ball and a neutral rod hang by threads. They are close but not touching. A positively charged glass rod touches the hanging rod on the end opposite the ball, then the rod is removed.



a. Draw a picture of the final positions of the hanging rod and the ball if the rod is made of glass.

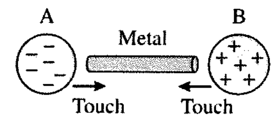


The hanging glass rod did not pick up charge by merely touching it with a charged object. But the neutral rod and the charged ball are attracted to each other. The angles from the verticals are likely small.

b. Draw a picture of the final positions of the hanging rod and the ball if the rod is metal.

The metal gives up some electrons when contact with the charged rod is made. The positively charged metal and ball repel each other.

13. Two oppositely charged metal spheres A and B have equal quantities of charge. They are brought into contact with a neutral metal rod.

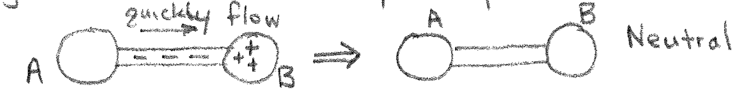


a. What is the final charge state of each sphere and of the rod?

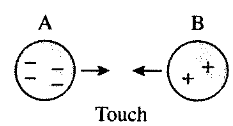
The final charge state of each sphere and of the rod is neutral.

b. Give a microscopic explanation, in terms of fundamental charges, of how these final states are reached. Use both charge diagrams and words.

Electrons in metal move freely until electrostatic equilibrium (no net force on any charge) is achieved. So, the excess electrons in sphere A quickly travel through the metal rod and pair up with excess positive charges in sphere B.

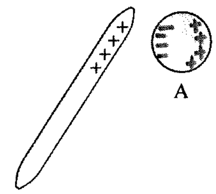


14. Metal sphere A has 4 units of negative charge and metal sphere B has 2 units of positive charge. The two spheres are brought into contact. What is the final charge state of each sphere? Explain.



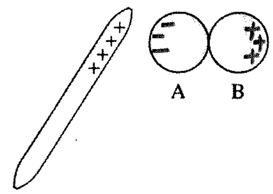
Once the two spheres touch, they become essentially one conductor. The overall net charge is $-4+2=-2$ and spreads out over the surfaces of the spheres. Each sphere has 1 unit of negative charge.

15. a. Metal sphere A is initially neutral. A positively charged rod is brought near, but not touching. Is A now positive, negative, or neutral? Explain.



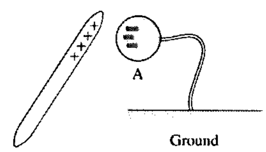
A remains neutral but becomes polarized (− and + charges are separated).

b. Metal spheres A and B are initially neutral and are touching. A positively charged rod is brought near A, but not touching. Is A now positive, negative, or neutral? Explain.



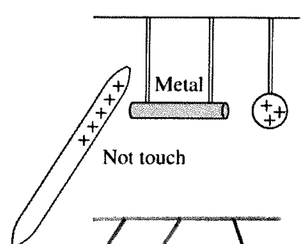
Sphere A is negative, but the combined conductor of both spheres in contact is neutral and polarized (as shown).

c. Metal sphere A is initially neutral. It is connected by a metal wire to the ground. A positively charged rod is brought near, but not touching. Is A now positive, negative, or neutral? Explain.



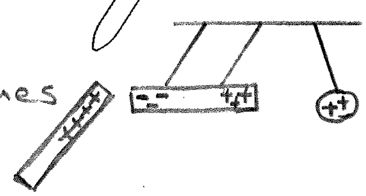
Sphere A is negative as the result of electrons from the ground being pulled onto the sphere.

16. A lightweight, positively charged ball and a neutral metal rod hang by threads. They are close but not touching. A positively charged rod is held close to, but not touching, the hanging rod on the end opposite the ball.



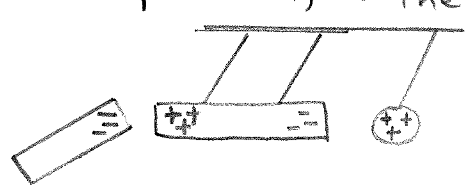
a. Draw a picture of the final positions of the hanging rod and the ball. Explain your reasoning.

Assume the excess charge on the rod is much greater than the excess charge on the ball. The metal is attracted to the rod and becomes polarized. The ball swings away since positive charges repel each other.

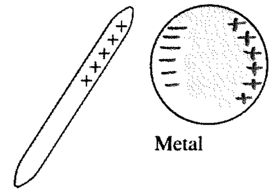


b. Suppose the positively charged rod is replaced with a negatively charged rod. Draw a picture of the final positions of the hanging rod and the ball. Explain your reasoning.

Assume the magnitude of excess charge on the rod is much greater than that on the ball. The metal is attracted to the rod and becomes polarized. But now the polarization is the reverse of that found in part (a), so the ball swings toward the metal.

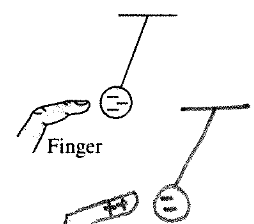


17. A positively charged rod is held near, but not touching, a neutral metal sphere.
   a. Add plusses and minuses to the figure to show the charge distribution on the sphere.
   b. Does the sphere experience a net force? If so, in which direction? Explain.



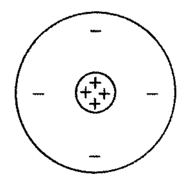
Yes, the net force on the metal is towards the rod (to the left). The rod and metal exert an equal (but opposite) electric force on each other. (The negative side of the metal is closer to the rod and experiences a larger force than the positive side.)

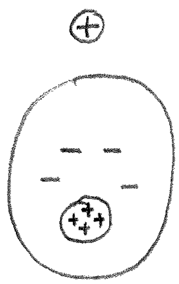
18. If you bring your finger near a lightweight, negatively charged hanging ball, the ball swings over toward your finger. Use charge diagrams and words to explain this observation.



Your body is a conductor. Negative charges in your finger are repelled by the negatively charged ball, leaving an excess of positive charges on your fingertip. (Your body remains neutral.)

19. The figure shows an atom with four protons in the nucleus and four electrons in the electron cloud.
   a. Draw a picture showing how this atom will look if a positive charge is held just *above* the atom.





The four electrons are still in motion about the nucleus, but the electron cloud is now elongated towards the added positive charge.

   b. Is there a net force on the atom? If so, in which direction? Explain.

Yes, the net force on the atom is up. The atom and the additional charge exert an equal (but opposite) electric force on each other. The atom is attracted to the additional charge since the electrons in the atom experience a larger force than the positive nucleus (farther away from the added positive charge).

22.4 Coulomb's Law

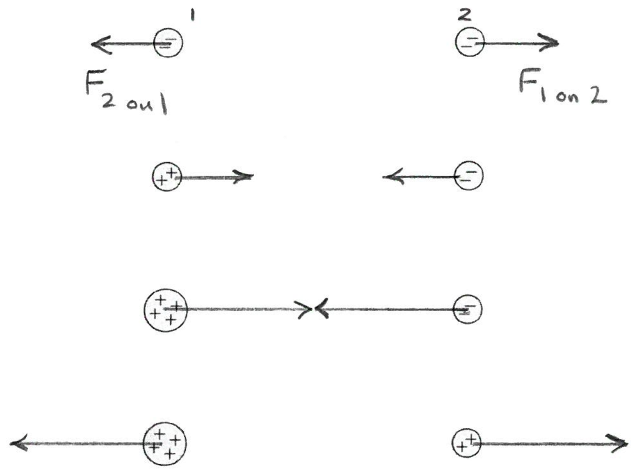
20. For each pair of charged particles, draw a force vector on each particle to show the electric force on that particle. The length of each vector should be proportional to the magnitude of the force. Each + and − symbol represents the same quantity of charge.

a.

b.

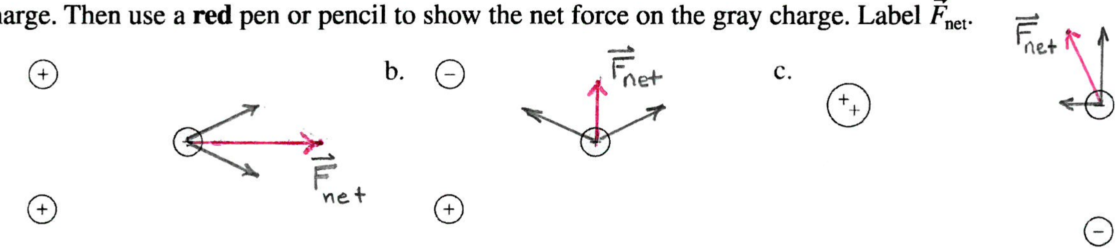
c.

d.



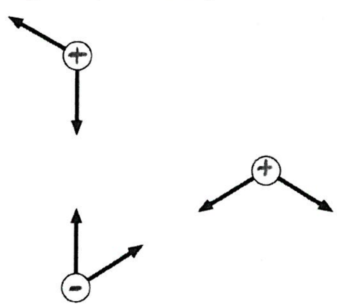
21. For each group of charged particles, use a **black** pen or pencil to draw the forces acting on the gray charge. Then use a **red** pen or pencil to show the net force on the gray charge. Label $\vec{F}_{net}$.

a. b. c.

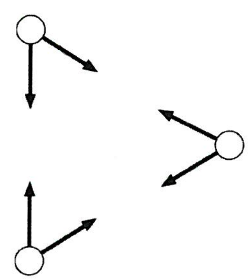


22. Can you assign charges (positive or negative) so that these forces are correct? If so, show the charges on the figure. (There may be more than one correct response.) If not, why not?

a.



b.



Not correct. Three different mutually attractive charges have never been observed.

c.

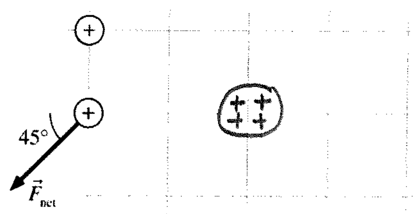
Not correct Forces must be equal in size.

d.

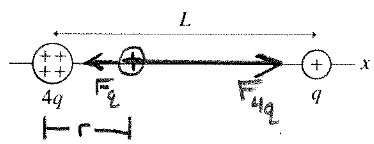
23. Draw a + on the figure below at the position or positions where a proton would experience no net force.

24. Draw a − on the figure below at the position or positions where an electron would experience no net force.

25. The gray positive charge experiences a net force due to two other charges: the +1 charge that is seen and a +4 charge that is not seen. Add the +4 charge to the figure at the correct position.



26. Positive charges $4q$ and q are distance L apart. Let them be on the x-axis with $4q$ at the origin.
PSS 22.1



a. Suppose a proton were placed on the x-axis to the *right* of q. Is it *possible* that the net electric force on the proton is zero? Explain.

No. The proton is repelled by both q and 4q, so the net force on the proton is to the right.

b. *On the figure*, draw a proton at an arbitrary point on the x-axis to the *left* of q, between $4q$ and q. Draw two force vectors and label them $\vec{F}_{4q}$ and $\vec{F}_q$ to show the two forces on this proton. Is it *possible* that, for the proper choice of r, the net electric force on the proton is zero? Explain.

Yes, if r gives a distance that is twice the size of the separation distance between q and the proton.

c. Write expressions for the magnitudes of forces $\vec{F}_{4q}$ and $\vec{F}_q$. Your expressions should be in terms of K, q, e, L, and r.

$F_{4q} =$ $k\, 4qe/r^2$ $\qquad F_q =$ $k\, qe/(L-r)^2$

d. Find the specific position—as a fraction of L—at which the net force is zero.

The two forces must be equal in size, so

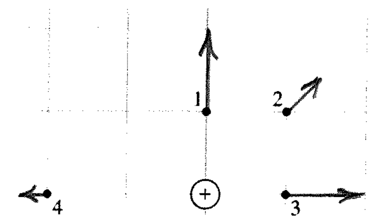
$$\frac{4}{r^2} = \frac{1}{(L-r)^2} \quad \text{or} \quad 4(L-r)^2 = r^2$$

or $2(L-r) = r$ so $\boxed{r = \frac{2}{3}L}$

22.5 The Electric Field

27. At points 1 to 4, draw an electric field vector with the proper direction and whose length is proportional to the electric field strength at that point.

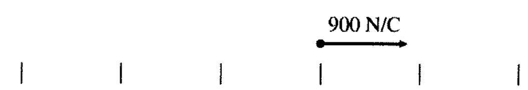
Use $E \propto \frac{1}{r^2}$



28. Dots 1 and 2 are two points in space. The electric field $\vec{E}_1$ at point 1 is shown. Can you determine the electric field at point 2? If so, draw it on the figure. If not, why not?

No, the electric field at point 2 cannot be found without more information. $\vec{E}_1$ only reveals the electric field at point 1.

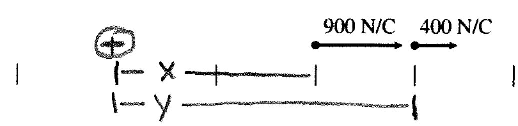
29. a. The electric field of a point charge is shown at *one* point in space.



Can you tell if the point charge is + or −? If not, why not?

Can't tell. The point charge will be positive if to the left of the field point but will be negative if to the right of the field point.

b. Here the electric field of a point charge is shown at two positions in space.



Now can you tell if the point charge is + or −? Explain.

Yes, the point charge must be + and to the left since the field must weaken as the distance from the point charge increases

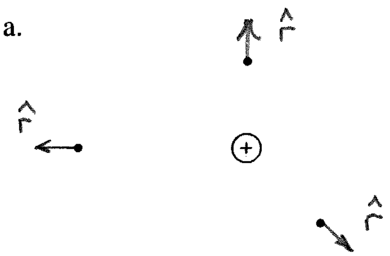
c. Can you determine the location of the charge? If so, draw it on the figure. If not, why not?

Yes. $\frac{1}{x^2} \propto 900$, $\frac{1}{y^2} \propto 400$

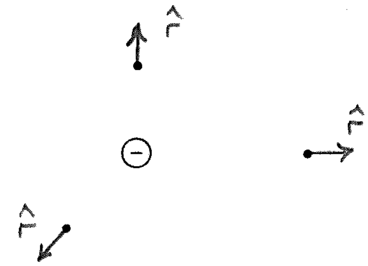
$\frac{y^2}{x^2} = \frac{900}{400}$ and $\frac{y}{x} = \frac{30}{20} = \frac{3}{2}$

30. At the three points in space indicated with dots, draw the unit vector $\hat{r}$ that you would use to determine the electric field of the point charge.

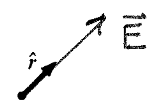
a.



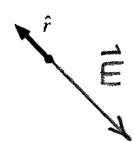
b.



31. a. This is the unit vector $\hat{r}$ associated with a positive point charge. Draw the electric field vector at this point in space.



b. This is the unit vector $\hat{r}$ associated with a negative point charge. Draw the electric field vector at this point in space.



32. The electric field strength at a point in space near a point charge is 1000 N/C.

a. What will be the field strength if the quantity of charge is halved? Explain.

500 N/C. $E \propto$ source charge

b. What will be the field strength if the distance to the point charge is halved? The quantity of charge is the original amount, not the value of part a. Explain.

4000 N/C. $E \propto \frac{1}{r^2}$ where r is the separation distance between the source charge and the field point.