26 Electric Charges and Forces

26.1 Developing a Charge Model

Note: Your answers in Section 26.1 should make *no* mention of electrons or protons.

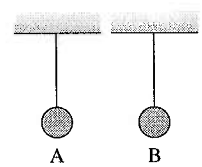
1. Can an insulator be charged? If so, how would you charge an insulator? If not, why not?

   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?

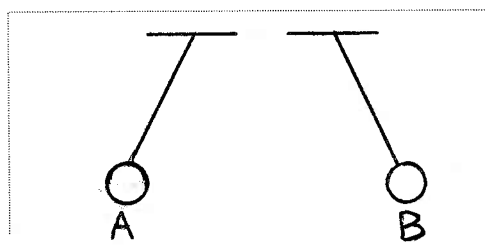
   A conductor can be charged. A conductor can be charged by touching it with another charged object.

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:



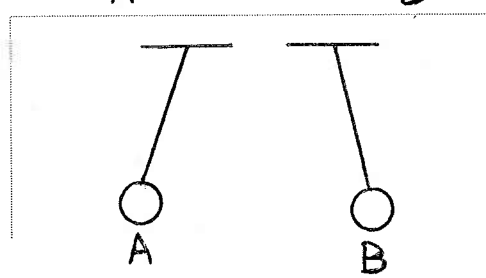
   a. Both are touched with a plastic rod that was rubbed with wool.

   They move away from each other.



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

   They still move away from each other but not as much.



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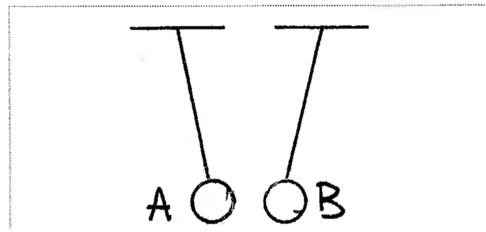
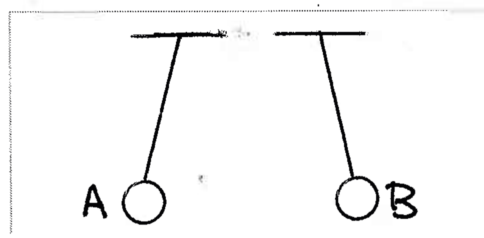
c. Ball A is touched by a plastic rod that was rubbed with wool and ball B is touched by a glass rod that was rubbed with silk.

Now they move toward each other.



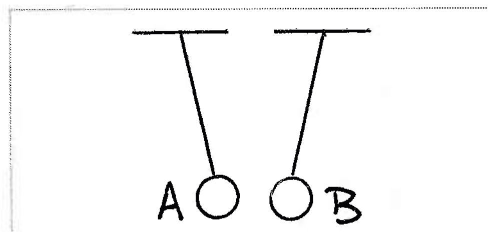
d. Both are charged by a plastic rod, but ball A is charged more than ball B.

They move away from each other by the same angles.



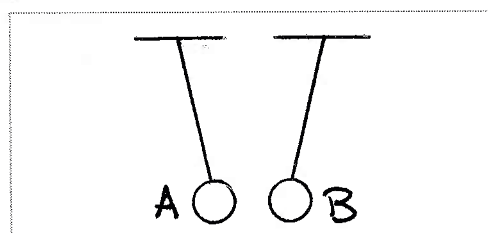
e. Ball A is charged by a plastic rod. Ball B is neutral.

They will again move toward each other by the same angle.



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

They move toward each other by the same angle.



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.

B and D are both neutral because they have no effect on each other and neutral is still attracted to either glass or plastic. Since ball A has been touched by plastic it is also now plastic. Since ball C is attracted to plastic(A) and neutral (B) then it must be glass.

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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 exert repulsive forces on each other. So the object must also be plastic. Therefore it will attract the glass rod.

   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 this because the object could be glass or neutral. Glass will repel the glass rod but neutral will be attracted to 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.

If you have a neutral object it would attract charged pieces of paper but have no effect on uncharged pieces.

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

Yes. "Fly-away" hair are strands of hair with like charge repelling each other. Rubbing hair with plastic creates oppositely charged hair and plastic.

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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 by touching a charged object it can acquire charge. However, because the clothes are charged, they will be attracted to a neutral object. Your body is initialy uncharged but can become charged by touching a charged object or by rubbing it just like other objects.

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. Afterward, if the second metal sphere can pick up small pieces of paper, then the material was a conductor. If not, then the material was 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.

Suspend two X-charged object from a thread and move charged plastic and glass rods near them. If there is an attraction to both the plastic and the glass, yet there is also repulsion between the two X-charged objects, then you've discovered a third type of charge. Alternatively, if the allegedly X-charged object is repelled by both the plastic and glass, it must be a different type of charge also.

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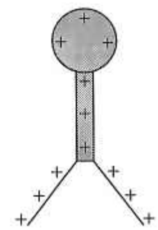
26.2 Charge

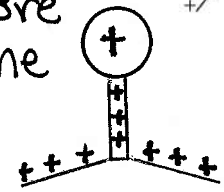
26.3 Insulators and Conductors

10. A positively charged electroscope has separated leaves.



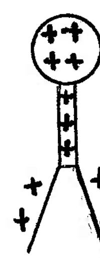
a. Suppose you bring a positively charged rod close to the top of the electroscope, but not touching. How will the leaves respond? Use both charge diagrams and words to explain.

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



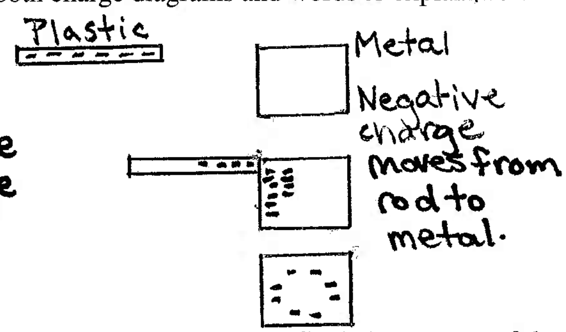
b. How will the leaves respond if you bring a negatively charged rod close to the top of the electroscope, but not touching? Use both charge diagrams and words to explain.

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.



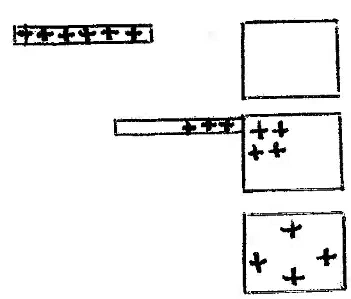
11. a. A negatively charged plastic rod touches a neutral piece of metal. What is the final charge state (positive, negative, or neutral) of the metal? Use both charge diagrams and words to explain how this charge state is achieved.

The final charge state of the metal is negative. The metal is charged by contact. Some of the negative charges flow onto the metal and then remain there when the rod is removed.



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 final charge state of the metal is positive. Here some negative charges flow from the metal to the rod neutralizing some positive charge on the rod. The loss of negative charge by the metal leaves it with an overall positive charge.



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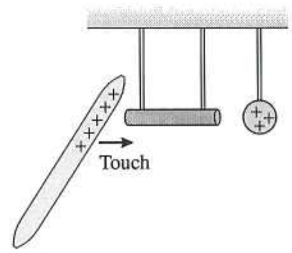
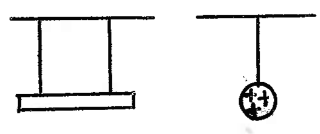
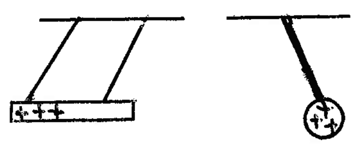
12. A lightweight, positively charged ball and a neutral rod hang by threads. They are close but not touching. A positively charged glass rod touches the hanging rod on the end opposite the ball, then the rod is removed.



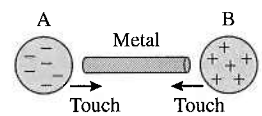
a. Draw a picture of the final positions of the hanging rod and the ball if the rod is made of glass.



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



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

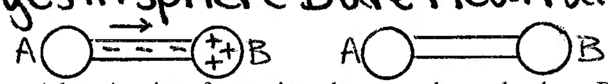


a. What is the final charge state of each sphere and of the rod?

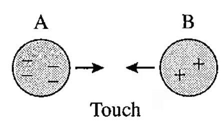
The final charge state of each sphere and of the rod is neutral.

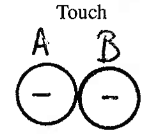
b. Give a microscopic explanation, in terms of fundamental charges, of how these final states are reached. Use both charge diagrams and words.

The charge carriers in metals are electrons. Electrons travel far enough to shove the next electron in the sea of electrons. The entire sea shifts until the positive charges in sphere B are neutralized.



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.





Each sphere ends up with 1 unit of negative charge. Once they touch, the two spheres become essentially one conductor. The overall net charge is $-4 + 2 = -2$. Charge is spread uniformly over the surface of a conductor.

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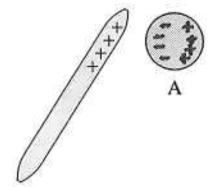
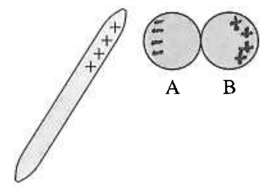
15. a. Metal sphere A is initially neutral. A positively charged rod is brought near, but not touching. Is A now positive, negative, or neutral? Explain.



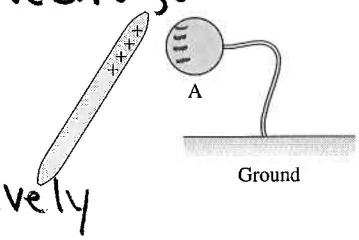
A has an overall neutral charge but the charges are now polarized.

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.



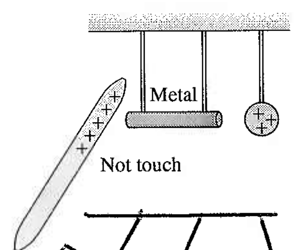
The rod will polarize the charges in the combined conductor A+B, effectively attracting negative charges to A and leaving B with positive charges. The combined conductor is still neutral, while A has net negative charge.

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.



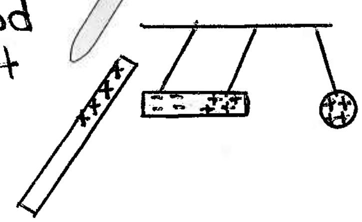
Negative charge is attracted from the ground onto sphere A by the positively charged rod. A is negative.

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.



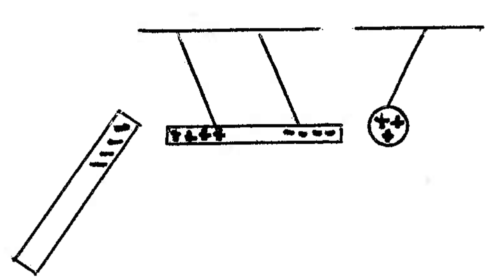
a. Draw a picture of the final positions of the hanging rod and the ball. Explain your reasoning.

The charged rod polarizes the metal rod attracting negative charges to the left leaving positive charge on the right. Positive charges repel.



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.

Now the hanging rod is polarized with negative charges on the right so it is attracted to the ball.



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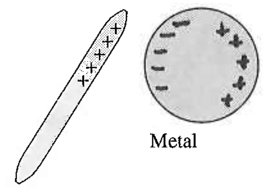
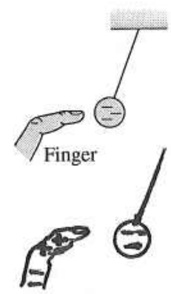
17. A positively charged rod is held near, but not touching, a neutral metal sphere.
    a. Add plusses and minuses to the figure to show the charge distribution on the sphere.
    b. Does the sphere experience a net force? If so, in which direction? Explain.



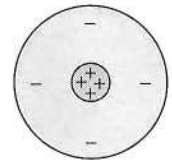
To the left. The negative charges experience an attractive force to the left and the positive charges experience a repulsive force to the right. But the positive charges on the metal are further away from the rod so the force to the right is smaller than the force to the left. The net force is to the left.

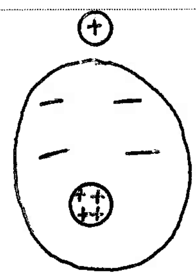
18. If you bring your finger near a lightweight, negatively charged hanging ball, the ball swings over toward your finger. Use charge diagrams and words to explain this observation.



The molecules in your finger are polarized. Positive charge is left on the tip when negative charges are repelled by the ball. Then the closer positive charge attracts the negative ball more than the further negative charge repells it.

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.





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

Yes. The net force is up. There is an upward attractive force exerted on the electrons and a downward repulsive force on the protons exerted by the external charge. Since the protons are further away from the charge, the downward force is less than the upward force.

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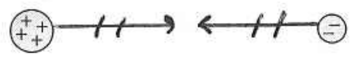
26.4 Coulomb's Law

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

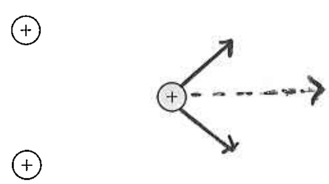
a. 

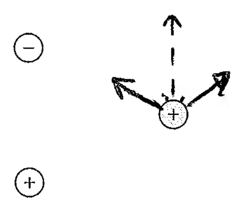
b. 

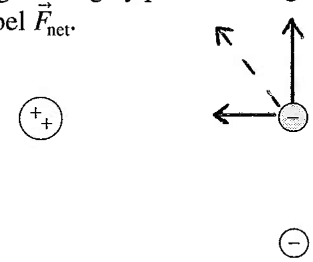
c. 

d. 

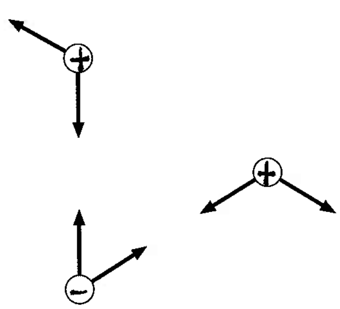
21. For each group of charges, use a **black** pen or pencil to draw the forces acting on the gray positive charge. Then use a **red** pen or pencil to show the net force on the gray charge. Label $\vec{F}_{net}$.

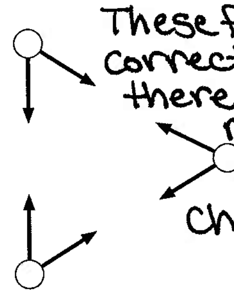
a. 

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. 

These forces are not correct because there cannot be 3 mutually attractive charges.

c. 

These forces are not correct because they must be equal in magnitude.

d. 

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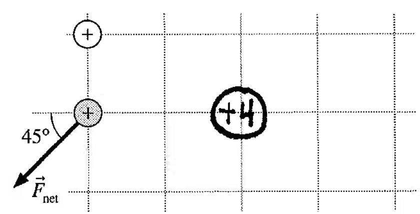
23. a. Draw a + on the figure below to show the position or positions where a proton would experience no net force.

b. Would the force on an electron at this position (or positions) be to the left, to the right, or zero?

Zero. There would not be a net force on an electron in this position either. Though the forces are reversed, they are still equal and opposite.

24. Draw a − on the figure below to show 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.



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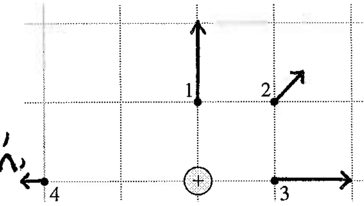
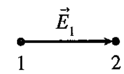
26.5 The Field Model

26. 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.



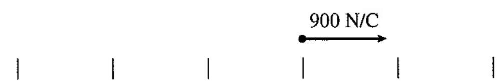
The arrows at 1 and 3 are equal in length, while the arrow at 2 is half their length, and the arrow at 4 is 1/4 their length.

27. 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 you cannot determine the magnitude or direction of the field at point 2. The vector shown only tells about the field at point 1.

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



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

No. The electric field could be due to a positive charge to the left of the field point or a negative charge 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 charge is + or –? Explain.

Yes. The charge is positive and is on the left of the field points. We can tell this because the electric field decreases with the square of the distance from the charge.

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

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

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

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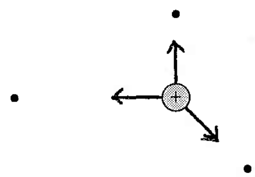
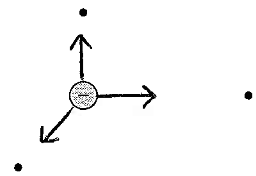
29. At the three points in space indicated with dots, draw the unit vector $\hat{r}$ that you would use to determine the electric field of the point charge.

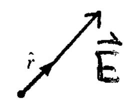
a.



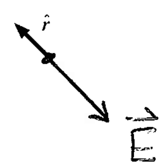
b.



30. 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.



31. 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. The magnitude of the electric field is proportional to the charge that created it.

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. The magnitude of the electric field due to a point charge is inversely proportional to the square of the distance from the point charge.

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