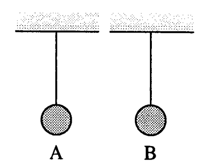
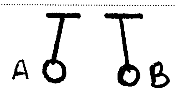
20 Electric Forces and Fields

20.1 Charges and Forces

1. Two lightweight balls 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:

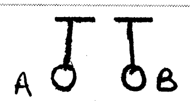


a. Both are touched with a plastic rod that was rubbed with wool.



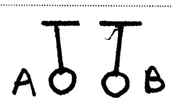
They move away from each other.

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



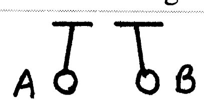
They still move away from each other but not as much.

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.



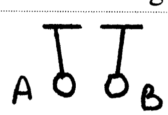
Now they move toward each other.

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 amount.

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



They still move toward each other.

2. 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.

   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 charges repelling each other.

   d. What kind of charge is the comb likely to have? Why?

   Negative. We previously learned that plastic rubbed by wool becomes negatively charged. The comb is probably plastic and wool is made from sheep hair.

   e. How could you test your answer to part d?

   Rub a plastic rod with wool. If it is repulsed by the comb, then the comb also had a negative charge.

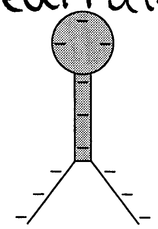
3. You've been given a piece of material. Propose an experiment or a series of experiments to determine if the material is a conductor or an insulator. State clearly what the outcome of each experiment will be if the material is a conductor and if it is an insulator.

   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.

4. Suppose there exists a third type of charge in addition to the two types we've called positive and negative. 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.

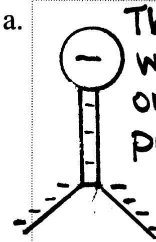
Suspend the object from a thread. Move a negative rod near the object. If there is an attraction, then the object has a positive charge or is neutral. If repulsion, then the object also has a negative charge. If there was attraction, then now test it by moving a positive rod close. If repulsion, the object has positive charge also. If attraction, then it must be neutral.

5. A negatively charged electroscope has separated leaves.

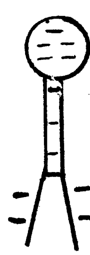


a. Suppose you bring a negatively charged rod close to the top of the electroscope, but not touching. How will the leaves respond? Use both charge diagrams and words to explain.

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

a. 

The negatively charged rod will repel the negative charges on the top of the electroscope pushing more negative charge down onto the leaves. The leaves will separate more.

b. 

The positively charged rod will attract more negative charges to the top of the electroscope. As they leave, the leaves will move closer together.

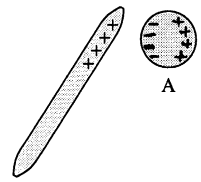
6. Four lightweight balls A, B, C, and D are suspended by threads. Ball A has been touched by a plastic rod that was rubbed with wool. When the balls are brought close together, without touching, the following observations are made:

- 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 (postive, negative, or neutral) of balls A, B, C, and D? Explain.

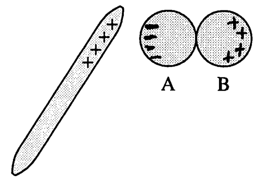
B and D are both neutral because they have no effect on each other. Neutral is attracted to both positive and negative. Because Ball A has been touched by plastic, it is negative like the plastic. Because C is attracted to the negatively charged A and neutral B, it must be positively charged.

7. 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.



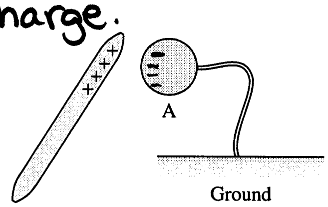
A has an overall neutral charge but the charges are now separated

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.



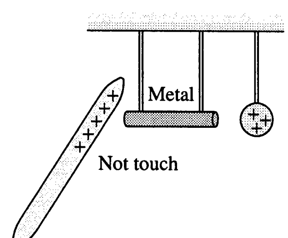
The rod will separate the charges in the combined conductor A+B, effectively attracting negative charges to A and leaving B with positive charges. The combined conductor is still neutral, while A has a net negative charge.

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.



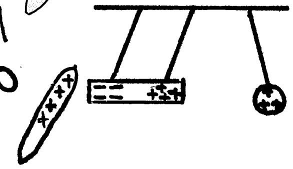
Negative charge is attracted from the ground onto sphere A by the positively charged rod. A is negative.

8. 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.



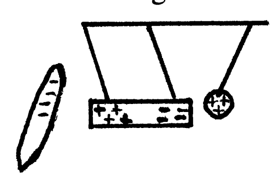
a. Draw a picture of the final positions of the hanging rod and the ball. Explain your reasoning.

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



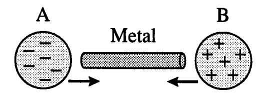
b. Suppose the positively charged rod is replaced with a negatively charged rod. Draw a picture of the final positions of the hanging rod and the ball. Explain your reasoning.

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



20.2 Charges, Atoms, and Molecules

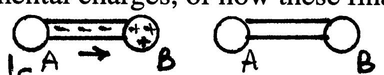
9. Two oppositely charged metal spheres have equal quantities of charge. They are brought into contact with a neutral metal rod.



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

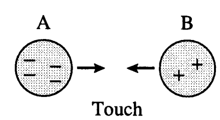
The final charge state of each sphere and of the rod is neutral.

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 B are neutralized.

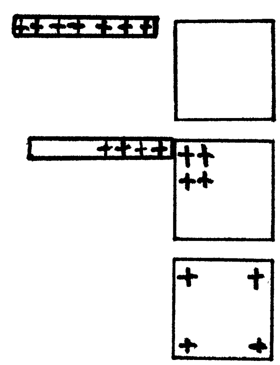
10. Metal sphere A has 4 units of negative charge and metal sphere B has 2 units of positive charge. The two spheres are brought into contact. What is the final charge state of each sphere? Explain.



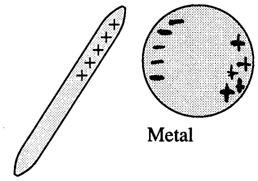
One unit of negative charge. The total charge is $-4+2=-2$ and it is shared equally between them. (assuming identical spheres)

11. 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.



12. A positively charged rod is held near, but not touching, a neutral metal sphere.

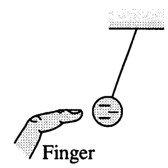


a. Add plusses and minuses to the figure to show the charge distribution on the sphere.

b. Does the sphere experience a net force? If so, in which direction? Explain.

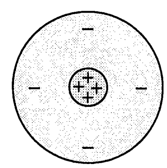
Yes. The positive charges on the rod are closer to the negative charges on the metal and so cause a greater force of attraction than the repulsion between the more distant positive charges.

13. 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.

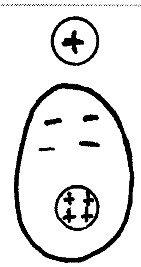


The charges on your finger are polarized. Positive charge is left on the tip when negative charges are repelled down the finger by the ball. Then the positive charge attracts the negative ball.

14. 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.

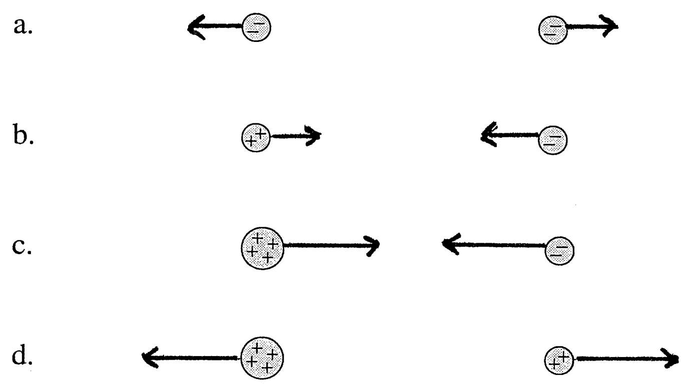


b. Is there a net force on the atom? If so, in which direction? Explain.

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.

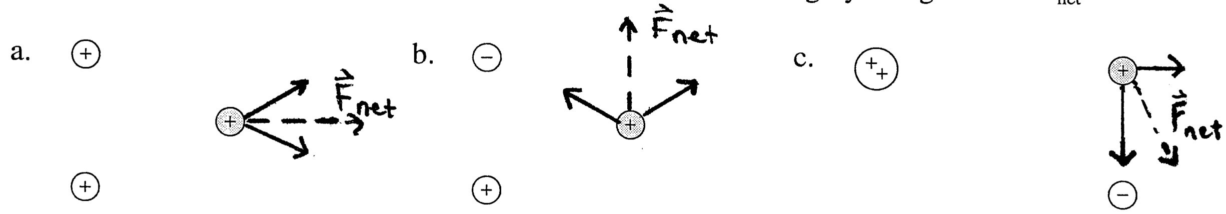
20.3 Coulomb's Law

15. 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.

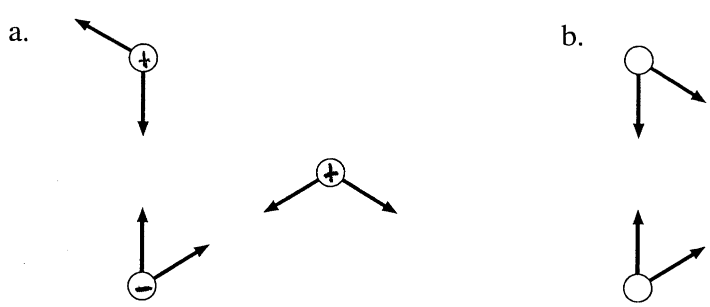


16. For each group of charges, use a **black** pen or pencil to draw the forces acting on the gray positive charge. Then use a **red** pen or pencil to show the net force on the gray charge. Label $\vec{F}_{net}$.

——— Black
- - - Red



17. 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?



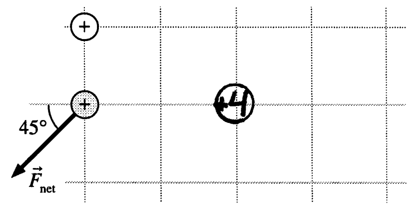
These forces are not correct because there cannot be three mutually attractive charges.

These forces are not correct because they must be equal in magnitude. (Newton's third law)

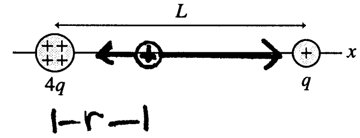
18. Draw a + on the figure below to show the position or positions where a proton would experience no net force.

19. Draw a − on the figure below to show the position or positions where an electron would experience no net force.

20. 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.



21. Positive charges $4q$ and q are distance L apart. Let them be on the x-axis with $4q$ at the origin.
PSS 20.1



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 the q and 4q charges and so only experiences force to the right.

b. <u>On the figure</u>, draw a proton at an arbitrary point on the x-axis between $4q$ and q. Label its distance from $4q$ as r. 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 at twice the distance from 4q than q, the forces will be equal.

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

$F_{4q} = k\dfrac{4q^2}{r^2}$ $\qquad$ $F_q = \dfrac{Kq^2}{(L-r)^2}$

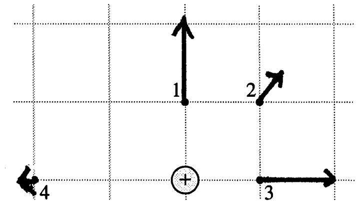
d. Find the specific position—as a fraction of L—at which the net force is zero.

$\sum\vec{F} = 0$ if $\dfrac{4}{r^2} = \dfrac{1}{(L-r)^2}$ or $2L - 2r = r$

or $r = \dfrac{2}{3}L$

20.4 The Concept of the Electric Field

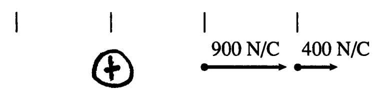
22. At points 1 to 4, draw an electric field vector with the proper direction and with a length proportional to the electric field strength at that point. The arrows at 1 and 3 are equal in length, while the arrow at 2 is half their length, and the arrow at 4 is 1/4 their length.



23. 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, see figure.

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

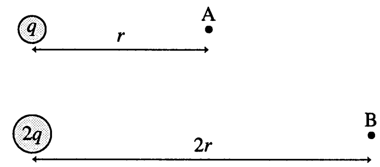
a. What will be the field strength if the quantity of charge is halved? Explain.

500 N/C. The field strength is proportional to the charge that creates 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.

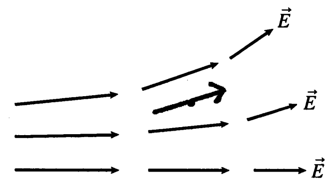
4000 N/C. The field varies as the inverse square of the distance from the charge

25. Is the electric field strength at point A larger than, smaller than, or the same as the electric field strength at point B? Explain.



A. $\frac{q}{r^2} > \frac{2q}{(2r)^2} = \frac{q}{2r^2}$

26. Is there an electric field at the position of the dot? If so, draw the electric field vector on the figure. If not, what would you need to do to create an electric field at this point?

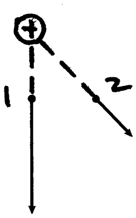


Yes. There is an electric field at this position. The field vectors shown represent the field in the region.

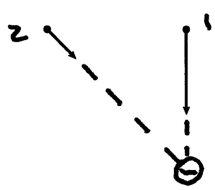
27. Each figure shows two vectors. Can a point charge create an electric field that looks like this at these two points? If so, add the charge to the figure. If not, why not?

Note: The dots are the points to which the vectors are attached. There are no charges at these points.

a.

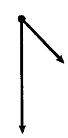


b.



c.

d.



a. Yes. Point 2 is further away from charge.

b. Yes. Point 2 is further away.

c. Yes. The field vector shows the field only at the dot.

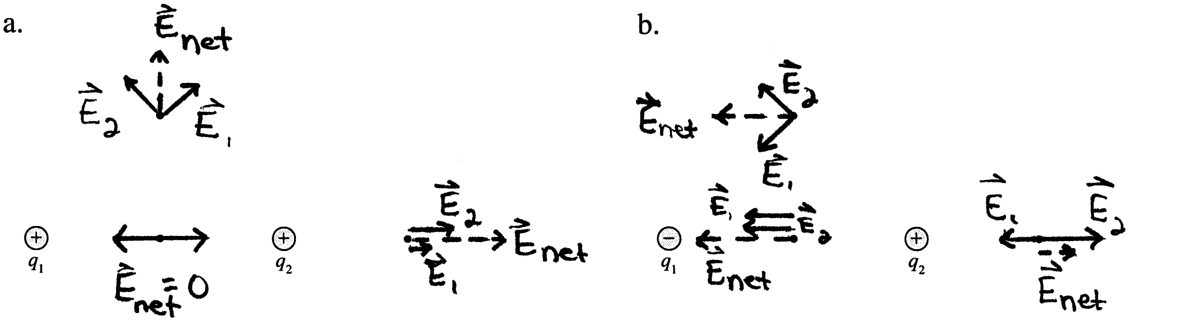
d. No. The field due to a point charge cannot go in 2 directions.

20.5 Applications of the Electric Field

—— Black
- - - Red

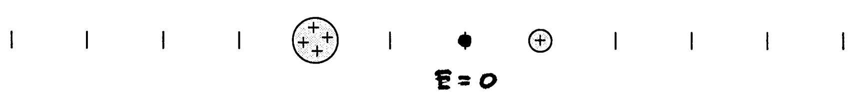
28. At each of the dots, use a **black** pen or pencil to draw and label the electric fields $\vec{E}_1$ and $\vec{E}_2$ due to the two point charges. Make sure that the *relative* lengths of your vectors indicate the strength of each electric field. Then use a **red** pen or pencil to draw and label the net electric field $\vec{E}_{net}$.

a. b.

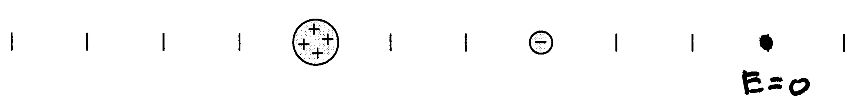


29. For each of the figures, use dots to mark any point or points (other than infinity) where $\vec{E} = \vec{0}$.

a.

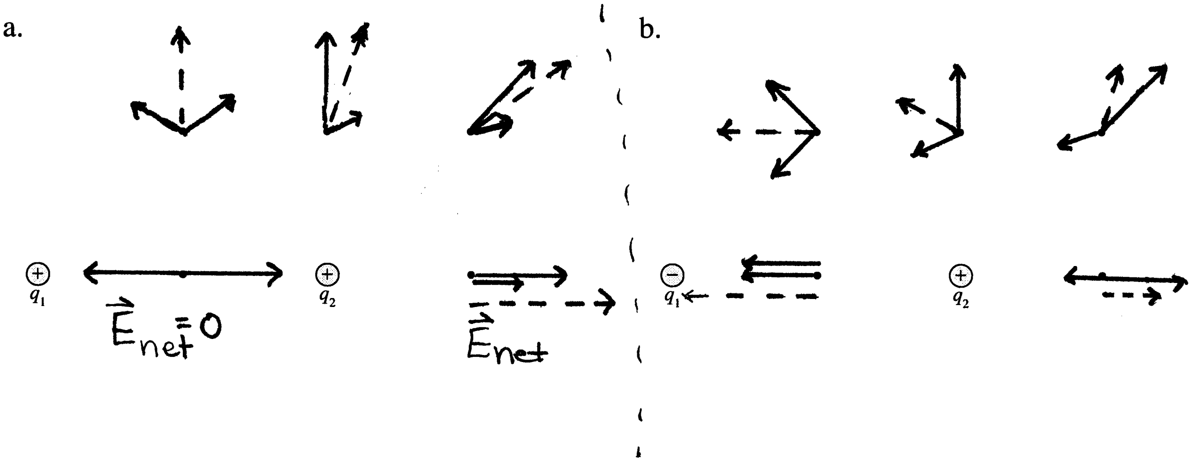


b.

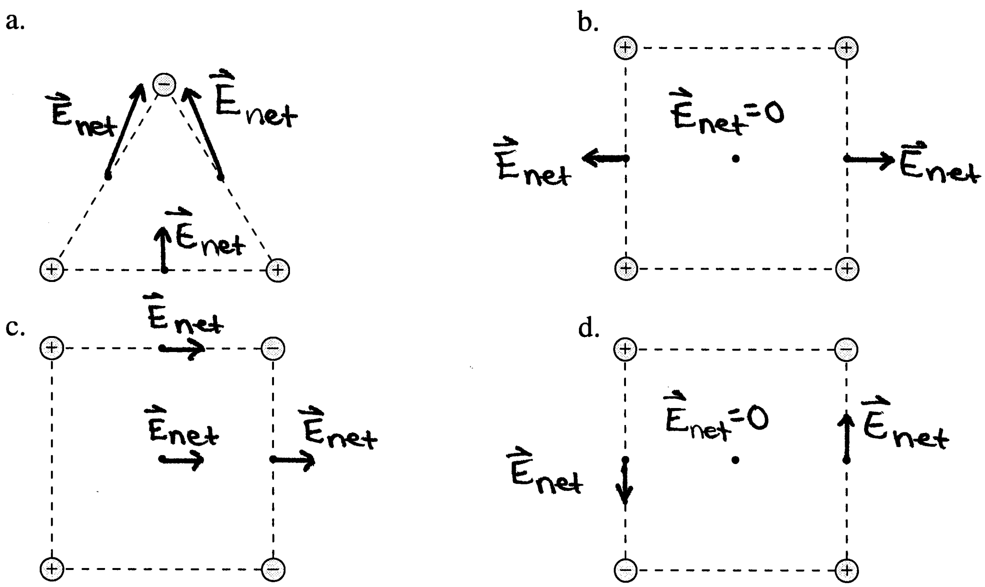


30. Use a **black** pen or pencil to draw the two electric fields $\vec{E}_1$ and $\vec{E}_2$ at each dot. Then use a **red** pen or pencil to draw $\vec{E}_{net}$. The lengths of your vectors should indicate the magnitude of $\vec{E}$ at each point.

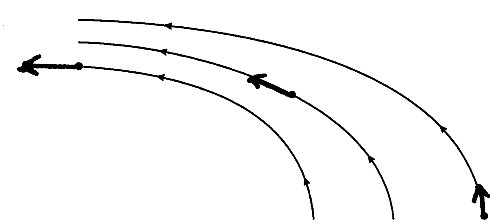
a. b.



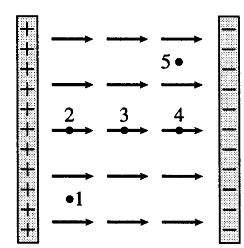
31. For each figure, draw and label the net electric field vector $\vec{E}_{net}$ at each of the points marked with a dot or, if appropriate, label the dot $\vec{E}_{net} = \vec{0}$. The lengths of your vectors should indicate the magnitude of $\vec{E}$ at each point.



32. The figure shows the electic field lines in a region of space. Draw the electric field vectors at the three dots.



33. Rank in order, from largest to smallest, the electric field strengths E_1 to E_5 at each of these points.



Order: $E_1 = E_2 = E_3 = E_4 = E_5$

Explanation:

The electric field is constant everywhere between the plates. This is indicated by the electric field vectors which are all the same length and in the same direction.

34. A parallel-plate capacitor is constructed of two square plates, size $L \times L$, separated by distance d. The plates are given charge $\pm Q$. What is the ratio E_f/E_i of the final electric field strength E_f to the initial electric field strength E_i if:

a. Q is doubled?

$$\frac{E_f}{E_i} = \frac{Q_f/\epsilon_0 A}{Q_i/\epsilon_0 A} = \frac{Q_f}{Q_i} = 2$$

If Q is doubled (A = constant)

$$\frac{E_f}{E_i} = \frac{Q_f}{Q_i} = 2$$

b. L is doubled?

If L is doubled then $A_f = 4A_i$ (Q = constant)

$$\frac{E_f}{E_i} = \frac{A_i}{A_f} = \frac{A_i}{4A_i} = \frac{1}{4}$$

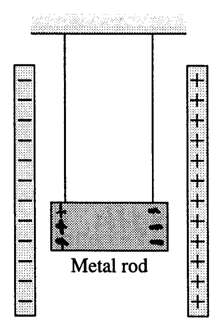
c. d is doubled?

E does not depend on d.

$$\frac{E_f}{E_i} = 1$$

20.6 Conductors in Electric Fields

35. A neutral metal rod is suspended in the center of a parallel-plate capacitor. Then the capacitor is charged as shown.



a. Is the rod now positive, negative, or neutral? Explain.

The rod is still neutral.
No charges have been added to or removed from the metal rod.

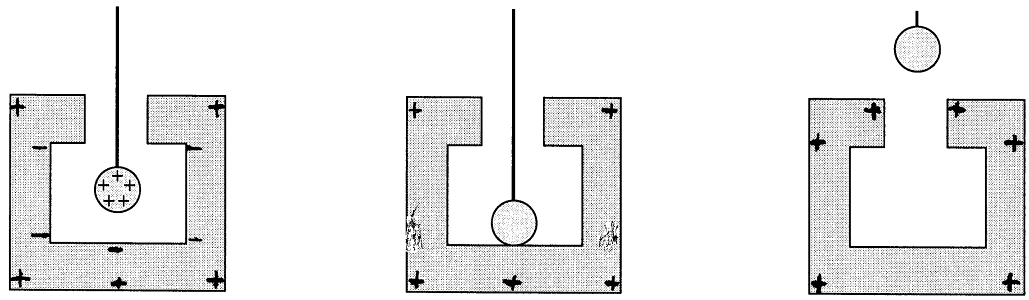
b. Is the rod polarized? If so, draw plusses and minuses on the figure to show the charge distribution. If not, why not?

The rod is polarized.

c. Does the rod swing toward one of the plates, or does it remain in the center? If it swings, which way? Explain.

The rod remains in the center because there are equal forces pulling the left end of the rod to the left and pulling the right end of the rod to the right.

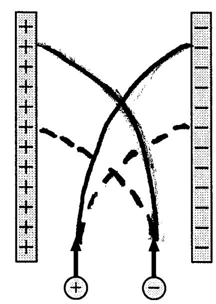
36. An insulating thread is used to lower a positively charged metal ball into a metal container. Initially, the container has no net charge. Use plus and minus signs to show the charge distribution on the inner and outer surfaces of the container and any charge on the ball. (The ball's charge is already shown in the first frame.)



Ball hasn't touched | Ball has touched | Ball has been withdrawn

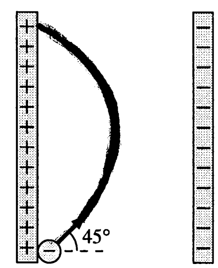
20.7 Forces and Torques in Electric Fields

37. Positively and negatively charged particles, with equal masses and equal quantities of charge, are shot into a capacitor in the directions shown.
   a. Use solid lines to draw their trajectories on the figure if their initial velocities are fast.
   b. Use dotted lines to draw their trajectories on the figure if their initial velocities are slow.



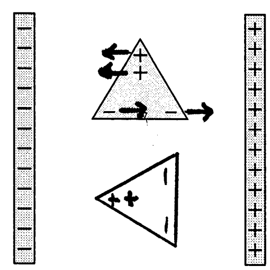
parabolic opening to the right or left

38. An electron is launched from the positive plate at a 45° angle. It does not have sufficient speed to make it to the negative plate. Draw its trajectory on the figure.



Parabolic

39. Three charges are placed at the corners of a triangle. The + + charge has twice the quantity of charge of the two – charges; the net charge is zero.
   a. Draw the force vectors on each of the charges.
   b. Is the triangle in equilibrium? No If not, draw the equilibrium orientation directly beneath the triangle that is shown.
   c. Once in the equilibrium orientation, will the triangle move to the right, move to the left, rotate steadily, or be at rest? Explain.



The triangle will move left without rotating.