## Understanding Concepts

1. One of the children in **Figure 1** is touching an electrostatic generator.
   (a) Why does the hair of the child touching the electrostatic generator stand on end?
   (b) Why does the hair of the other child likewise stand on end?
   (c) Are the children grounded? Explain your answer.



**Figure 1**
Two children holding hands; one is touching an electrostatic generator.

2. In a chart, compare similarities and differences between Newton's law of universal gravitation and Coulomb's law.

3. Coulomb's law may be used to calculate the force between charges only under certain conditions. State the conditions, and explain why they are imposed.

4. Two small, oppositely charged conducting spheres experience a mutual electric force of attraction of magnitude $1.6 \times 10^{-2}$ N. What does this magnitude become if each sphere is touched with its identical, neutral mate, the initially neutral spheres are taken far away, and the separation of the two initially charged spheres is doubled?

5. What is the distance between two protons experiencing a mutually repelling force of magnitude $4.0 \times 10^{-11}$ N?

6. One model of the structure of the hydrogen atom consists of a stationary proton with an electron moving in a circular path around it. The orbital path has a radius of $5.3 \times 10^{-11}$ m. The masses of a proton and an electron are $1.67 \times 10^{-27}$ kg and $9.1 \times 10^{-31}$ kg, respectively.

   (a) Calculate the electrostatic force between the electron and the proton.
   (b) Calculate the gravitational force between them.
   (c) Which force is mainly responsible for the electron's circular motion?
   (d) Calculate the speed and period of the electron in its orbit around the proton.

7. Two point charges, $+4.0 \times 10^{-5}$ C and $-1.8 \times 10^{-5}$ C, are placed 24 cm apart. What is the force on a third small charge, of magnitude $-2.5 \times 10^{-6}$ C, if it is placed on the line joining the other two,
   (a) 12 cm outside the originally given pair of charges, on the side of the negative charge?
   (b) 12 cm outside the originally given pair of charges, on the side of the positive charge?
   (c) midway between the originally given pair of charges?

8. Explain why we use a "small" test charge to detect and measure an electric field.

9. If a stationary charged test particle is free to move in an electric field, in what direction will it begin to travel?

10. Why is it safer to stay inside an automobile during a lightning storm? (*Hint:* It is not due to the insulating rubber tires.)

11. Three small, negatively charged spheres are located at the vertices of an equilateral triangle. The magnitudes of the charges are equal. Sketch the electric field in the region around this charge distribution, including the space inside the triangle.

12. A small test charge of $+1.0$ $\mu$C experiences an electric force of $6.0 \times 10^{-6}$ N to the right.
    (a) What is the electric field strength at that point?
    (b) What force would be exerted on a charge of $-7.2 \times 10^{-4}$ C located at the same point, in place of the test charge?

13. What are the magnitude and direction of the electric field strength 1.5 m to the right of a positive point charge of magnitude $8.0 \times 10^{-3}$ C?

14. What are the magnitude and direction of the electric field strength at point Z in **Figure 2**?
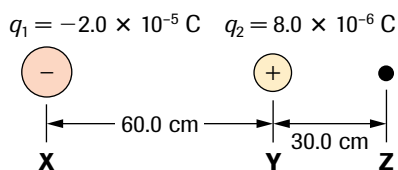


**Figure 2**

15. A ping-pong ball of mass $3.0 \times 10^{-4}$ kg hangs from a light thread 1.0 m long, between two vertical parallel plates 10.0 cm apart (**Figure 3**). When the potential difference across the plates is 420 V, the ball comes to equilibrium 1.0 cm to one side of its original position.
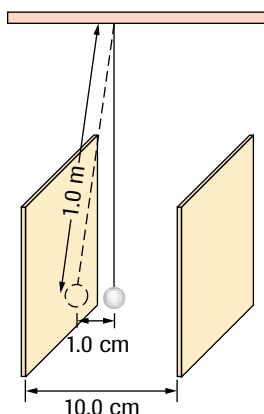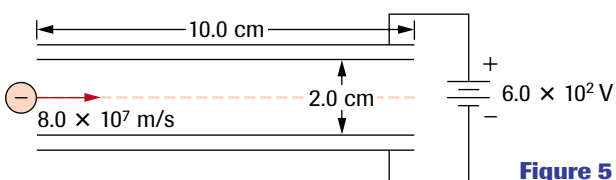


**Figure 3**

   (a) Calculate the electric field strength between the plates.
   (b) Calculate the tension in the thread.
   (c) Calculate the magnitude of the electric force deflecting the ball.
   (d) Calculate the charge on the ball.

16. If two points have the same electric potential, is it true that no work is required to move a test charge from one point to the other? Does that mean that no force is required, as well?

17. How much work is required to move a charged particle through an electric field if it moves along a path that is always perpendicular to an electric field line? How would the potential change along such a path?

18. A charge of $1.2 \times 10^{-3}$ C is fixed at each corner of a rectangle 30.0 cm wide and 40.0 cm long. What are the magnitude and direction of the electric force on each charge? What are the electric field and the electric potential at the centre?

19. Calculate the electric potential 0.50 m from a $4.5 \times 10^{-4}$ C point charge.

20. A $1.0 \times 10^{-6}$ C test charge is 40.0 cm from a $3.2 \times 10^{-3}$ C charged sphere. How much work was required to move it there from a point $1.0 \times 10^2$ cm away from the sphere?

21. How much kinetic energy is gained by an electron that is allowed to move freely through a potential difference of $2.5 \times 10^4$ V?

22. How much work must be done to bring two protons, an infinite distance apart, to within $1.0 \times 10^{-15}$ m of each other, a distance comparable to the width of an atomic nucleus? (The work required, while small, is enormous in relation to the typical kinetic energies of particles in a school lab. This shows why particle accelerators are needed.)

23. What is the magnitude of the electric field between two large parallel plates 2.0 cm apart if a potential difference of 450 V is maintained between them?

24. What potential difference between two parallel plates, at a separation of 8.0 cm, will produce an electric field strength of magnitude $2.5 \times 10^3$ N/C?

25. Most experiments in atomic physics are performed in a vacuum. Discuss the appropriateness of performing the Millikan oil drop experiment in a vacuum.

26. Assume that a single, isolated electron is fixed at ground level. How far above it, vertically, would another electron have to be so that its mass would be supported against gravitation by the force of electrostatic repulsion between them?

27. An oil droplet of mass $2.6 \times 10^{-15}$ kg, suspended between two parallel plates 0.50 cm apart, remains stationary when the potential difference between the plates is 270 V. What is the charge on the oil droplet? How many excess or deficit electrons does it have?

28. A metallic table tennis ball of mass 0.10 g has a charge of $5.0 \times 10^{-6}$ C. What potential difference, across a large parallel plate apparatus of separation 25 cm, would be required to keep the ball stationary?

29. Calculate the electric potential and the magnitude of the electric field at a point 0.40 m from a small sphere with an excess of $1.0 \times 10^{12}$ electrons.

30. An electron is released from rest at the negative plate in a parallel plate apparatus kept under vacuum and maintained at a potential difference of $5.0 \times 10^2$ V. With what speed does the electron collide with the positive plate?

31. What potential difference would accelerate a helium nucleus from rest to a kinetic energy of $1.9 \times 10^{-15}$ J? (For a helium nucleus, $q = +2e$.)

32. An electron with a speed of $5.0 \times 10^6$ m/s is injected into a parallel plate apparatus, in a vacuum, through a hole in the positive plate. The electron collides with the negative plate at $1.0 \times 10^6$ m/s. What is the potential difference between the plates?

33. Four parallel plates are connected in a vacuum as in **Figure 4**. An electron, essentially at rest, drifts into the hole in plate X and is accelerated to the right. The vertical motion of the electron continues to be negligible. The electron passes through holes W and Y, then continues moving toward plate Z. Using the information given in the diagram, calculate
    (a) the speed of the electron at hole W
    (b) the distance from plate Z to the point at which the electron changes direction
    (c) the speed of the electron when it arrives back at plate X



**Figure 4**
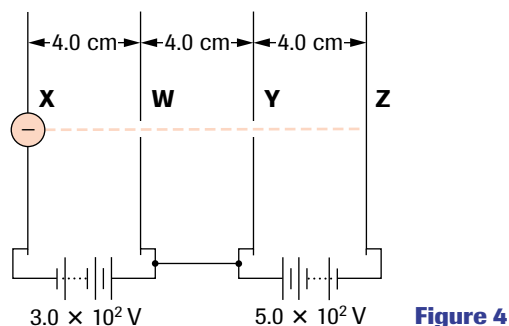
34. Two $\alpha$ particles, separated by an enormous distance, approach each other. Each has an initial speed of $3.0 \times 10^6$ m/s. Calculate their minimum separation, assuming no deflection from their original path.

35. An electron enters a parallel plate apparatus 10.0 cm long and 2.0 cm wide, moving horizontally at $8.0 \times 10^7$ m/s, as in **Figure 5**. The potential difference between the plates is $6.0 \times 10^2$ V. Calculate
    (a) the vertical deflection of the electron from its original path
    (b) the velocity with which the electron leaves the parallel plate apparatus



**Figure 5**

## Applying Inquiry Skills

36. A versorium is a device that detects the presence of an electric charge on an object. The device consists of any convenient material (e.g., a straw or a long strip of folded paper) balanced on a needle or tack with some sort of base, such as modelling clay. The straw will rotate if a charged object is brought close to one end.

Build your own versorium. Charge several objects and try your device. Also try it on an operating television screen. Examine the effect of turning the television off and on while keeping your versorium near the screen. Write a short report on your findings.

37. Design an experiment that can be used to test the properties of conductors in electric fields. You may use either or both of the following as is convenient: a probe that can detect electric fields; a charged neutral object attached to an insulating rod.

38. The electric field of Earth always points toward Earth. The magnitude of the field strength varies locally from as low as 100 N/C in fair weather to 20 000 N/C in a thunderstorm. A field mill measures the local electric field strength. In this device, the lower plate, parallel to the ground, is connected to Earth through an ammeter. The upper plate can be moved horizontally, and it, too, is connected to Earth.
    (a) When the mill is arranged as in **Figure 6(a)**, what kind of charge is on the surface of Earth and on each plate? (*Hint:* Examine the field lines.)
    (b) What will the ammeter show when you move the upper plate rapidly over the lower plate, as in **Figure 6(b)**? Explain your answer.
    (c) What will the ammeter show when the upper plate is quickly pushed away from the lower plate? Explain your answer.
    (d) What will the ammeter show if the upper plate is attached to a motor and is rotated in a circle, passing periodically over the lower plate?
    (e) How is the ammeter reading related to the magnitude of the electric field of Earth?
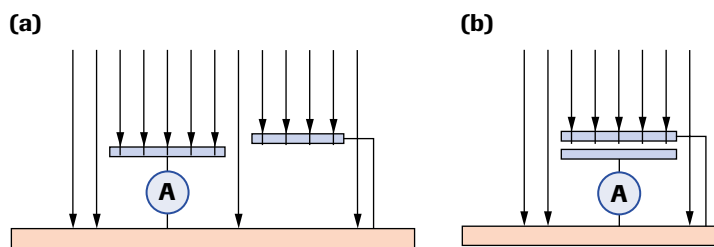
**(a)**                                  **(b)**



**Figure 6**
A field mill is used to detect the magnitude of Earth's electric field.

39. You place a circular conductor near a charged plate in oil with suspended rayon fibres, as in **Figure 7**. The configuration assumed by the fibres indicates the geometry of the electric field. Explain what conclusions this demonstration suggests regarding the nature of electric fields (a) near the surfaces of conductors and (b) inside conductors.
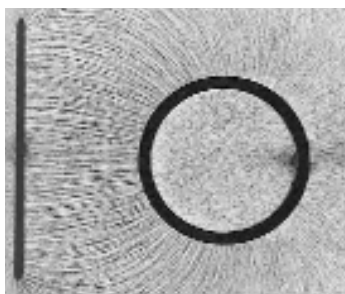
**Figure 7**

40. Using different materials—wool, fur, plastic, and paper—charge a small fluorescent tube in a dark room. A 45-cm tube, rated at 15 W, works well. The brightness of the tube depends on the potential difference achieved. Charge a plastic rod or a length of PVC pipe and move it close to the fluorescent tube. (**Figure 8** depicts this phenomenon using large fluorescent bulbs.) Write a short report on your observations.



**Figure 8**
Power lines in rural areas are operated at a potential difference of several hundred thousand volts relative to Earth. This voltage drop is high enough to create a significant potential difference across these fluorescent bulbs, causing them to glow.

## Making Connections

41. When laboratories process photographs, the film often becomes positively charged, attracting dust and even causing sparks. One variety of static eliminator uses a radioactive source, polonium-210, that emits positively charged particles ($\alpha$ particles). Explain how this can help to reduce dust on the film.

42. Research the principles of piezoelectric crystals and the use of these crystals in wrist watches. Write a one-page report.

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43. **Figure 9** shows the climbing arc, or "Jacob's ladder." It operates by applying a potential difference to the plates. If the potential difference is large enough, an arc will jump between the gap between the two plates, where they are closest. The arc will then slowly climb up the ever-widening gap between the two plates. Discuss how the device operates by explaining the conditions necessary to start the arc, why it starts where the plates are closest, and why it then "climbs" up the space between the plates.



**Figure 9**
Climbing arc (or Jacob's ladder)

## Extension

44. Gauss's law is considered even more general than Coulomb's law and is useful in relating the electric field to the total charge. Research Gauss's law and its applications and make a display showing what you have found.

45. An electron with an initial velocity of $2.4 \times 10^6$ m/s [45° up from the horizontal] passes into two parallel plates separated by 2.5 mm, as in **Figure 10**. The potential difference between the plates is $1.0 \times 10^2$ V.
    (a) How close does the electron come to the top plate?
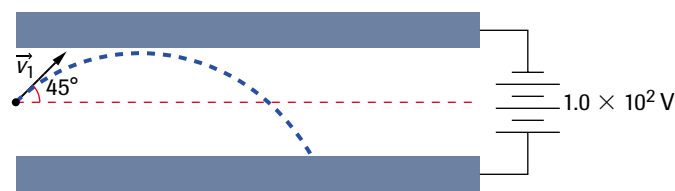    (b) Determine where it strikes the bottom plate.



**Figure 10**

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