The Language of Physics

Electric field
It is an intrinsic property of nature that an electric field exists in the space around an electric charge. The electric field is considered to be a force field that exerts a force on charges placed in the field (p. 535).

Electric field intensity
The electric field is measured in terms of the electric field intensity. The magnitude of the electric field intensity is defined as the ratio of the force acting on a small test charge to the magnitude of the small test charge. The direction of the electric field is in the direction of the force on the positive test charge (p. 535).

Electric field intensity of a point charge
The electric field of a point charge is directly proportional to the charge that creates it, and inversely proportional to the square of the distance from the point charge to the position where the field is being evaluated (p. 537).

Superposition of electric fields
When more than one charge contributes to the electric field, the resultant electric field is the vector sum of the electric fields produced by each of the various charges (p. 538).

Electric potential
The electric potential is defined as the potential energy per unit charge. It is measured in volts (p. 544).

Equipotential line
A line along which the electric potential is the same everywhere (p. 545).

Equipotential surface
A surface along which the electric potential is the same everywhere (p. 545).

Potential difference
The difference in electric potential between two points (p. 546).

Superposition of potentials
When there are several charges present, the total potential at any arbitrary point is the algebraic sum of the potentials for each of the various point charges (p. 551).

Battery
A battery is a combination of electrolytic cells that supplies a potential difference and in the process converts chemical energy to electrical energy (p. 557).

Summary of Important Equations

Definition of the electric field intensity

$$\mathbf{E} = \frac{\mathbf{F}}{q_0} \quad (19.1)$$

Electric field intensity of a point charge

$$E = \frac{kq}{r^2} \quad (19.2)$$

Force on a charge q in an electric field

$$\mathbf{F} = q\mathbf{E} \quad (19.3)$$

Superposition principle

$$\mathbf{F} = \mathbf{F}_1 + \mathbf{F}_2 + \mathbf{F}_3 + \cdots \quad (19.4)$$

$$\mathbf{E} = \mathbf{E}_1 + \mathbf{E}_2 + \mathbf{E}_3 + \cdots \quad (19.9)$$

$$V = V_1 + V_2 + V_3 + \cdots \quad (19.32)$$

Electric dipole moment

$$p = 2aq \quad (19.15)$$

Potential energy of a charge in a uniform electric field

$$\text{PE} = qEy \quad (19.18)$$

The potential

$$V = \frac{\text{PE}}{q} = \frac{W}{q} \quad (19.19)$$

Potential between parallel plates

$$V = Ey \quad (19.20)$$

The potential difference

$$\Delta V = E\Delta y \quad (19.22)$$

Average value of the electric field intensity

$$E = \frac{\Delta V}{\Delta y} \quad (19.23)$$

The electric field intensity

$$E = \lim_{\Delta y \to 0} \frac{\Delta V}{\Delta y} \quad (19.24)$$

Potential of a point charge

$$V = \frac{kq}{r} \quad (19.31)$$

Acceleration of a charged particle in an electric field

$$\mathbf{a} = \frac{\mathbf{F}}{m} = \frac{q\mathbf{E}}{m} \quad (19.33)$$

Questions for Chapter 19

1. Describe as many different types of fields as you can.

†2. Because you cannot really see an electric field, is anything gained by using the concept of a field rather than an "action at a distance" concept?

†3. Is there any experimental evidence that can substantiate the existence of an electric field rather than the concept of an "action at a distance"?

4. Is the force of gravity also an "action at a distance"? Should a gravitational field be introduced to explain gravity? What is the equivalent gravitational charge?

†5. If there are positive and negative electrical charges, could there be positive and negative masses? If there were, what would their characteristics be?

†6. Michael Faraday introduced the concept of lines of force to explain electrical interactions. What is a line of force and how is it like an electric field line? Is there any difference?

7. If the electric potential is equal to zero at a point, must the electric field also be zero there?

8. Can two different equipotential lines ever cross?

9. If the electric potential is a constant, what does this say about the electric field?

10. If there are electrical charges at rest on a conducting sphere, what can you say about the potential at any part of the sphere?

Problems for Chapter 19

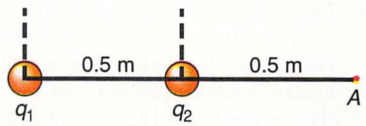
19.2 The Electric Field of a Point Charge

1. Find the electric field 2.00 m from a point charge of 3.00 pC.

2. A point charge, $q = 3.75\ \mu C$, is placed in an electric field of 250 N/C. Find the force on the charge.

19.3 Superposition of Electric Fields

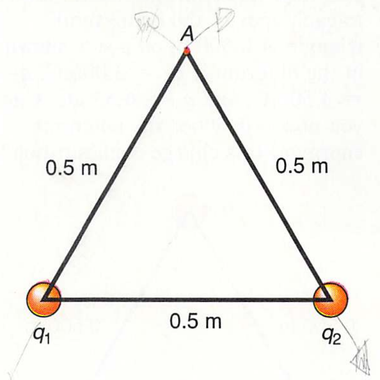
3. Find the electric field at point A in the diagram if (a) $q_1 = 2.00\ \mu C$ and $q_2 = 3.00\ \mu C$ and (b) $q_1 = 2.00\ \mu C$ and $q_2 = -3.00\ \mu C$.



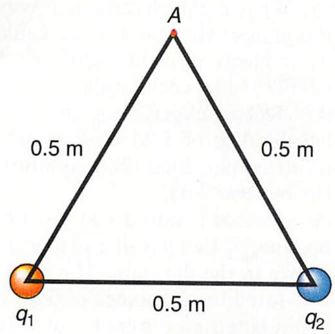
†4. A point charge of $+2.00\ \mu C$ is 30.0 cm from a charge of $+3.00\ \mu C$. Where is the electric field between the charges equal to zero? What is the value of the potential there?

5. A charge $q_1 = -5.00\ \mu C$ is at the origin, while a second charge $q_2 = 3.00\ \mu C$ is located on the x-axis at the point $x = 5.00$ cm. At what point on the x-axis is the electric field zero?

†6. Find the electric field at the apex of the triangle shown in the diagram if $q_1 = 2.00\ \mu C$ and $q_2 = 3.00\ \mu C$. What force would act on a 6.00 μC charge placed at this point?



†7. Find the electric field at point A in the diagram if $q_1 = 2.00\ \mu C$ and $q_2 = -3.00\ \mu C$.



8. Electrons are located at the points (10.0 cm,0), (0,10.0 cm), and (10.0 cm,10.0 cm). Find the magnitude and direction of the electric field at the origin.

9. Find the electric dipole moment of a charge of 4.50 μC separated by 5.00 cm from a charge of $-4.50\ \mu C$.

†10. If a charge of 2.00 μC is separated by 4.00 cm from a charge of $-2.00\ \mu C$, find the electric field at a distance of 5.00 m, perpendicular to the axis of the dipole.

†11. Charges of 2.00 μC, 4.00 μC, $-6.00\ \mu C$, and 8.00 μC are placed at the corners of a square of 50.0 cm length. Find the electric field at the center of the square.

†12. (a) Find the electric field at point A in the diagram if charges $q_1 = 2.63\ \mu C$ and $q_2 = -2.63\ \mu C$, $d = 10.0$ cm, $r_1 = 50.0$ cm, $r_2 = 42.2$ cm, $\theta_1 = 35.0°$, and $\theta_2 = 42.8°$. (b) Find the force on a charge of 1.75 μC if it is placed at point A.

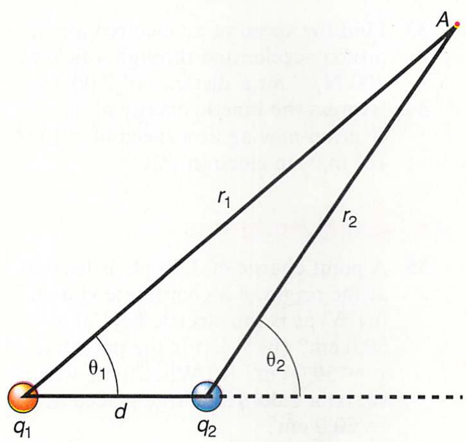


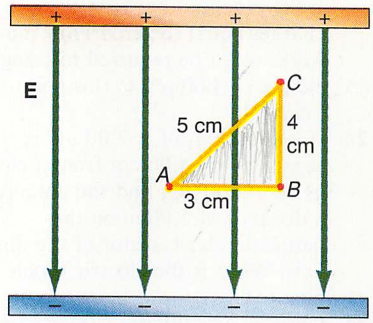
Diagram for problems 12, 13, 27, 28 and 44.

†13. Find the electric field at point A in the diagram if charges $q_1 = 2.63\ \mu C$ and $q_2 = -2.63\ \mu C$, $d = 10.0$ cm, $r_1 = 50.0$ cm, $\theta_1 = 25.0°$. (*Hint:* first find r_2 by the law of cosines, then with r_2 known, use the law of cosines again to find the angle θ_2.)

19.6 Electric Potential Energy and the Potential

14. Two charged parallel plates are separated by a distance of 2.00 cm. If the potential difference between the plates is 300 V, what is the value of the electric field between the plates?

†15. A charge of 3.00 pC is placed at point A in the diagram. The electric field is 200 N/C downward. Find the work done in moving the charge along the path ABC and the work done in going from A to C directly.



19.7 Potential of a Point Charge

16. A charge of 1.53×10^{-8} C is placed at the origin of a coordinate system. (a) Find the potential at point A located on the x-axis at $x = -5.00$ cm, and at point B located at $x = 20.0$ cm. (b) Find the difference in potential between points A and B.

17. Repeat problem 16 but with point A located at the coordinates $x = 0$ and $y = -5.00$ cm.

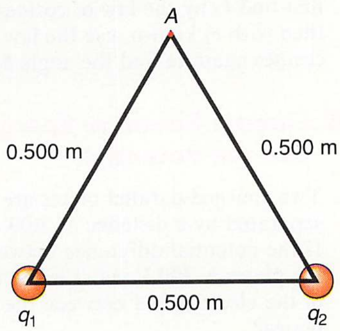
18. How much work is done in moving a charge of 3.00 μC from a point where the potential is 50.0 V to another point where the potential is (a) 150 V and (b) -150 V?

19. The potential difference between two terminals of a battery is 12.0 V. How much work is done by the battery in transferring 200 C of charge from one terminal to the other?

20. Find the potential 2.00 m from a point charge of 3.00 μC. How much work is required to bring a charge of 2.00 μC to this point from infinity?

19.8 Superposition of Potentials

21. Find the potential at the apex of the equilateral triangle shown in the diagram if (a) $q_1 = 2.00\ \mu C$ and $q_2 = 3.00\ \mu C$ and (b) if $q_1 = 2.00\ \mu C$ and $q_2 = -3.00\ \mu C$.



22. Electrons are located at the points (10.0 cm,0), (0,10.0 cm), and (10.0 cm,10.0 cm). Find the value of the electric potential at the origin.

23. A point charge of 2.00 μC is 30.0 cm from a charge of $-3.00\ \mu C$. Where is the potential between the two charges equal to zero? How much work would be required to bring a charge of 4.00 μC to this point from infinity?

24. If a charge q_1 of $+2.00\ \mu C$ is separated by 4.00 cm from a charge q_2 of $-2.00\ \mu C$, find the potential at a distance of 5.00 m on the perpendicular bisector of the dipole axis. What is the electric dipole moment?

†25. Charges of 2.00 μC, 4.00 μC, $-6.00\ \mu C$, and 8.00 μC are placed at the corners of a square of 50.0-cm sides. Find the potential at the center of the square.

26. Find the potential of a point charge of 5.00×10^{-10} C at distances of 10.0, 20.0, 30.0, 40.0, and 50.0 cm.

27. (a) Find the potential at point A in the diagram (see previous page) if charges $q_1 = 2.63\ \mu C$ and $q_2 = -2.63\ \mu C$, $d = 10.0$ cm, $r_1 = 50.0$ cm, $r_2 = 42.2$ cm, $\theta_1 = 35.0°$, and $\theta_2 = 42.8°$. (b) How much work is necessary to bring a charge of 1.75 μC from infinity to the point A?

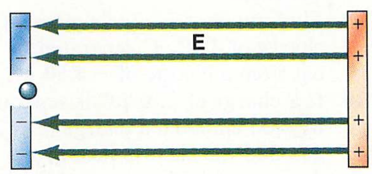
28. Find the potential at point A in the diagram (see previous page) if charges $q_1 = 2.63\ \mu C$ and $q_2 = -2.63\ \mu C$, $d = 10.0$ cm, $r_1 = 50.0$ cm, $\theta_1 = 25.0°$. (*Hint:* first find r_2 by the law of cosines, then with r_2 known, use the law of cosines again to find the angle θ_2.)

19.9 Dynamics of a Charged Particle in an Electric Field

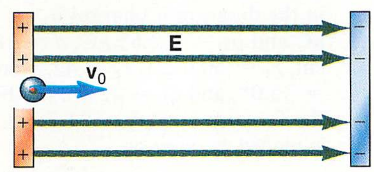
29. The parallel plates of a cathode ray oscilloscope are 1.00 cm apart. A voltage difference of 1000 V is maintained between the plates. (a) What is the electric field between the plates? (b) What force would act on an electron in this field? (c) What would be its acceleration?

30. An electron experiences an acceleration of 5.00 m/s^2 in an electric field. Find the magnitude of the electric field.

31. An electron is initially at rest at the opening of two parallel plates, as shown in the diagram. The plates are separated by a distance of 5.00 mm, and a potential difference of 150 V is maintained between the plates. (a) What is the initial potential energy of the electron? (b) What is the kinetic energy of the electron when it reaches the opposite side?



†32. An electron with an initial velocity of 1.00×10^6 m/s enters a region of a uniform electric field of 50.0 N/C, as shown in the diagram. How far will the electron move before coming to rest and reversing its motion?



33. Find the speed of an electron and a proton accelerated through a field of 200 N/C for a distance of 2.00 cm.

34. Express the kinetic energy of an electron moving at a speed of 3.00×10^5 m/s, in electron volts.

Additional Problems

35. A point charge of 3.00 pC is located at the origin of a coordinate system. (a) What is the electric field at $x = 50.0$ cm? (b) What is the potential at $x = 50.0$ cm? (c) What force would act on a 2.00-μC charge placed at $x = 50.0$ cm?

36. A point charge of 2.00 μC is 30.0 cm from a charge of 3.00 μC. Find the electric field half way between the charges. Find the potential half way between the charges. How much work would be done in bringing a 4.00-μC charge to this point from infinity?

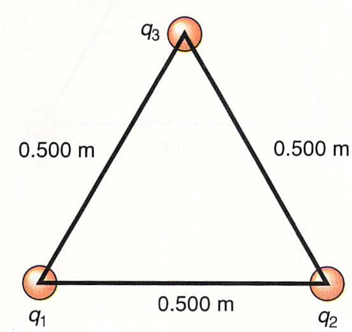
37. From symmetry considerations what should the electric field be at the center of a ring of charge? What assumptions did you make? Draw a diagram to substantiate your assumptions.

38. An electron is placed between two charged parallel horizontal plates. What must the value of the electric field be in order that the electron be in equilibrium between the electric force and the gravitational force?

39. Two metal plates are oriented horizontally and are 6.50 mm apart. They are connected to a source of electric potential, so that the top plate is positively charged and the bottom plate is negatively charged. What must be the potential difference between the plates if the electric force on an electron between the plates is to balance the weight of the electron, leaving the electron in equilibrium?

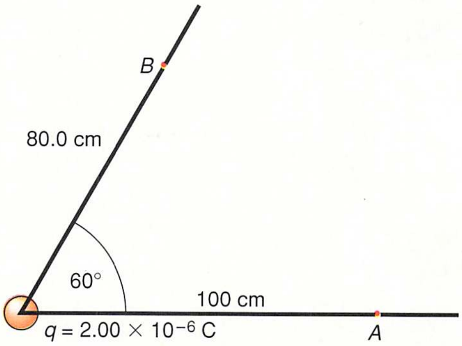
40. In the Bohr theory of the hydrogen atom the electron circles the proton in a circular orbit of 5.29×10^{-11} m radius. Find the electric potential, produced by the proton, at this orbital radius. From the definition of the potential, determine the potential energy of the electron in this orbit.

†41. How much work is necessary to assemble three charges from infinity to each apex of the equilateral triangle of 0.500 m on a side shown in the diagram if $q_1 = 3.00\ \mu C$, $q_2 = 4.50\ \mu C$, and $q_3 = 6.53\ \mu C$. Can you now talk about the potential energy of this charge configuration?



42. How much work must be done to assemble four protons at the corners of a square of edge 10.0 cm? (Assume that the protons start out very far apart.)

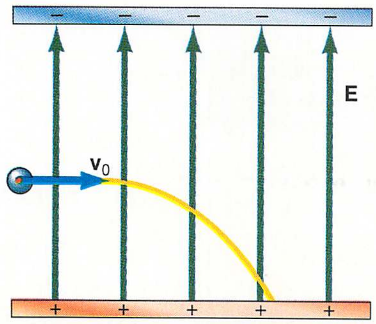
43. (a) Find the potential at the points A and B shown in the diagram. (b) Find the potential difference between the points A and B. (c) Find the work required to move a charge of 1.32 μC from point A to point B. (d) Find the work required to move the same charge from point B to point A.



†44. (a) Find the potential for an electric dipole at point A in the diagram (see page 559) if charges $q_1 = 2.00\ \mu$C and $q_2 = -2.00\ \mu$C, $d = 10.0$ cm, $r_1 = 50.0$ cm, $r_2 = 42.2$ cm, $\theta_1 = 35.0°$, and $\theta_2 = 42.8°$. (b) Repeat part a with q_1 now equal to 6.00 μC. Do you get the same result if you superimpose the potential field of the dipole of part a with the potential field of a point charge of 4.00 μC located at the same place as the original charge q_1?

†45. Find the potential of a point charge of 3.00 pC at 10.0, 20.0, 25.0, 28.0, 29.0, 30.0, 31.0, 32.0, 35.0, 40.0, and 50.0 cm. Calculate the electric field at 30.0 cm by taking intervals of Δr from 40.0 cm down to 2.00 cm in the formula $E = \Delta V/\Delta r$. What is the value of E at 30.0 cm as computed by $E = kq/r^2$?

†46. An electron enters midway through a uniform electric field of 200 N/C at an initial velocity of 400 m/s, as shown in the diagram. If the plates are separated by a distance of 2.00 cm, how far along the x-axis will the electron hit the bottom plate?



Interactive Tutorials

47. Calculate the value of the electric field E every meter along the line that connects the positive charges $q_1 = 2.40 \times 10^{-6}$ C located at the point (0,0) and $q_2 = 2.00 \times 10^{-6}$ C located at the point (10,0) meters.

48. Multiple charges and the electric field. Two charges $q_1 = 8.32 \times 10^{-6}$ C and $q_2 = -2.55 \times 10^{-6}$ C lie on the x-axis and are separated by the distance $r_{12} = 0.823$ m. (a) Find the resultant electric field at the point A, a distance $r = 0.475$ m from charge q_2, caused by the two charges q_1 and q_2. The line between charge 2 and the point A makes an angle $\phi = 60.0°$ with respect to the positive x-axis. (b) Find the force F acting on a third charge $q = 3.87 \times 10^{-6}$ C, if it is placed at the point A. See figure 19.5 for a picture of a similar problem.

49. The electric potential for multiple charges. Two charges $q_1 = 8.32 \times 10^{-6}$ C and $q_2 = -2.55 \times 10^{-6}$ C lie on the x-axis and are separated by the distance $r_{12} = 0.823$ m. (a) Find the resultant electric potential at the point A, a distance $r = 0.475$ m from charge q_2, caused by the two charges q_1 and q_2. The line between charge 2 and the point A makes an angle $\phi = 60.0°$ with respect to the $+x$-axis. (b) How much work is required to bring a charge $q = 3.87 \times 10^{-6}$ C from infinity to the point A?

50. The electric field of a continuous charge distribution. A rod of charge of length $L = 0.100$ m lies on the x-axis. One end of the rod lies at the origin and the other end is on the positive x-axis. A charge $q' = 7.36 \times 10^{-6}$ C is uniformly distributed over the rod. (a) Find the electric field at the point A that lies on the x-axis at a distance $x_0 = 0.175$ m from the origin of the coordinate system. (b) Find the force F that would act on a charge $q = 2.95 \times 10^{-6}$ C when placed at the point A.

51. The electric potential of a continuous charge distribution. A rod of charge of length $L = 0.100$ m lies on the x-axis. One end of the rod lies at the origin and the other end is on the positive x-axis. A charge $q' = 7.36 \times 10^{-6}$ C is uniformly distributed over the rod. (a) Find the electric potential at the point A that lies on the x-axis at a distance $x_0 = 0.175$ m from the origin of the coordinate system. (b) Find the work done to bring a charge $q = 2.95 \times 10^{-6}$ C from infinity to the point A.