that point. Like work and energy, electric potential is a scalar quantity. If work must be done to move a positively charged particle from point A to point B in an electric field, point B has a higher (more positive) potential than point A. If the positively charged particle is allowed to "fall" from point B to point A, the same amount of work will be done on the particle by the field. These work relationships are exactly the opposite for a *negatively* charged particle. Work must be done to move a negatively charged particle from higher to lower potential, but a negatively charged particle will fall freely from lower potential to higher.

Potential Difference. The **potential difference,** or **potential drop,** between two points in an electric field is the change in potential energy (or the work done) per unit charge as a charged particle is moved between the points. The potential difference is given by the formula

$$V = \frac{W}{q} \qquad \text{(Eq. 3-3)}$$

where W is the work in joules, q is the charge in coulombs, and V is the electric potential difference in joules/coulomb. If one joule of work is done against an electric field to transfer one coulomb of charge between two points in the field, a potential difference of one **volt** is said to exist between the two points. That is,

$$1 \text{ joule/coulomb} = 1 \text{ volt}$$

The volt, V, is the derived *SI* unit of electric potential and potential difference. Because the volt is a measure of the electric potential difference between points in an electric field, it can be used to calculate the energy required to transfer a given charge between these points. For example, to move 2 coulombs of charge across a potential difference of 3 volts, the work required is:

$$W = Vq = (3 \text{ V})(2 \text{ C}) = 6 \text{ J}$$

For example, an electric toaster connected to two points at a potential difference of 120 volts will receive 120 joules of energy for each coulomb of charge that passes through the toaster. On the other hand, when a 12-volt storage battery is charged from some external energy source, for every coulomb of charge transferred from one terminal of the battery to the other, 12 joules of energy are expended by the outside source.

The Electronvolt. If an elementary charge (the charge on an electron) is moved against an electric field through a potential difference of one volt, the work done on the charge is given by

$$W = Vq = (1.0 \text{ V})(1.6 \times 10^{-19} \text{ C}) = 1.6 \times 10^{-19} \text{ J}$$

This amount of work, or gain in potential energy, is called the **electronvolt,** eV. That is,

$$1 \text{ eV} = 1.6 \times 10^{-19} \text{ J}$$

(Do not confuse the italic symbol V, electric potential difference, with V, the *SI* unit for measuring the amount of electric potential difference.) The electronvolt is extremely small in comparison with the joule, but its size is convenient for expressing the energy commonly involved in chemical reactions between atoms and ions. For example, the energy needed to ionize (remove the electron from) a hydrogen atom when the electron is in its lowest possible energy level is 13.6 eV.

Relationship of Field Intensity to Field Potential. The electric field intensity of a uniform field is the rate at which electric potential changes with position. That is,

$$E = \frac{V}{d} \qquad \text{(Eq. 3-4)}$$

where V is potential in volts, d is change in position in meters, and E is the electric field intensity expressed in units of **volts/meter,** V/m. The volt/meter is identical with the unit newton/coulomb for E in Equation 3-2:

$$\frac{\text{volt}}{\text{meter}} = \frac{\text{joule/coulomb}}{\text{meter}} = \frac{\text{joule}}{\text{coulomb} \cdot \text{meter}} = \frac{\text{newton} \cdot \text{meter}}{\text{coulomb} \cdot \text{meter}} = \frac{\text{newton}}{\text{coulomb}}$$

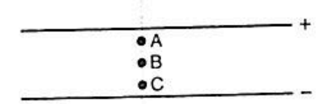
QUESTIONS

1. A metal (conducting) sphere with an excess charge of +11 elementary charges touches an identical sphere with an excess charge of +15 elementary charges. After the spheres touch, the excess of elementary charges on the first sphere is (1) +13 (2) +26 (3) −4 (4) +4

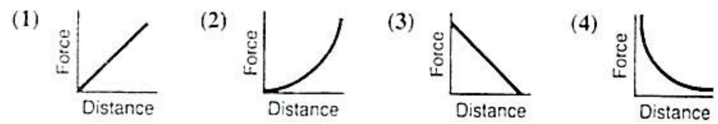
2. How much work is required to transfer 10. coulombs of charge between two points having a potential difference of 120 volts? (1) 0.083 J (2) 12 J (3) 600 J (4) 1,200 J

3. If a positively charged rod is brought near the knob of an uncharged electroscope without touching it, the leaves will diverge because
(1) negative charges are transferred from the electroscope to the rod
(2) negative charges are attracted to the knob of the electroscope
(3) positive charges are repelled to the leaves of the electroscope
(4) positive charges are transferred from the rod to the electroscope

4. An electron may be placed at positions A, B, or C between the two parallel charged metal plates shown. The electric force on the electron will be (1) greatest at A (2) greatest at B (3) greatest at C (4) the same at all three positions

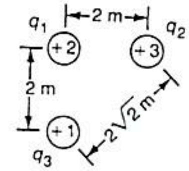


5. Which graph best represents the relationship between electrostatic force and distance of separation for two point charges?



6. When a positively charged body touches a neutral body, the neutral body will (1) gain protons (2) lose protons (3) gain electrons (4) lose electrons
7. Two point charges that are separated by a distance of 1.0 meter repel each other with a force equal to 9.0 newtons. What is the force of repulsion when these two charges are 3.0 meters apart? (1) 1.0 N (2) 27 N (3) 3.0 N (4) 81 N
8. An electron gains 2 electronvolts of energy as it is transferred from point A to point B. The potential difference between points A and B is (1) 3.2×10^{-19} V (2) 2.0 V (3) 32 V (4) 1.3×10^{19} V
9. Two parallel metal plates have a potential difference of 50. volts. How much work is done in moving a charge of 4.0×10^{-5} coulomb from one plate to the other? (1) 8.0×10^{-7} J (2) 1.6×10^{-3} J (3) 2.0×10^{-3} J (4) 1.3×10^{6} J
10. One metallic sphere has a charge of +16 units and a second, identical sphere has a charge of −4 units. After the two spheres touch, the charge on each sphere is (1) +6 units (2) +12 units (3) +20 units (4) −20 units
11. If object A becomes positively charged when rubbed with object B, then object B has (1) gained electrons (2) lost electrons (3) gained protons (4) lost protons
12. The main purpose of an electroscope is to (1) neutralize a charge (2) produce a charge (3) measure a charge (4) find the sign of a charge
13. If the distance between 2 protons is tripled, then the force they exert on each other, compared with the original force, will be (1) one-ninth as great (2) one-third as great (3) three times as great (4) nine times as great
14. Why does a neutral hard rubber rod become negatively charged when rubbed with wool? (1) The rod loses protons. (2) The rod loses electrons. (3) The wool loses protons. (4) The wool loses electrons.
15. An energy of 2.0×10^{4} electronvolts is equal to (1) 1.6×10^{-19} J (2) 3.2×10^{-19} J (3) 3.2×10^{-15} J (4) 5.0×10^{-5} J
16. A and B are two identical uncharged metal spheres. Sphere A is given an electrical charge of $+q$, touched to sphere B, and then removed. The charge on sphere A after separation is (1) $+q$ (2) $-q$ (3) $+q/2$ (4) $-q/2$

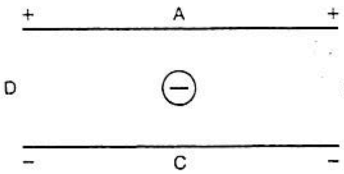
17. Three electric charges are arranged as shown. Which vector best represents the resultant force that charges q_2 and q_3 exert on charge q_1?



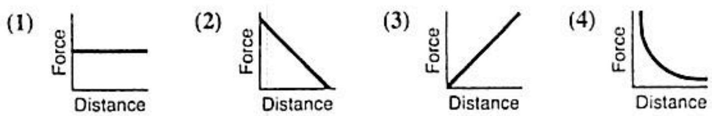
18. The work required to move 1.0 coulomb of charge through a potential difference of 2.0 volts is (1) 0.50 J (2) 2.0 J (3) 3.0 J (4) 4.0 J
19. An electron moves through a potential difference of 3.00 volts. The energy acquired by the charge is (1) 5.33×10^{-19} J (2) 1.60×10^{-19} J (3) 4.80×10^{-19} J (4) 3.00 J
20. A and B are two points in an electric field. If 6.0 joules of work are done in transferring 2.0 coulombs of electric charge from point A to point B, then the potential difference between points A and B is (1) 0.0 V (2) 1.5 V (3) 3.0 V (4) 12 V
21. A neutral object can become positively charged by (1) gaining electrons (2) losing electrons (3) gaining protons (4) losing protons
22. When two objects are rubbed together, which particle is most likely to be transferred? (1) nucleus (2) electron (3) proton (4) neutron
23. The electronvolt is a unit of (1) current (2) power (3) resistance (4) energy
24. If the charge on one of two positively charged spheres is doubled, the electrostatic force of repulsion between the spheres will be (1) halved (2) doubled (3) quartered (4) quadrupled
25. The electric force between two charged spheres is 18 newtons. If the distance between the centers of the spheres is tripled, the resulting electric force will be (1) 6.0 N (2) 2.0 N (3) 3.0 N (4) 54 N
26. The electric force between two charged spheres is 64 newtons. If the distance between the centers of the spheres is quadrupled the resulting electric force will be (1) 8.0 N (2) 2.0 N (3) 16 N (4) 4.0 N
27. In general, solid materials become electrically charged because of transfer of (1) positrons (2) electrons (3) protons (4) neutrons
28. As an electron approaches a proton, electrostatic force acts on (1) the electron only (2) the proton only (3) both the electron and the proton (4) neither the electron nor the proton
29. The energy of an electron may be increased by 8×10^{-17} joule if it is moved through a potential difference of (1) 0.002 V (2) 200 V (3) 500 V (4) 5,000 V
30. If the distance between two point sources of equal charge is halved, the electrical force between the sources will be (1) halved (2) doubled (3) quartered (4) quadrupled

31. A charge of 8.0×10^{-5} coulomb is moved by a force of 2.0×10^{-2} newton between two points 0.10 meter apart in a uniform electric field. The potential difference between the two points is (1) 25 V (2) 40. V (3) 75 V (4) 160 V

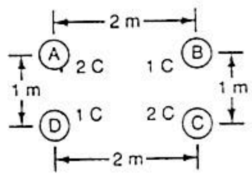
32. An electron is projected from *D* toward *B* between two parallel charged plates as shown in the illustration. The electric force acting on the electron is directed toward (1) *A* (2) *B* (3) *C* (4) *D*



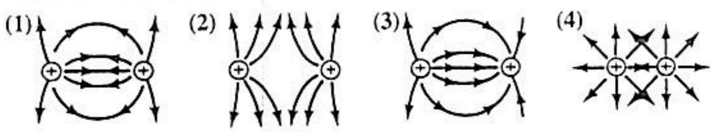
33. A battery of constant potential is connected to two parallel metal plates. Which graph best represents the relationship between the force on an electron between the plates and the distance between the plates?



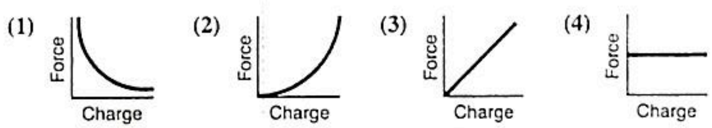
34. Four electric charges, *A*, *B*, *C*, and *D*, are arranged as shown. The electric force will be least between charges (1) *A* and *B* (2) *A* and *C* (3) *A* and *D* (4) *B* and *D*



35. Which diagram best represents the electric field surrounding two positively charged spheres?



36. Which graph best illustrates the relationship between electrostatic force and the charge on two positive point charges that are always equal to each other in magnitude?



37. As the amount of charge held on an object increases, the potential difference required to add additional charges of the same sign to it (1) decreases (2) increases (3) remains the same

38. As a charged object located between two oppositely charged parallel plates is moved parallel to the surfaces of the plates, the electric force on the object (1) decreases (2) increases (3) remains the same

39. As the electric charge on the surface of a hollow metal sphere increases, the electric field intensity inside the sphere (1) decreases (2) increases (3) remains the same

40. As an electron moves toward a positively charged body, the electron's kinetic energy (1) decreases (2) increases (3) remains the same

41. As an electron approaches a proton, the electrical force between them (1) decreases (2) increases (3) remains the same

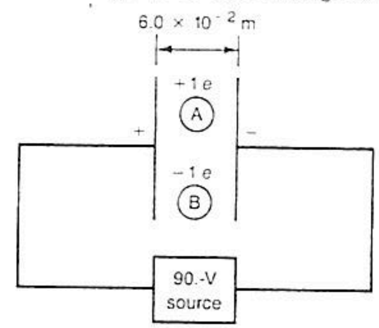
42. As charged body *A* charges neutral body *B* by direct contact, the quantity of charge on body *A* (1) is decreased (2) is increased (3) remains the same

43. As a negatively charged rod is moved toward the tip of a positively charged electroscope, the number of electrons in the tip of the electroscope (1) decreases (2) increases (3) remains the same

44. A battery of constant potential difference is connected to two parallel metal plates. As the distance between the plates is increased, the electric field intensity between the plates (1) decreases (2) increases (3) remains the same

45–49. Base your answers to Questions 45 through 49 on the drawing and the following information.

Two particles, *A* and *B*, are placed between two parallel plates 6.0×10^{-2} meter apart in a vacuum. The potential difference across the plates is 90. volts. The charge on *A* is +1 elementary charge and that on *B* is −1 elementary charge. The mass of *A* is 4 times the mass of *B*.



45. What is the increase in the kinetic energy of particle *A* as it moves from the positive to the negative plate? (1) 1.44×10^{-17} eV (2) 1.60×10^{-19} eV (3) 90 eV (4) 360 eV

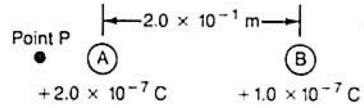
46. What is the increase in the kinetic energy of particle *B* as it moves from the negative to the positive plate? (1) 1.44×10^{-17} J (2) 1.60×10^{-19} J (3) 22.5 J (4) 90 J

47. The ratio of the increase in the kinetic energy of particle *A* to the increase in the kinetic energy of particle *B* is (1) 1/1 (2) 2/1 (3) 1/2 (4) 4/1

48. What is the electric field intensity between the two plates? (1) 5.4 N/C (2) 1.5×10^{3} N/C (3) 6.7×10^{-2} N/C (4) 2.4×10^{-16} N/C

49. If the distance between the plates is decreased while other factors remain the same, there will be no change in the (1) charge on the plates (2) force on an electron between the plates (3) electric field between the plates (4) potential difference across the plates

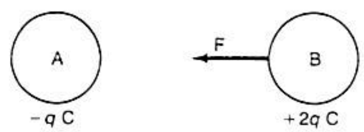
50–54. Base your answers to Questions 50 through 54 on the following information and the illustration at the right.



Two identical metal spheres, A and B, are given charges of $+2.0 \times 10^{-7}$ coulomb and $+1.0 \times 10^{-7}$ coulomb, respectively. The separation between their centers is 2.0×10^{-1} meter.

50. The electric force exerted on B by A will be directed (1) to the left (2) to the right (3) toward the top of the page (4) into the page
51. If the magnitude of the electric force on B is equal to F, the magnitude of the electric force on A will be equal to (1) F (2) $2F$ (3) $F/2$ (4) $4F$
52. The magnitude of the electric force exerted on B is equal to (1) 9.0×10^3 N (2) 9.0×10^{-4} N (3) 4.5×10^4 N (4) 4.5×10^{-3} N
53. A positive charge of 1.0×10^{-10} coulomb at a point P near sphere A is acted upon by a force of 2.0×10^{-15} newton. What is the intensity of the electrical field at point P? (1) 2.0×10^{-15} N/C (2) 2.0×10^{-5} N/C (3) 2.0×10^5 N/C (4) 5.0×10^{-6} N/C
54. If A and B are brought into contact, which will gain electrons? (1) A only (2) B only (3) both A and B (4) neither A nor B

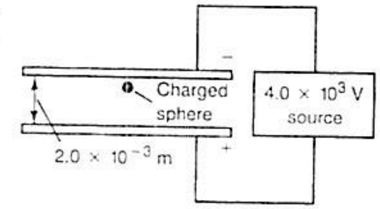
55–59. Base your answers to Questions 55 through 59 on the following information.



A metal sphere, A, has a charge of $-q$ coulombs. An identical metal sphere, B, has a charge of $+2q$ coulombs. The magnitude of the electric force on B due to A is F newtons.

55. The magnitude of the electric force on A due to B, in newtons, is (1) F (2) $2F$ (3) $F/2$ (4) $4F$
56. If the distance between the centers of the spheres is halved, the magnitude of the force on B due to A, in newtons, will be (1) F (2) $2F$ (3) $F/2$ (4) $4F$
57. If an electron were placed midway between A and B, the resultant electric force on the electron would be (1) toward A (2) toward B (3) up (4) down
58. If A and B are connected by a copper wire whose surface is negligible compared with that of the spheres, charge will flow through the connecting wire until the charge on B in coulombs becomes (1) 0 C (2) $+q/2$ C (3) $+q$ C (4) $-q$ C
59. The current in the wire consists of a flow of (1) protons from A to B (2) protons from B to A (3) electrons from B to A (4) electrons from A to B

60–63. Base your answers to Questions 60 through 63 on the diagram, which represents two large parallel metal plates with a small charged sphere between them.



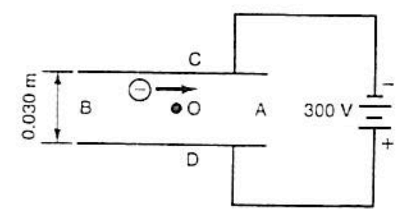
60. The energy gained by the charged sphere as it moves from the negative plate to the positive plate can be measured in (1) electronvolts (2) volt · meters (3) coulombs/volt (4) volts/meter
61. What is the intensity of the electric field between the two charged plates? (1) 5.0×10^{-17} m/V (2) 2.0×10^6 V/m (3) 1.6×10^{-16} C/m (4) 8.0 V · m
62. If the distance between the plates were increased, the field intensity would (1) decrease (2) increase (3) remain the same
63. As the sphere moves from the negative plate to the positive plate, the force on the sphere (1) decreases (2) increases (3) remains the same

64–66. Base your answers to Questions 64 through 66 on the following information.

Charge $+q$ is located a distance r from charge $+Q$. Each charge is 1.0 coulomb.

64. The electric field due to charge $+Q$ at distance r is equal to (1) $\frac{kQ}{F}$ (2) $\frac{kQq}{r}$ (3) $\frac{Q}{r^2}$ (4) $\frac{kQ}{r^2}$
65. If 200 joules of work is required to move $+q$ through distance r to $+Q$, the potential difference between the two charges is (1) 100 V (2) 200 V (3) 800 V (4) 50 V
66. If distance r is doubled, then the force that $+Q$ exerts on $+q$ is (1) halved (2) doubled (3) unchanged (4) quartered

67–71. Base your answers to Questions 67 through 71 on the following information.



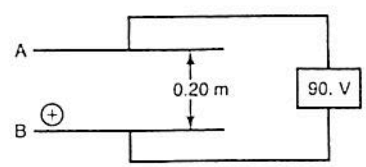
An electron is projected into the vacuum space between two charged parallel plates, as shown. The plates are 0.030 meter apart. The potential difference between the plates is 300 volts.

67. The direction of the electric field at point O between the plates is toward (1) A (2) B (3) C (4) D

68. The magnitude of the electric field at point O between the plates is (1) 1.0×10^4 N/C (2) 1.5×10^{-3} N/C (3) 9.0×10^{-3} N/C (4) 6.7×10^{-11} N/C
69. An electron moving from B toward A between the plates will be acted upon by an electric force that is always directed (1) toward the positive plate (2) toward the negative plate (3) parallel to the plate surfaces (4) at right angles to the instantaneous velocity of the electron
70. As the electron moves between the plates, its kinetic energy (1) decreases (2) increases (3) remains the same
71. If the distance between the plates is increased, the intensity of the electric field between them (1) decreases (2) increases (3) remains the same

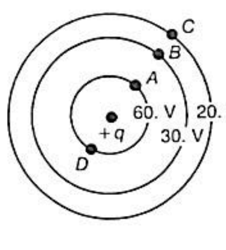
72–76. Base your answers to Questions 72 through 76 on the following information.

A proton (represented by ⊕) is placed between the two parallel plates, A and B, as shown. The plates are 0.20 meter apart and connected to a 90.-volt battery. The proton has a force exerted on it toward A.



72. The direction of the electric field between the two plates is from (1) positive plate A to negative plate B (2) negative plate A to positive plate B (3) positive plate B to negative plate A (4) negative plate B to positive plate A
73. The magnitude of the electric field intensity between the two plates is (1) 18 N/C (2) 45 N/C (3) 180 N/C (4) 450 N/C
74. The kinetic energy gained by the proton in moving from plate B to plate A is (1) 1.4×10^{-21} J (2) 1.8×10^{-21} J (3) 1.4×10^{-17} J (4) 1.8×10^{-17} J
75. If the proton is now moved back toward plate B, its potential energy will (1) decrease (2) increase (3) remain the same
76. As the separation between plates A and B is increased, the electric field intensity between the plates will (1) decrease (2) increase (3) remain the same

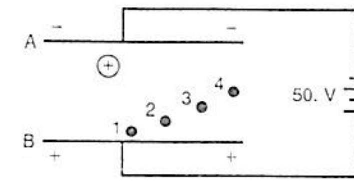
77–81. Base your answers to Questions 77 through 81 on the diagram, in which circular lines are drawn at 60. volts, 30. volts, and 20. volts about electric charge $+q$.



77. The total work done in moving 1.0 coulomb of charge from A to D is (1) 0.0 J (2) 40. J (3) 60. J (4) 80. J
78. The total work done in moving 2.0 coulombs of positive charge from position C to position A is (1) 0.0 J (2) 40. J (3) 60. J (4) 80. J
79. If 5.0 coulombs of charge moves from position A to position B, the energy expended will be (1) 5.0 J (2) 6.0 J (3) 30. J (4) 150 J
80. Compared with A, the magnitude of the electric field intensity at B is (1) less (2) greater (3) the same
81. If $+q$ is increased to $+2q$, the potential at B (1) decreases (2) increases (3) remains the same

82–86. Base your answers to Questions 82 through 86 on the following information.

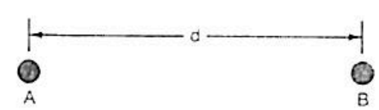
There is a potential difference of 50. volts across parallel plates A and B. A positive charge is located as shown.



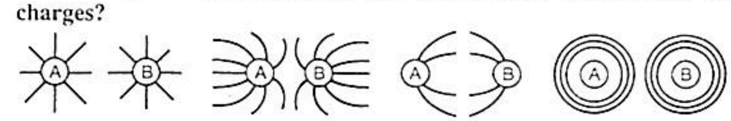
82. If the separation of the plates is 1.0×10^{-1} meter, then the electric field intensity between them is (1) 8.0×10^{-16} V/m (2) 5.0×10^2 V/m (3) 5.0×10^{-1} V/m (4) 3.1×10^{18} V/m
83. How much work would be required to move +2.0 coulombs of charge from plate A to plate B? (1) 5.0×10^1 J (2) 2.0×10^1 J (3) 1.0×10^2 J (4) 6.25×10^{18} J
84. The greatest amount of work would be required to move the positive charge from its present position to point (1) 1 (2) 2 (3) 3 (4) 4
85. An electron moving freely from plate A to plate B would acquire a maximum kinetic energy of (1) 4.5×10^{-3} eV (2) 2.5 eV (3) 5.0×10^1 eV (4) 1.0×10^2 eV
86. The electrical potential energy of the positive charge is greatest if the charge is located at position (1) 1 (2) 2 (3) 3 (4) 4

87–91. Base your answers to Questions 87 through 91 on the following information.

The diagram represents two equal negative point charges, A and B, that are a distance d apart.



87. Which diagram best represents the electric field between the two charges?



(1) (2) (3) (4)