[*The potential due to an **electric dipole** drops off as $1/r^2$. The **dipole moment** is $p = Ql$, where ℓ is the distance between the two equal but opposite charges of magnitude *Q.*]
A **capacitor** is a device used to store charge (and electric energy), and consists of two nontouching conductors. The two conductors hold equal and opposite charges, of magnitude *Q.* The ratio of this charge *Q* to the potential difference *V* between the conductors is called the **capacitance**, *C*:

(17–7)

$$C = \frac{Q}{V}, \quad \text{or} \quad Q = CV\,.$$

The capacitance of a parallel-plate capacitor is proportional to the area *A* of each plate and inversely proportional to their separation *d*:

(17–8)

$$C = \epsilon_0 \frac{A}{d}\,.$$

The space between the two conductors of a capacitor contains a nonconducting material such as air, paper, or plastic. These materials are referred to as **dielectrics**, and the capacitance is proportional to a property of dielectrics called the **dielectric constant**, *K* (equal to 1 for air).

A charged capacitor stores an amount of electric energy given by

(17–10)

$$\mathrm{PE} = \frac{1}{2}QV = \frac{1}{2}CV^2 = \frac{1}{2}\frac{Q^2}{C}\,.$$

This energy can be thought of as stored in the electric field between the plates.

The energy stored in any electric field *E* has a density

(17–11)

$$\frac{\text{electric PE}}{\text{volume}} = \frac{1}{2}\epsilon_0 E^2\,.$$

Digital electronics converts an analog **signal voltage** into an approximate digital voltage based on a **binary code**: each **bit** has two possibilities, 1 or 0 (also "on" or "off"). The binary number 1101 equals 13. A **byte** is 8 bits and provides $2^8 = 256$ voltage levels. **Sampling rate** is the number of voltage measurements done on the analog signal per second. The **bit depth** is the number of digital voltage levels available at each sampling. CDs are 44.1 kHz, 16-bit.

[*TV and computer monitors traditionally used a **cathode ray tube** (CRT) which accelerates electrons by high voltage, and sweeps them across the screen in a regular way using magnetic coils or electric deflection plates. **LCD flat screens** contain millions of **pixels**, each with a red, green, and blue **subpixel** whose brightness is addressed

every $\frac{1}{60}\,\mathrm{s}$ via a **matrix** of horizontal and vertical wires using a **digital** (**binary**) code.]

[*An **electrocardiogram** (ECG or EKG) records the potential changes of each heart beat as the cells depolarize and repolarize.]

Questions

1. If two points are at the same potential, does this mean that no net work is done in moving a test charge from one point to the other? Does this imply that no force must be exerted? Explain.
   F=qE
   E=-DV/d
   so E=0 and F=0
2. If a negative charge is initially at rest in an electric field, will it move toward a region of higher potential or lower potential? What about a positive charge? How does the potential energy of the charge change in each instance? Explain.
   neg: to higher V
   pos: to lower V
   PE ~~increases~~ decreases
3. State clearly the difference (*a*) between electric potential and electric field, (*b*) between electric potential and electric potential energy.
4. An electron is accelerated from rest by a potential difference of 0.20 V. How much greater would its final speed be if it is accelerated with four times as much voltage? Explain.
   KE new=4KE old
   So, v new = 2 v old
5. Is there a point along the line joining two equal positive charges where the electric field is zero? Where the electric potential is zero? Explain.
   Field zero in mid
   potential never zero
   (is pos and adds)
6. Can a particle ever move from a region of low electric potential to one of high potential and yet have its electric potential energy decrease? Explain.
   Yes, neg charge
7. If *V* = 0 at a point in space, must $\vec{\mathbf{E}} = 0$? If $\vec{\mathbf{E}} = 0$ at some point, must *V* = 0 at that point? Explain. Give examples for each.
   No (pos and neg charges)
   No (see Q5)
8. Can two equipotential lines cross? Explain. **No (different lines have diff pot)**
9. Draw in a few equipotential lines in **Fig. 16–32b** and c.

10. When a battery is connected to a capacitor, why do the two plates acquire charges of the same magnitude? Will this be true if the two plates are different sizes or shapes?
11. A conducting sphere carries a charge *Q* and a second identical conducting sphere is neutral. The two are initially isolated, but then they are placed in contact. (*a*) What can you say about the potential of each when they are in contact? (*b*) Will charge flow from one to the other? If so, how much?
12. The parallel plates of an isolated capacitor carry opposite charges, *Q.* If the separation of the plates is increased, is a force required to do so? Is the potential difference changed? What happens to the work done in the pulling process?

YES

Q stays same; C down so V up

W goes into PE

13. If the electric field $\vec{\mathbf{E}}$ is uniform in a region, what can you infer about the electric potential *V*? If *V* is uniform in a region of space, what can you infer about $\vec{\mathbf{E}}$?

V=-Ed

E=0

14. Is the electric potential energy of two isolated unlike charges positive or negative? What about two like charges? What is the significance of the sign of the potential energy in each case?

NEG
POS

E change

15. If the voltage across a fixed capacitor is doubled, the amount of energy it stores (*a*) doubles; (*b*) is halved; (*c*) is quadrupled; (*d*) is unaffected; (*e*) none of these. Explain.

Text

16. How does the energy stored in a capacitor change when a dielectric is inserted if (*a*) the capacitor is isolated so *Q* does not change; (*b*) the capacitor remains connected to a battery so *V* does not change? Explain.

17. A dielectric is pulled out from between the plates of a capacitor which remains connected to a battery. What changes occur to (*a*) the capacitance, (*b*) the charge on the plates, (*c*) the potential difference, (*d*) the energy stored in the capacitor, and (*e*) the electric field? Explain your answers.
18. We have seen that the capacitance C depends on the size and position of the two conductors, as well as on the dielectric constant K. What then did we mean when we said that C is a constant in **Eq. 17–7** ?

MisConceptual Questions

1. A +0.2 μC charge is in an electric field. What happens if that charge is replaced by a +0.4 μC charge?
    a. The electric potential doubles, but the electric potential energy stays the same.
    b. The electric potential stays the same, but the electric potential energy doubles.
    c. Both the electric potential and electric potential energy double.
    d. Both the electric potential and electric potential energy stay the same.

2. Two identical positive charges are placed near each other. At the point halfway between the two charges,
    a. the electric field is zero and the potential is positive.
    b. the electric field is zero and the potential is zero.
    c. the electric field is not zero and the potential is positive.
    d. the electric field is not zero and the potential is zero.
    e. None of these statements is true.

3. Four identical point charges are arranged at the corners of a square [*Hint*: Draw a figure]. The electric field E and potential V at the center of the square are
    a. $E = 0$, $V = 0$.
    b. $E = 0$, $V \neq 0$.
    c. $E \neq 0$, $V \neq 0$.
    d. $E \neq 0$, $V = 0$.
    e. $E = V$ regardless of the value.

4. Which of the following statements is valid?
    a. If the potential at a particular point is zero, the field

at that point must be zero.

b. If the field at a particular point is zero, the potential at that point must be zero.

c. If the field throughout a particular region is constant, the potential throughout that region must be zero.

d. If the potential throughout a particular region is constant, the field throughout that region must be zero.

5. If it takes an amount of work W to move two $+q$ point charges from infinity to a distance d apart from each other, then how much work should it take to move three $+q$ point charges from infinity to a distance d apart from each other?
    a. $2W$.
    b. $3W$.
    c. $4W$.
    d. $6W$.

6. A proton ($Q = +e$) and an electron ($Q = -e$) are in a constant electric field created by oppositely charged plates. You release the proton from near the positive plate and the electron from near the negative plate. Which feels the larger electric force?
    a. The proton.
    b. The electron.
    c. Neither—there is no force.
    d. The magnitude of the force is the same for both and in the same direction.
    e. The magnitude of the force is the same for both but in opposite directions.

7. When the proton and electron in MisConceptual Question 6 strike the opposite plate, which one has more kinetic energy?

a. The proton.
b. The electron.
c. Both acquire the same kinetic energy.
d. Neither—there is no change in kinetic energy.
e. They both acquire the same kinetic energy but with opposite signs.

8. Which of the following do not affect capacitance?
   a. Area of the plates.
   b. Separation of the plates.
   c. Material between the plates.
   d. Charge on the plates.
   e. Energy stored in the capacitor.

9. A battery establishes a voltage *V* on a parallel-plate capacitor. After the battery is disconnected, the distance between the plates is doubled without loss of charge. Accordingly, the capacitance _____and the voltage between the plates_____.

   Q=CV
   C prop A/d

   a. increases; decreases.
   b. decreases; increases.
   c. increases; increases.
   d. decreases; decreases.
   e. stays the same; stays the same.

10. Which of the following is a vector?
    a. Electric potential.
    b. Electric potential energy.
    c. Electric field.
    d. Equipotential lines.
    e. Capacitance.

11. A +0.2 μC charge is in an electric field. What happens if that charge is replaced by a –0.2 μC charge?

a. The electric potential changes sign, but the electric potential energy stays the same.
b. The electric potential stays the same, but the electric potential energy changes sign.
c. Both the electric potential and electric potential energy change sign.
d. Both the electric potential and electric potential energy stay the same.

Problems

17–1 to 17–4 Electric Potential

1. (I) How much work does the electric field do in moving a −7.7 μC charge from ground to a point whose potential is +65 V higher? **5 X 10^(-4)J**
2. (I) How much work does the electric field do in moving a proton from a point at a potential of +125 V to a point at −45 V? Express your answer both in joules and electron volts. **2.7 X 10^(-17), 170 eV**
3. (I) What potential difference is needed to stop an electron that has an initial velocity $v = 6.0 \times 10^5$ m/s?
4. (I) How much kinetic energy will an electron gain (in joules and eV) if it accelerates through a potential difference of 18,500 V?
5. (I) An electron acquires 6.45×10^{-16}J of kinetic energy when it is accelerated by an electric field from plate A to plate B. What is the potential difference between the plates, and which plate is at the higher potential?
6. (I) How strong is the electric field between two parallel plates 6.8 mm apart if the potential difference between them is 220 V?
7. (I) An electric field of 525 V/m is desired between two parallel plates 11.0 mm apart. How large a voltage should be applied?
8. (I) The electric field between two parallel plates connected to a 45-V battery is 1900 V/m. How far apart are the plates?
9. (I) What potential difference is needed to give a helium nucleus ($Q = 2e$) 85.0 keV of kinetic energy?
10. (II) Two parallel plates, connected to a 45-V power supply, are separated by an air gap. How small can the gap be if the air is not to become conducting by exceeding its breakdown value of $E = 3 \times 10^6$ V/m?
11. (II) The work done by an external force to move a −6.50 μC

charge from point A to point B is 15.0×10^{-4}J. If the charge was started from rest and had 4.82×10^{-4}J of kinetic energy when it reached point B, what must be the potential difference between A and B?

12. (II) What is the speed of an electron with kinetic energy (*a*) 850 eV, and (*b*) 0.50 keV? **a) 1.7 X 10^7 m/s (b) 1.3 X 10^7 m/s**
13. (II) What is the speed of a proton whose KE is 4.2 keV?
14. (II) An alpha particle (which is a helium nucleus, $Q = +2e$, $m = 6.64 \times 10^{-27}$ kg) is emitted in a radioactive decay with KE = 5.53 MeV. What is its speed?
15. (II) An electric field greater than about 3×10^{6} V/m causes air to break down (electrons are removed from the atoms and then recombine, emitting light). See **Section 17–2** and **Table 17–3**. If you shuffle along a carpet and then reach for a doorknob, a spark flies across a gap you estimate to be 1 mm between your finger and the doorknob. Estimate the voltage between your finger and the doorknob. Why is no harm done?
16. (II) An electron starting from rest acquires 4.8 keV of KE in moving from point A to point B. (*a*) How much KE would a proton acquire, starting from rest at B and moving to point A? (*b*) Determine the ratio of their speeds at the end of their respective trajectories.
17. (II) Draw a conductor in the oblong shape of a football. This conductor carries a net negative charge, -*Q*. Draw in a dozen or so electric field lines and equipotential lines.

17–5 Potential Due to Point Charges

[Let $V = 0$ at $x = \infty$.]

18. (I) What is the electric potential 15.0 cm from a 3.00 μC point charge? **1.8 X 10^5V**
19. (I) A point charge Q creates an electric potential of +165 V at a distance of 15 cm. What is Q? **2.75 X 10^(-9) C**
20. (II) A +35 μC point charge is placed 46 cm from an identical +35 μC charge. How much work would be required to move a +0.50 μC test charge from a point midway between them to a point 12 cm closer to either of the charges?
21. (II) (*a*) What is the electric potential 2.5×10^{-15} m away from a proton (charge $+e$)? (*b*) What is the electric potential energy of a system that consists of two protons 2.5×10^{-15} m apart—as might occur inside a typical nucleus?
22. (II) Three point charges are arranged at the corners of a square of side ℓ as shown in **Fig. 17–39** . What is the potential at the fourth corner (point A)?

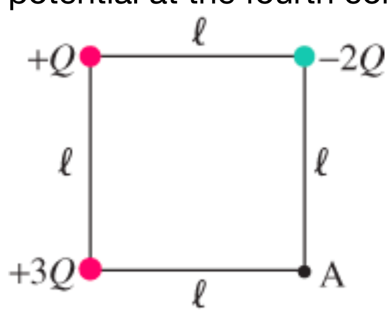

Figure 17–39

Problem 22.

23. (II) An electron starts from rest 24.5 cm from a fixed point charge with $Q = -6.50$ nC. How fast will the electron be moving when it is very far away?
24. (II) Two identical +9.5 μC point charges are initially 5.3 cm

from each other. If they are released at the same instant from rest, how fast will each be moving when they are very far away from each other? Assume they have identical masses of 1.0 mg.

25. (II) Two point charges, 3.0 μC and –2.0 μC, are placed 4.0 cm apart on the *x* axis. At what points along the *x* axis is (*a*) the electric field zero and (*b*) the potential zero?
26. (II) How much work must be done to bring three electrons from a great distance apart to 1.0×10^{-10} m from one another (at the corners of an equilateral triangle)?
27. (II) Point a is 62 cm north of a –3.8 μC point charge, and point b is 88 cm west of the charge (**Fig. 17–40**).

Determine (*a*) $V_b - V_a$ and (*b*) $\vec{\mathbf{E}}_\mathrm{b} - \vec{\mathbf{E}}_\mathrm{a}$ (magnitude and direction).

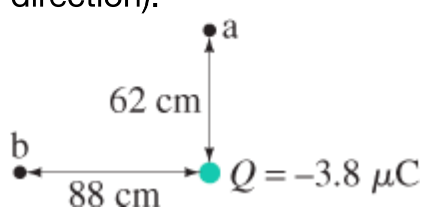

Figure 17–40
Problem 27.

28. (II) Many chemical reactions release energy. Suppose that at the beginning of a reaction, an electron and proton are separated by 0.110 nm, and their final separation is 0.100 nm. How much electric potential energy was lost in this reaction (in units of eV)?
29. (III) How much voltage must be used to accelerate a proton (radius 1.2×10^{-15} m) so that it has sufficient energy to just "touch" a silicon nucleus? A silicon nucleus has a charge of

+ 14*e*, and its radius is about 3.6×10^{-15} m. Assume the potential is that for point charges.

30. (III) Two equal but opposite charges are separated by a distance *d*, as shown in **Fig. 17–41**. Determine a formula for $V_{BA} = V_B - V_A$ for points B and A on the line between the charges situated as shown.

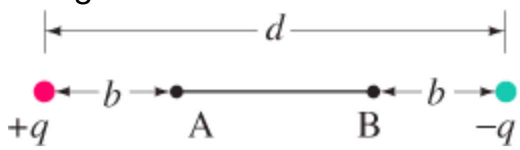

Figure 17–41

Problem 30.

31. (III) In the Bohr model of the hydrogen atom, an electron orbits a proton (the nucleus) in a circular orbit of radius 0.53×10^{-10} m. (*a*) What is the electric potential at the electron's orbit due to the proton? (*b*) What is the kinetic energy of the electron? (*c*) What is the total energy of the electron in its orbit? (*d*) What is the *ionization energy*—that is, the energy required to remove the electron from the atom and take it to $r = \infty$, at rest? Express the results of parts (*b*), (*c*), and (*d*) in joules and eV.

*17–6 Electric Dipoles

32. * (I) An electron and a proton are 0.53×10^{-10} m apart. What is their dipole moment if they are at rest?
33. * (II) Calculate the electric potential due to a dipole whose dipole moment is $4.2 \times 10^{-30}\ \mathrm{C \cdot m}$ at a point 2.4×10^{-9} m away if this point is (*a*) along the axis of the dipole nearer the positive charge; (*b*) 45° above the axis but nearer the positive charge; (*c*) 45° above the axis but nearer the negative charge.
34. * **(III)** The dipole moment, considered as a vector, points from the negative to the positive charge. The water molecule, **Fig. 17–42**, has a dipole moment $\vec{\mathbf{p}}$ which can be considered as the vector sum of the two dipole moments, $\vec{\mathbf{p}}_1$ and $\vec{\mathbf{p}}_2$, as shown. The distance between each H and the O is about 0.96×10^{-10} m. The lines joining the center of the O atom with each H atom make an angle of 104°, as shown, and the net dipole moment has been measured to be $p = 6.1 \times 10^{-30}\ \mathrm{C \cdot m}$. Determine the charge q on each H atom.

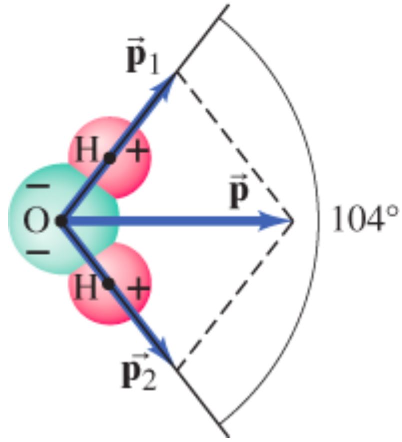

Figure 17–42

Problem 34. A water molecule, H_2O.

17–7 Capacitance

35. (I) The two plates of a capacitor hold +2500 μC and –2500 μC of charge, respectively, when the potential difference is 960 V. What is the capacitance? **2.6 muF**
36. (I) An 8500-pF capacitor holds plus and minus charges of 16.5×10^{-8} C. What is the voltage across the capacitor? **19V**
37. (I) How much charge flows from each terminal of a 12.0-V battery when it is connected to a 5.00-μF capacitor?
38. (I) A 0.20-F capacitor is desired. What area must the plates have if they are to be separated by a 3.2-mm air gap?
39. (II) The charge on a capacitor increases by 15 μC when the voltage across it increases from 97 V to 121 V. What is the capacitance of the capacitor?
40. (II) An electric field of 8.50×10^5 V/m is desired between two parallel plates, each of area 45.0 cm^2 and separated by 2.45 mm of air. What charge must be on each plate?
41. (II) If a capacitor has opposite 4.2 μC charges on the plates, and an electric field of 2.0 kV/mm is desired between the plates, what must each plate's area be?
42. (II) It takes 18 J of energy to move a 0.30-mC charge from one plate of a 15-μF capacitor to the other. How much charge is on each plate?
43. (II) To get an idea how big a farad is, suppose you want to make a 1-F air-filled parallel-plate capacitor for a circuit you are building. To make it a reasonable size, suppose you limit the plate area to 1.0 cm^2. What would the gap have to be between the plates? Is this practically achievable?
44. (II) How strong is the electric field between the plates of a 0.80-μF air-gap capacitor if they are 2.0 mm apart and each has a charge of 62 μC?
45. (III) A 2.50-μF capacitor is charged to 746 V and a 6.80-μF capacitor is charged to 562 V. These capacitors are then

disconnected from their batteries. Next the positive plates are connected to each other and the negative plates are connected to each other. What will be the potential difference across each and the charge on each? [*Hint*: Charge is conserved.]

46. (III) A 7.7-μF capacitor is charged by a 165-V battery (**Fig. 17–43a**) and then is disconnected from the battery. When this capacitor (C_1) is then connected (**Fig. 17–43b**) to a second (initially uncharged) capacitor, C_2, the final voltage on each capacitor is 15 V. What is the value of C_2? [*Hint*: Charge is conserved.]

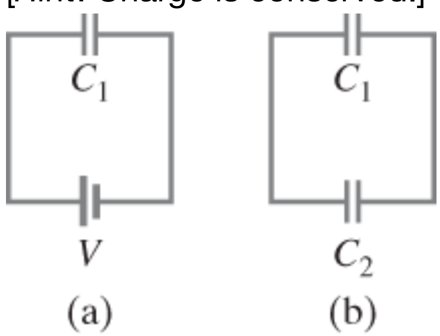

Figure 17–43

Problems 46 and 58.

17–8 Dielectrics

47. (I) What is the capacitance of two square parallel plates 6.6 cm on a side that are separated by 1.8 mm of paraffin?
48. (I) What is the capacitance of a pair of circular plates with a radius of 5.0 cm separated by 2.8 mm of mica?
49. (II) An uncharged capacitor is connected to a 21.0-V battery until it is fully charged, after which it is disconnected from the battery. A slab of paraffin is then inserted between the plates. What will now be the voltage between the plates?
50. (II) A 3500-pF air-gap capacitor is connected to a 32-V battery. If a piece of mica is placed between the plates, how much charge will flow from the battery?
51. (II) The electric field between the plates of a paper-separated ($K = 3.75$) capacitor is 8.24×10^4 V/m. The plates are 1.95 mm apart, and the charge on each is 0.675 μC. Determine the capacitance of this capacitor and the area of each plate.

PHY12, HW2: Work

1) $W = Q\Delta V = (-7.7 \times 10^{-6})(65) = -5 \times 10^{-6}$ J.

2) $W = Q\Delta V = (1.6 \times 10^{-19})(-170) = -2.7 \times 10^{-17}$ J. Or, -170 eV.

12) Let KE be T. Then $T = \frac{1}{2}mv^2$, or $v = \sqrt{2T/m}$.

a) $v = \sqrt{(2 \times 850 \times 1.6 \times 10^{-19})/(9.1 \times 10^{-31})}$
$= 1.7 \times 10^7$ m/s.

b) $v = \sqrt{(2 \times 500 \times 1.6 \times 10^{-19})/(9.1 \times 10^{-31})}$
$= 1.3 \times 10^7$ m/s.

18) $V = k\frac{q}{d} = 9 \times 10^9 \frac{3 \times 10^{-6}}{0.15} = 1.8 \times 10^5$ V.

19) $165 = 9 \times 10^9 \frac{Q}{0.15}$.

So $Q = \frac{165 \times 0.15}{9 \times 10^9} = 2.75 \times 10^{-9}$ C.

35) $Q = CV$, so $C = \frac{Q}{V} = \frac{2500 \times 10^{-6}}{960} = 2.6\,\mu$F.

36) $V = \frac{Q}{C} = \frac{16.5 \times 10^{-8}}{8500 \times 10^{-12}} = 19$ V.