[*The potential due to an **electric dipole** drops off as $1/r^2$. The **dipole moment** is $p = Q\ell$, 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:

$$C = \frac{Q}{V}, \quad \text{or} \quad Q = CV. \qquad (17\text{–}7)$$

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

$$C = \epsilon_0 \frac{A}{d}. \qquad (17\text{–}8)$$

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

$$\text{PE} = \tfrac{1}{2}QV = \tfrac{1}{2}CV^2 = \tfrac{1}{2}\frac{Q^2}{C}. \qquad (17\text{–}10)$$

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

$$\frac{\text{electric PE}}{\text{volume}} = \tfrac{1}{2}\epsilon_0 E^2. \qquad (17\text{–}11)$$

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 $\frac{1}{60}$ 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.
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.
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.
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.
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.
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.
8. Can two equipotential lines cross? Explain.
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?
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 $\vec{\mathbf{E}}$?
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?
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.
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 $+0.2\,\mu$C charge is in an electric field. What happens if that charge is replaced by a $+0.4\,\mu$C 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 ________.
(*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 $+0.2\,\mu$C charge is in an electric field. What happens if that charge is replaced by a $-0.2\,\mu$C 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.