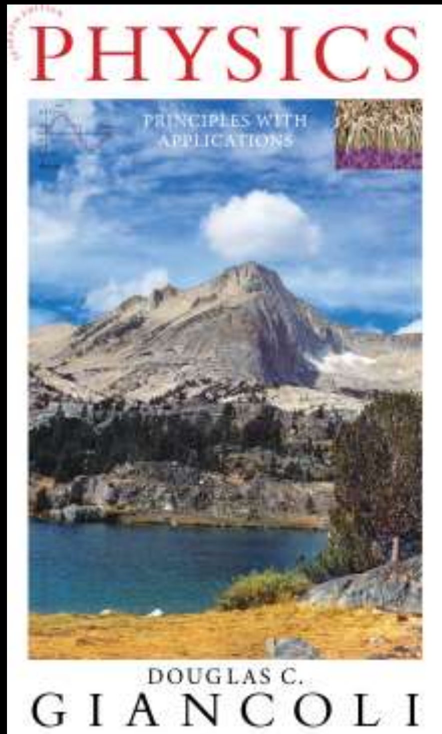

Lecture PowerPoints

Chapter 17

Physics: Principles with Applications, 7th edition

Giancoli

Chapter 17

Electric Potential

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- Relation between Electric Potential and Electric Field
- Equipotential Lines and Surfaces
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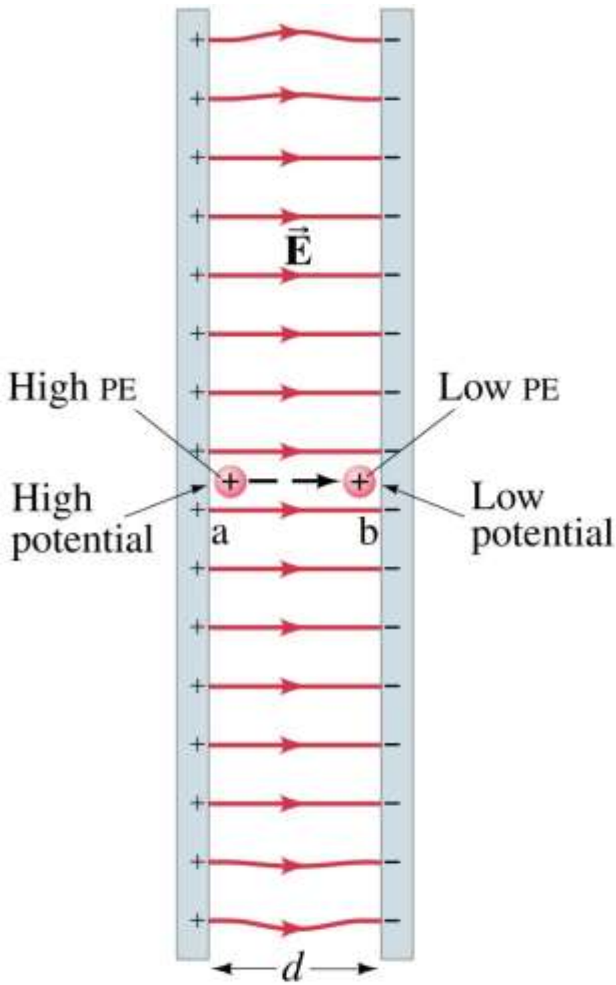
- Storage of Electric Energy
- Digital; Binary Numbers; Signal Voltage
- TV and Computer Monitors: CRT, Flat Screens
- Electrocardiogram (ECG or EKG)

17.1 Electric Potential Energy and Potential Difference



The electrostatic force is conservative—potential energy can be defined

Change in electric potential energy is negative of work done by electric force:

$$\mathrm{PE_b} - \mathrm{PE_a} = -qEd \quad (17\text{-}1)$$

17.1 Electric Potential Energy and Potential Difference

Electric potential is defined as potential energy per unit charge; analogous to definition of electric field as force per unit charge:

$$V_a = \frac{PE_a}{q}. \quad (17\text{-}2a)$$

Unit of electric potential: the volt (V).

1 V = 1 J/C.

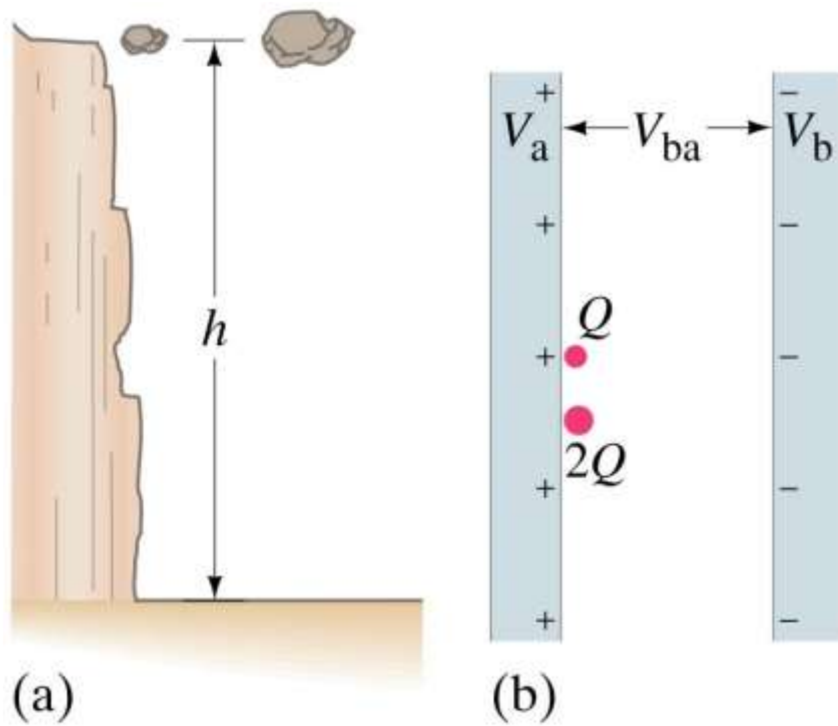
17.1 Electric Potential Energy and Potential Difference

Only changes in potential can be measured, allowing free assignment of $V = 0$.

$$V_{\mathrm{ba}} = V_{\mathrm{b}} - V_{\mathrm{a}} = \frac{\mathrm{PE_b} - \mathrm{PE_a}}{q} = -\frac{W_{\mathrm{ba}}}{q}. \quad (17\text{-}2b)$$

17.1 Electric Potential Energy and Potential Difference

Analogy between gravitational and electrical potential energy. Just as the more massive rock has more potential energy, so does the larger charge:



17.2 Relation between Electric Potential and Electric Field

Work is charge multiplied by potential:

$$W = -q(V_{\mathrm{b}} - V_{\mathrm{a}}) = -qV_{\mathrm{ba}}.$$

Work is also force multiplied by distance:

$$W = Fd = qEd,$$

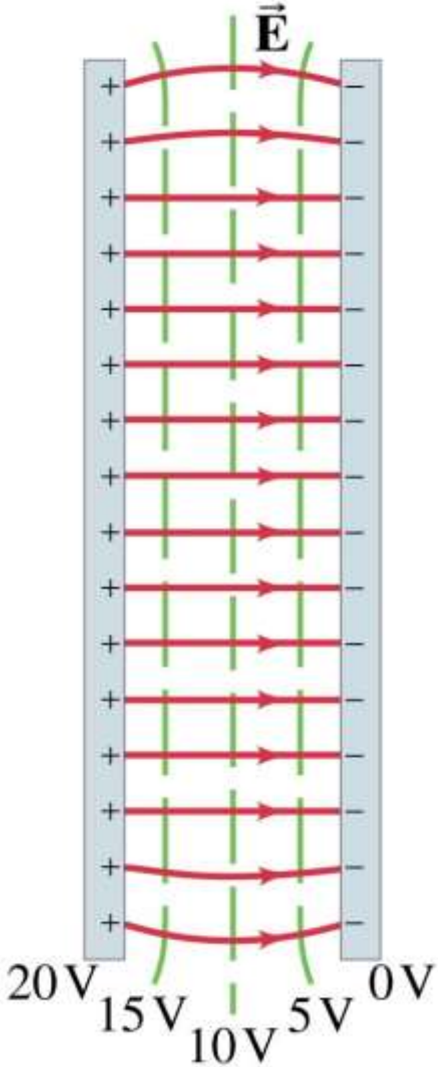
17.2 Relation between Electric Potential and Electric Field

Solving for the field,

$$E = -\frac{V_{ba}}{d}. \qquad [\text{uniform } \vec{\mathbf{E}}] \qquad (17\text{-}4b)$$

In general, the electric field in a given direction at any point in space is equal to the rate at which the electric potential decreases over distance in that direction.

17.3 Equipotential Lines and Surfaces



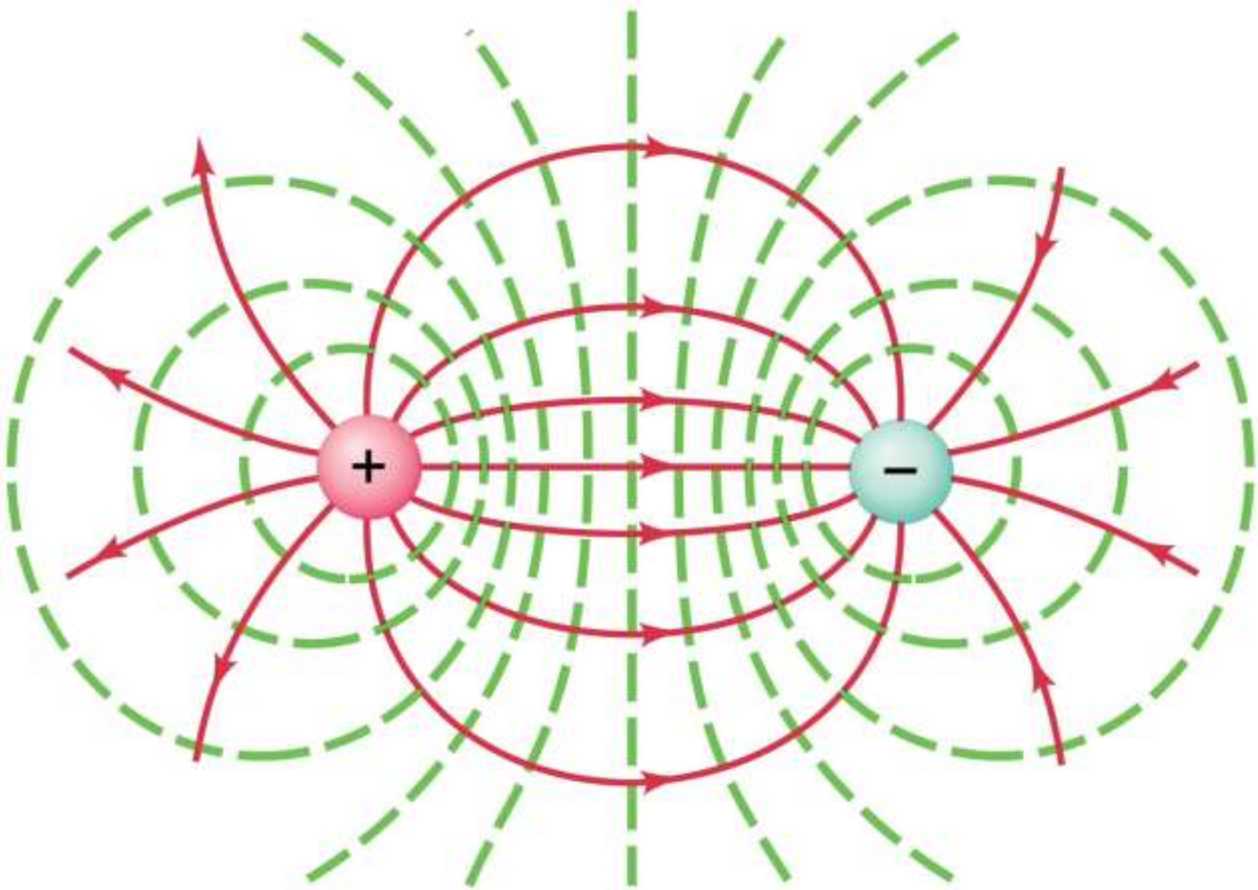
An equipotential is a line or surface over which the potential is constant.

Electric field lines are perpendicular to equipotentials.

The surface of a conductor is an equipotential.

17.3 Equipotential Lines and Surfaces

Equipotential lines of an electric dipole:



17.4 The Electron Volt, a Unit of Energy

One electron volt (eV) is the energy gained by an electron moving through a potential difference of one volt.

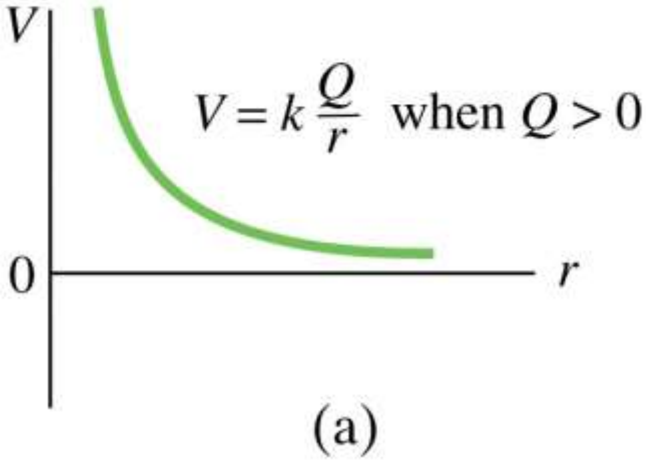
$$1\ \text{eV} = 1.6022 \times 10^{-19} \approx 1.60 \times 10^{-19}\ \text{J}.$$

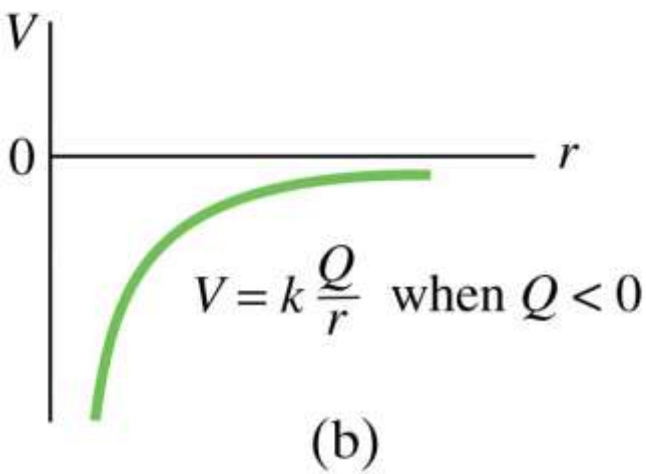
17.5 Electric Potential Due to Point Charges

The electric potential due to a point charge can be derived using calculus.

$$V = k\frac{Q}{r} = \frac{1}{4\pi\epsilon_0}\frac{Q}{r}, \qquad (17\text{-}5)$$

17.5 Electric Potential Due to Point Charges





These plots show the potential due to (a) positive and (b) negative charge.

17.5 Electric Potential Due to Point Charges

Using potentials instead of fields can make solving problems much easier—potential is a scalar quantity, whereas the field is a vector.

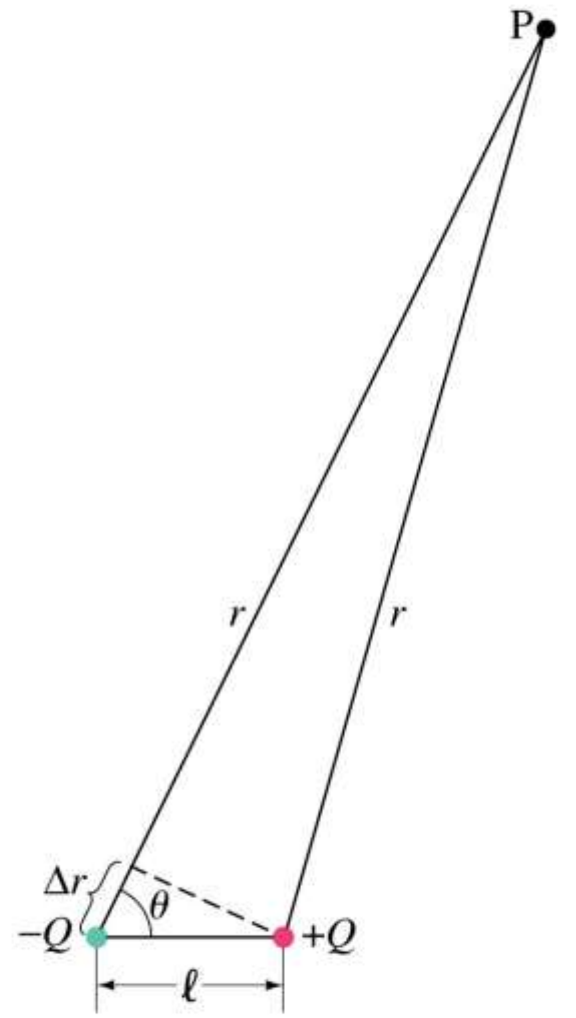
17.6 Potential Due to Electric Dipole; Dipole Moment

The potential due to an electric dipole is just the sum of the potentials due to each charge, and can be calculated exactly.

17.6 Potential Due to Electric Dipole; Dipole Moment

Approximation for potential far from dipole:

$$V \approx \frac{kQ\ell\cos\theta}{r^2}. \quad (17\text{-}6a)$$



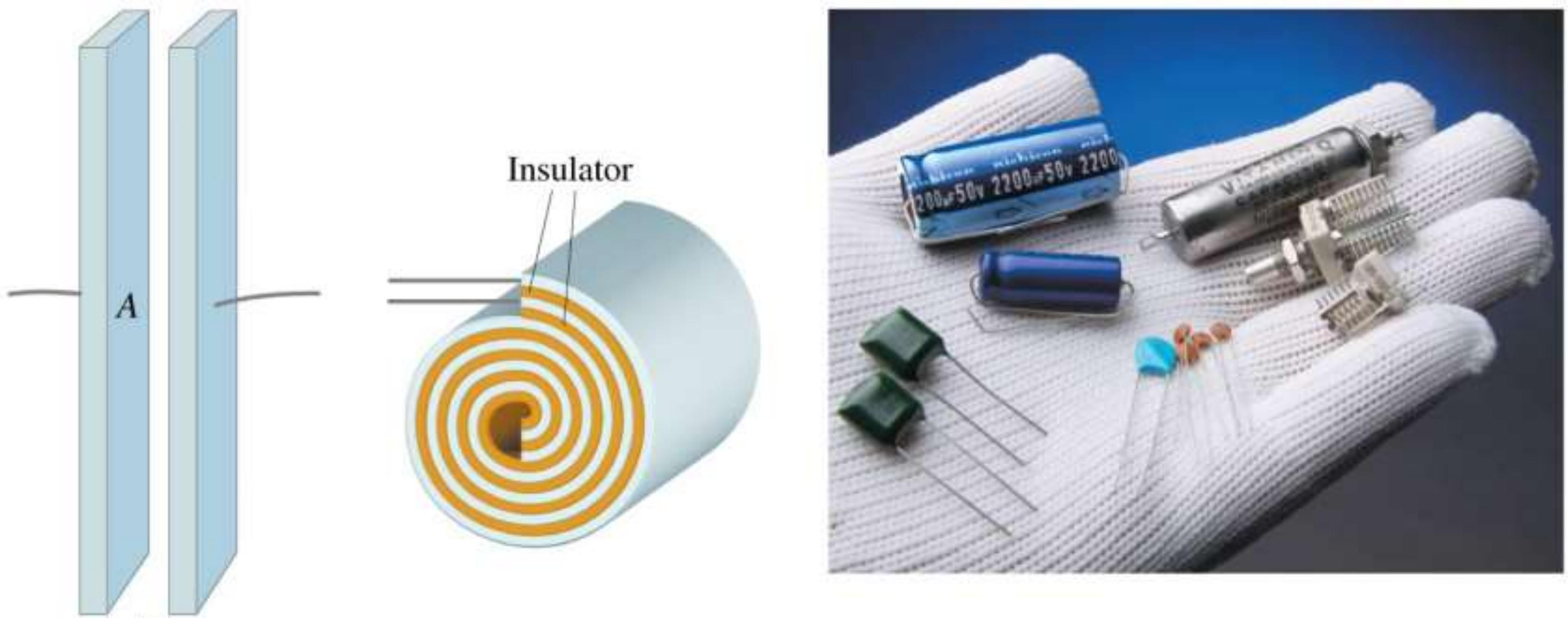
17.6 Potential Due to Electric Dipole; Dipole Moment

Or, defining the dipole moment $p = Ql$,

$$V \approx \frac{kp\cos\theta}{r^2}. \quad (17\text{-}6b)$$

17.7 Capacitance

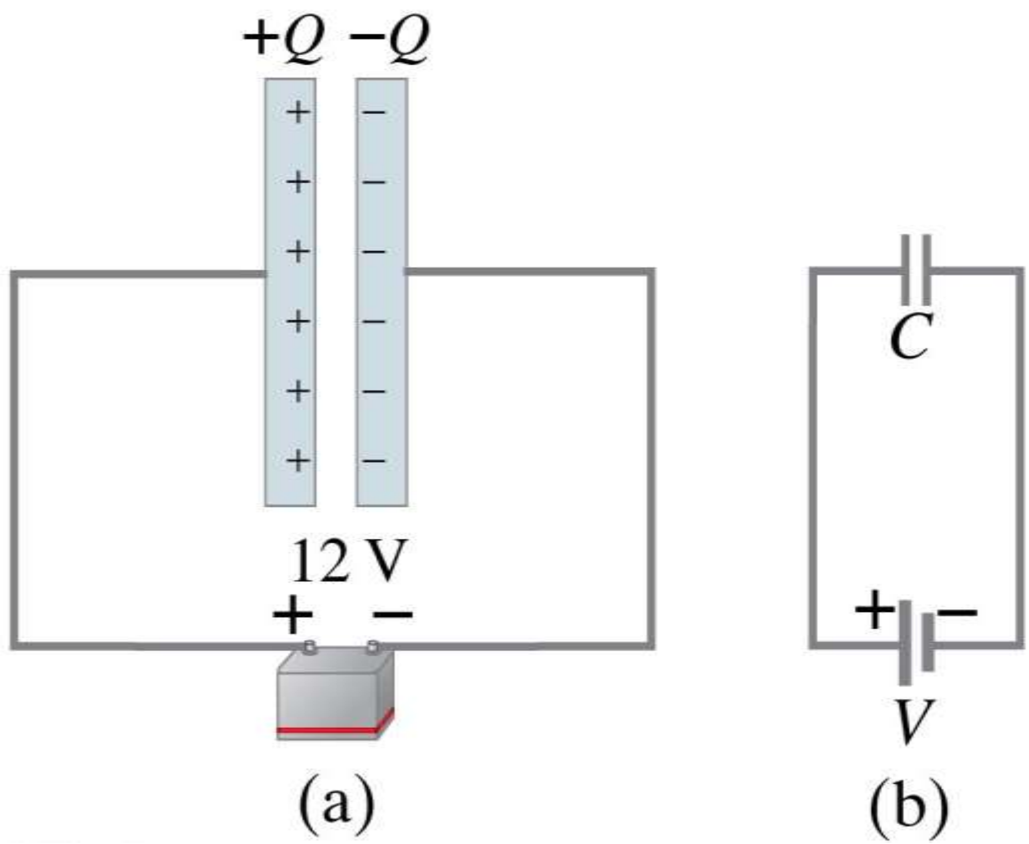
A capacitor consists of two conductors that are close but not touching. A capacitor has the ability to store electric charge.



(a) (b) (c)

17.7 Capacitance

Parallel-plate capacitor connected to battery. (b) is a circuit diagram.



17.7 Capacitance

When a capacitor is connected to a battery, the charge on its plates is proportional to the voltage:

$$Q = CV. \quad (17\text{-}7)$$

The quantity *C* is called the capacitance.

Unit of capacitance: the farad (F)

$$1\ \text{F} = 1\ \text{C/V}$$

17.7 Capacitance

The capacitance does not depend on the voltage; it is a function of the geometry and materials of the capacitor.

For a parallel-plate capacitor:

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

17.8 Dielectrics

A dielectric is an insulator, and is characterized by a dielectric constant *K*.

Capacitance of a parallel-plate capacitor filled with dielectric:

$$C = K\epsilon_0 \frac{A}{d}. \quad (17\text{-}9)$$

17.8 Dielectrics

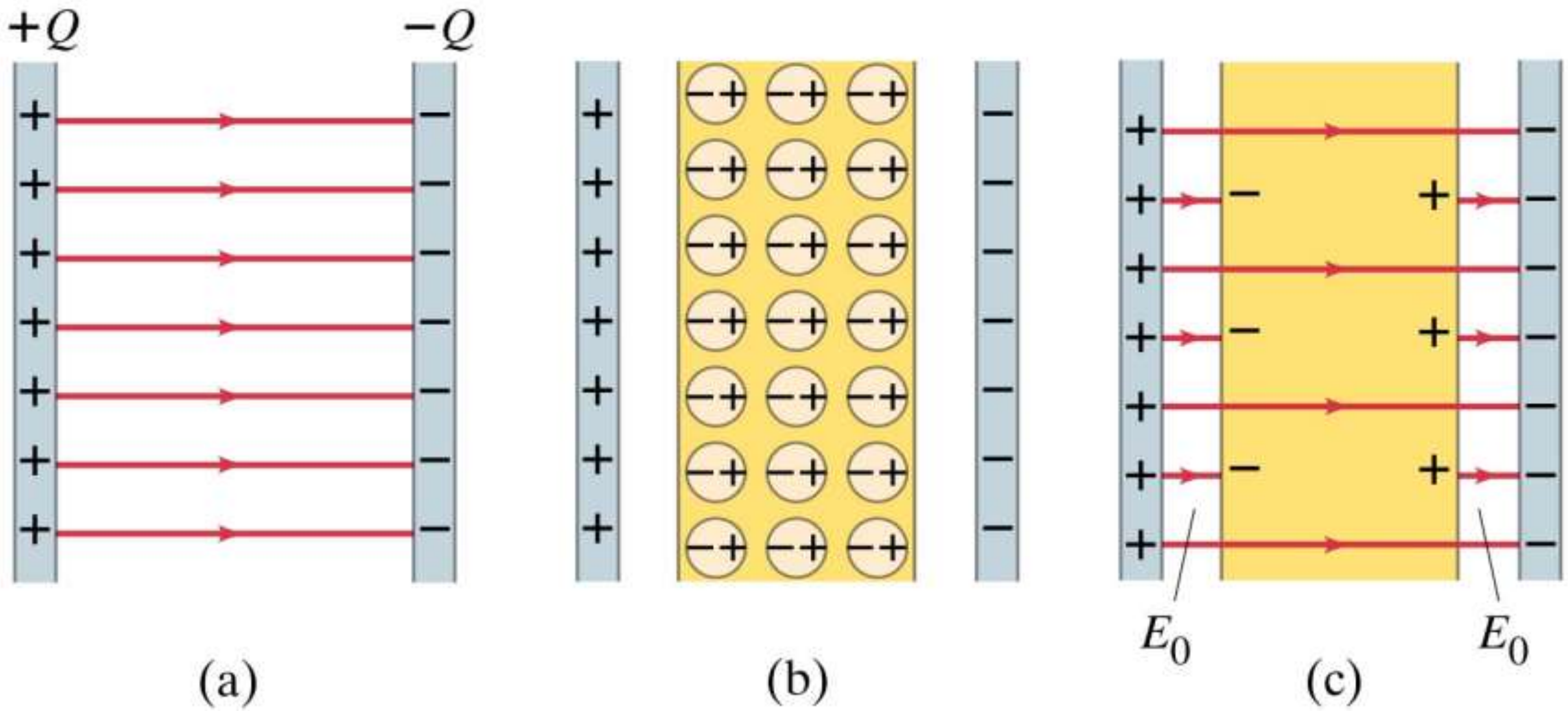
TABLE 17–3
Dielectric Constants (at 20°C)

Material	Dielectric constant K	Dielectric strength (V/m)
Vacuum	1.0000	
Air (1 atm)	1.0006	3×10^6
Paraffin	2.2	10×10^6
Polystyrene	2.6	24×10^6
Vinyl (plastic)	2–4	50×10^6
Paper	3.7	15×10^6
Quartz	4.3	8×10^6
Oil	4	12×10^6
Glass, Pyrex	5	14×10^6
Rubber, neoprene	6.7	12×10^6
Porcelain	6–8	5×10^6
Mica	7	150×10^6
Water (liquid)	80	
Strontium titanate	300	8×10^6

Dielectric strength is the maximum field a dielectric can experience without breaking down.

17.8 Dielectrics

The molecules in a dielectric tend to become oriented in a way that reduces the external field.



17.8 Dielectrics

This means that the electric field within the dielectric is less than it would be in air, allowing more charge to be stored for the same potential.

17.9 Storage of Electric Energy

A charged capacitor stores electric energy; the energy stored is equal to the work done to charge the capacitor.

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

17.9 Storage of Electric Energy

The energy density, defined as the energy per unit volume, is the same no matter the origin of the electric field:

$$\text{energy density} = \frac{\text{PE}}{\text{volume}} = \frac{1}{2}\epsilon_0 E^2. \quad (17\text{-}11)$$

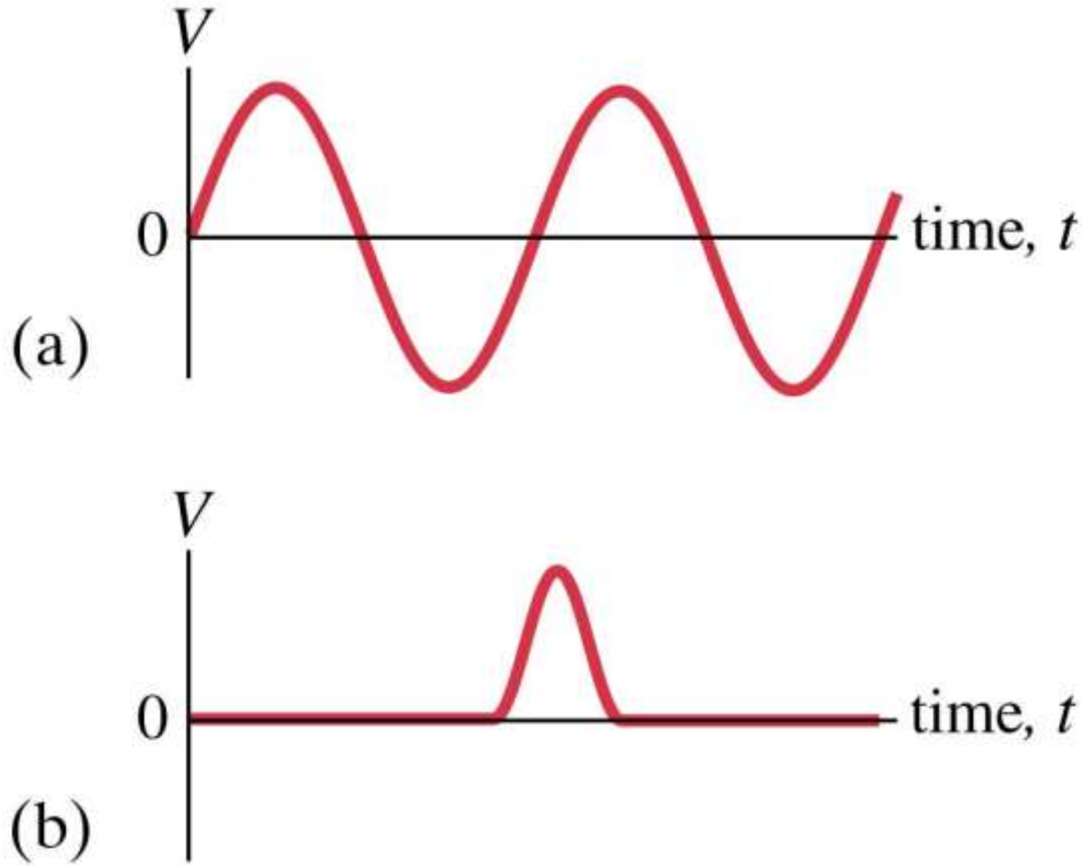
The sudden discharge of electric energy can be harmful or fatal. Capacitors can retain their charge indefinitely even when disconnected from a voltage source—be careful!

17.9 Storage of Electric Energy

Heart defibrillators use electric discharge to “jump-start” the heart when its beats become irregular, and can save lives.

17.10 Digital; Binary Numbers; Signal Voltage

Analog signal voltages vary continuously.



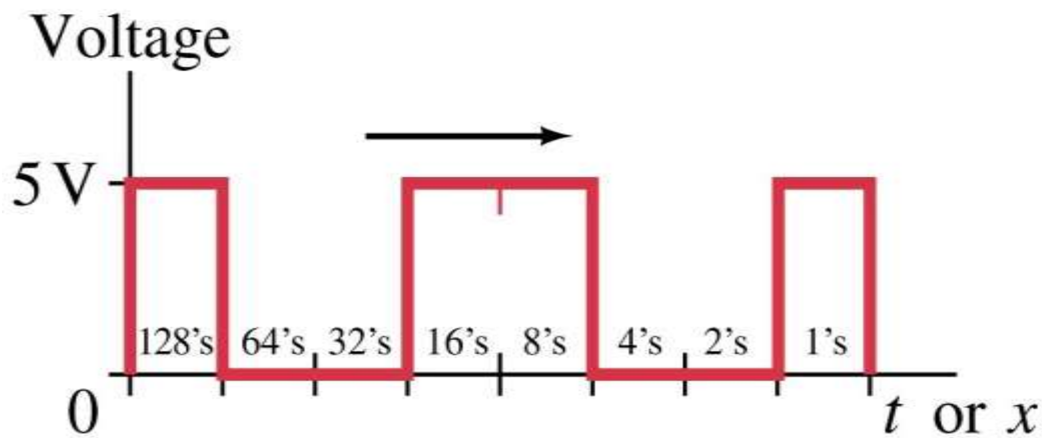
17.10 Digital; Binary Numbers; Signal Voltage

TABLE 17–4
Binary to Decimal

Binary† number	Decimal number
00000000	0
00000001	1
00000010	2
00000011	3
00000100	4
00000111	7
00001000	8
00100101	37
11111111	255

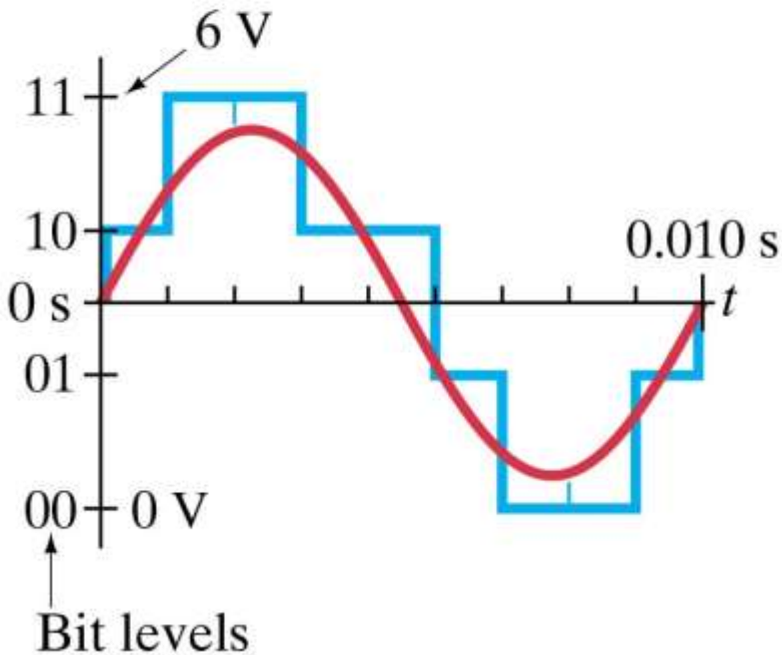
†Note that we start counting from right to left: the 1's digit is on the far right, then the 2's, the 4's, the 8's, the 16's, the 32's, the 64's, and the 128's.

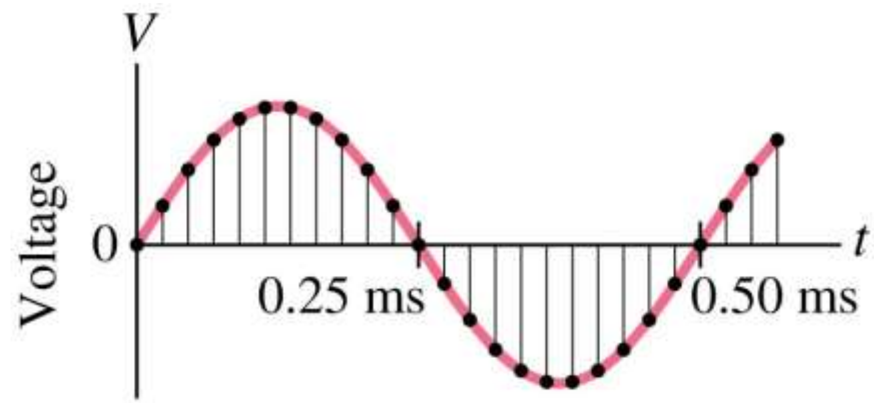
Digital signals use binary numbers to represent numerical values.



17.10 Digital; Binary Numbers; Signal Voltage

In order to convert an analog signal to digital, the signal must be sampled. A higher sampling rate reproduces the signal more precisely.



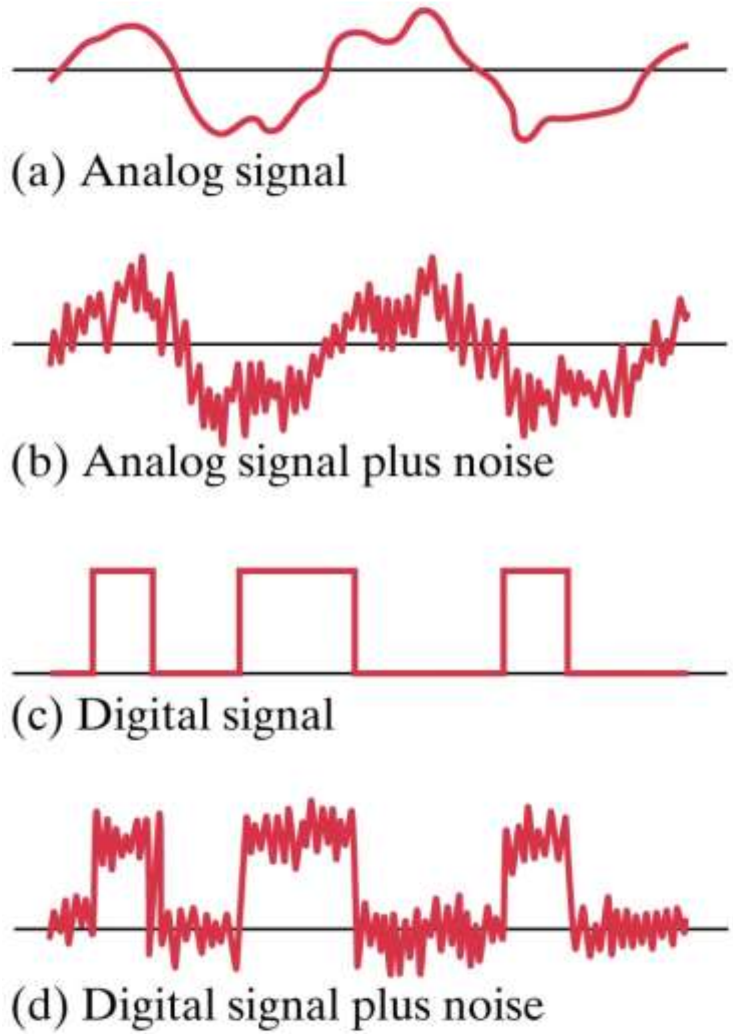


17.10 Digital; Binary Numbers; Signal Voltage

Before it is sent to a loudspeaker or headset, a digital audio signal must be converted back to analog.

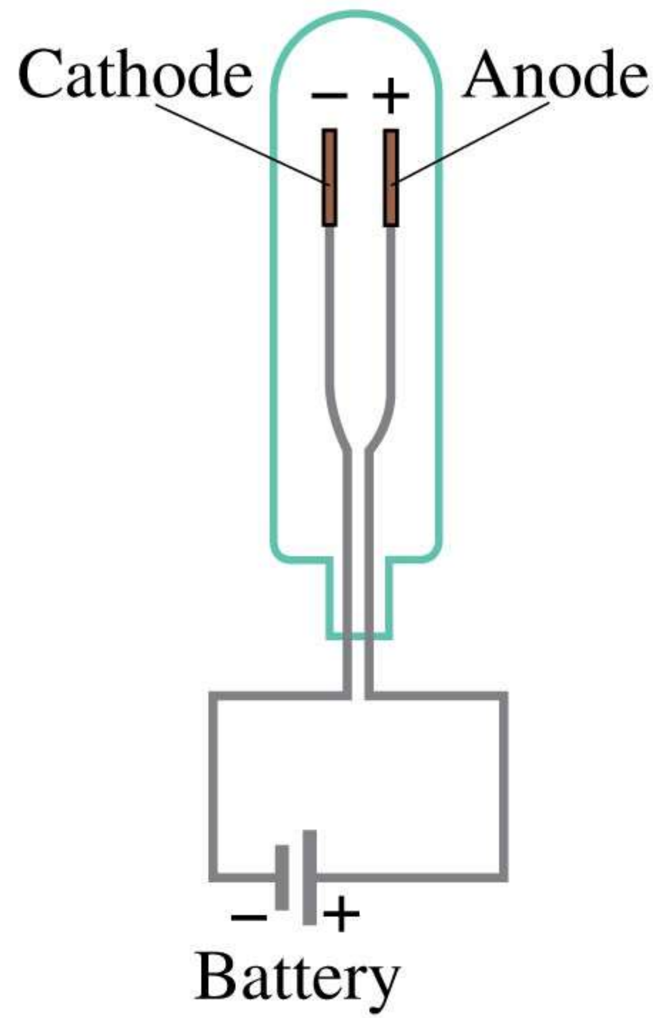
17.10 Digital; Binary Numbers; Signal Voltage

Noise can easily corrupt an analog signal; a digital signal is much less sensitive to noise.



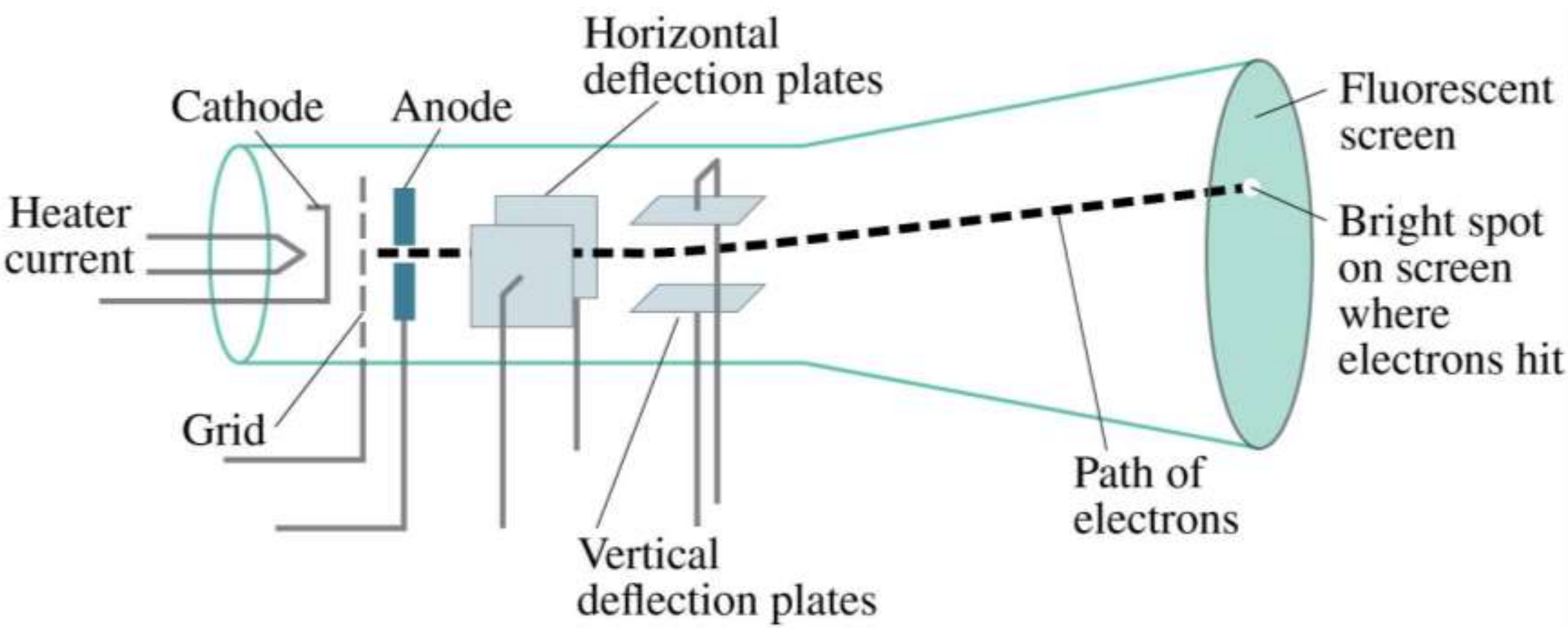
17.11 TV and Computer Monitors: CRTs, Flat Screens

A cathode ray tube contains a wire cathode that, when heated, emits electrons. A voltage source causes the electrons to travel to the anode.



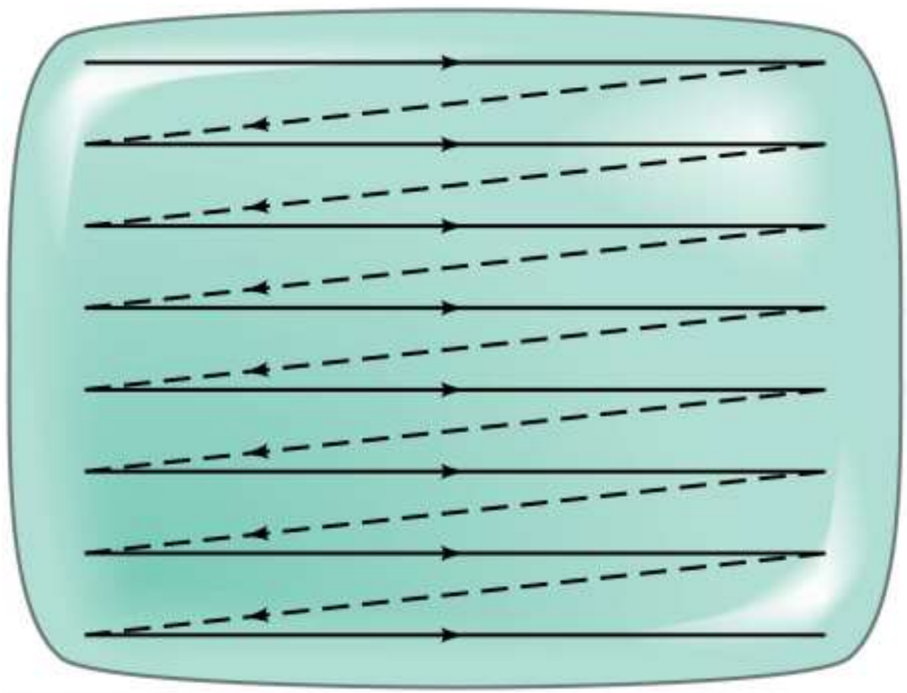
17.11 TV and Computer Monitors: CRTs, Flat Screens

The electrons can be steered using electric or magnetic fields.



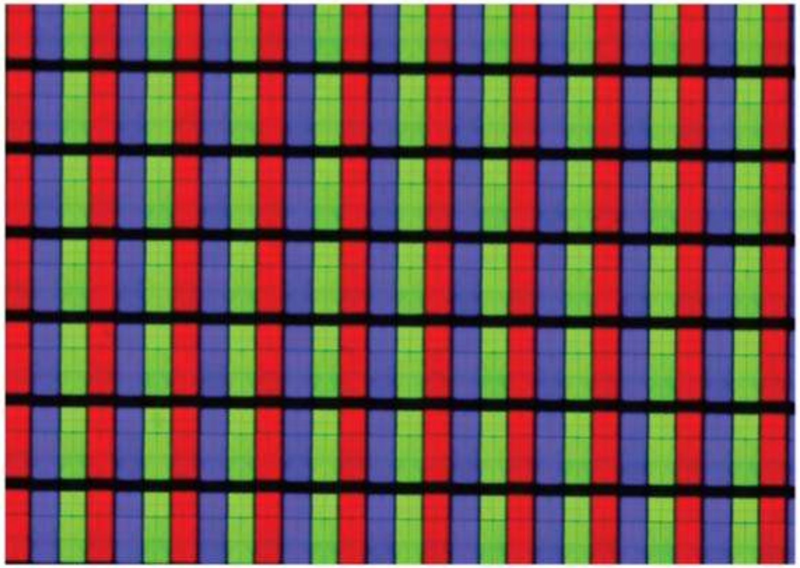
17.11 TV and Computer Monitors: CRTs, Flat Screens

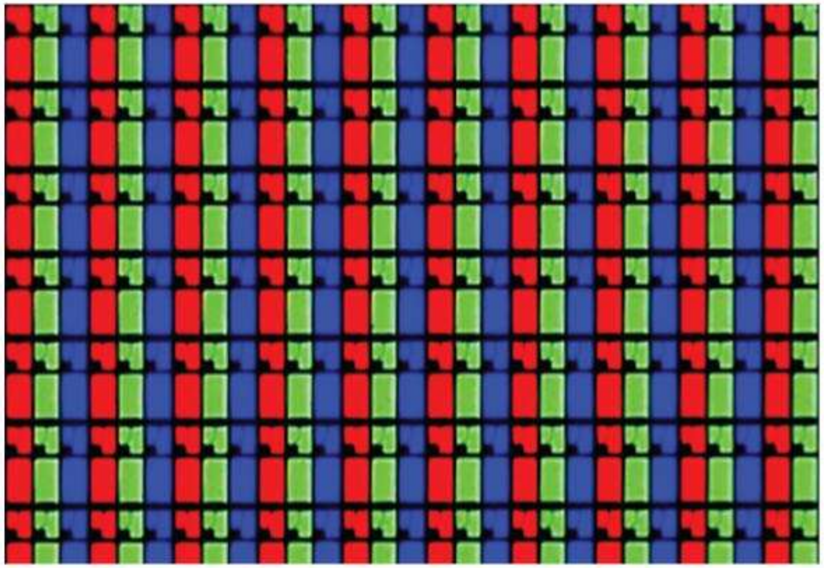
CRT monitors have a large cathode ray tube as their display. Variations in the field steer the electrons on their way to the screen.



17.11 TV and Computer Monitors: CRTs, Flat Screens

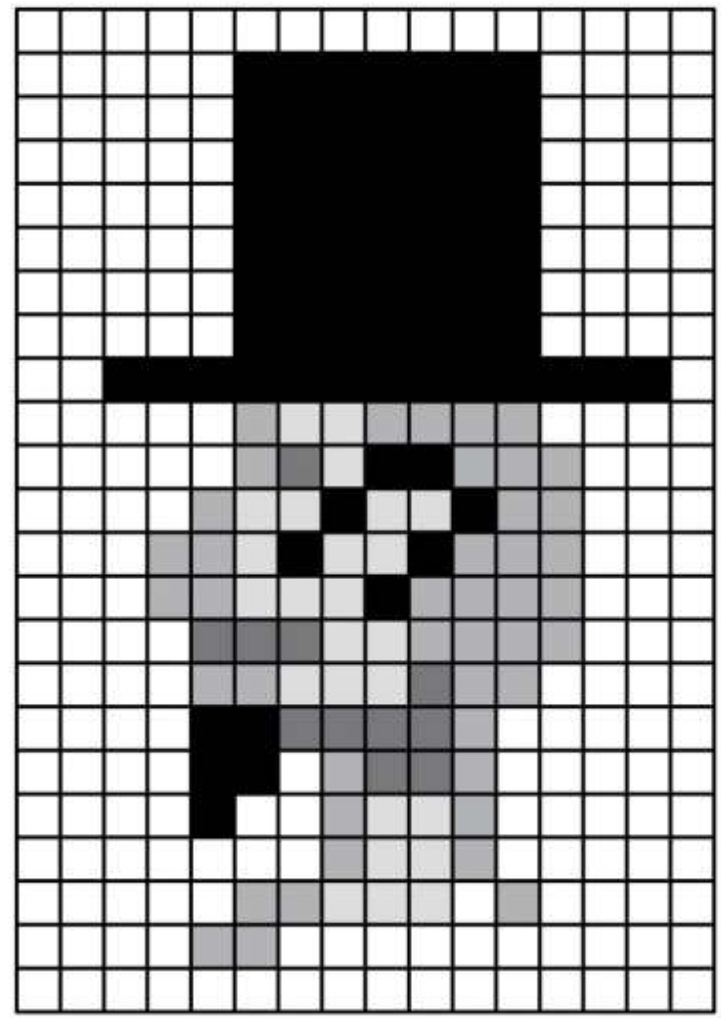
Flat screens contain tiny pixels in red, green, and blue whose brightness can be changed.





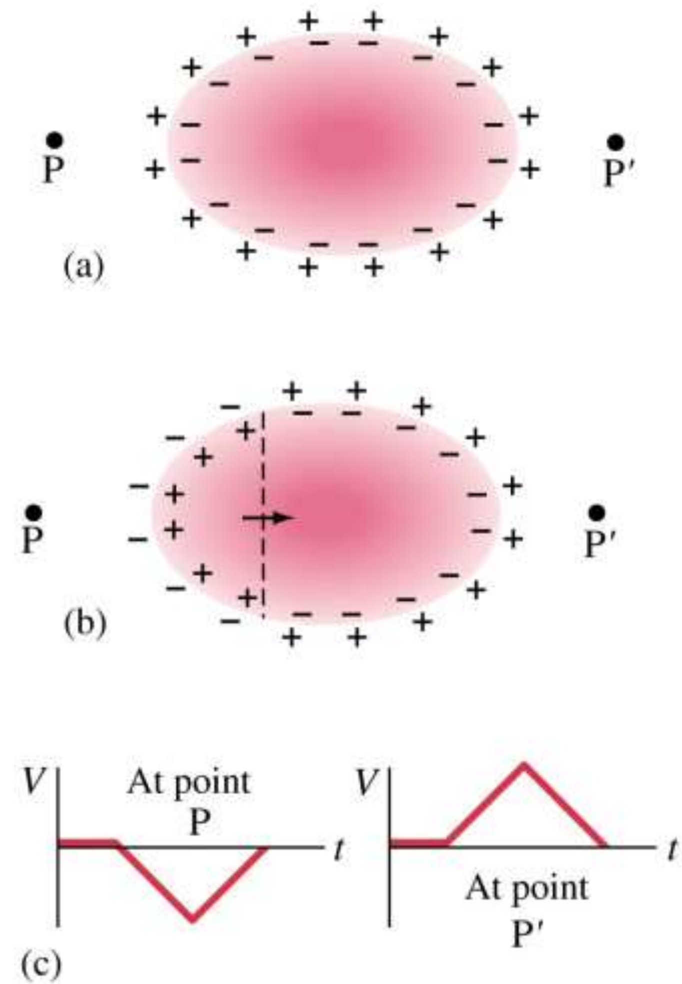
17.11 TV and Computer Monitors: CRTs, Flat Screens

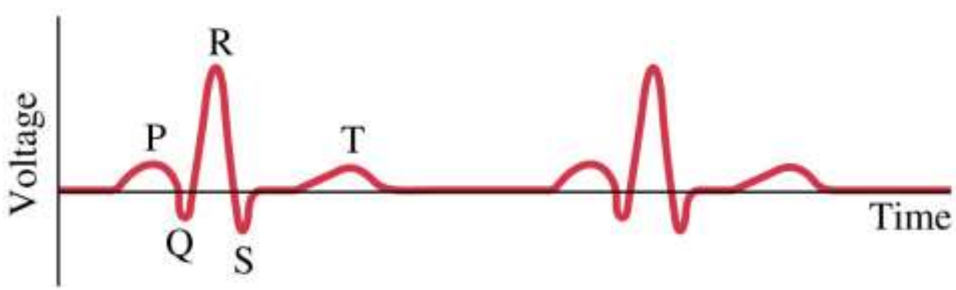
The array of pixels then creates an image; this example has very low resolution. HD screens have 1080 × 1920 pixels.



17.12 Electrocardiogram (ECG or EKG)

The electrocardiogram detects heart defects by measuring changes in potential on the surface of the heart.





Summary of Chapter 17

- Electric potential is potential energy per unit charge:

$$V_a = \frac{PE_a}{q}. \quad (17\text{-}2a)$$

- Electric potential difference: work done to move charge from one point to another

- Relationship between potential difference and field:

$$V_{ba} = -Ed. \qquad [\text{uniform } \vec{\mathbf{E}}] \quad (17\text{-}4a)$$

Summary of Chapter 17

- Equipotential: line or surface along which potential is the same
- Electric potential of a point charge:

$$V = k\frac{Q}{r} = \frac{1}{4\pi\epsilon_0}\frac{Q}{r}, \qquad \left[\begin{array}{l}\text{single point charge} \\ V = 0 \text{ at } r = \infty\end{array}\right] \tag{17-5}$$

- Electric dipole potential drops off as $1/r^2$

Summary of Chapter 17

- Capacitor: nontouching conductors carrying equal and opposite charge
- Capacitance:

$$Q = CV. \quad (17\text{-}7)$$

- Capacitance of a parallel-plate capacitor:

$$C = \epsilon_0 \frac{A}{d}. \qquad \text{[parallel-plate capacitor]} \quad (17\text{-}8)$$

Summary of Chapter 17

- A dielectric is an insulator
- Dielectric constant gives ratio of total field to external field
- Energy density in electric field:

$$\text{energy density} = \frac{\text{PE}}{\text{volume}} = \tfrac{1}{2}\epsilon_0 E^2. \quad (17\text{-}11)$$

- Digital electronics convert analog signal to digital approximation using binary numbers