

Chapter 24

Capacitance and Dielectrics

PowerPoint® Lectures for
University Physics, Thirteenth Edition
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Goals for Chapter 24

- To understand capacitors and calculate capacitance
- To analyze networks of capacitors
- To calculate the energy stored in a capacitor
- To examine dielectrics and how they affect capacitance

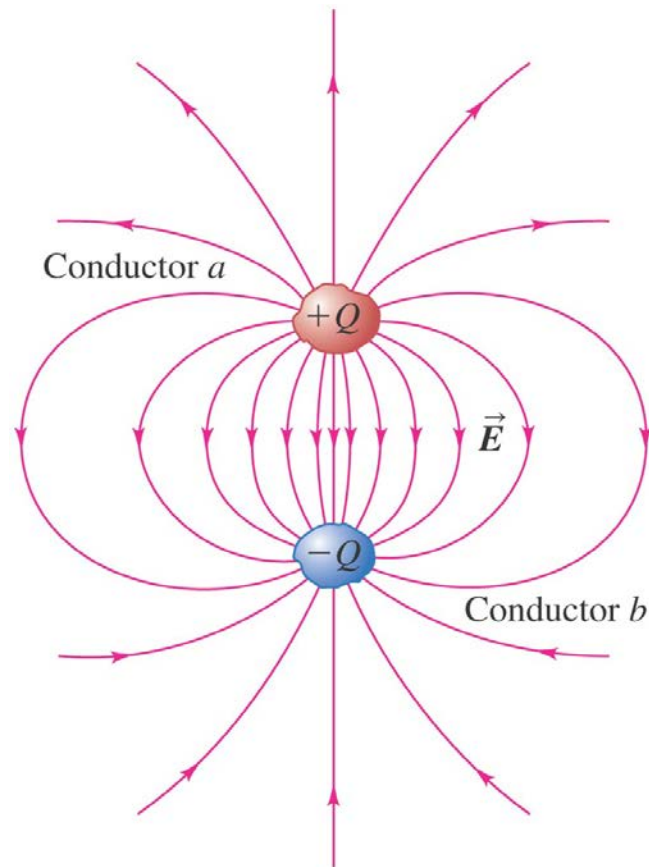
Introduction

- How does a camera's flash unit store energy?
- Capacitors are devices that store electric potential energy.
- The energy of a capacitor is actually stored in the electric field.



Capacitors and capacitance

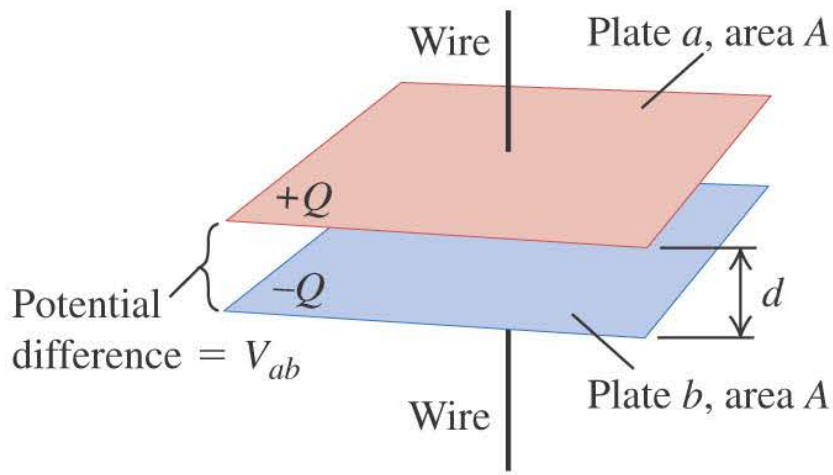
- Any two conductors separated by an insulator form a *capacitor*, as illustrated in Figure 24.1 below.
- The definition of capacitance is $C = Q/V_{ab}$.



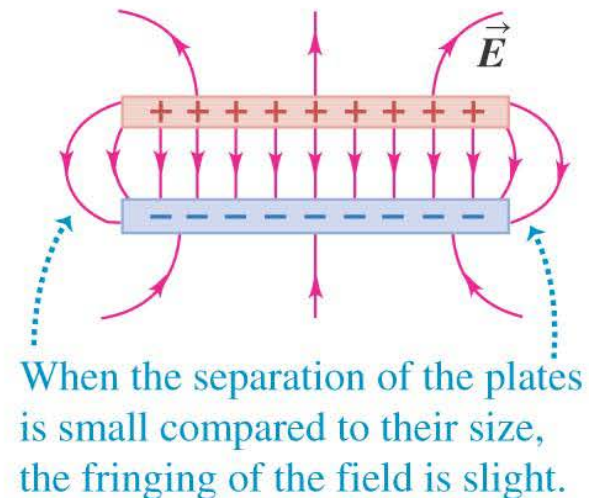
Parallel-plate capacitor

- A *parallel-plate capacitor* consists of two parallel conducting plates separated by a distance that is small compared to their dimensions. (See Figure 24.2 below.)
- The capacitance of a parallel-plate capacitor is $C = \epsilon_0 A/d$.
- Follow Examples 24.1 and 24.2.

(a) Arrangement of the capacitor plates

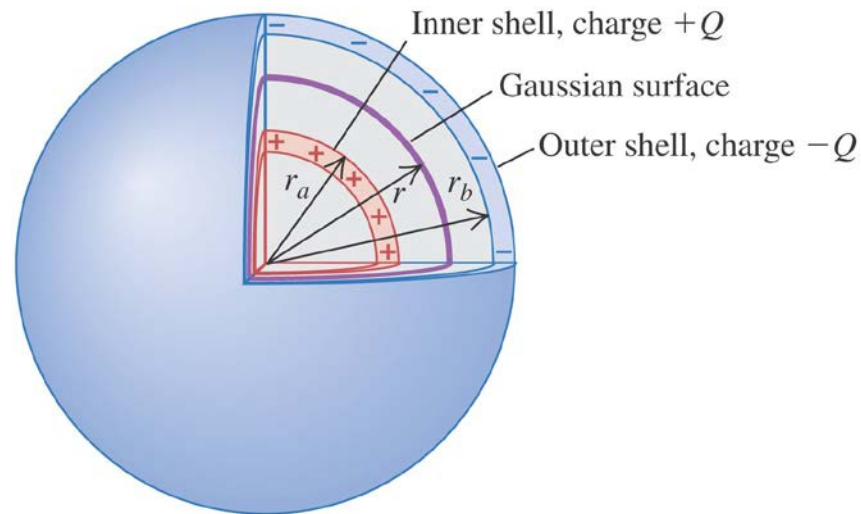


(b) Side view of the electric field \vec{E}



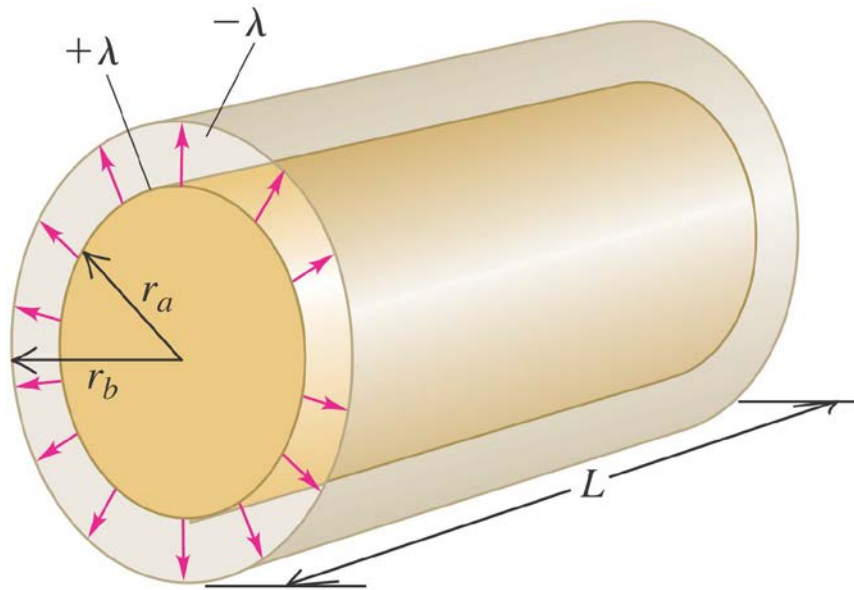
A spherical capacitor

- Follow Example 24.3 using Figure 24.5 to consider a spherical capacitor.



A cylindrical capacitor

- Follow Example 24.4 and Figure 24.6 to investigate a cylindrical capacitor.



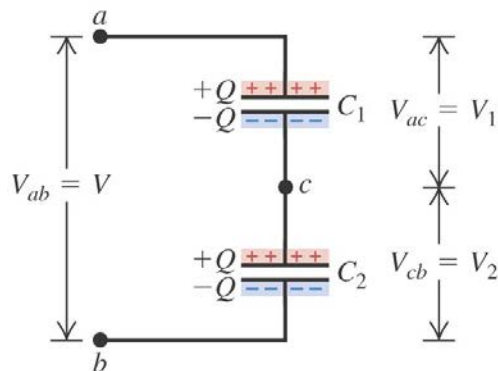
Capacitors in series

- Capacitors are in *series* if they are connected one after the other, as illustrated in Figure 24.8 below.
- The *equivalent capacitance* of a series combination is given by $1/C_{eq} = 1/C_1 + 1/C_2 + 1/C_3 + \dots$

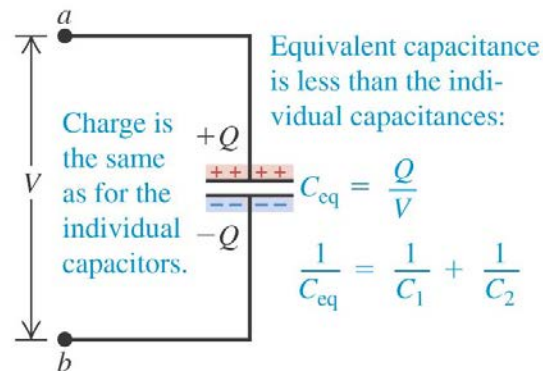
(a) Two capacitors in series

Capacitors in series:

- The capacitors have the same charge Q .
- Their potential differences add:
 $V_{ac} + V_{cb} = V_{ab}$.



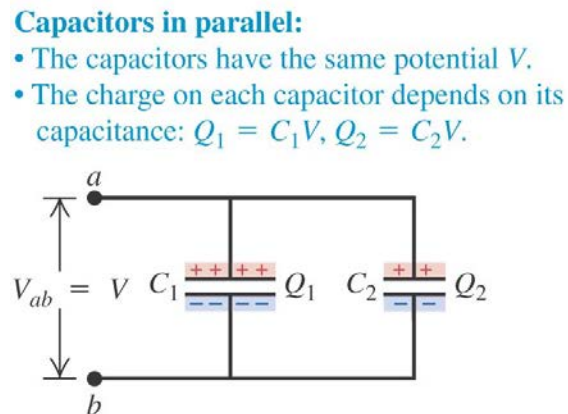
(b) The equivalent single capacitor



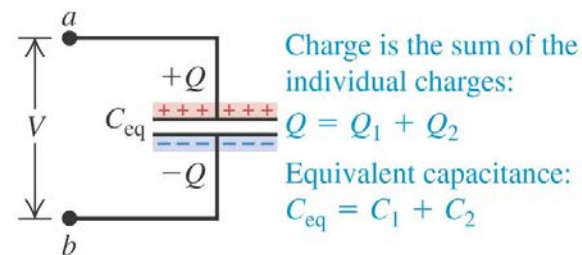
Capacitors in parallel

- Capacitors are connected in *parallel* between a and b if the potential difference V_{ab} is the same for all the capacitors. (See Figure 24.9 below.)
- The *equivalent capacitance* of a parallel combination is the *sum* of the individual capacitances: $C_{\text{eq}} = C_1 + C_2 + C_3 + \dots$

(a) Two capacitors in parallel

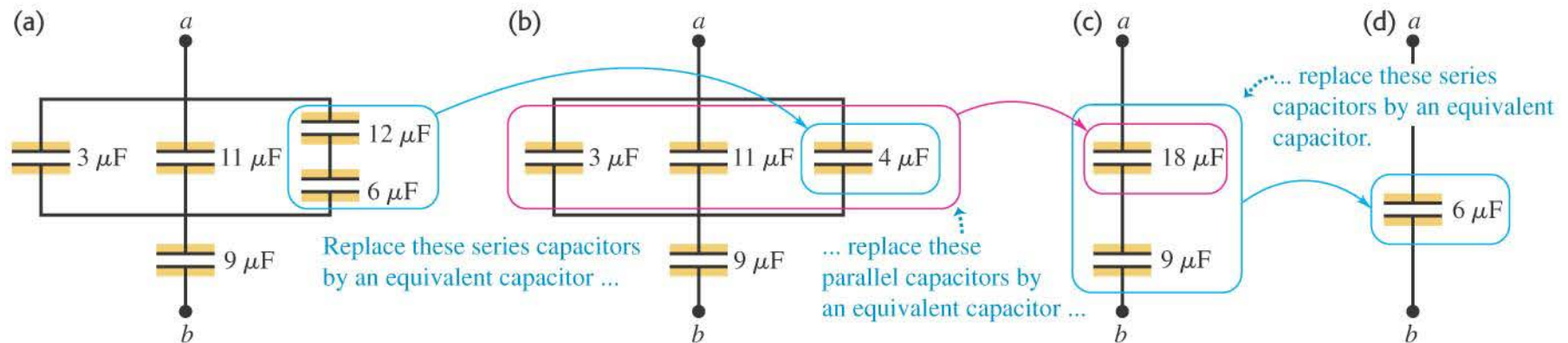


(b) The equivalent single capacitor



Calculations of capacitance

- Refer to Problem-Solving Strategy 24.1.
- Follow Example 24.5.
- Follow Example 24.6, a capacitor network, using Figure 24.10 below.

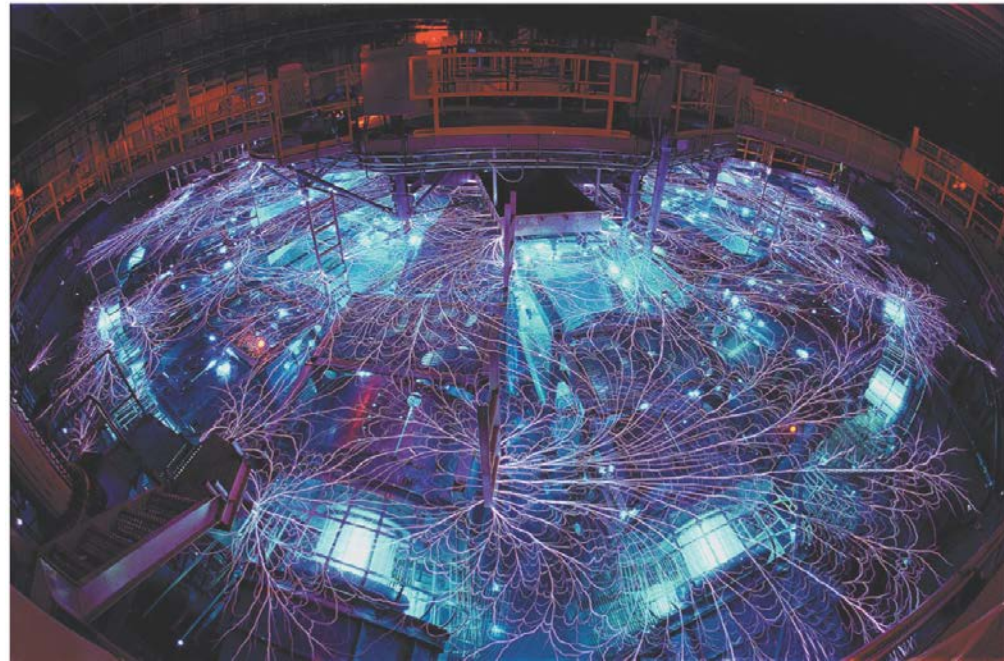


Energy stored in a capacitor

- The potential energy stored in a capacitor is

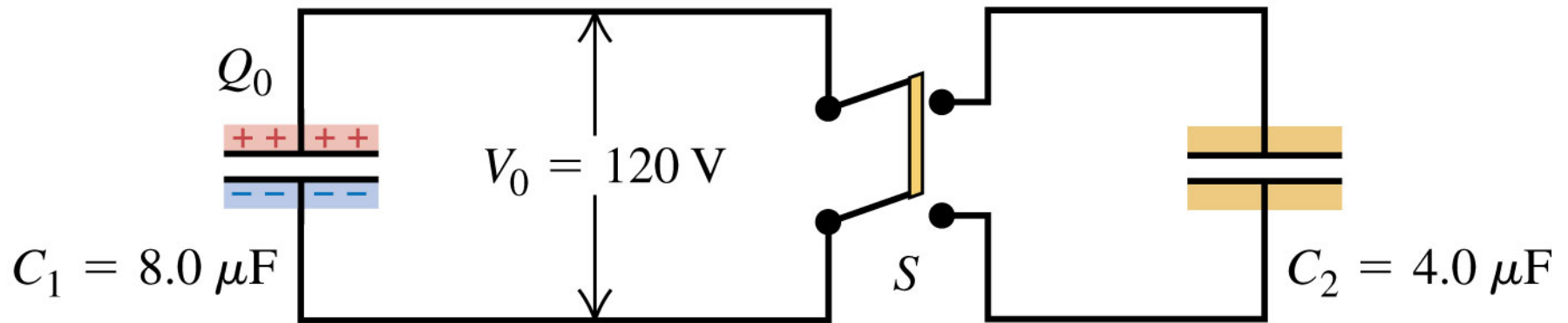
$$U = Q^2/2C = 1/2 CV^2 = 1/2 QV.$$

- The capacitor energy is stored in the *electric field* between the plates. The *energy density* is $u = 1/2 \epsilon_0 E^2$.
- The Z machine shown below can produce up to 2.9×10^{14} W using capacitors in parallel!



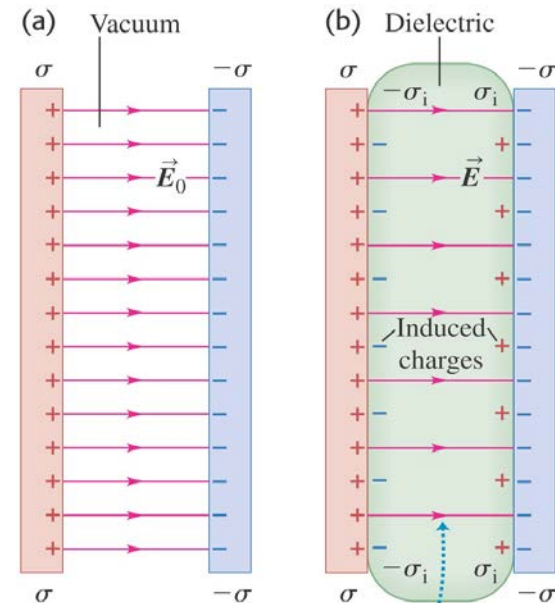
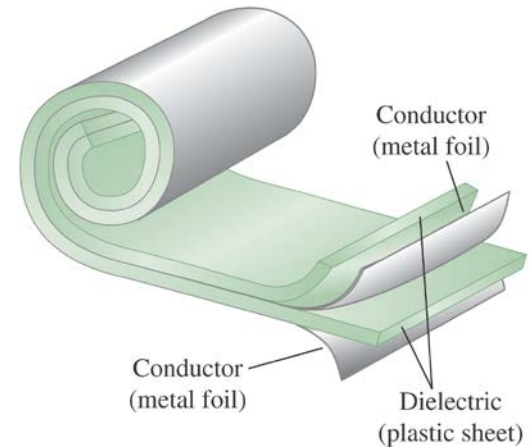
Some examples of capacitor energy

- Follow Example 24.7 using Figure 24.12 below.
- Follow Example 24.8.
- Follow Example 24.9.



Dielectrics

- A *dielectric* is a nonconducting material. Most capacitors have dielectric between their plates. (See Figure 24.13 at upper right.)
- The *dielectric constant* of the material is $K = C/C_0 > 1$.
- Dielectric *increases* the capacitance and the energy density by a factor K .
- Figure 24.15 (lower right) shows how the dielectric affects the electric field between the plates.
- Table 24.1 on the next slide shows some values of the dielectric constant.



For a given charge density σ , the induced charges on the dielectric's surfaces reduce the electric field between the plates.

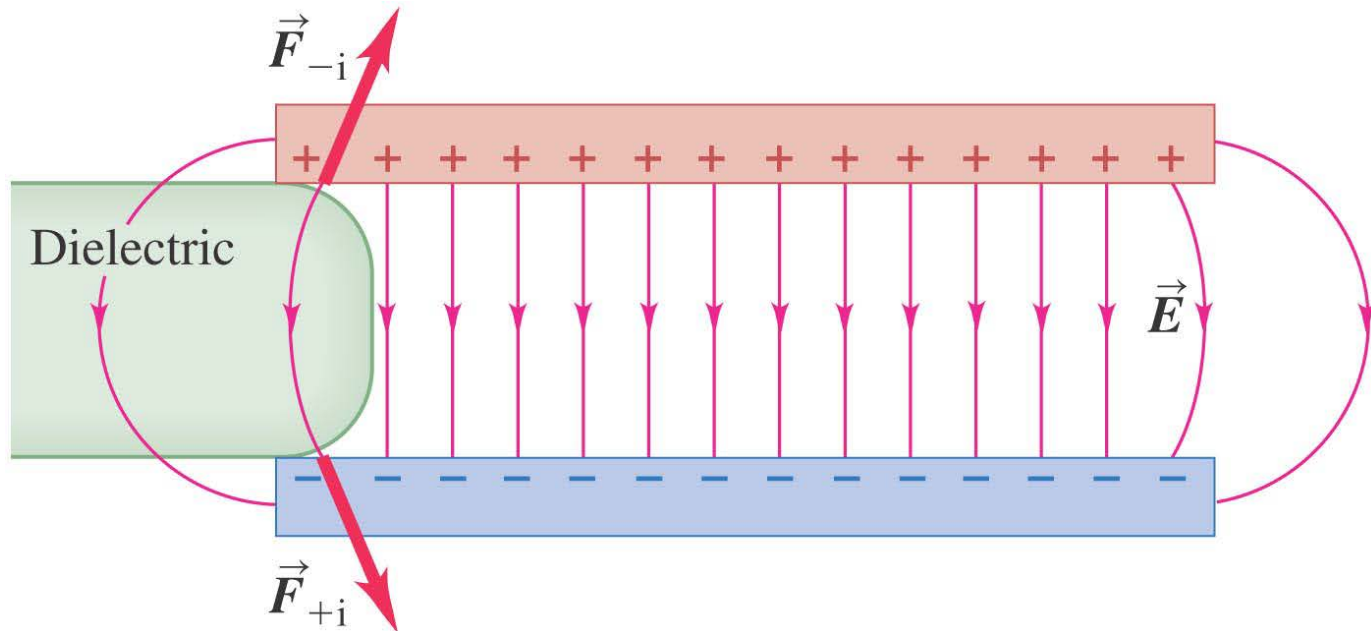
Table 24.1—Some dielectric constants

Table 24.1 Values of Dielectric Constant K at 20°C

Material	K	Material	K
Vacuum	1	Polyvinyl chloride	3.18
Air (1 atm)	1.00059	Plexiglas	3.40
Air (100 atm)	1.0548	Glass	5–10
Teflon	2.1	Neoprene	6.70
Polyethylene	2.25	Germanium	16
Benzene	2.28	Glycerin	42.5
Mica	3–6	Water	80.4
Mylar	3.1	Strontium titanate	310

Examples with and without a dielectric

- Refer to Problem-Solving Strategy 24.2.
- Follow Example 24.10 to see the effect of the dielectric.
- Follow Example 24.11 to see how the dielectric affects energy storage. Use Figure 24.16 below.



Dielectric breakdown

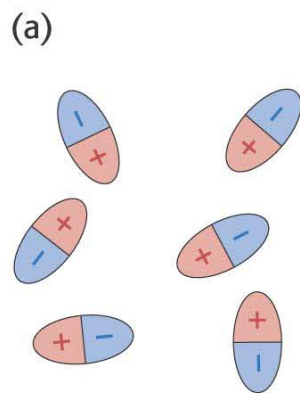
- If the electric field is strong enough, *dielectric breakdown* occurs and the dielectric becomes a conductor.
- The *dielectric strength* is the maximum electric field the material can withstand before breakdown occurs.
- Table 24.2 shows the dielectric strength of some insulators.

Table 24.2 Dielectric Constant and Dielectric Strength of Some Insulating Materials

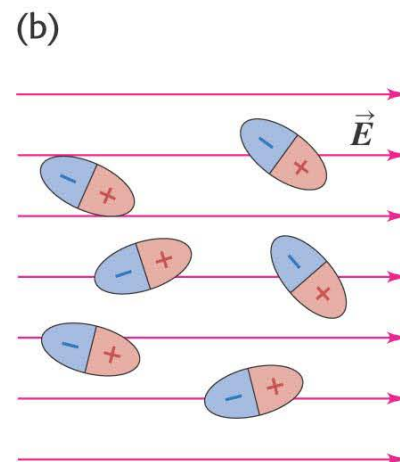
Material	Constant, K	E_m (V/m)
Polycarbonate	2.8	3×10^7
Polyester	3.3	6×10^7
Polypropylene	2.2	7×10^7
Polystyrene	2.6	2×10^7
Pyrex glass	4.7	1×10^7

Molecular model of induced charge - I

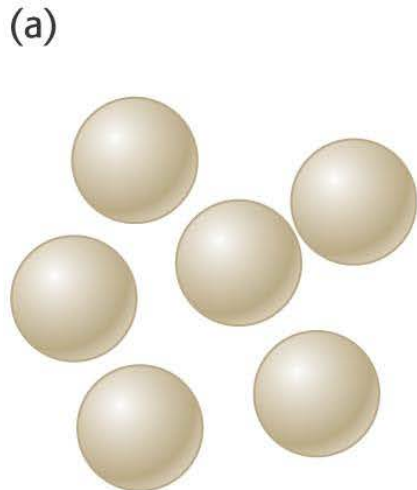
- Figures 24.17 (right) and 24.18 (below) show the effect of an applied electric field on polar and nonpolar molecules.



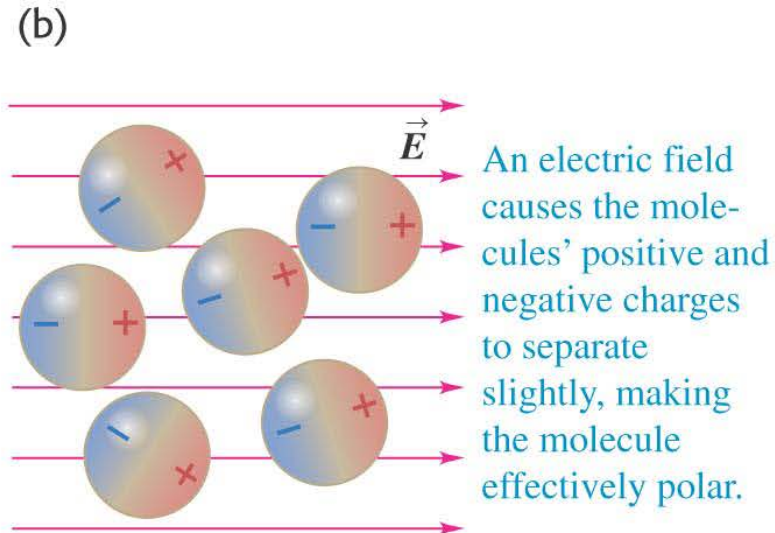
In the absence of an electric field, polar molecules orient randomly.



When an electric field is applied, the molecules tend to align with it.



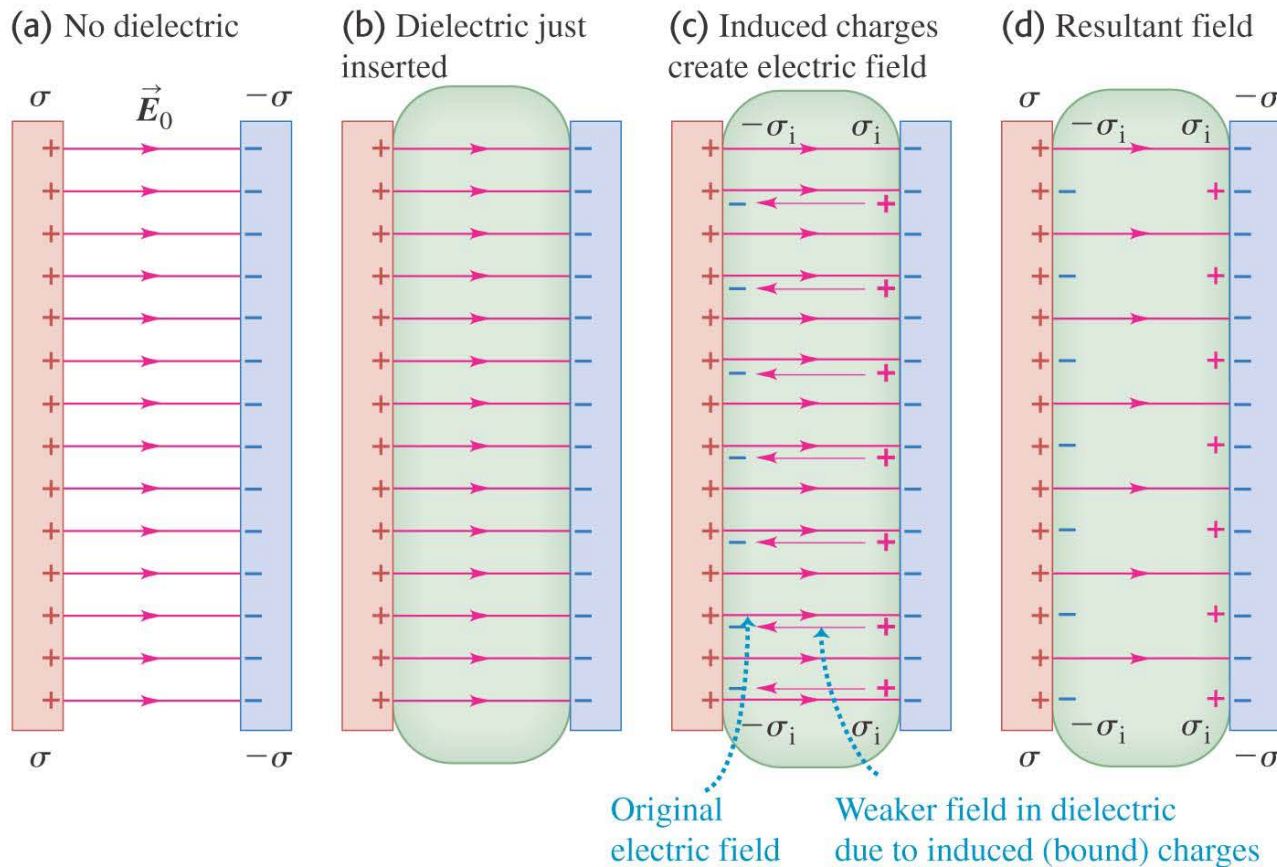
In the absence of an electric field, nonpolar molecules are not electric dipoles.



An electric field causes the molecules' positive and negative charges to separate slightly, making the molecule effectively polar.

Molecular model of induced charge - II

- Figure 24.20 below shows *polarization* of the dielectric and how the induced charges reduce the magnitude of the resultant electric field.



Gauss's law in dielectrics

- Follow the text discussion of Gauss's law in dielectrics, using Figure 24.22 at the right.
- Follow Example 24.12 for a spherical capacitor

