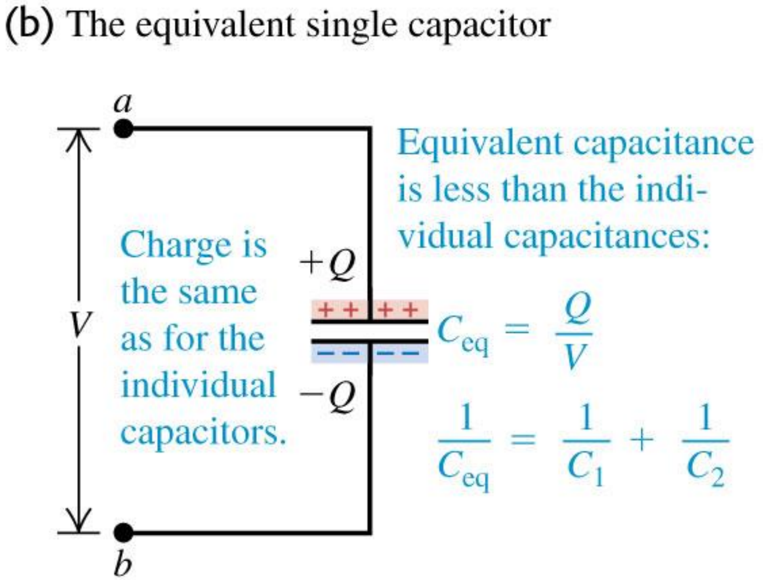
Lecture 19

PHYC 161 Fall 2016

Capacitors in Series

- If you wanted to replace these capacitors with just one equivalent capacitor:



$$C_{eq} = \frac{Q}{V} = \frac{Q}{V_1 + V_2} \Rightarrow$$

$$\frac{1}{C_{eq}} = \frac{V_1 + V_2}{Q} = \frac{V_1}{Q} + \frac{V_2}{Q} = \frac{1}{C_1} + \frac{1}{C_2} \Rightarrow$$

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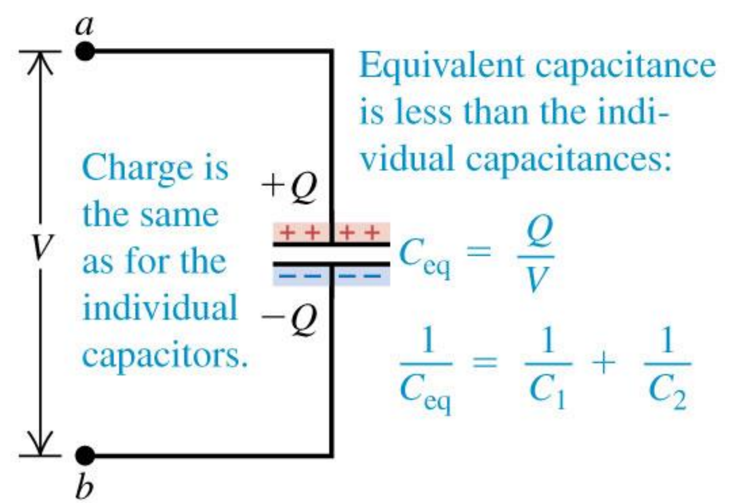
(b) The equivalent single capacitor

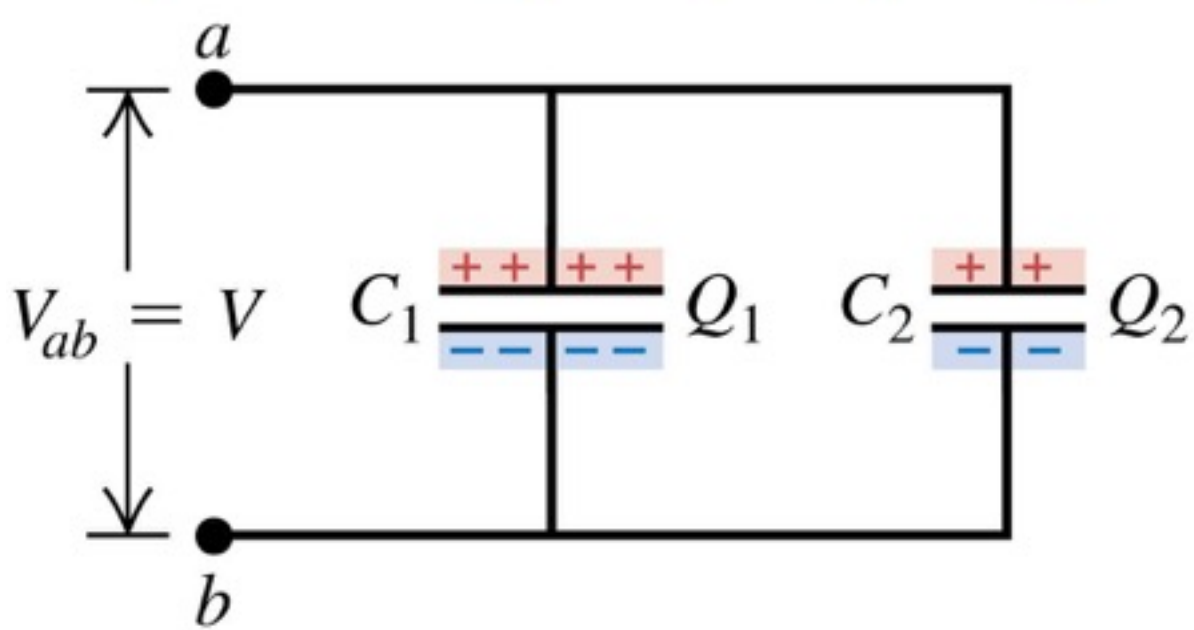


Capacitors in parallel: Slide 1 of 3

- Capacitors are connected in *parallel* between *a* and *b* if the potential difference V_{ab} is the same for all the capacitors.

Capacitors in parallel:

- The capacitors have the same potential V.
- The charge on each capacitor depends on its capacitance: $Q_1 = C_1V$, $Q_2 = C_2V$.



Capacitor in Parallel

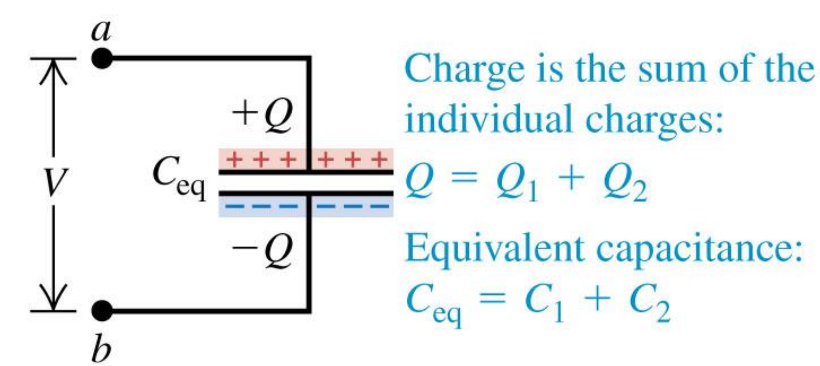
- If you wanted to replace these capacitors with just one equivalent capacitor:

$$C_{eq} = \frac{Q}{V} = \frac{Q_1 + Q_2}{V} \Rightarrow$$

$$C_{eq} = \frac{Q_1}{V} + \frac{Q_2}{V} = C_1 + C_2 \Rightarrow$$

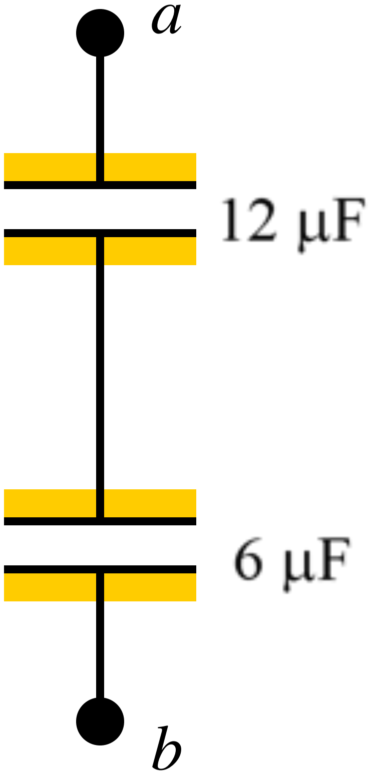
$$C_{eq} = C_1 + C_2$$

(b) The equivalent single capacitor



Q24.3

A 12-μF capacitor and a 6-μF capacitor are connected together as shown. What is the equivalent capacitance of the two capacitors as a unit?



A. $C_{eq} = 18\ \mu F$

B. $C_{eq} = 9\ \mu F$

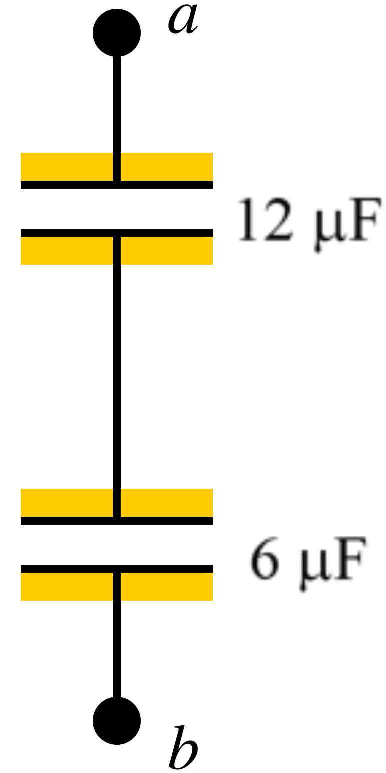
C. $C_{eq} = 6\ \mu F$

D. $C_{eq} = 4\ \mu F$

E. $C_{eq} = 2\ \mu F$

Q24.4

A 12-μF capacitor and a 6-μF capacitor are connected together as shown. If the charge on the 12-μF capacitor is 24 microcoulombs (24 μC), what is the charge on the 6-μF capacitor?



A. 48 μC

B. 36 μC

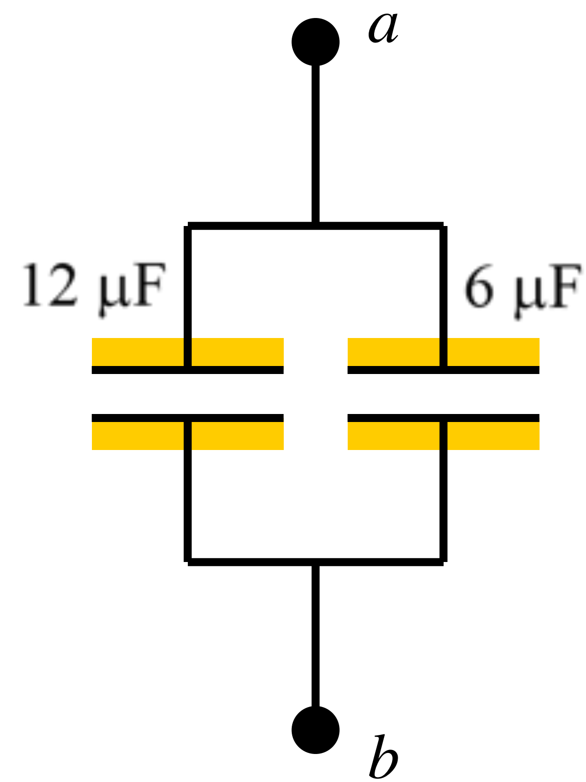
C. 24 μC

D. 12 μC

E. 6 μC

Q24.5

A 12-μF capacitor and a 6-μF capacitor are connected together as shown. What is the equivalent capacitance of the two capacitors as a unit?



A. $C_{eq} = 18\ \mu F$

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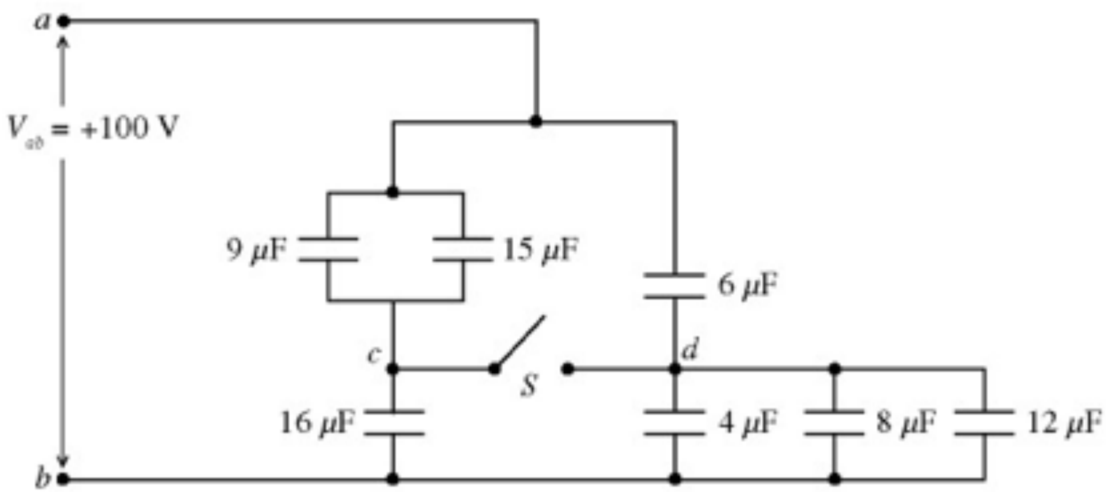
Problem 24.15

Description: (a) The capacitive network shown in the figure is assembled with initially uncharged capacitors. A potential difference, Vab = +100V, is applied across the network. The switch S in the network is kept open. Assume that all the capacitances shown...

Part A

The capacitive network shown in the figure is assembled with initially uncharged capacitors. A potential difference, V_{ab} = +100V, is applied across the network. The switch S in the network is kept open. Assume that all the capacitances shown are accurate to two significant figures. What is potential difference V_{cd} across the open switch S?



Energy stored in a capacitor

- The potential energy stored in a capacitor is:

Potential energy stored in a capacitor:

$$U = \frac{Q^2}{2C} = \frac{1}{2}CV^2 = \frac{1}{2}QV$$

Magnitude of charge on each plate (Q); Capacitance (C); Potential difference between plates (V)

- The capacitor energy is stored in the *electric field* between the plates.

- The *energy density* is:

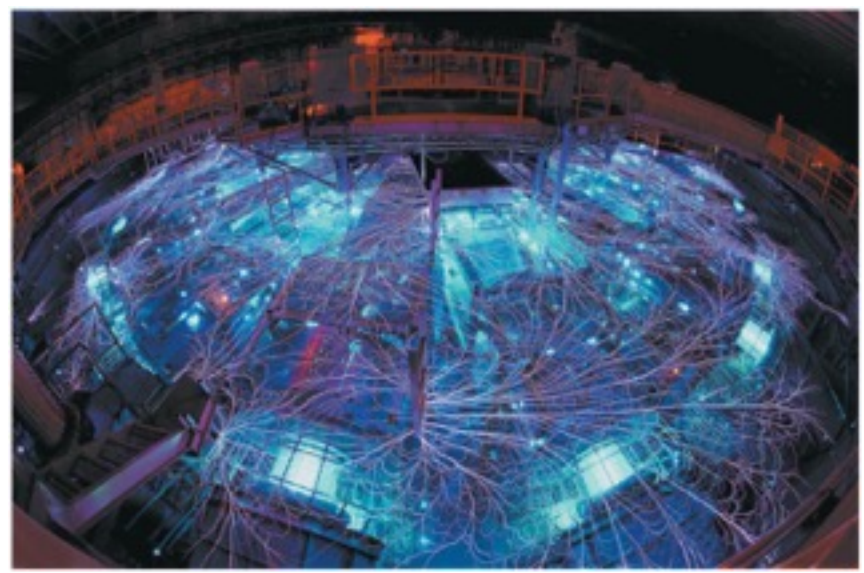
Electric energy density in a vacuum:

$$u = \frac{1}{2}\epsilon_0 E^2$$

Magnitude of electric field (E); Electric constant (ϵ_0)

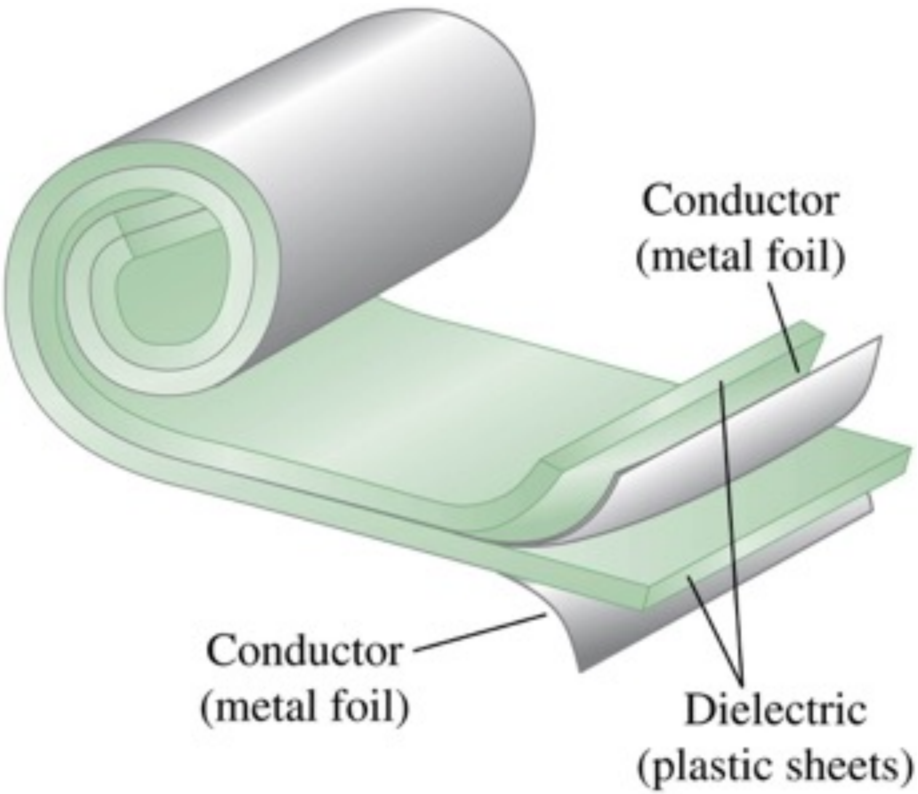
Energy stored in a capacitor

- A practical application of capacitors is their ability to store energy and release it quickly.
- An extreme example of the same principle is the Z machine at Sandia National Laboratories in New Mexico, which is used in experiments in controlled nuclear fusion.
- The Z machine uses a large number of capacitors in parallel to give a tremendous equivalent capacitance.
- The arcs shown here are produced when the capacitors discharge their energy into a target, which is heated to a temperature higher than 2×10^9 K.



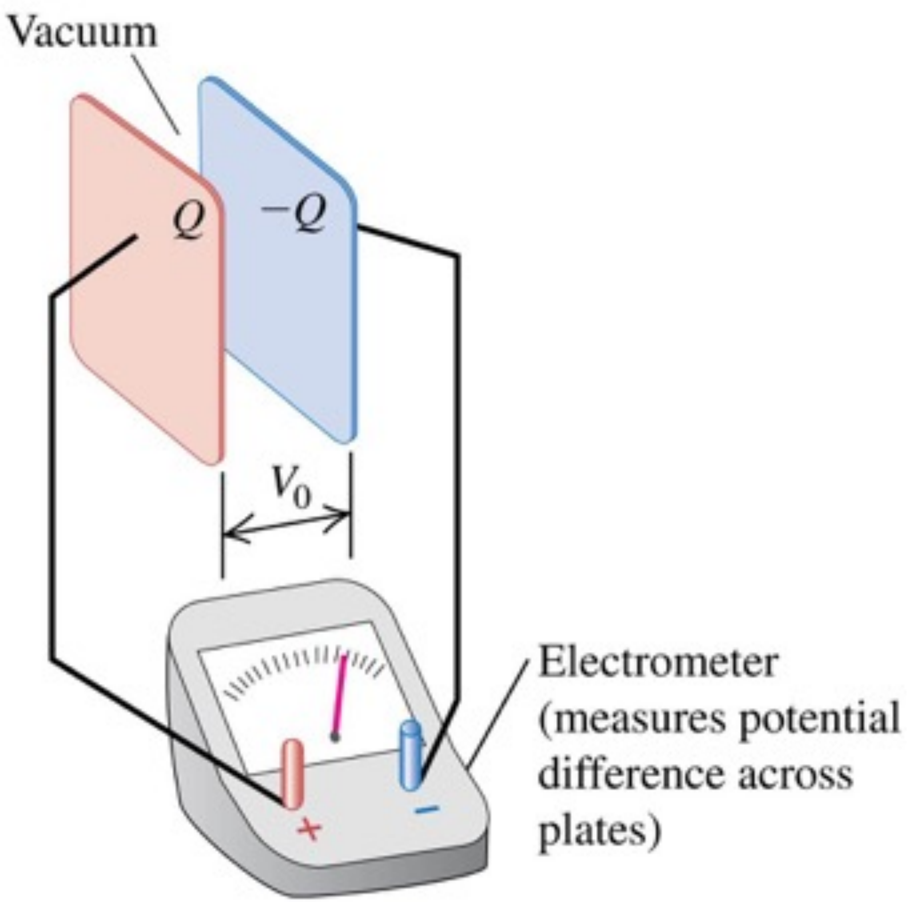
Dielectrics

- Most capacitors have a nonconducting material, or dielectric, between their conducting plates.
- A common type of capacitor uses long strips of metal foil for the plates, separated by strips of plastic sheet such as Mylar.



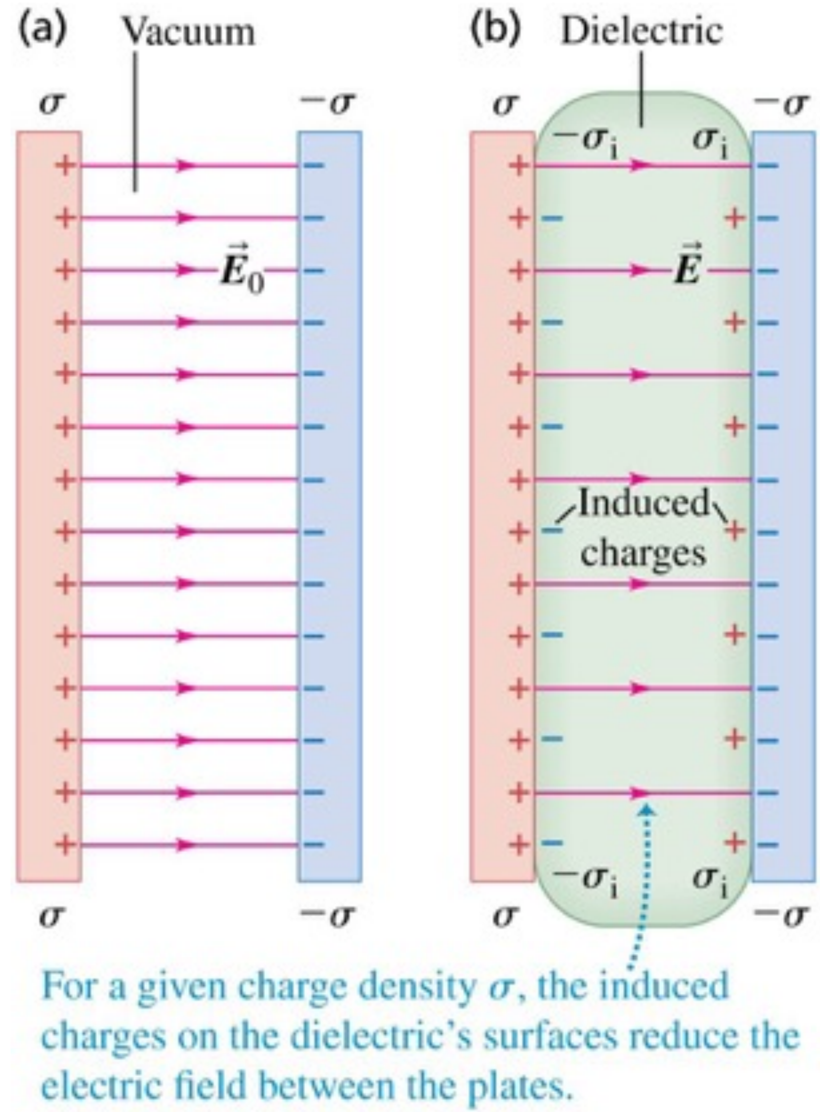
Dielectrics increase capacitance: Slide 1 of 2

- Consider an electrometer connected across a charged capacitor, with magnitude of charge Q on each plate and potential difference V_0.



Dielectrics

- When a dielectric is inserted between the plates of a capacitor, the electric field *decreases*.
- This is due to **polarization** of the charge within the dielectric, which results in induced surface charges, as shown.



The dielectric constant

- When an insulating material is inserted between the plates of a capacitor whose original capacitance is C_0, the new capacitance is greater by a factor K, where K is the **dielectric constant** of the material.

$$C = KC_0 = K\epsilon_0\frac{A}{d} = \epsilon\frac{A}{d}$$

Capacitance of a parallel-plate capacitor, dielectric between plates
Dielectric constant
Area of each plate
Permittivity $= K\epsilon_0$
Capacitance without dielectric
Electric constant
Distance between plates

- The energy density in the capacitor also increases:

$$u = \tfrac{1}{2}K\epsilon_0E^2 = \tfrac{1}{2}\epsilon E^2$$

Electric energy density in a dielectric
Dielectric constant
Permittivity $= K\epsilon_0$
Electric constant
Magnitude of electric field

Table 24.1—Some dielectric constants

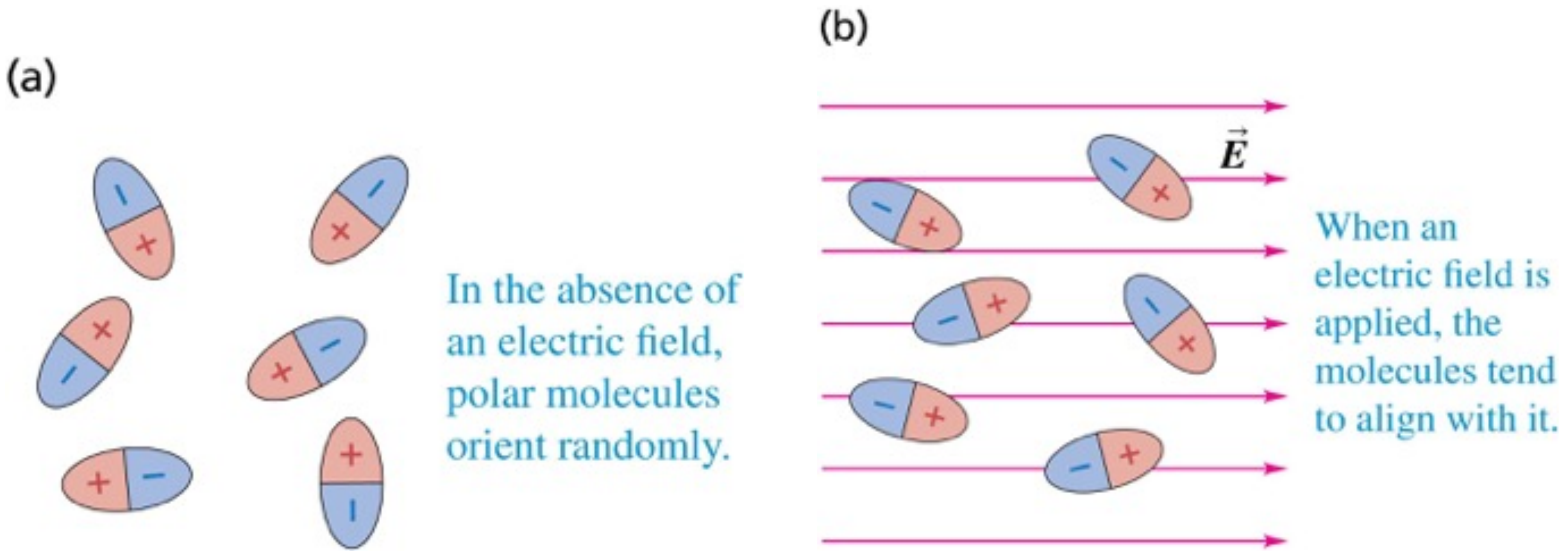
Material	K
Vacuum	*1*
Air (1 atm)	*1.00059*
Teflon	*2.1*
Mylar	*3.1*
Glass	*5 – 10*
Glycerin	*42.5*
Water	*80.4*

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.
- For example, Pyrex glass has a dielectric constant of $K = 4.7$, and a dielectric strength of $E_m = 1 \times 107$ V/m.
- Dry air has a dielectric constant of $K = 1.00059$ and a dielectric strength of $E_m = 3 \times 106$ V/m.

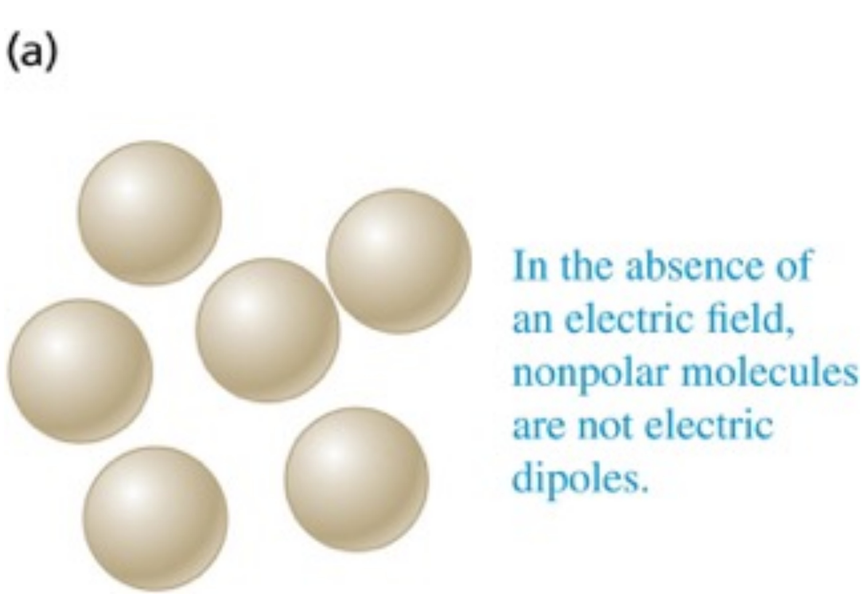
Molecular model of induced charge

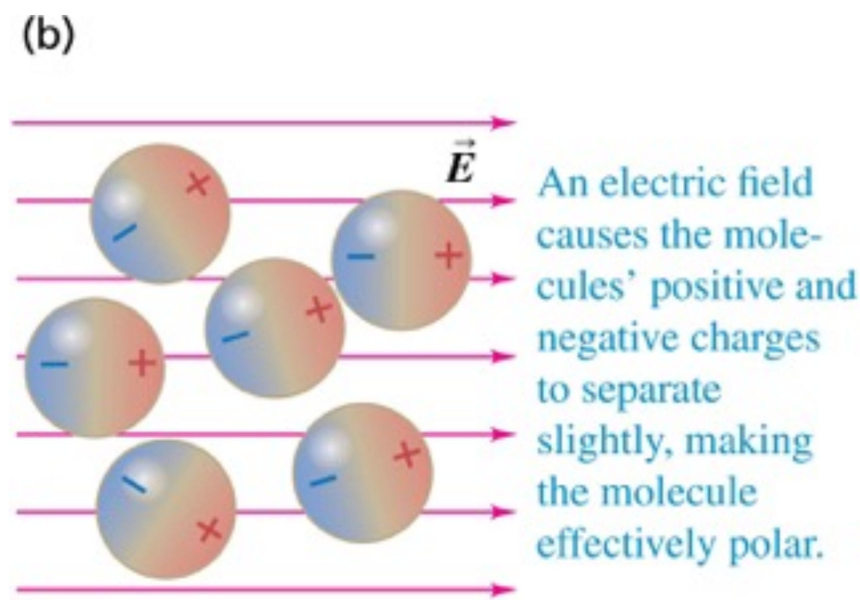
- Some molecules, such as H_2O and N_2O, form natural electric dipoles, and the molecule is called a **polar molecule**.
- When no electric field is present in a gas or liquid with polar molecules, the molecules are oriented randomly (a).
- In an electric field, however, they tend to orient themselves as in (b).



Molecular model of induced charge

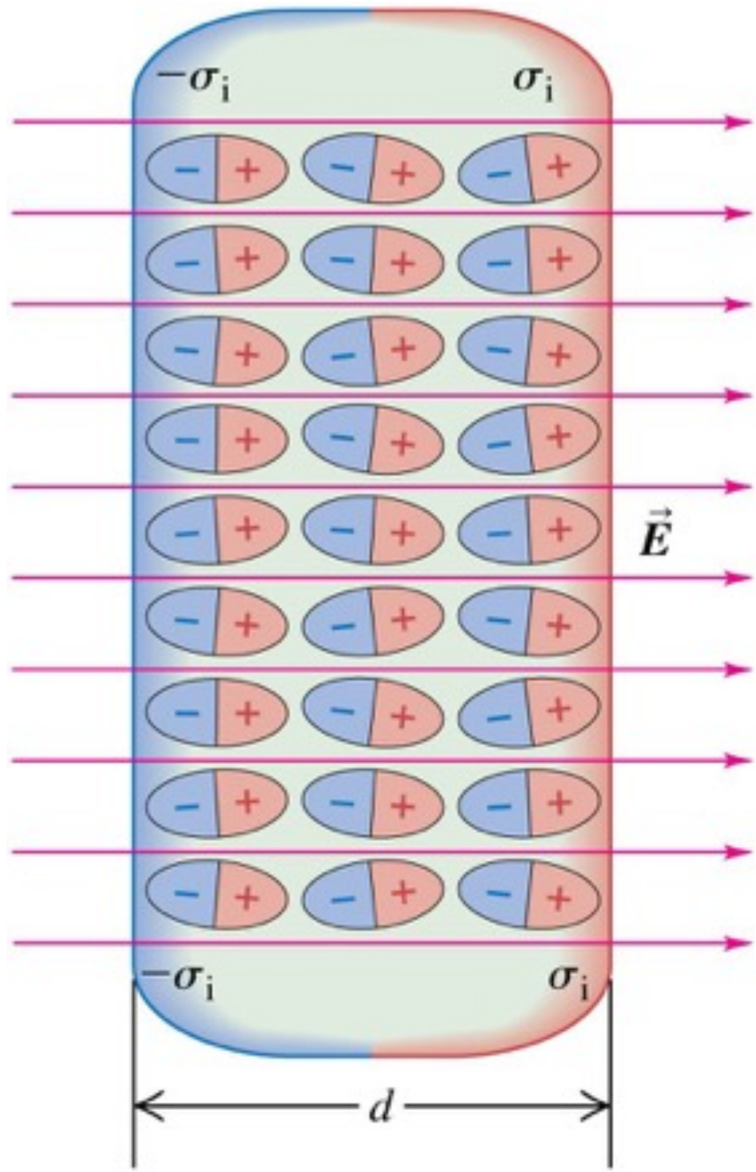
- Even a molecule that is not ordinarily polar (a) becomes a dipole when it is placed in an electric field because the field pushes the positive charges in the molecules in the direction of the field and pushes the negative charges in the opposite direction (b).
- Such dipoles are called *induced* dipoles.





Molecular model of induced charge

- The polarization of molecules within a dielectric leads to the formation of a layer of charge on each surface of the dielectric material.
- These layers have a surface charge density of magnitude σ_i.



Behavior of a dielectric in four steps