Chapter 20
Electric Potential and Electric potential Energy

Outline

20-1 Electric Potential Energy and the Electric Potential

20-2 Energy Conversation

20-3 The Electric Potential of Point Charges

20-4 Equipotential Surfaces and the Electric Field.

20-5 Capacitor and Dielectrics

20-6 Electric Energy Storage

20-5 Capacitor and Dielectric

A capacitor has a capacity to store electric charge and energy, which is determined by its capacitance C,

$$Q = CV$$

Where, Q and V are the charge and voltage, respectively.

Definition of Capacitance, C

$$C = \frac{Q}{V} \qquad (20-9)$$

SI units: coulomb/volt=farad, F (1F = 1 C/V)

Note: 1 pF = 10^{-12} F; 1 uF = 10^{-6} F

20-41 Capacitor

It is desired that 5.8 μC of charge be stored on each plate of a 3.2- μC capacitor. What potential difference is required between the plates?

Solution: Solve equation (20-9) for *V*:

$$V = \frac{Q}{C} = \frac{5.8\times 10^{-6}\,\mathrm{C}}{3.2\times 10^{-6}\,\mathrm{F}} = \boxed{1.8\ \mathrm{V}}$$

Parallel-Plate Capacitor

Deriving capacitance C: determined by geometrical parameters

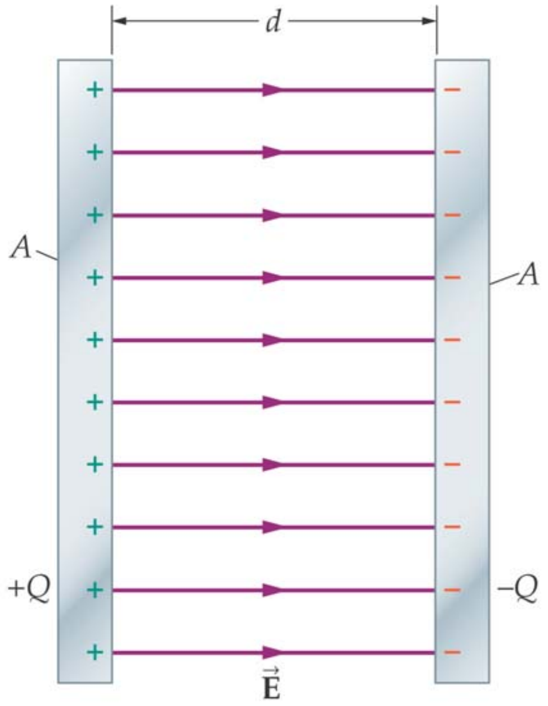


Figure 20-13
A Parallel-Plate Capacitor

Deriving capacitance C

From Active Example 19-3, we have

$$E = \frac{\sigma}{\varepsilon_0} = \frac{Q}{\varepsilon_0 A} \qquad (20-1)$$

The magnitude of the potential difference is

$$\Delta V = V = Ed = \frac{Qd}{\varepsilon_0 A}$$

Therefore,

$$C = \frac{Q}{V} = \frac{Q}{(Qd/\varepsilon_0 A)}$$

Capacitance of a parallel-plate capacitor in Air is

$$C = \frac{\varepsilon_0 A}{d} \qquad (20-12)$$

SI units: coulomb/volt=farad, F

The constant “Permittivity of free space” is

$$\varepsilon_0 = \frac{1}{4\pi k} = 8.85\times 10^{-12} C^2 / N\cdot m^2$$

Note:

The capacitance of a capacitor is determined by its geometrical parameters.

CONCEPTUAL CHECKPOINT 20–5

A parallel-plate capacitor is connected to a battery that maintains a constant potential difference V between the plates. If the plates are pulled away from each other, increasing their separation, does the magnitude of the charge on the plates **(a)** increase, **(b)** decrease, or **(c)** remain the same?

Dielectrics

How to increase the Capacitance?

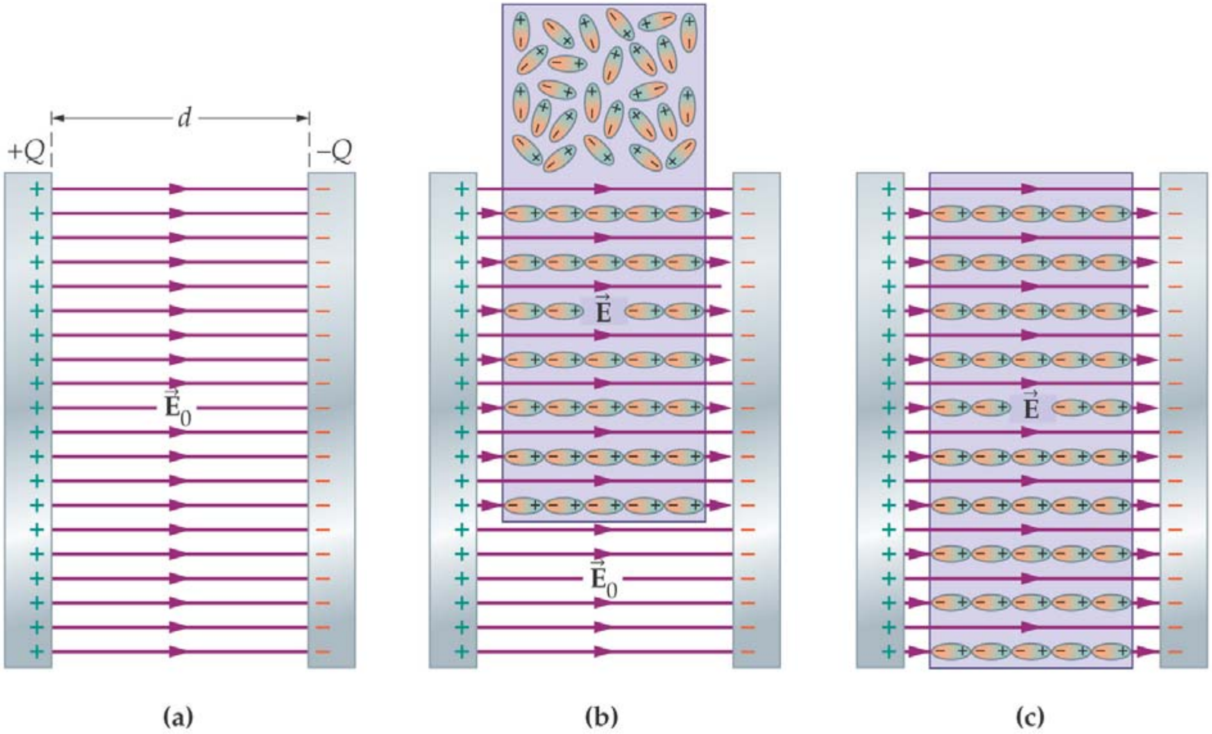


Figure 20-15
The Effect of a Dielectric on the Electric Field of a Capacitor

After a permanent dipole material is inserted into the capacitor, for the same amount of charge Q, the electric field E_0 is decreased as

$$E = \frac{E_0}{\kappa}$$

Where κ is the dielectric constant, which is greater than 1, and is determined by the material.

Now we have

$$V = Ed = \frac{E_0}{\kappa} d = \frac{E_0 d}{\kappa} = \frac{V_0}{\kappa}$$

$$C = \frac{Q}{V} = \frac{Q}{(V_0 / \kappa)} = \kappa \frac{Q}{V_0} = \kappa C_0$$

Capacitance of a parallel-plate capacitor with Dielectric

$$C = \frac{\kappa \varepsilon_0 A}{d} \qquad (20-15)$$

The capacitance of a dielectric capacitor is determined by

- its geometric parameters (A, d)
- and its material κ

20-45

A parallel-plate capacitor has plates with an area 0.012 m^2 for each plate, and a separation of 0.88 mm. The space bewteen the plates is filled with a dielectric whose dielectric constant is 2.0. What is the potential difference between the plates when the charge on the capacitor plate is 4.7 μC.

Solution:

Solve equation 20-9 for *V* and substitute equation 20-15 for *C*:

$$V = \frac{Q}{C} = \frac{Qd}{\kappa \varepsilon_0 A} = \frac{\left(4.7\times 10^{-6}\ \text{C}\right)\left(0.88\times 10^{-3}\ \text{m}\right)}{\left(2.0\right)\left(8.85\times 10^{-12}\ \text{C}^2/\ \text{N}\cdot\text{m}^2\right)\left(0.012\,\text{m}^2\right)} = \boxed{19\ \text{kV}}$$

Dielectric Breakdown

If the electric field applied to a capacitor is too large, the dielectric material make be damaged, which is referred to as ***breakdown***. The maximum filed a dielectric can withstand without breakdown is called ***dielectric strength***.

Table 20-2 Dielectric strengths

Substance	Dielectric Strength (V/m)
Mica	100×10^6
Air	3×10^6

20-6 Electrical Energy Storage

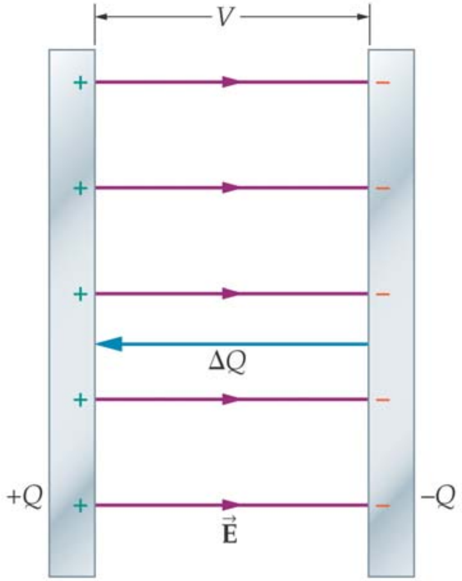
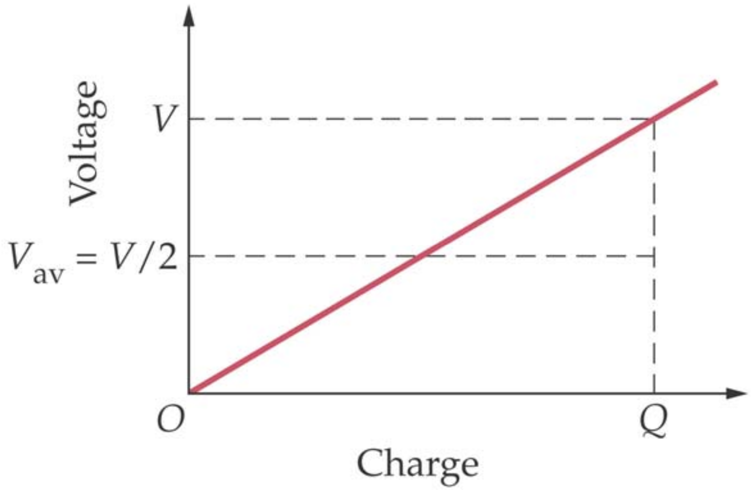


Figure 20-17
The Energy Required to Charge a Capacitor

The total energy U (average) in a capacitor is

$$U = QV_{av} = \frac{1}{2}QV \qquad (20-16)$$



Since Q=CV, we have

$$U = \frac{1}{2}CV^2 \qquad (20-17)$$

With V=Q/C, we have

$$U = \frac{Q^2}{2C} \qquad (20-18)$$

20-53

Calculate the work done by a 3.0-V battery as it charges a 7.2-μF capacitor in the flash unit of a camera.

Summary

1) Capacitance of a parallel-plate capacitor in Air is

$$C = \frac{\varepsilon_0 A}{d} \qquad (20-12)$$

2) Capacitance of a parallel-plate capacitor with Dielectric

$$C = \frac{\kappa \varepsilon_0 A}{d} \qquad (20-15)$$

3) The total energy U (average) in a capacitor is

$$U = QV_{av} = \frac{1}{2} QV \qquad (20-16)$$

Exercise 20-3

A capacitor of 0.75 uF is charged to a voltage 16 V. What is the magnitude of the charge on each plate of capacitor?

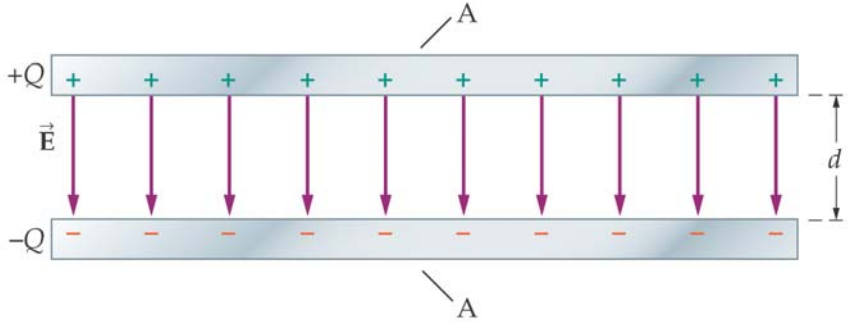
Solution

$Q=CV$

$= (0.75\times10^{-6}\ F)(16\ V) = 1.2\times10^{-5}\ C$

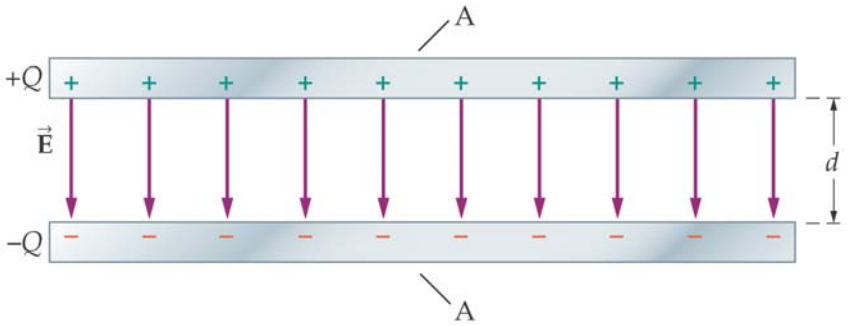
Example 20-5 All charge up

A capacitor is constructed with plates of areas 0.0280 m^2 and separation 0.550 mm. Find the magnitude of the charge on each plate of this capacitor when the potential difference between the plates is 20.1 V



Solution

1) Find the capacitance



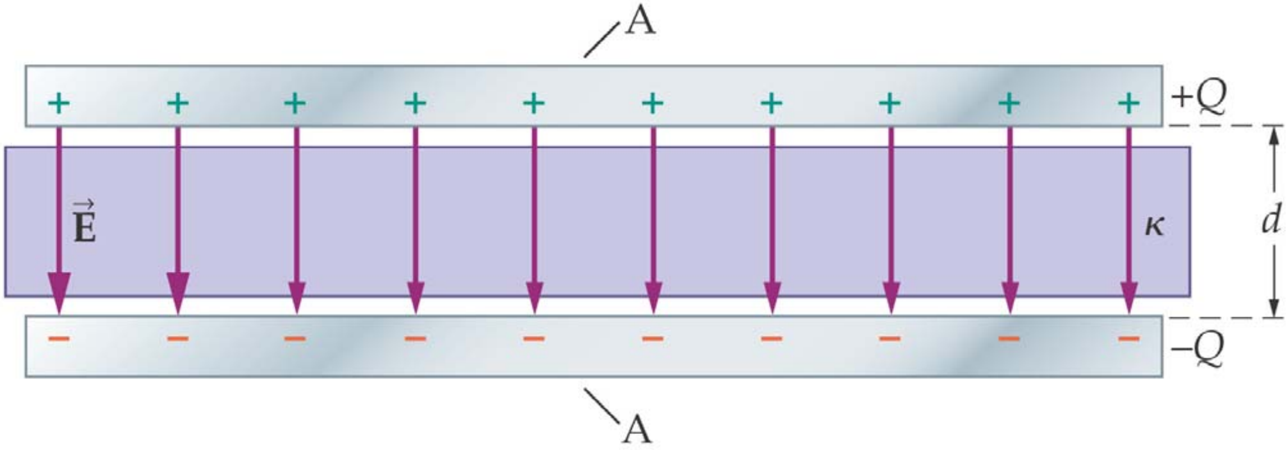
$$C = \frac{\varepsilon_0 A}{d} = \frac{(8.85\times10^{-12} C^2 / N.m^2)(0.0280 m^2)}{0.550\times10^{-3} m} = 4.51\times10^{-10} \quad F$$

2) Find the charge

$$Q = CV = (4.51\times10^{-10} F)(20.1V) = 9.06\times10^{-9} C$$

Example 20-6 **Even More charge up**

A capacitor is constructed with plates of areas 0.0280 m^2 and separation 0.550 mm. It is filled with dielectric with dielectric constant κ. When it is connected to 12.0-V battery, each plate has a charges of magnitude 3.26×10^{-8} C. What is the value of dielectric constant κ ?



Picture the Problem **Example 20-6**
Even More Charged Up

Solution

1) The capacitance

$$C = \frac{Q}{V} = \frac{(3.62\times10^{-8}C)}{12V} = 3.02\times10^{-9}F$$

2) Find the dielectric constant κ

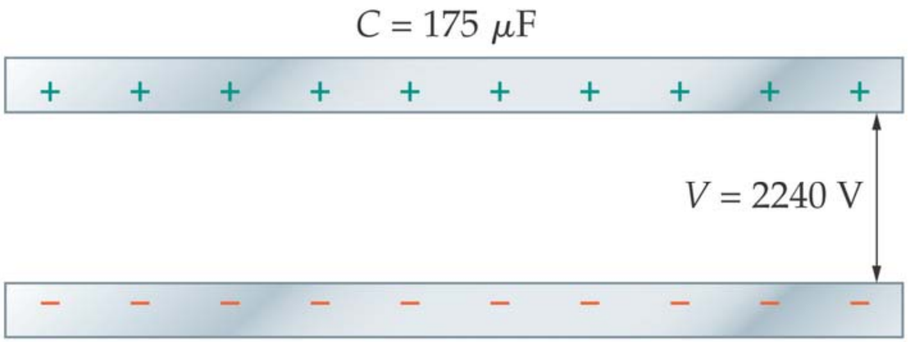
$$C = \frac{\kappa\varepsilon_0 A}{d}$$

$$\kappa = \frac{Cd}{\varepsilon_0 A}$$

$$= \frac{(3.02\times10^{-9}F)(0.550\times10^{-3}m)}{(8.85\times10^{-12}C^2/N\cdot m^2)(0.0280m^2)} = 6.70$$

Example 20-7

In a typical defibrillator, a 175-uF capacitor is charged until the potential difference is 2240V. **(a)** What is the magnitude of the charge on each plate of the final capacitor? **(b)** find the energy stored in the charged-up defibrillator.



Picture the problem **Example 20-7**

The Defibrillator: Adding a Shock to the System

Solution

Part (a)

$$Q = CV = (175\times10^{-6}\ F)(2240\ V) = 0.392\ C$$

Part (b)

$$U = \frac{1}{2}CV^2$$

$$= \frac{1}{2}(175\times10^{-6}F)(2240V)^2 = 439\quad J$$