# PHYS 111
# 1ST semester 1439-1440

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**Lecture 11**

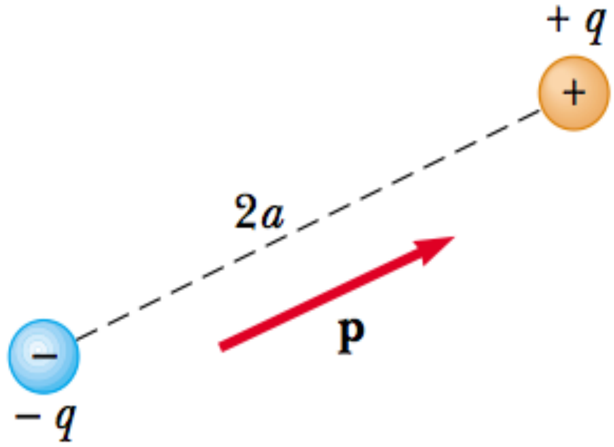
# Chapter 26

# Capacitance and Dielectrics

# 26.6 Electric Dipole in an Electric Field

- The electric dipole consists of two charges of equal magnitude and opposite sign separated by a distance 2*a*,
- The **electric dipole moment** of this configuration is defined as the vector **p** directed from -*q* toward +*q* along the line joining the charges and having magnitude 2*aq* :

$$p = 2aq$$



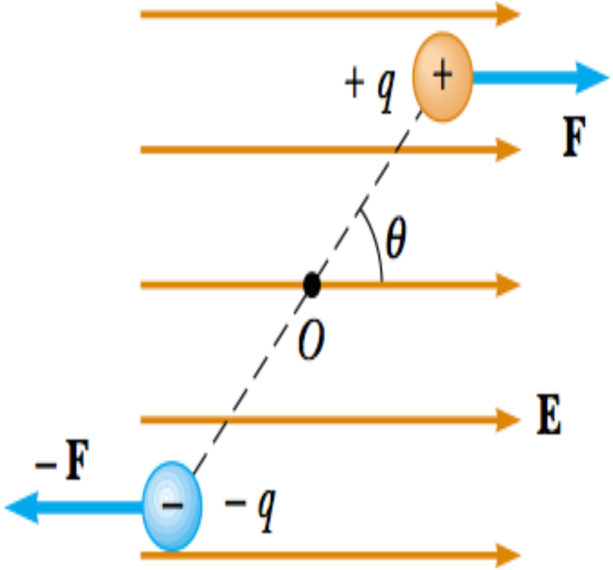
# 26.6 Electric Dipole in an Electric Field

- Now suppose that an electric dipole is placed in a uniform electric field **E**,
- The electric forces acting on the two charges are equal in magnitude (*F*=*qE*) and opposite in direction.
- The two forces produce a net **torque** on the dipole; as a result, the dipole rotates.
- This forces tend to produce a clockwise rotation.
- The magnitude of the net torque about *O* is

$$\tau = 2Fa \sin \theta$$

- Because *F*=*qE* and *p*=2*aq*, we can express τ as $\tau = 2aqE \sin \theta = pE \sin \theta$
- **Torque on an electric dipole in an external electric field**

$$\boldsymbol{\tau} = \mathbf{p} \times \mathbf{E}$$



# 26.6 Electric Dipole in an Electric Field

- The change in potential energy of the system

$$U_f - U_i = \int_{\theta_i}^{\theta_f} \tau \, d\theta = \int_{\theta_i}^{\theta_f} pE \sin\theta \, d\theta = pE \int_{\theta_i}^{\theta_f} \sin\theta \, d\theta$$

$$= pE[-\cos\theta]_{\theta_i}^{\theta_f} = pE(\cos\theta_i - \cos\theta_f)$$

It is convenient for us to choose a reference angle of $\theta_i = 90°$, so that $\cos\theta_i = \cos 90° = 0$. Furthermore, let us choose $U_i = 0$ at $\theta_i = 90°$ as our reference of potential energy. Hence, we can express a general value of $U = U_f$ as

$$U = -pE\cos\theta$$

- **Potential energy of the system of an electric dipole in an external electric field**

$$U = -\mathbf{p} \cdot \mathbf{E}$$

## Example 26.8 The $H_2O$ Molecule

The water ($H_2O$) molecule has an electric dipole moment of $6.3 \times 10^{-30}$ C·m. A sample contains $10^{21}$ water molecules, with the dipole moments all oriented in the direction of an electric field of magnitude $2.5 \times 10^5$ N/C. How much work is required to rotate the dipoles from this orientation ($\theta = 0°$) to one in which all the moments are perpendicular to the field ($\theta = 90°$)?

***Solution*** The work required to rotate one molecule 90° is equal to the difference in potential energy between the 90° orientation and the 0° orientation. Using Equation 26.19, we obtain

$$W = U_{90°} - U_{0°} = (-pE\cos 90°) - (-pE\cos 0°)$$
$$= pE = (6.3 \times 10^{-30}\ \text{C}\cdot\text{m})(2.5 \times 10^5\ \text{N/C})$$
$$= 1.6 \times 10^{-24}\ \text{J}$$

Because there are $10^{21}$ molecules in the sample, the *total* work required is

$$W_{\text{total}} = (10^{21})(1.6 \times 10^{-24}\ \text{J}) = 1.6 \times 10^{-3}\ \text{J}$$

# Problems

**9.** When a potential difference of 150 V is applied to the plates of a parallel-plate capacitor, the plates carry a surface charge density of 30.0nC/cm$^2$. What is the spacing between the plates?

$$Q = \frac{\epsilon_0 A}{d}(\Delta V) \qquad \frac{Q}{A} = \sigma = \frac{\epsilon_0 (\Delta V)}{d}$$

$$d = \frac{\epsilon_0 (\Delta V)}{\sigma} = \frac{\left(8.85 \times 10^{-12}\ \mathrm{C^2/N \cdot m^2}\right)(150\ \mathrm{V})}{\left(30.0 \times 10^{-9}\ \mathrm{C/cm^2}\right)\left(1.00 \times 10^{4}\ \mathrm{cm^2/m^2}\right)} = \boxed{4.42\ \mu\mathrm{m}}$$

**13.** An air-filled spherical capacitor is constructed with inner and outer shell radii of 7.00 and 14.0 cm, respectively.

(a) Calculate the capacitance of the device.

(b) What potential difference between the spheres results in a charge of 4.00 μC on the capacitor?

(a) $$C = \frac{ab}{k_e(b-a)} = \frac{(0.0700)(0.140)}{(8.99 \times 10^9)(0.140 - 0.0700)} = \boxed{15.6\ \text{pF}}$$

(b) $$C = \frac{Q}{\Delta V} \qquad \Delta V = \frac{Q}{C} = \frac{4.00 \times 10^{-6}\ \text{C}}{15.6 \times 10^{-12}\ \text{F}} = \boxed{256\ \text{kV}}$$

**21.** Four capacitors are connected as shown in Figure P26.21.

(a) Find the equivalent capacitance between points *a* and *b*.

(b) Calculate the charge on each capacitor if $\Delta V_{ab}$ =15.0 V.

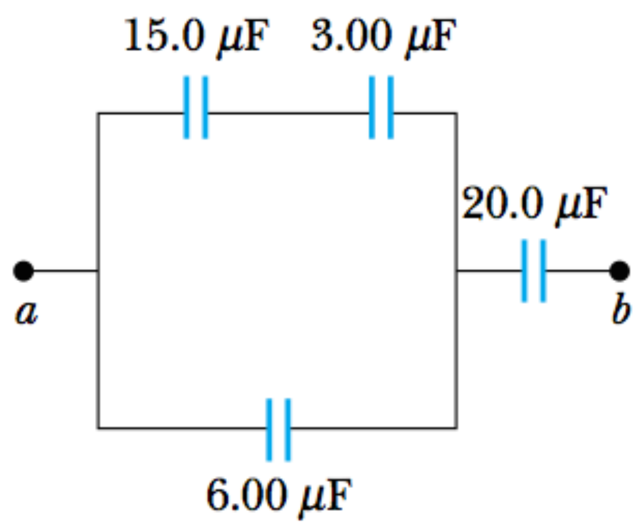



**Figure P26.21**

(a) $$\frac{1}{C_s} = \frac{1}{15.0} + \frac{1}{3.00}$$

$$C_s = 2.50\ \mu\text{F}$$

$$C_p = 2.50 + 6.00 = 8.50\ \mu\text{F}$$

$$C_{eq} = \left(\frac{1}{8.50\ \mu\text{F}} + \frac{1}{20.0\ \mu\text{F}}\right)^{-1} = \boxed{5.96\ \mu\text{F}}$$

(b) $$Q = C\Delta V = (5.96\ \mu\text{F})(15.0\ \text{V}) = \boxed{89.5\ \mu\text{C}}\ \text{on } 20.0\ \mu\text{F}$$

$$\Delta V = \frac{Q}{C} = \frac{89.5\ \mu\text{C}}{20.0\ \mu\text{F}} = 4.47\ \text{V}$$

$$15.0 - 4.47 = 10.53\ \text{V}$$

$$Q = C\Delta V = (6.00\ \mu\text{F})(10.53\ \text{V}) = \boxed{63.2\ \mu\text{C}}\ \text{on } 6.00\ \mu\text{F}$$

$$89.5 - 63.2 = \boxed{26.3\ \mu\text{C}}\ \text{on } 15.0\ \mu\text{F and } 3.00\ \mu\text{F}$$

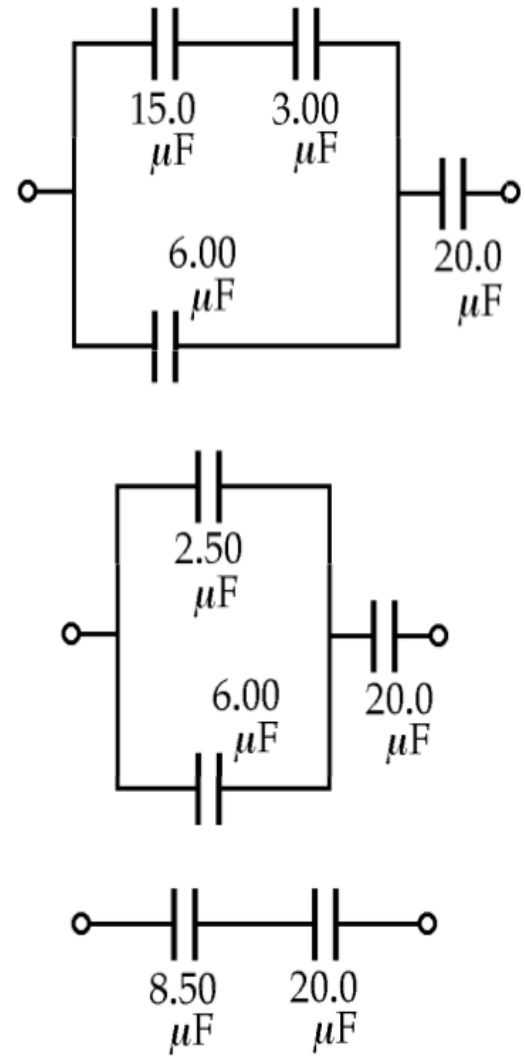



FIG. P26.21