Lecture 20

PHYC 161 Fall 2016

Q24.8

You want to connect a 12-μF capacitor and a 6-μF capacitor. How should you connect them so that when the capacitors are charged, the 12-μF capacitor will have a greater amount of stored energy than the 6-μF capacitor?

A. The two capacitors should be in series.

B. The two capacitors should be in parallel.

C. The two capacitors can be either in series or in parallel—in either case, the 12-μF capacitor will have a greater amount of stored energy.

D. The connection should be neither series nor parallel.

E. This is impossible no matter how the two capacitors are connected.

Energy stored in a capacitor

- The potential energy stored in a capacitor is:

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

Potential energy stored in a capacitor: U; Magnitude of charge on each plate: Q; Capacitance: C; Potential difference between plates: V

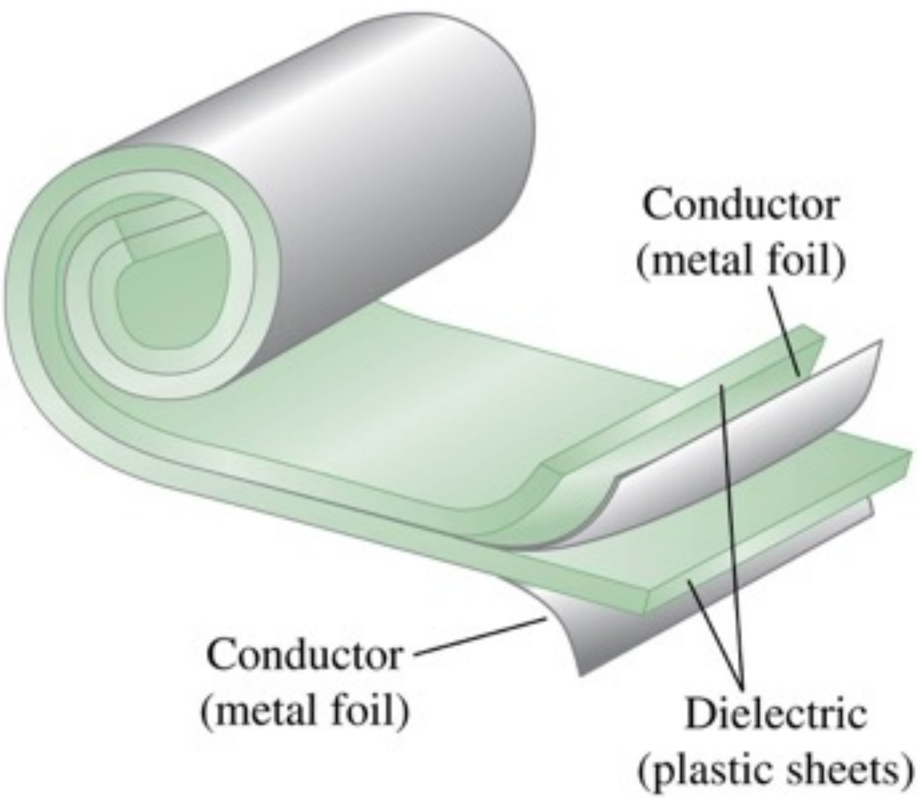
- The capacitor energy is stored in the *electric field* between the plates.
- The *energy density* is:

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

Electric energy density in a vacuum: u; Electric constant: ϵ_0; Magnitude of electric field: E

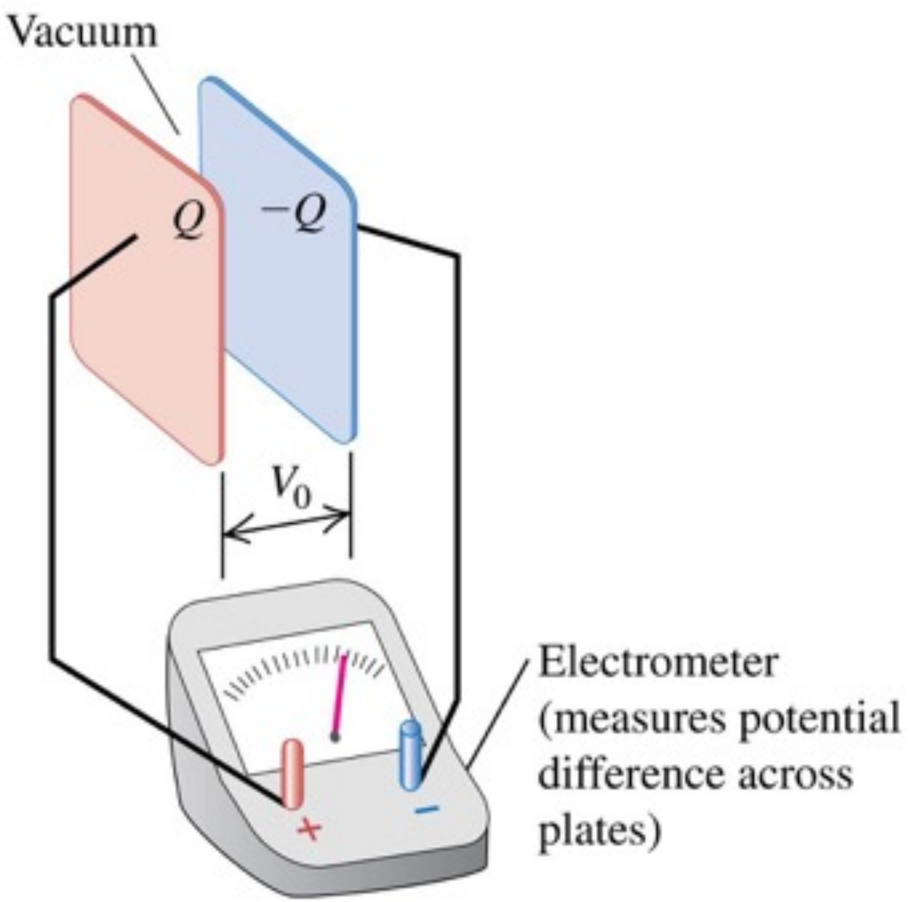
Dielectrics

- 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.



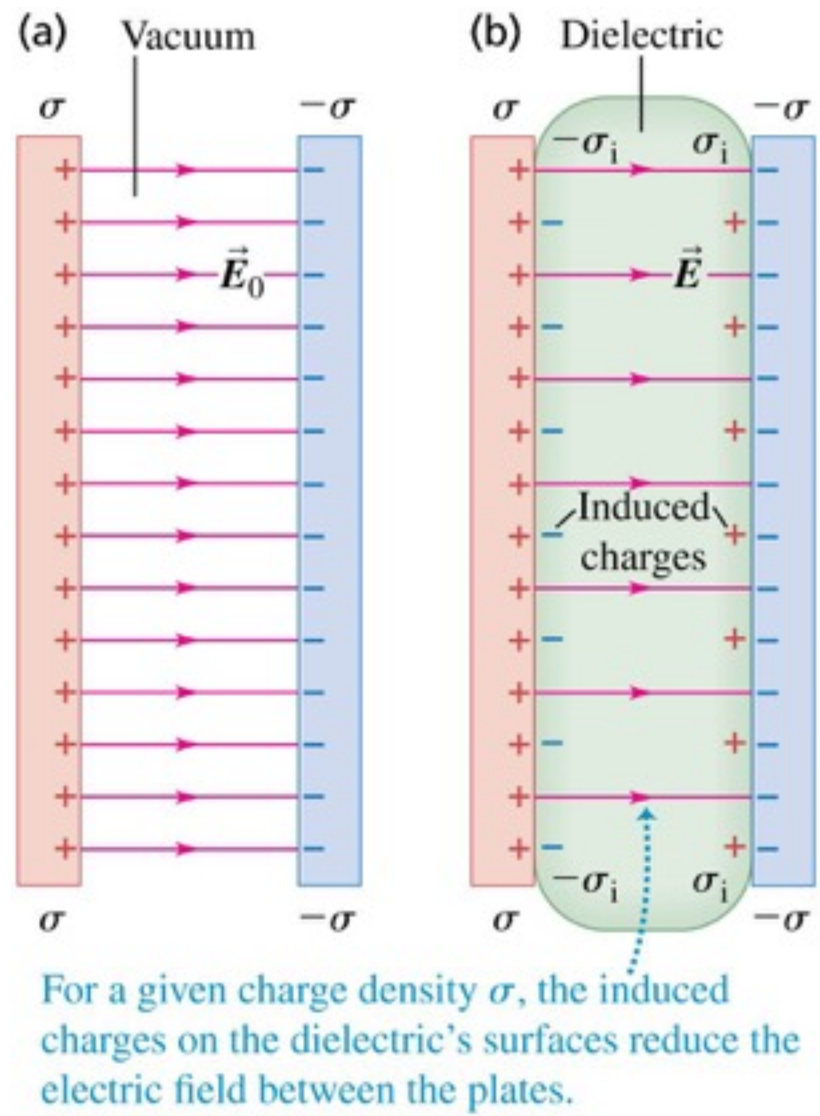
Dielectrics increase capacitance: Slide 1 of 2

- 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.

Capacitance of a parallel-plate capacitor, dielectric between plates

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

Dielectric constant
Area of each plate
Permittivity $= K\epsilon_0$
Capacitance without dielectric
Electric constant
Distance between plates

- The energy density in the capacitor DECREASES:

Electric energy density in a dielectric

$$u = \tfrac{1}{2}K\epsilon_0 E^2 = \tfrac{1}{2}\epsilon E^2$$

Dielectric constant
Permittivity $= K\epsilon_0$
Electric constant
Magnitude of electric field

Table 24.1—Some dielectric constants

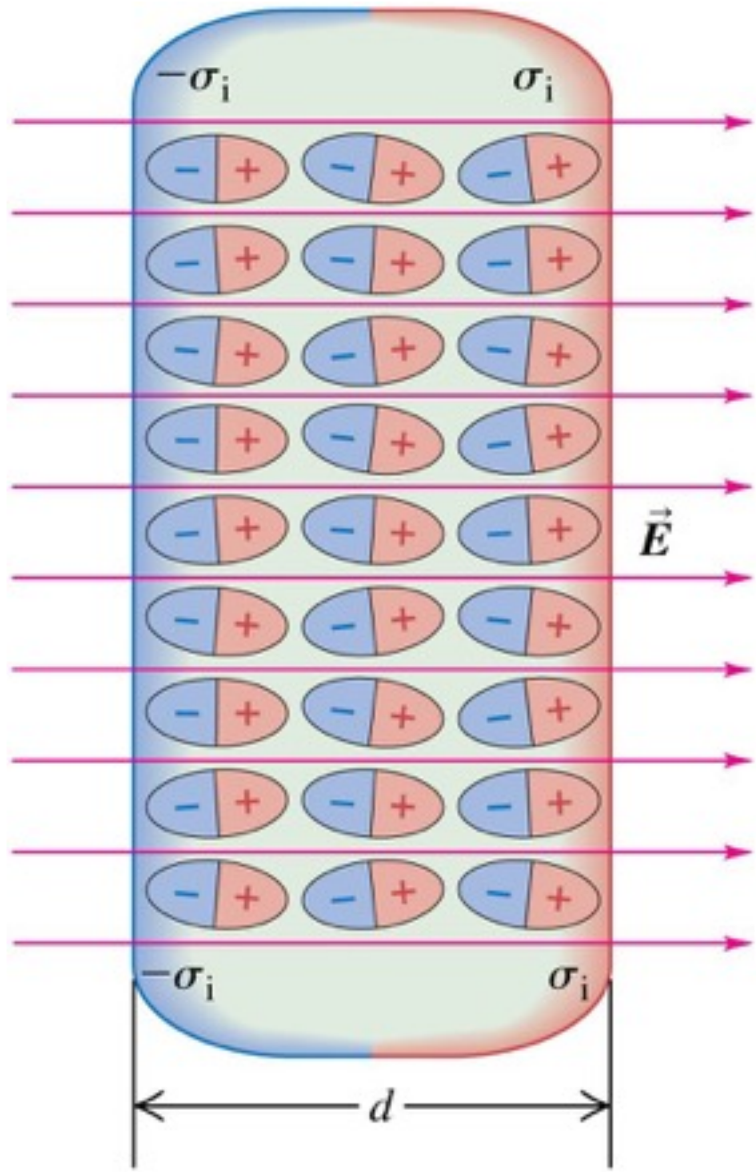
Material	*K*
Vacuum	*1*
Air (1 atm)	*1.00059*
Teflon	*2.1*
Mylar	*3.1*
Glass	*5 – 10*
Glycerin	*42.5*
Water	*80.4*

Dielectric breakdown

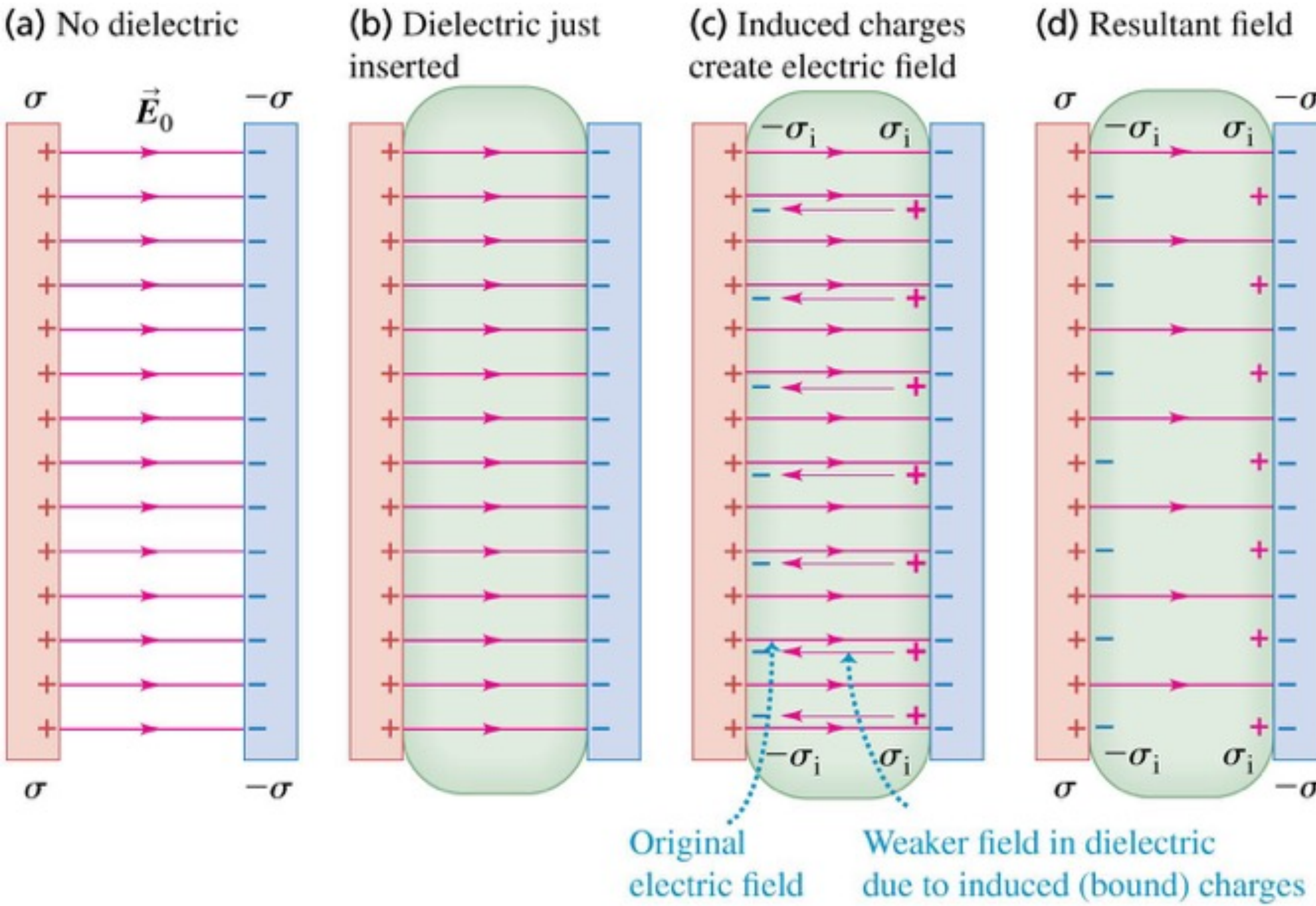
- If the electric field is strong enough, **dielectric breakdown** occurs and the dielectric becomes a conductor.
- The **dielectric strength** is the maximum electric field the material can withstand before breakdown occurs.
- For example, Pyrex glass has a dielectric constant of $K = 4.7$, and a dielectric 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

- 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



Q24.9

You slide a slab of dielectric between the plates of a parallel-plate capacitor. As you do this, the *charges* on the plates remain constant. What effect does adding the dielectric have on the *potential difference* between the capacitor plates?

A. The potential difference increases.

B. The potential difference decreases.

C. The potential difference remains the same.

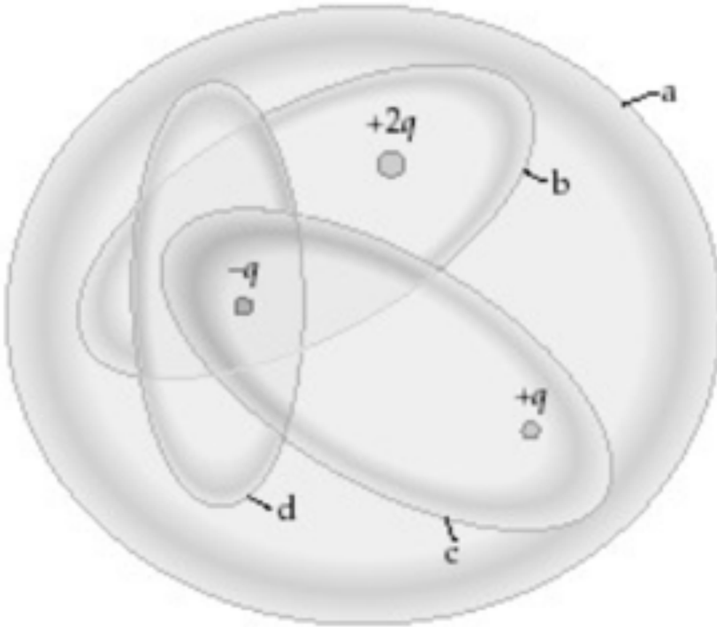
D. Two of A, B, and C are possible.

E. All three of A, B, or C are possible.

Gauss' Law

Part A

The figure shows four Gaussian surfaces surrounding a distribtuion of charges.



(a) Which Gaussian surfaces have an electric flux of $+q/\epsilon_0$ through them?

Concentric spheres with uniform charge

Part A

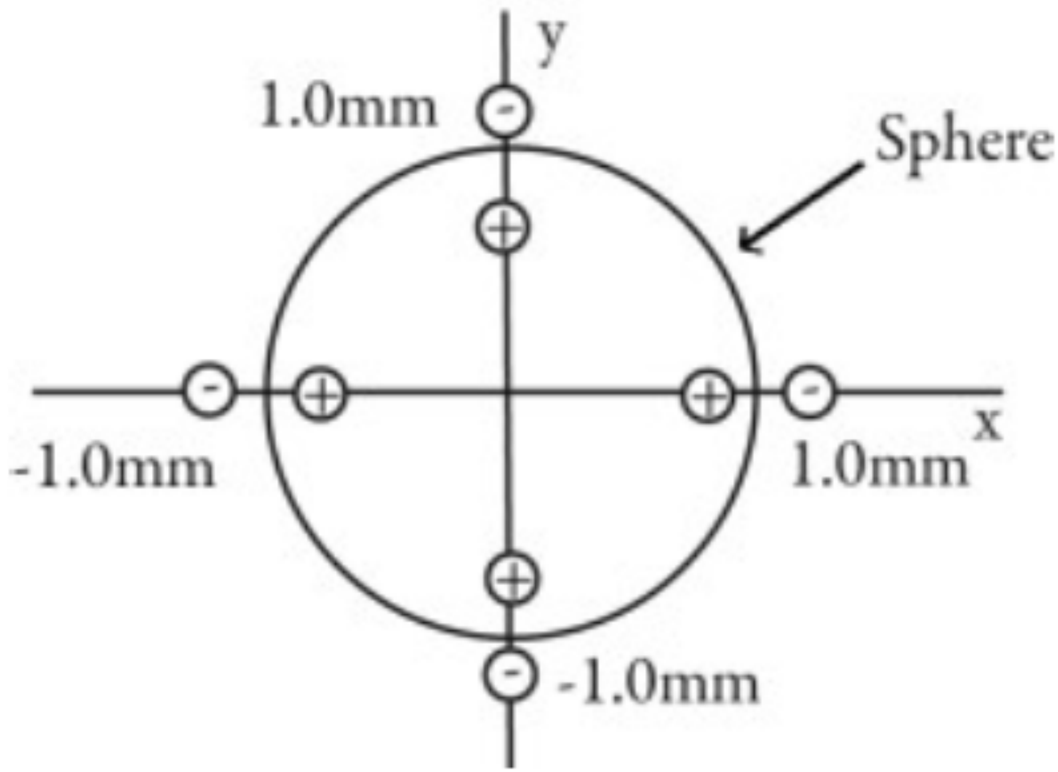
The graph in the figure shows the electric field strength (*not* the field lines) as a function of distance from the center for a pair of concentric uniformly charged spheres. Which of the following situations could the graph plausibly represent? (There may be more than one correct choice.)

- [x] a positively charged conducting sphere within another positively charged conducting sphere
- [ ] a solid nonconducting sphere, uniformly charged throughout its volume, inside of a positively charged conducting sphere
- [x] a positively charged nonconducting thin-walled spherical shell inside of a positively charged conducting sphere
- [ ] a positively charged conducting sphere within an uncharged conducting sphere
- [ ] a positively charged nonconducting thin-walled spherical shell inside of another positively charged nonconducting thin-walled spherical shell

Gauss

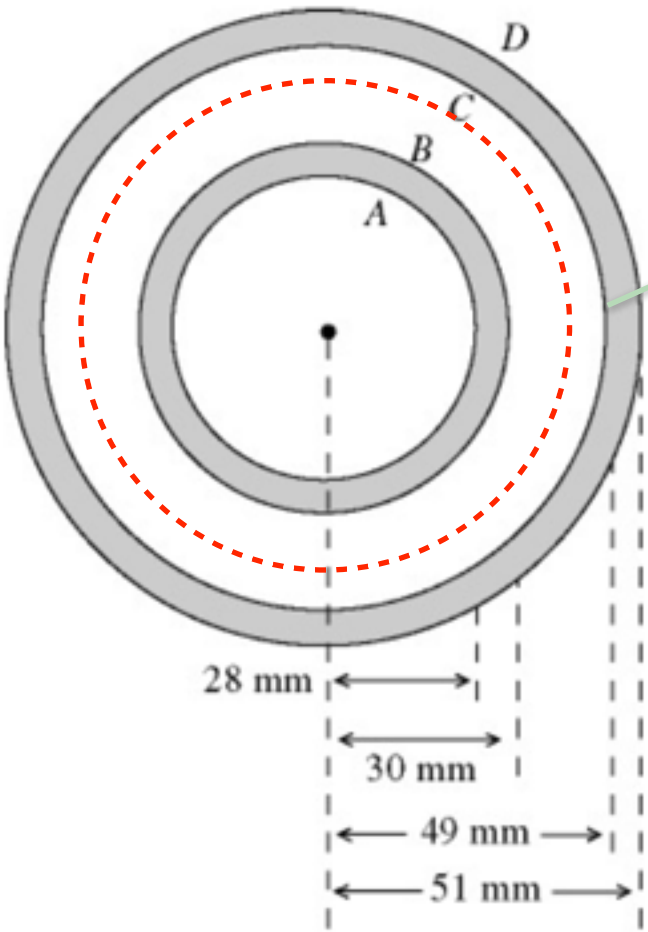
Part A

Four dipoles, each consisting of a +10-μC charge and a -10-μC charge, are located in the *xy*-plane with their centers 1.0 mm from the origin, as shown. A sphere passes through the dipoles, as shown in the figure. What is the electric flux through the sphere due to these dipoles? (ε_0 = 8.85 × 10^{-12} $C^2/N \cdot m^2$)

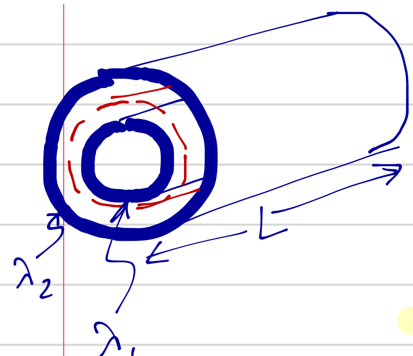


Part A

The cross section of a long coaxial cable is shown in the figure, with radii as given. The linear charge density on the inner conductor is -40 nC/m and the linear charge density on the outer conductor is -80 nC/m. The inner and outer cylindrical surfaces are respectively denoted by *A*, *B*, *C*, and *D*, as shown. ($\varepsilon_0 = 8.85 \times 10^{-12}\ C^2/N \cdot m^2$) The radial component of the electric field at a point that 44 mm from the axis is closest to



Use Gauss' Law



$$\oint \bar{E} \cdot d\bar{A} = \frac{Q_{enc}}{\epsilon_0}$$

By symmetry, $\bar{E}$ radial and constant on Gaussian sphere

$$\Rightarrow E(2\pi r L) = \frac{Q_{enc}}{\epsilon_0} = \frac{\lambda_1 L}{\epsilon_0}$$

$$E = \frac{\lambda_1}{2\pi \epsilon_0 r}$$

Finding the potential…

Exercise 23.28

Description: A solid conducting sphere has net positive charge and radius R. At a point 1.20 m from the center of the sphere, the electric potential due to the charge on the sphere is V. Assume that V = 0 at an infinite distance from the sphere. (a) ...

A solid conducting sphere has net positive charge and radius R = 0.400 m . At a point 1.20 m from the center of the sphere, the electric potential due to the charge on the sphere is 18.0 V . Assume that V = 0 at an infinite distance from the sphere.

Part A

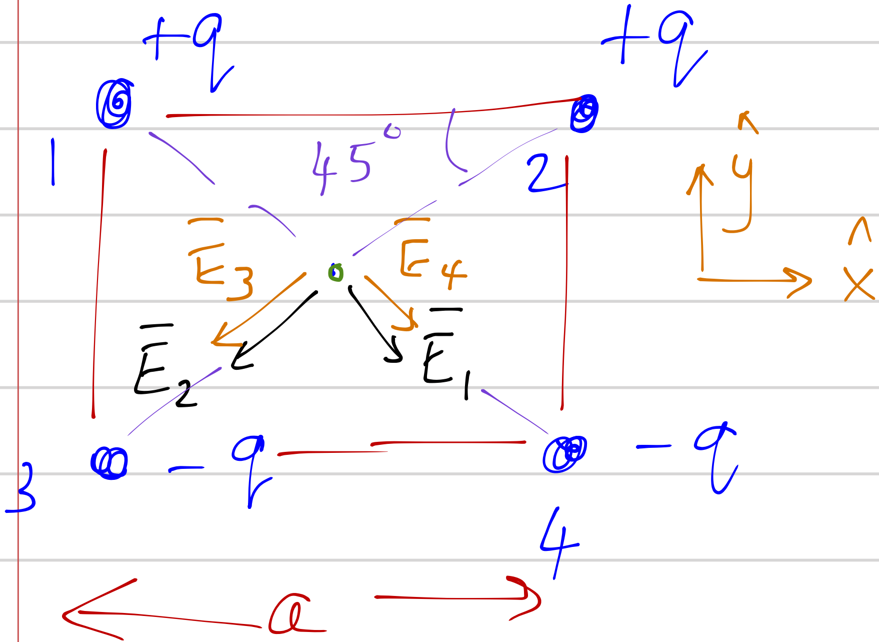
What is the electric potential at the center of the sphere?

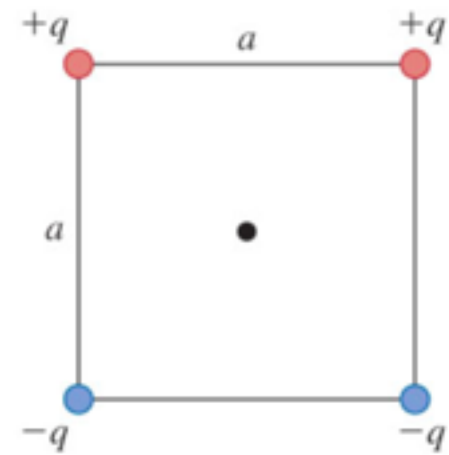
Express your answer with the appropriate units.

ANSWER:

$$V = \frac{1.2V}{R} = 54.0\,\mathrm{V}$$

Field and potential at center?





Field and potential at center?

$$\bar{E} = \bar{E}_1 + \bar{E}_2 + \bar{E}_3 + \bar{E}_4$$

$$\bar{E}_3 = \frac{-q}{4\pi\epsilon_0}\left(\frac{1}{2\sqrt{a}}\right)^2 \cos(45^\circ)\,\hat{x} - \frac{q}{4\pi\epsilon_0}\left(\frac{1}{2\sqrt{a}}\right)^2 \sin(45^\circ)\,\hat{y}$$

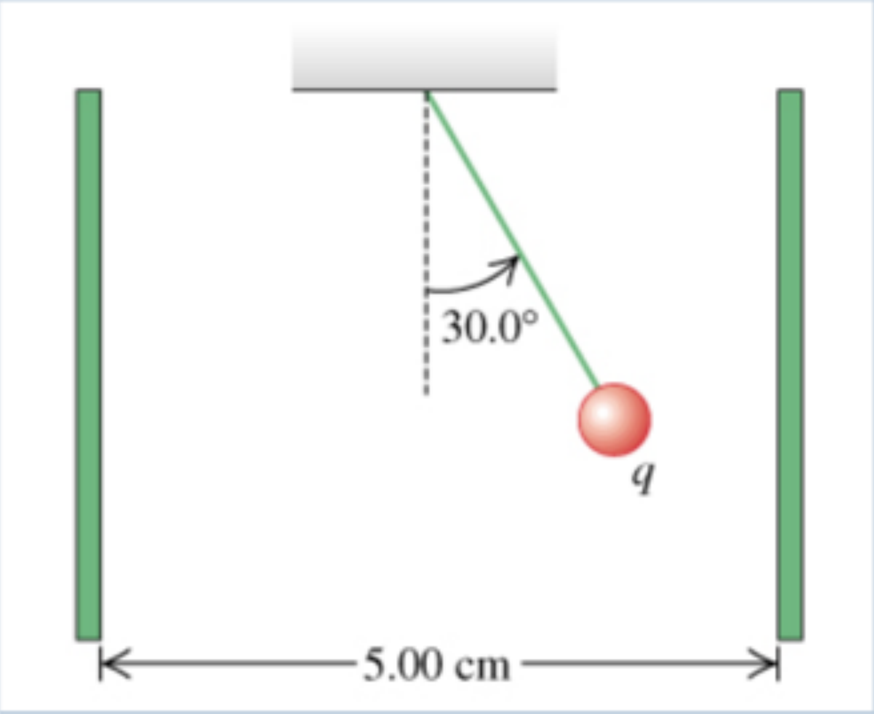
$$V = V_1 + V_2 + V_3 + V_4$$

$$V = 2\left(\frac{+q}{4\pi\epsilon_0}\,\frac{1}{2\sqrt{a}}\right) - 2\left(\frac{q}{4\pi\epsilon_0}\,\frac{1}{2\sqrt{a}}\right)$$

$$= 0$$

Find potential difference

A small sphere with mass 1.70 g hangs by a thread between two large parallel vertical plates 5.00 cm apart . The plates are insulating and have uniform surface charge densities $+\sigma$ and $-\sigma$. The charge on the sphere is q = 9.30×10^{-6} C .



Part A

What potential difference between the plates will cause the thread to assume an angle of 30.0° with the vertical?

Discharging a capacitor

The four identical capacitors in the circuit shown in the figure are initially uncharged. Let the charges on the capacitors be Q_1, Q_2, Q_3, and Q_4 and the potential differences across them be V_1, V_2, V_3, and V_4. The switch is thrown first to position A and kept there for a long time. It is then thrown to position B. Which of the following conditions is true with the switch in position B?