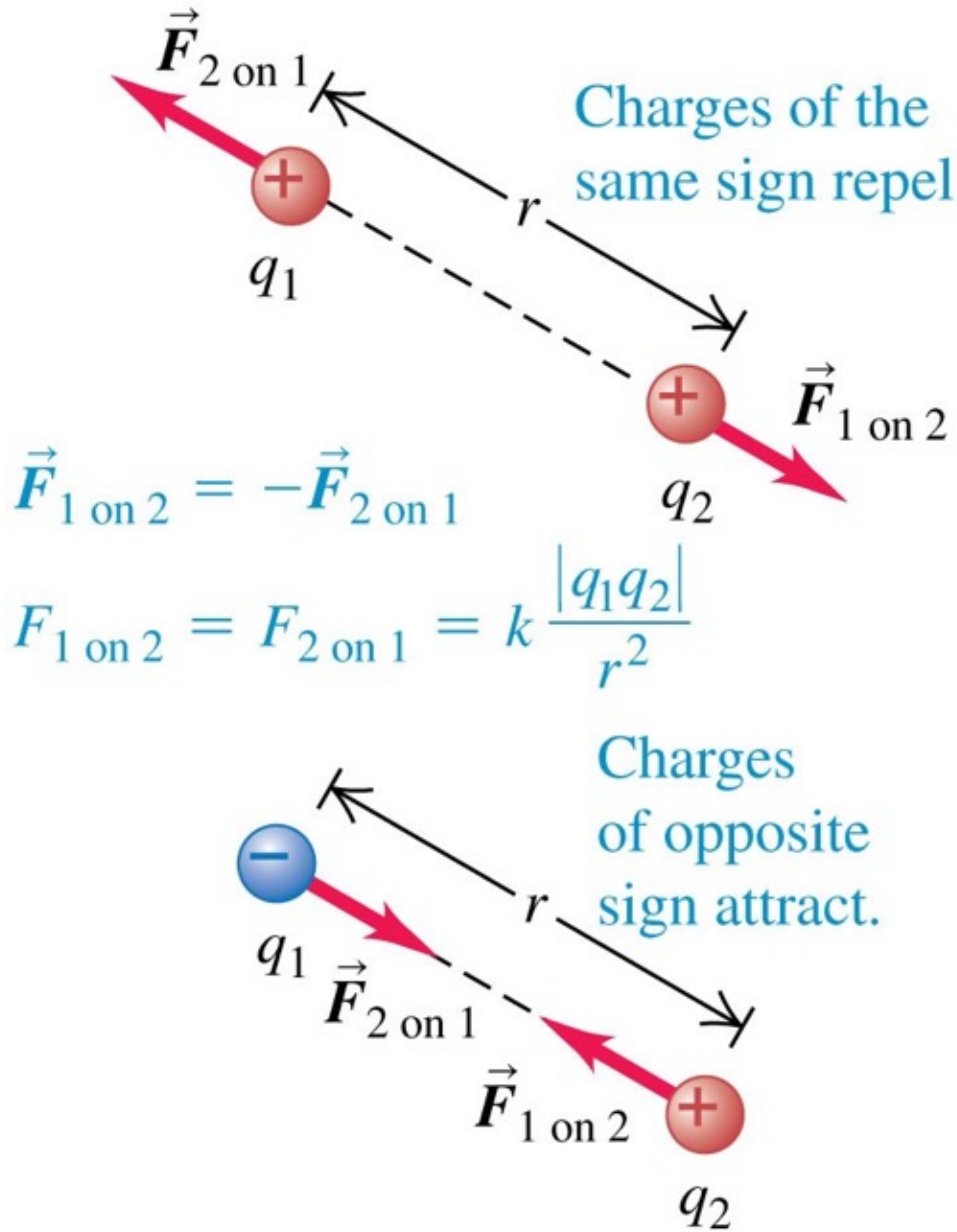
Coulomb's Law

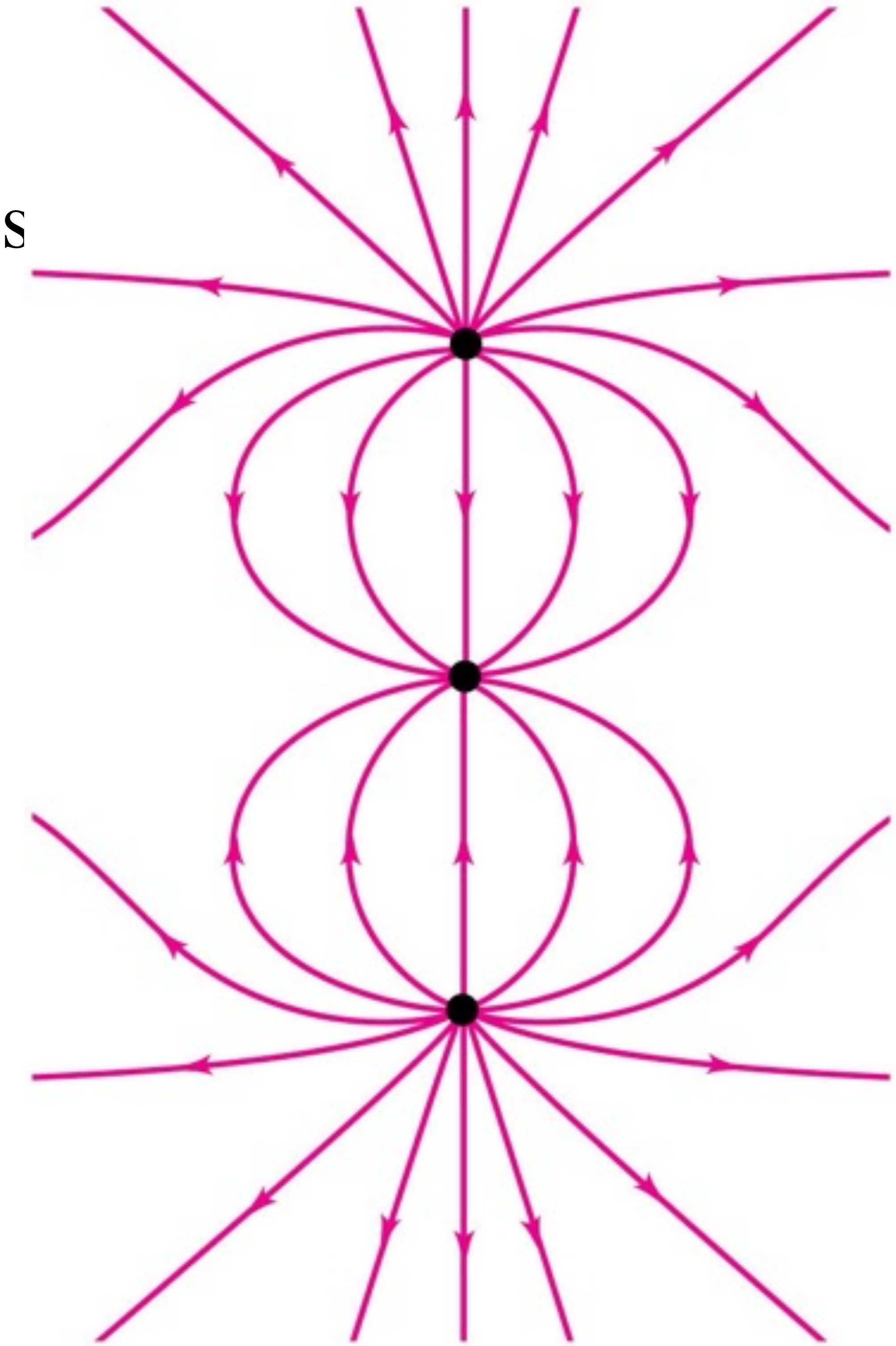
- **Coulomb's Law**: The magnitude of the electric force between two point charges is directly proportional to the product of their charges and inversely proportional to the square of the distance between them.

$$F = k\frac{|q_1 q_2|}{r^2}$$



Q21.9

The illustration shows the electric field lines due to three point charges (shown by the black dots). The electric field is strongest



A. where adjacent field lines are closes together.

B. where adjacent field lines are farthest apart.

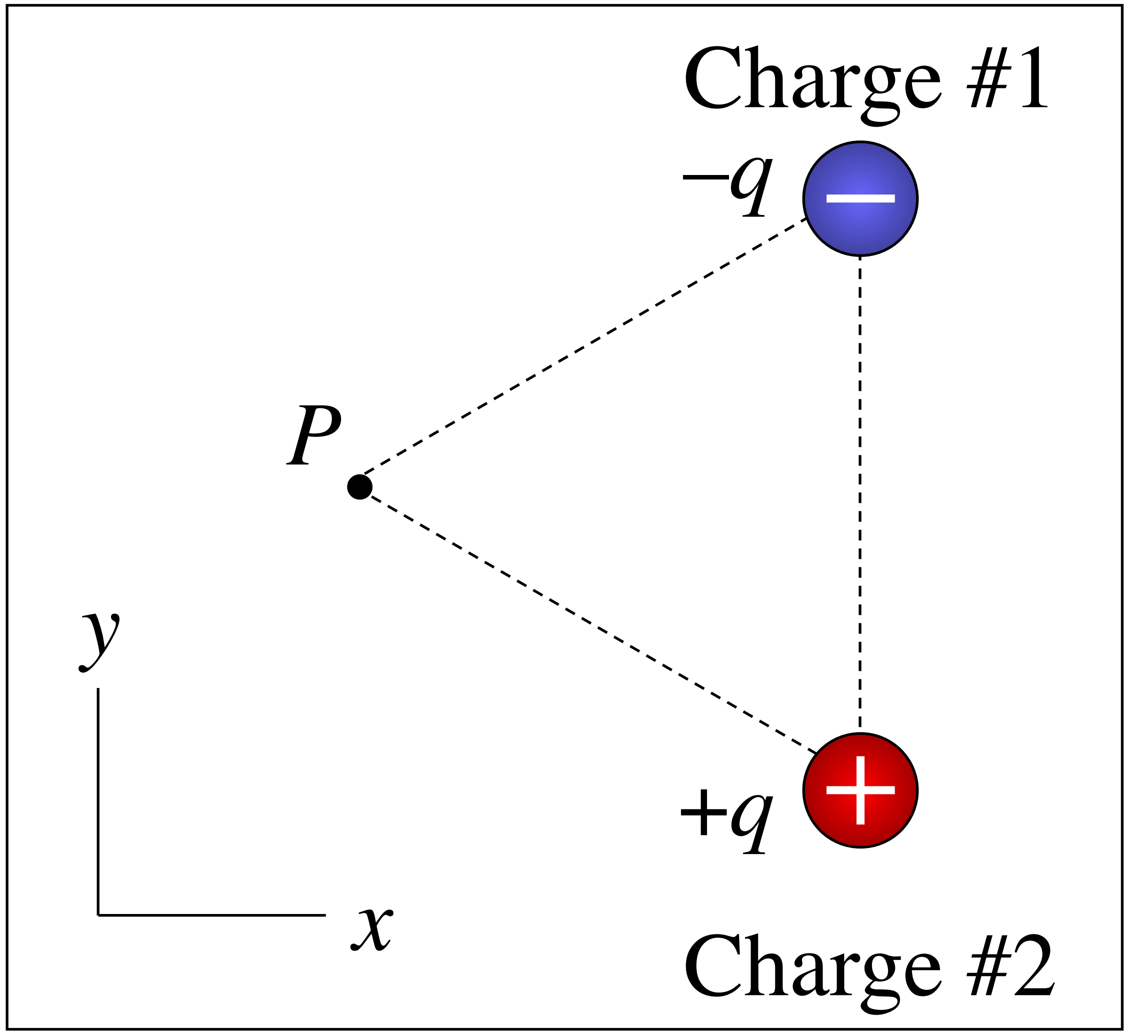
C. where adjacent field lines are parallel.

D. where the field lines are most strongly curved.

E. at none of the above locations.

Q21.6

Two point charges and a point *P* lie at the vertices of an equilateral triangle as shown. Both point charges have the same magnitude *q* but opposite signs. There is nothing at point *P*. The net electric field that charges #1 and #2 produce at point *P* is in



A. the +x-direction.

B. the –x-direction.

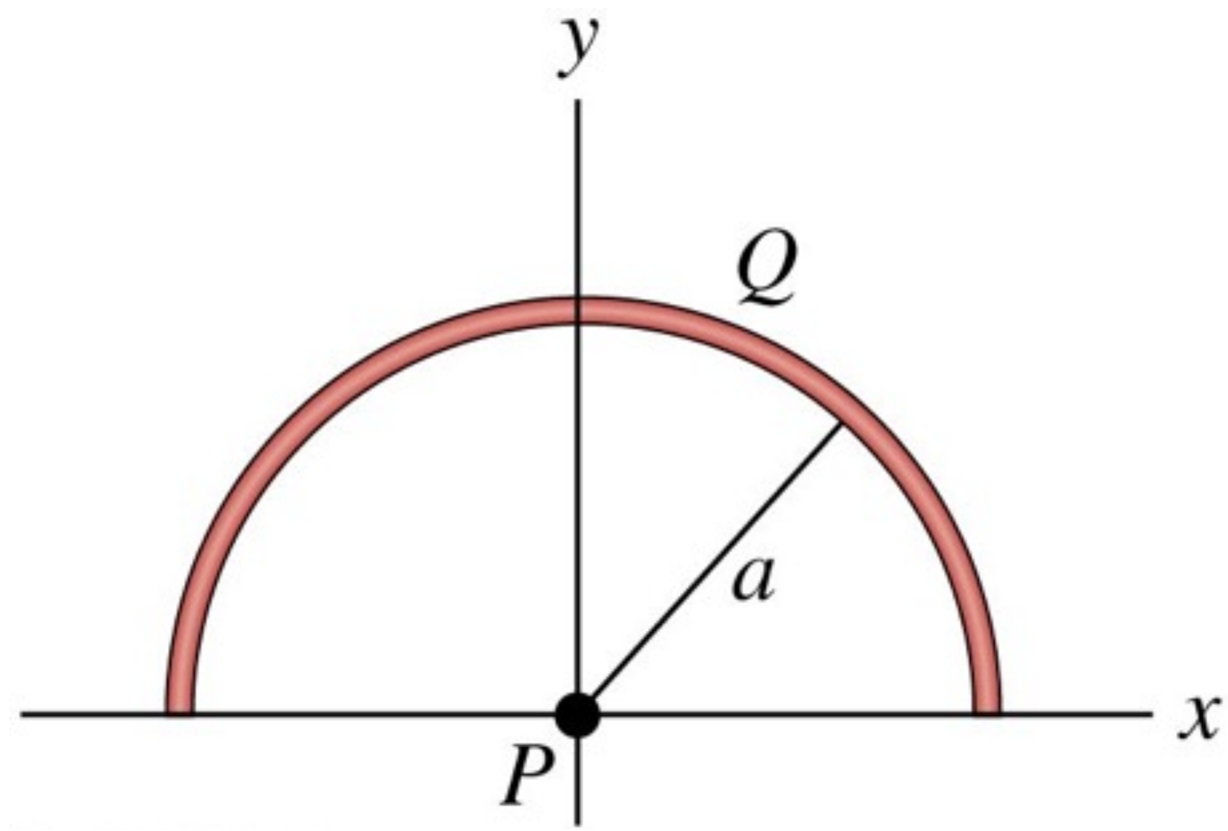
C. the +y-direction.

D. the –y-direction.

E. none of the above.

Q21.10

Positive charge is uniformly distributed around a semicircle. The electric field that this charge produces at the center of curvature P is in



A. the $+x$-direction.

B. the $-x$-direction.

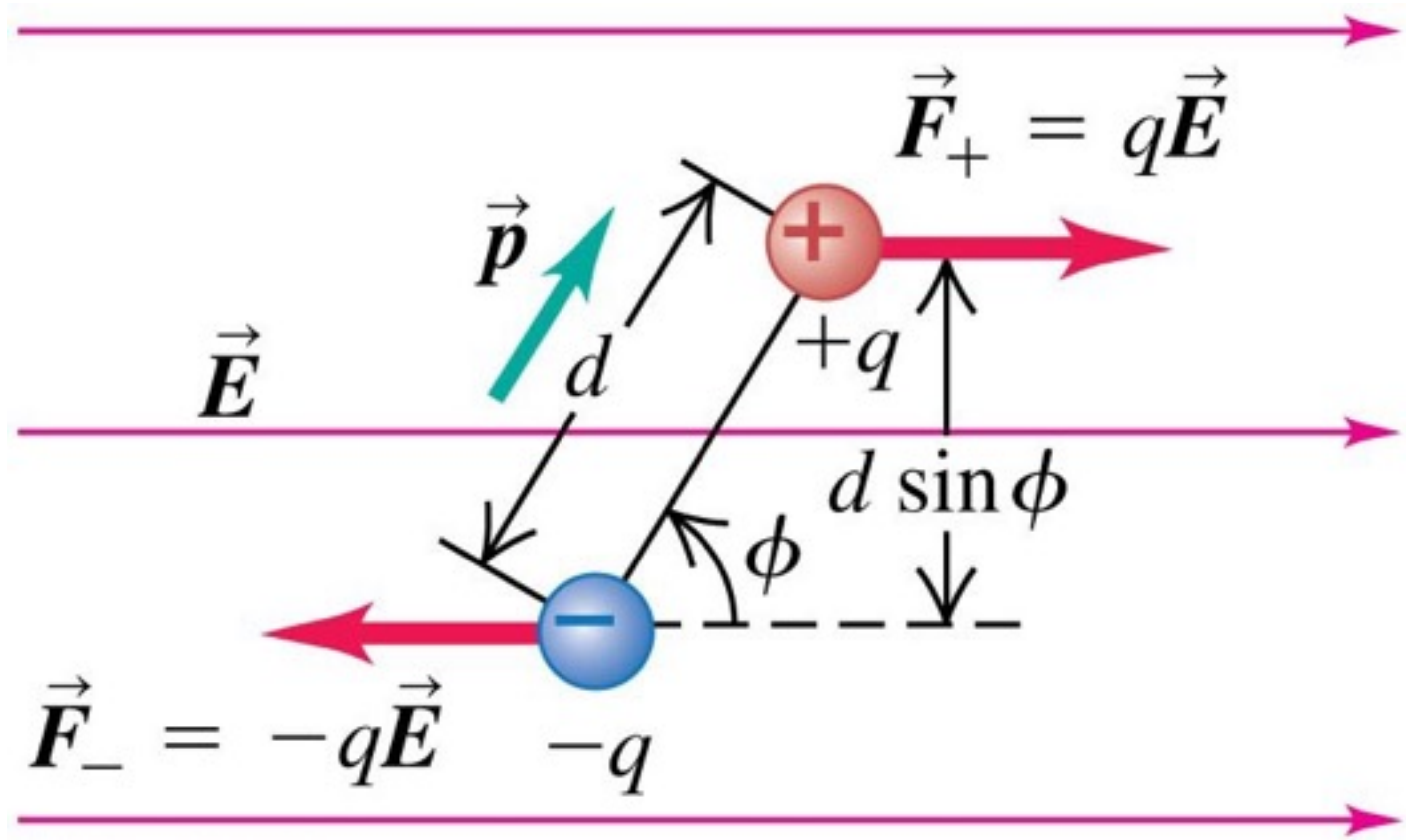
C. the $+y$-direction.

D. the $-y$-direction.

E. none of the above.

Force and torque on a dipole

- When a dipole is placed in a uniform electric field, the net *force* is always zero, but there can be a net *torque* on the dipole.

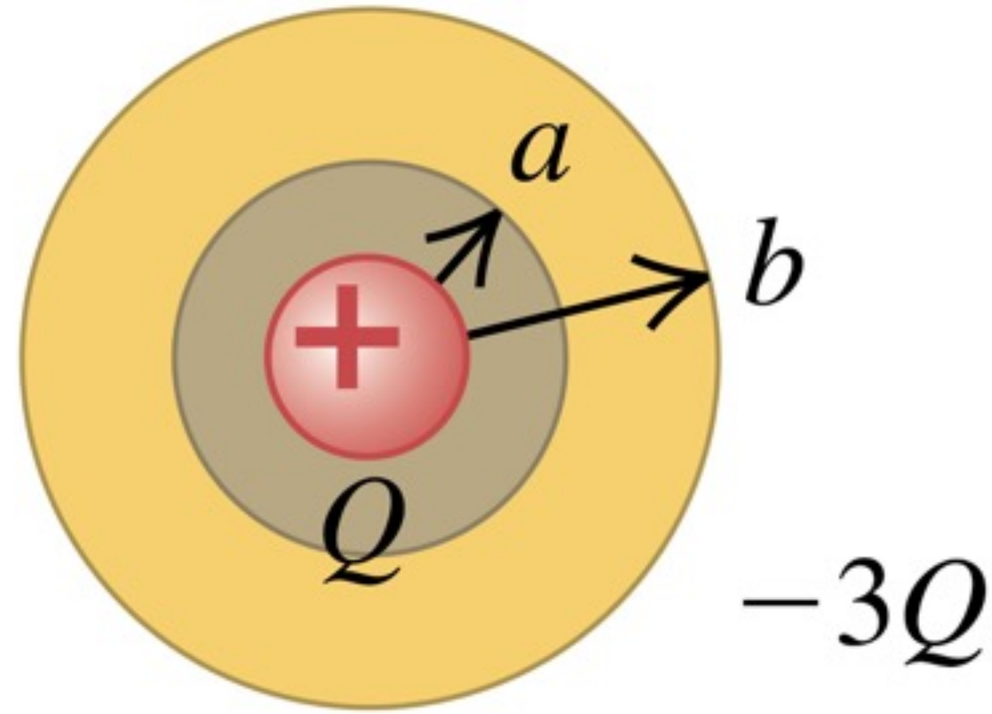


Vector torque on an electric dipole: $\vec{\tau} = \vec{p} \times \vec{E}$, where $\vec{p}$ is the electric dipole moment and $\vec{E}$ is the electric field.

Potential energy for an electric dipole in an electric field: $U = -\vec{p} \cdot \vec{E}$, where $\vec{E}$ is the electric field and $\vec{p}$ is the electric dipole moment.

Q22.4

A conducting spherical shell with inner radius a and outer radius b has a positive point charge Q located at its center. The total charge on the shell is $-3Q$, and it is insulated from its surroundings. In the region $a < r < b$,



A. the electric field points radially outward.

B. the electric field points radially inward.

C. the electric field points radially outward in parts of the region and radially inward in other parts of the region.

D. the electric field is zero.

E. Not enough information is given to decide.

EC Q2 The indicated **positive and negative charge densities** are placed in **infinite sheets** and arranged as shown in the figure below. What is the **magnitude and direction** of the **electric field** in each of the 4 regions, E_1, E_2, E_3, E_4?

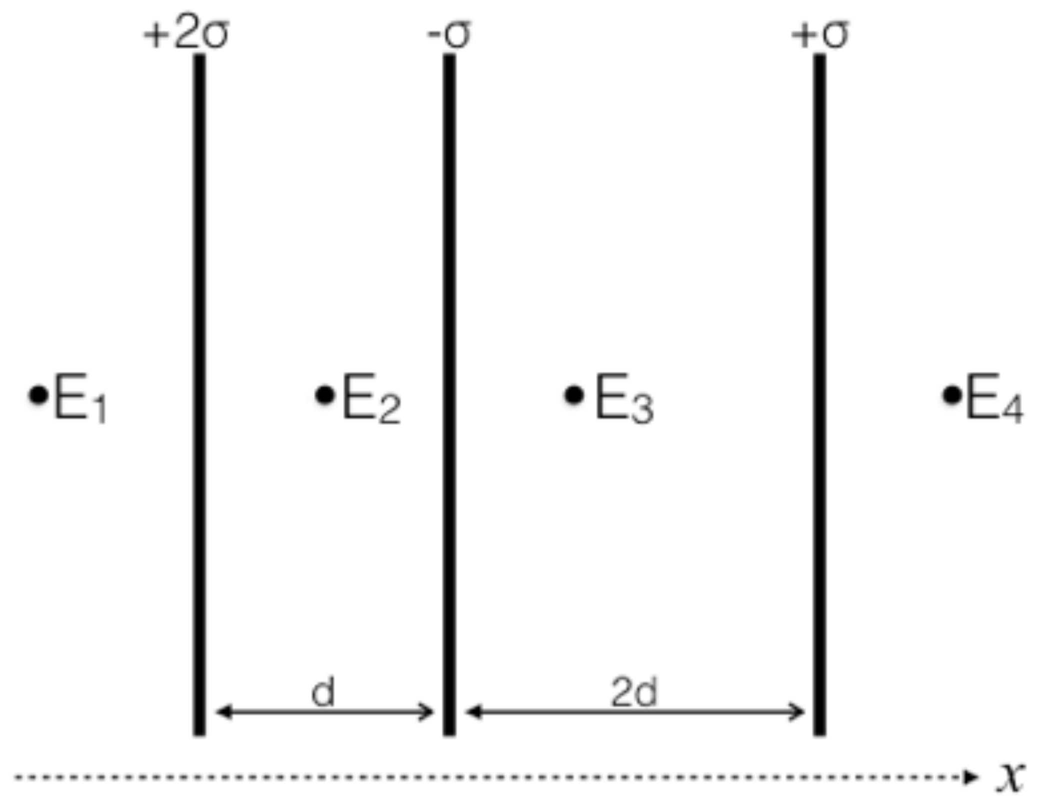
A. $E_1=\frac{\sigma}{2\varepsilon_0}\hat{x}$, $E_2=\frac{\sigma}{2\varepsilon_0}\hat{x}$, $E_3=\frac{\sigma}{\varepsilon_0}\hat{x}$, $E_4=\frac{\sigma}{2\varepsilon_0}\hat{x}$

B. $E_1=\frac{-\sigma}{\varepsilon_0}\hat{x}$, $E_2=\frac{\sigma}{\varepsilon_0}\hat{x}$, $E_3=0$, $E_4=\frac{\sigma}{\varepsilon_0}\hat{x}$

C. $E_1=\frac{-\sigma}{2\varepsilon_0}\hat{x}$, $E_2=\frac{\sigma}{2\varepsilon_0}\hat{x}$, $E_3=0$, $E_4=\frac{\sigma}{2\varepsilon_0}\hat{x}$

D. $E_1=\frac{\sigma}{2\varepsilon_0}\hat{x}$, $E_2=\frac{\sigma}{2\varepsilon_0}\hat{x}$, $E_3=\frac{-\sigma}{\varepsilon_0}\hat{x}$, $E_4=0$

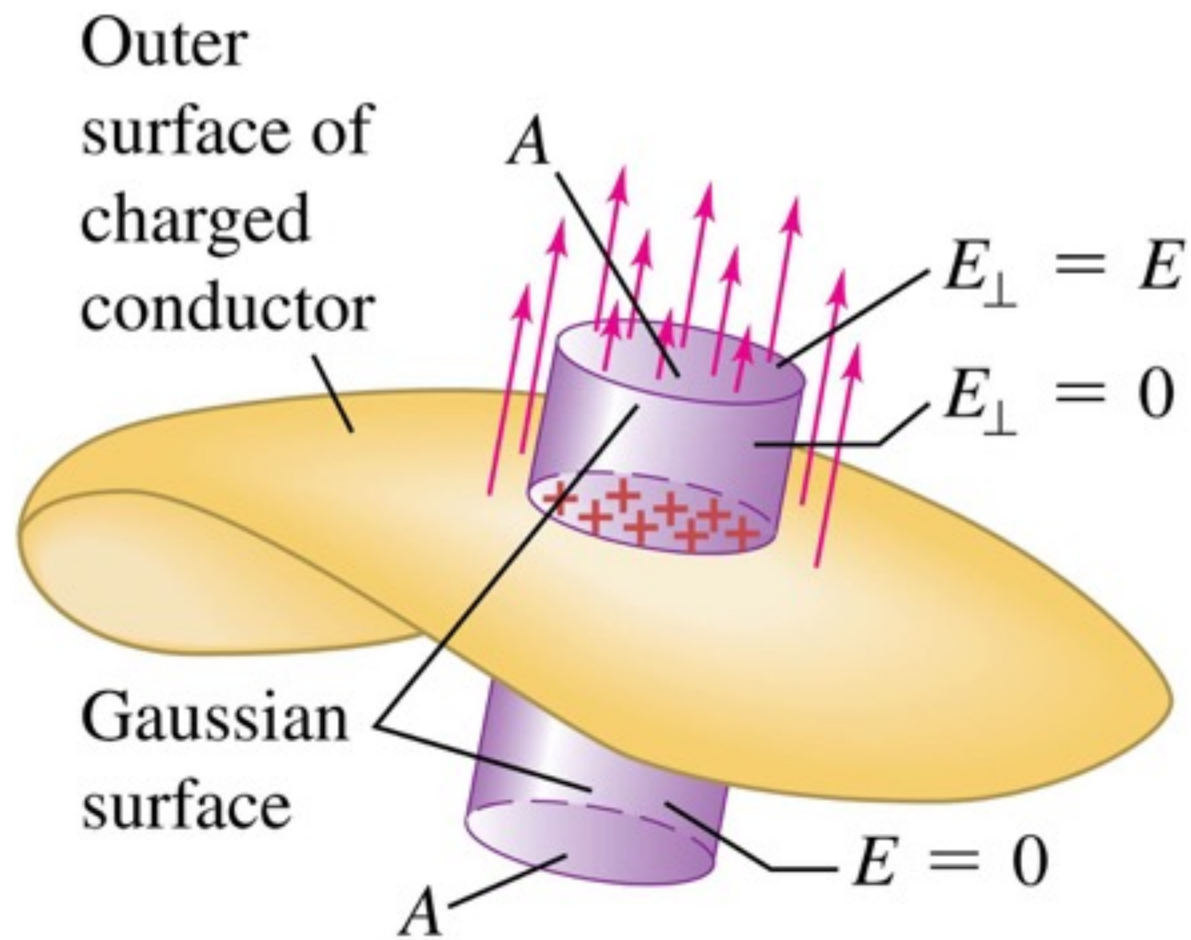
E. Cant answer – it depends on *d*



Choices are different for TestID AA and BB

Field at the surface of a conductor

- Gauss's law can be used to show that the direction of the electric field at the surface of any conductor is always perpendicular to the surface.
- The magnitude of the electric field just outside a charged conductor is proportional to the surface charge density σ.



Electric field at surface of a conductor, $\vec{E}$ perpendicular to surface

$$E_\perp = \frac{\sigma}{\epsilon_0}$$

σ: Surface charge density; ϵ_0: Electric constant

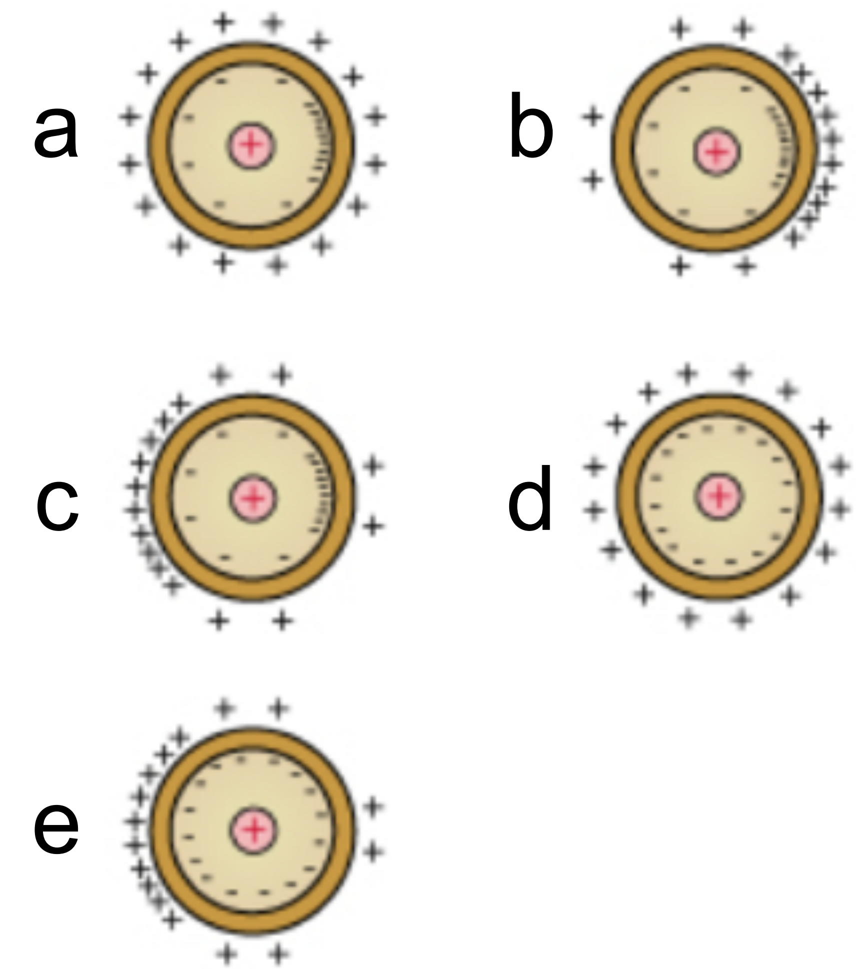
Charge Distribution on a Conducting Shell - 1

Description: Conceptual problem. A positive charge sits in the center of a conducting spherical shell. Find the charge distribution on the inside and outside surfaces of the shell.

A positive charge is kept (fixed) at the center inside a fixed spherical neutral conducting shell.

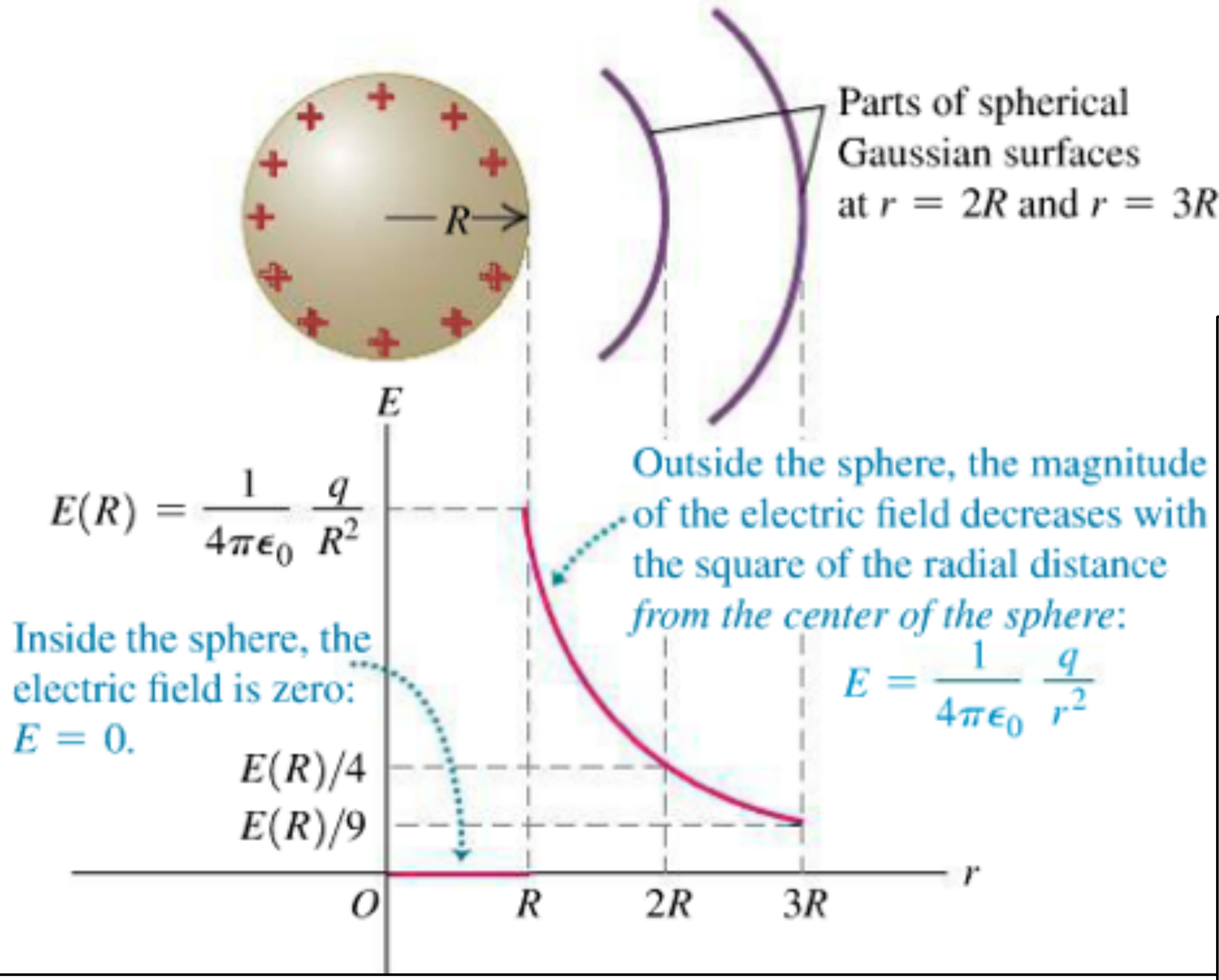
Part A

The positive charge is equal to roughly 16 of the smaller charges shown on the surfaces of the spherical shell. Which of the pictures best represents the charge distribution on the inner and outer walls of the shell?

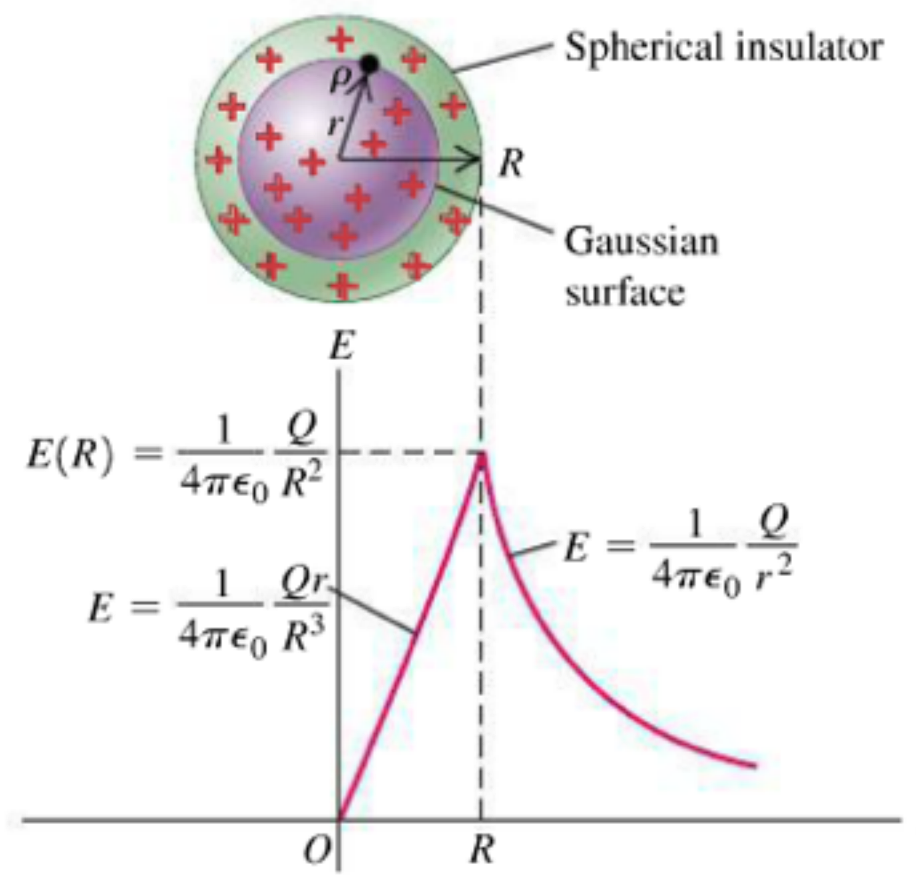


Ex. 22.5 and 22.9

22.18 Calculating the electric field of a conducting sphere with positive charge q. Outside the sphere, the field is the same as if all of the charge were concentrated at the center of the sphere.



22.22 The magnitude of the electric field of a uniformly charged insulating sphere. Compare this with the field for a conducting sphere (see Fig. 22.18).



Electric potential energy of two point charges

- The electric potential energy of two point charges only depends on the distance between the charges.

Electric potential energy of two point charges

$$U = \frac{1}{4\pi\epsilon_0}\frac{qq_0}{r}$$

Values of two charges

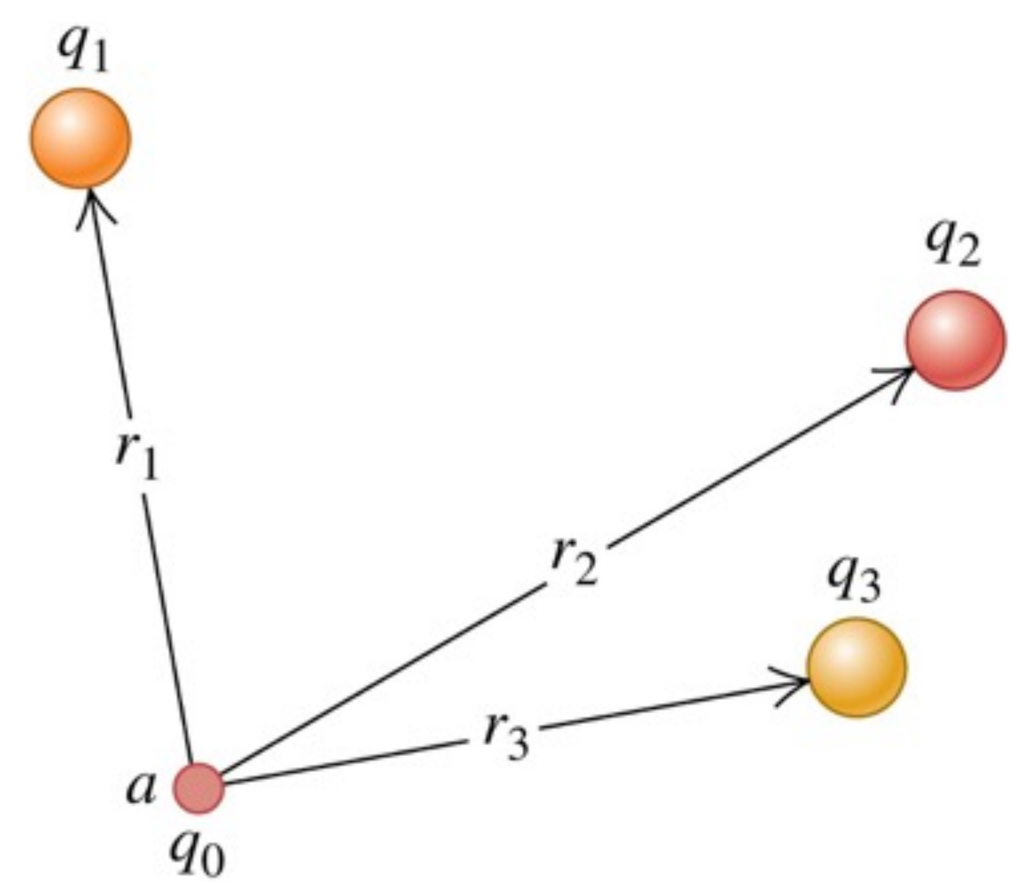
Electric constant

Distance between two charges

- This equation is valid no matter what the signs of the charges are.
- Potential energy is defined to be zero when the charges are infinitely far apart.

Electrical potential with several point charges

- The potential energy associated with q_0 depends on the other charges and their distances from q_0.
- The electric potential energy associated with q_0 is the *algebraic* sum:



Electric potential energy of point charge q_0 and collection of charges $q_1, q_2, q_3, \ldots$

$$U = \frac{q_0}{4\pi\epsilon_0}\left(\frac{q_1}{r_1} + \frac{q_2}{r_2} + \frac{q_3}{r_3} + \cdots\right) = \frac{q_0}{4\pi\epsilon_0}\sum_i \frac{q_i}{r_i}$$

Electric constant

Distances from q_0 to $q_1, q_2, q_3, \ldots$

But, this is not the TOTAL potential energy of the system!

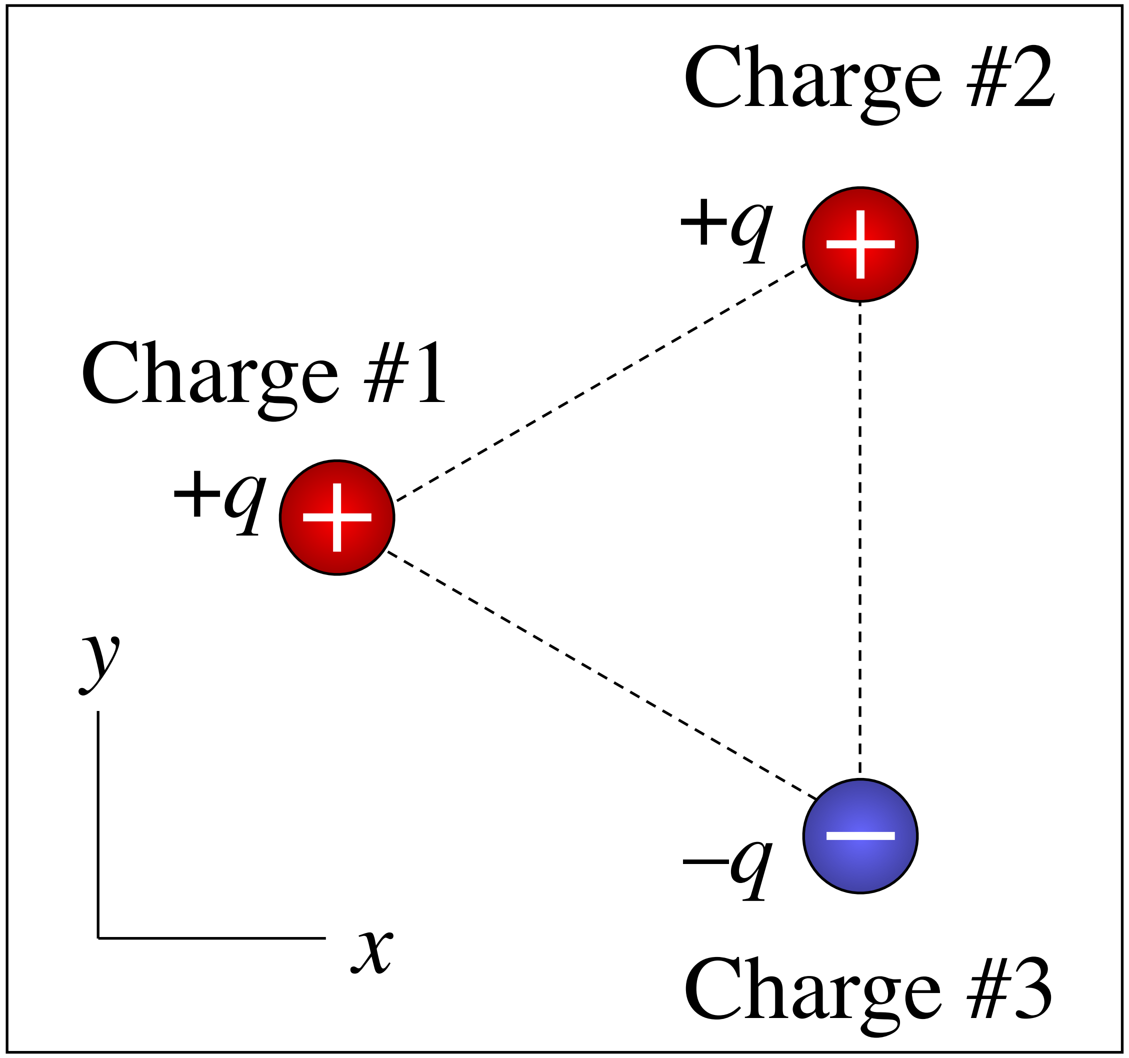
Total potential energy of the system of charges

$$U = \frac{1}{4\pi\epsilon_0} \sum_{i<j} \frac{q_i q_j}{r_{ij}}$$

Sum over all unique pairs of point charges

Q23.5

The electric potential energy of two point charges approaches zero as the two point charges move farther away from each other. If the three point charges shown here lie at the vertices of an equilateral triangle, the electric potential energy of the system of three charges is



A. positive.

B. negative.

C. zero.

D. either positive or negative.

E. either positive, negative, or zero.

Electric potential

- The potential due to a single point charge is:

$$V = \frac{1}{4\pi\epsilon_0}\frac{q}{r}$$

Electric potential due to a point charge: V; Value of point charge: q; Distance from point charge to where potential is measured: r; Electric constant: ϵ_0

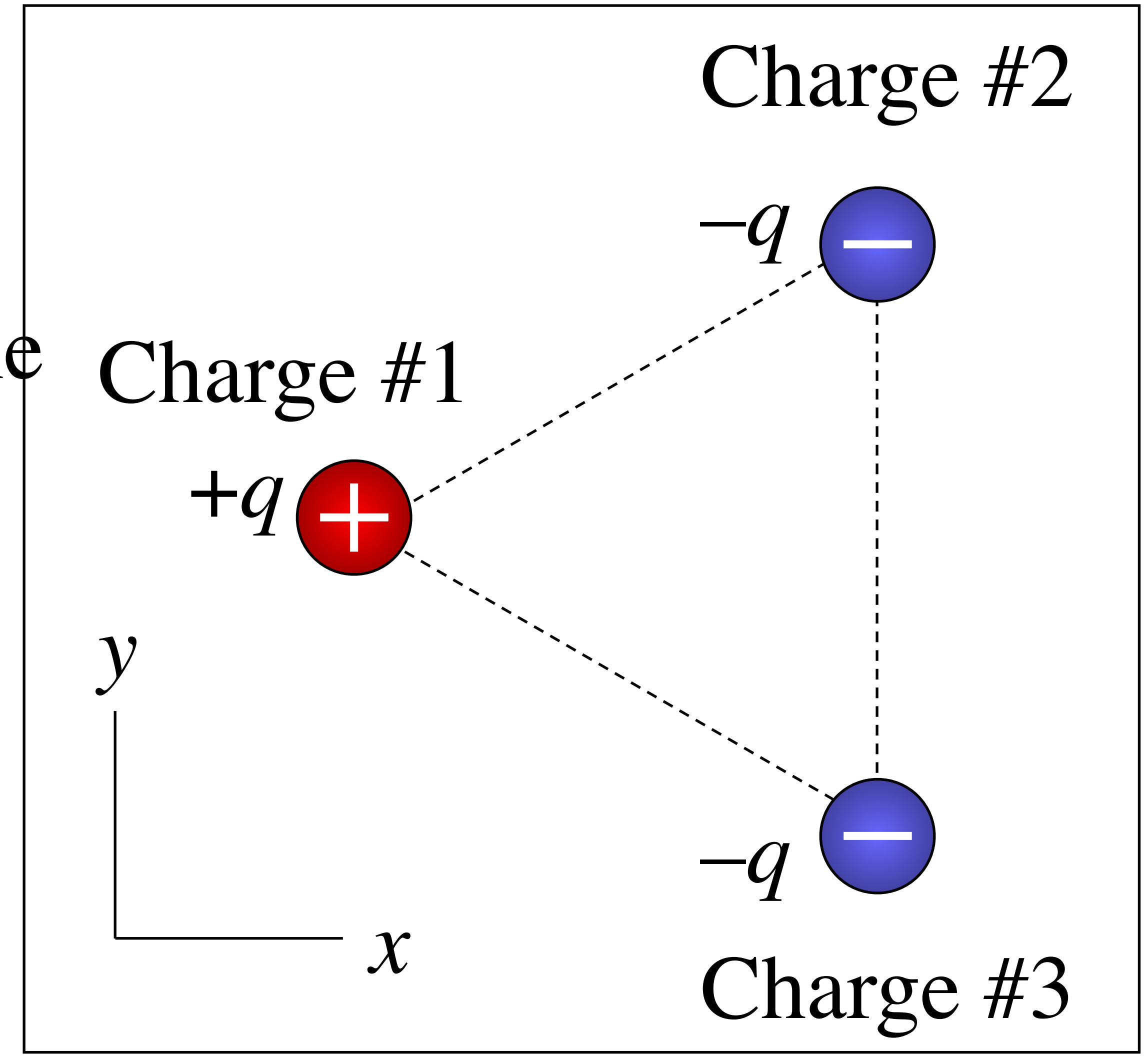
- Like electric field, potential is independent of the test charge that we use to define it.
- For a collection of point charges:

$$V = \frac{1}{4\pi\epsilon_0}\sum_i \frac{q_i}{r_i}$$

Electric potential due to a collection of point charges: V; Value of *i*th point charge: q_i; Distance from *i*th point charge to where potential is measured: r_i; Electric constant: ϵ_0

Q23.8

The electric potential due to a point charge approaches zero as you move farther away from the charge. If the three point charges shown here lie at the vertices of an equilateral triangle, the electric potential at the center of the triangle is



A. positive.

B. negative.

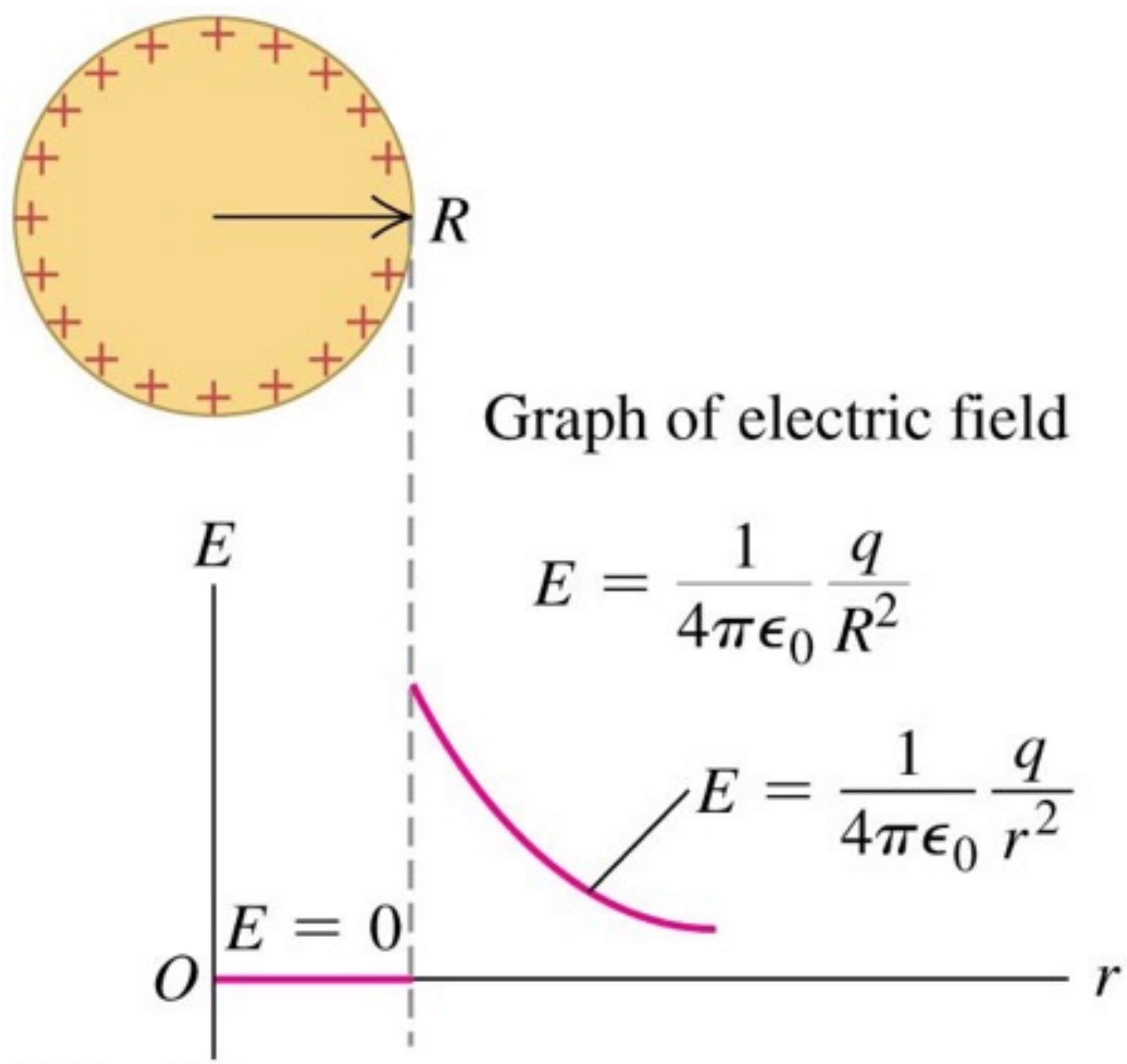
C. zero.

D. either positive or negative.

E. either positive, negative, or zero.

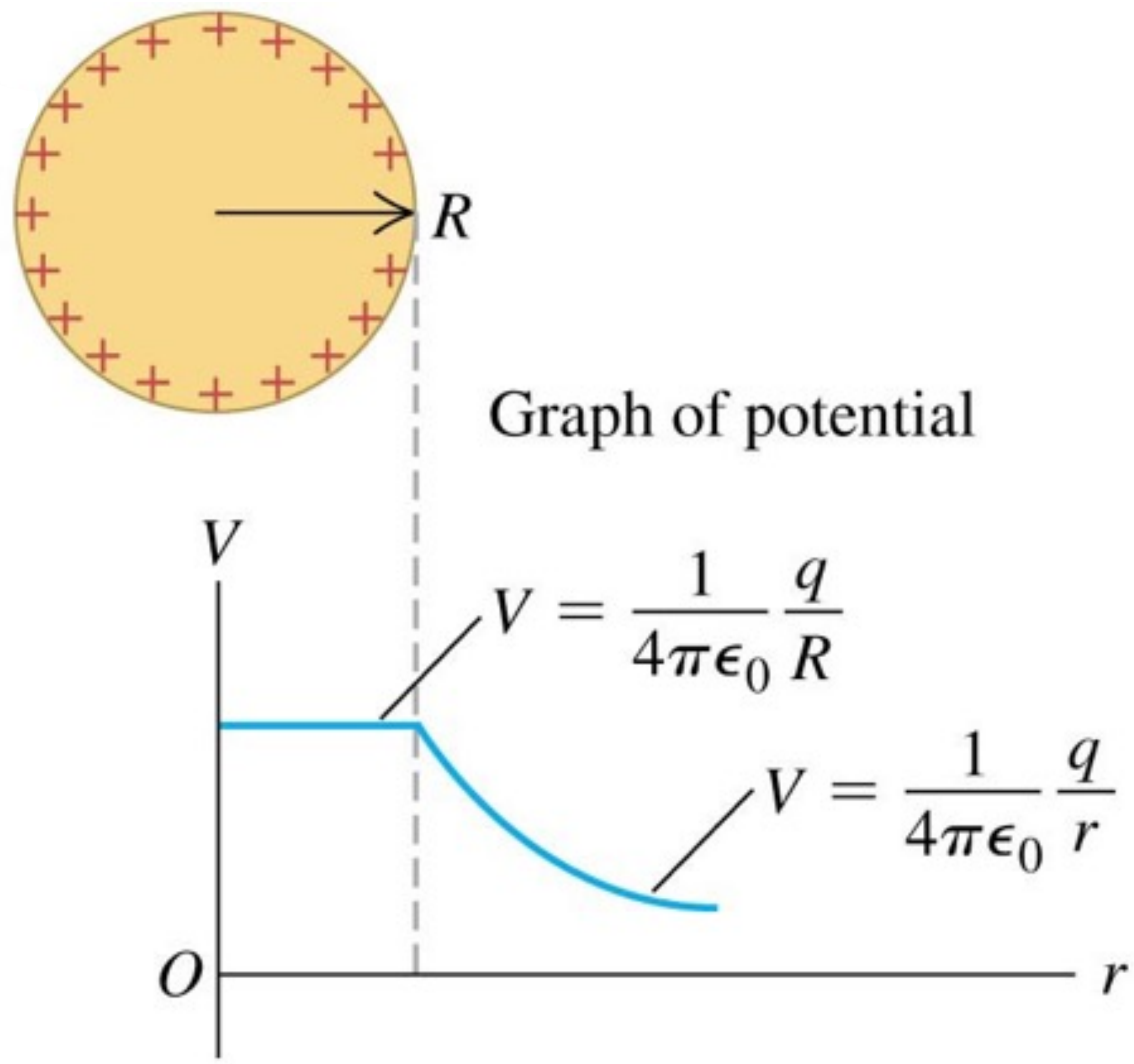
Electric potential and field of a charged conductor

- A solid conducting sphere of radius R has a total charge q.
- The electric field *inside* the sphere is zero everywhere.



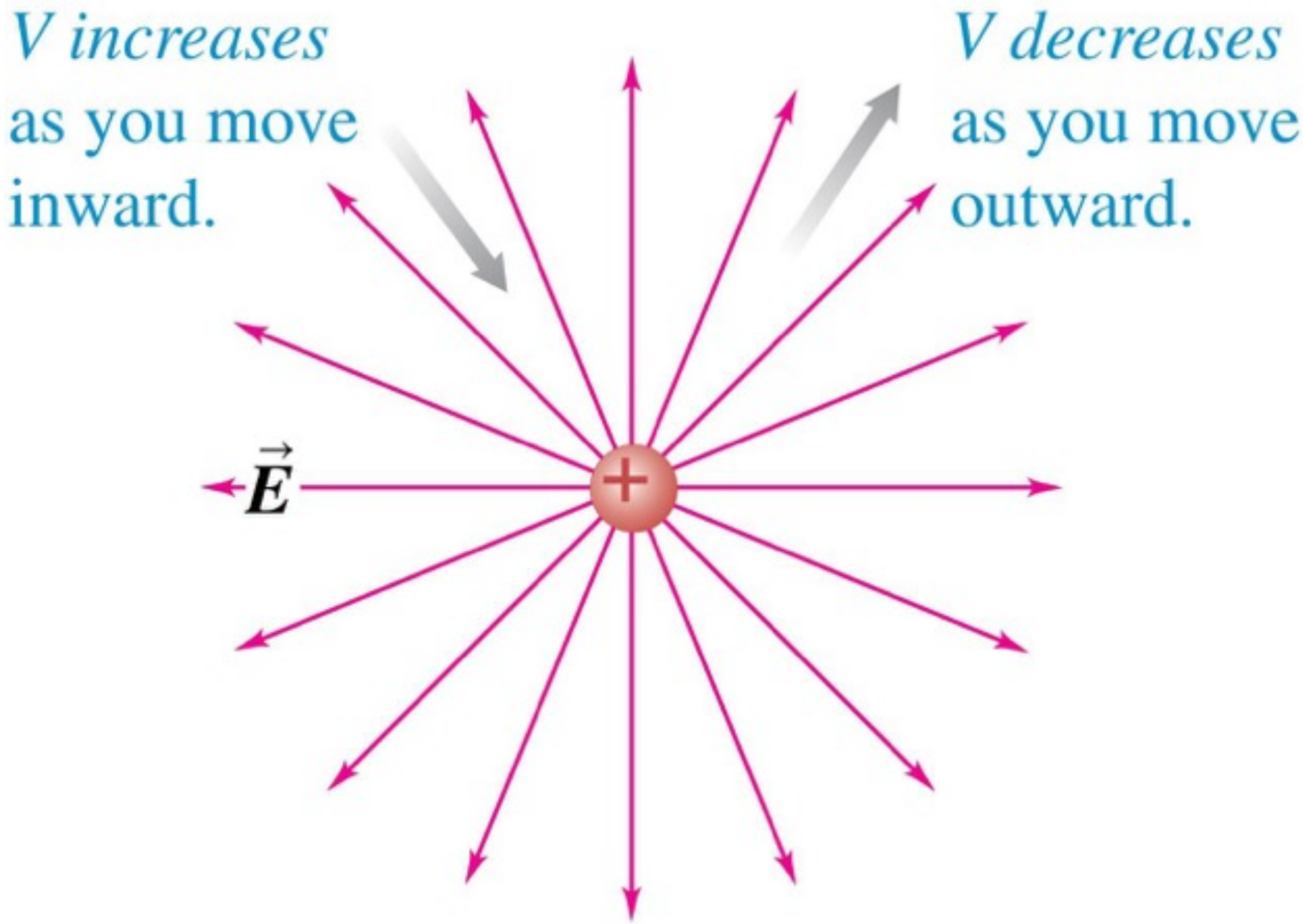
Electric potential and field of a charged conductor

- The potential is the *same* at every point inside the sphere and is equal to its value at the surface.



Finding electric potential from the electric field

- If you move in the direction of the electric field, the electric potential *decreases*, but if you move opposite the field, the potential *increases*.



Potential gradient

- The components of the electric field can be found by taking partial derivatives of the electric potential:

Electric field components found from potential:

$$E_x = -\frac{\partial V}{\partial x} \qquad E_y = -\frac{\partial V}{\partial y} \qquad E_z = -\frac{\partial V}{\partial z}$$

Each electric field component ... equals the negative of the corresponding partial derivative of electric potential function V.

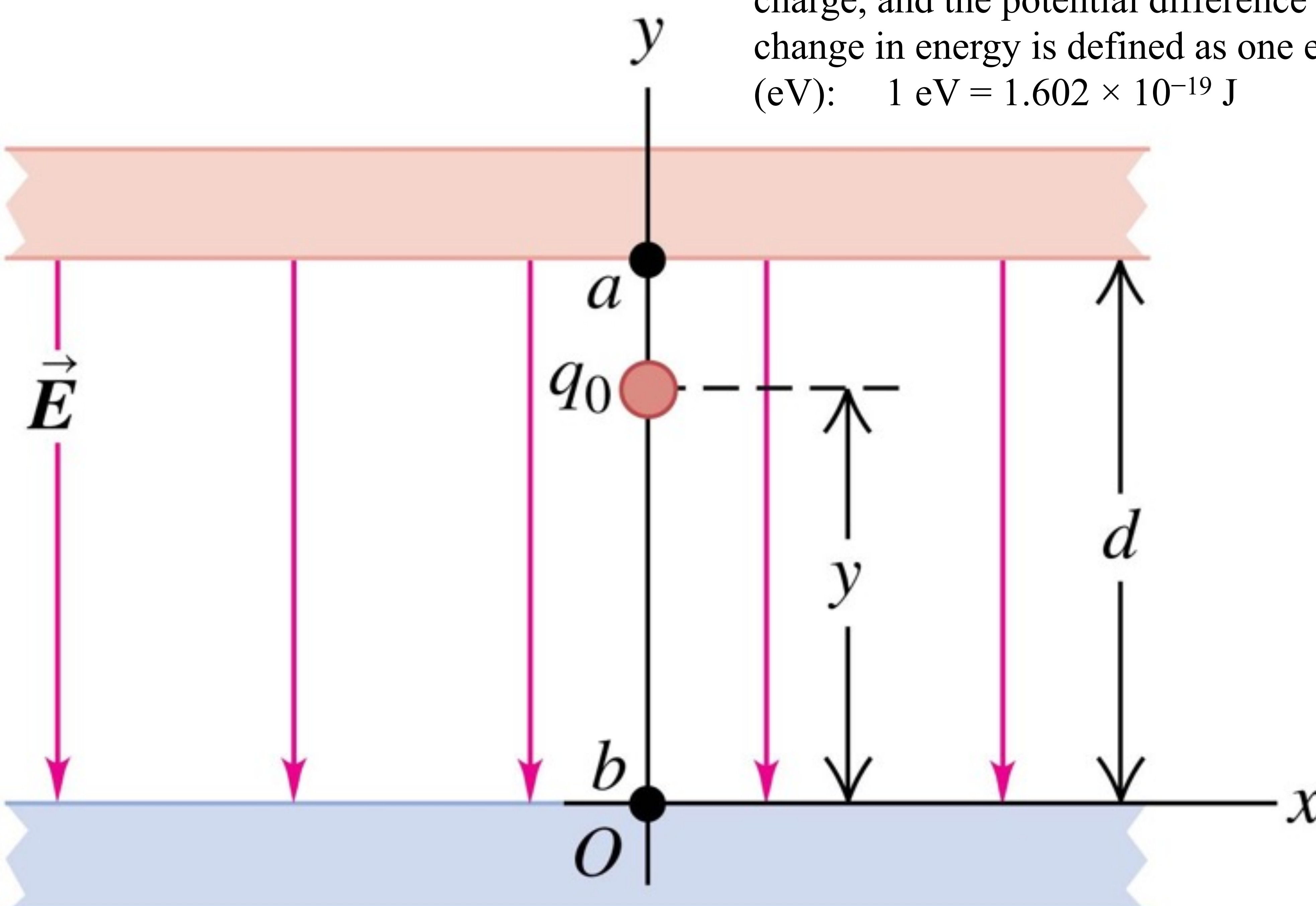
- The electric field is the negative gradient of the potential:

$$\vec{\boldsymbol{E}} = -\vec{\nabla} V$$

$$V_a - V_b = -\int_b^a \vec{\boldsymbol{E}} \cdot d\vec{\boldsymbol{l}}$$

Oppositely charged parallel plates

- The potential at any height y between the two large oppositely charged parallel plates is $V = Ey$.



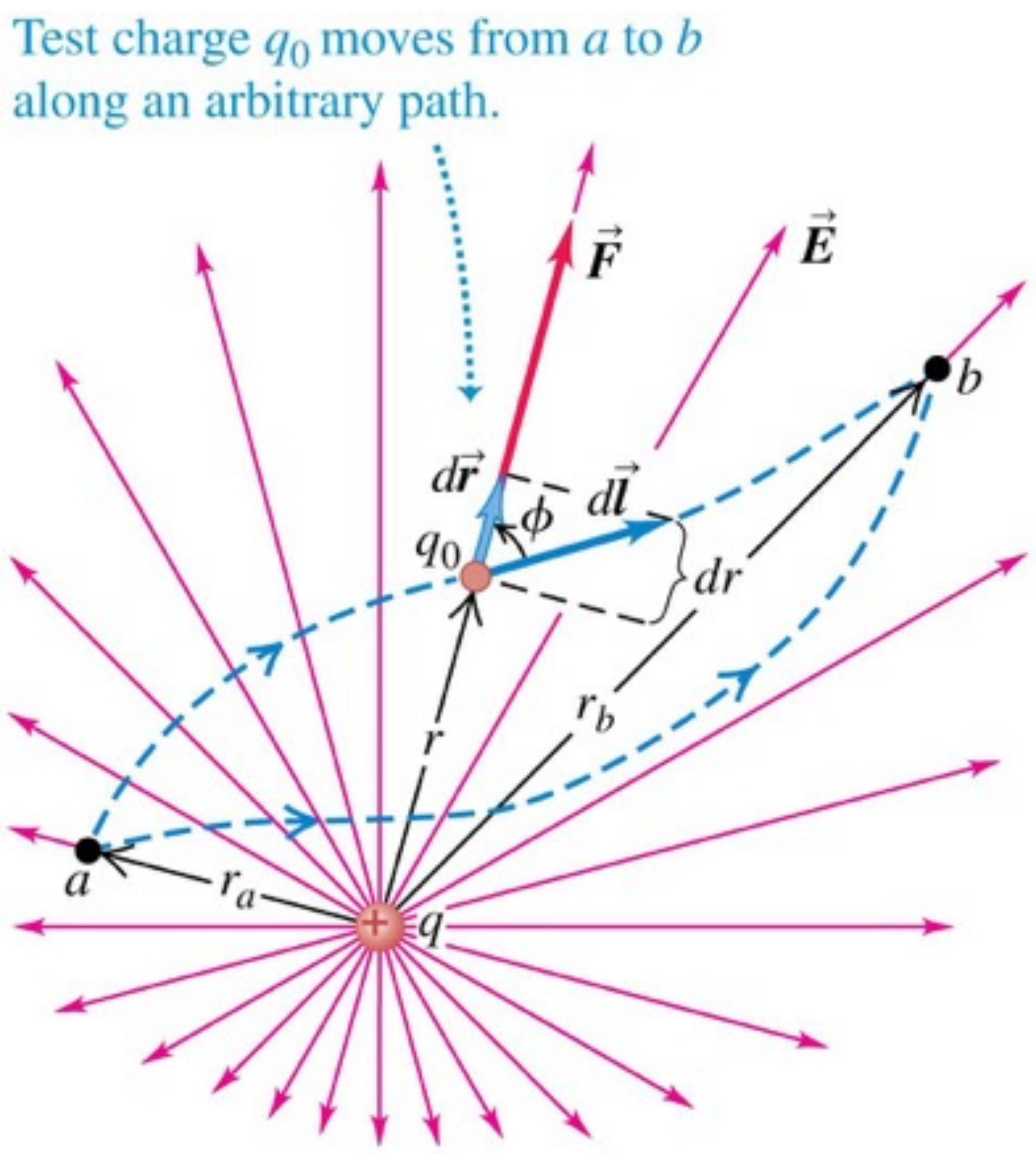
- If charge q equals the magnitude e of the electron charge, and the potential difference is 1 V, the change in energy is defined as one electron volt (eV): $1 \text{ eV} = 1.602 \times 10^{-19} \text{ J}$

Electrical Potential Energy and Work Done by Field on Charges

Change in EPE

was defined as:

$$\Delta U_g = -W_g = -\int_1^2 \vec{F}_g \cdot d\vec{r}$$



If moving from a —> b

positive (test) charge

W>0, ΔU <0

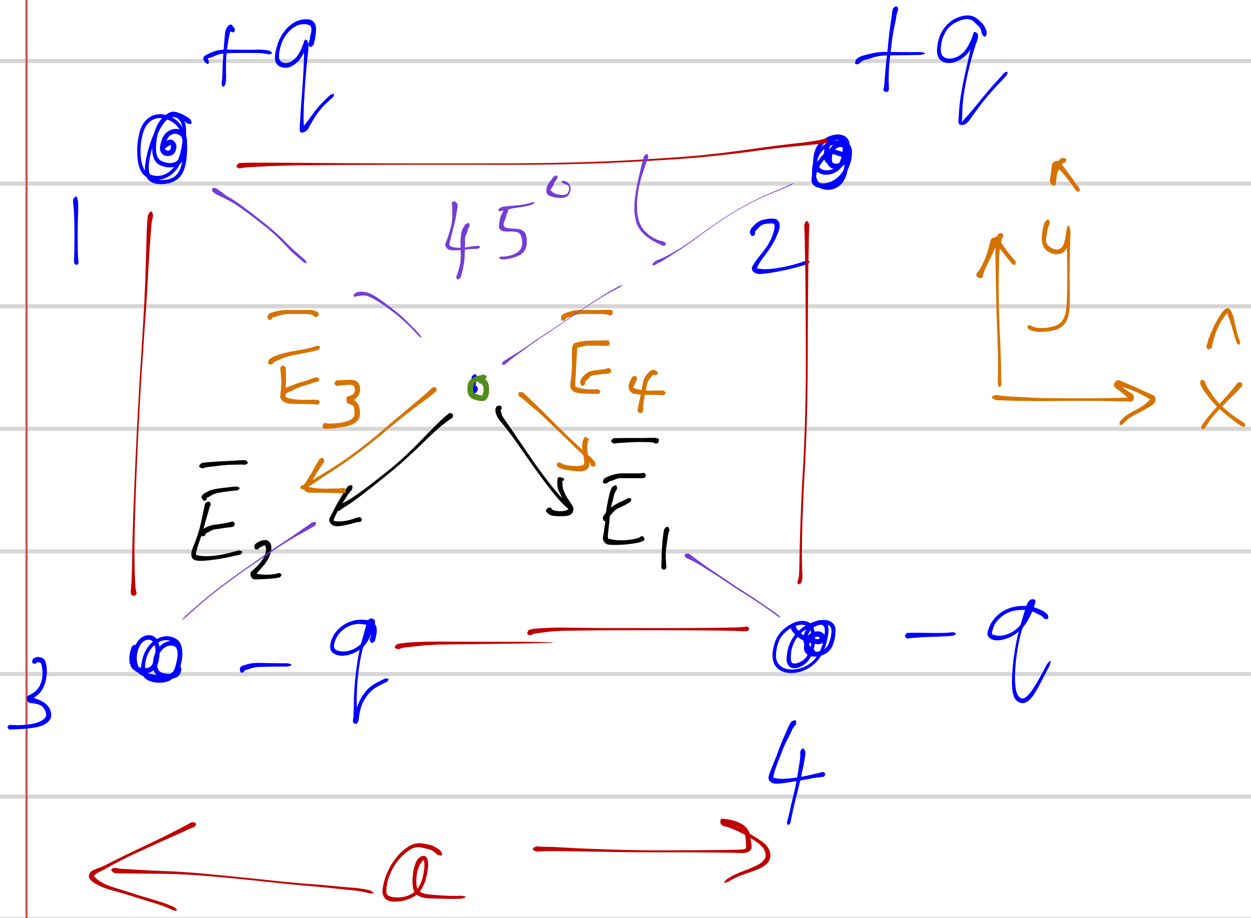
decreases potential energy

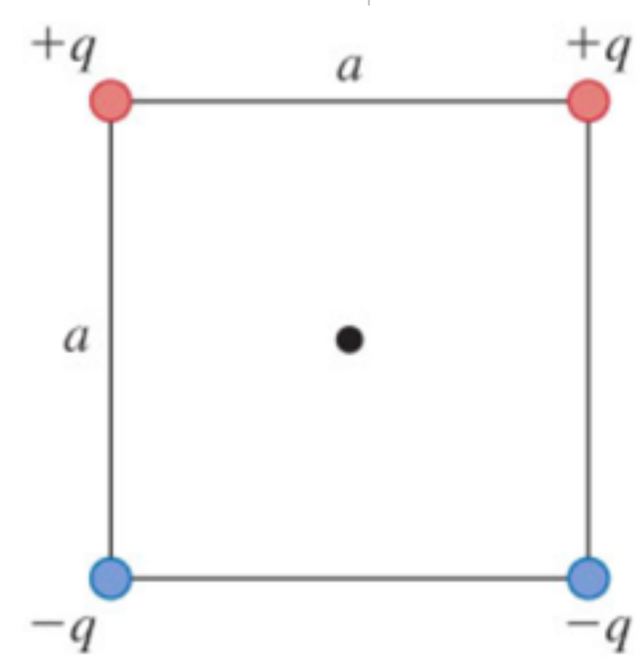
imagine a negative charge

W<0, ΔU >0

*inc*reases potential energy

Field and potential at center?





Field and potential at center?

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

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

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

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

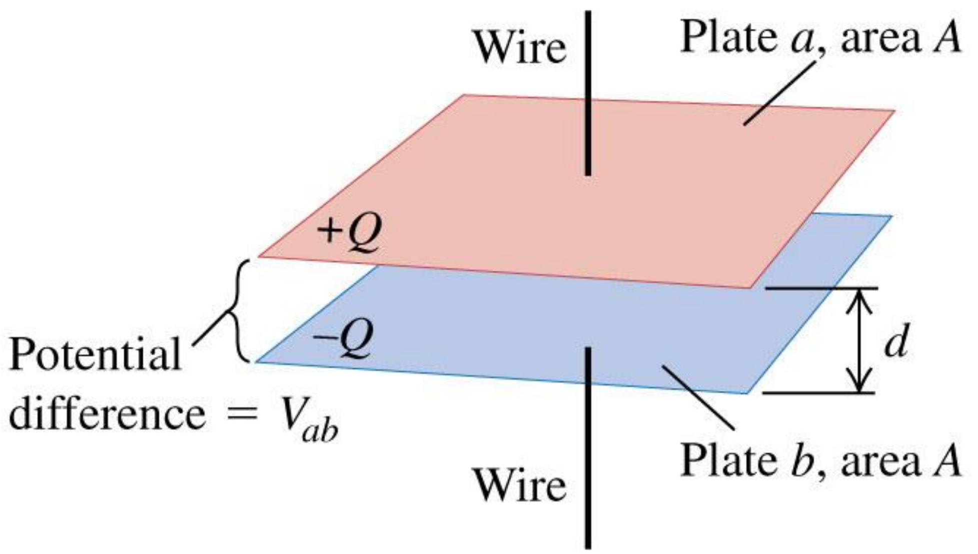
$$= 0$$

Parallel Plate Capacitor

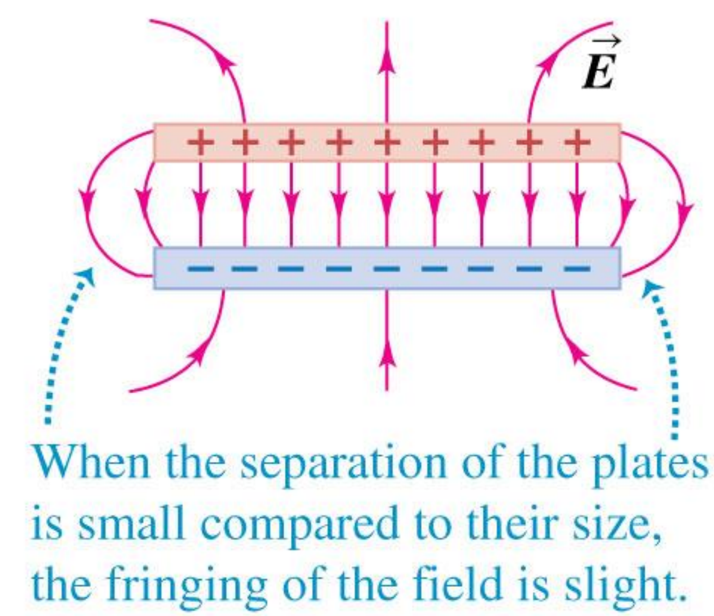
- Steps to find capacitance:
  - Find the potential given a certain amount of charge.
    - Do this by first finding the electric field, then integrating the field to find the potential.
  - Then just divide the charge by the potential difference

$$C = \frac{Q}{V} = \frac{\sigma A}{Ed} = \frac{\sigma A}{\frac{\sigma}{\varepsilon_0} d} = \frac{\varepsilon_0 A}{d}$$

(a) Arrangement of the capacitor plates

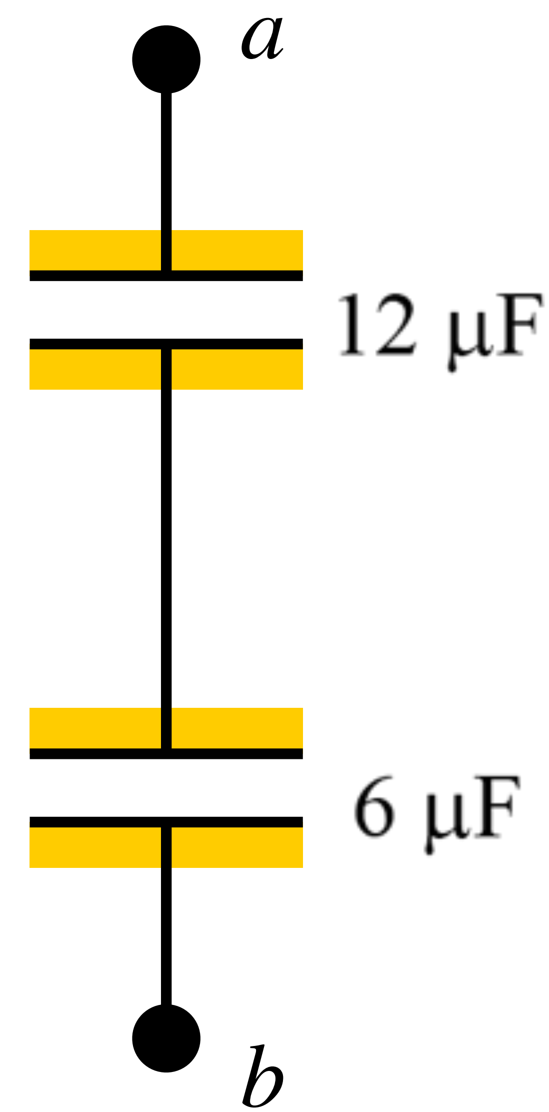


(b) Side view of the electric field $\vec{E}$



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

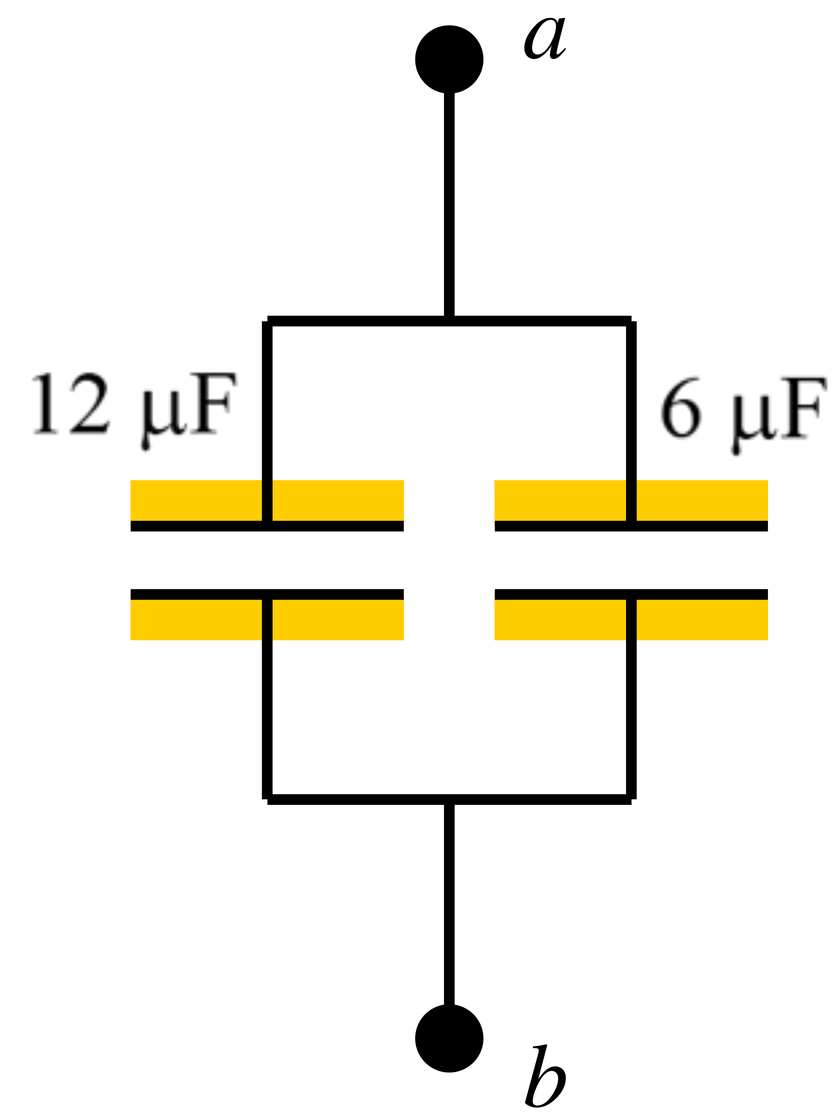
C. $C_{eq} = 6\ \mu F$

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

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

Q24.5

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

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

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

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

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

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

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.

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 (K); Area of each plate (A); Permittivity $= K\epsilon_0$ (ϵ); Capacitance without dielectric (C_0); Electric constant (ϵ_0); Distance between plates (d)

- 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 (K); Permittivity $= K\epsilon_0$ (ϵ); Electric constant (ϵ_0); Magnitude of electric field (E)

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.

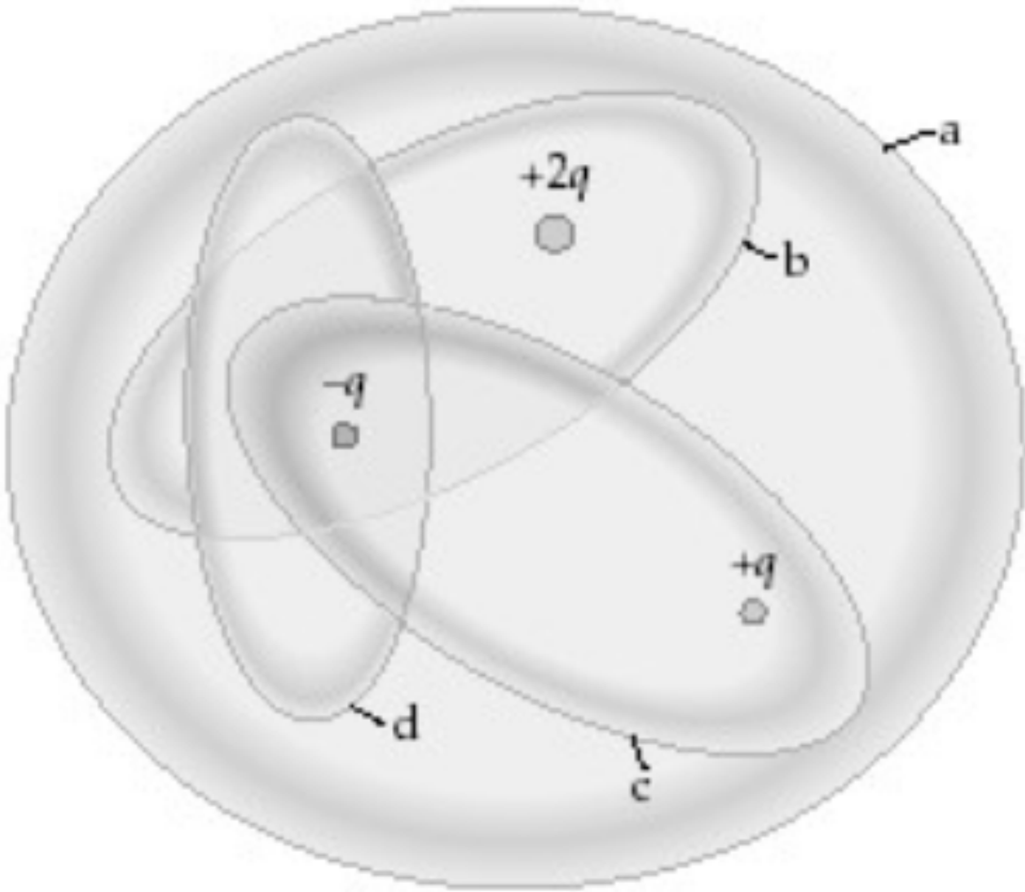
D. Two of A, B, and C are possible.

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

Gauss' Law

Part A

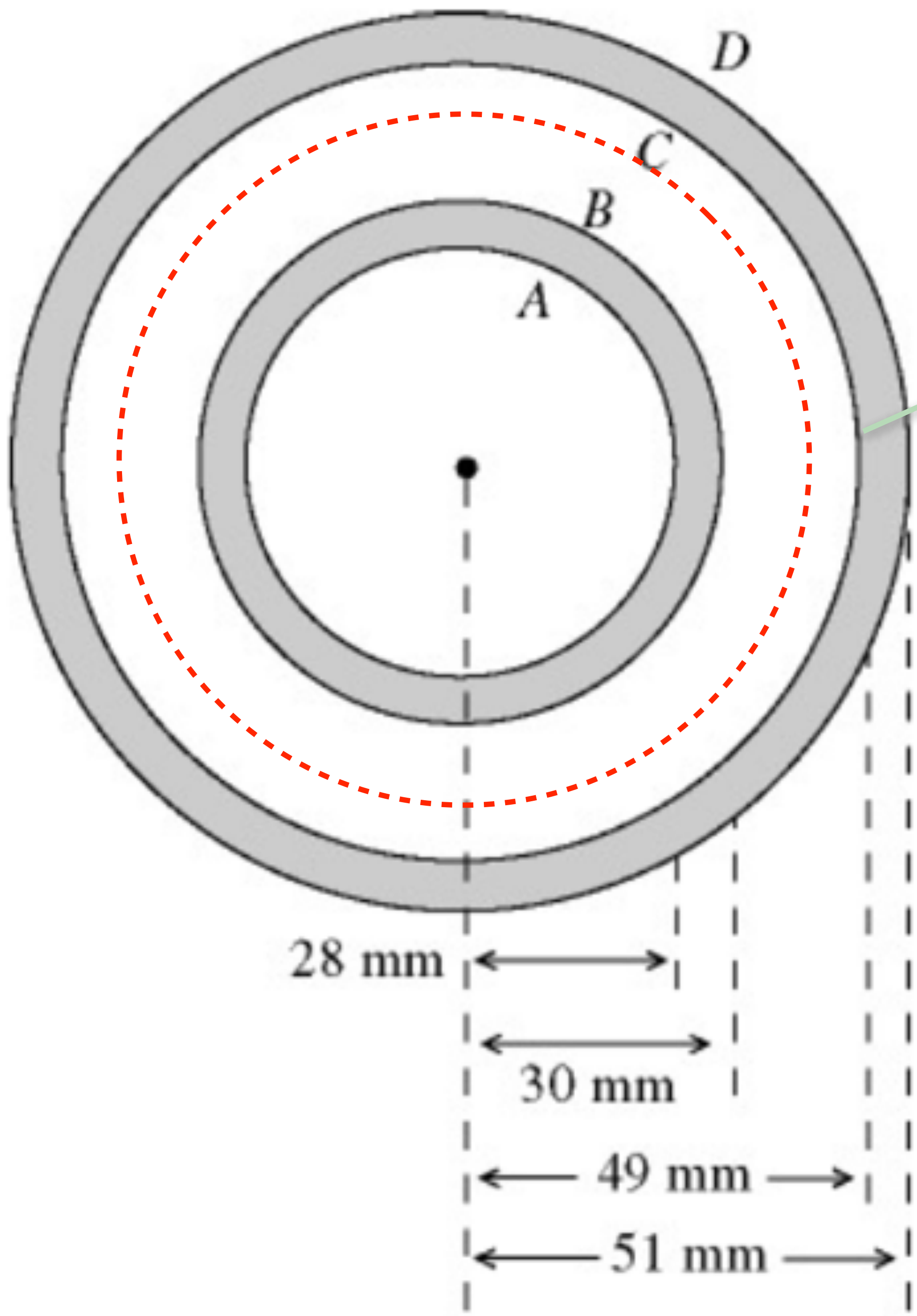
The figure shows four Gaussian surfaces surrounding a distribtuion of charges.



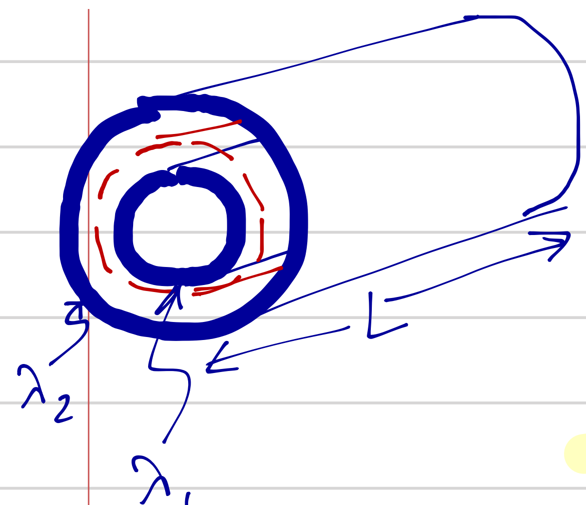
(a) Which Gaussian surfaces have an electric flux of $+q/\epsilon_0$ through them?

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



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

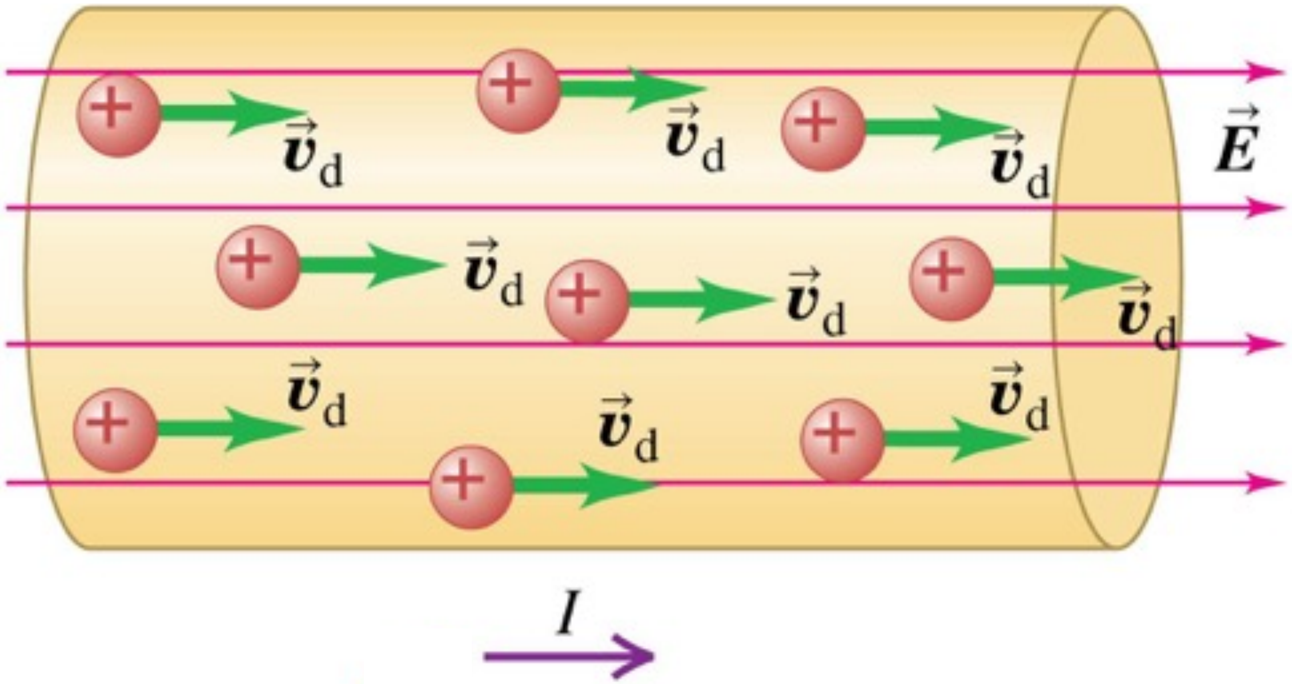
By symmetry, $\bar{E}$ radial and constant on Gaussian sphere

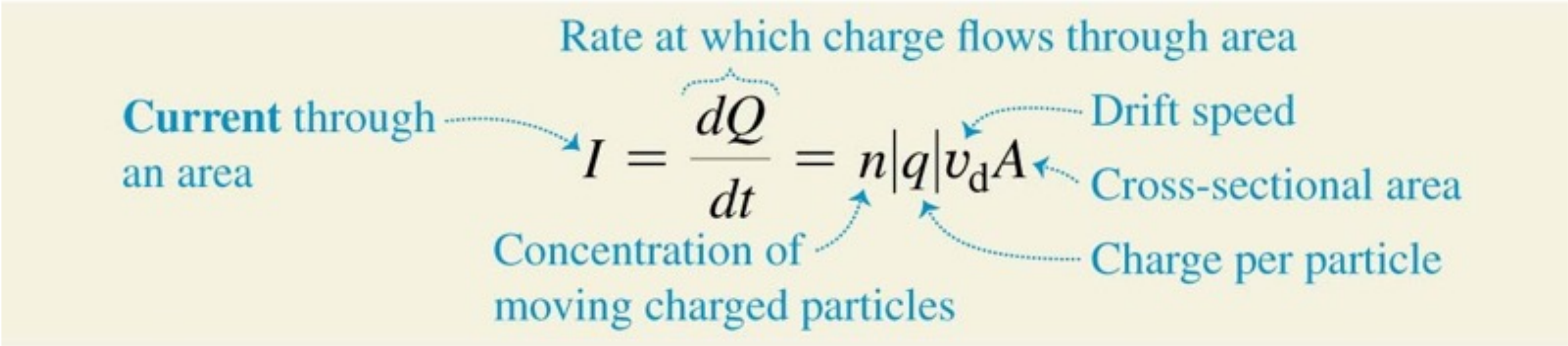
$$\Rightarrow E(2\pi r L) = \frac{Q_{enc}}{\epsilon_0} = \frac{\lambda_1 L}{\epsilon_0}$$

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

Current

- A **current** is any motion of charge from one region to another.





Q25.2

A source of emf is connected by wires to a resistor, and electrons flow in the circuit. The wire diameter is the same throughout the circuit. Compared to the *drift speed* of the electrons before entering the *resistor*, the *drift speed* of the electrons after leaving the *resistor* is

A. faster.

B. slower.

C. the same.

D. either A or B depending on circumstances.

E. any of A, B, or C depending on circumstances.