Recap

Lecture 4

- Electric Field $\vec{E}$
  - caused by electric charges ⇒ present around charges
  - has magnitude + direction ⇒ vector field
  - can be detected by force exerted on a "test charge"
  - defined as

$$\vec{E}_{\text{at location of } q_t \text{ by other charges}} = \frac{\vec{F}_{\text{on } q_t}}{q_t}$$

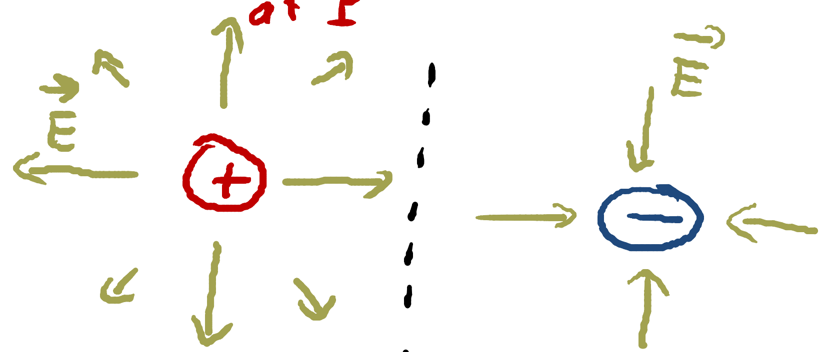
  - obeys superposition principle

$$\vec{E}_{\text{at point } P} = \vec{E}_{\text{by charge \#1 at } P} + \vec{E}_{\text{by charge \#2 at } P} + \ldots$$

  - $\vec{E}$ of point charge Q:

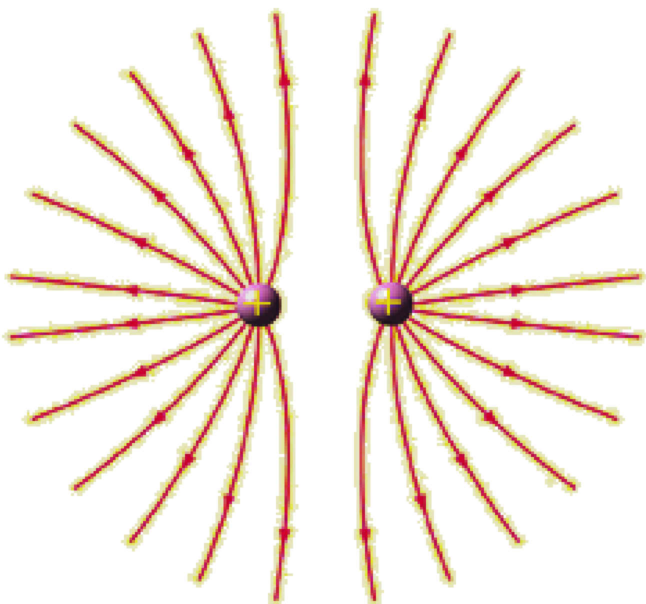
$$|E| = \frac{1}{4\pi\varepsilon_0}\frac{|Q|}{r^2}$$

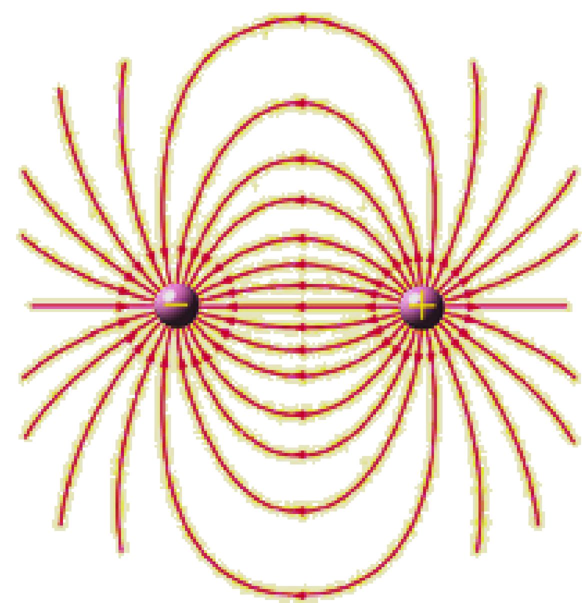
points radially inward or outward, depending on sign of Q



Today:

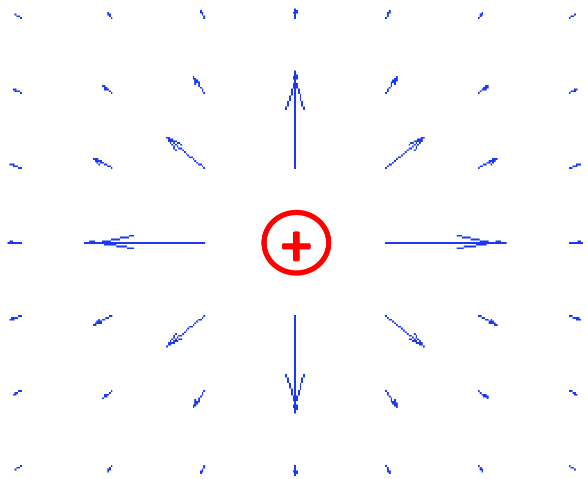
- Electric field lines
  - Lightning rods
- Electric dipoles
  - Microwave oven





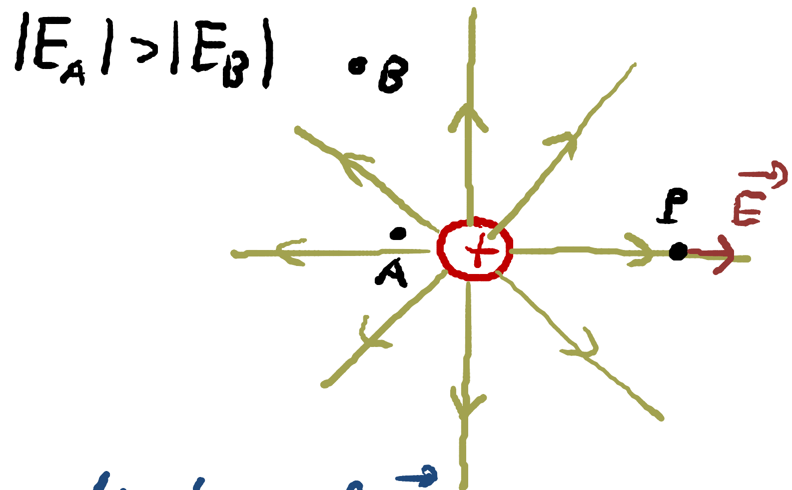
Ways of Visually Representing an Electric Field

Collection of vector arrows:



- direction of vector ⇒ direction of $\vec{E}$
- $|\text{vector}| \Rightarrow |\vec{E}|$

Electric field lines:

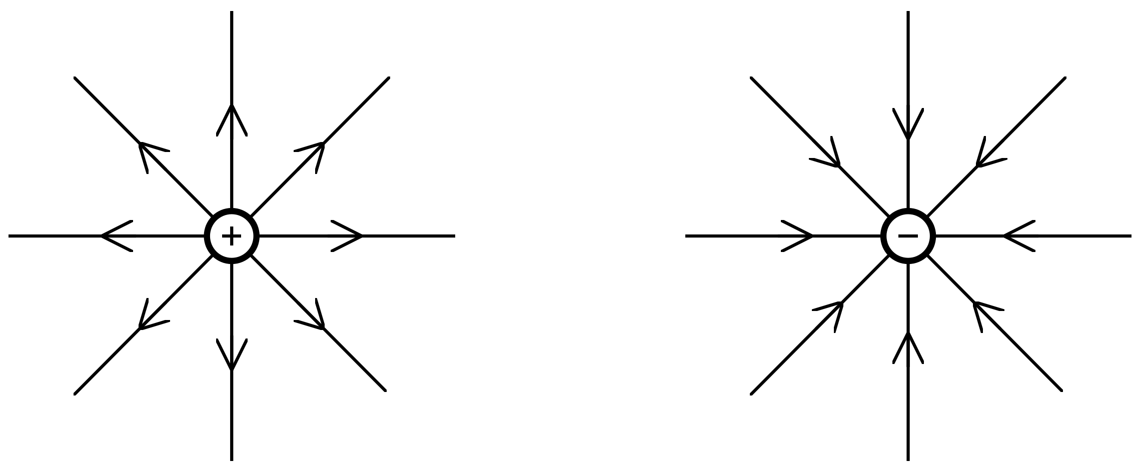


- direction of $\vec{E}$ at a given point is tangent to field line at that point.
- Electric field is strong where the field lines are close together, and weak where they are far apart.

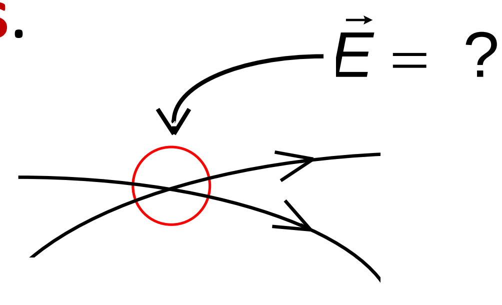
Electric Field Line Model

1. **Electric field lines point in the direction of the (total) electric field** at each point in space

2. Electric field lines **start on + charges and end on − charges**

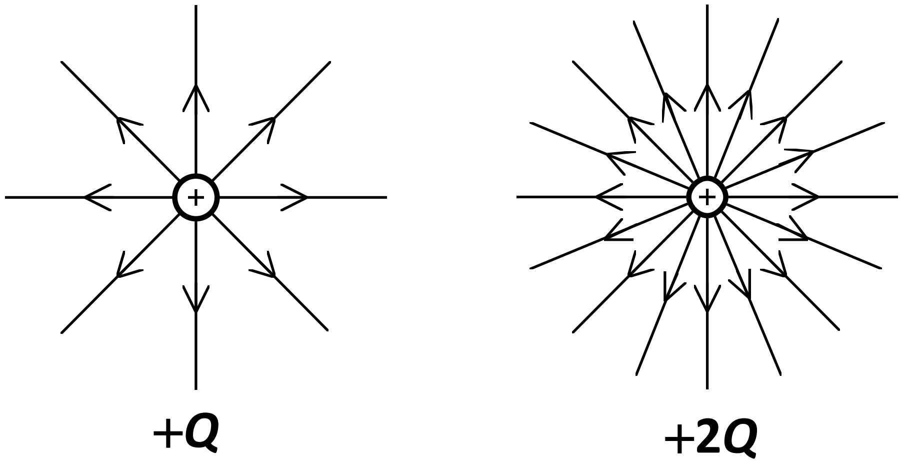


3. Electric field lines **cannot cross**.



4. The **number of field lines *N* coming out of or going into a charge is proportional to the magnitude of the charge |*Q*|,** i.e., $N \propto |Q|$.

N lines over all directions in 3-D.



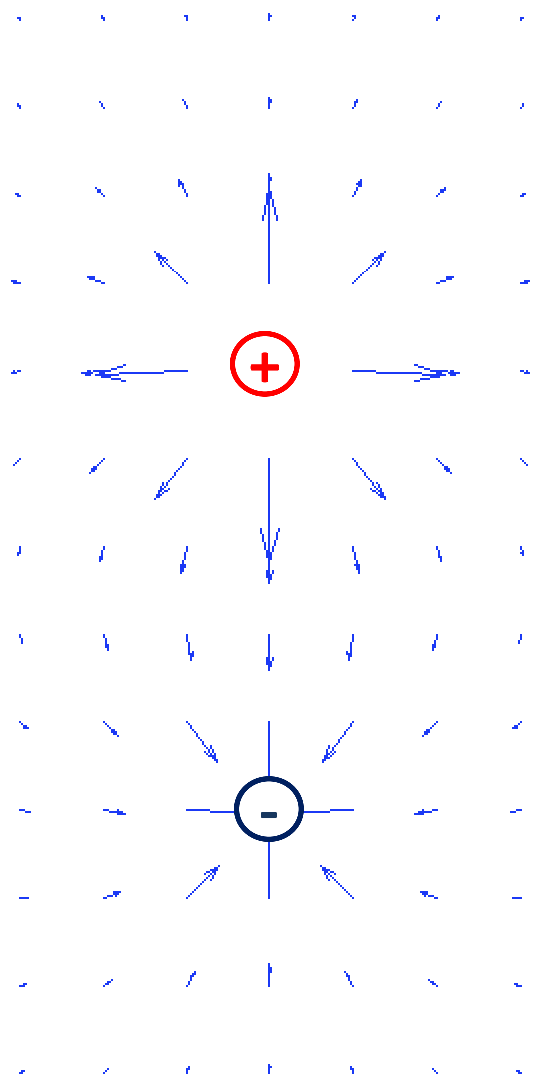
2*N* lines over all directions in 3-D

5. The **strength (magnitude) of the electric field at any place is proportional to the density of field lines** there, i.e.,

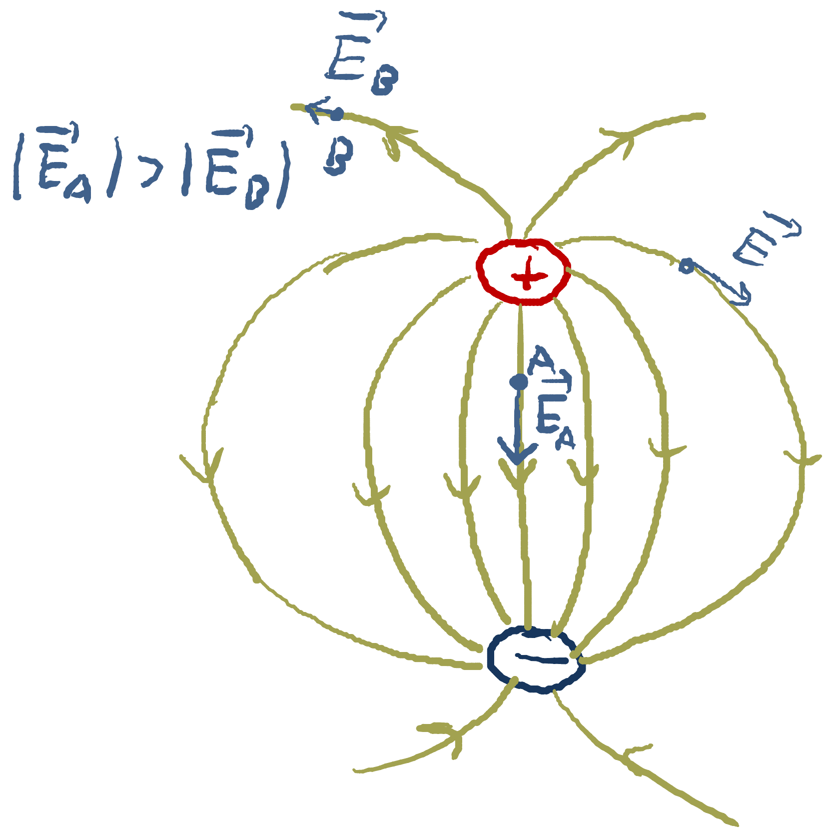
$$E \propto \frac{(\#\ \text{of field lines})}{(\text{area} \perp \text{lines})}$$

Electric Dipole

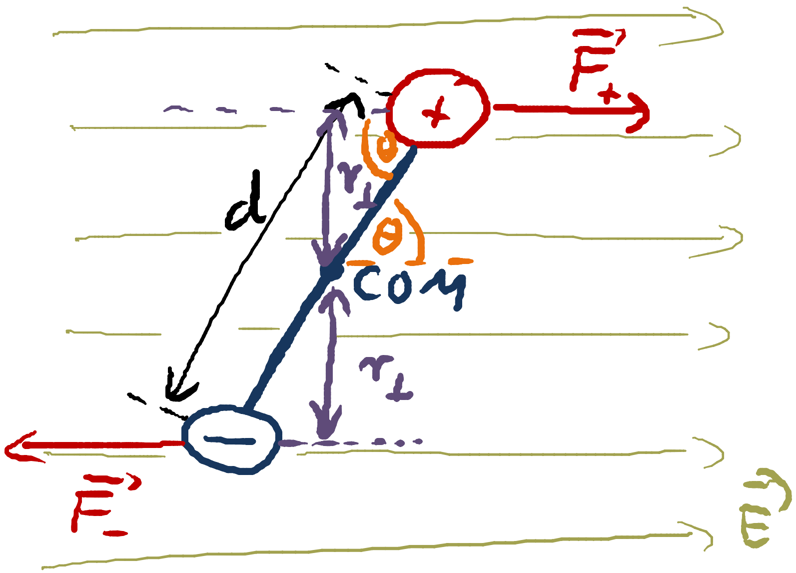
Collection of vector arrows:



Electric field lines:



Dipole in a Uniform Electric Field:



external electric field (i.e. not by dipole itself)

force on each charge:

$$|\vec{F}_+| = |\vec{F}_-| = |q| \cdot |E|$$

$$\Rightarrow \sum \vec{F} = 0 \Rightarrow \vec{a}_{com} = 0$$

but: creates net torque

$\Rightarrow$ dipole rotates

$$|\tau_{net,\,dipole}| = F_+ r_\perp + F_- r_\perp$$

$$= q E \cdot \sin\theta \cdot \frac{d}{2} + q E \frac{d}{d} \sin\theta$$

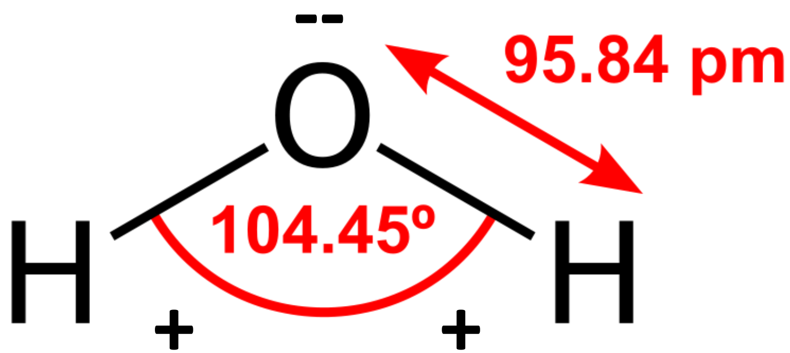
$$= q d E \sin\theta$$

$$= p E \sin\theta$$

with electric dipole moment: $p = q \cdot d$

How does a microwave oven heat?

- In 1947, Raytheon built the "Radarange", the first commercial microwave oven. It was almost 6’ tall, weighed 750 lb and cost about US$5000 each.
- Uses microwave energy, usually at a frequency of 2.45 GHz from a magnetron



Uses dielectric heating:

- Many molecules (such as those of water) are electric dipoles
- High-frequency alternating electric field causes molecular dipole rotation within the food -> heating

Consider the four field patterns shown. Assuming there are **no charges in the regions shown**, which of the patterns represent(s) a **possible electrostatic field**:

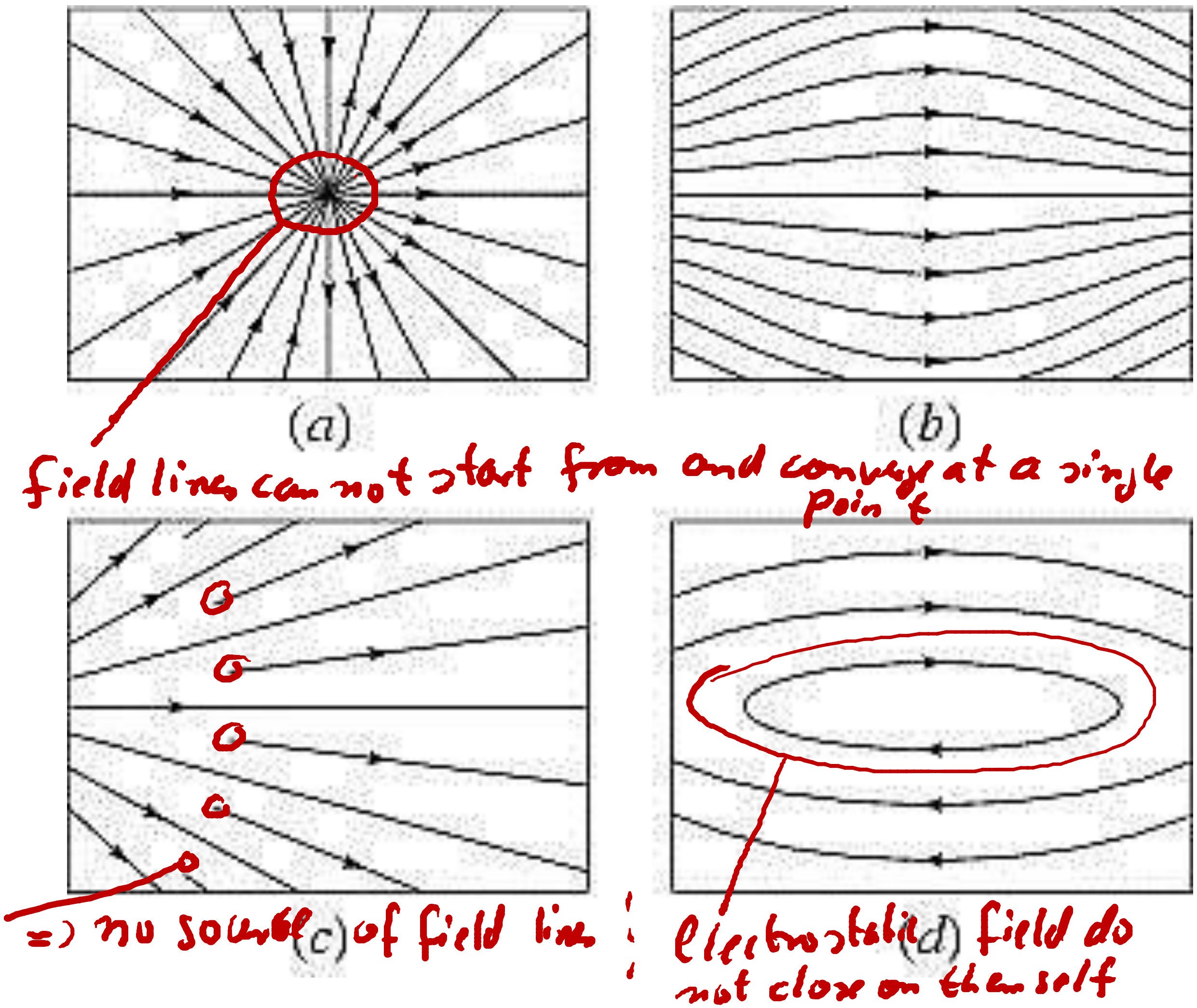
A. (*a*)

B. (*b*)

C. (*b*) and (*d*)

D. (*a*) and (*c*)

E. (*b*) and (c)



How are charges Q_1 and Q_2 related?

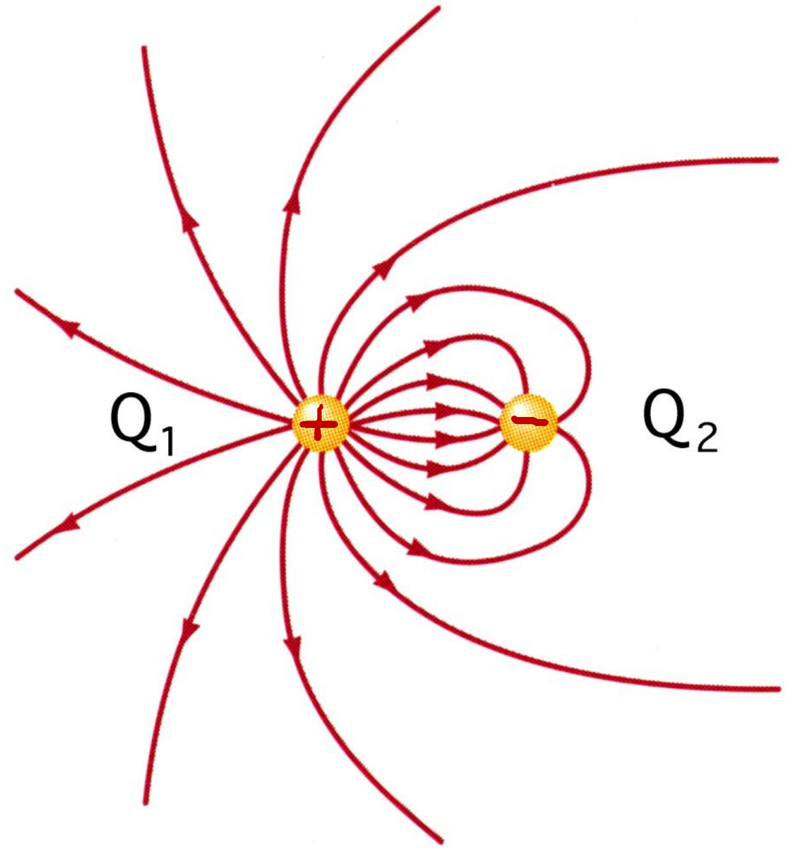
A. Same sign and $|Q_1| < |Q_2|$.

B. Same sign and $|Q_1| > |Q_2|$.

C. Opposite sign and $|Q_1| < |Q_2|$.

D. Opposite sign and $|Q_1| > |Q_2|$.

E. Opposite sign and $|Q_1| = |Q_2|$.



more field lines starting at Q_1
=> higher |charge|

At which of the labeled points is the electric field magnitude the largest?

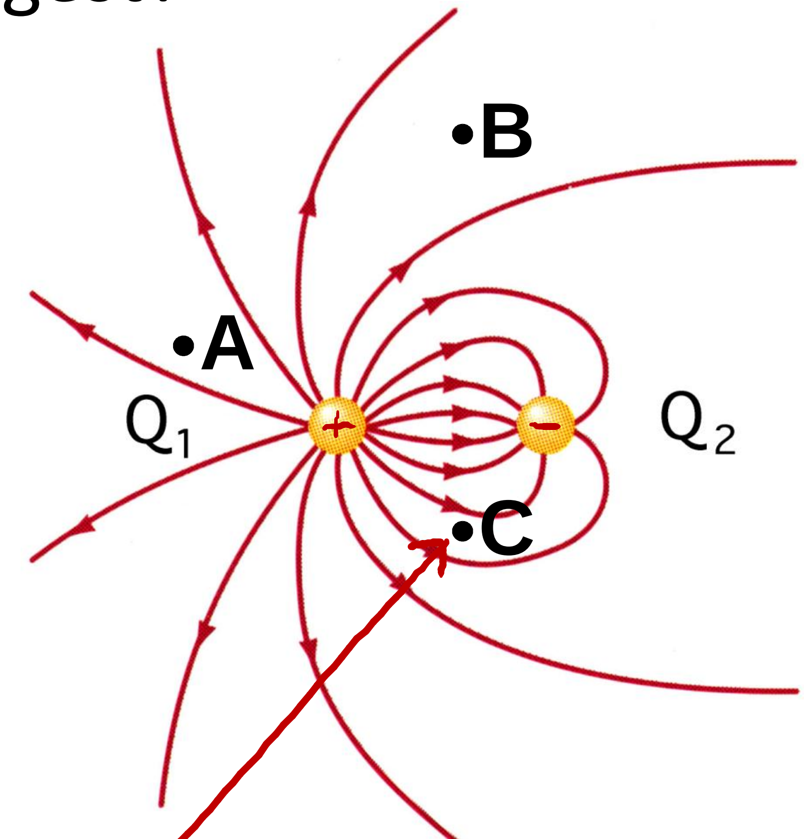
A. A

B. B

C. C

D. A and C tie

E. Same at all three points

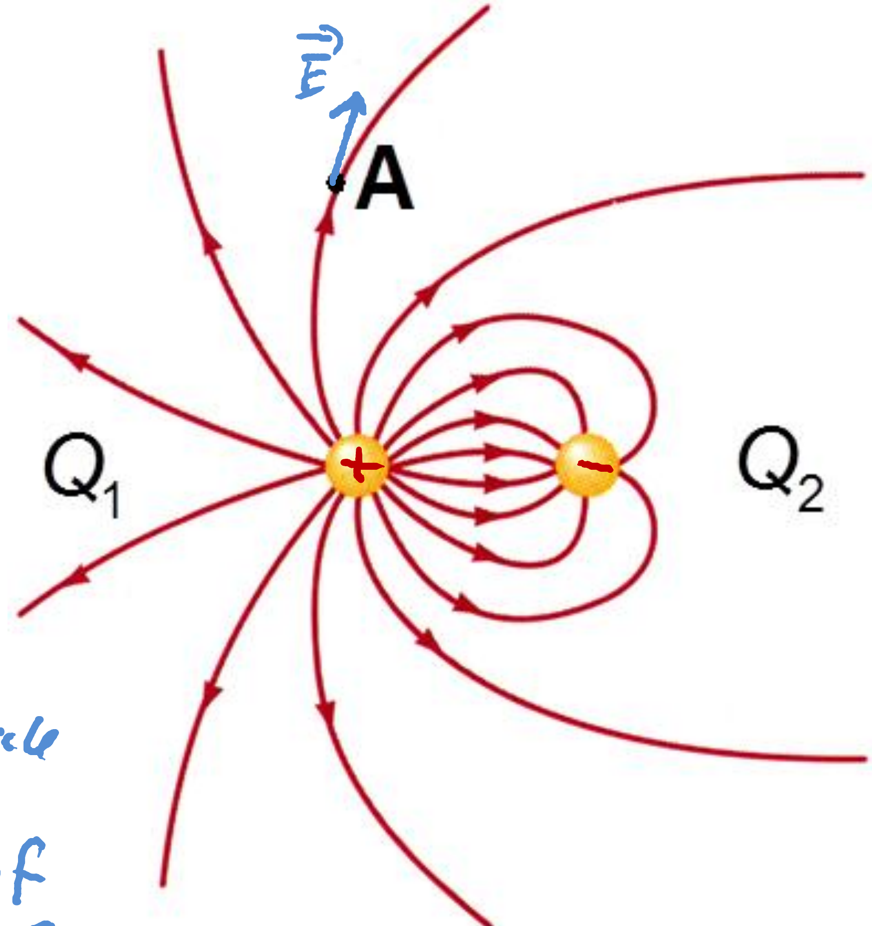


has largest density of field lines
=> largest |E|

If a proton were released from rest at point **A**, would the proton's subsequent path follow the electric field line on which it starts?

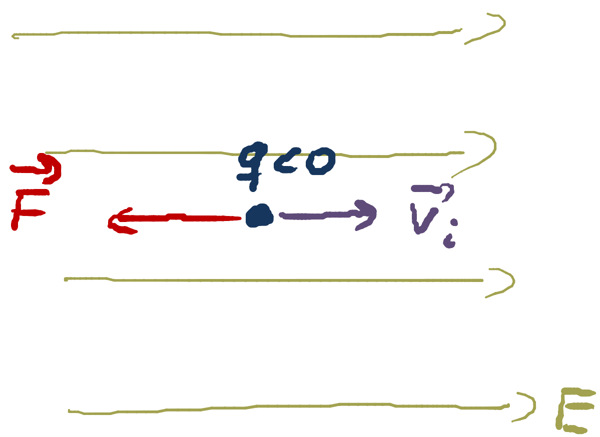
A. Yes

B. No



Field lines point in direction of electric field at each point, but do not show path a charged particle would take in E field. Path depends on charge of test particle and its mass!

Example: Motion of a Point Charge in a Uniform Electric Field:



external, uniform electric field

force on charge: $\vec{F} = q \cdot \vec{E}$

$\Downarrow$

acceleration: $\vec{a} = \frac{\vec{F}}{m} = \frac{q}{m} \vec{E}$

↗ path depends on charge q and mass m of particle!

$\Rightarrow$ measure path of particle in given uniform electric field gives q/m ratio of particle

$\rightarrow$ particle detector

Which best describes the **path of the proton between the two plates** with equal charge magnitudes but opposite signs?

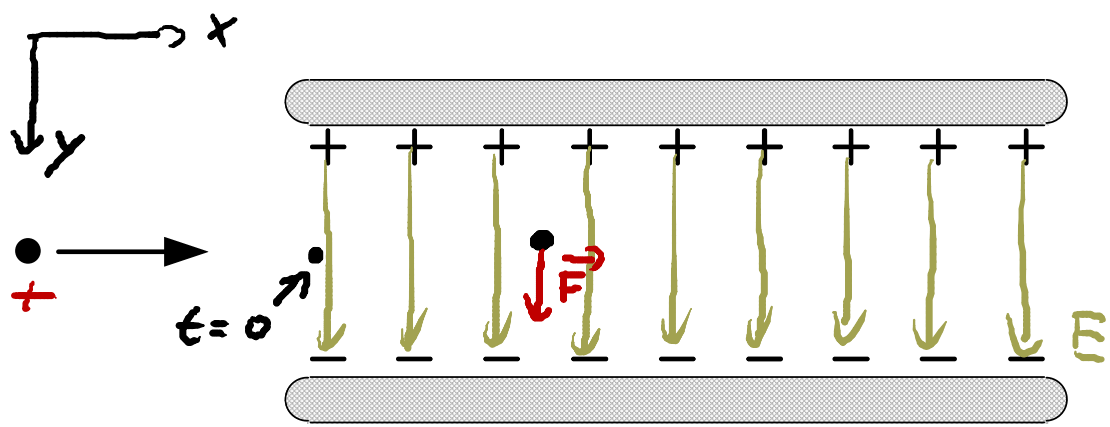
$\vec{F} = q\vec{E} = m\vec{a}$

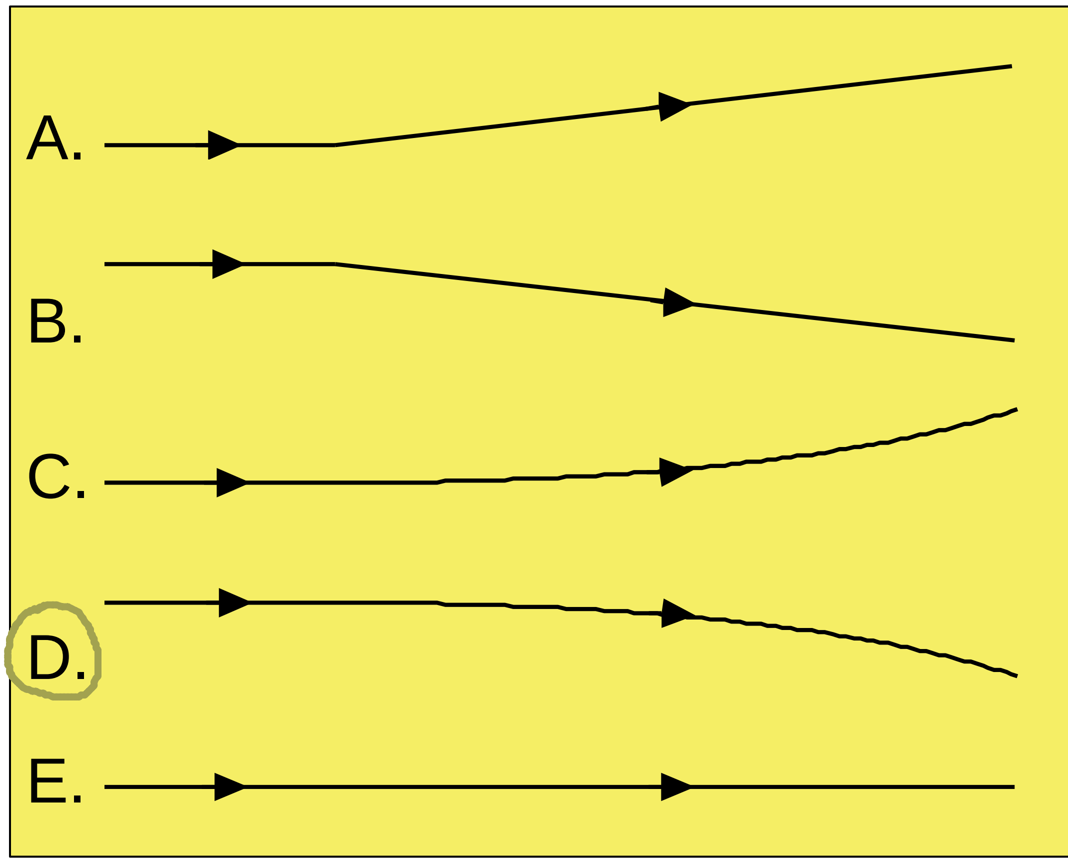
$q > 0$ here

$V_x = \text{const}$

$V_y = a\,t = \frac{q}{m} E\,t$

(like projectile motion path with initial horizontal velocity)



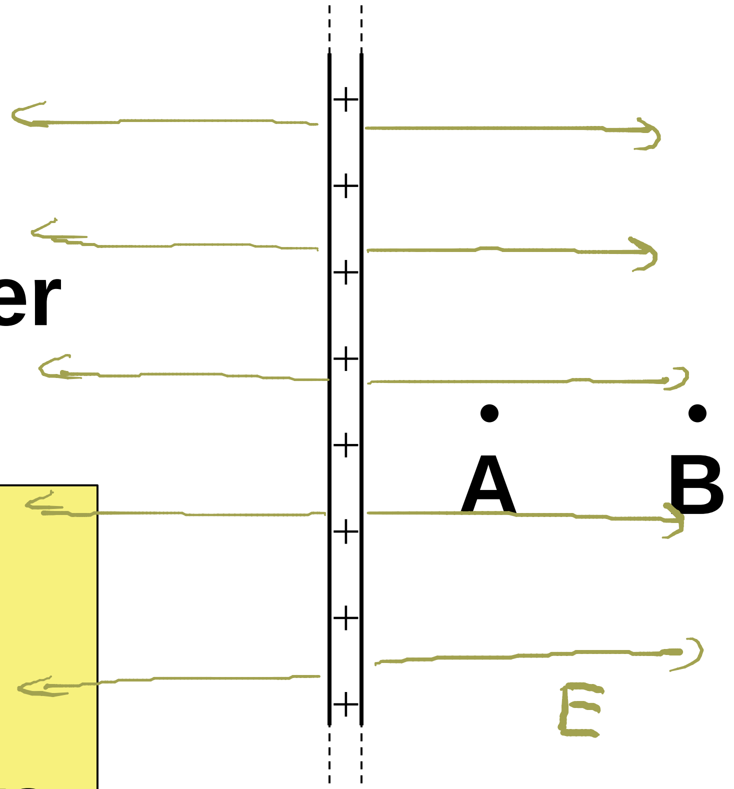


At which point near the flat infinite uniform sheet of positive charge does the electric field have the **greater magnitude**?

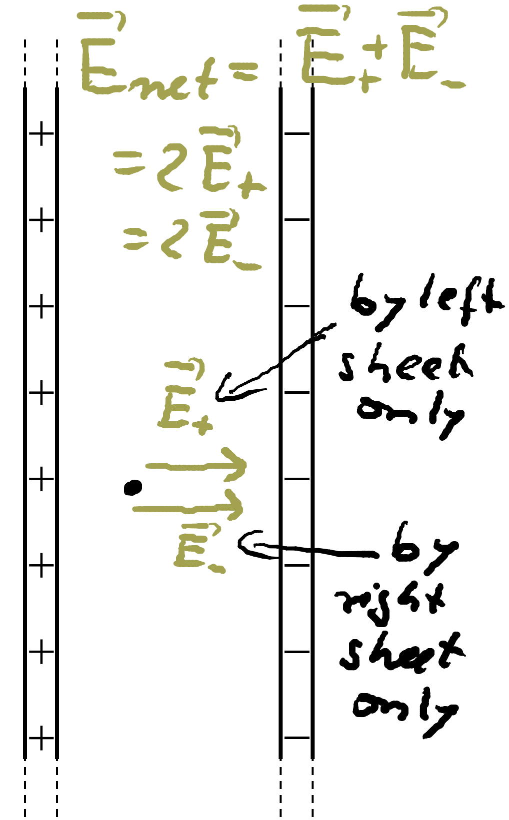
A. **A**

B. **B**

C. The field has the same magnitude at both points.



A flat infinite uniform sheet of positive charge is parallel to a flat infinite uniform sheet of negative charge. The magnitude of the surface charge density of both sheets is the same, i.e., $\sigma_+ = -\sigma_-$. If E_+ is the electric field magnitude due to the positive sheet alone, what is the **electric field magnitude between the sheets**?



A. E_+

B. $2E_+$

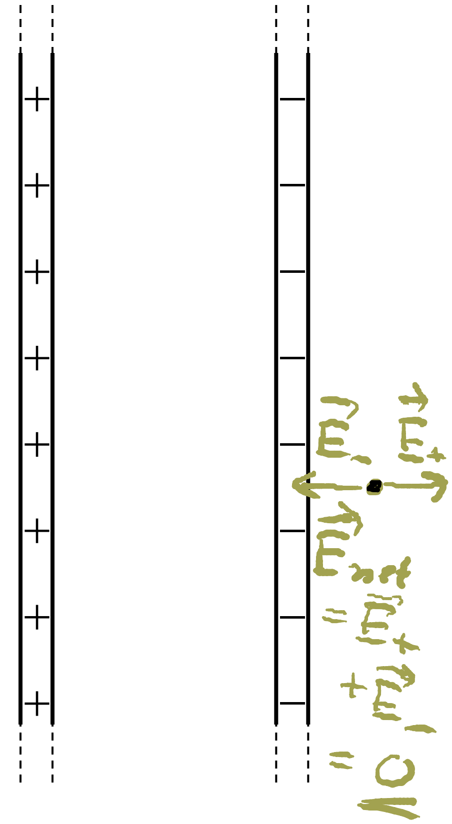
C. $E_+/2$

D. Zero

E. Not enough information.

⇒ Use superposition principle!

A flat infinite uniform sheet of positive charge is parallel to a flat infinite uniform sheet of negative charge. The magnitude of the surface charge density of both sheets is the same, i.e., $\sigma_+ = -\sigma_-$. If E_+ is the electric field magnitude due to the positive sheet alone, what is the **electric field magnitude to the right of the sheets**?



A. E_+

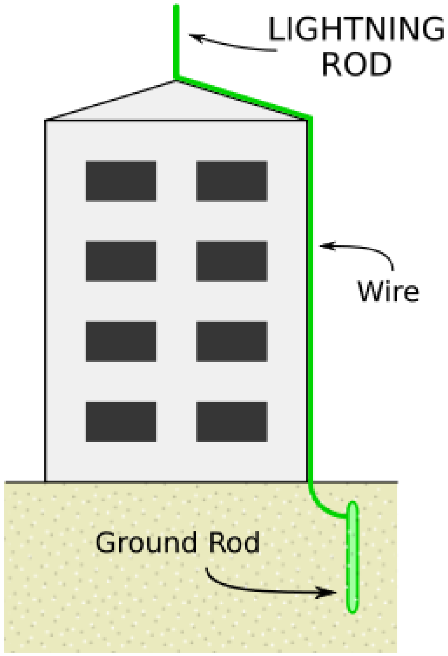
B. $2E_+$

C. $E_+/2$

D. Zero

E. Not enough information.

How does a lightening rod work?



Lightning:

- Atmospheric electrostatic discharge
- Path of ionized air starts from a negatively charged thundercloud
- When it approaches the ground, a conductive discharge (called a positive streamer) can develop from ground-connected objects whose tops are closest to the base of the thundercloud, such as trees and tall buildings.

Lightning rod:

- Invented by Benjamin Franklin in 1749
- Thundercloud attracts charge at top of rod
- Strong electric fields at top of rod ionizes nearby air molecules -> attracts and intercepts a strike that terminates near a protected structure