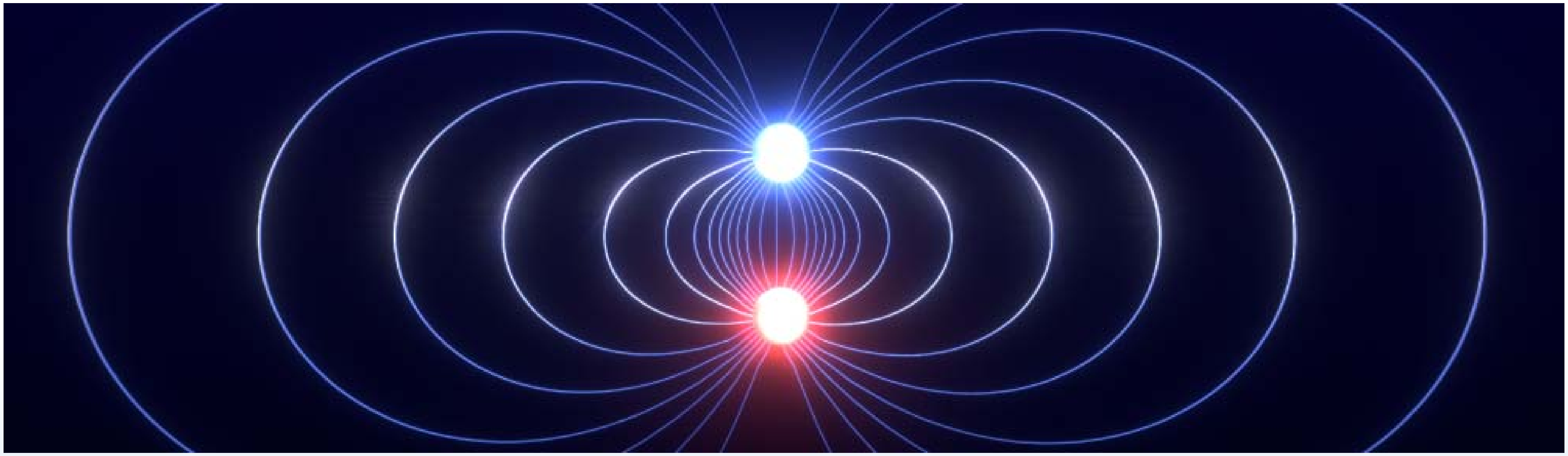
Your questions/comments

“This lesson in general was very hard for me to conceptualize. I can conceptualize what a point charge is in my mind, and understand the relationship between charged particles, but when it comes to electric fields, it's not as clear in my mind.”

“Electric fields and how to read them. Especially when some of the arrows aren't there to show the magnitude of attraction or repulsion.”

“Not sure how to quantify differences in magnitude of electric fields/charges simply based on the map of the electric field.”

“The directionality of electric fields is very confusing, even with the pre-lectures. If the electric field checkpoint could be explained in lecture, that would be really nice as well.”



Phys 102 – Lecture 3

The Electric field

Today we will...

- Learn about the *electric field*
- Apply the superposition principle

  Ex: Dipole, line of charges, plane of charges

- Represent the E field using electric field lines
- Apply these concepts!

  Dipoles in electric fields

  Conductors in electric fields

The electric field

The electric field is defined at a *location* in space around a charge or set of charges

Field at position *P*

$$\boxed{\vec{E} \equiv \frac{\vec{F}}{q}}$$

Force a charge *q* at position *P* *would* feel

Charge *q*

Magnitude

Magnitude given by: $E = \frac{F}{|q|}$ Units: N/C

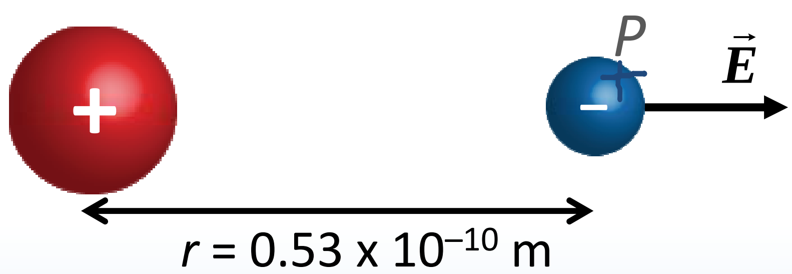
Direction

Direction is the same as for the force that a + charge *would feel* at that location

− charge, opposite

Calculation: Electric field in H atom

What is the magnitude of the electric field due to the proton at the *position* of the electron?



$$E = \frac{F}{|q_e|} = \frac{k|q_p|}{r^2} = \frac{9\times10^9\,N\cdot m^2/C^2\,|1.6\times10^{-19}\,C|}{(0.53\times10^{-10}\,m)^2} = 5.1\times10^{11}\,\frac{N}{C}$$

This is a large electric field!
Inside electrical wire: 10^{-2} N/C
Needed to create a spark in air: 10^{6} N/C

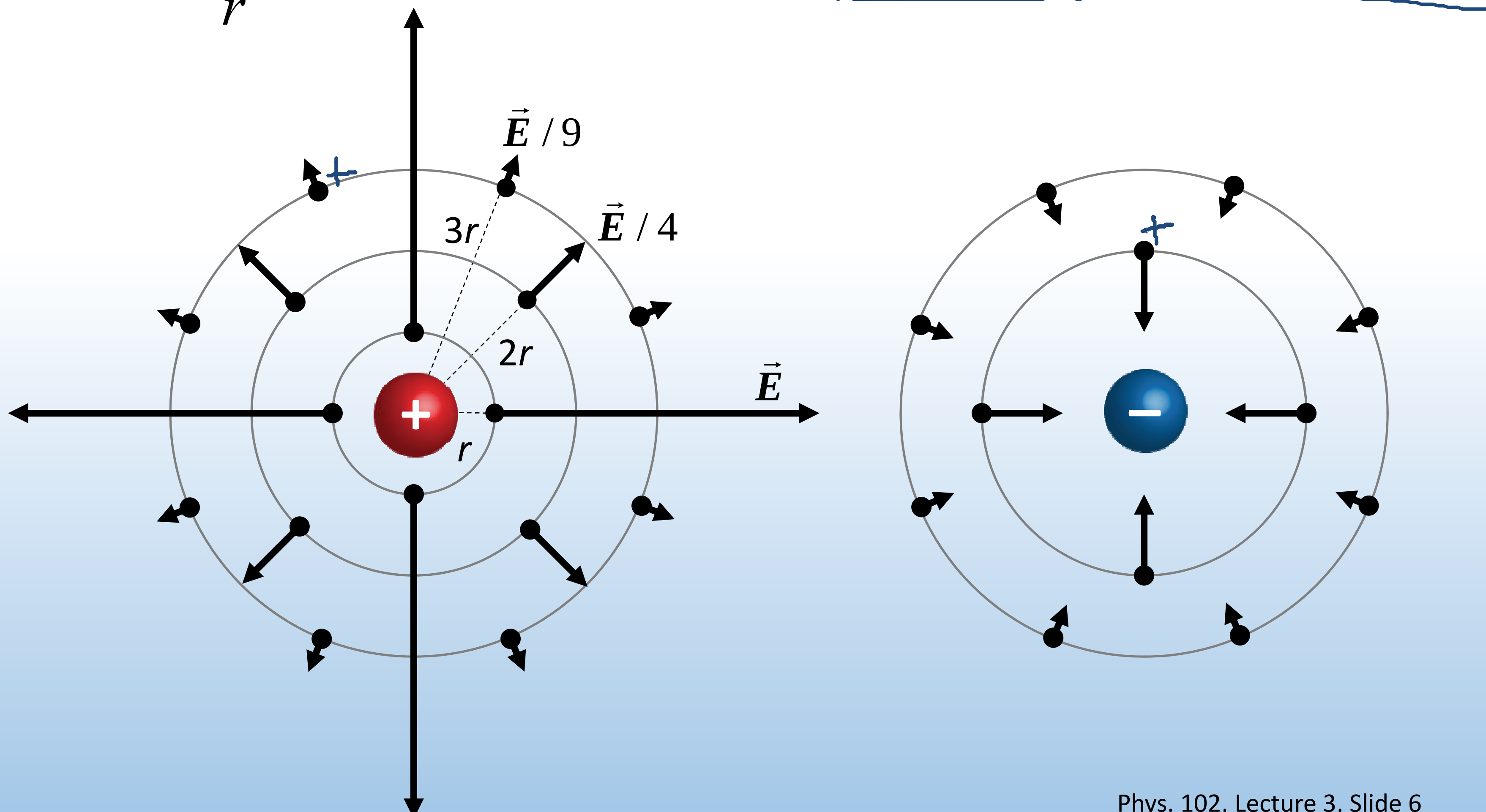
What is the direction?

Direction is the same as for the force that a + charge *would feel* at that location

Electric field from + and – charges

Magnitude $E = \dfrac{k|q|}{r^2}$

Direction Away from + charge, toward – charge

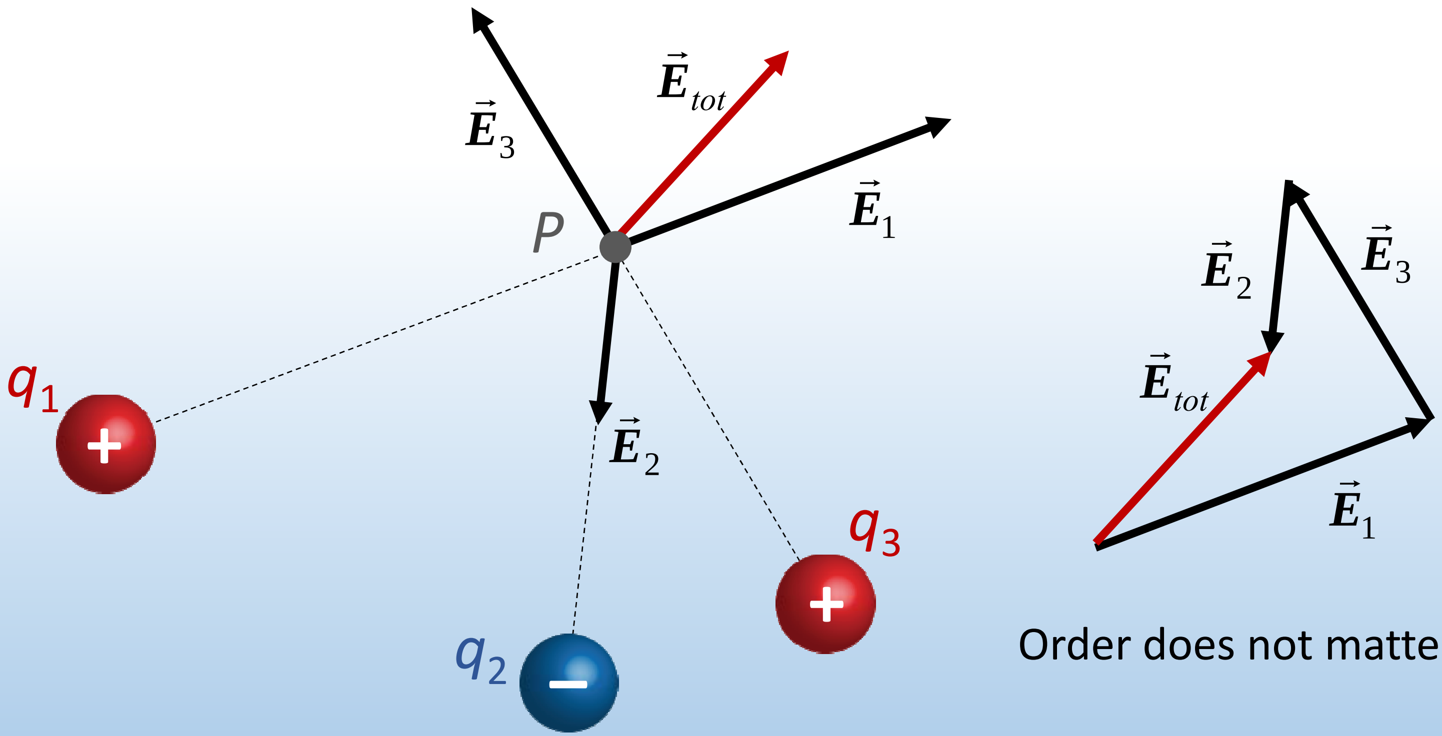


Superposition principle

Total E-field due to several charges = sum of individual E-fields

$$\vec{E}_{tot} = \sum \vec{E}$$

Ex: what is the E-field at point P due to q_1, q_2, and q_3?



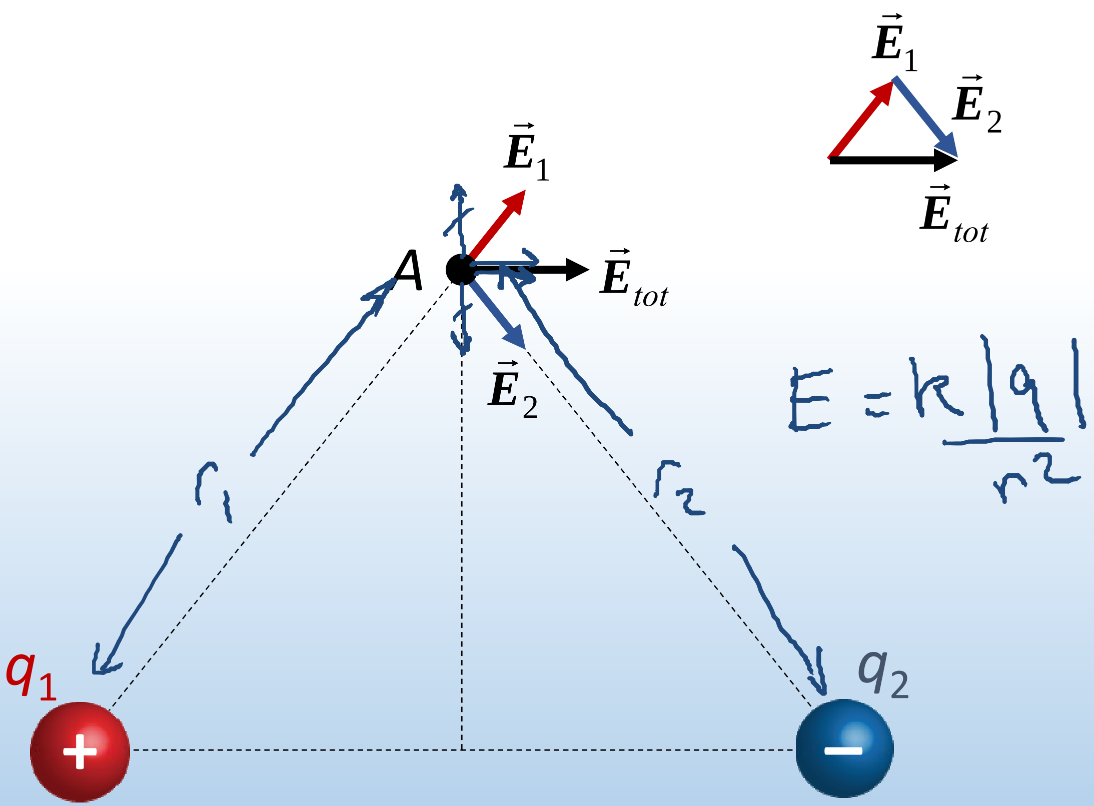
Order does not matter!

Same approach
as for force

$$\vec{E}_{tot} = \vec{E}_1 + \vec{E}_2 + \vec{E}_3$$

CheckPoint 1.1

Two equal, but opposite charges are placed on the *x*-axis at $x = -5$ and $x = +5$. What is the direction of the electric field at point A on the *y*-axis?



A. Up

B. Down

C. Left

D. Right

E. Zero

ACT: CheckPoint 1.2

What is the direction of the electric field at point *B*?

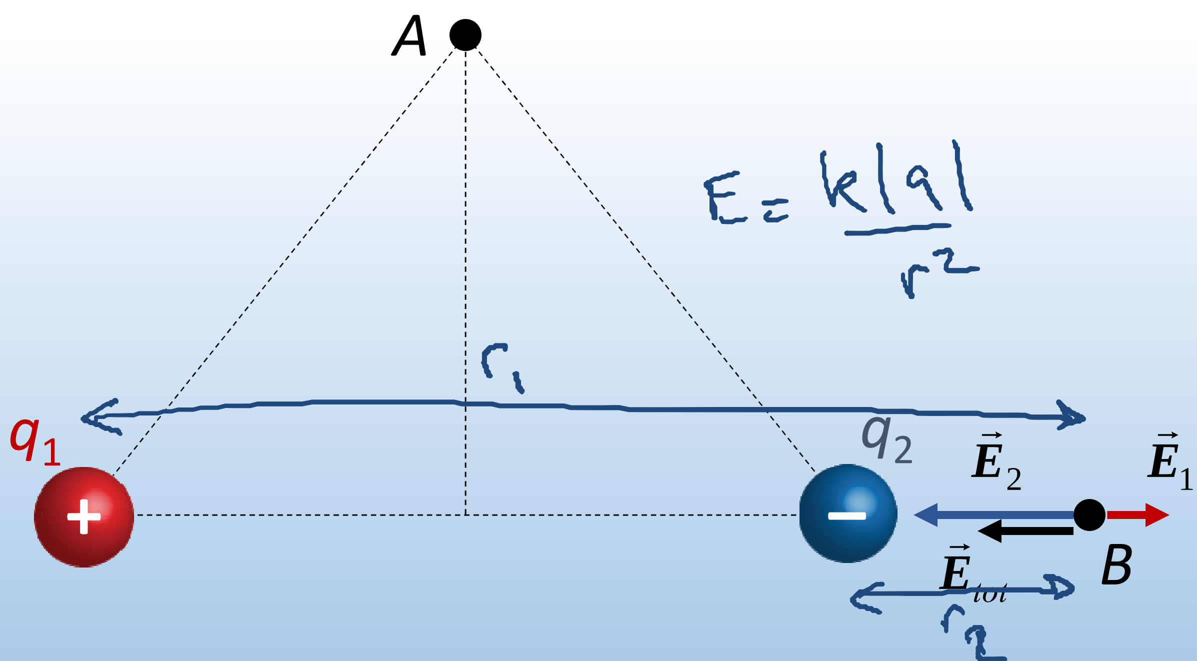
Other locations?

A. Left

B. Right

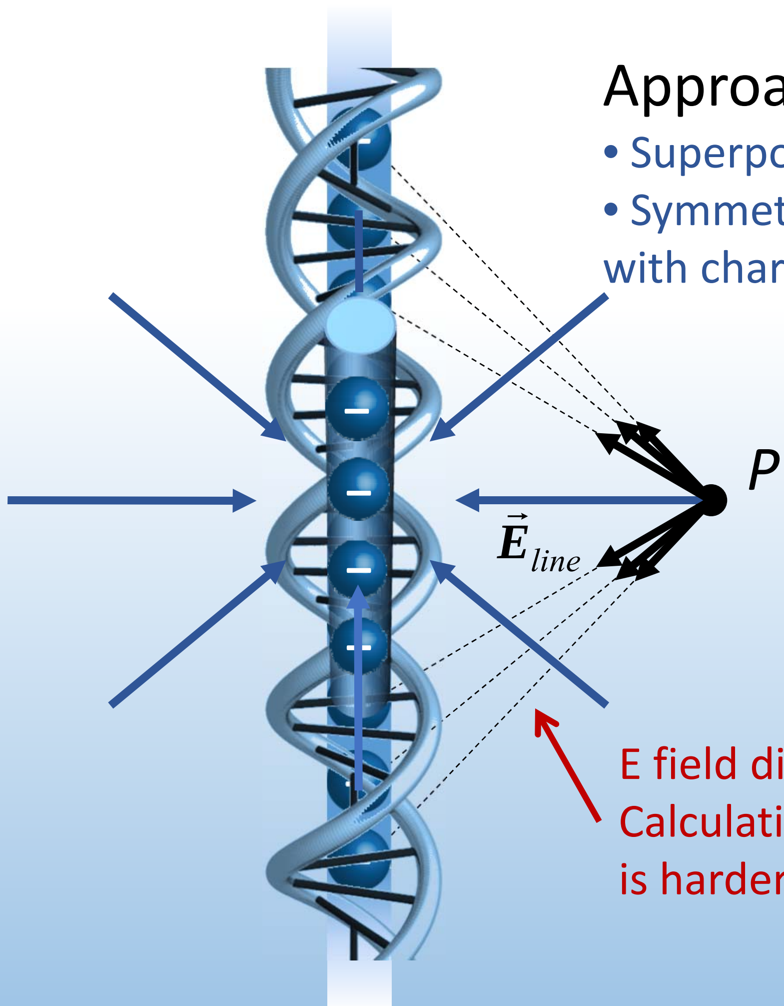
C. Zero

$$E = \frac{k|q|}{r^2}$$



ACT: Line of charge

Consider a very long line of negative charges (ex: DNA). What is the direction of electric field at point *P*?



Approach:

- Superposition principle
- Symmetry: charge above *P* pairs up with charge below *P*

A. Up

B. Down

C. Left

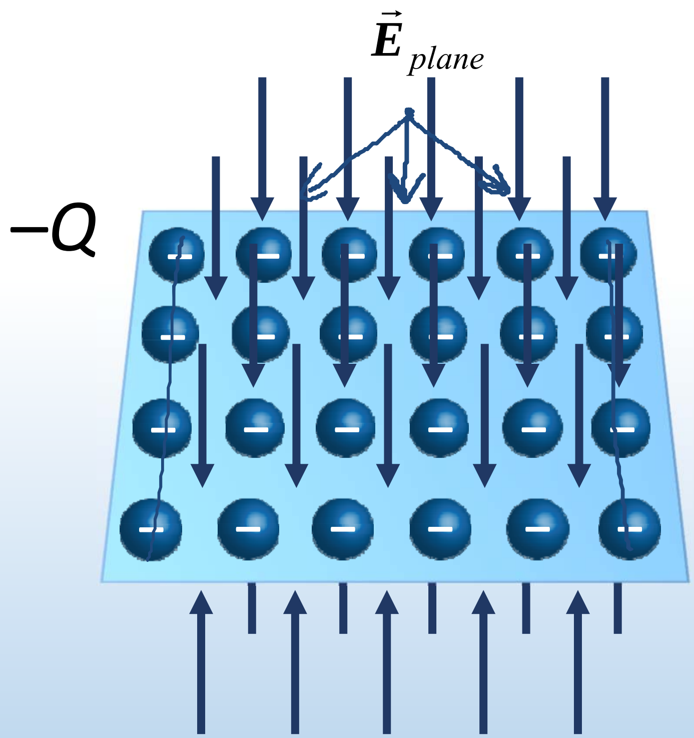
D. Right

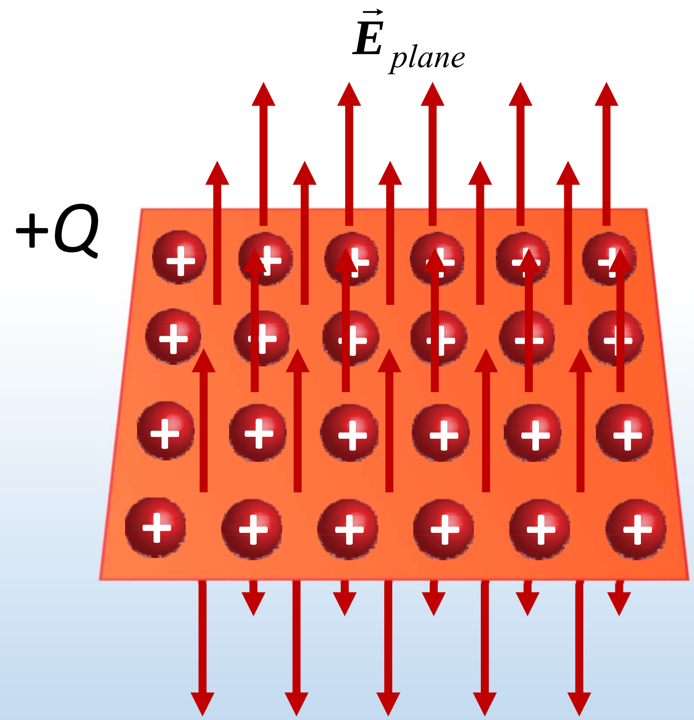
E. Zero

E field direction is radial. Calculating a magnitude is harder. Need calculus!

Plane of charge

A large plane of charges creates a *uniform* electric field (constant magnitude, direction)



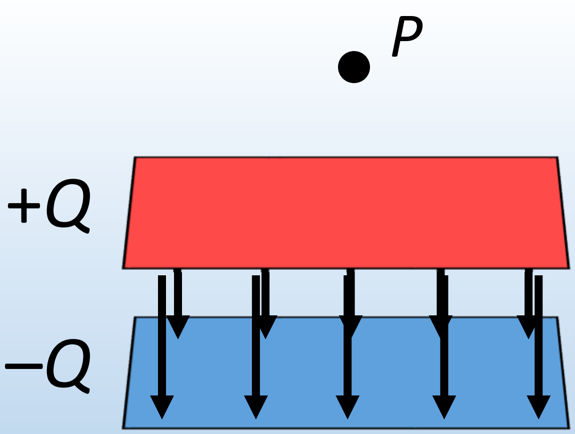


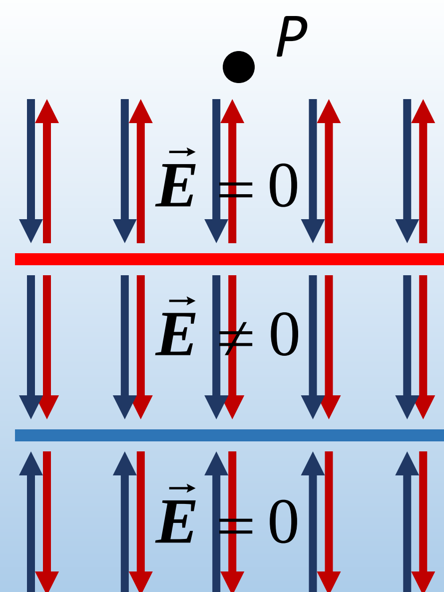
Approach: Superposition principle & symmetry

ACT: two charged planes

Consider two large parallel planes with equal and opposite charge $+Q$ and $-Q$ separated by a small distance

If the electric field from one plane is E_{plane}, what is the magnitude of total electric field at position P <u>above</u> the two parallel planes?





A. 0

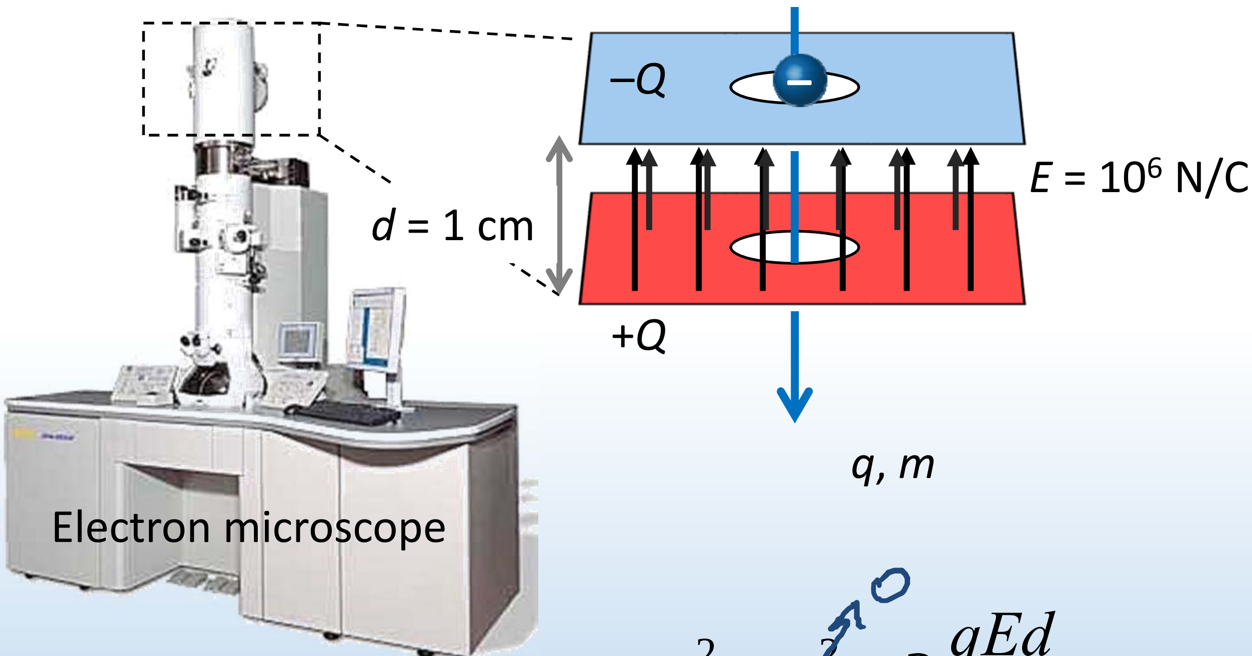
B. $E_{plane}/2$

C. $2E_{plane}$

E field is uniform between plates, 0 everywhere else!

Calculation: Electron microscope

A uniform E field generated by parallel plates accelerates electrons in an electron microscope. If an electron starts from rest at the top plate what is its final velocity?



$$F_e = qE = ma$$

$$\cancel{v = v_0 + at}$$

$$\cancel{x = x_0 + v_0 t + \tfrac{1}{2}at^2}$$

$$\underbrace{v^2 = v_0^2 + 2a\Delta x}_{\text{Kinematics! (Phys. 101)}}$$

$$v^2 = \cancel{v_0^2}^{\,0} + 2\frac{qEd}{m}$$

$$v = \sqrt{2\frac{1.6\times10^{-19}\cdot10^{6}\cdot0.01}{9.11\times10^{-31}}} = 5.9\times10^{7}\ m/s$$

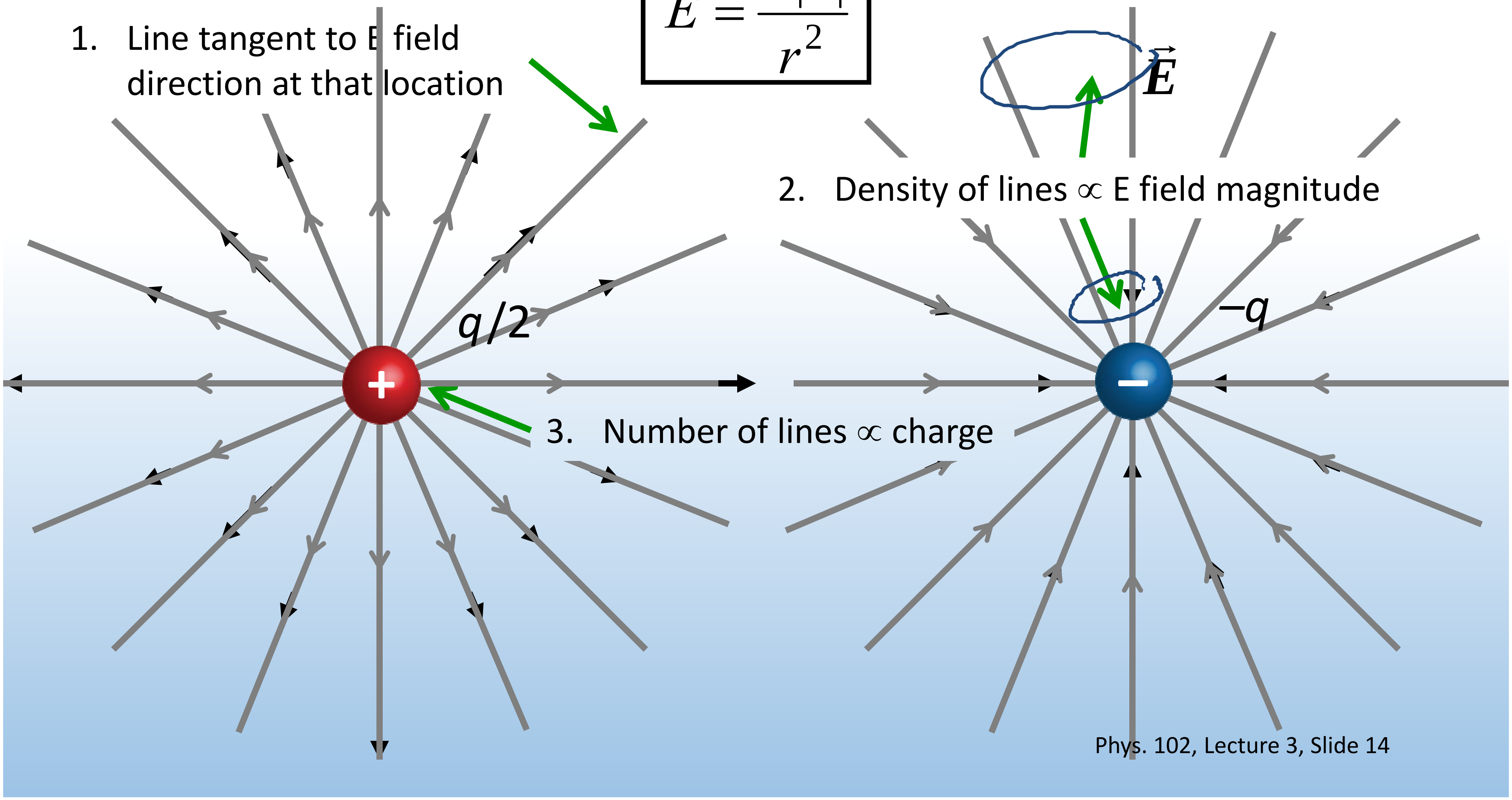
$$\boxed{\text{We'll learn an easier way to solve this in Lect. 4}}$$

Electric field lines for charges

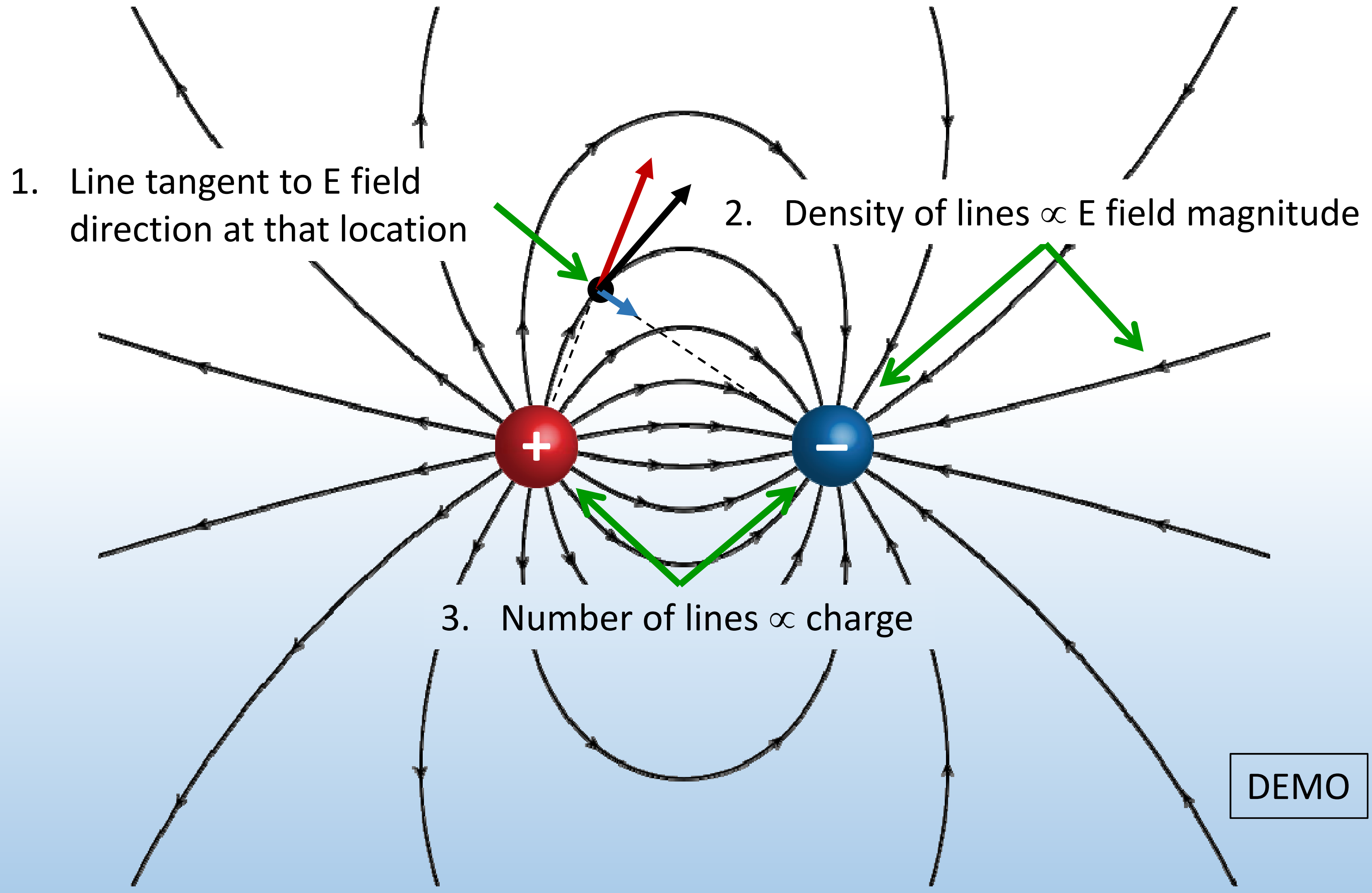
Electric field lines represent E field direction and magnitude graphically

$$\boxed{E = \frac{k|q|}{r^2}}$$

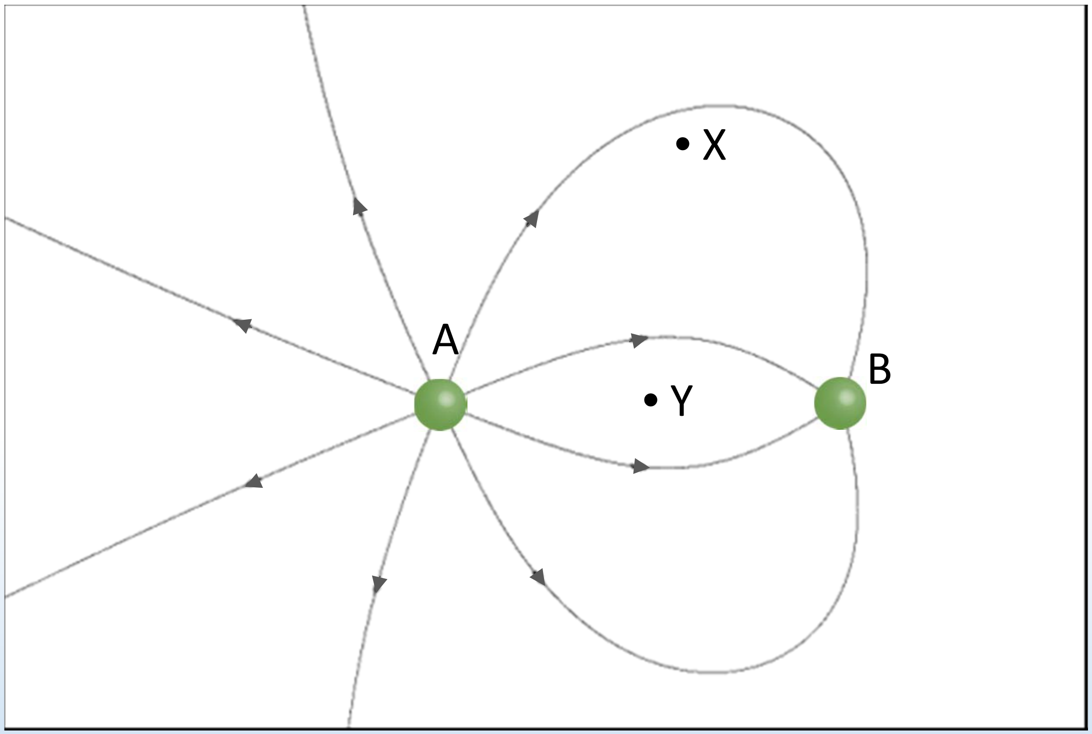
1. Line tangent to E field direction at that location
2. Density of lines ∝ E field magnitude
3. Number of lines ∝ charge



Electric field lines for dipoles



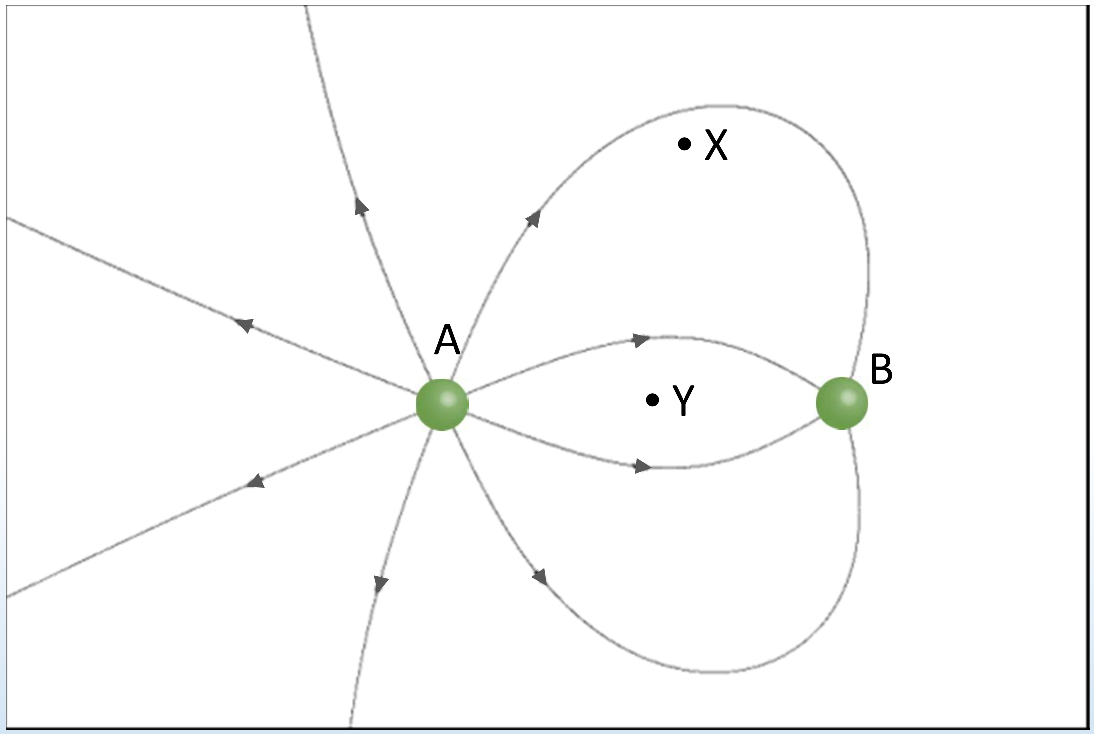
CheckPoint 2.1



Charge A is Field lines start on positive charge, end on negative.

A. positive B. negative C. unknown

ACT: CheckPoint 2.2

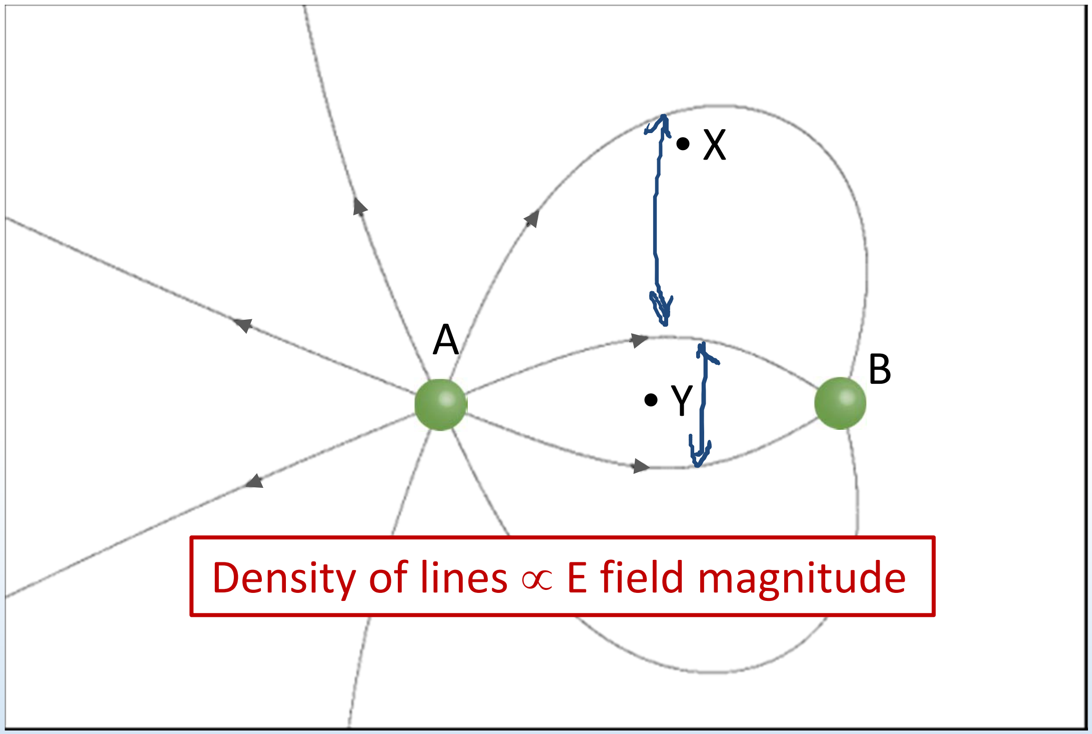


Compare the charges Q_A & Q_B

lines proportional to Q

A. $Q_A = Q_B/2$ B. $Q_A = Q_B$ C. $Q_A = 2Q_B$

ACT: CheckPoint 2.4



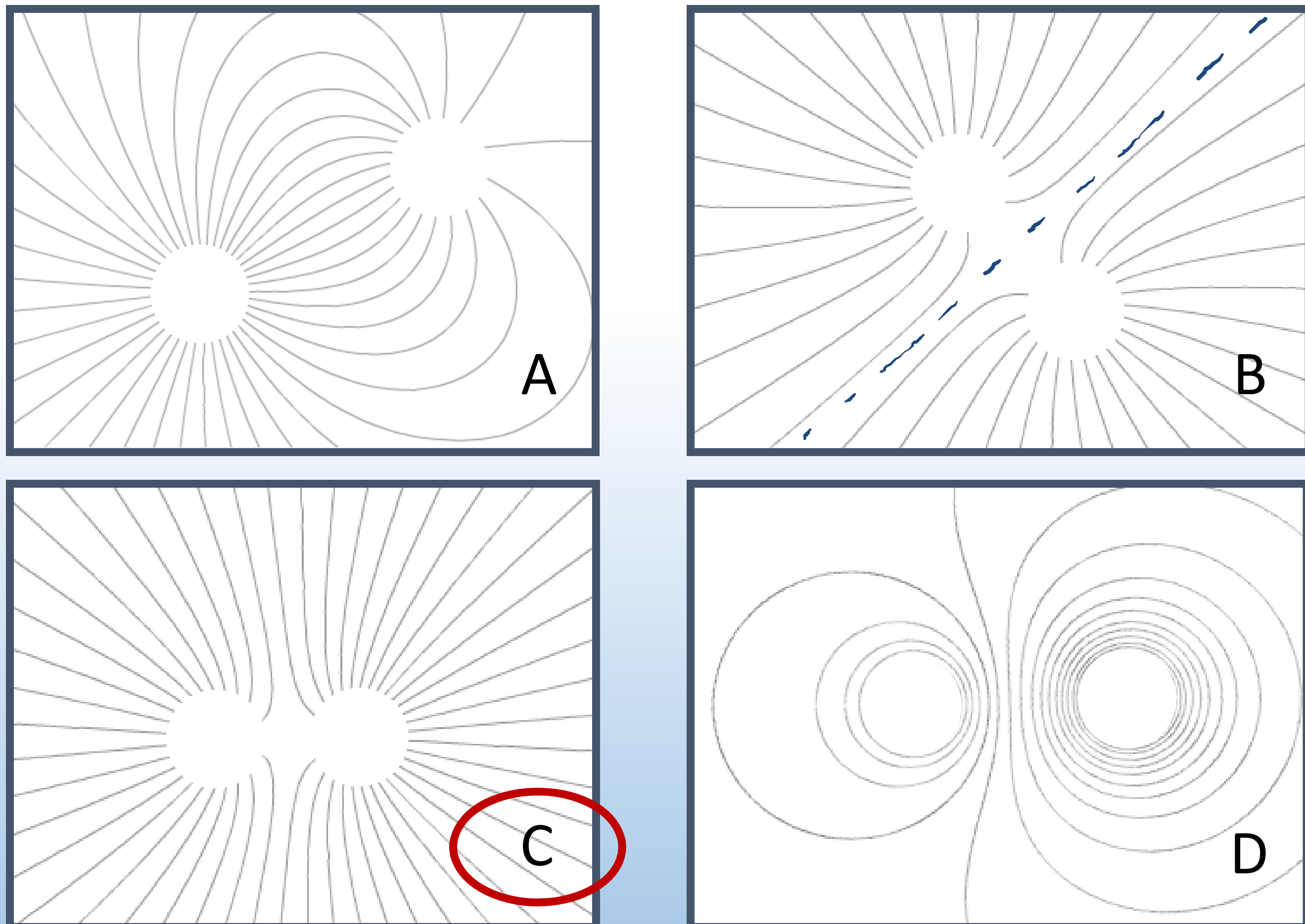
The magnitude of the electric field at point X is greater than at point Y

A. True

B. False

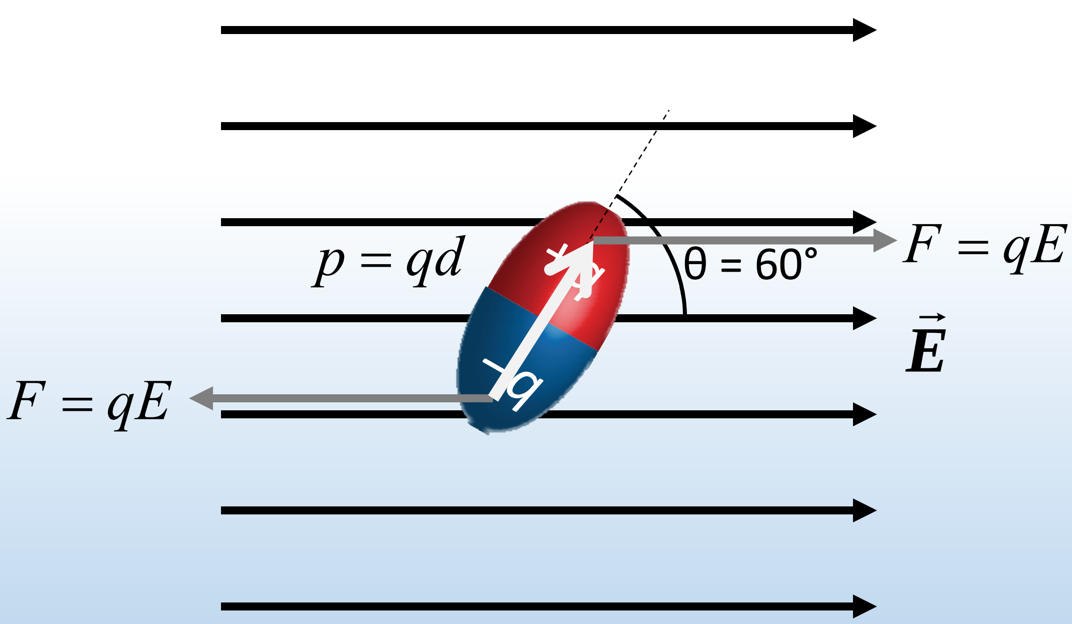
ACT: Electric field lines

Which of the following pictures best represents the electric field from two charges that have the *same* sign but different magnitudes?



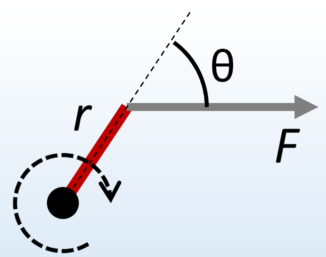
Calculation: dipole in E-field

An electric dipole with moment p = 6.2 x 10^{-30} C·m is placed in a uniform external electric field E = 10^6 N/C at an angle θ = 60°. Calculate the total *force* and *torque* on the dipole.



Force: $F_{tot} = 0$

Torque: $\tau = Fr\sin\theta$



Torque! (Phys. 101)

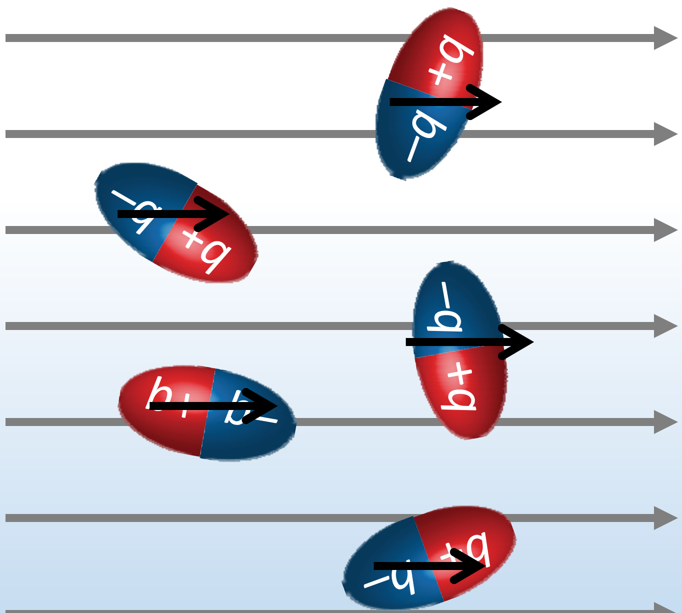
$$\tau_{tot} = 2qE\frac{d}{2}\sin\theta = pE\sin\theta$$
$$= 6.2\times10^{-30}\cdot10^{6}\sin(60^\circ)$$
$$= 5.4\times10^{-24}\,Nm$$

Dipole rotates until *τ* = 0, *i.e.* when θ = 0°
Dipole moment aligns to E field

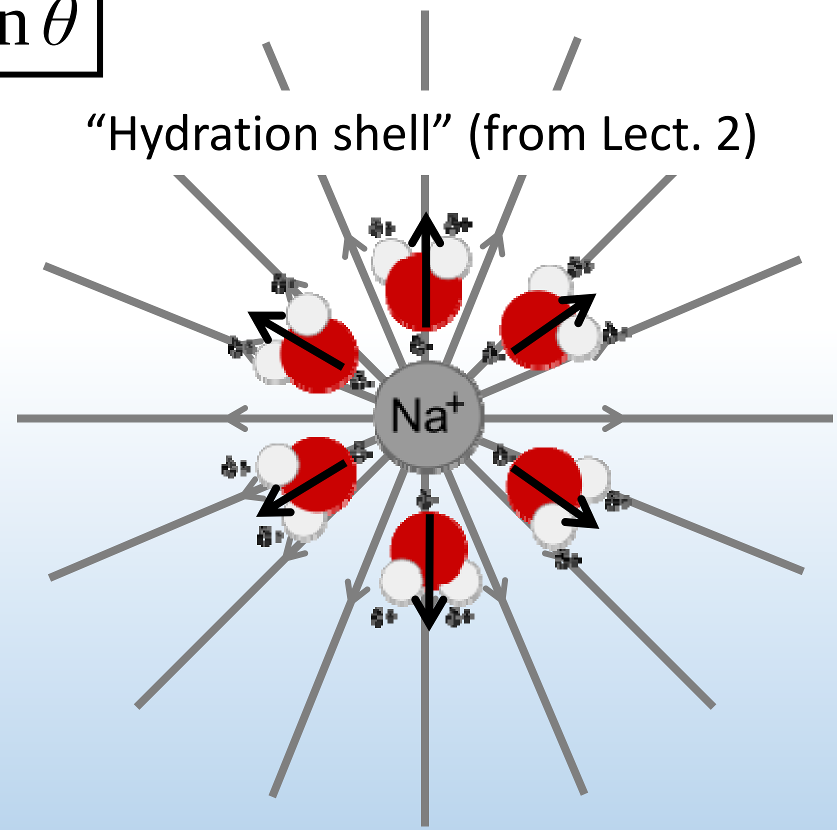
Dipole in E field

Electric dipole moments align parallel to electric field

$$\boxed{\tau = pE\sin\theta}$$



Dipoles in a uniform E field



Dipoles near a charge

DEMO

Conductors & electric fields

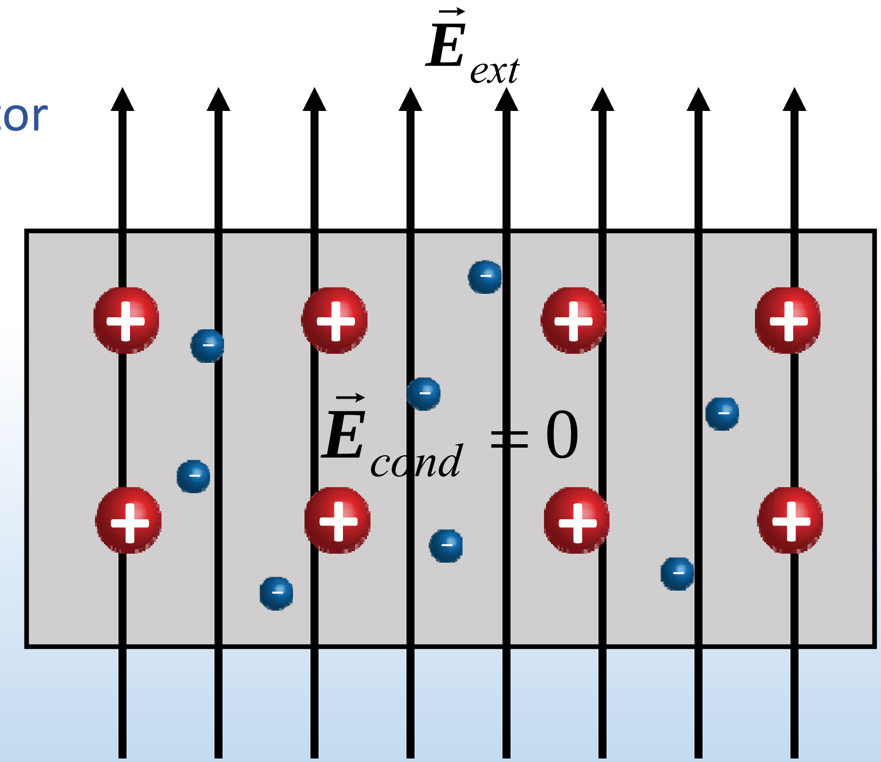
Imagine placing a conductor inside a uniform external E field

Charges are free to move in a conductor

Electrons move due to electric force until they feel no more force (***F*** = 0)

$$\vec{E}_{cond} = \frac{\vec{F}}{q} = 0$$

True everywhere inside conductor



Conductors & electric fields

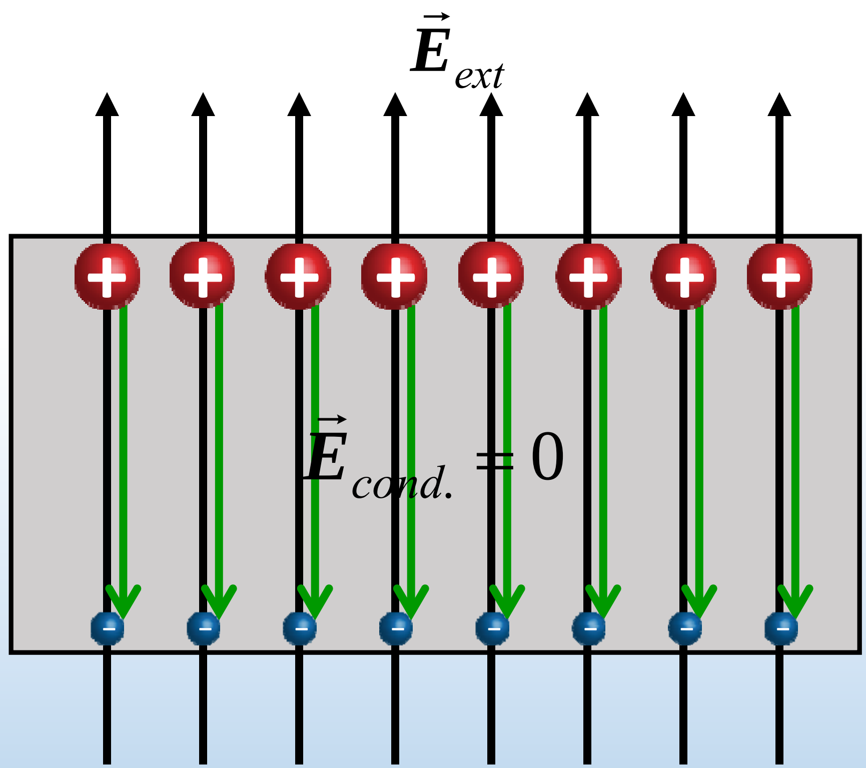
Imagine placing a conductor inside a uniform external E field

Another way to look at it:

–*Q* moves to the bottom surface
leaving excess +*Q* on top surface

Parallel planes of +*Q* and –*Q*
create own E field, cancel out external E field

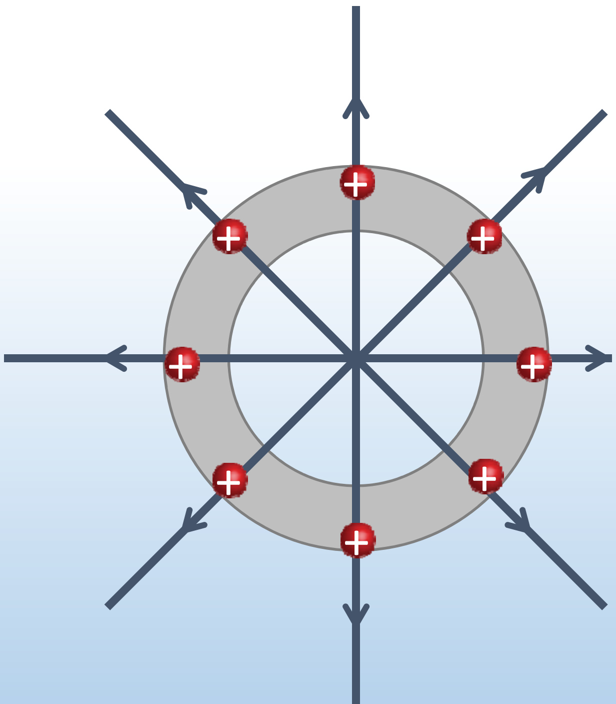
$$\vec{E}_{cond} = \vec{E}_{ext} + \vec{E}_{charges} = 0$$



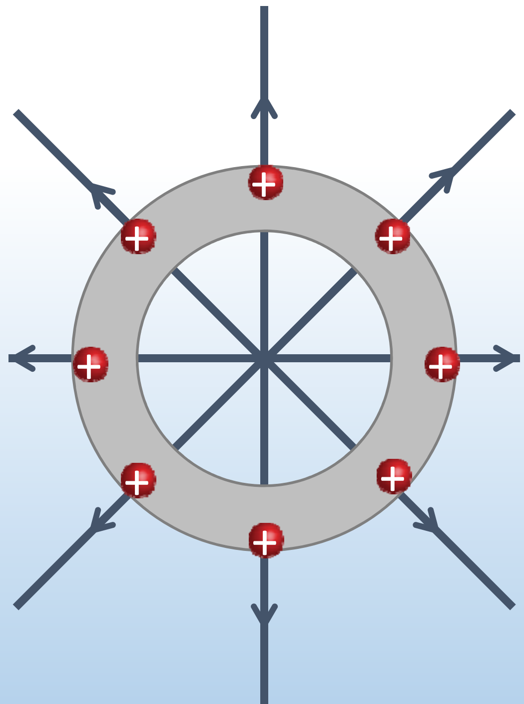
True for *electrostatic equilibrium*
We'll see exception to this later in semester

ACT: Conductor & E field

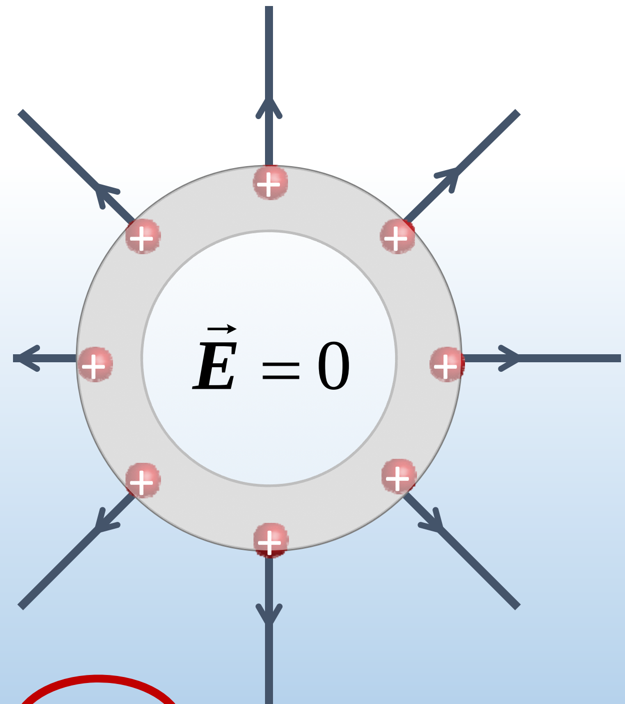
Which diagram best represents the *E* field around a positively charged conducting spherical shell?



A.



B.



C.

Summary of today's lecture

- Electric fields

  Electric field lines

- Superposition principle $\vec{E}_{tot} = \sum \vec{E}$

  Dipole, line, plane

- Dipoles & electric fields
- Conductors & electric fields $\vec{E}_{cond.} = 0$