

Quick Announcements

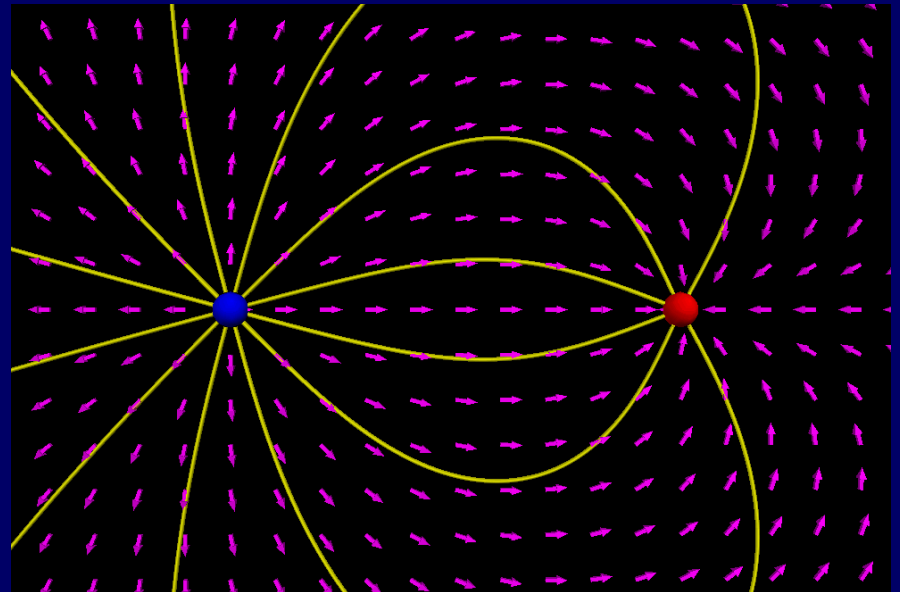
- iClickers
 - Check gradebook for iClicker scores
 - Register on gradebook (takes up to 24 hours)
 - Frequency set to “AA”
- Lab manuals now available at bookstore
- Not getting course emails?
 - Check @illinois account

Physics 102: Lecture 02

Coulomb's Law and Electric Fields

Today we will ...

- get some practice using Coulomb's Law
- learn the concept of an Electric Field



Recall Coulomb's Law

Force between charges q_1 and q_2 separated distance r :

Magnitude

$$F = k \frac{|q_1||q_2|}{r^2} \geq 0$$

“Coulomb constant”

$$k = 9 \times 10^9 \text{ Nm}^2/\text{C}^2$$

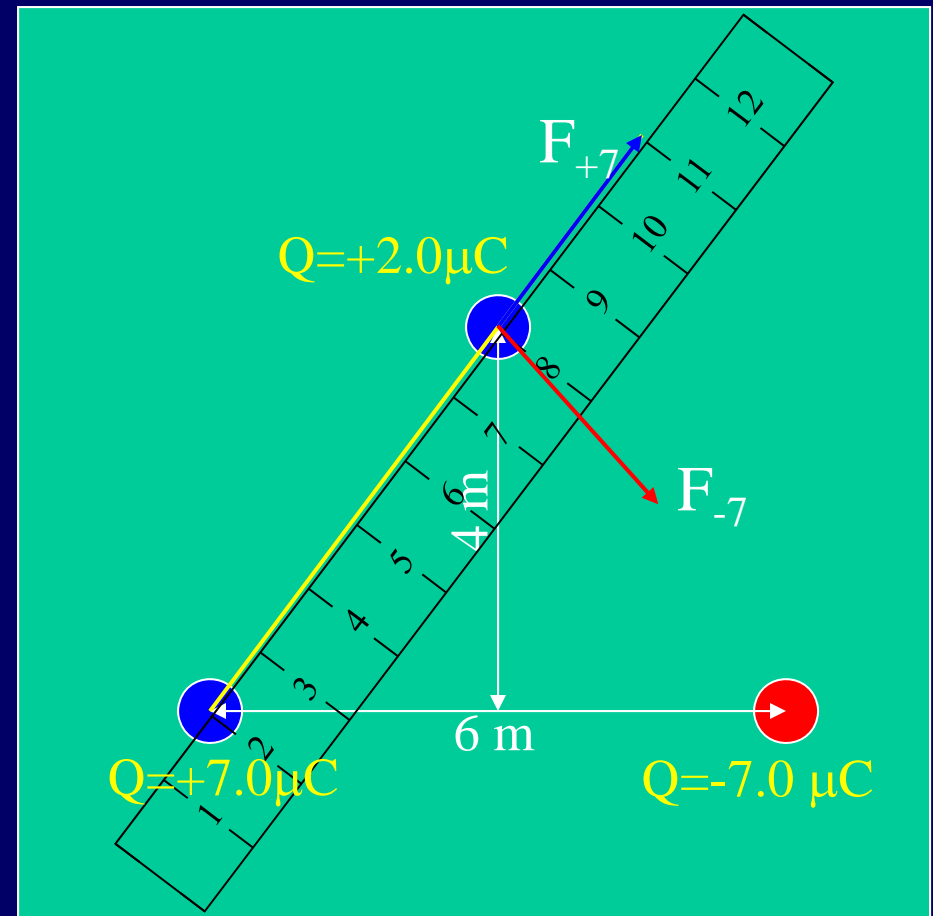
Direction

Opposite charges attract, like charges repel

Example

Coulomb Law practice: Three Charges

- Calculate force on $+2\mu\text{C}$ charge due to other two charges
 - Draw forces
 - Calculate force from $+7\mu\text{C}$ charge
 - Calculate force from $-7\mu\text{C}$ charge
 - Add (VECTORS!)



Example

Three Charges – Calculate forces

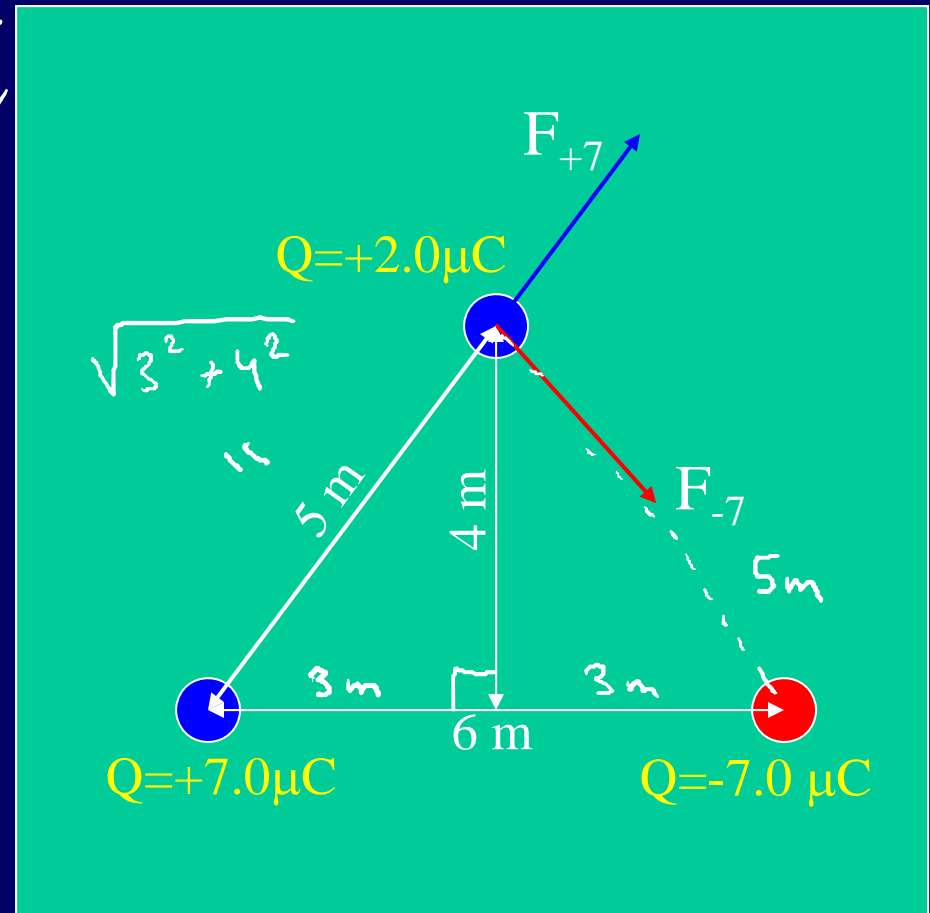
- Calculate force on $+2\mu\text{C}$ charge due to other two charges

- Draw forces ✓
- Calculate force from $+7\mu\text{C}$ charge ✓
- Calculate force from $-7\mu\text{C}$ charge ✓
- Add (VECTORS!)

- Calculate magnitudes $F = k \frac{q_1 q_2}{r^2}$

$$F_{+7} = 9 \times 10^9 \frac{|2 \times 10^{-6}| |7 \times 10^{-6}|}{5^2}$$
$$= 5 \times 10^{-3} \text{ N}$$

$$F_{-7} = 9 \times 10^9 \frac{|2 \times 10^{-6}| |-7 \times 10^{-6}|}{5^2}$$
$$= 5 \times 10^{-3} \text{ N}$$



Example

Three charges – Adding Vectors $F_{+7} + F_{-7}$

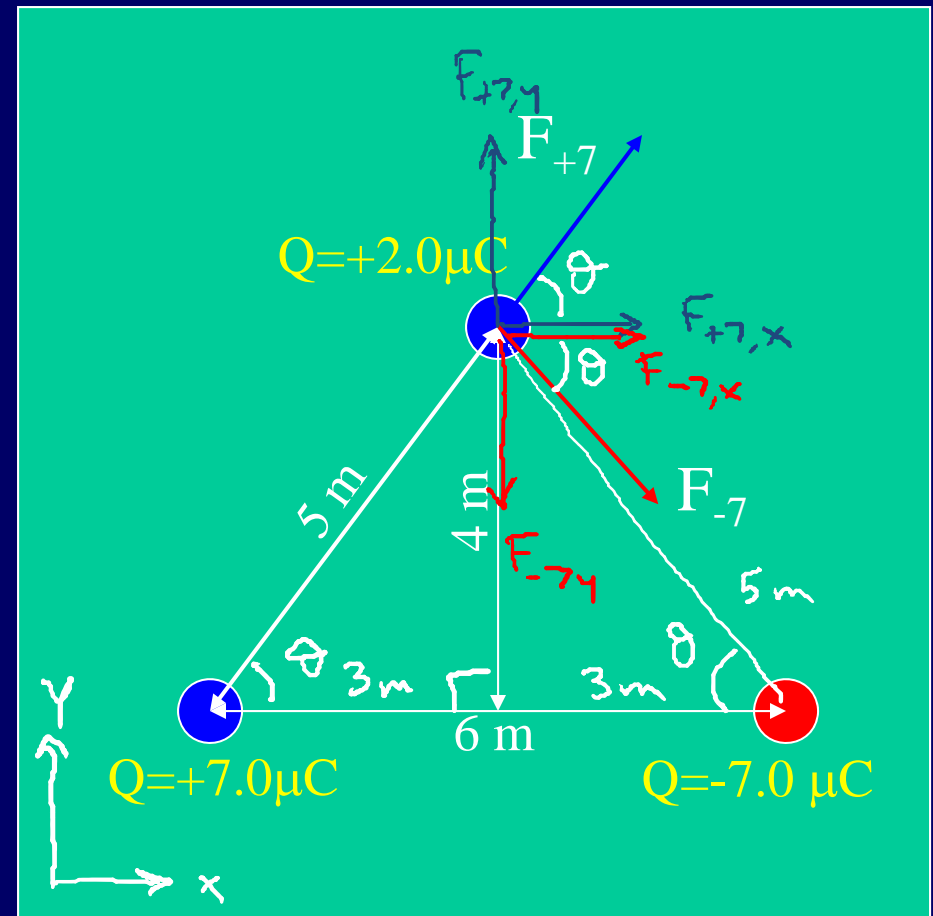
- Calculate components of vectors F_{+7} and F_{-7} :

$$F_{+7,x} = F_{+7} \cos \theta = 5 \times 10^{-3} \text{ N} \frac{3}{5} \\ = 3 \times 10^{-3} \text{ N}$$

$$F_{+7,y} = F_{+7} \sin \theta = 5 \times 10^{-3} \text{ N} \frac{4}{5} \\ = 4 \times 10^{-3} \text{ N}$$

$$F_{-7,x} = F_{-7} \cos \theta = 5 \times 10^{-3} \text{ N} \frac{3}{5} \\ = 3 \times 10^{-3} \text{ N}$$

$$F_{-7,y} = -F_{-7} \sin \theta = -5 \times 10^{-3} \text{ N} \frac{4}{5} \\ = -4 \times 10^{-3} \text{ N}$$



Example

Three charges – Adding Vectors $F_{+7} + F_{-7}$

- Add like components of vectors F_{+7} and F_{-7} :

$$F_x = F_{+7,x} + F_{-7,x} = 6 \times 10^{-3} N$$

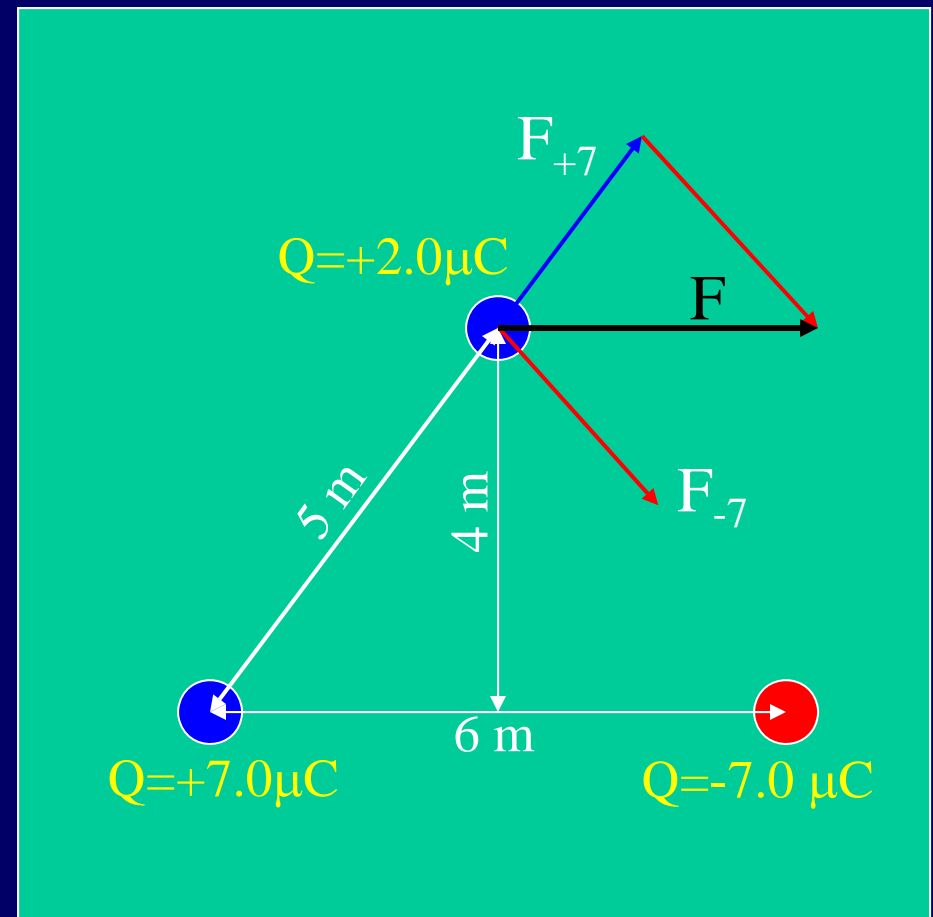
$$F_y = F_{+7,y} + F_{-7,y} = 0$$

- Final vector F has magnitude and direction

$$F = \sqrt{F_x^2 + F_y^2} = 6 \times 10^{-3} N$$

$$\varphi = \tan^{-1} \frac{F_y}{F_x} = 0$$

- Double-check with drawing



Electric Field

- Charged particles create electric fields.

Vectors at a location

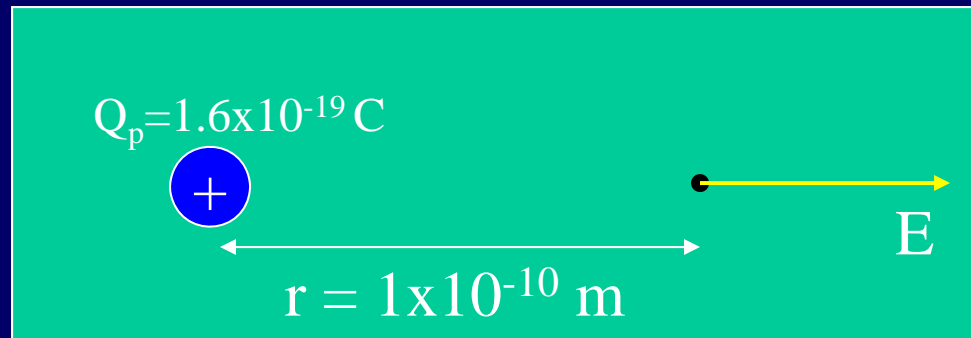
- Direction is the same as for the force that a + charge would feel at that location.

Always true!

- Magnitude given by:

$$E \equiv F/q = kq/r^2$$

Example

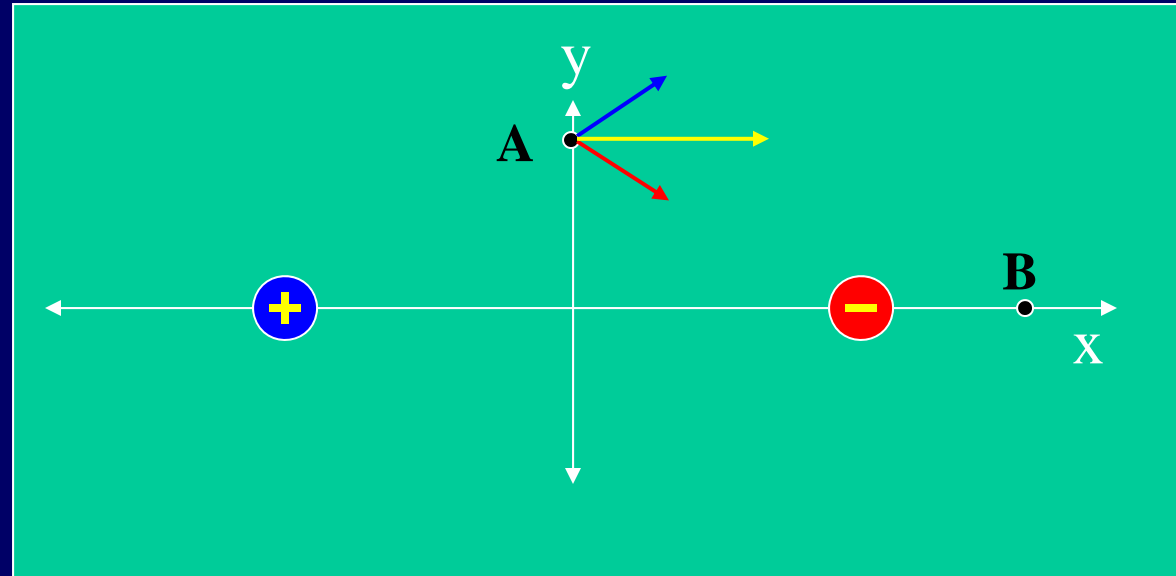


$$E = (9 \times 10^9)(1.6 \times 10^{-19}) / (10^{-10})^2 = 1.4 \times 10^{10} \text{ N/C} \quad (\text{to the right})$$

CheckPoint 2.1

What is the direction of the electric field at point A?

- 4% 1) Up
- 11% 2) Down
- 3% 3) Left
- 44% 4) Right
- 38% 5) Zero





ACT: E Field

What is the direction of the electric field at point C?

A. Left

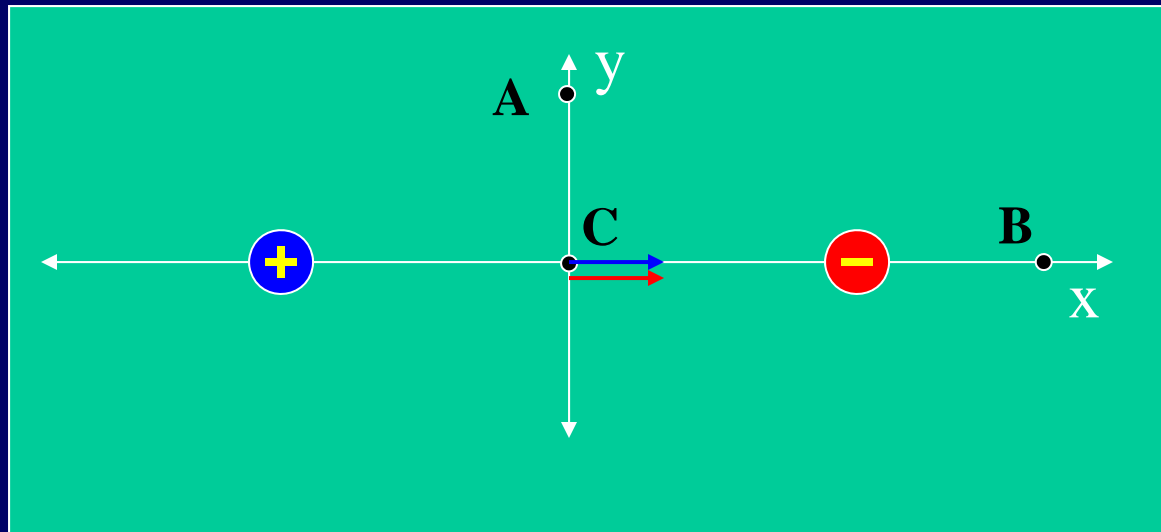
B. Right

C. Zero

Away from positive charge (right)

Towards negative charge (right)

Net E field is to right.



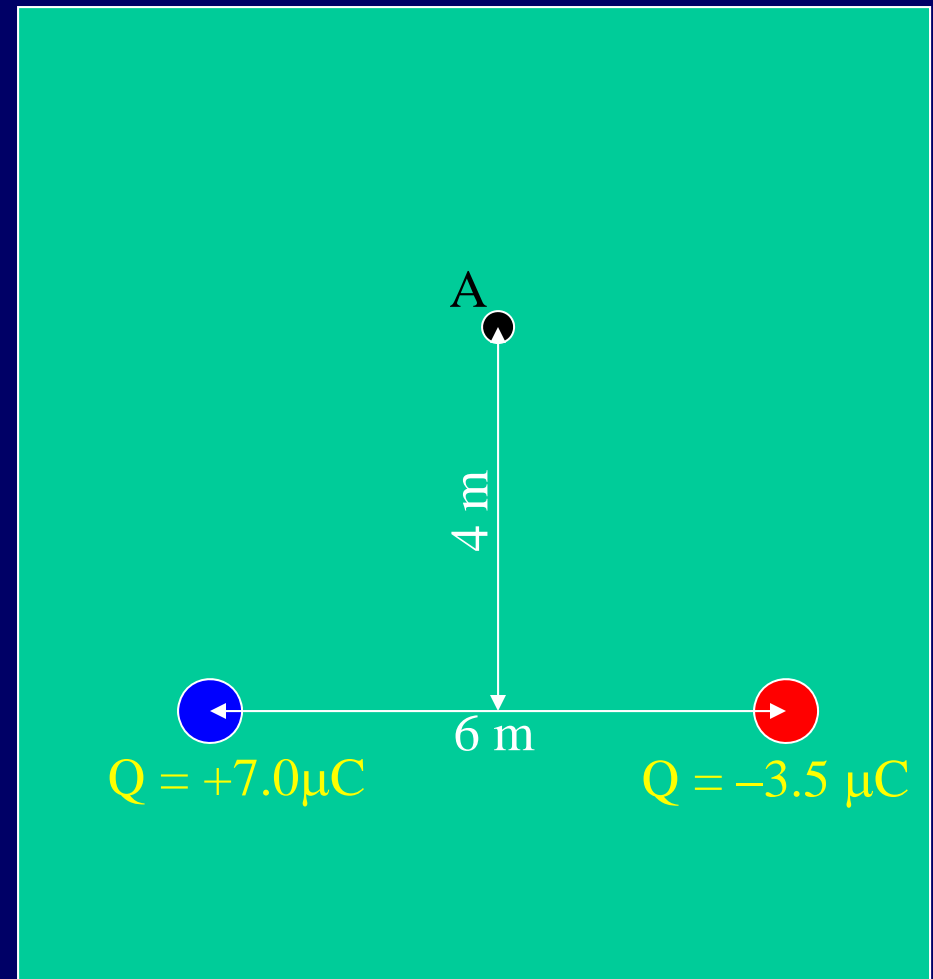
Example

E Field from 2 Charges

- Calculate electric field at point A due to two unequal charges
 - Draw electric fields
 - Calculate E from $+7\mu\text{C}$ charge
 - Calculate E from $-3.5\mu\text{C}$ charge
 - Add (VECTORS!)

Note: this is similar to (but a bit harder than) my earlier example.

We'll do some of this here... you try the rest at home!



Example

E Field from 2 Charges

- Calculate electric field at point A due to charges

- Calculate E from $+7\mu\text{C}$ charge
- Calculate E from $-3.5\mu\text{C}$ charge
- Add*

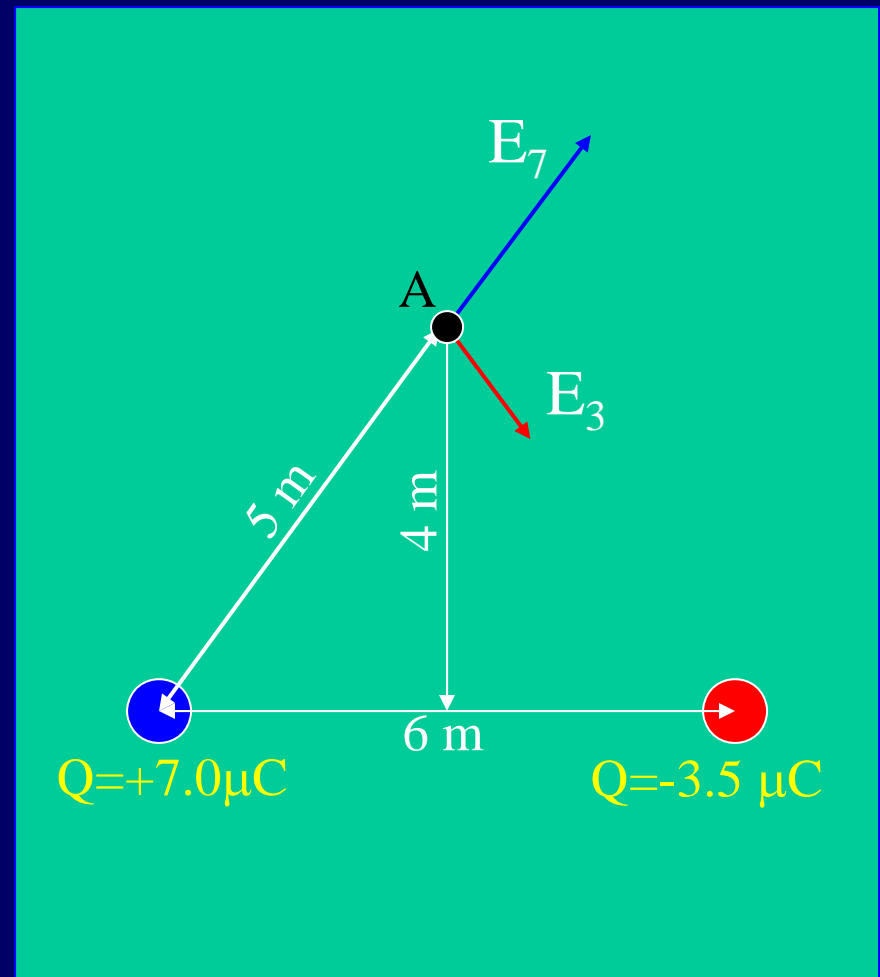
$$E = k q/r^2$$

$$E_7 = \frac{(9 \times 10^9)(7 \times 10^{-6})}{25} \text{ N/C}$$

$$E_7 = 2.5 \times 10^{+3} \text{ N/C}$$

$$E_3 = \frac{(9 \times 10^9)(3.5 \times 10^{-6})}{25} \text{ N/C}$$

$$E_3 = 1.25 \times 10^{+3} \text{ N/C}$$



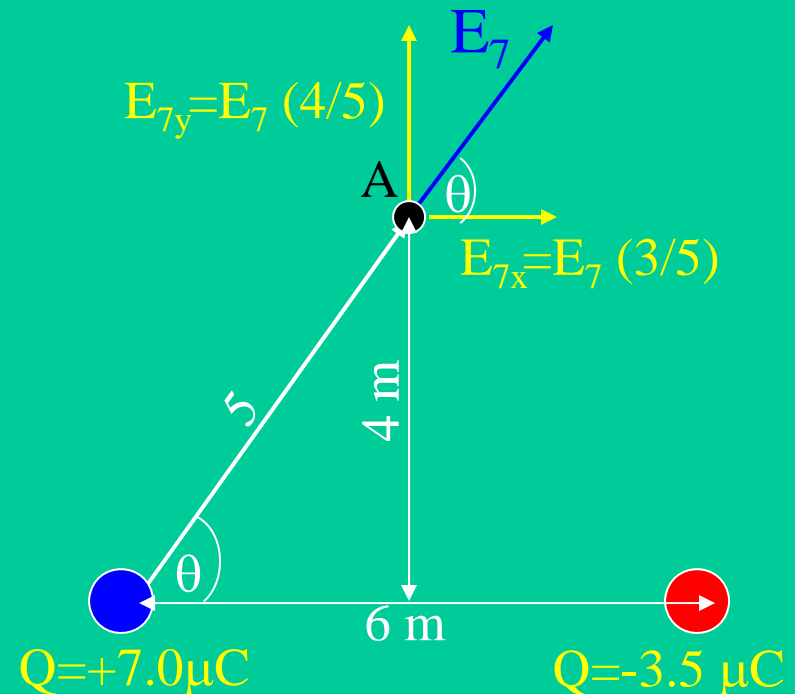
Example

Adding Vectors $E_7 + E_3$

- Decompose into x and y components.

$$E_{7x} = E_7 \cos(\theta) = E_7 \left(\frac{3}{5} \right) \\ = 1.5 \times 10^{+3} \text{ N/C}$$

$$E_{7y} = E_7 \sin(\theta) = E_7 \left(\frac{4}{5} \right) \\ = 2 \times 10^{+3} \text{ N/C}$$



Example

Adding Vectors $E_7 + E_3$

- Decompose into x and y components.
- Add components.

$$E_{7x} = 1.5 \times 10^{+3} \text{ N/C}$$

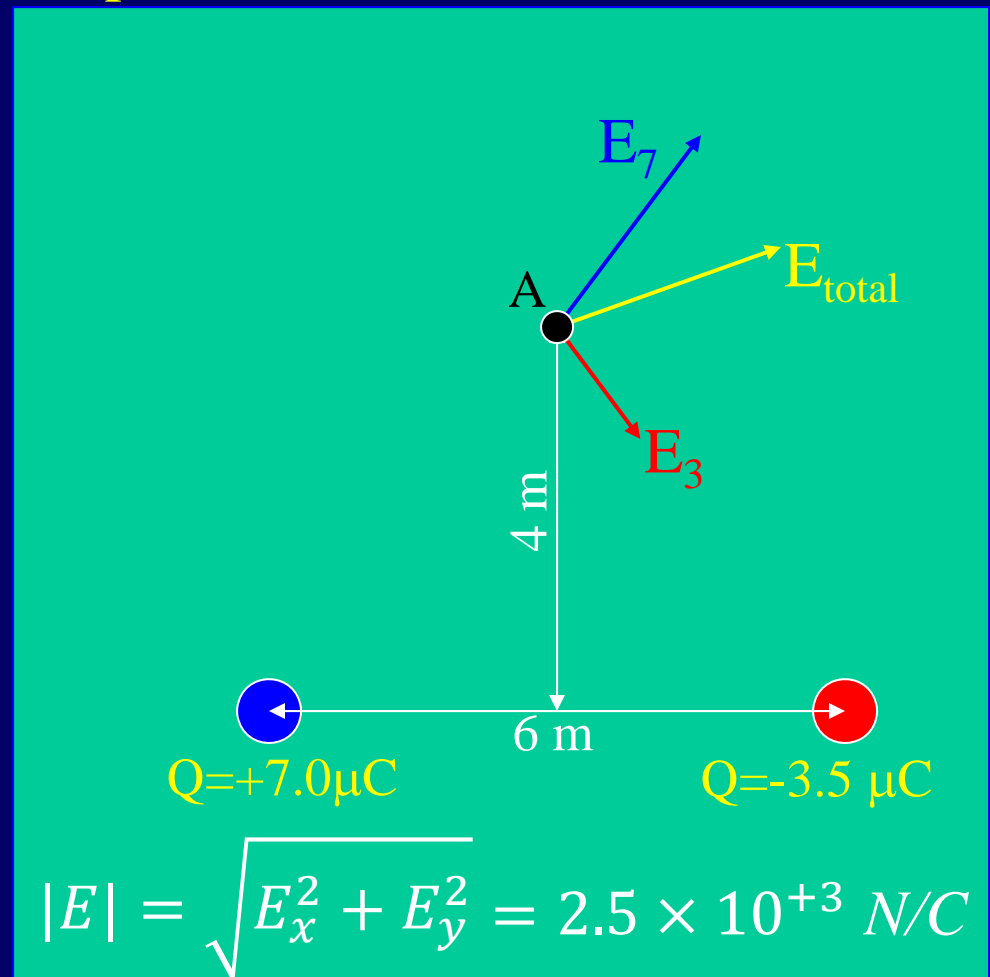
$$E_{3x} = 0.75 \times 10^{+3} \text{ N/C}$$

$$E_{7y} = 2 \times 10^{+3} \text{ N/C}$$

$$E_{3y} = -1 \times 10^{+3} \text{ N/C}$$

$$E_x = 2.25 \times 10^{+3} \text{ N/C}$$

$$E_y = 1.0 \times 10^{+3} \text{ N/C}$$



Comparison:

Electric *Force* vs. Electric *Field*

- Electric Force (F) – the force felt by a charge at some location
- Electric Field (E) – found for a location only (any location) – tells what the electric force *would be* if a + charge were located there:

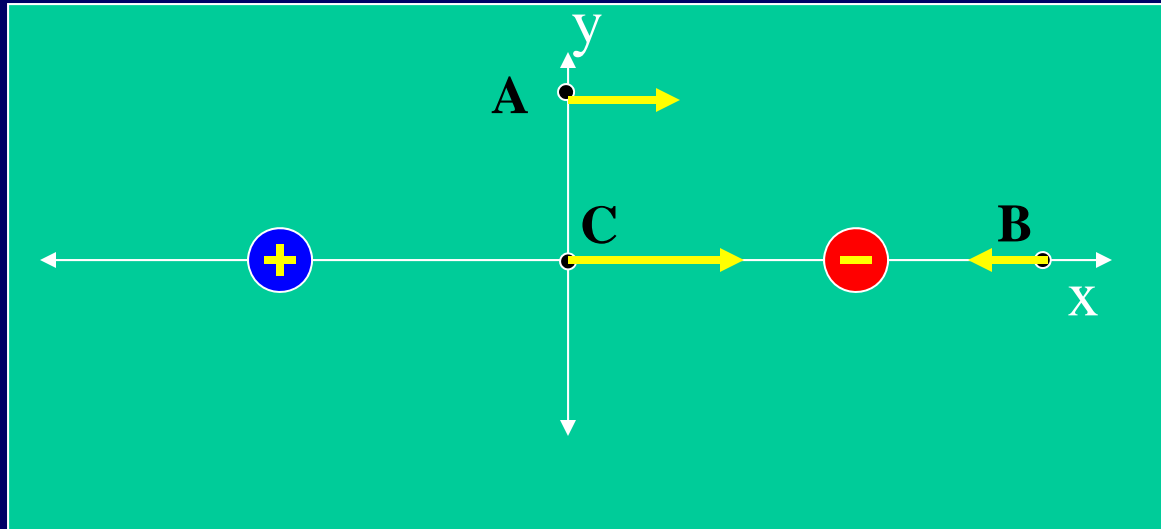
$$F = Eq$$

- Both are vectors, with magnitude and direction.

Ok, what is E actually good for?

Electric Field Map

- Electric field defined at any location

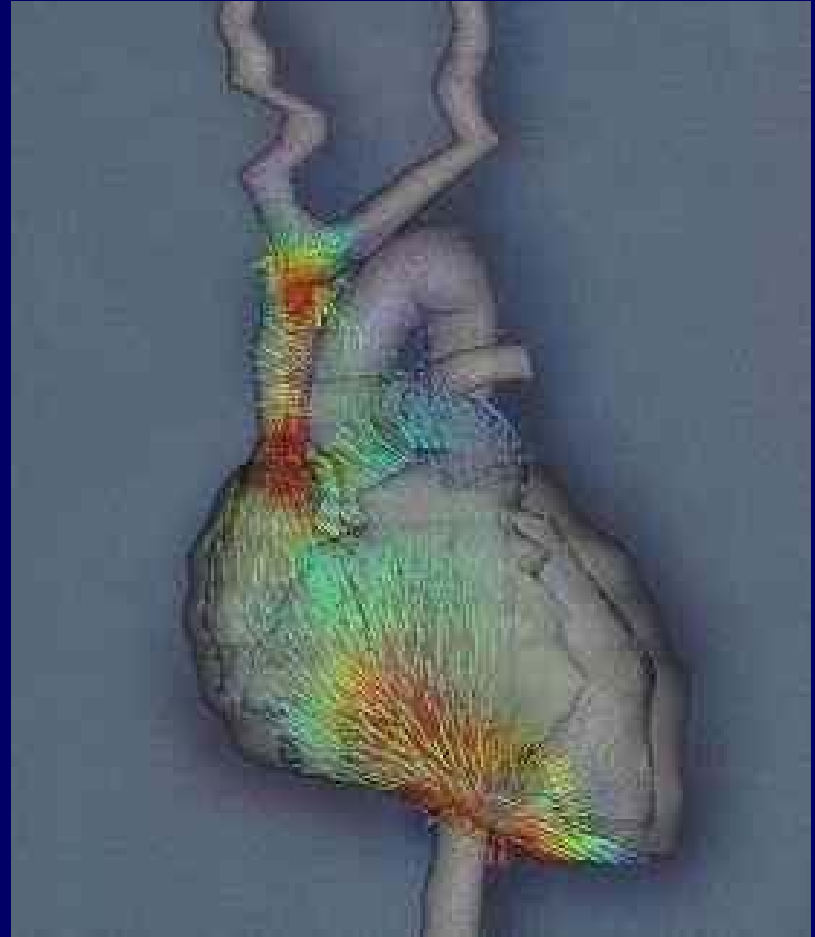


Electric fields:

A useful record-keeping tool!

Calculate once for fixed charges,
use to find force on other charges
(like ions/electrons in neurons,
heart tissue, and cell membranes)

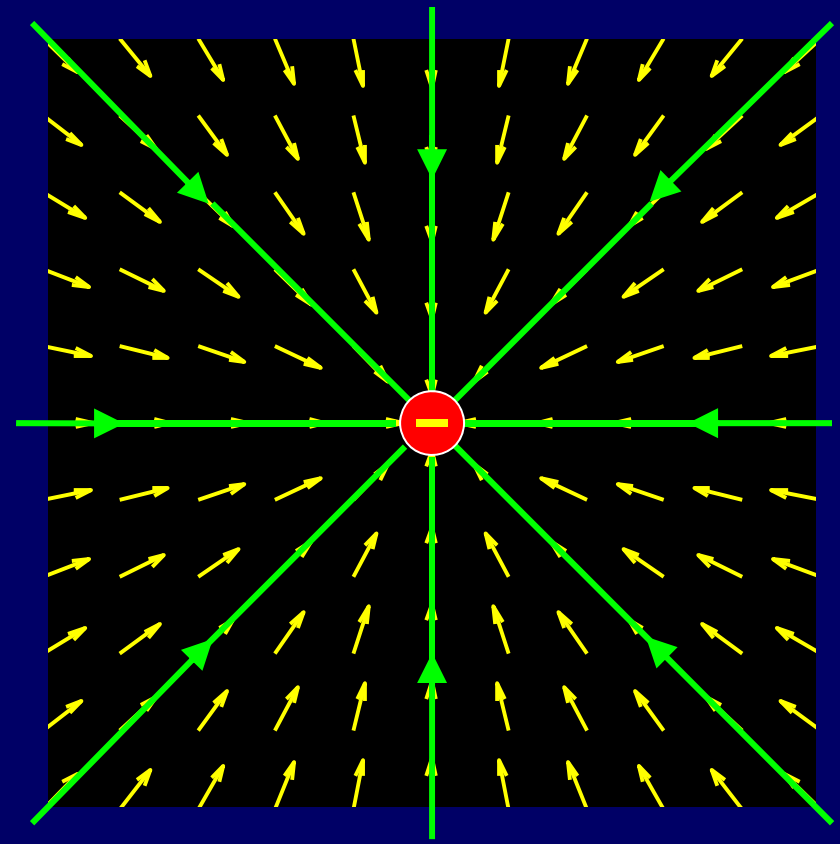
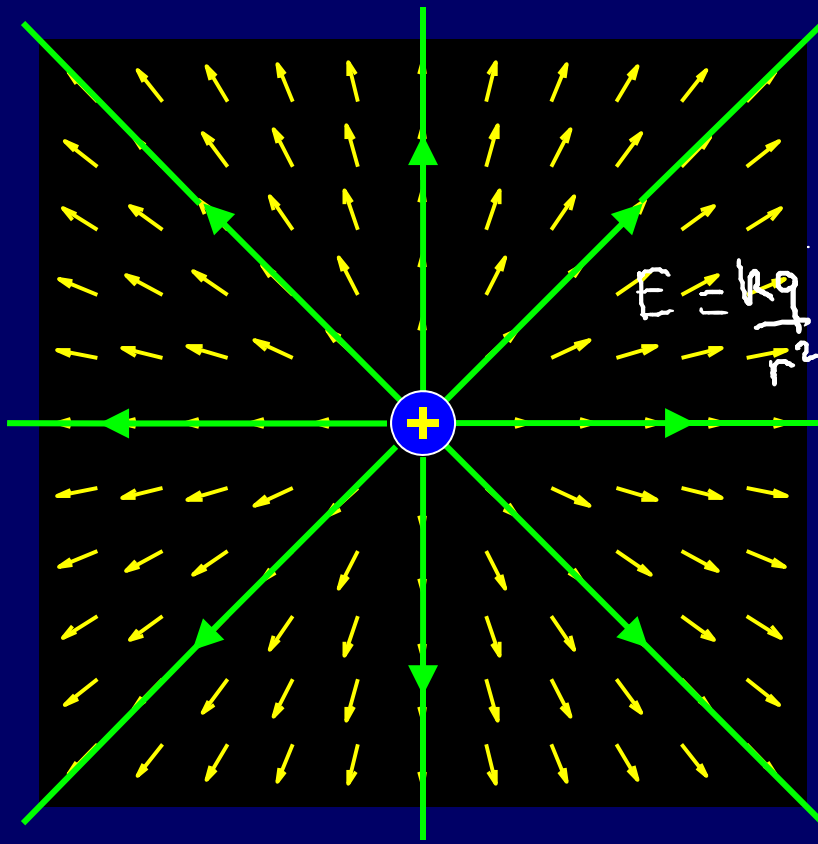
PhET simulation



Eisenberg, BU

Electric Field Lines

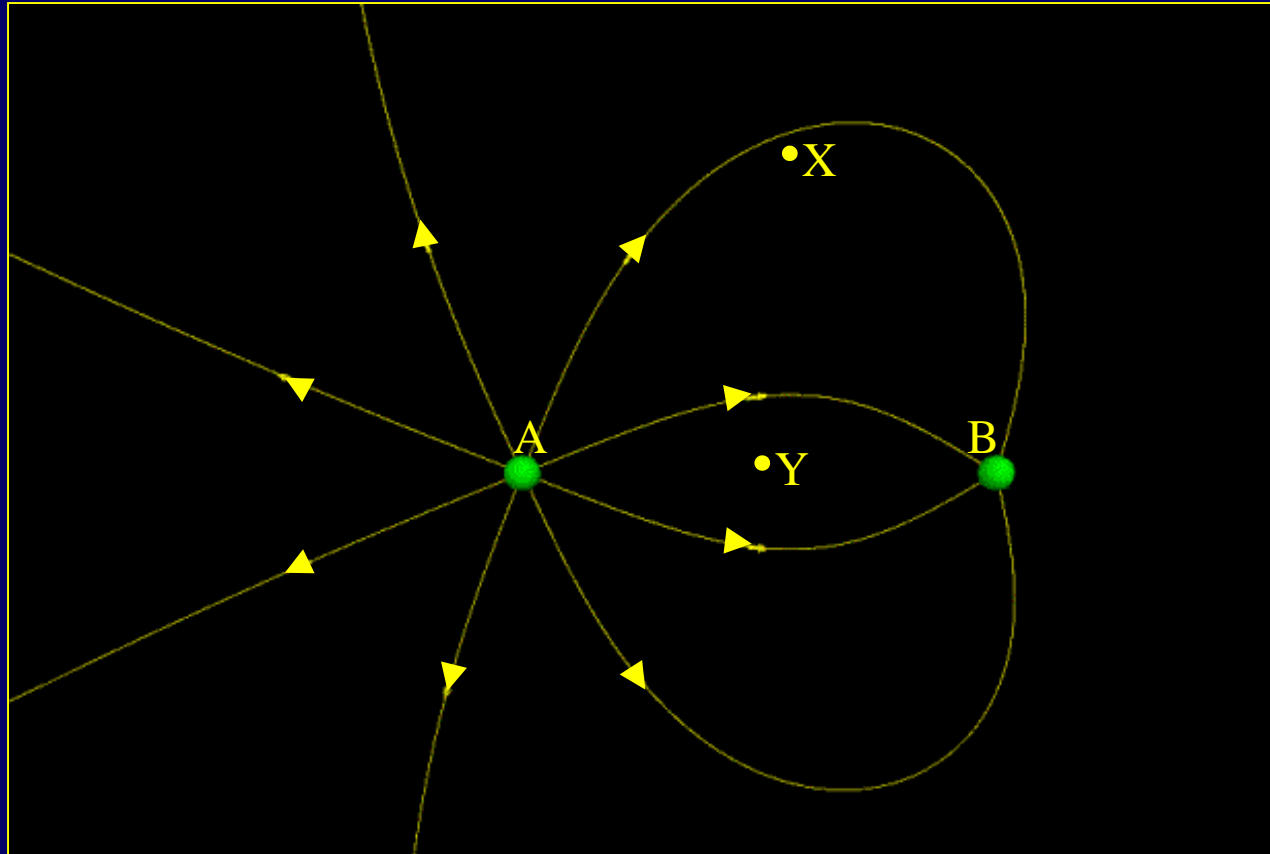
- Closeness of lines shows field strength (lines never cross)
- Number of lines at surface $\propto Q$
- Arrow gives direction of E (Start on +, end on -)



Physics 102: Lecture 2, Slide 18

This is becoming a mess!!!

CheckPoint 3.1



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

1) positive

71%

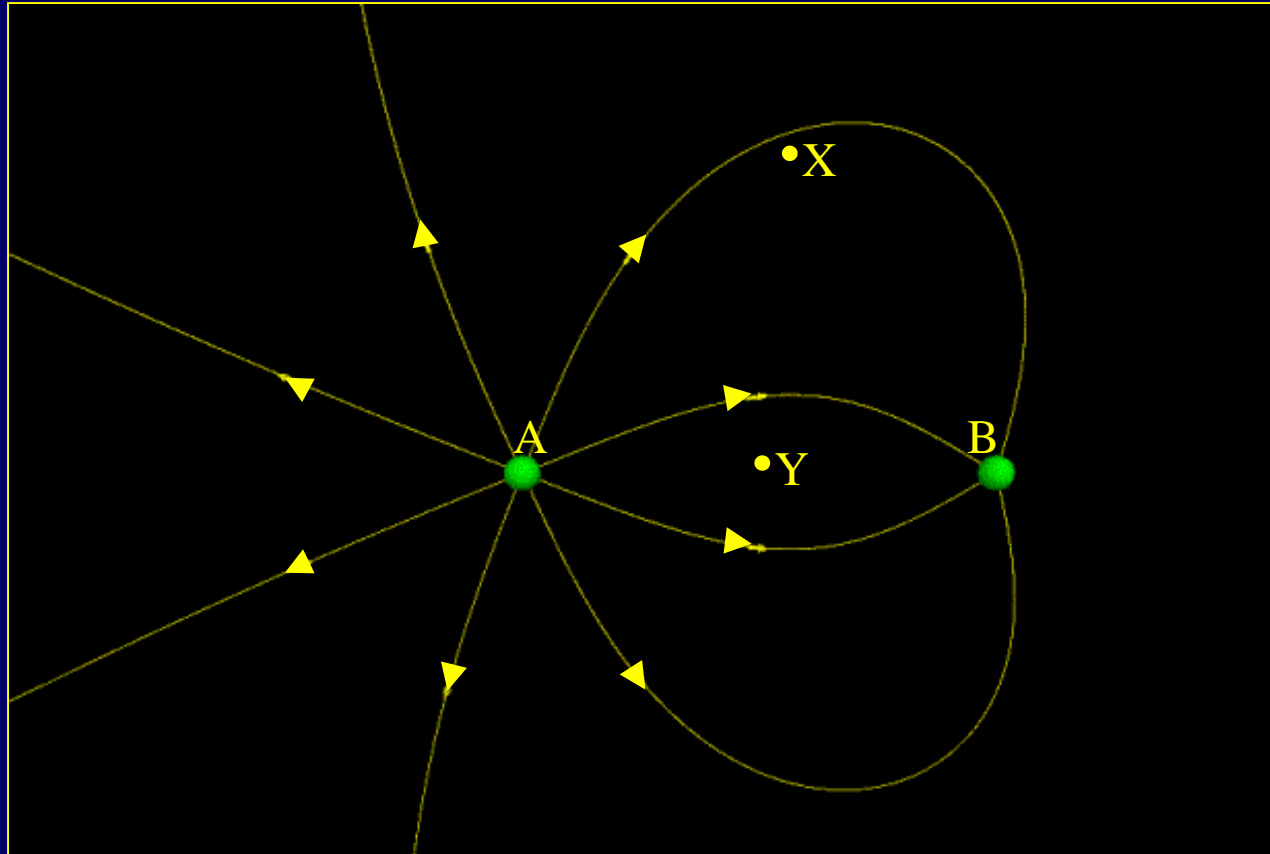
2) negative

8%

3) unknown

21%

CheckPoint 3.2 / ACT



Compare the ratio of charges Q_A / Q_B # lines proportional to Q

A) $Q_A = 0.5Q_B$

16%

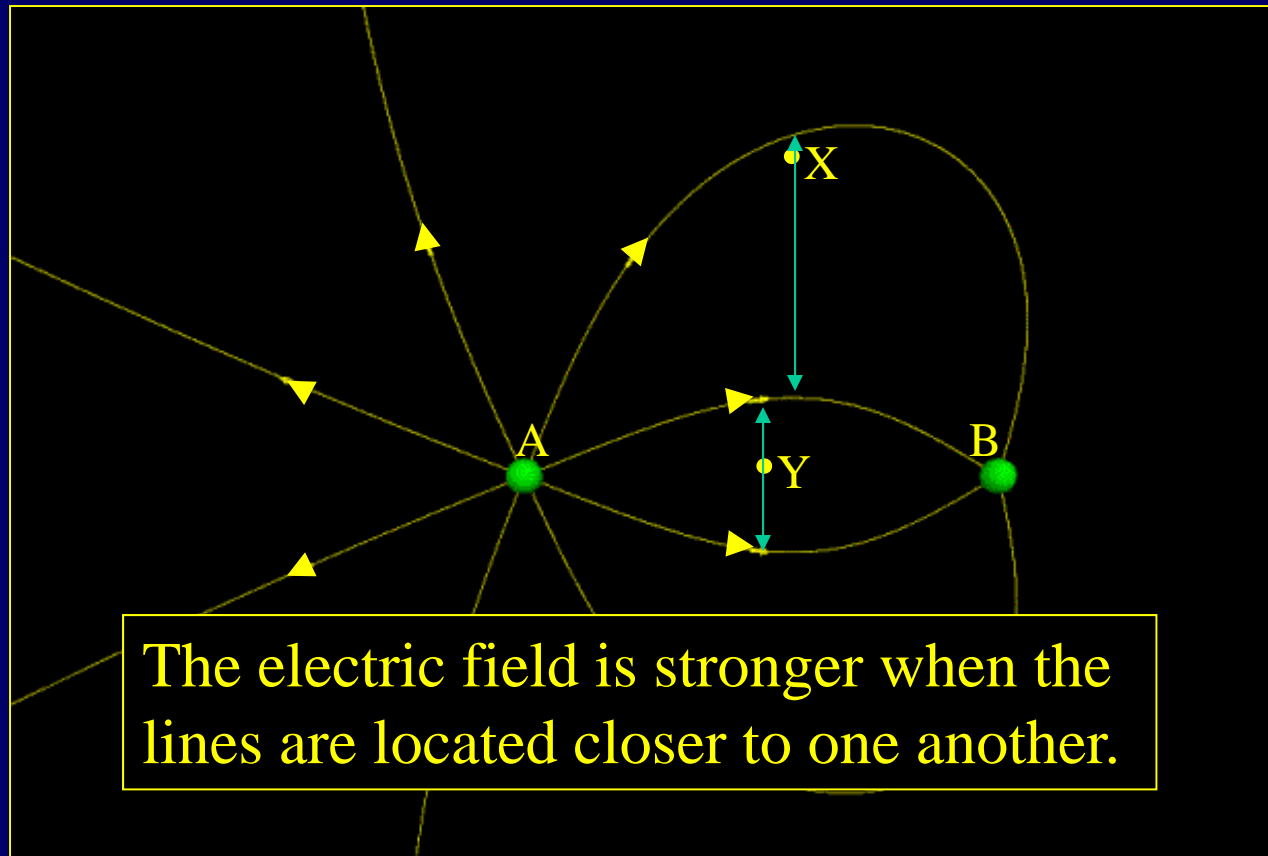
B) $Q_A = Q_B$

15%

C) $Q_A = 2Q_B$

57%

CheckPoint 3.4



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

1) True

19%

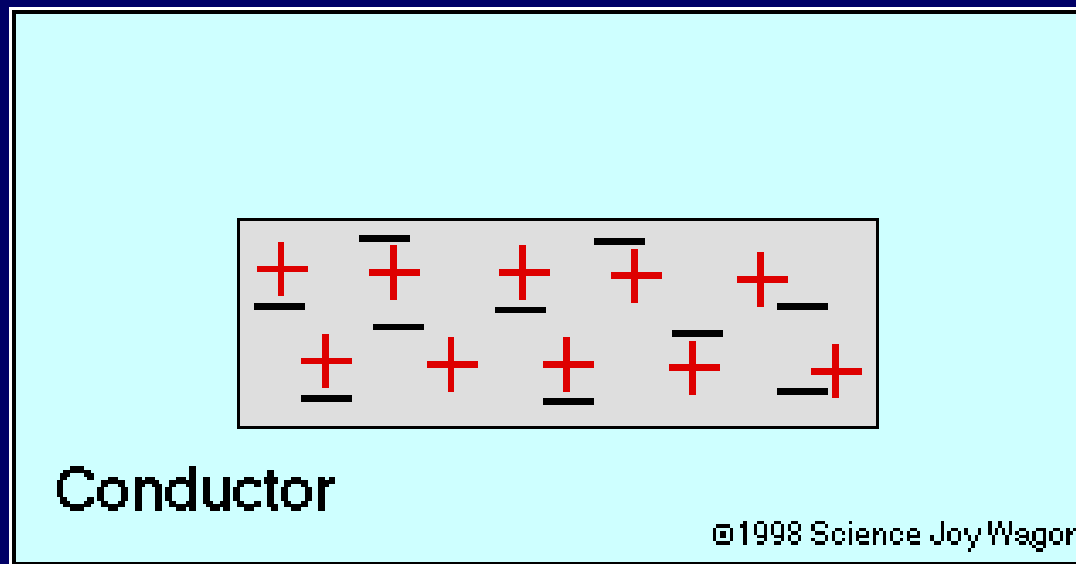
2) False

81%

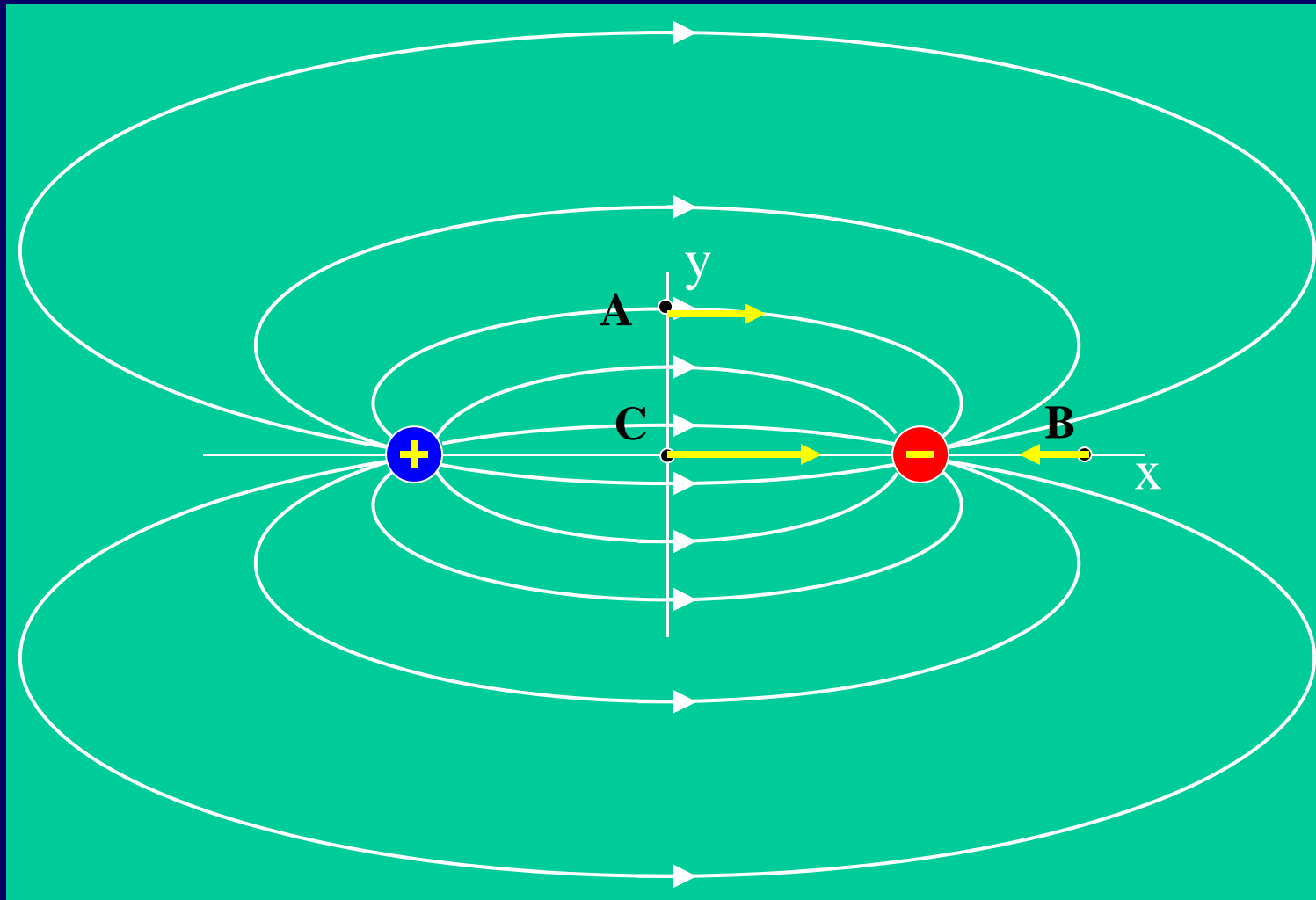
Density of field lines gives E

E inside of conductor

- Conductor \equiv electrons free to move
 - Electrons feel electric force - will move until they feel no more force ($F=0$)
 - $F=Eq$: if $F=0$ then $E=0$
- $E=0$ inside a conductor (Always!)



Demo: E-field from dipole



Recap

- E Field has magnitude and direction:
 - $E \equiv F/q$
 - Calculate just like Coulomb's law
 - Careful when adding vectors
- Electric Field Lines
 - Density gives strength (# proportional to charge.)
 - Arrow gives direction (Start + end on –)
- Conductors
 - Electrons free to move $\Rightarrow E = 0$

To Do

- Campus closed on Monday; no office hours.
- Homework 1 due Wednesday, Sept. 4 @ 8 AM!
- Do your Checkpoint by 8:00 AM Wednesday.