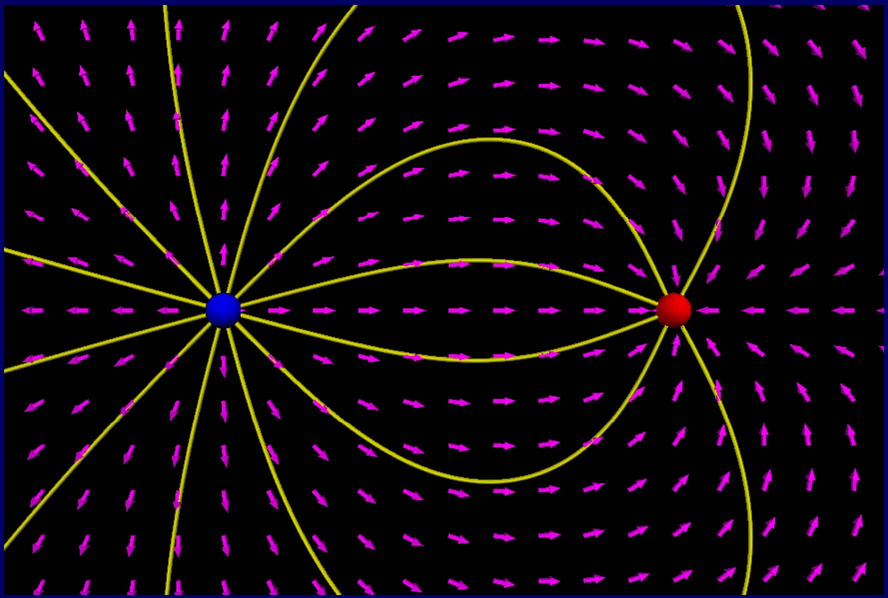
# Physics 102: Lecture 02

# 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

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

"Coulomb constant"
$k = 9 \times 10^9 Nm^2/C^2$

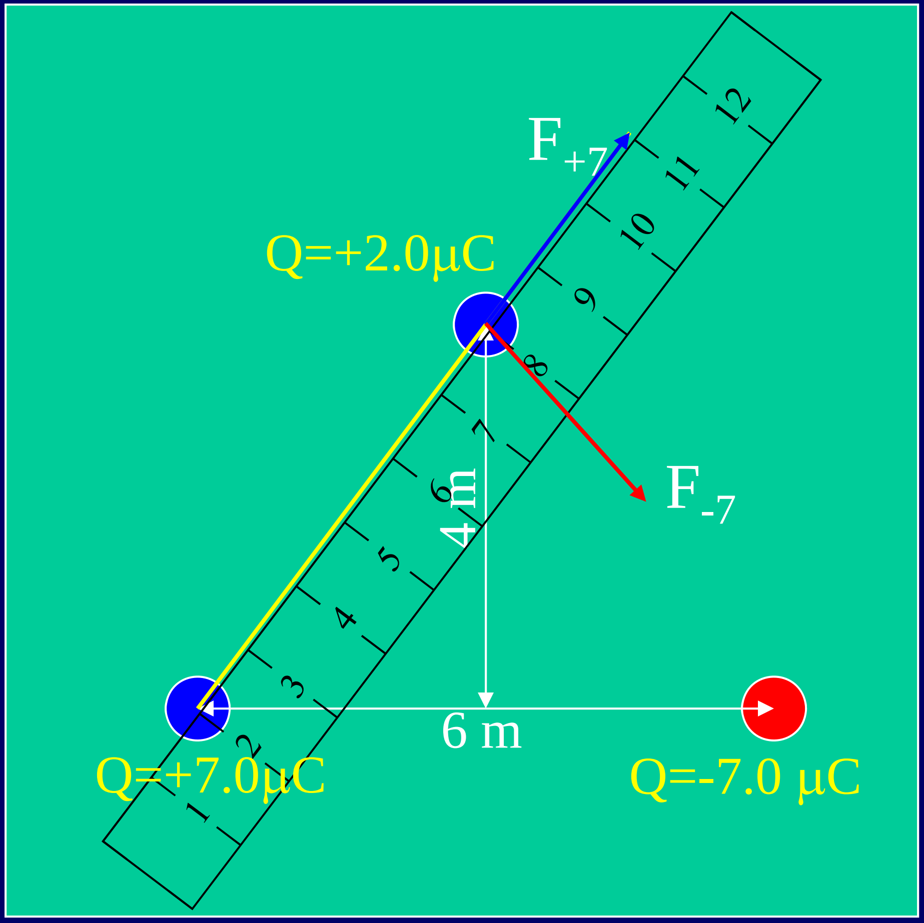
Direction

Opposite charges attract, like charges repel

Example

# Coulomb Law practice: Three Charges

- Calculate force on +2μC charge due to other two charges
  - Draw forces
  - Calculate force from +7μC charge
  - Calculate force from –7μC charge
  - Add (VECTORS!)



Example

# Three Charges – Calculate forces

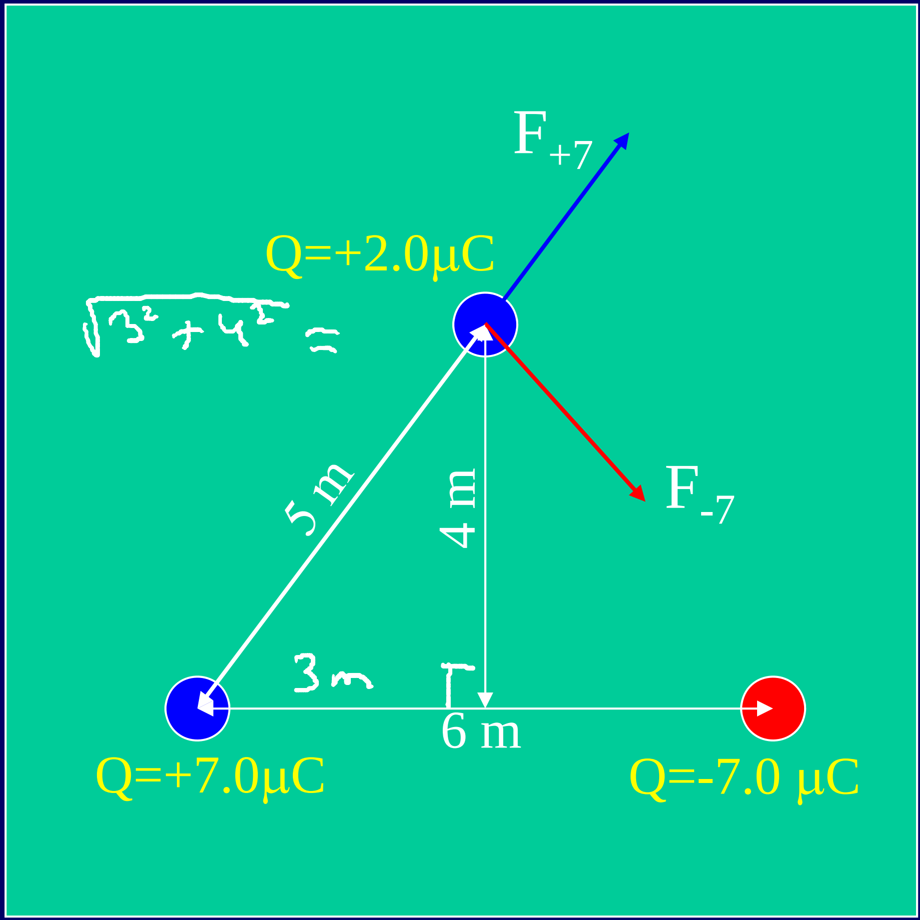
- Calculate force on +2μC charge due to other two charges
  - Draw forces
  - Calculate force from +7μC charge
  - Calculate force from –7μC charge
  - Add (VECTORS!)
- Calculate magnitudes $F = k\frac{q_1 q_2}{r^2}$

ALWAYS ≥0

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

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

$$= 5 \times 10^{-3} N$$



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

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

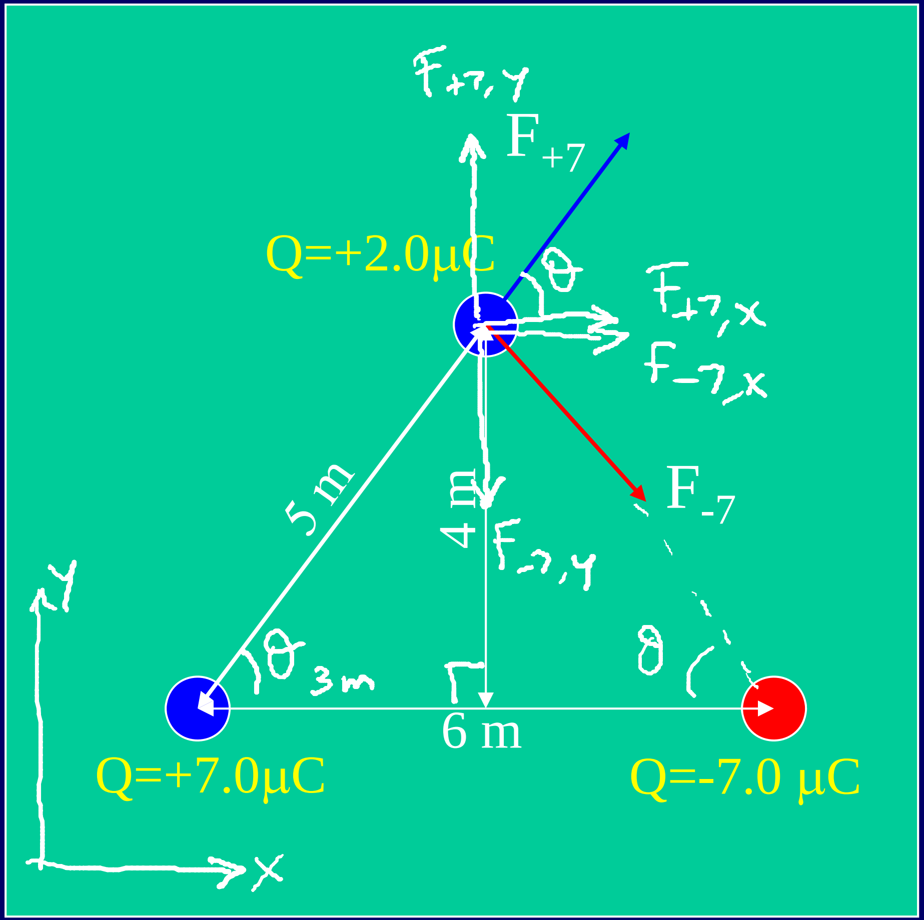
$$F_{+7,x} = F_{+7}\cos\theta = 5\times10^{-3}N\frac{3}{5}$$
$$= 3\times10^{-3}N$$

$$F_{+7,y} = F_{+7}\sin\theta = 5\times10^{-3}N\frac{4}{5}$$
$$= 4\times10^{-3}N$$

$$F_{-7,x} = F_{-7}\cos\theta = 5\times10^{-3}N\frac{3}{5}$$

$$F_{-7,y} = -F_{-7}\sin\theta = -5\times10^{-3}N\frac{4}{5}$$

Watch Signs !



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

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

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

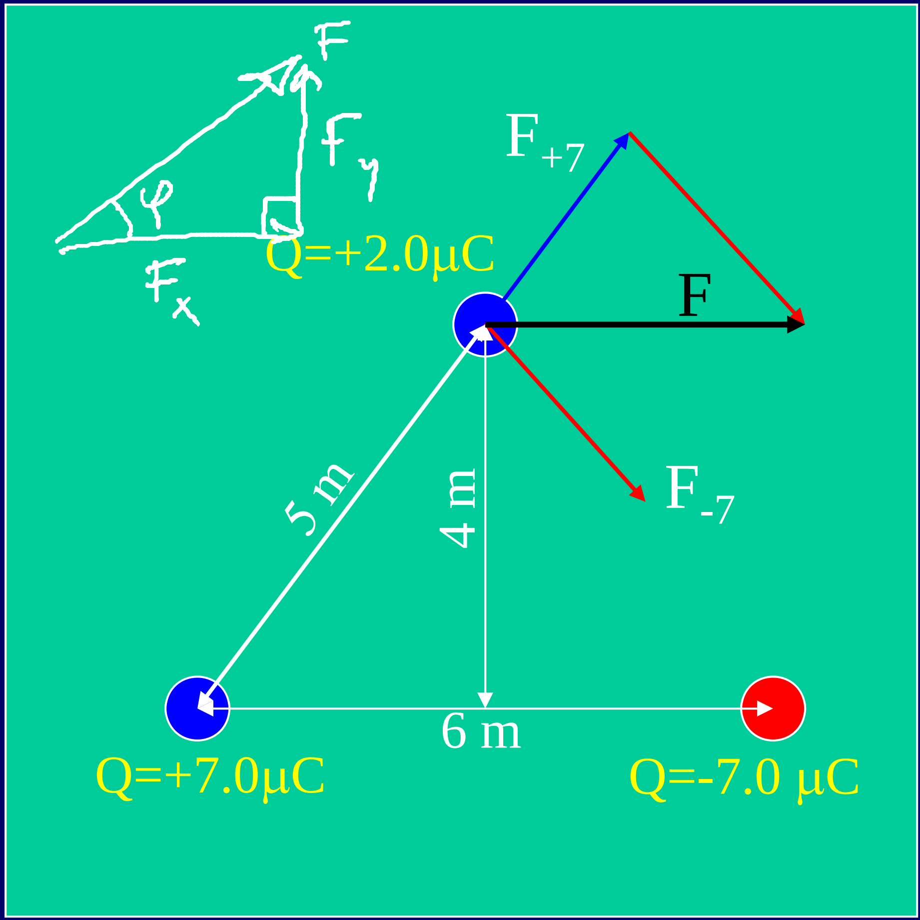
$$F_y = F_{+7,y} + F_{-7,y} = 0$$

- 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

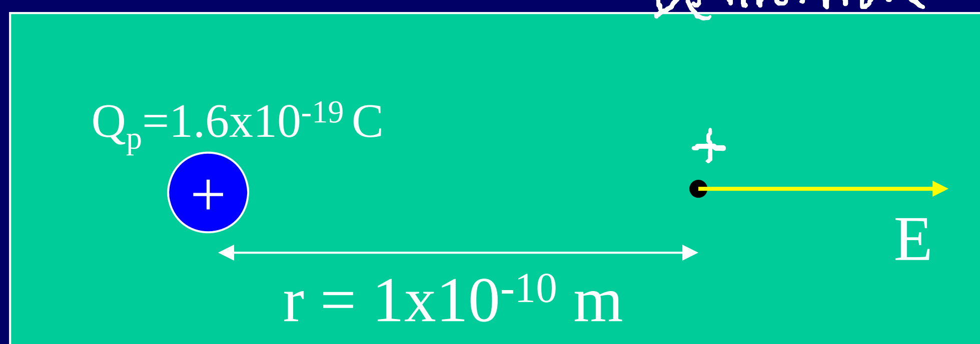


# Electric Field

- Charged particles create electric fields. vector defined at every pt. in space
  - Direction is the same as for the force that a + charge *would feel* at that location.
  - Magnitude given by: $\boxed{E \equiv F/q = kq/r^2}$

Definition　　　For a pt. charge

Example




$E = (9\times10^9)(1.6\times10^{-19})/(10^{-10})^2$ N $= 1.4\times10^{11}$ N/C (to the right)

Units

# CheckPoint 2.1

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

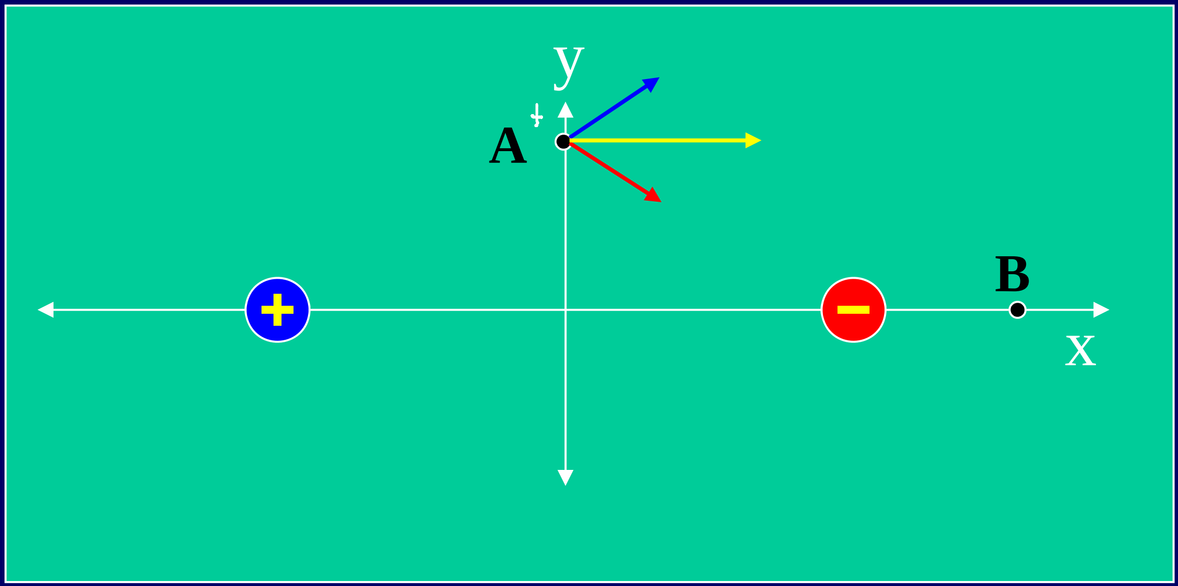
7% 1) Up

7% 2) Down

2% 3) Left

53% 4) Right

32% 5) Zero



# ACT: E Field

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

A. Left

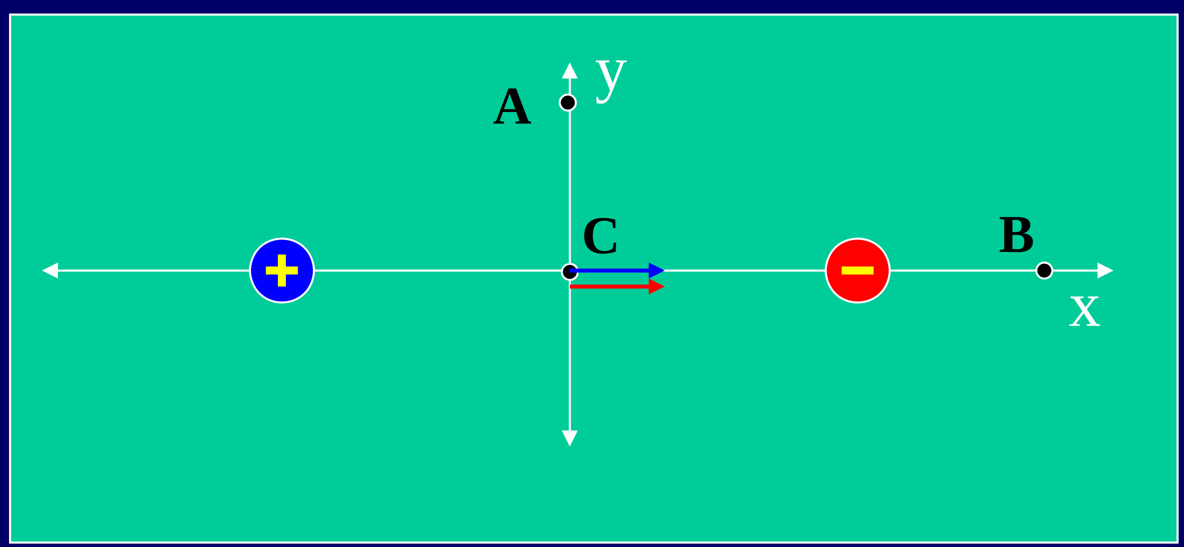
B. Right

C. Zero

Away from positive charge (right)

Towards negative charge (right)

Net E field is to right.



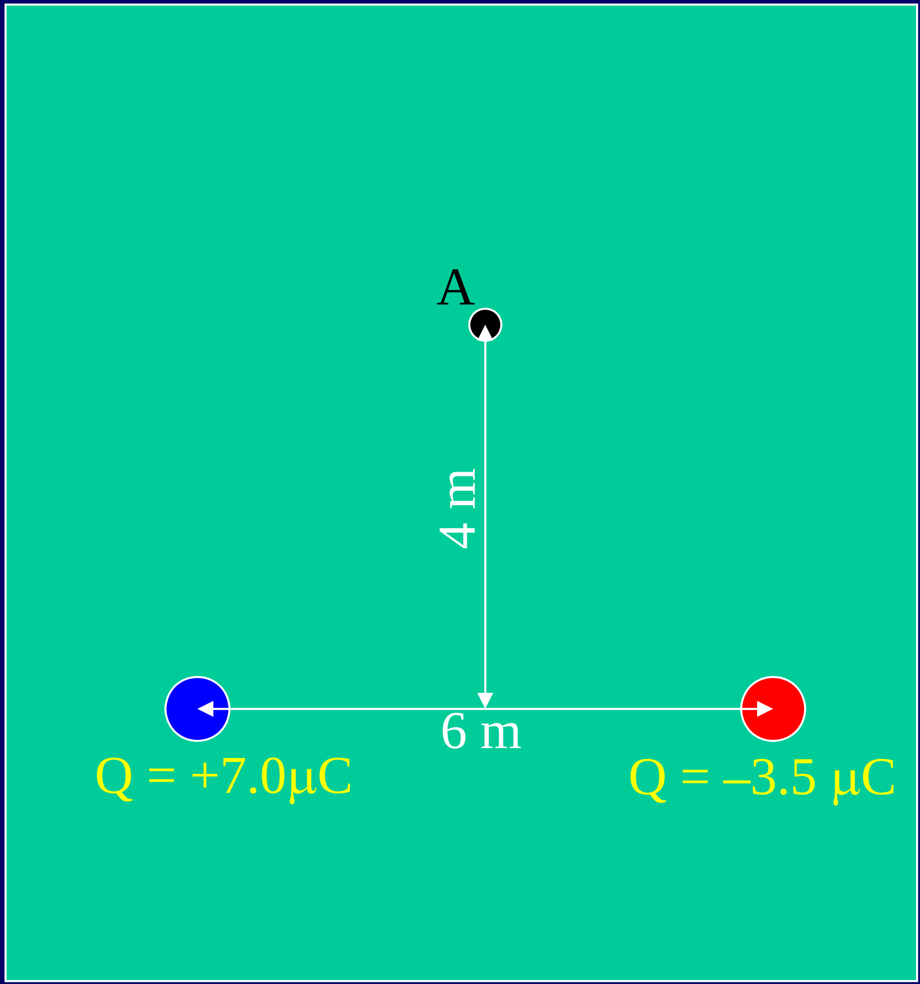
Example

# E Field from 2 Charges

- Calculate electric field at point A due to two unequal charges
  - Draw electric fields
  - Calculate E from +7μC charge
  - Calculate E from –3.5μC charge
  - Add (VECTORS!)

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

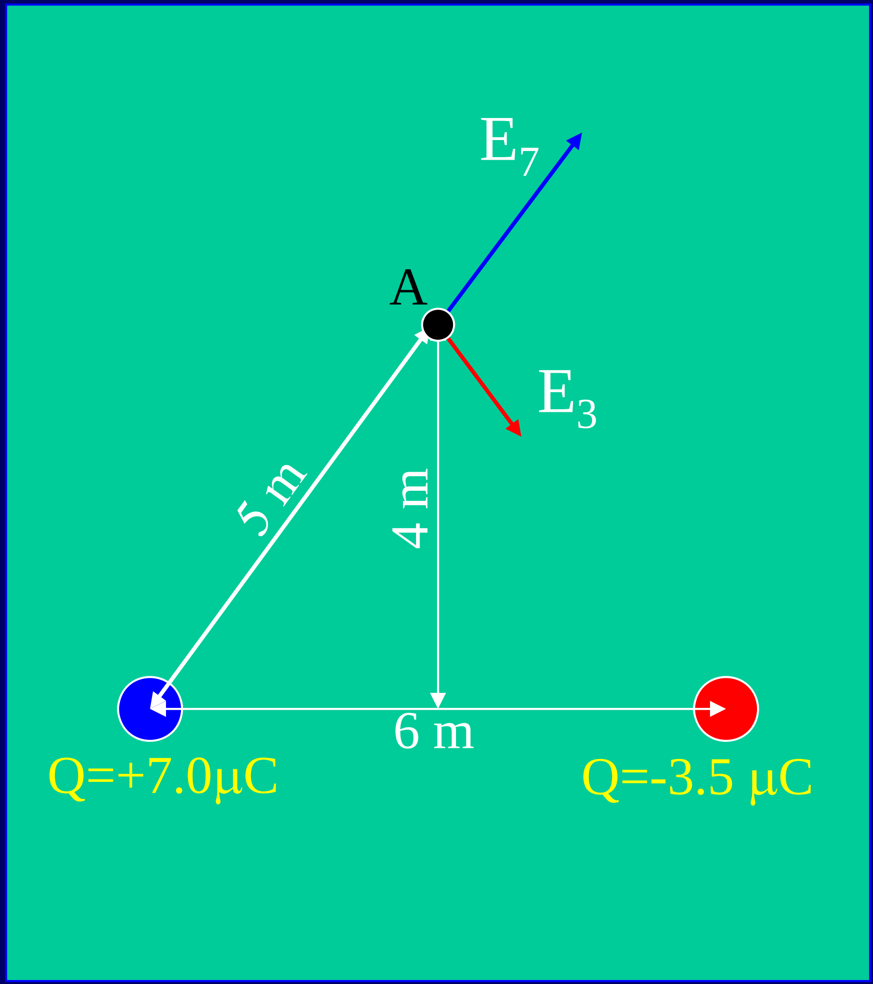
We'll do some of this here… you try the rest at home!



Example

# E Field from 2 Charges

- Calculate electric field at point A due to charges
  - Calculate E from +7μC charge
  - Calculate E from –3.5μC charge
  - Add*




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

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

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

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

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

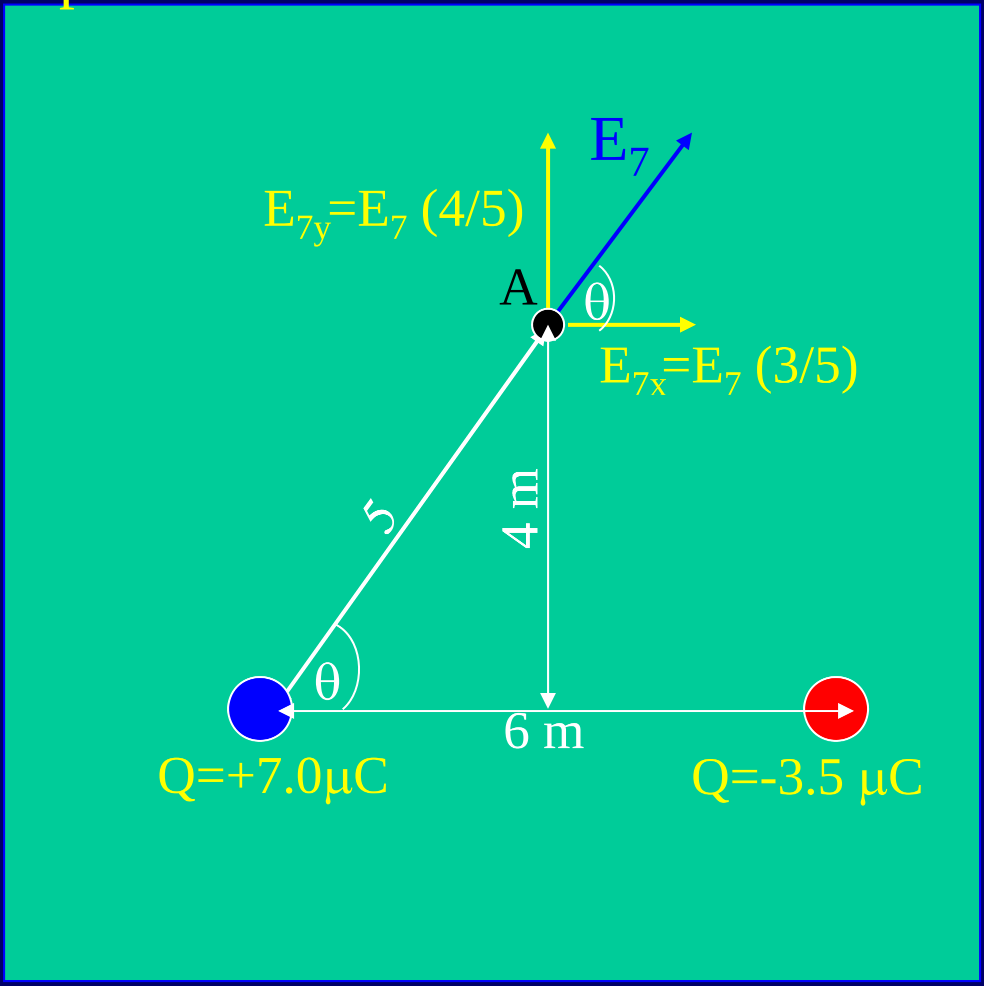
# Adding Vectors $E_7+E_3$

Example

- Decompose into x and y components.

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

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



Example

# Adding Vectors $E_7+E_3$

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

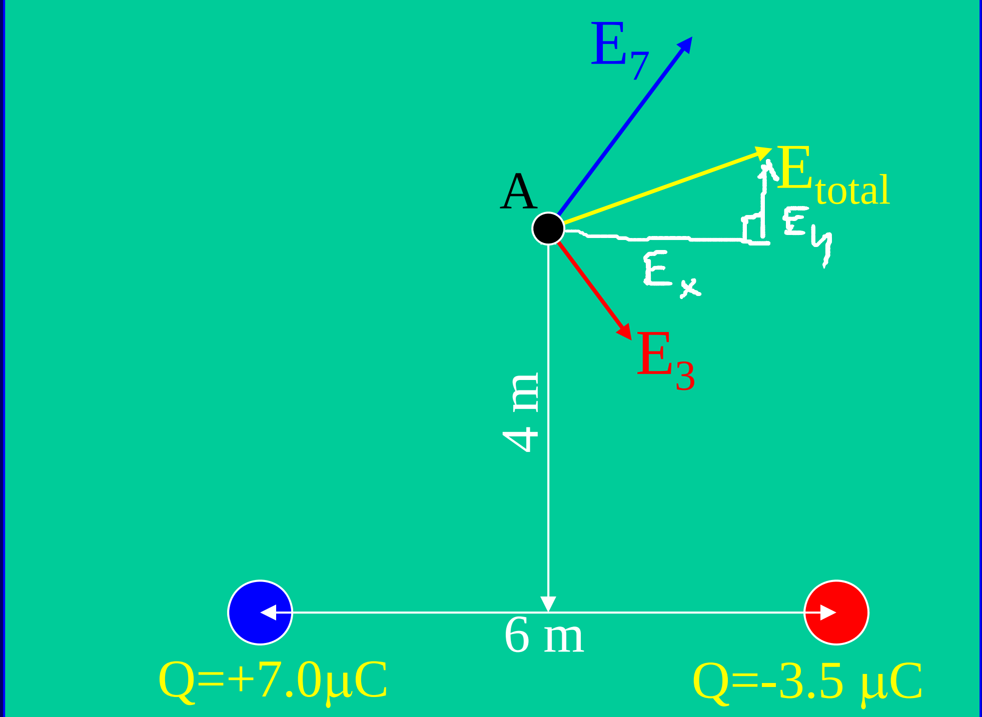
$$E_{7x} = 1.5 \times 10^{+3} N/C$$

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

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

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

$$\boxed{\begin{aligned} E_x &= 2.25\times10^{+3}\ \mathrm{N/C} \\ E_y &= 1.0\times10^{+3}\ \mathrm{N/C} \end{aligned}}$$




$$|E| = \sqrt{E_x^2 + E_y^2} = 2.5 \times 10^{+3}\ N/C$$

# 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:

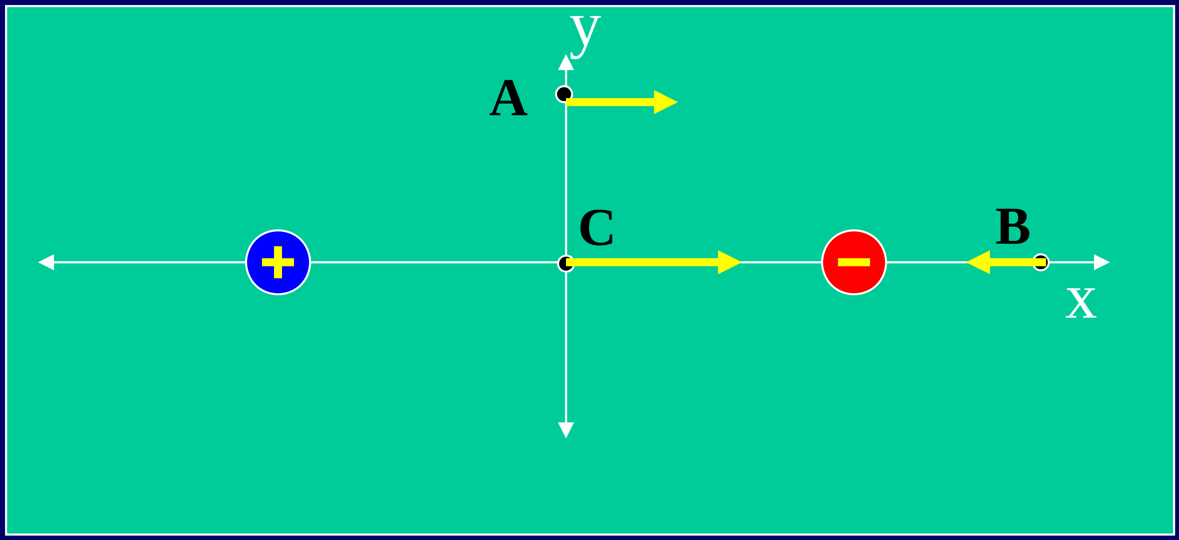
$$F = Eq$$

- Both are vectors, with magnitude and direction.

Ok, what is E actually good for?

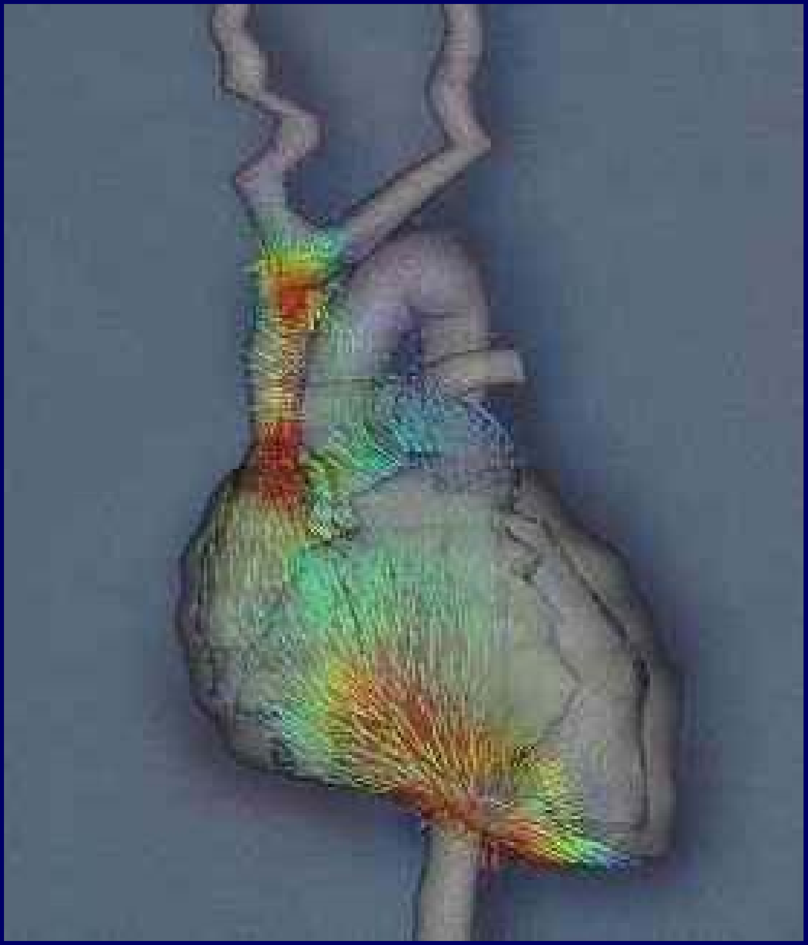
# Electric Field Map

- Electric field defined at any location



# Electric fields:
## A useful record-keeping tool!

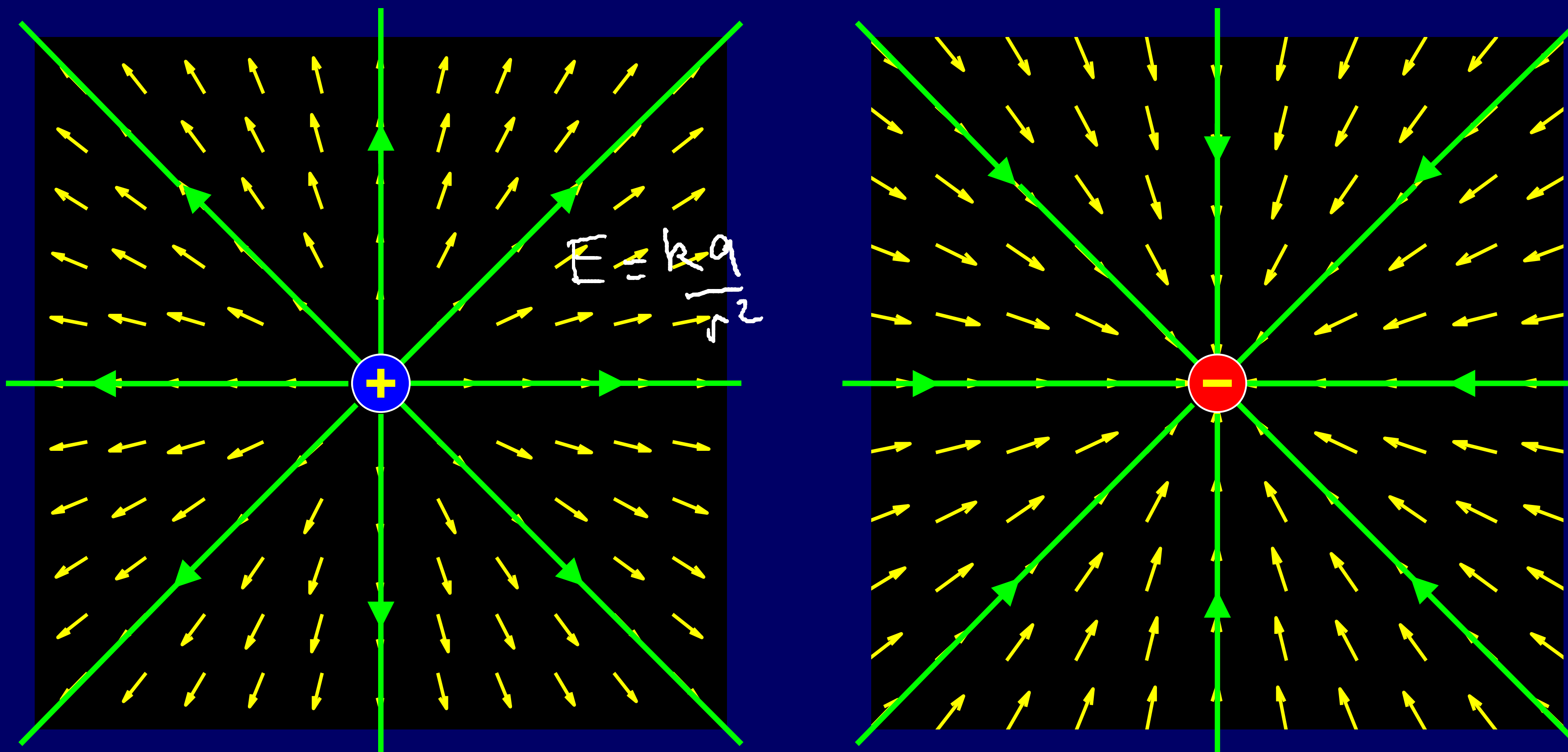
Calculate once for fixed charges, use to find force on other charges (like ions/electrons in neurons, heart tissue, and cell membranes)



*Eisenberg, BU*

# Electric Field Lines

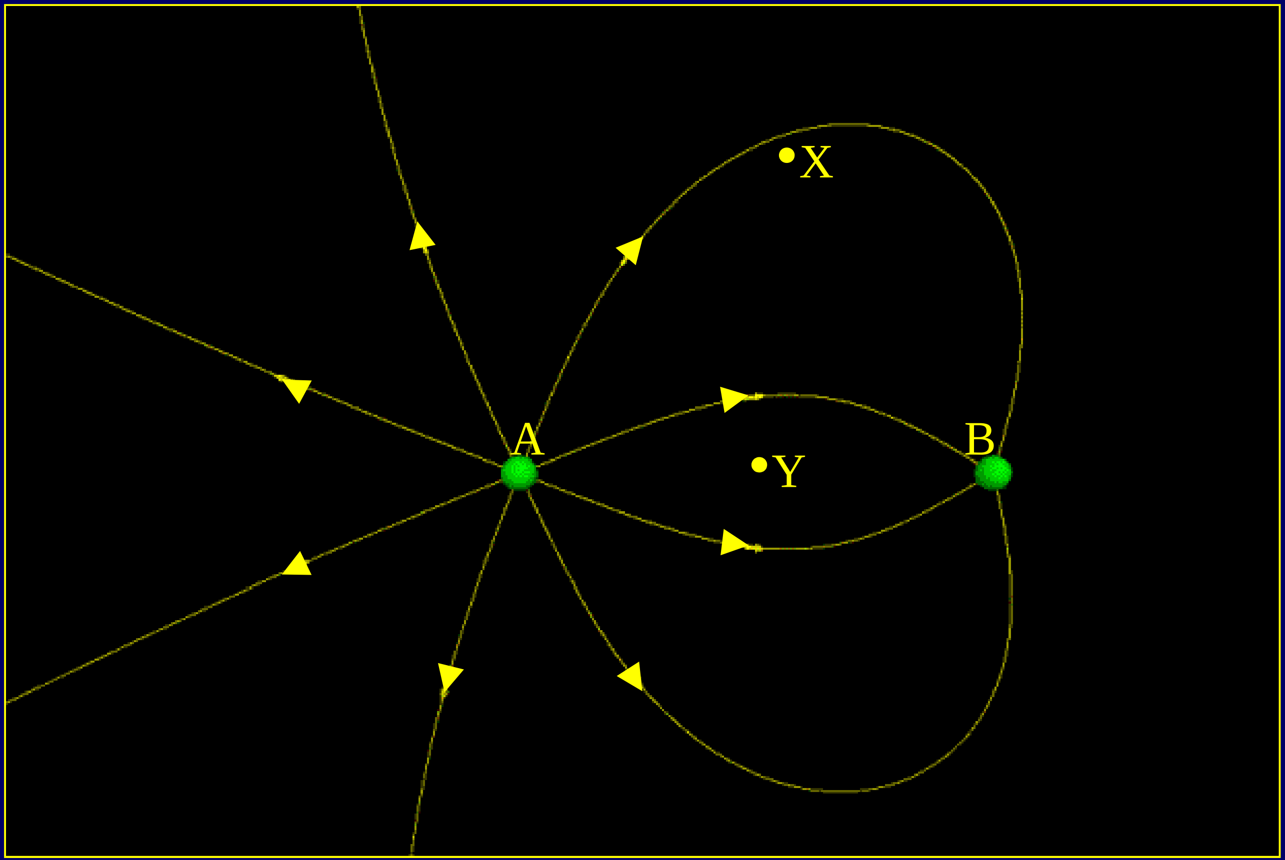
- Closeness of lines shows field strength (lines never cross)
- Number of lines at surface ó Q
- Arrow gives direction of E (Start on +, end on –)



$E = \frac{kq}{r^2}$

This is becoming a mess!!!

# CheckPoint 3.1

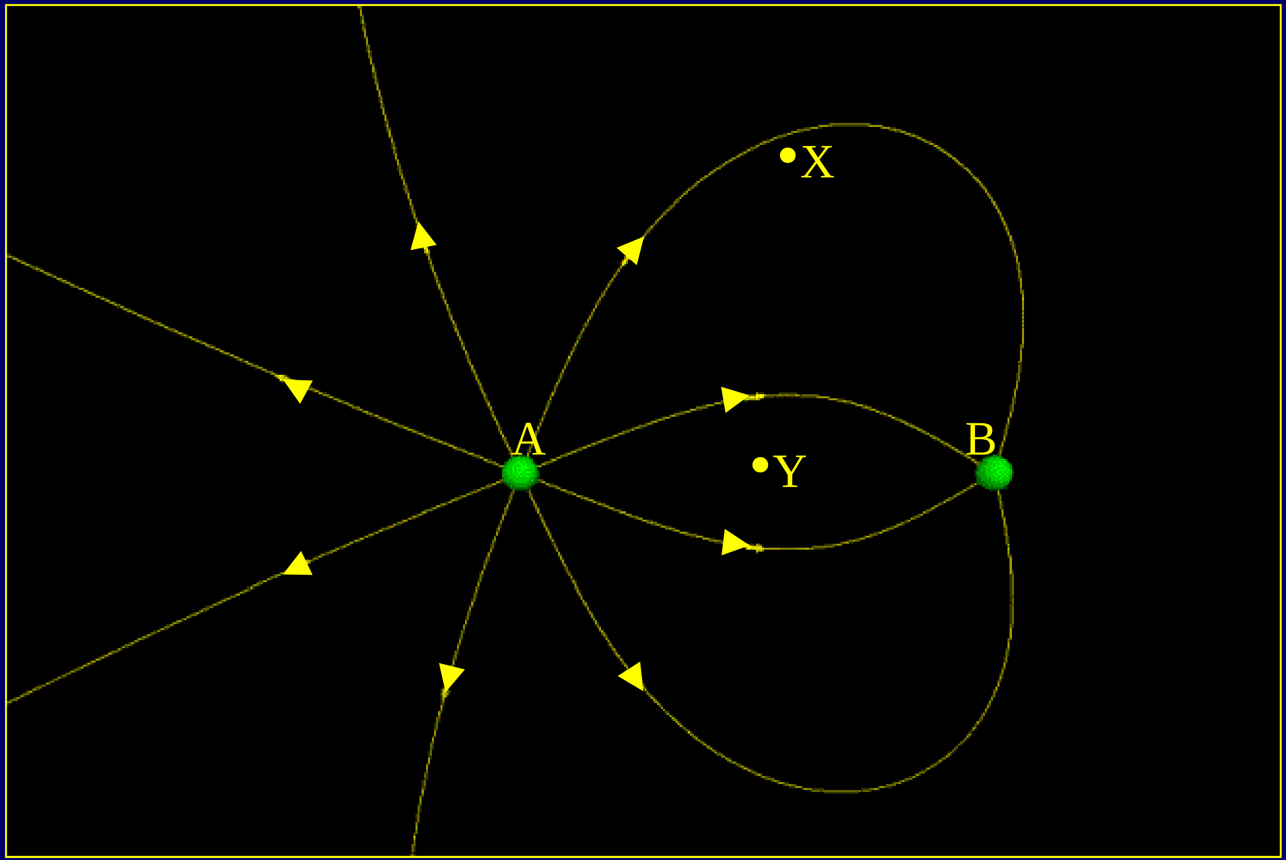



Charge A is  Field lines start on positive charge, end on negative.

1) positive  2) negative  3) unknown

93%  4%  3%

# CheckPoint 3.2 / ACT

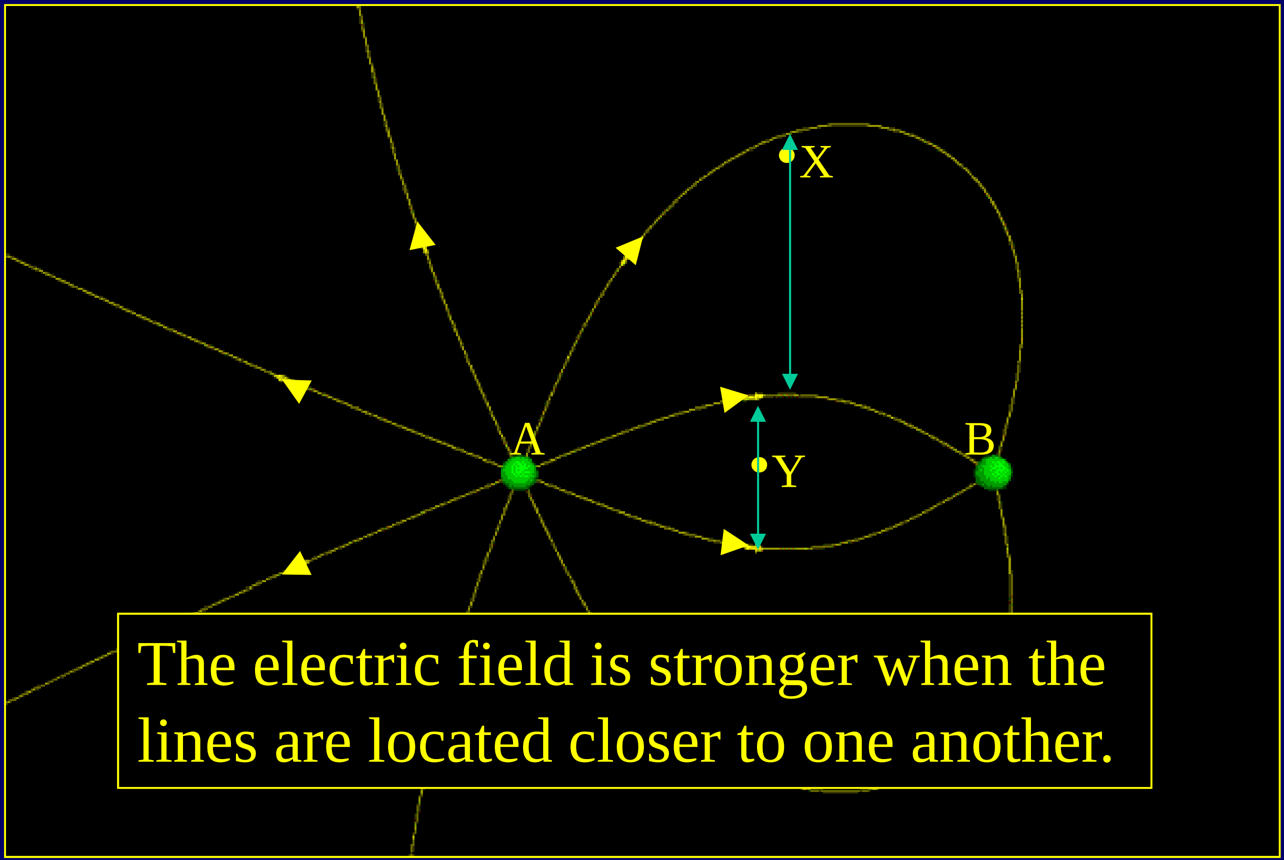



Compare the ratio of charges $Q_A / Q_B$ # lines proportional to Q

A) $Q_A = 0.5Q_B$ B) $Q_A = Q_B$ C) $Q_A = 2\ Q_B$

**15%** **17%** **53%**

# CheckPoint 3.4




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

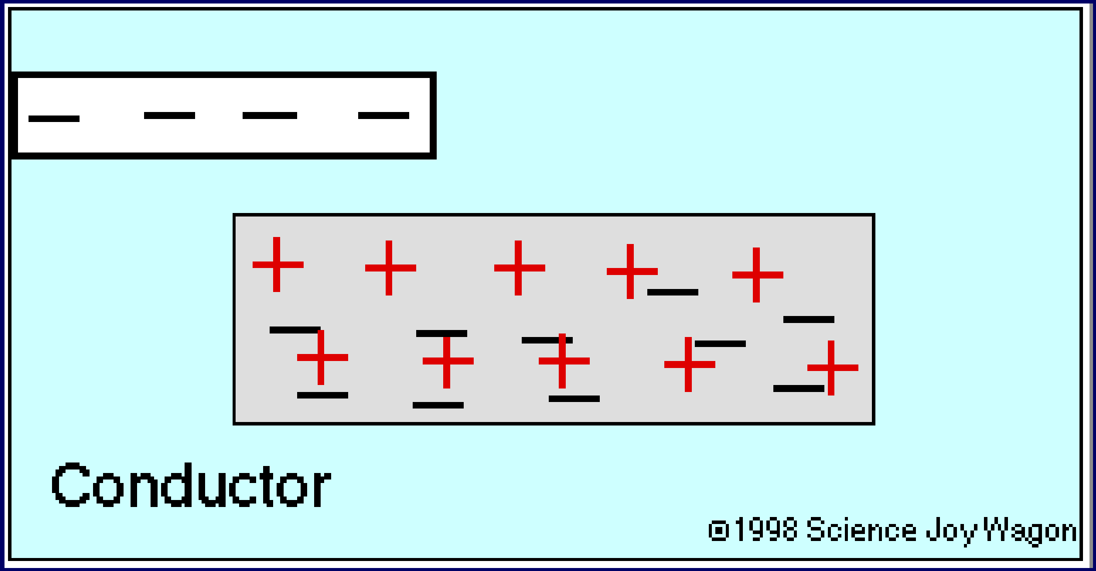
1) True **18%**

2) False **82%**

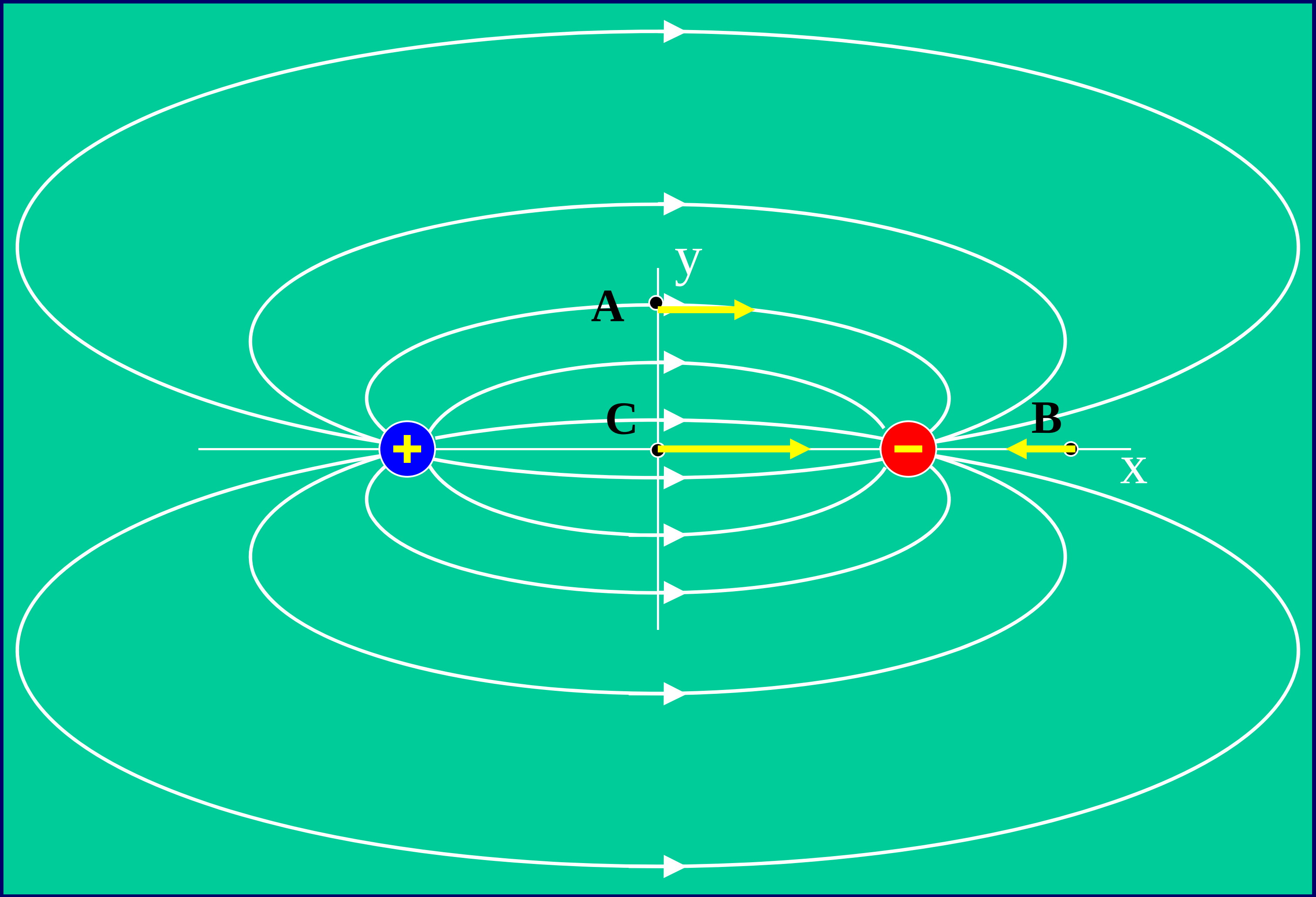
Density of field lines gives E

# E inside of conductor

- Conductor ≡ electrons free to move
  - Electrons feels 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 <u>and</u> 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 <u>Wednesday, Jan 23 @ 8 AM</u>!
- Do your Checkpoint by 8:00 AM Wednesday.