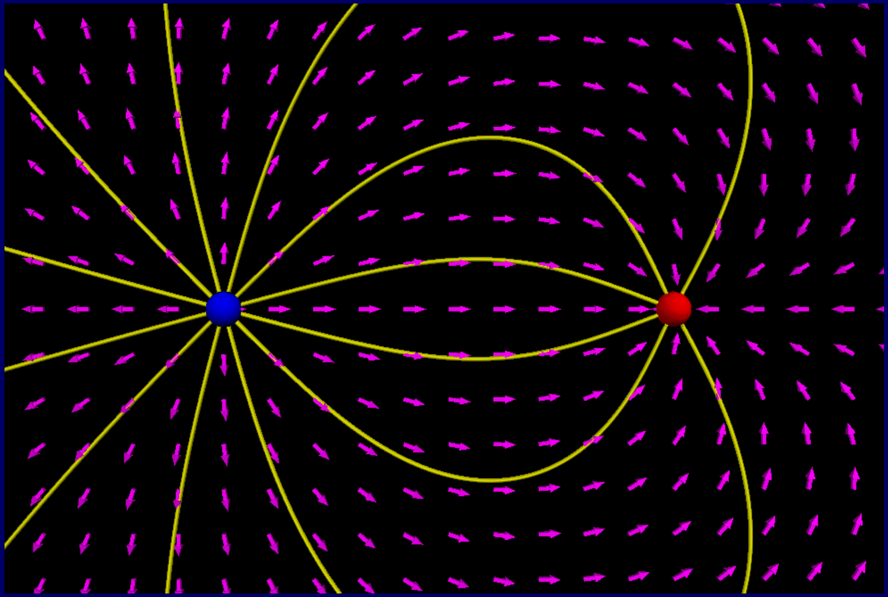
Physics 102: Lecture 02

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"

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

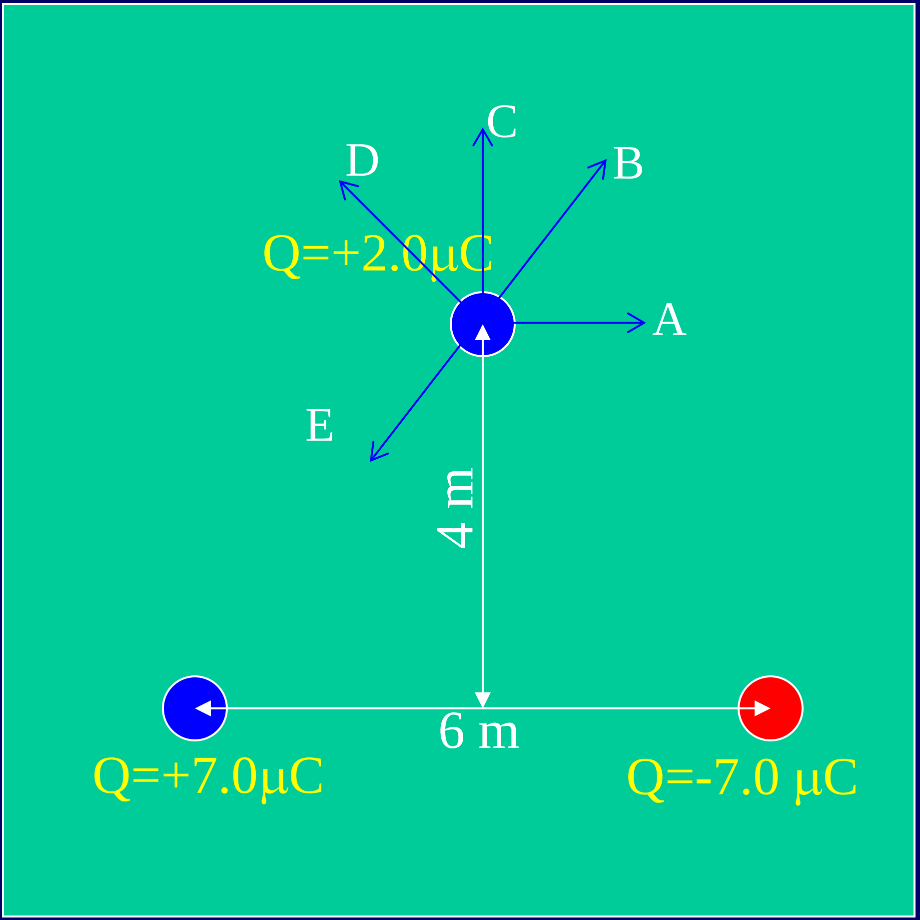
Direction

Opposite charges attract, like charges repel

Coulomb Law practice: Three Charges

Example

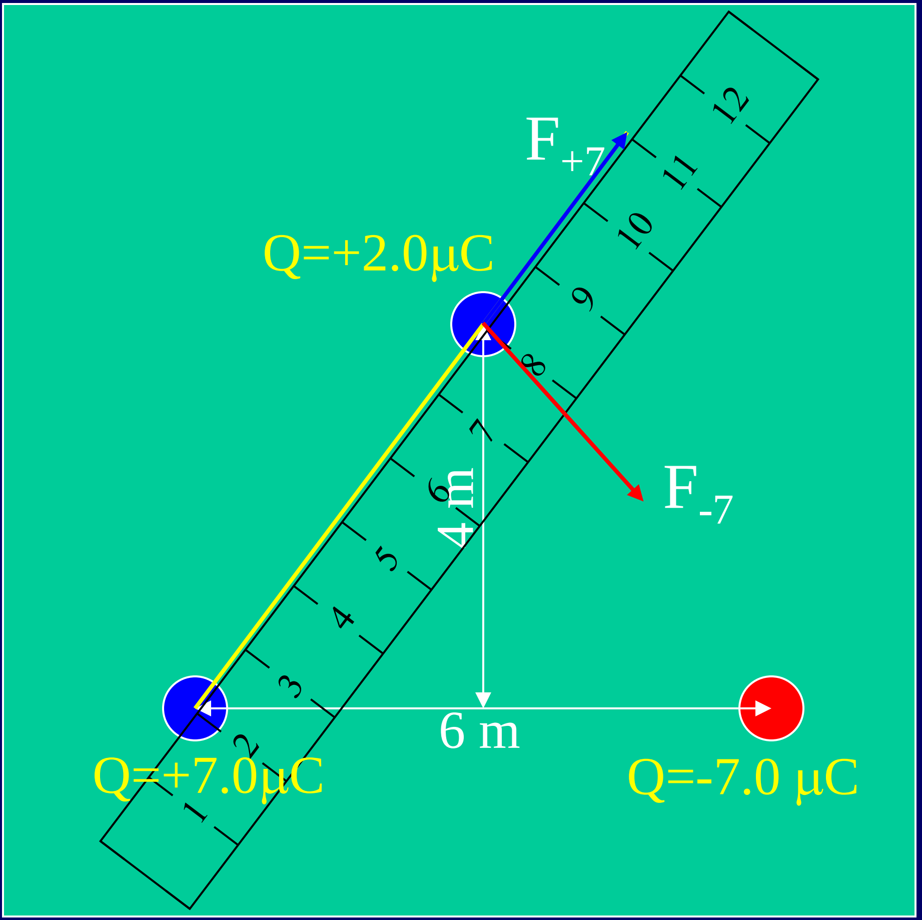
- Calculate force on +2μC charge due to other two charges
  - Draw forces
  - What is Force from +7 Charge?



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

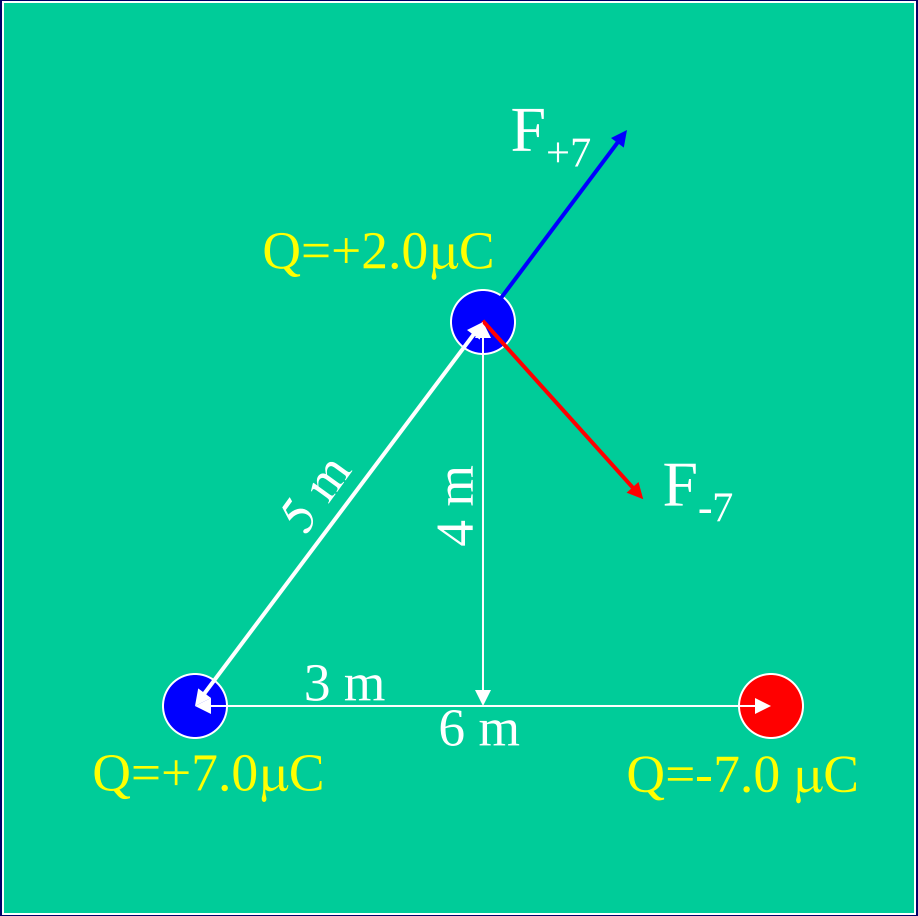
Three Charges – Calculate forces

- 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 $F = k\dfrac{q_1 q_2}{r^2}$

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

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

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



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

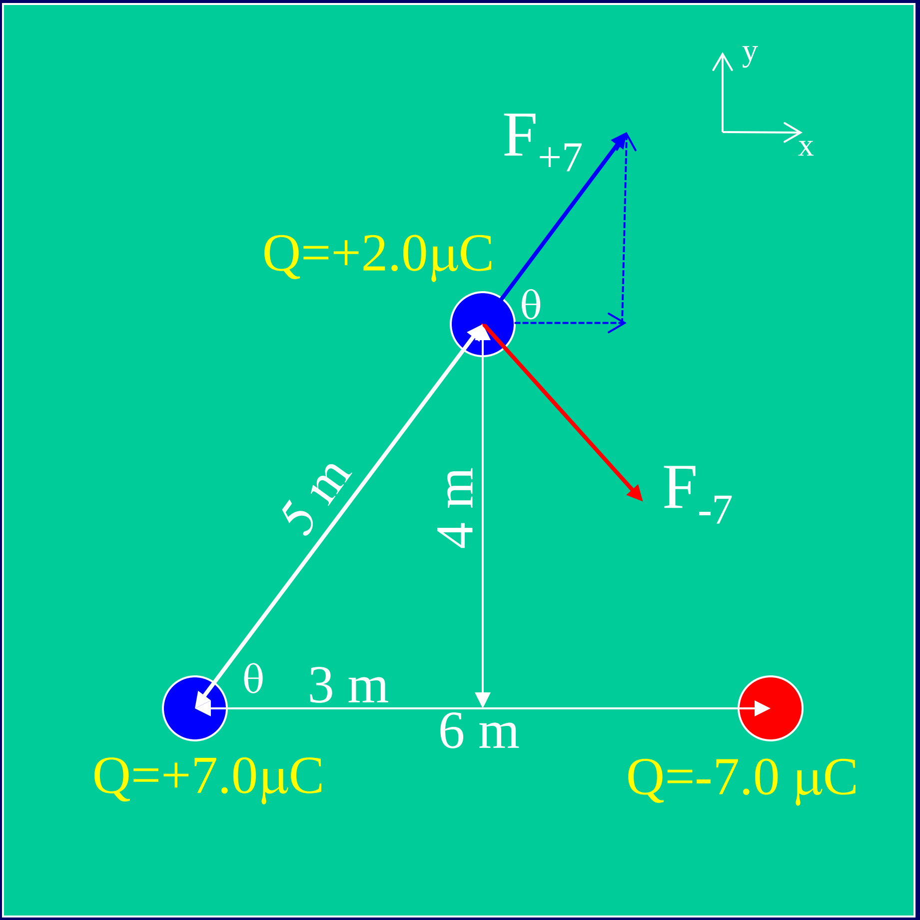
- Calculate components of vectors F_{+7} and F_{-7}:

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

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

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

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

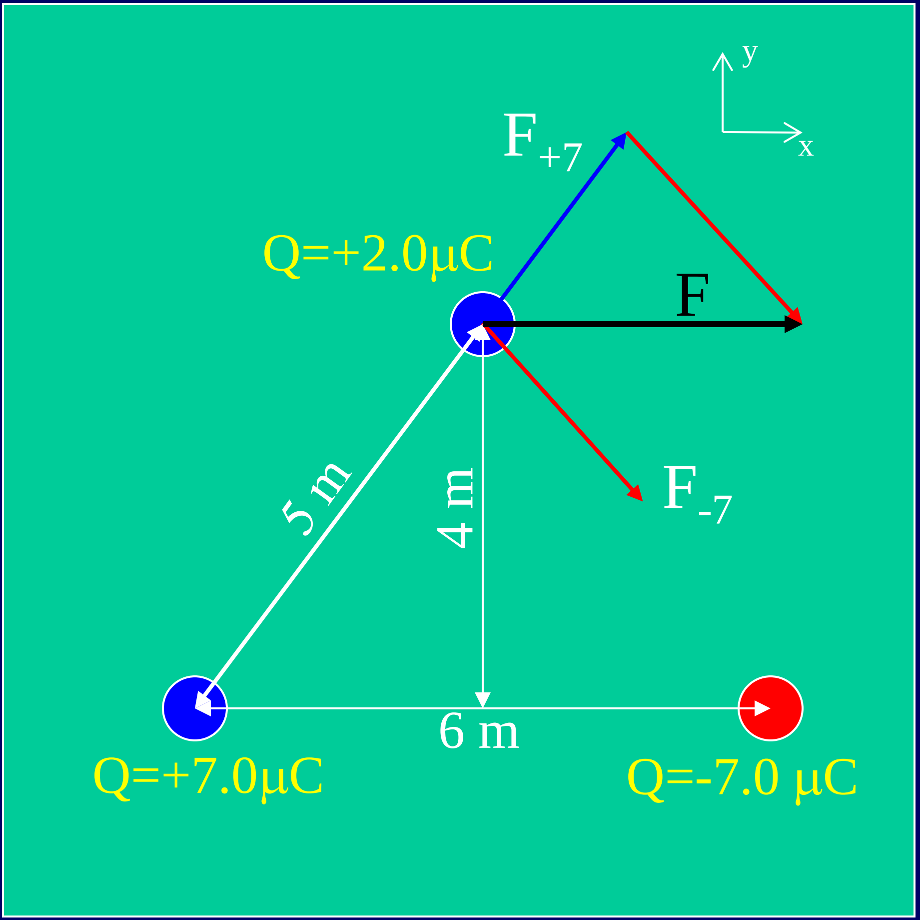


Example Three charges – Adding Vectors $F_{+7}+F_{-7}$

- 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

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

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

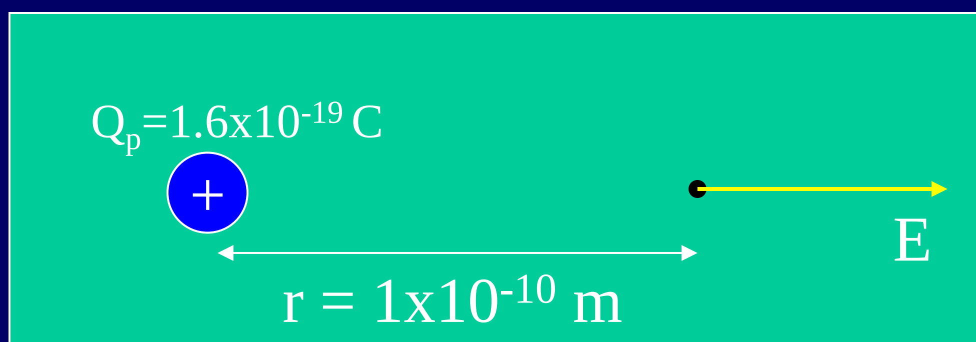
- Double-check with drawing

Electric Field

- Charged particles create electric fields.
  - Direction is the same as for the force that a + charge *would feel* at that location.
  - Magnitude given by:

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

Example

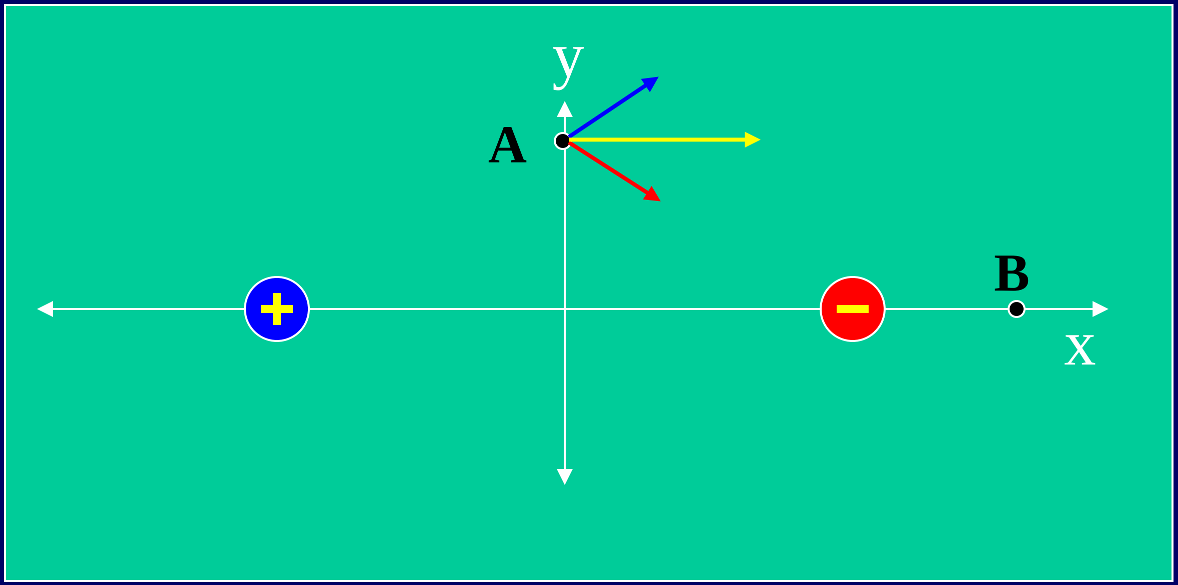


$E = (9\times10^{9})(1.6\times10^{-19})/(10^{-10})^{2} = 1.4\times10^{11}$ N/C (to the right)

CheckPoint 2.1

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

6%	1)	Up
13%	2)	Down
3%	3)	Left
46%	4)	Right
32%	5)	Zero



ACT: E Field

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

A. Up

B. Down

C. Left

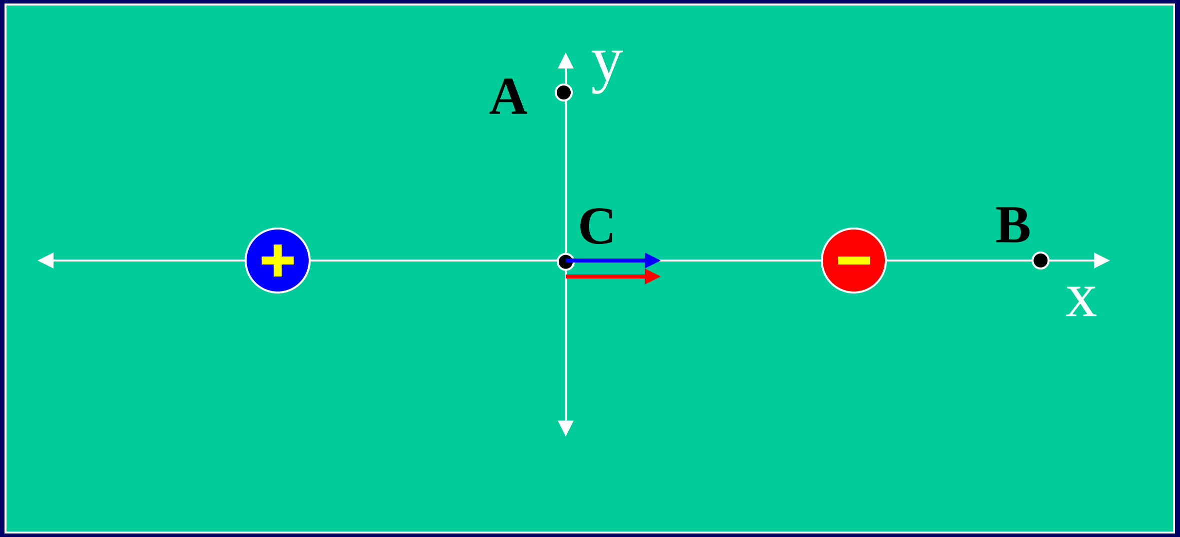
D. Right

E. Zero

Away from positive charge (right)

Towards negative charge (right)

Net E field is to right.

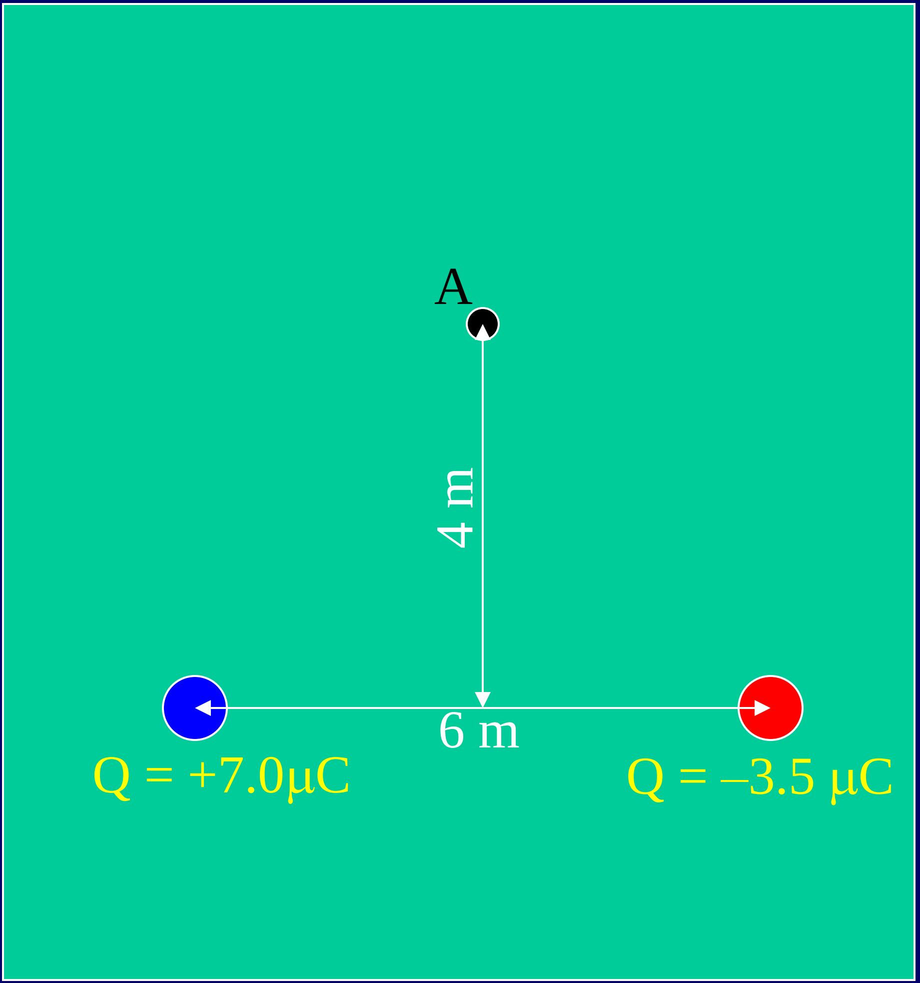


E Field from 2 Charges

- 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*

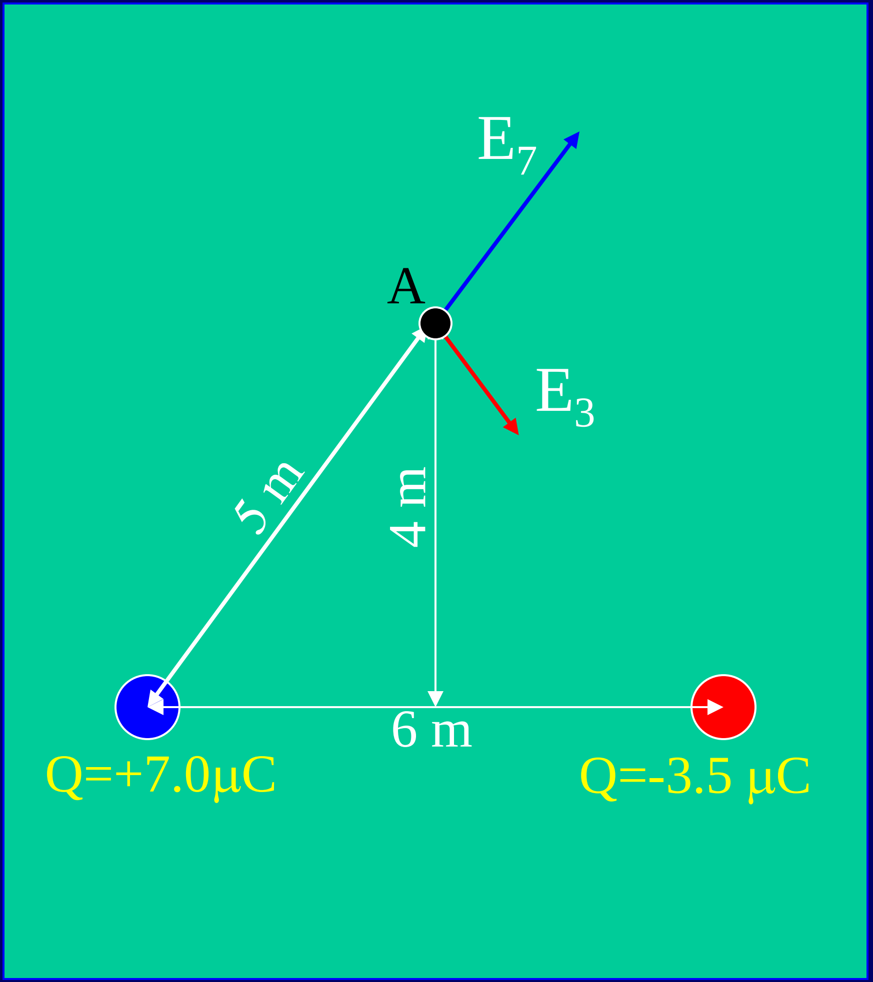
$$E = k\, q/r^2$$

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

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

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

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



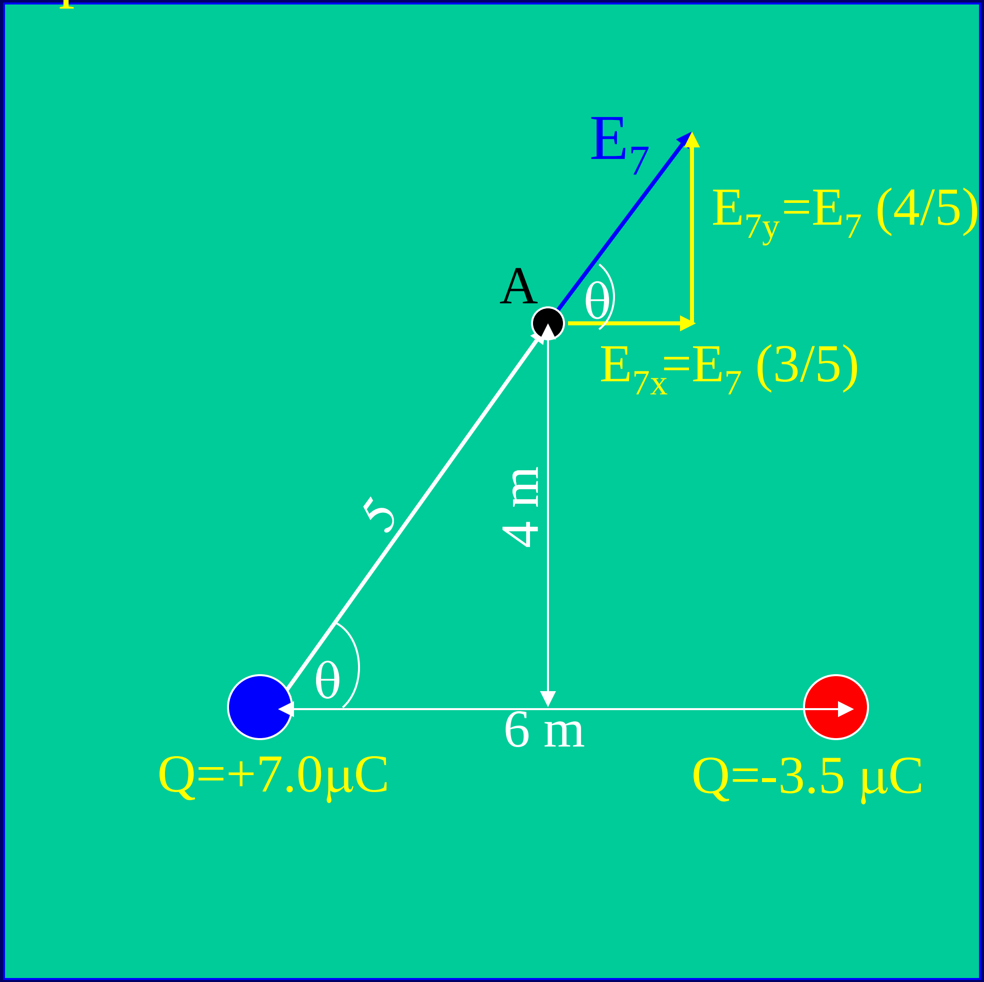
Example

Adding Vectors E_7+E_3

- Decompose into x and y components.

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

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



Adding Vectors $E_7 + E_3$

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

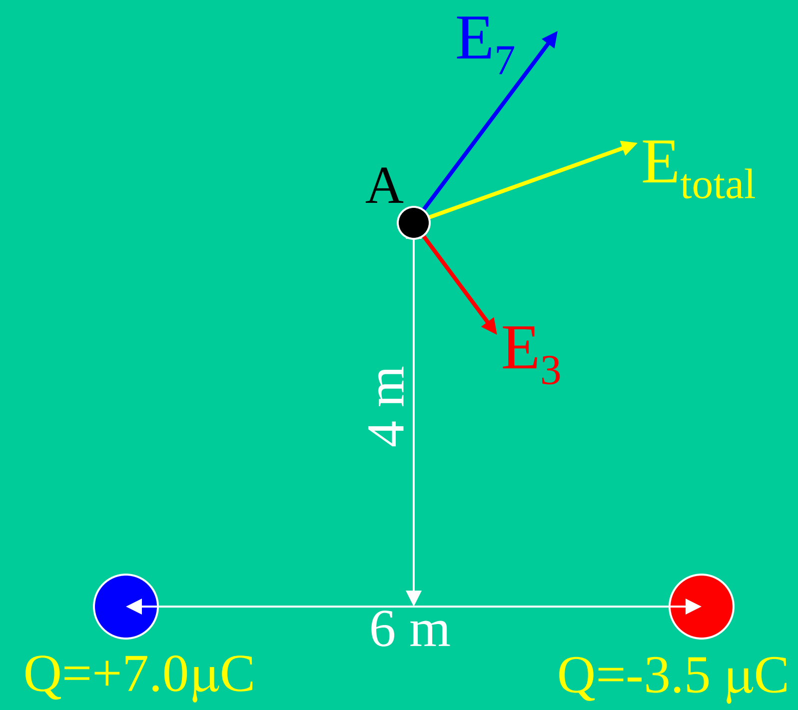
$$E_{7x} = 1.5 \times 10^{+3} N/C$$

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

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

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

$$\boxed{\begin{array}{l} E_x = 2.25 \times 10^{+3}\ \mathrm{N/C} \\ E_y = 1.0 \times 10^{+3}\ \mathrm{N/C} \end{array}}$$



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

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:

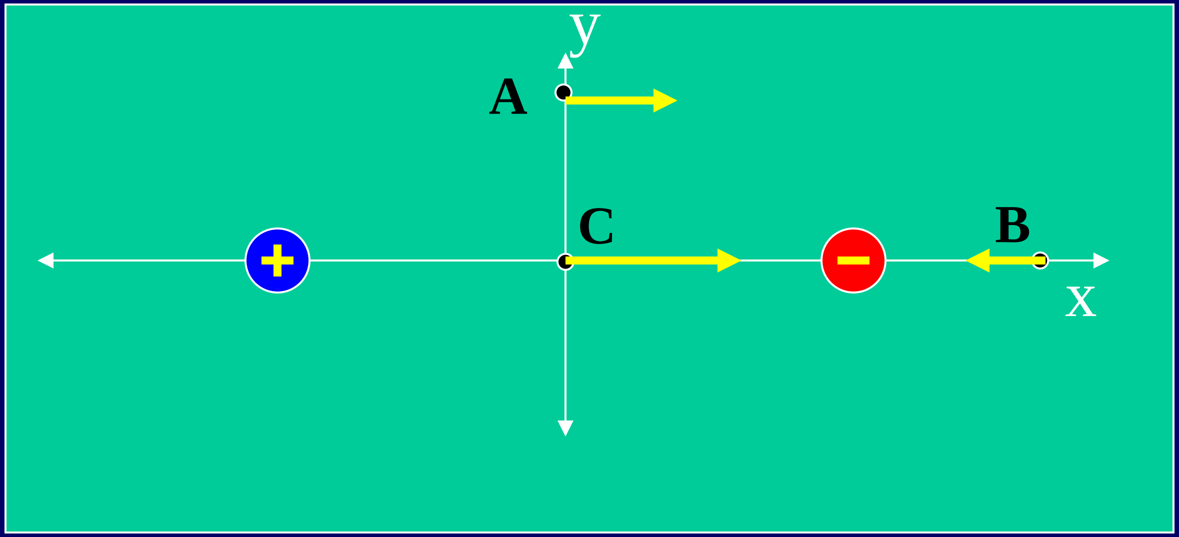
$$F = Eq$$

- Both are vectors, with magnitude and direction.

Ok, what is E actually good for?

Electric Field Map

- Electric field defined at any location

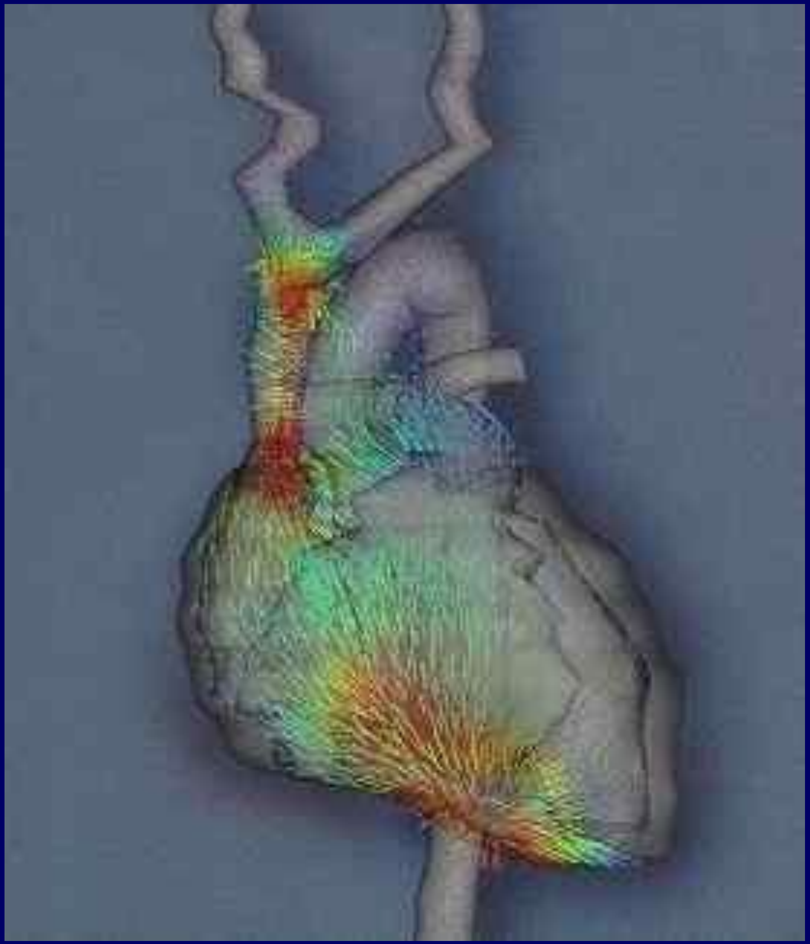


Electric fields:

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)

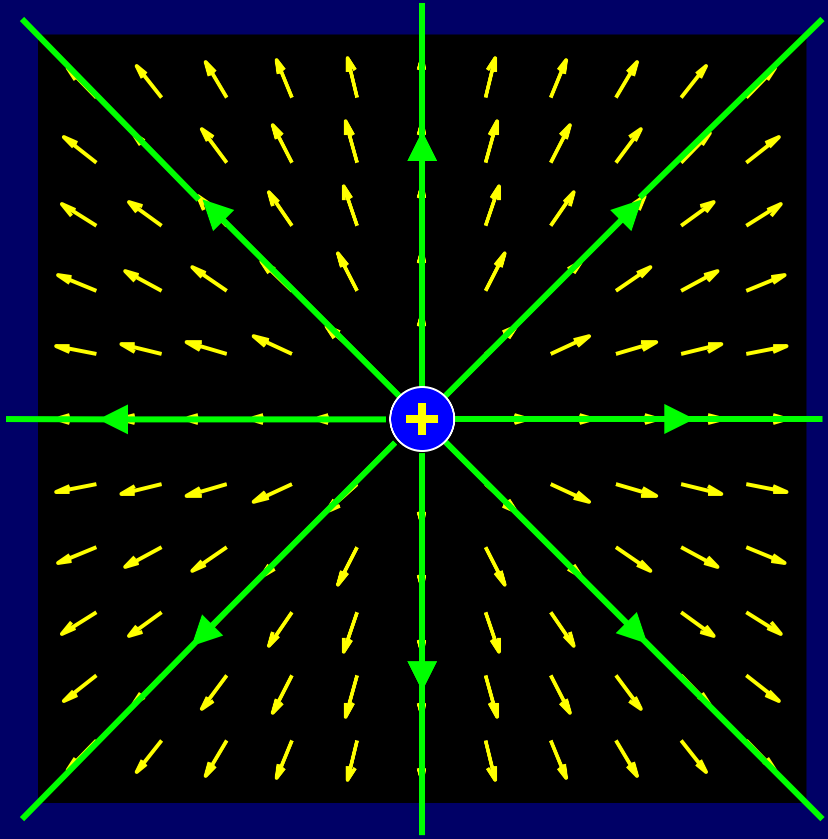
PhET simulation

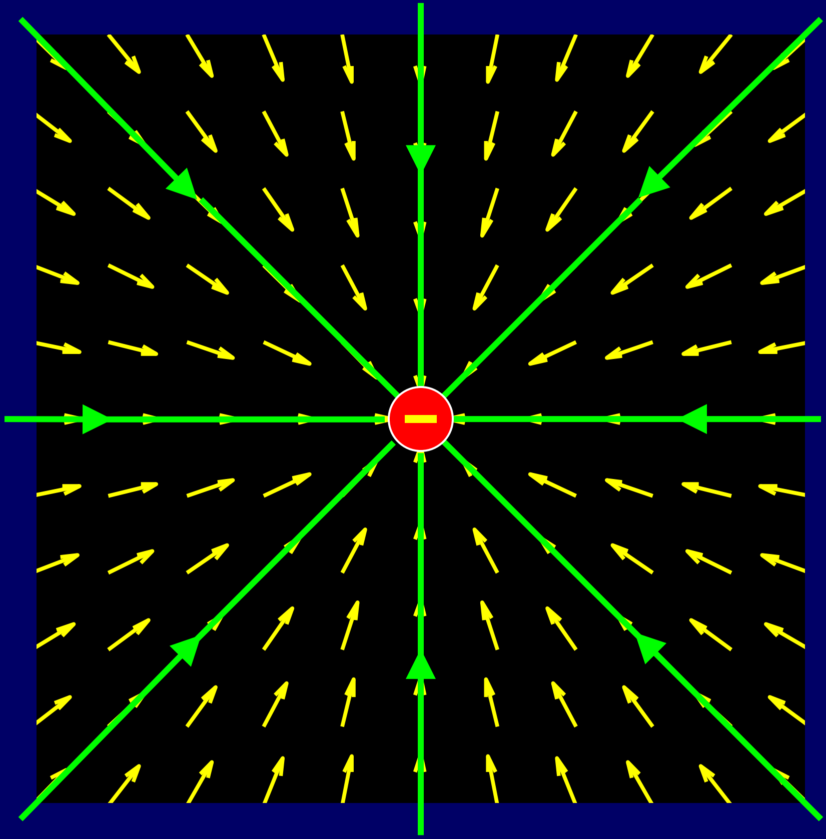


Eisenberg, BU

Electric Field Lines

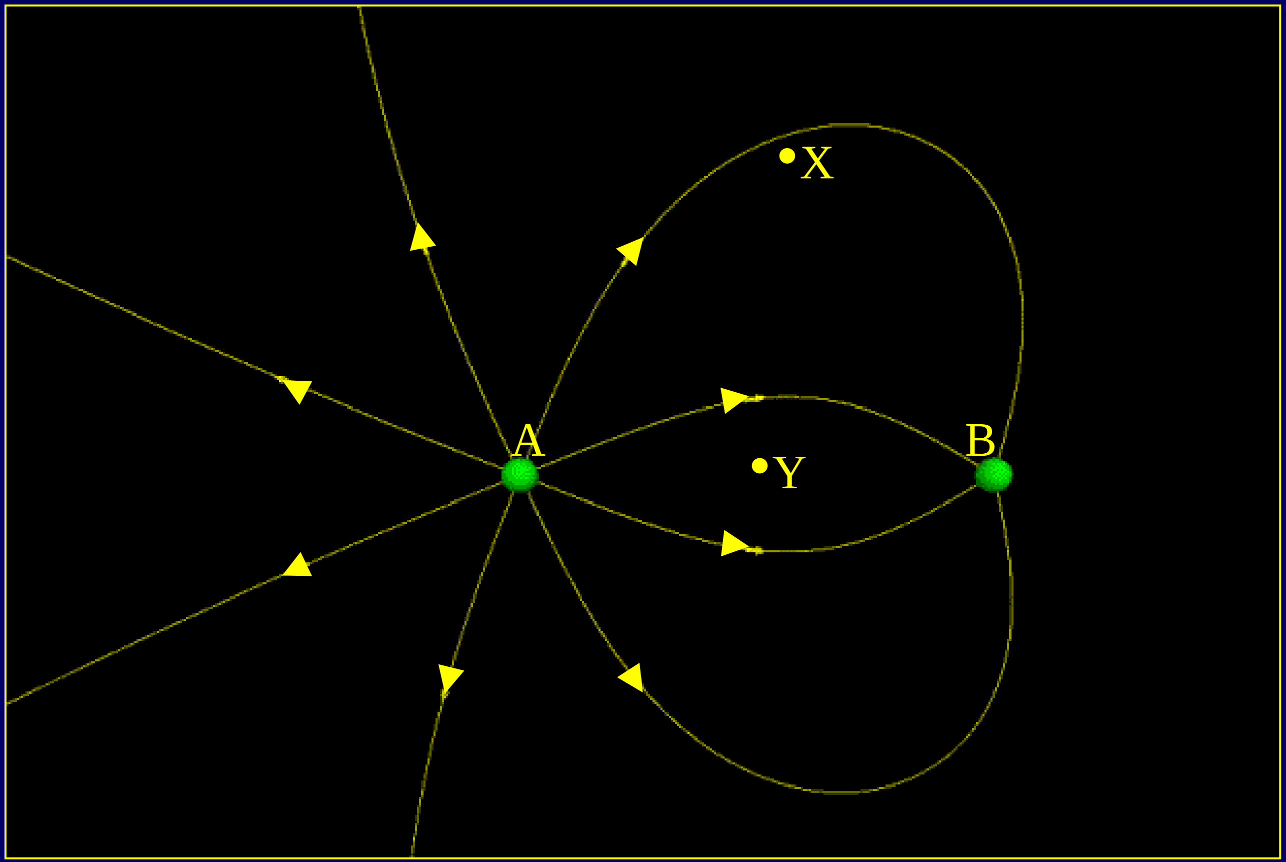
- Closeness of lines shows field strength (lines never cross)
- Number of lines at surface $\propto$ Q
- Arrow gives direction of E (Start on +, end on –)





This is becoming a mess!!!

CheckPoint 3.1

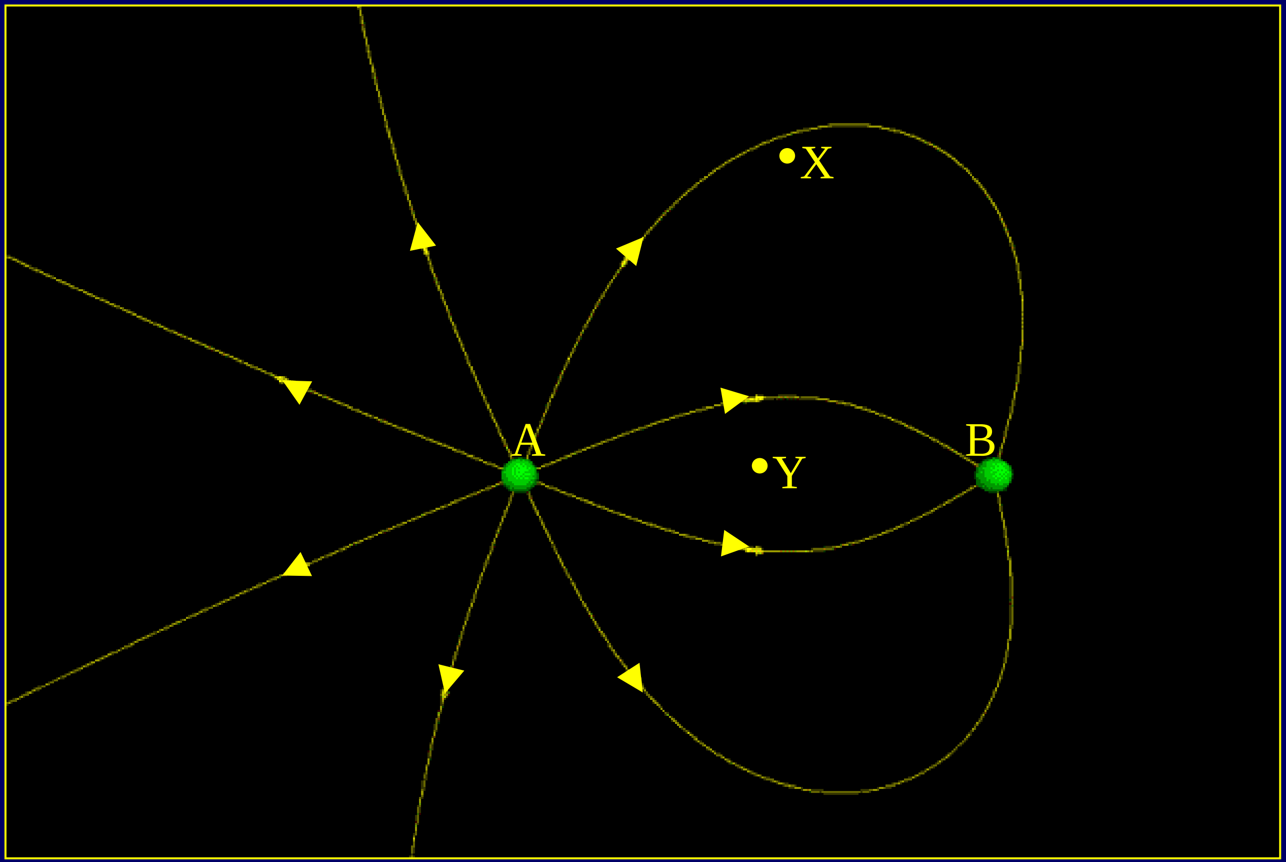


Charge A is Field lines start on positive charge, end on negative.

1) positive 2) negative 3) unknown

70% 10% 20%

CheckPoint 3.2 / ACT



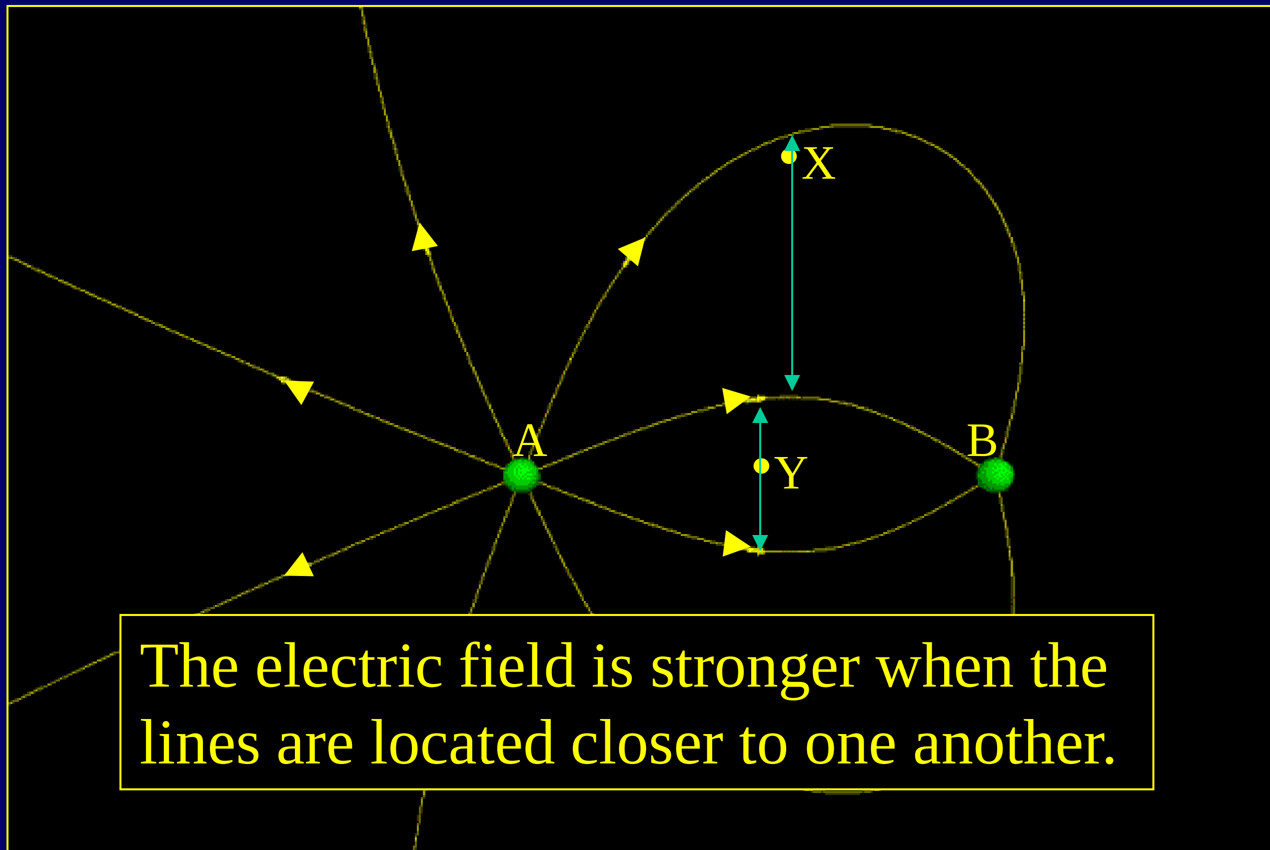
Compare the ratio of charges Q_A / Q_B # lines proportional to Q

A) $Q_A = 0.5Q_B$ 15%

B) $Q_A = Q_B$ 16%

C) $Q_A = 2\ Q_B$ 58%

CheckPoint 3.4



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

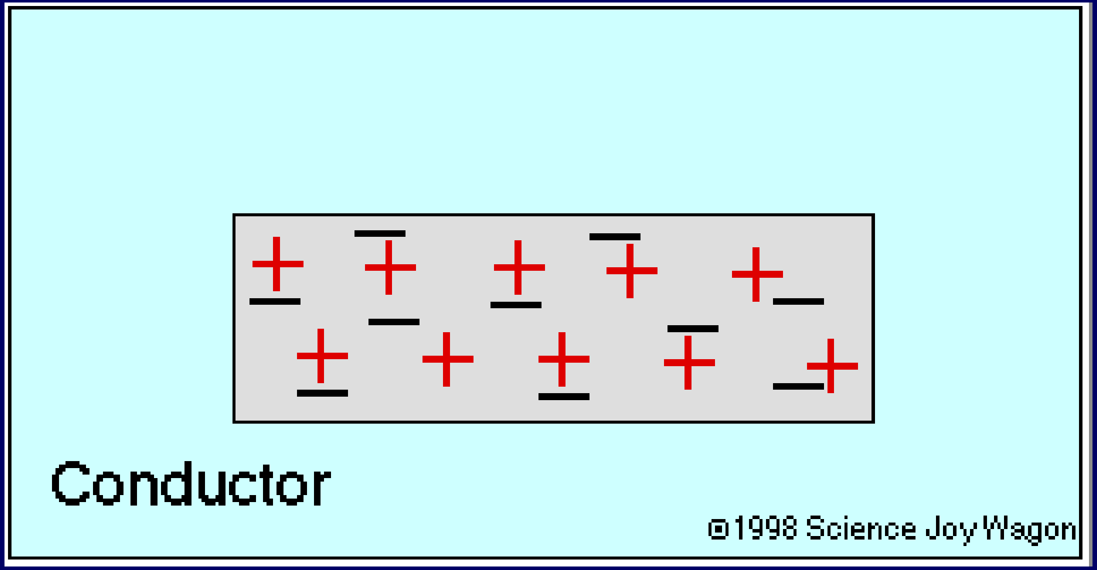
1) True **21%**

2) False **79%**

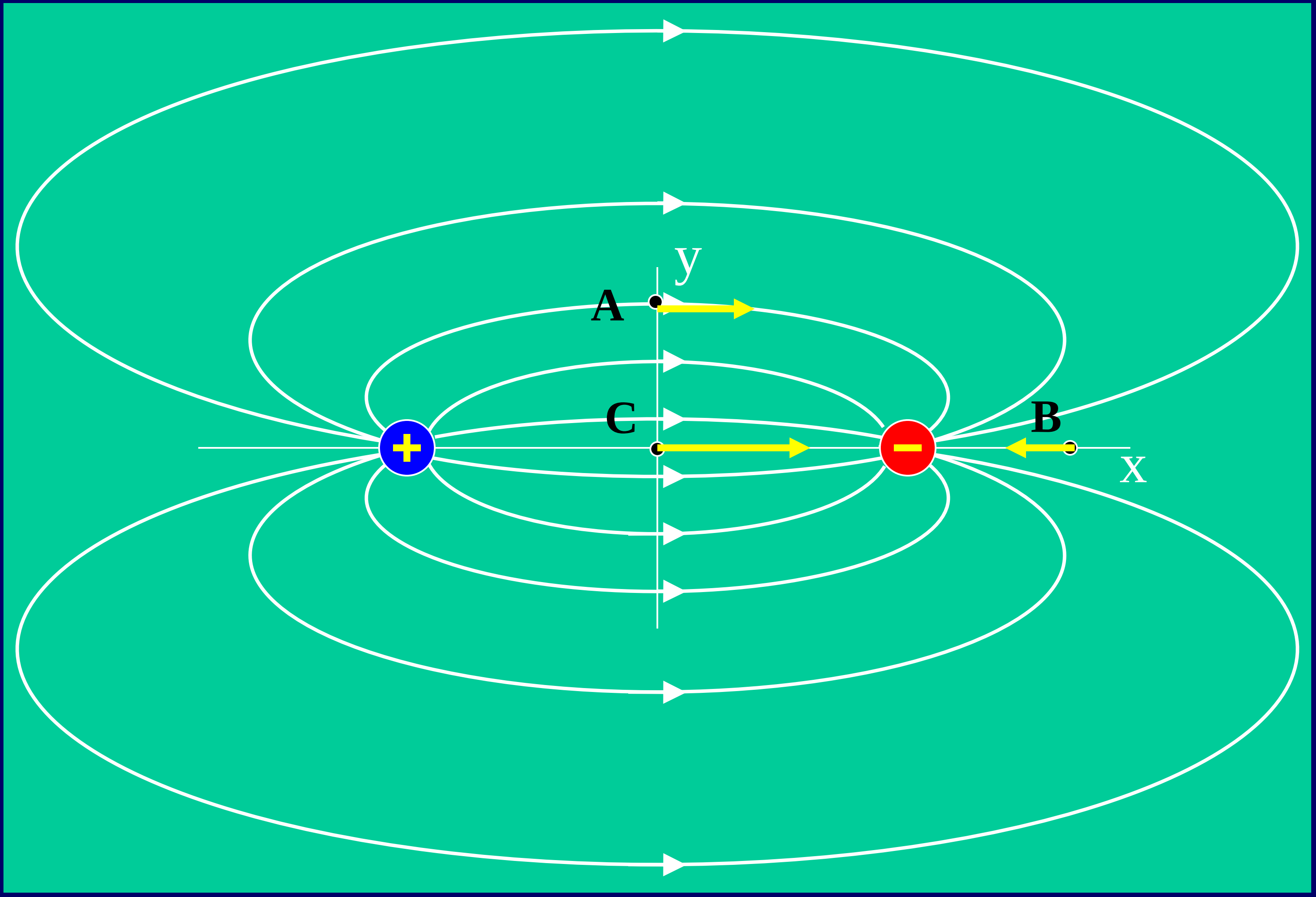
Density of field lines gives E

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

- .
- Homework 1 due <u>Tomorrow Morning</u>!
- Do your Checkpoint by 8:00 AM Wednesday.