PHY294H

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- email:huston@msu.edu
- office: BPS3230
- textbook: Knight, Physics for Scientists and Engineers: A Strategic Approach,

  Vol. 4 (Chs 25-36), 3/E + MasteringPhysics

  0321844297

  MasteringPhysics (complete ebook) access card stand alone

  0321753054
- Homework will be with Mastering Physics (and an average of 1 hand-written problem per week)
  - first MP assignment due Wed Jan. 20; first hand-written problem as well
- Quizzes by iclicker (sometimes hand-written)
- Lectures: MTWTh 11:30-12:20
- Course website: www.pa.msu.edu/~huston/phy294h/index.html
  - lectures will be posted frequently, mostly every day if I can remember to do so

see slide 11, 16, 17x, 18x, 19x, 20x, 21x

Electric field from a point charge

I put my (imaginary) test charge q_o at some point in space, and I measure the force

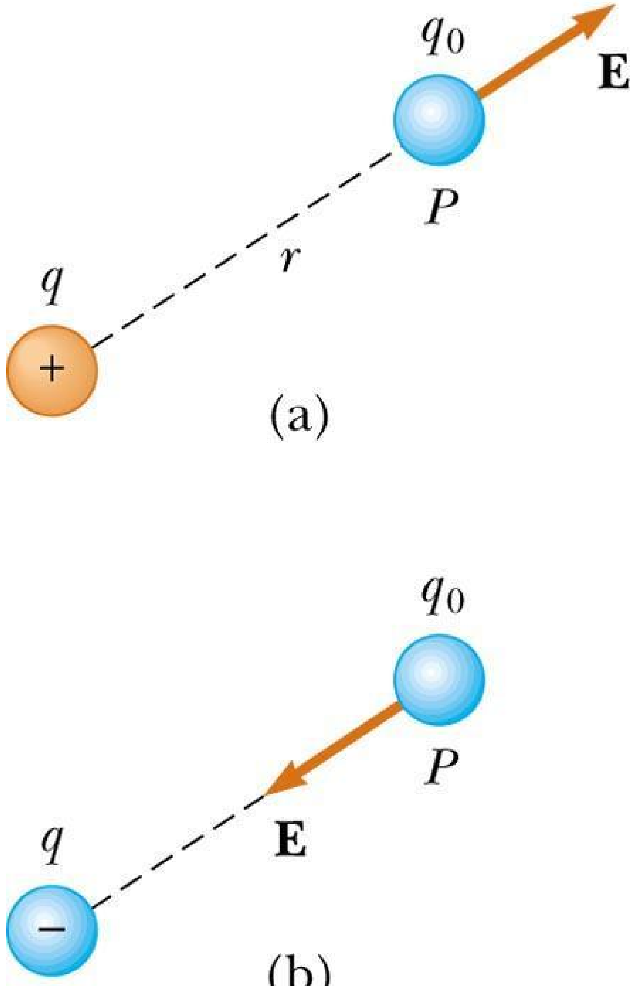
$$\vec{F} = \frac{1}{4\pi\epsilon_0}\frac{q q_0}{r^2}\hat{r}$$

I can then determine the electric field from the point charge q

$$\vec{E}_q(\vec{r}) = \frac{\vec{F}}{q_0} = \frac{1}{4\pi\epsilon_0}\frac{q}{r^2}\hat{r}$$

The electric field that I measure has nothing to do with the test charge q_o

- it's there whether or not I use a test charge to measure it

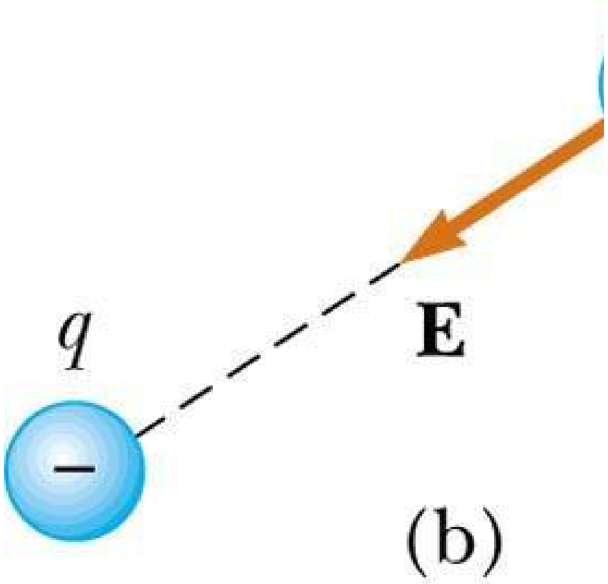


Electric field from a point charge

- Thus,

  the electric field from the point charge q is

$$\vec{E}_q(\vec{r}) = \frac{1}{4\pi\epsilon_0}\frac{q}{r^2}\hat{r}$$



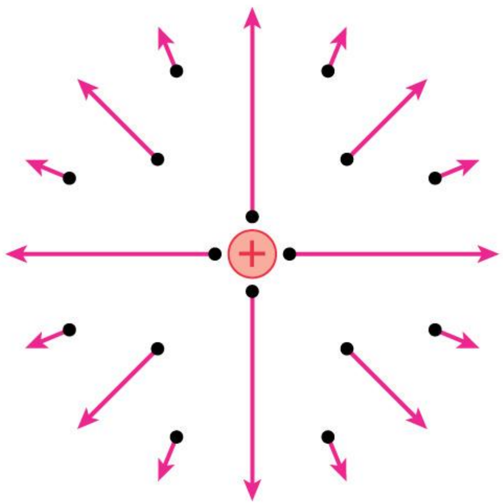
The unit vector, r-hat

Define a unit vector $\hat{\mathbf{r}}$ which points ***away from*** the charge.

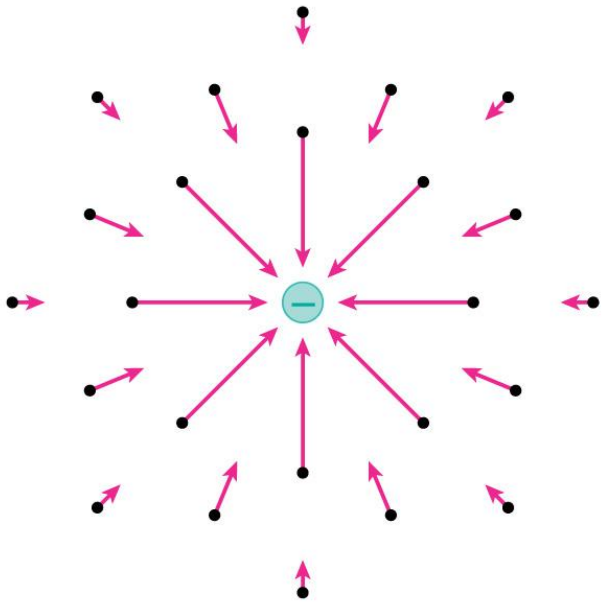
$$\vec{E} = \frac{1}{4\pi\epsilon_0}\frac{q}{r^2}\hat{r} \qquad \text{(electric field of a point charge)} \qquad (25.15)$$

Note that **E** field vectors are drawn larger at points closer to the charge (because |**E**| is larger)

(b)



The electric field diagram of a positive point charge

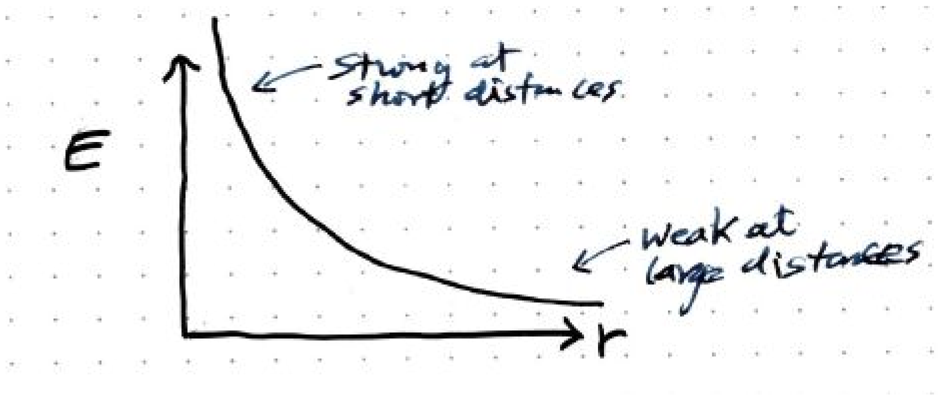


so electric field points away from + charge

and towards – charge

Shape of the electric field function

$$|\mathbf{E}_q| = \frac{1}{4\pi\,\varepsilon_0}\,\frac{q}{r^2}$$



The electric field from a point charge

goes to infinity as r⟶0;

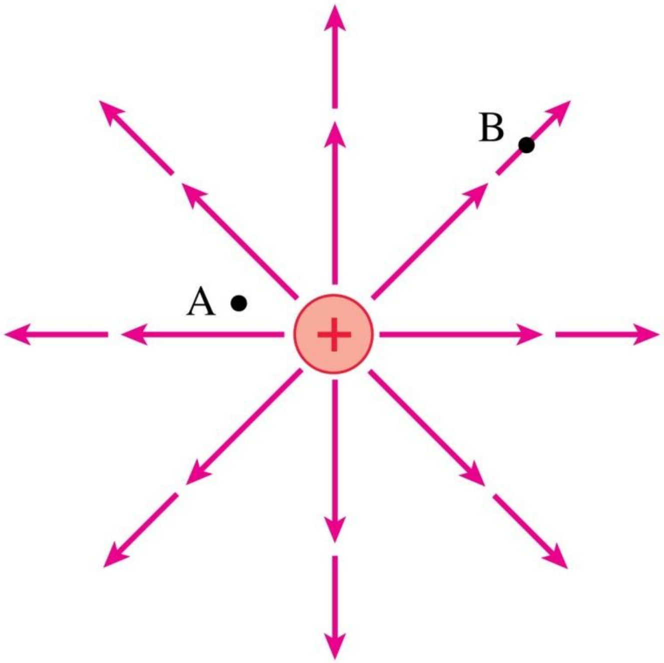
and it goes to 0 as r⟶∞

At which point is the electric field stronger?

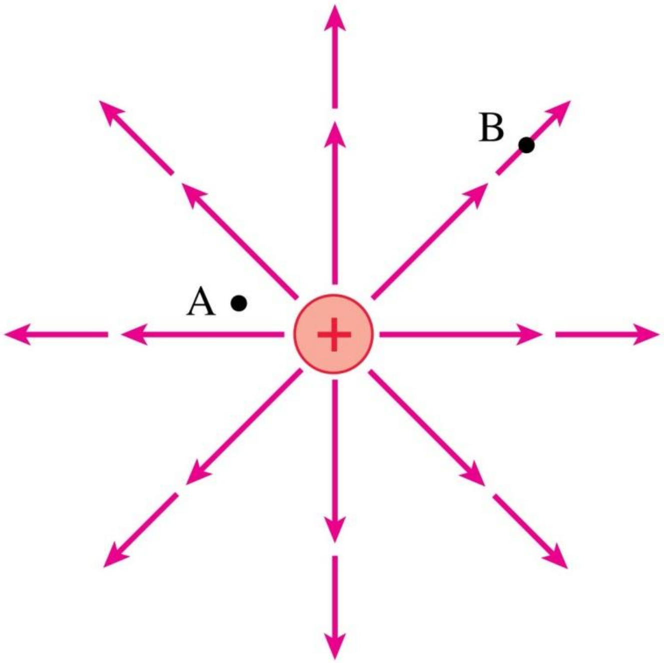
A. Point A.

B. Point B.

C. Not enough information to tell.



At which point is the electric field stronger?



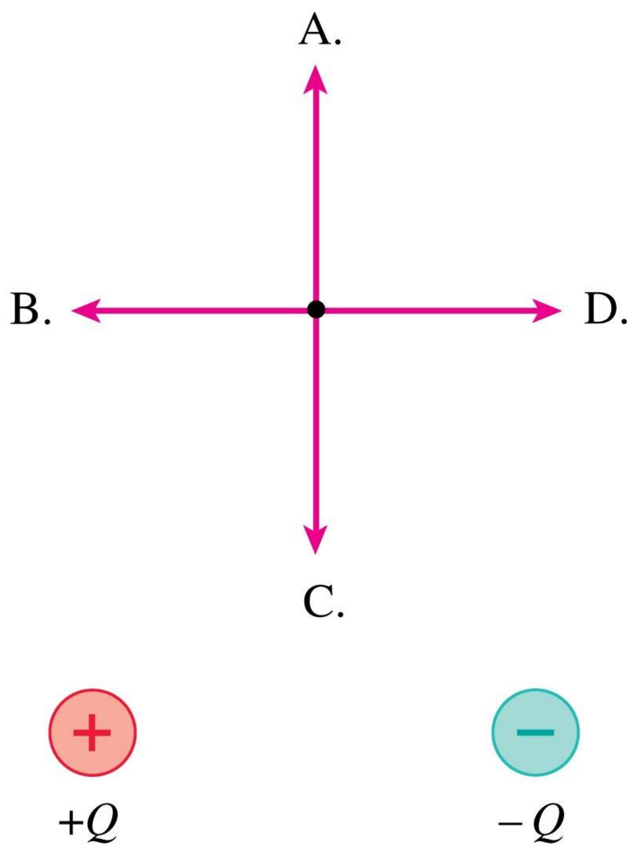
A. **Point A.**

B. Point B.

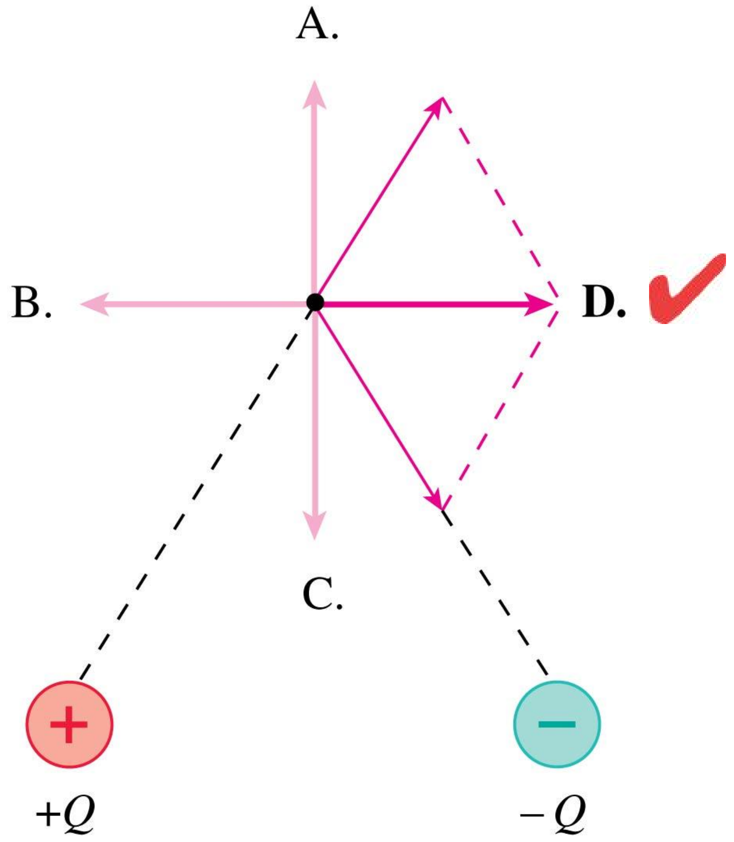
C. Not enough information to tell.

What is the direction of the electric field at the black dot?

A. A.
B. B.
C. C.
D. D.
E. None of these.



What is the direction of the electric field at the black dot?

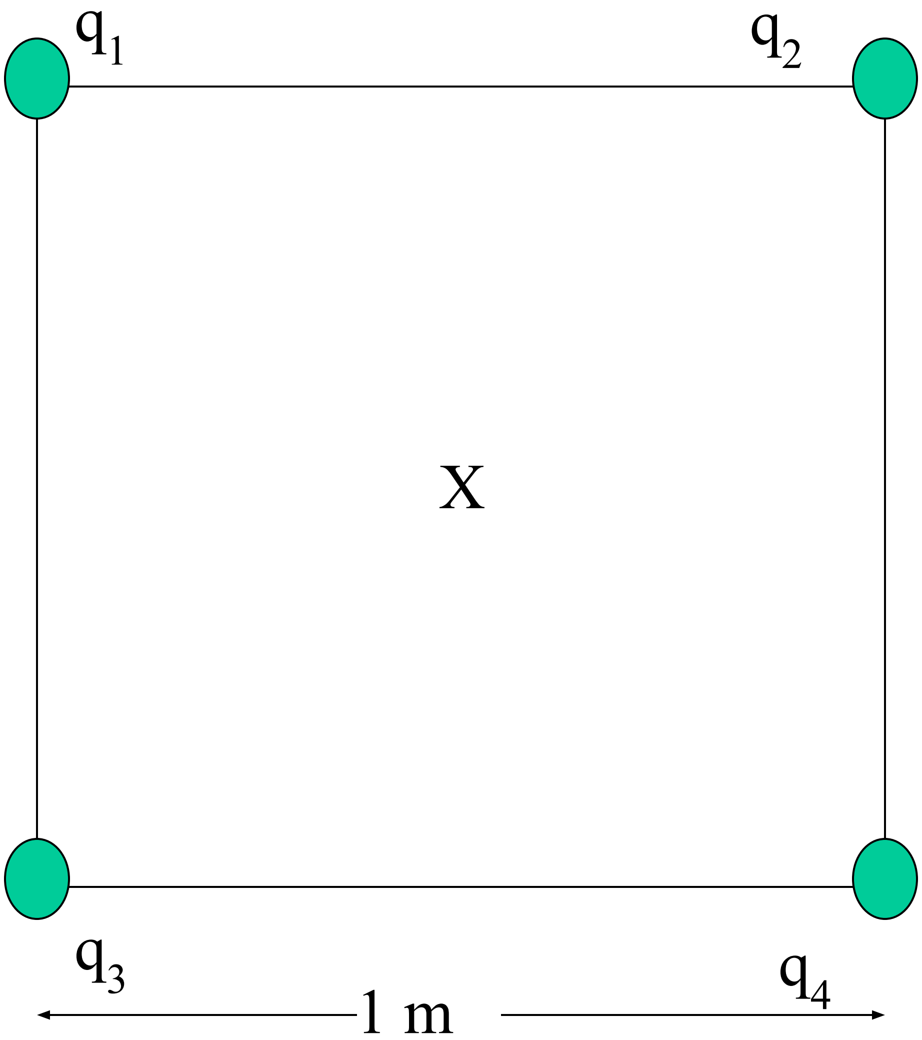


What if I have more than 1 charge?

- What is the electric field at the center of the square?

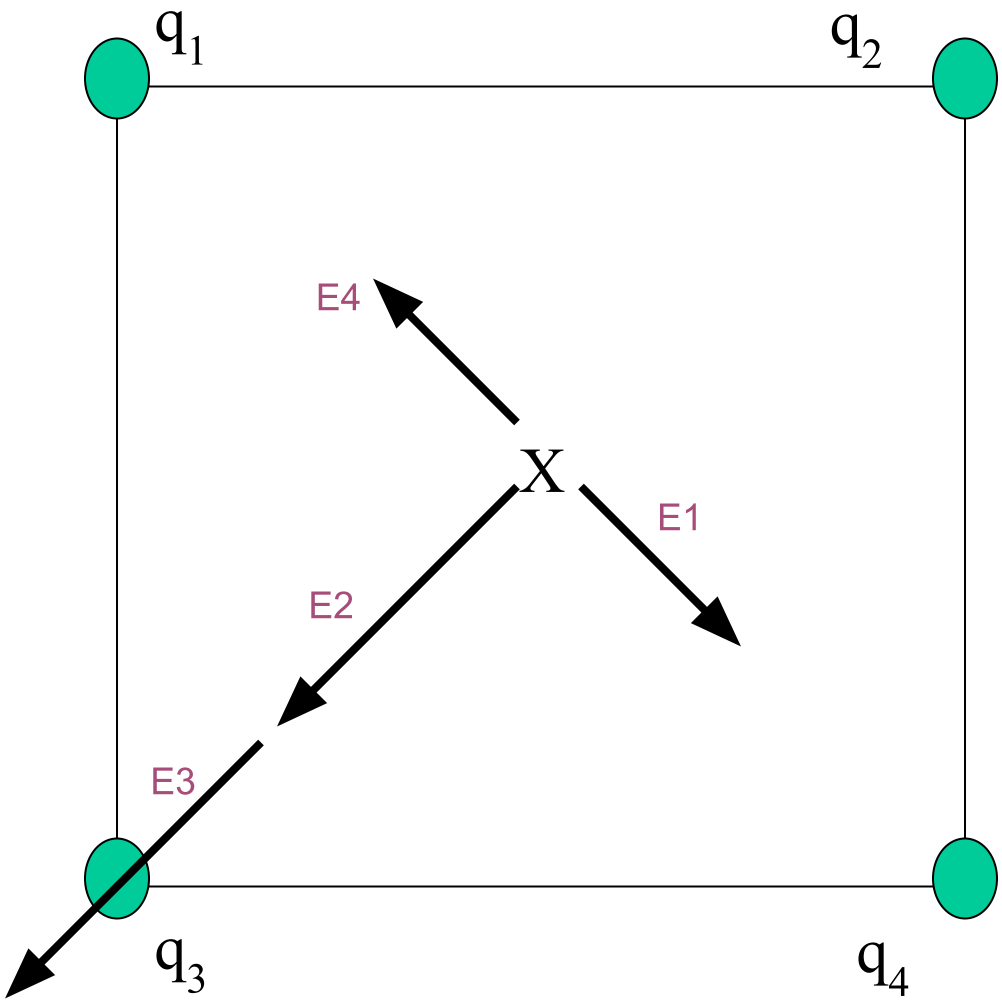
$$\mathbf{E} = \mathbf{E}_1 + \mathbf{E}_2 + \mathbf{E}_3 + \mathbf{E}_4$$

- Note that this is a vector addition of the electric fields from all 4 charges.



What if I have more than 1 charge?

- Suppose
  - $q_1 = +2\ \mu C$
  - $q_2 = +3\ \mu C$
  - $q_3 = -3\ \mu C$
  - $q_4 = +2\ \mu C$



What if I have more than 1 charge?

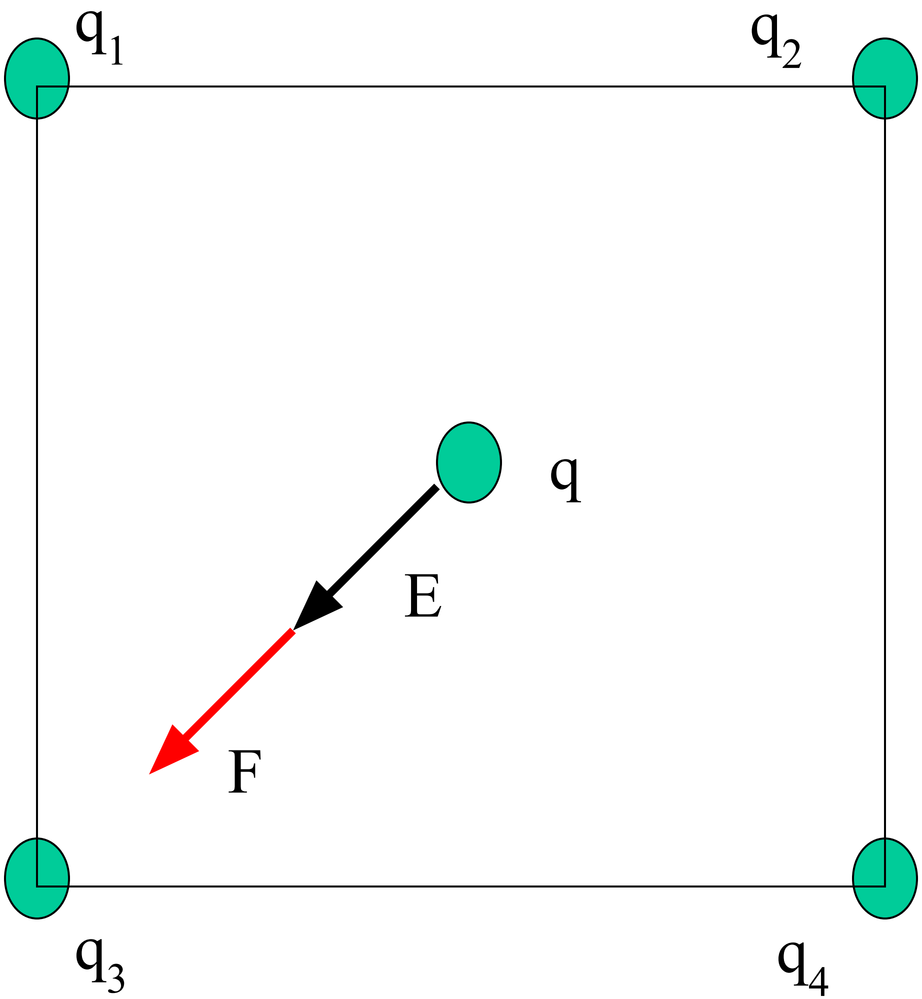
Now put a charge q (+1 μC) at the center of the square?

What is the force acting on the charge?

$\mathbf{F} = q\,\mathbf{E}$

$|\mathbf{E}| = 108{,}000$ N/C

$|\mathbf{F}| = 0.108$ N



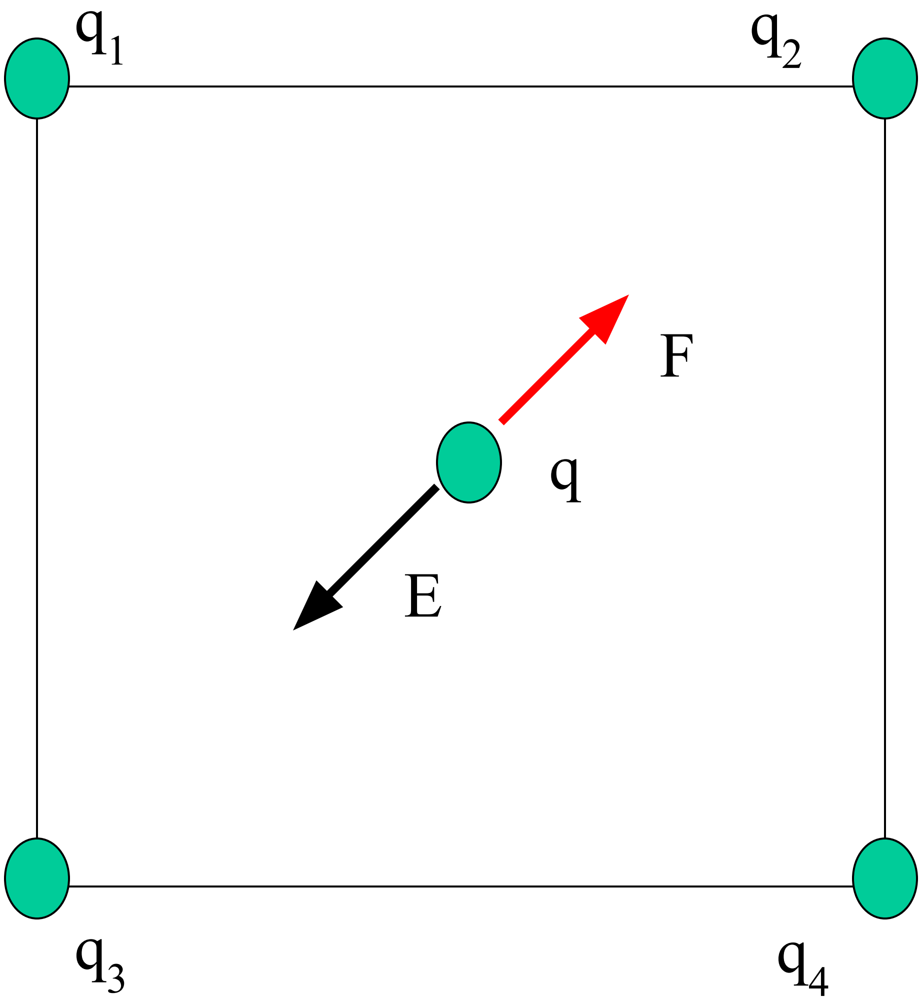
What if I have more than 1 charge?

What if I put a charge q (–1 μC) at the center of the square?

What is the force acting on the charge?

The electric field from the charges on the square has not changed.

The force on q is in the opposite direction as the electric field since q is negative; same magnitude as before, though.



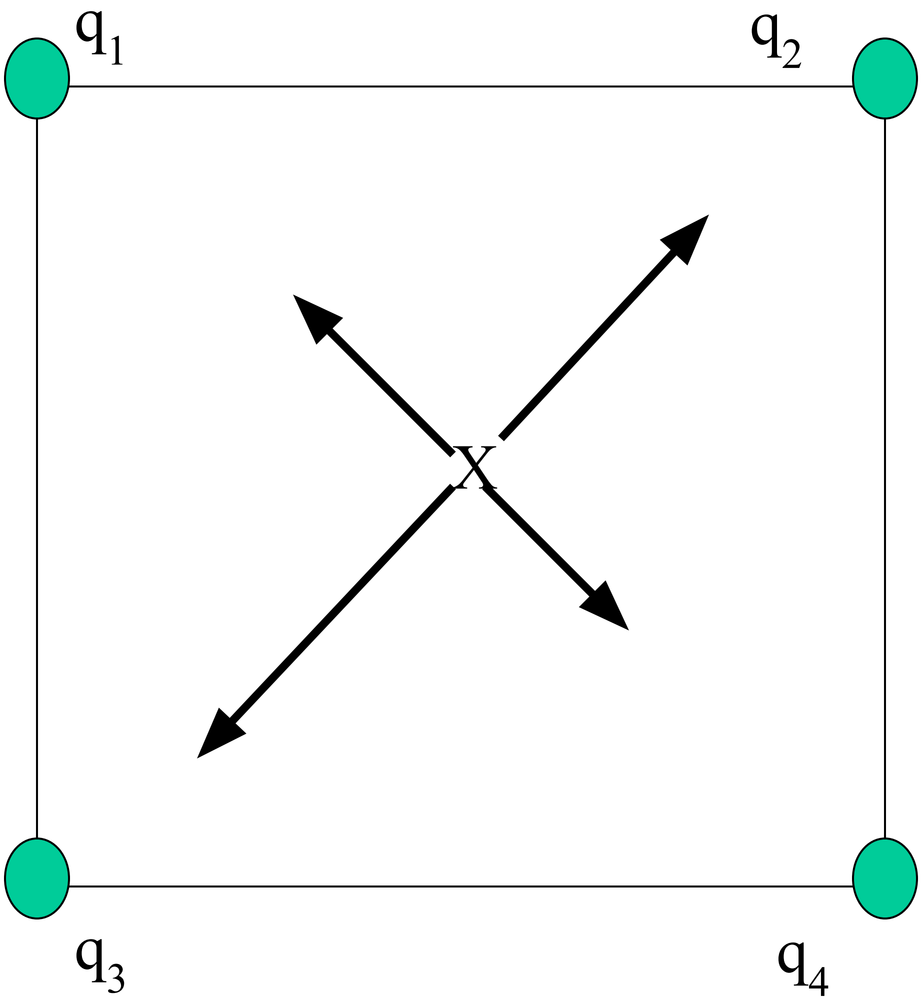
What if I have more than 1 charge?

- What if I change the value of q_3?

  - $q_1 = +2\ \mu C$
  - $q_2 = +3\ \mu C$
  - **$q_3 = +3\ \mu C$**
  - $q_4 = +2\ \mu C$

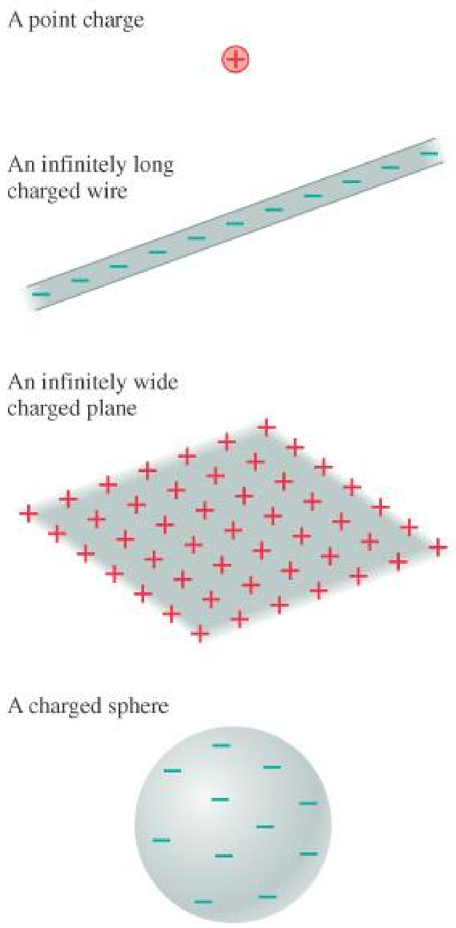
- What is the value of **E** at the center?

- What is the value of **F** on a charge q that I put at the center?



Electric fields to know and love

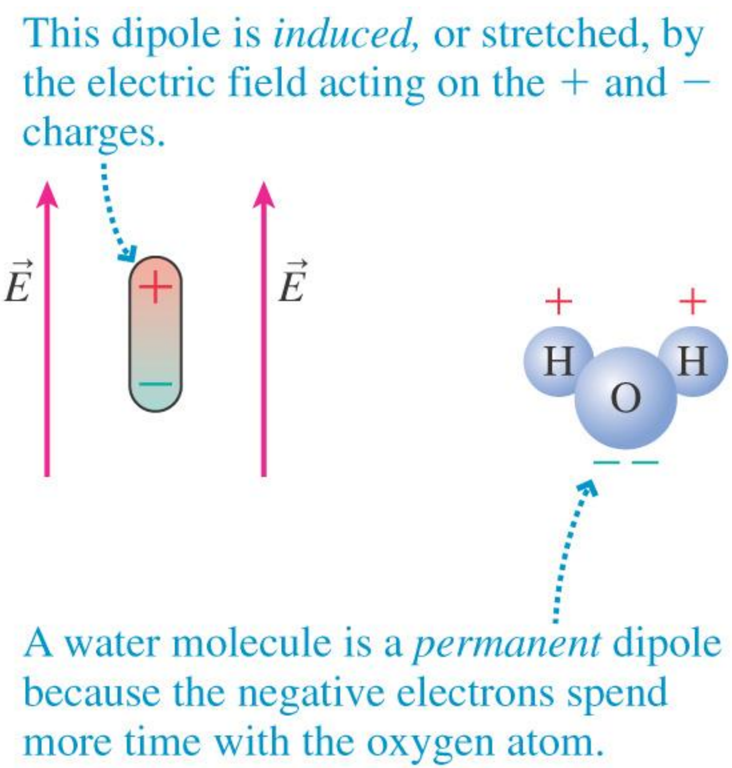
- Four different situations shown to the right will often be encountered in the problems you'll be solving for this course (and even in real life)
- ...or even if the problem doesn't quite look like one of these, you can make some approximations
- For example, if I get very far away from a (finite) charge distribution, I should find an electric field that looks like that due to a point charge
    - this is a good limiting circumstance to take to see if you've done a calculation correctly

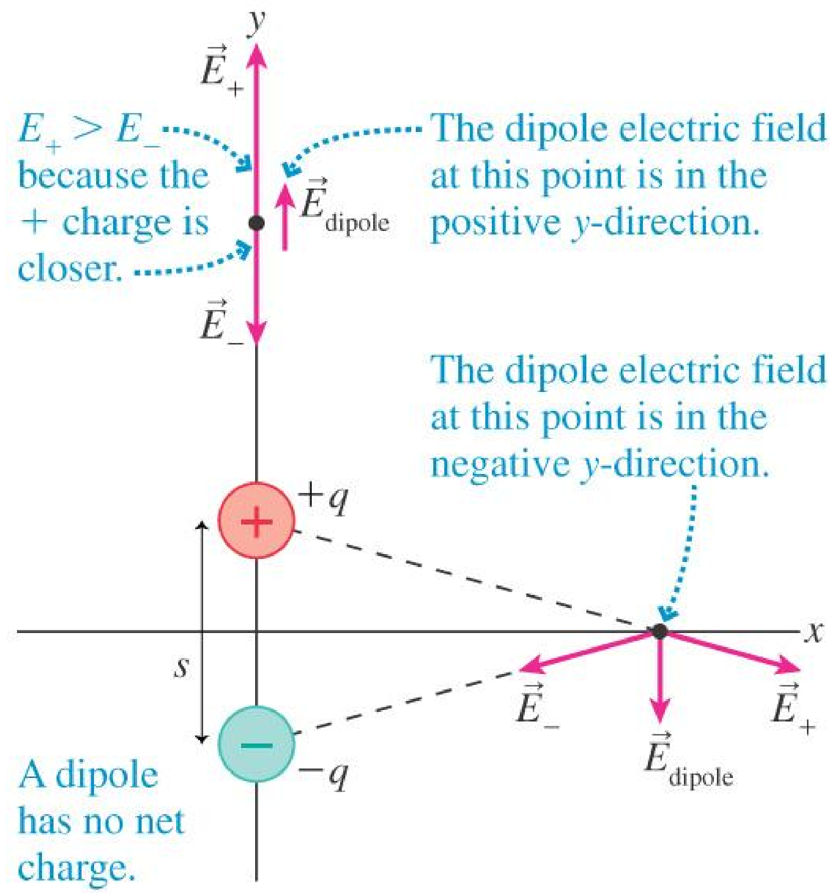


All these cases have a lot of symmetry. Remember that when we get to Gauss' Law.

Electrical dipoles

- We've encountered electric dipoles before, either induced or permanent.
- Now we can calculate the electric field from a dipole





…let's set it up on the blackboard

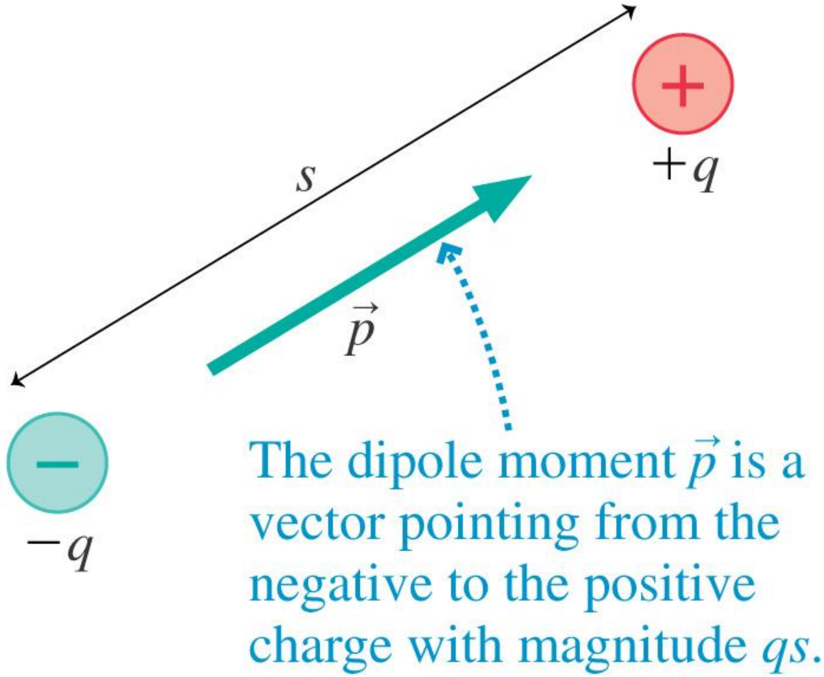
Dipole moments

$\mathbf{p} = q\,\mathbf{s}$

- Define the ***dipole moment p***
  - see the figure
  - **p** is a vector
  - $|\mathbf{p}| = q\,s$

- Then we can write the formula for the electric field of a dipole on the axis of the dipole as

$$\mathbf{E}_{\text{dipole}} \approx \frac{1}{4\pi\,\varepsilon_0}\,\frac{2\,\mathbf{p}}{r^3}$$



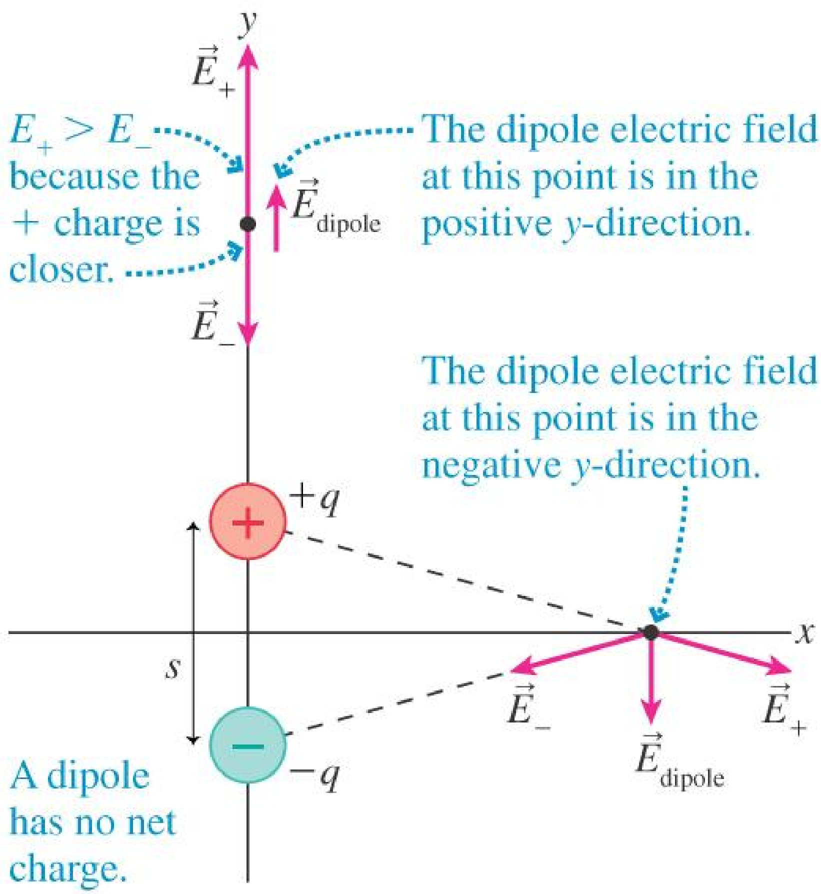
Note that the dipole electric field drops off as $1/r^3$ rather than the $1/r^2$ of a point charge.

Electric dipole

- Along the *x axis*, the general formula for the electric field from a dipole is

$$\mathbf{E}_{\text{dipole}} \approx -\frac{1}{4\pi\,\varepsilon_0}\,\frac{\mathbf{p}}{r^3}$$

- This is opposite the direction of the dipole moment, and half of the magnitude of the field along the y-axis



Remember the demo/calculation with the water

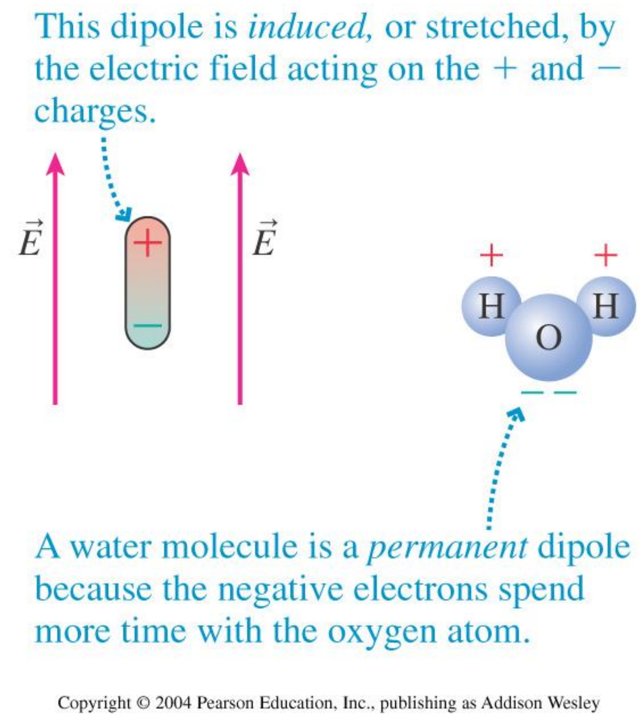
- In the water molecule there is an effective separation of **+** and **−** charge by 3.9 X 10^{-11} m
- So now we can say it has a dipole moment p = (1.6 X 10^{-19} C) (3.9 X 10^{-11} m)

  = 6.2 X 10^{-30} C·m
- We can calculate the electric field on the dipole axis according to the formula on the previous page

$$\mathbf{E}_{\text{dipole}} \approx \frac{1}{4\pi\,\varepsilon_0}\,\frac{2\,\mathbf{p}}{\mathbf{r}^3}$$

- 2 cm away from the molecule, the E field

Suppose we transferred 1E9 electrons from the rod by rubbing it with the silk.



There are equal but opposite forces on the glass rod and on the molecule.

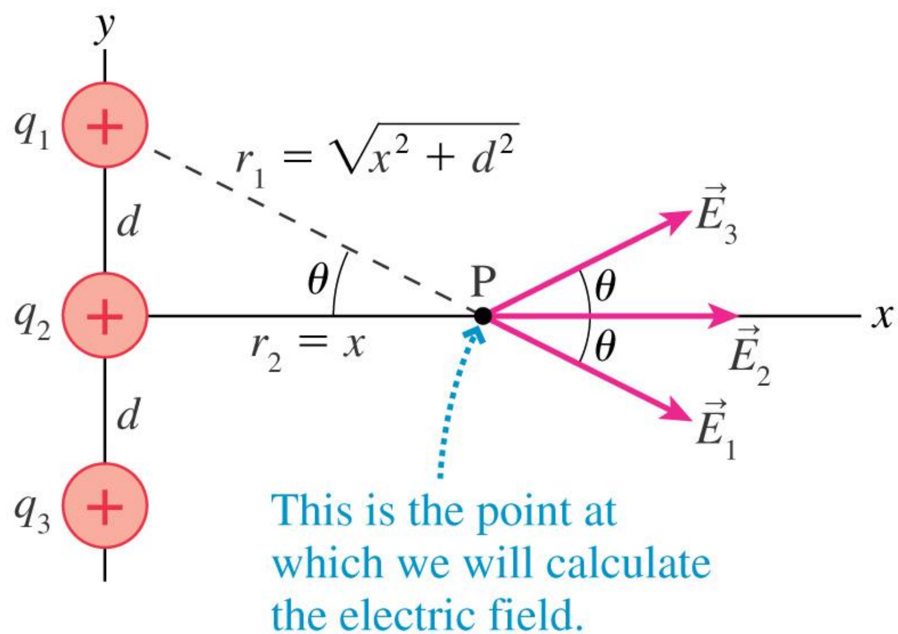
F(on the rod) = $q_{rod}\,E_{dipole}$

= (1.6 X 10^{-10} C) (1.4 X 10^{-14} N/C)

= 2.24 X 10^{-24} N

Electric field from 3 equal + point charges

- In general, $\mathbf{E}_{net} = \mathbf{E}_1 + \mathbf{E}_2 + \mathbf{E}_3$
- I can start by simplifying (for this problem)
  - no component along z direction so $E_z=0$
  - $(E_3)_y$ and $(E_1)_y$ will cancel each other out so there is only a component along the x direction
  - $(E_{net})_x=(E_1)_x + (E_2)_x + (E_3)_x = 2(E_1)_x + (E_2)_x$



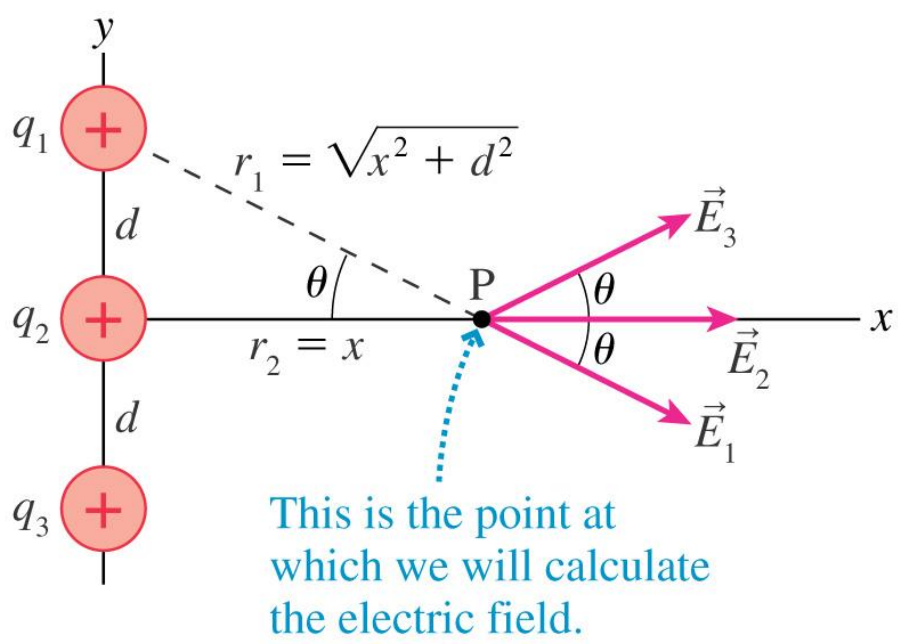
$$\mathbf{E}_{net} = \frac{q}{4\pi\varepsilon_0}\left[\frac{1}{x^2} + \frac{2x}{(x^2+d^2)^{3/2}}\right]\hat{i}$$

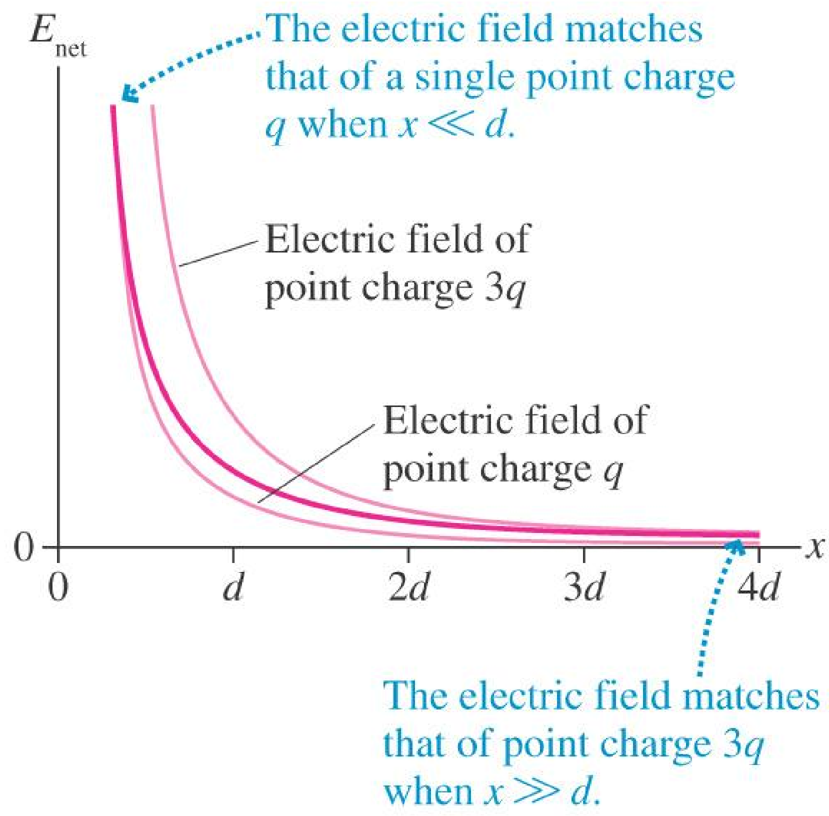
- Far from the charges

$$\vec{E}_{net} \sim \frac{1}{4\pi\epsilon_0}\frac{3q}{x^2}\hat{\imath} \quad \text{for } x \gg d.$$

Limiting cases

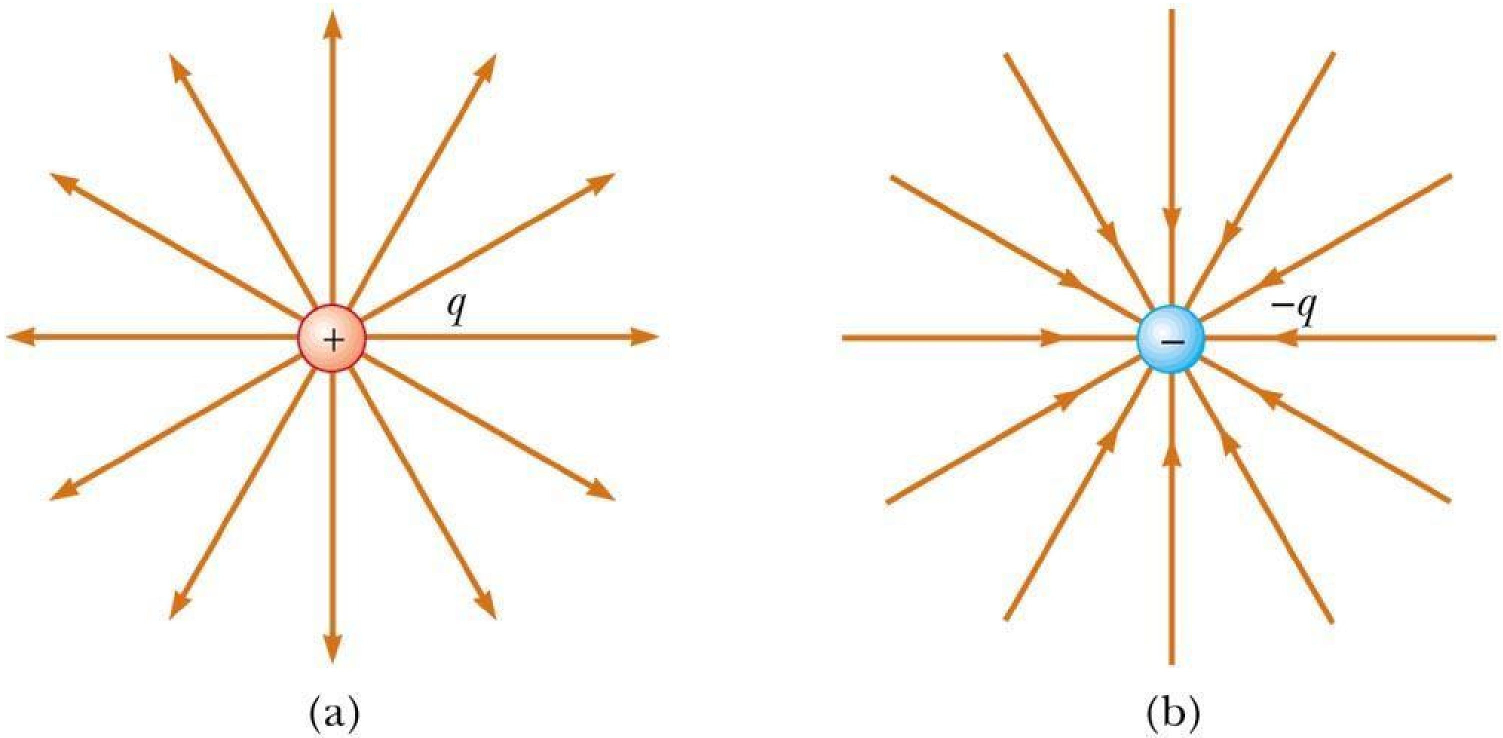
$$E_{net} = \frac{q}{4\pi\,\varepsilon_0}\left[\frac{1}{x^2} + \frac{2x}{(x^2+d^2)^{3/2}}\right]\hat{i}$$





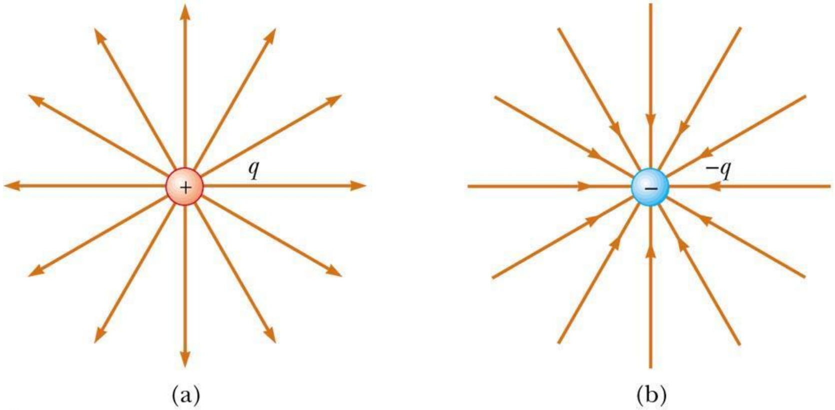
Electric Field Lines ...

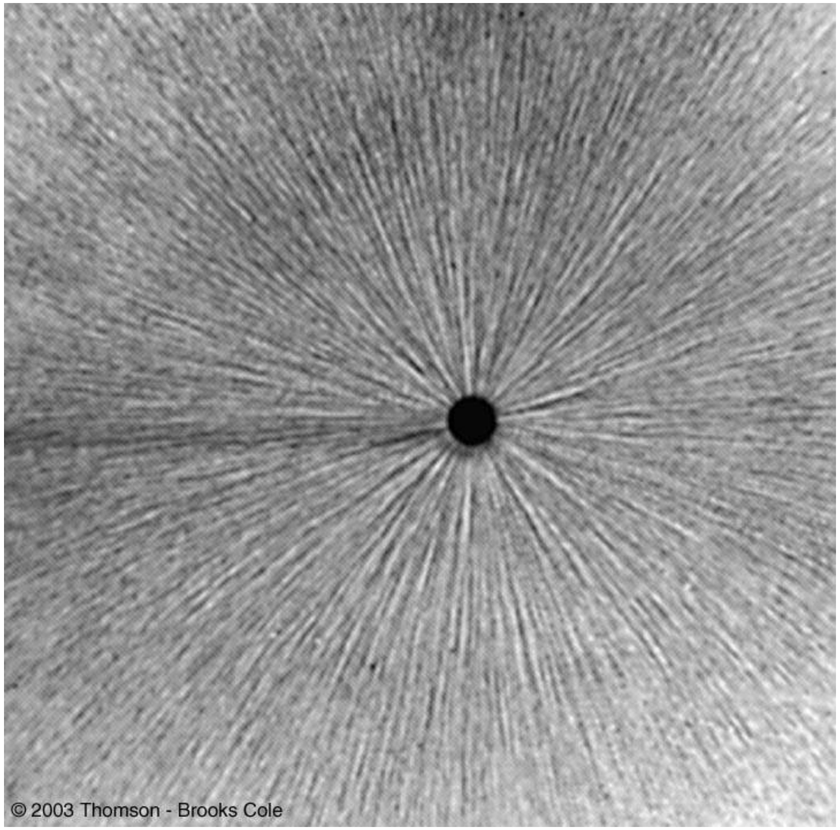
... indicate the direction and magnitude
of the electric field in a region of space



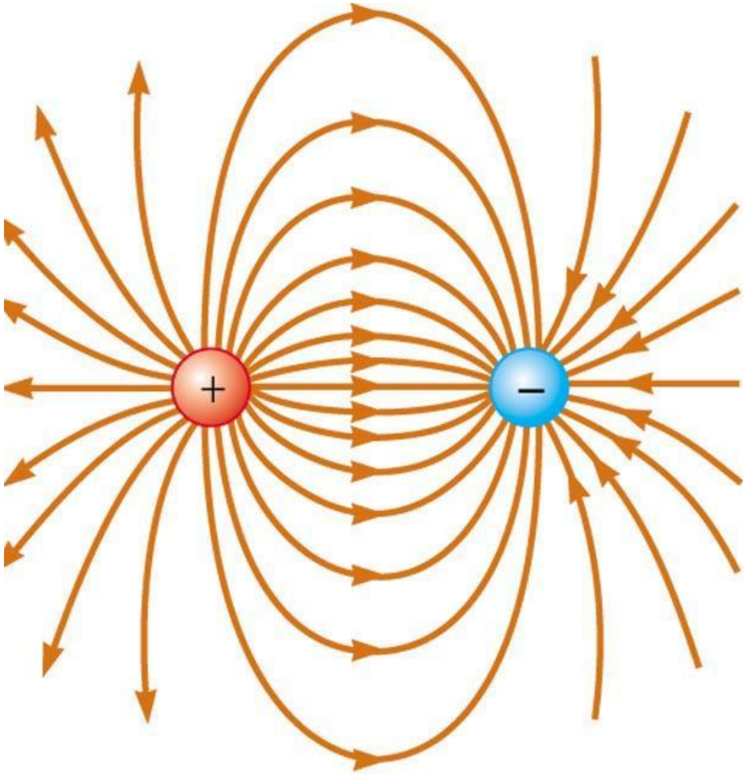
Can we actually **see** the field lines? No, but ...

Single Point Charge

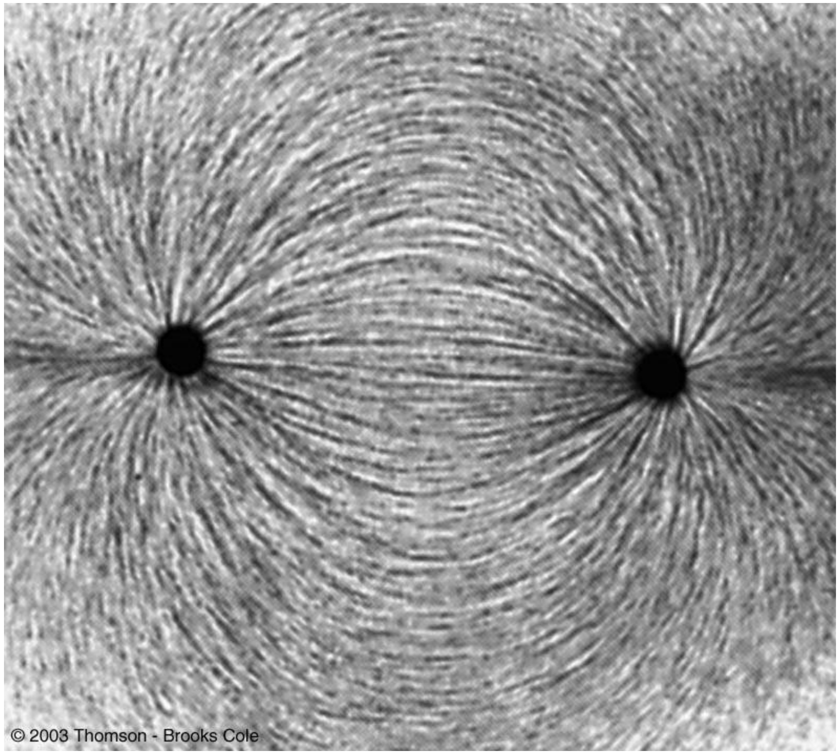




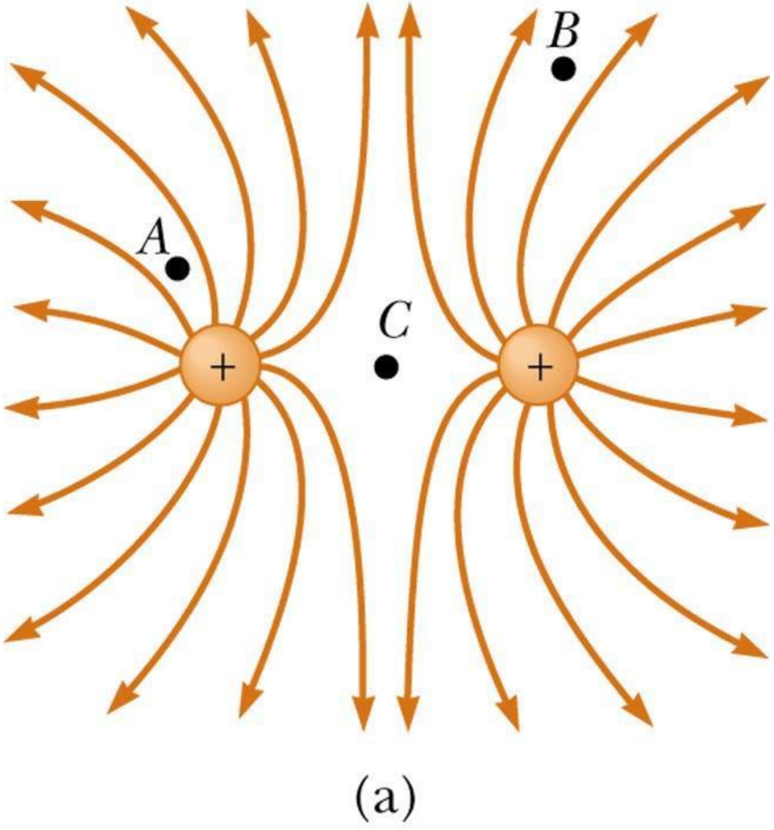
Electric Dipole

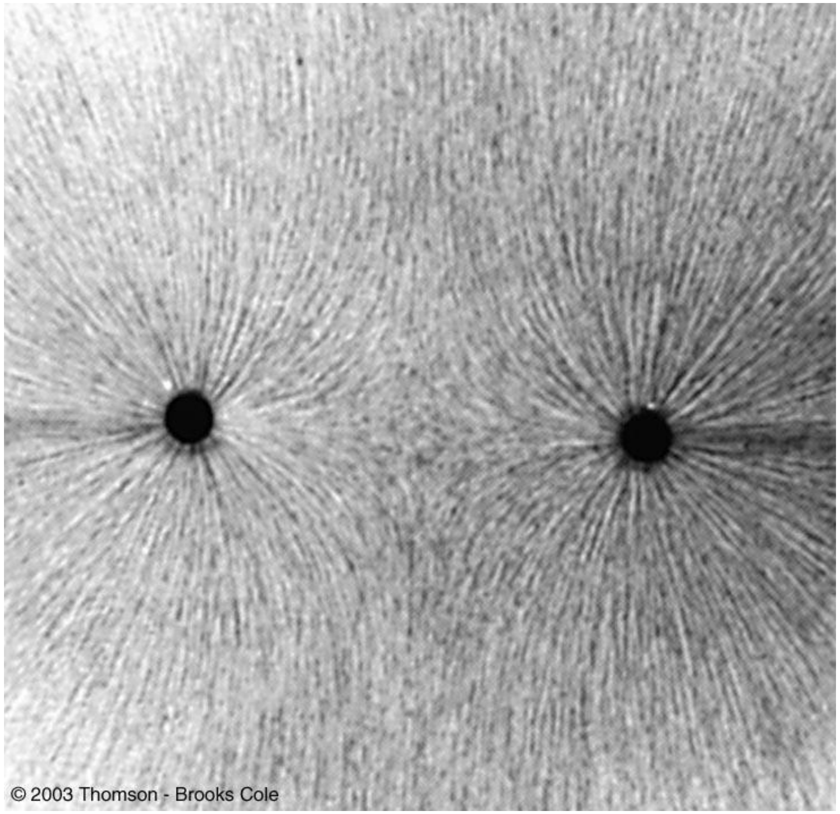


(a)



2 equal positive charges





Drawing and interpreting electric field lines

- Pretty useful idea but we need some guidelines
  - ➔ electric field lines point in direction of field at that point in space
  - ➔ the total number of electric field lines is proportional to the size of the charge
  - ➔ close to an electric charge, the field lines look like that due to the point charge alone
  - ➔ the density of field lines is proportional to the strength of the electric field
  - ➔ electric field lines originate on + charges and terminate on - charges
  - ➔ no 2 field lines can cross in free space
    - ***don't cross the streams***