PURDUE UNIVERSITY DEPARTMENT OF PHYSICS

Physics 21900

# General Physics II

*Electricity, Magnetism and Optics*

*Lecture 4 – Chapter 15.1-2*

***The Electric Field***

Fall 2015 Semester

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# Electrostatic Force and Potential Energy

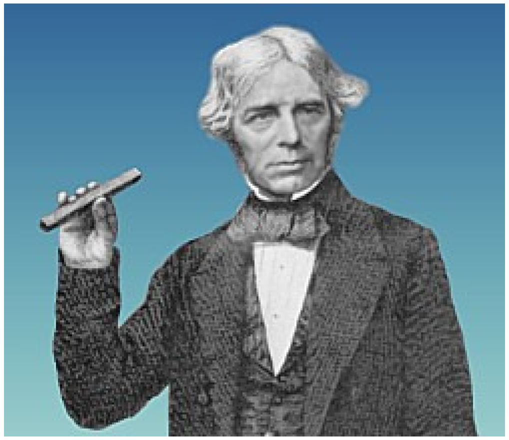
- So far we have seen that charges exert forces on one another:

$$F_q = k\frac{q_1 q_2}{r^2}$$ Coulomb's Law

- Energy can be stored in a configuration of charges:

$$U_q = k\frac{q_1 q_2}{r}$$ Electric potential energy

- How does one charge "know" about another charge when they are not in direct contact?

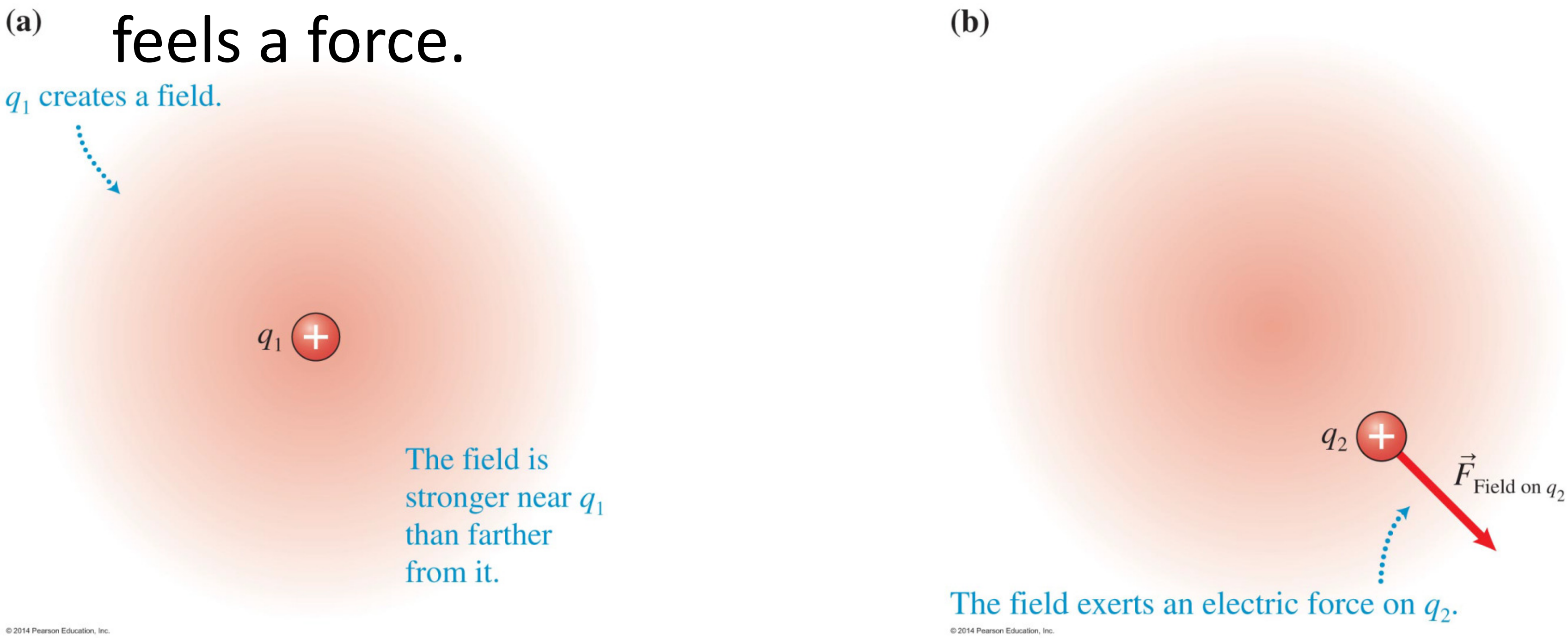


# The Electric Field

- Michael Faraday was very good at coming up with ways to describe electric and magnetic fields that did not rely on just mathematical definitions and equations.
- There is no “right way” to describe how charges influence each other.
- The concept of a “field” turns out to be one of the most fundamental ways of describing Nature…

# The Electric Field

- This time, consider a single charge, $q_1$.
- This charge "creates" an ***electric field*** in the space surrounding it… it modifies the properties of space itself in some way.
- Another charge, $q_2$, when placed in the electric field, feels a force.



# The Electric Field

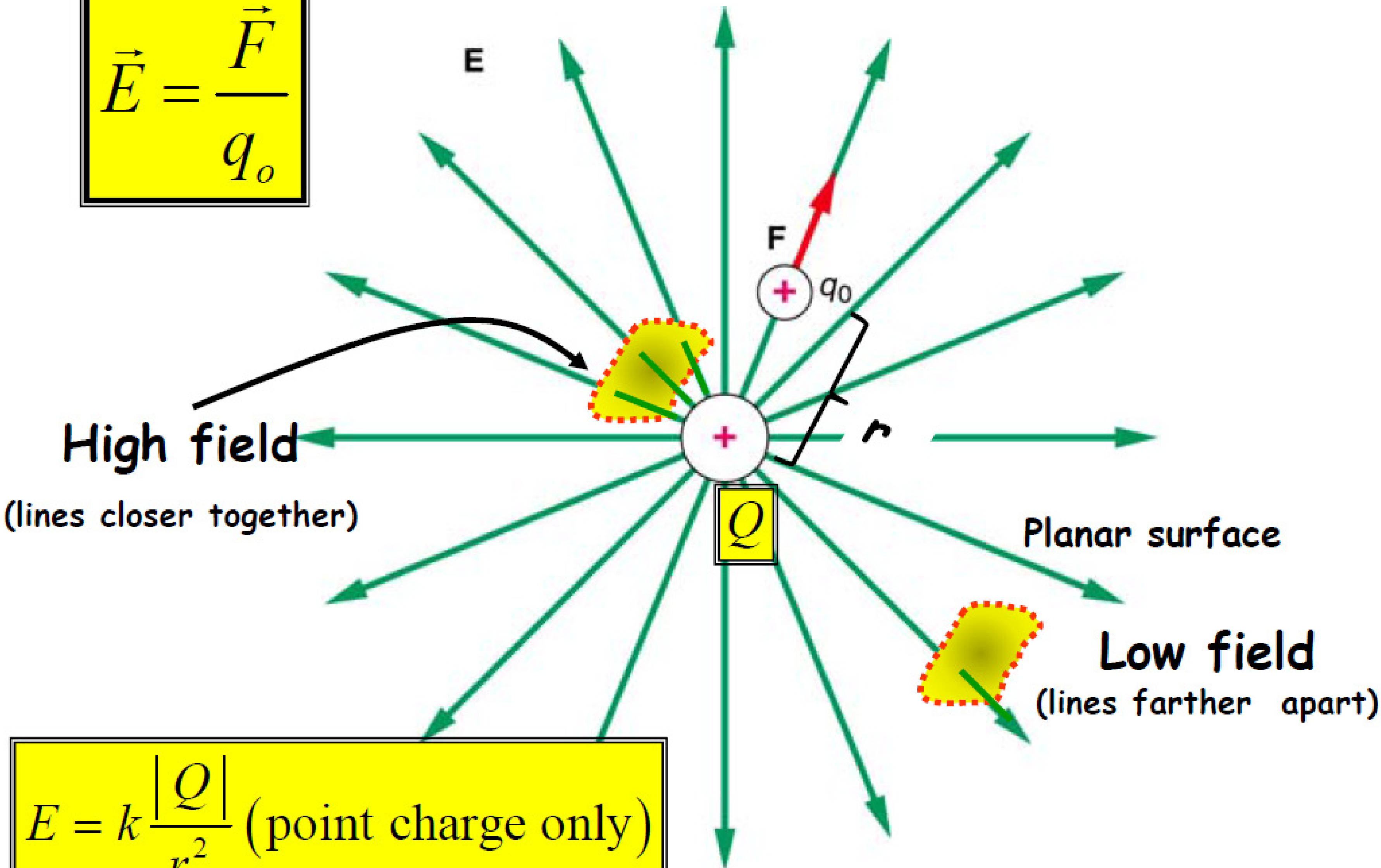
- The electric field produced by a charge $Q$ is a property only of $Q$ and not of other charges we place in its vicinity.
- We define the electric field in terms of the electric force that acts on a "test charge":

$$\vec{F}_Q = k\frac{q_{test}Q}{r^2}\hat{r}$$

$$\vec{E}_Q = \frac{\vec{F}_Q}{q_{test}}$$

# The Electric Field produced by a Positive Point Charge

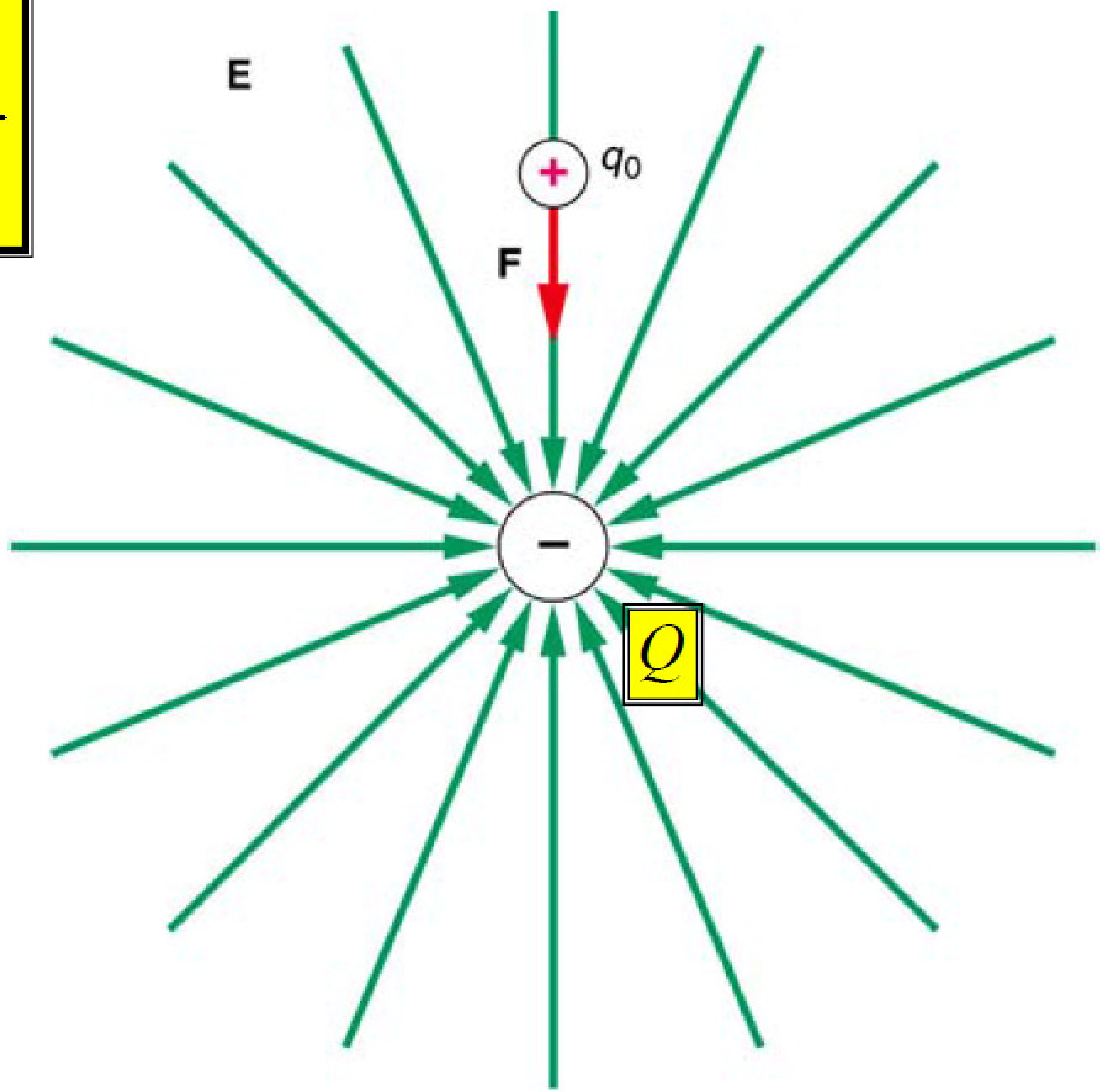
$$\vec{E} = \frac{\vec{F}}{q_o}$$




$$E = k\frac{|Q|}{r^2} \text{ (point charge only)}$$

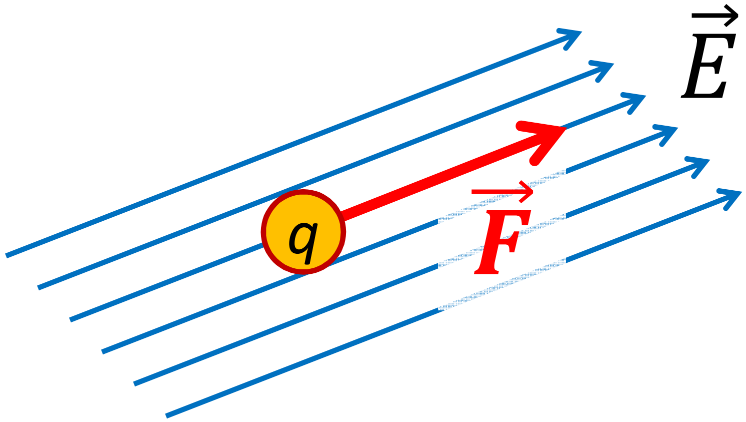
# The Electric Field produced by a Negative Point Charge

$$\vec{E} = \frac{\vec{F}}{q_o}$$



# Electric Field

- Now we can talk about electric fields that occupy a region of space.
- We do ***not*** need to specify the source of the electric field.




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

- Any charge that is placed in the electric field will experience a force.
- Units for electric field: Newtons/Coulomb.

# Electric Fields

- When we have multiple sources, the ***principle of superposition*** says that we get to add their electric fields.
- Just remember that they are vectors:

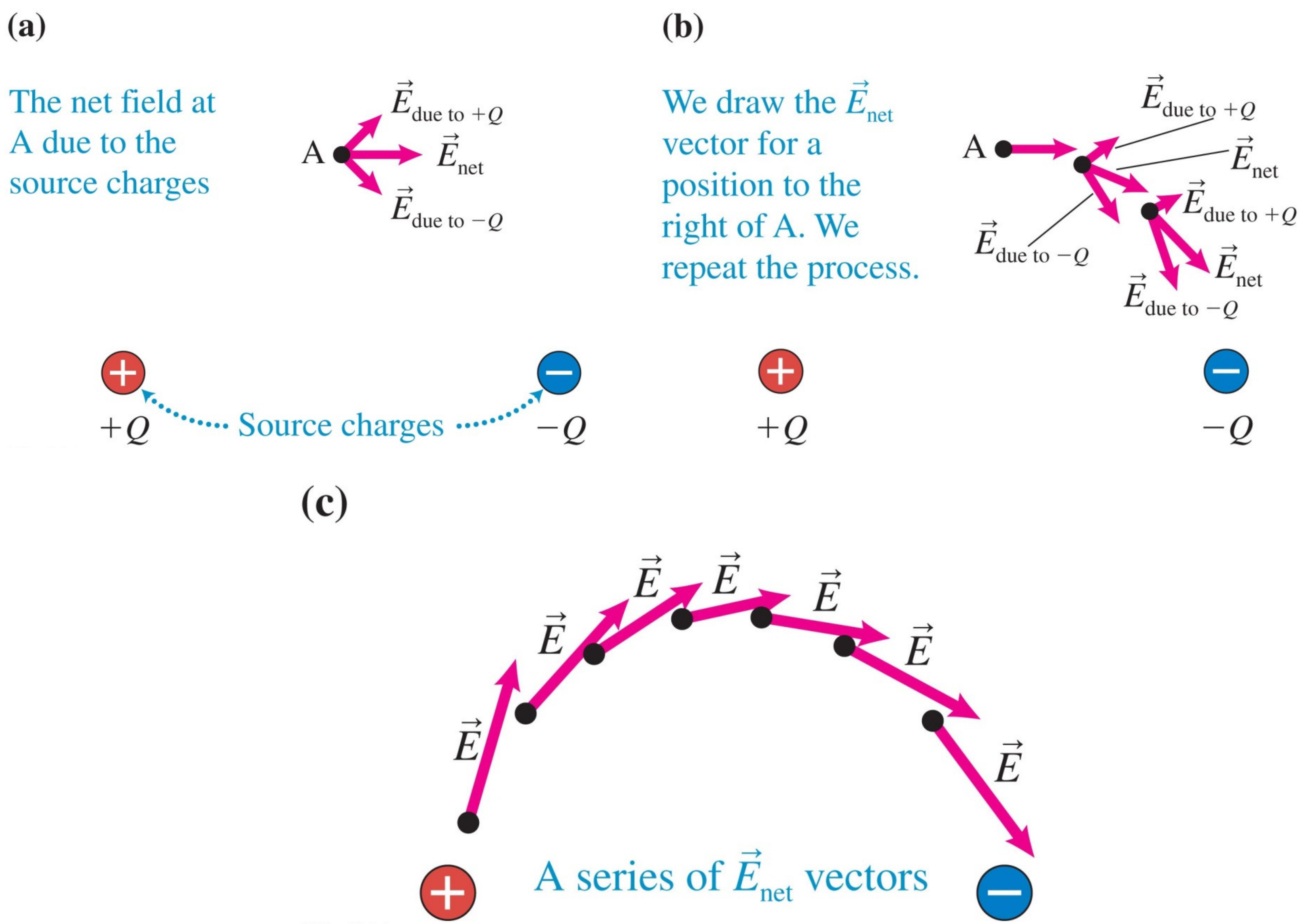
$$\vec{E}(\vec{x}) = \vec{E}_1 + \vec{E}_2 + \vec{E}_3 + \cdots$$

- Each $\vec{E}_i$ is for a single point charge calculated using

$$\vec{E}_i = k\frac{Q_i}{r_i^2}\widehat{r_i}$$

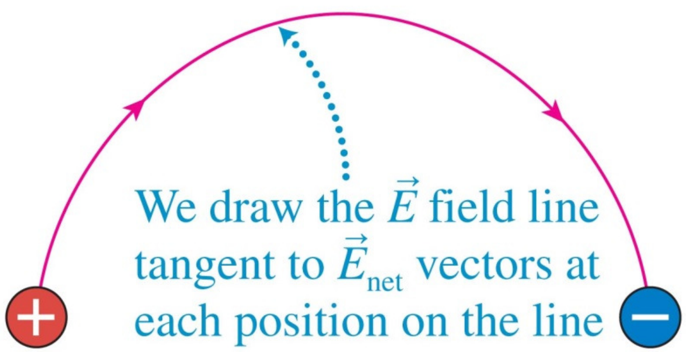
where $\vec{r}_i$ is a vector from the source $Q_i$ to the observation point $\vec{x}$.

# Electric Field Line Diagrams

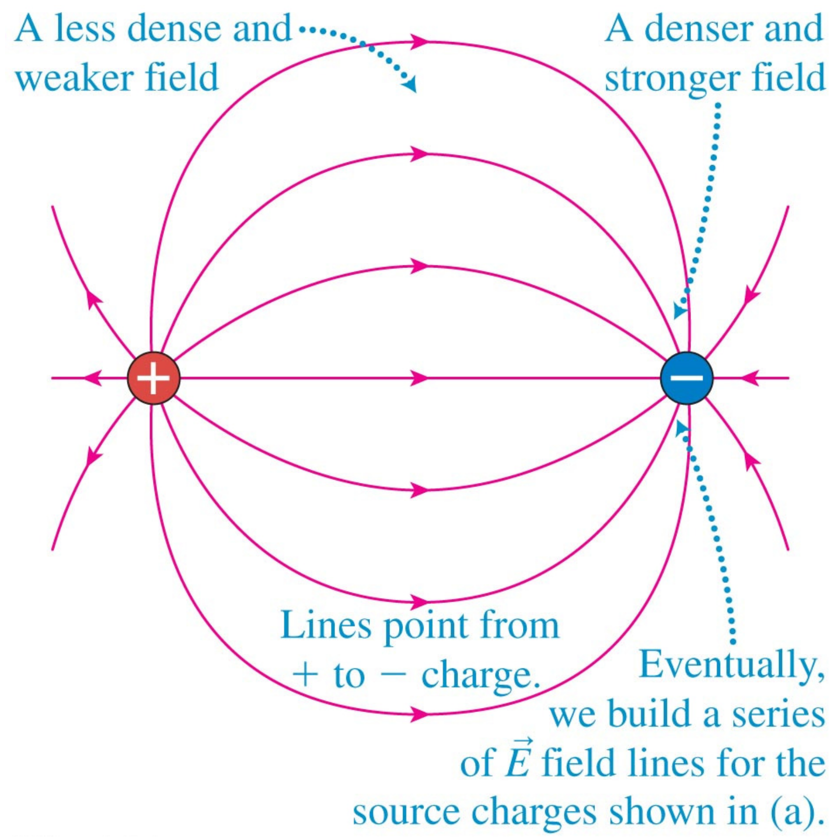


# Electric Field Line Diagrams

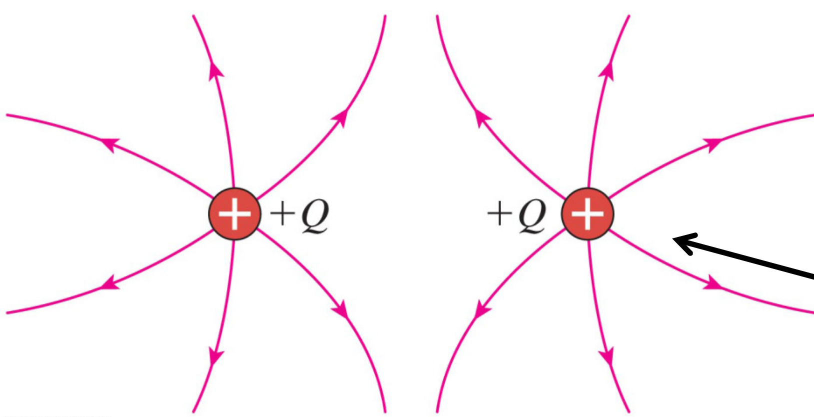
(d)




(e)




(c)

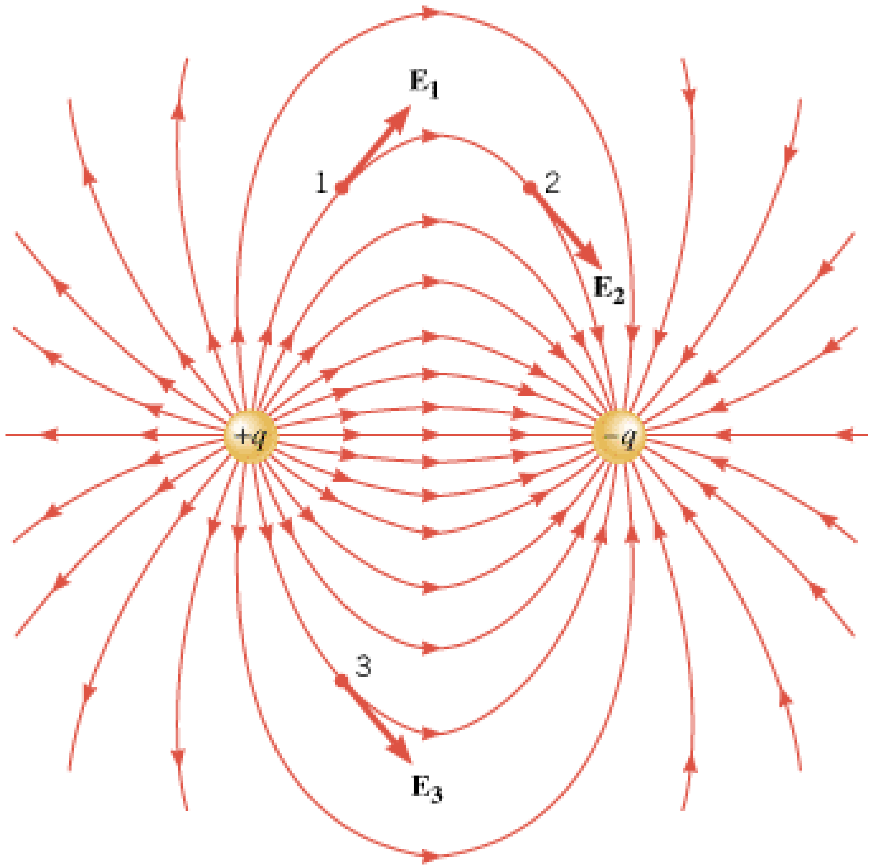




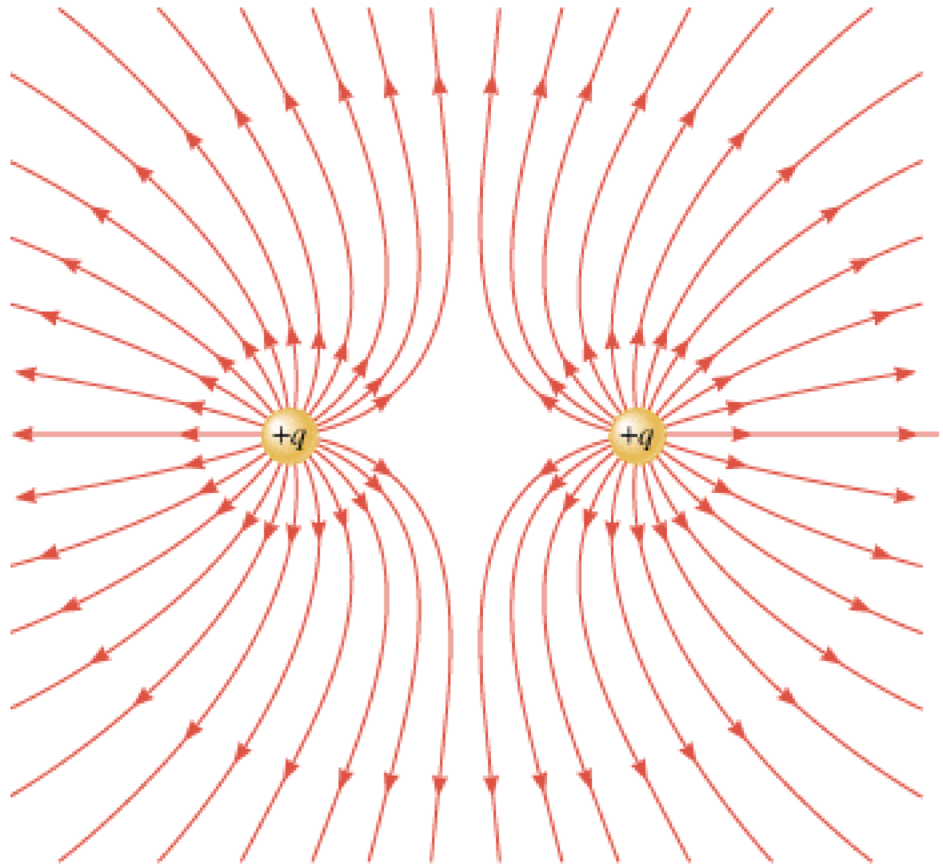

Example with like sign charges!

# Electric Field Lines

Electric Dipole: opposite signs but equal magnitude

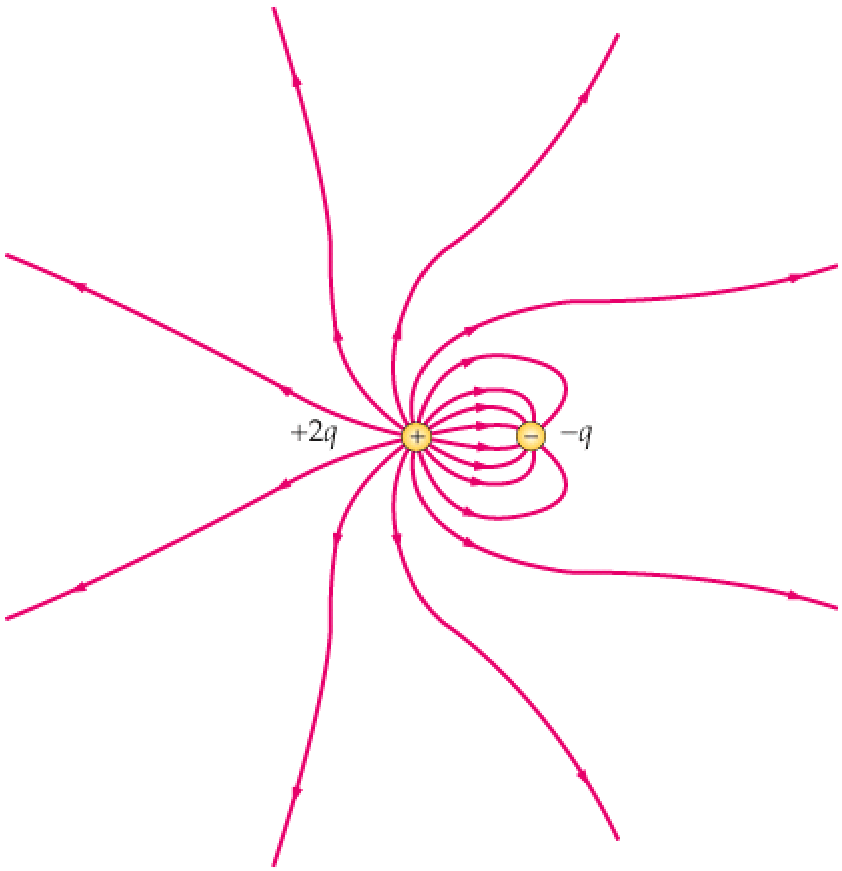



Two Positive Charges: with equal magnitude



# Electric Field Lines

Opposite charges with unequal magnitudes:

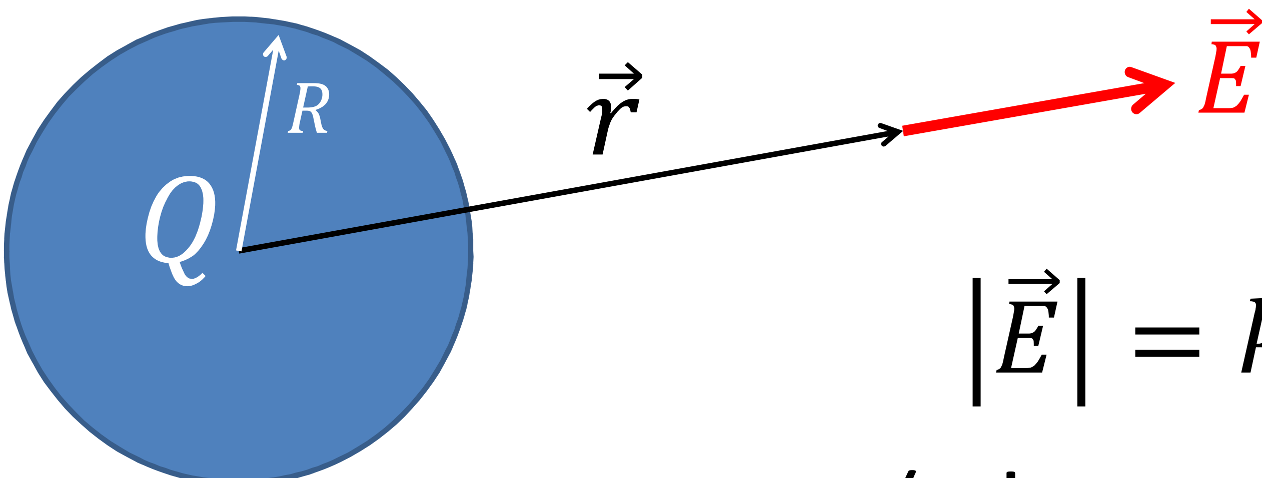



At very large distances, the electric field is the same as one produced by a single point charge with magnitude $Q = +2q - q = +q$.

Density of lines is proportional to the magnitude of the electric field.

# Another Example

- What if it isn't a point charge?
- If the charge distribution is spherically symmetric, the E-field is the same
  - At least it is *outside* the charge distribution…

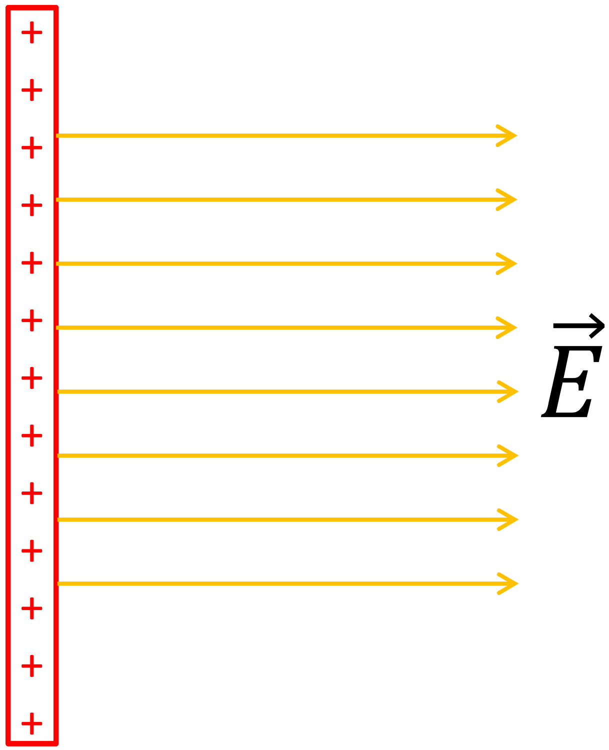



$$|\vec{E}| = k\frac{Q}{r^2}$$

(when $r > R$)

# Another Example

- What is the electric field produced by a large (ie, “infinitely” large) uniform sheet of charge?



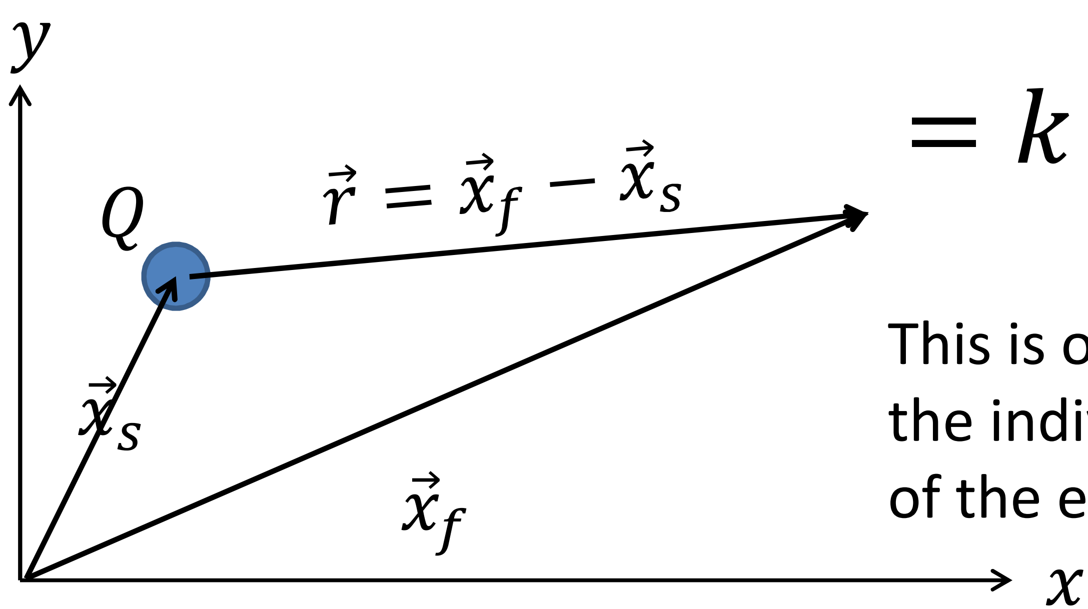

Except near the edges (which we assume are very far away) the electric field is uniform and perpendicular to the surface.

# Calculating The Electric Field

- For a single point charge (the source) located at a position $\vec{x}_s$ calculate the electric field at a point $\vec{x}_f$:

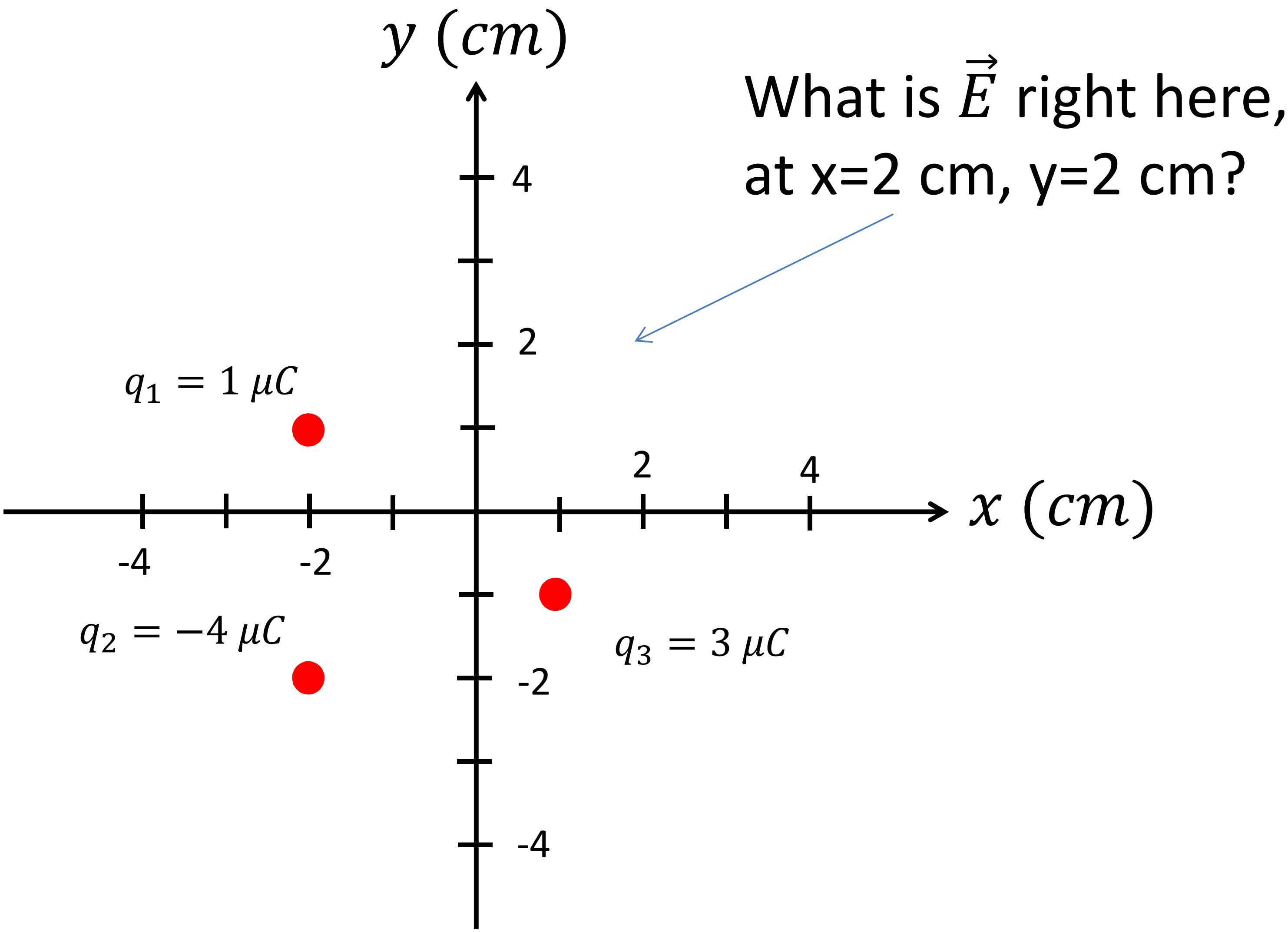
$$\vec{E} = k\frac{Q}{r^2}\,\hat{r} \qquad \hat{r} = \frac{\vec{r}}{r}$$

$$= k\frac{Q}{r^3}\,\vec{r}$$



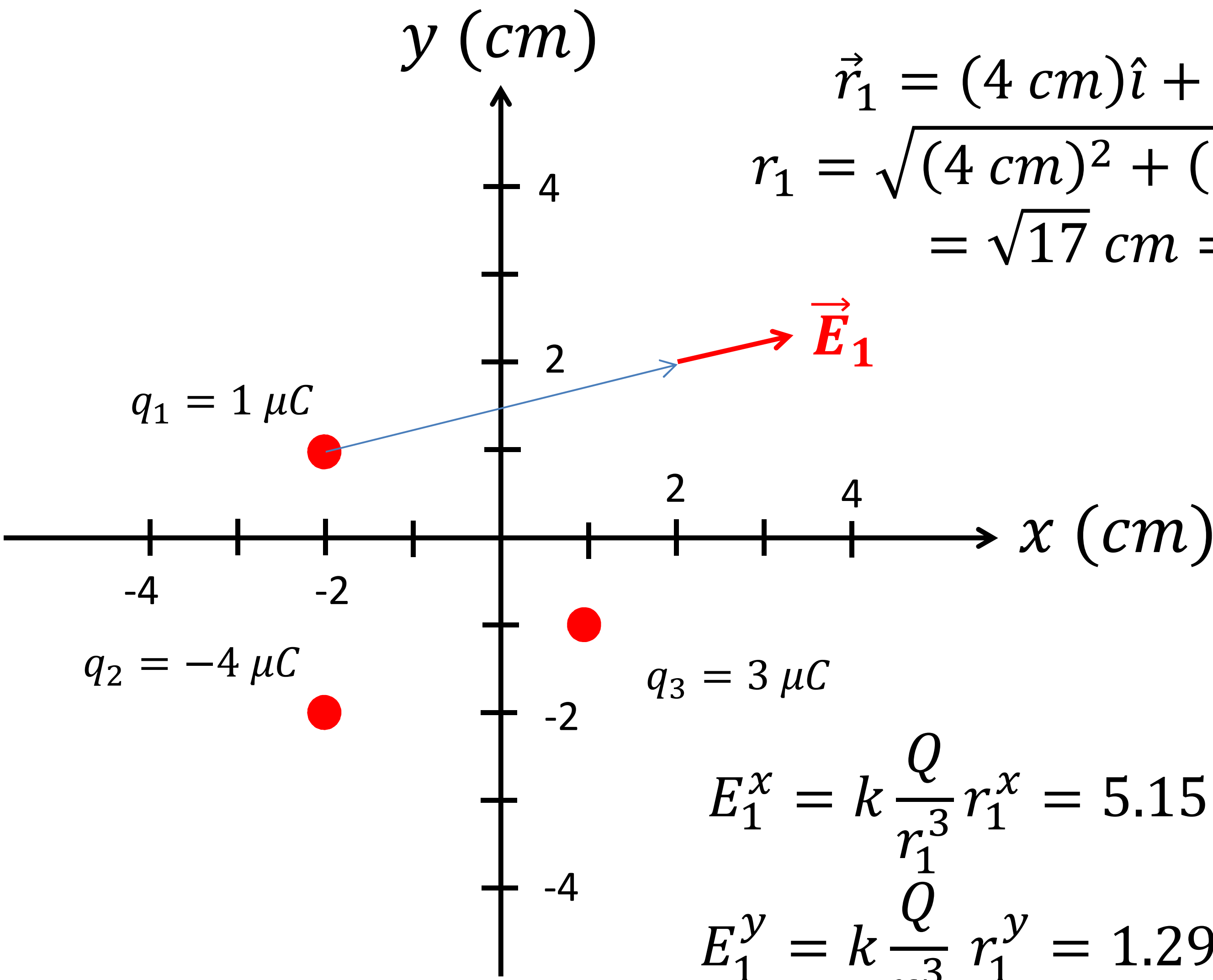

This is one way to calculate the individual components of the electric field vector.

# Example



$y\ (cm)$
4
2
-2
-4
-4
-2
2
4
$x\ (cm)$
$q_1 = 1\ \mu C$
$q_2 = -4\ \mu C$
$q_3 = 3\ \mu C$
What is $\vec{E}$ right here,
at x=2 cm, y=2 cm?

# Example



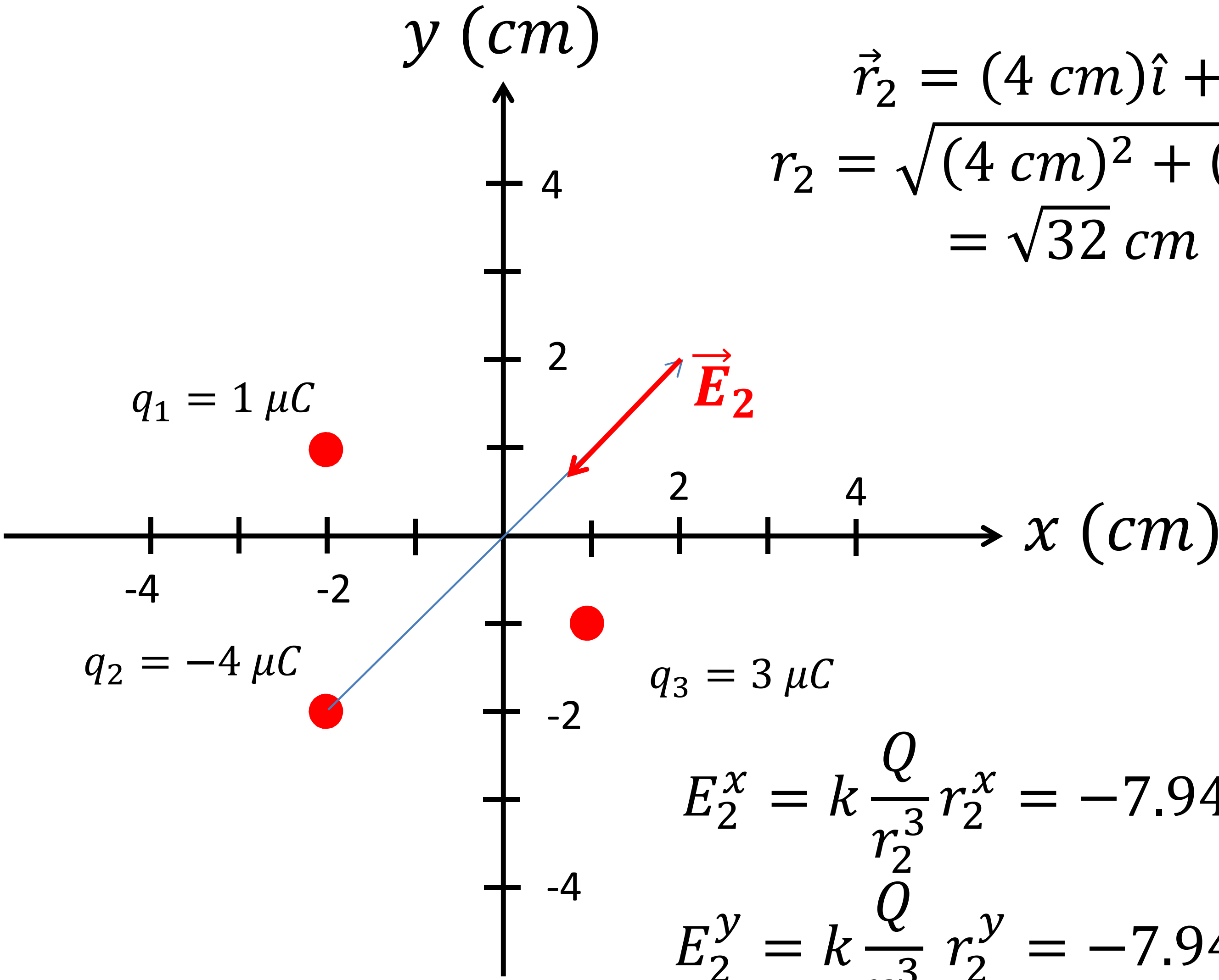

$$\vec{r}_1 = (4\ cm)\hat{\imath} + (1\ cm)\hat{\jmath}$$

$$r_1 = \sqrt{(4\ cm)^2 + (1\ cm)^2}$$
$$= \sqrt{17}\ cm = 0.0412\ m$$

$$E_1^x = k\frac{Q}{r_1^3} r_1^x = 5.15 \times 10^6\ N/C$$

$$E_1^y = k\frac{Q}{r_1^3}\ r_1^y = 1.29 \times 10^6\ N/C$$

# Example



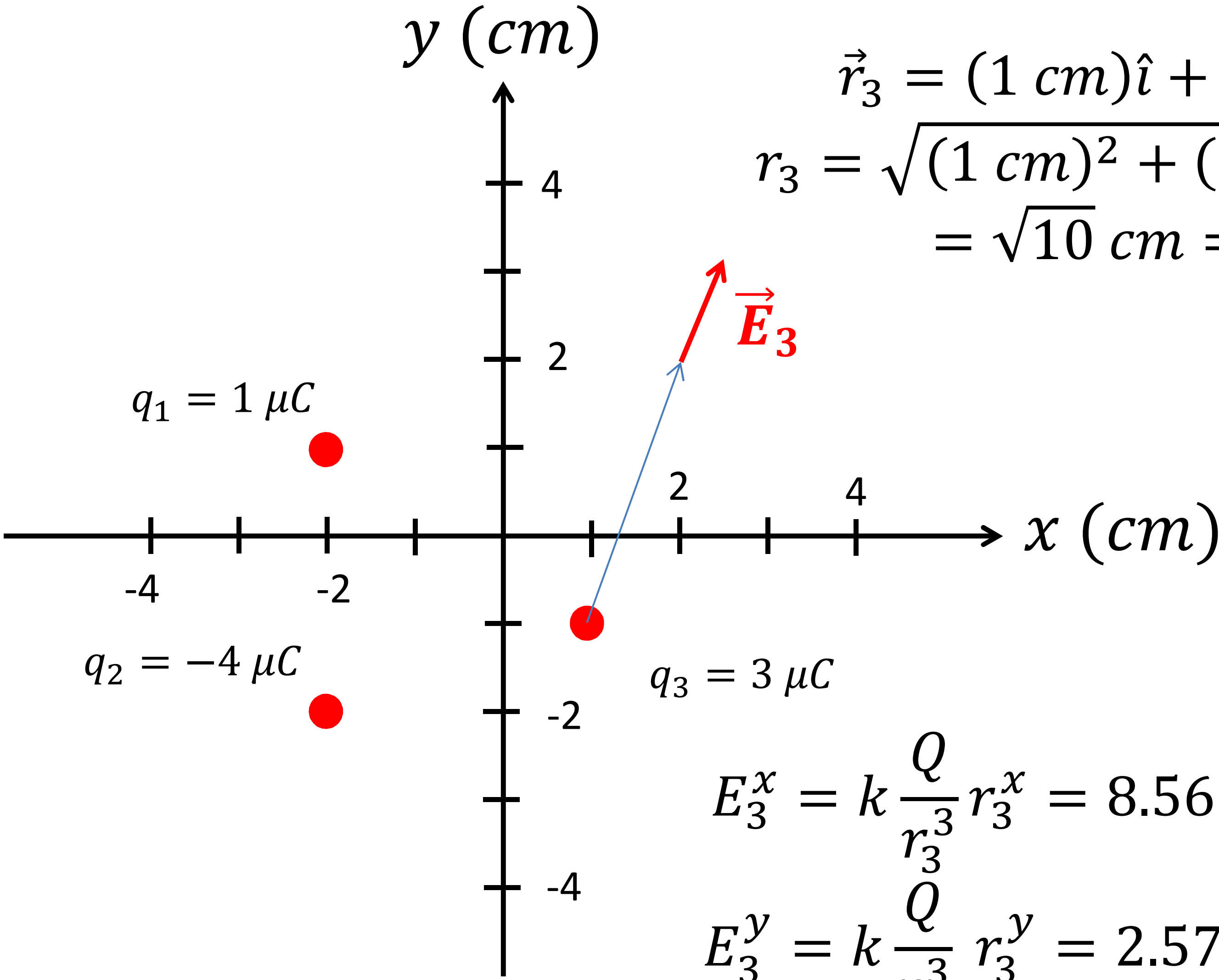

$$\vec{r}_2 = (4\ cm)\hat{\imath} + (4\ cm)\hat{\jmath}$$

$$r_2 = \sqrt{(4\ cm)^2 + (4\ cm)^2}$$
$$= \sqrt{32}\ cm = 0.0566\ m$$

$$E_2^x = k\frac{Q}{r_2^3} r_2^x = -7.94 \times 10^6\ N/C$$

$$E_2^y = k\frac{Q}{r_2^3}\ r_2^y = -7.94 \times 10^6\ N/C$$

# Example




$$\vec{r}_3 = (1\ cm)\hat{\imath} + (3\ cm)\hat{\jmath}$$

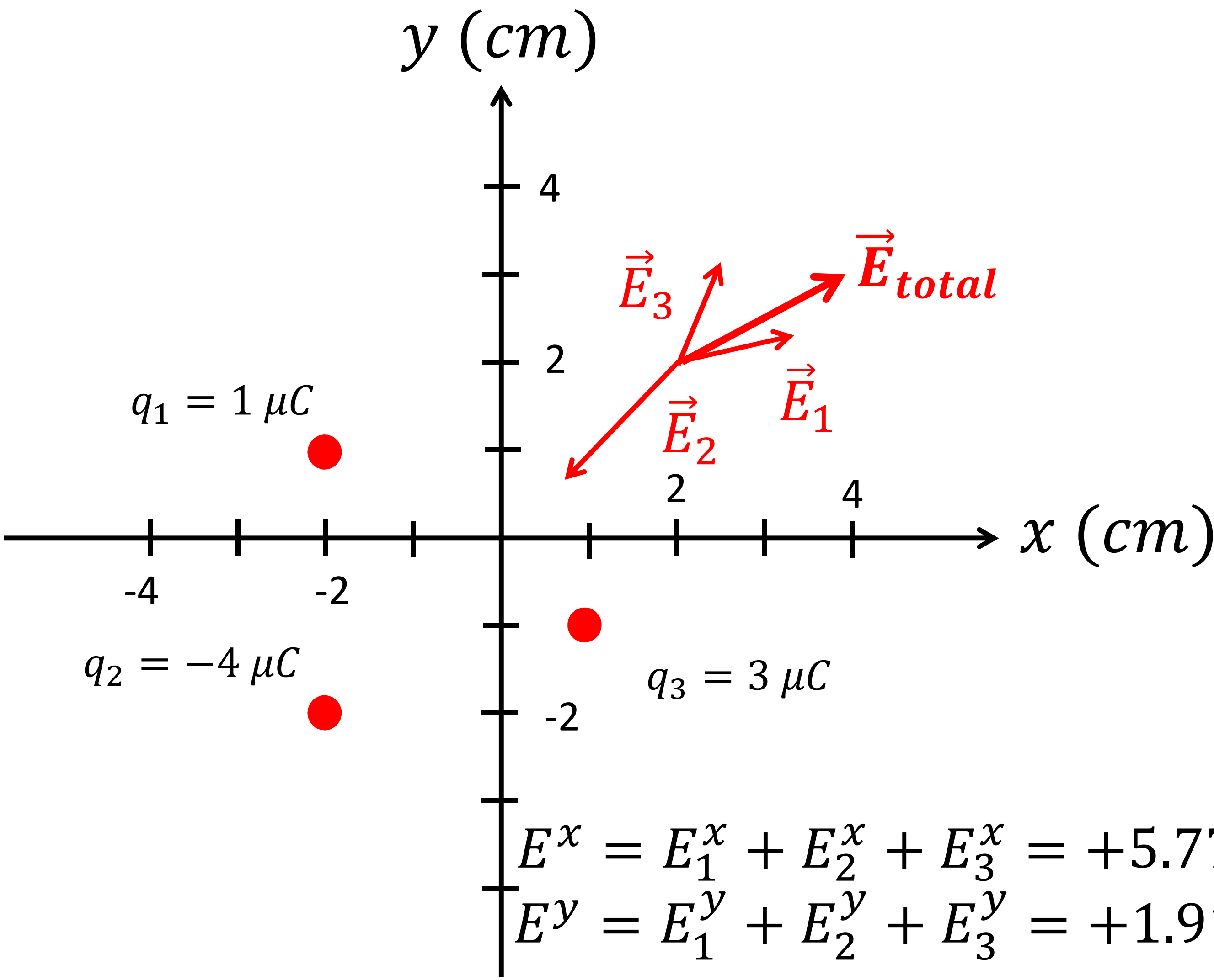
$$r_3 = \sqrt{(1\ cm)^2 + (3\ cm)^2}$$

$$= \sqrt{10}\ cm = 0.0316\ m$$

$$E_3^x = k\frac{Q}{r_3^3} r_3^x = 8.56 \times 10^6\ N/C$$

$$E_3^y = k\frac{Q}{r_3^3}\ r_3^y = 2.57 \times 10^7\ N/C$$

# Example




$$E^x = E_1^x + E_2^x + E_3^x = +5.77 \times 10^6\ N/C$$

$$E^y = E_1^y + E_2^y + E_3^y = +1.91 \times 10^6\ N/C$$

# Summary

- Electric field due to a point charge:

$$\vec{E} = k\frac{Q}{r^2}\,\hat{r}$$

- Force on a charge in an electric field:

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

- Some special cases to remember
  - Spherically symmetric charge distributions
  - Infinite uniform sheet of charge
- Remember that the electric field is a vector
  - Principle of superposition
  - In practice, it is good to be lazy… get a computer to do all the arithmetic for you.