Chapter 23 Section 3: Coulomb's Law

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Reference Book: "Physics for Scientists and Engineers" by R. A. Serway & J. W. Hewett

Similar Book: "Physics for Scientists&Engineers" by D.C.Giancoli

Charles-Augustin de Coulomb

Charles-Augustin de Coulomb 1736-1806

French Physicist (1736-1806)

Best known for discovering

Coulomb's Law

which defines the electrostatic force of attraction & repulsion.

The SI charge unit, *The Coulomb*, was named for him.

After the French revolution, he worked for the government & took part in the determination of weights & measures, which became the **SI unit system**. He did pioneering work in:

Magnetism, Material Strength, Geological Engineering, Structural Mechanics, Ergonomics.

Known for a particular **retaining wall design**.

Point Charge

- The term "***Point Charge***" refers to a particle of zero size that carries an electric charge.
  - It s assumed that a **Point Charge** has the infinitesimal size of a mathematical point.
  - A **Point Charge** is analogous to a **Point Mass**, as discussed in **Physics I.**
  - The (**classical***) electrical behavior of electrons and protons is well described by modeling them as point charges.

* ***A correct treatment should be quantum mechanical!***

Notation for Point Charges: **Either q or Q.**

- As we already discussed, the **SI Charge Unit** is

***The Coulomb* (C).**

- Further, **the electronic charge e** is the smallest possible charge (except for quarks in atomic nuclei).

$$e = 1.6 \times 10^{-19}\ C$$

- So a charge of **q = 1 C** must contain

6.24 x 10^18 *electrons or protons*!!

- Typically, the charges we'll deal with will be in the **μC** range.
- In the following discussion we will, of course, need to remember that

Forces are vector quantities!!!

Properties of Electrons, Protons, & Neutrons

TABLE 23.1 *Charge and Mass of the Electron, Proton, and Neutron*

Particle	Charge (C)	Mass (kg)
Electron (e)	$-1.602\,176\,5 \times 10^{-19}$	$9.109\,4 \times 10^{-31}$
Proton (p)	$+1.602\,176\,5 \times 10^{-19}$	$1.672\,62 \times 10^{-27}$
Neutron (n)	0	$1.674\,93 \times 10^{-27}$

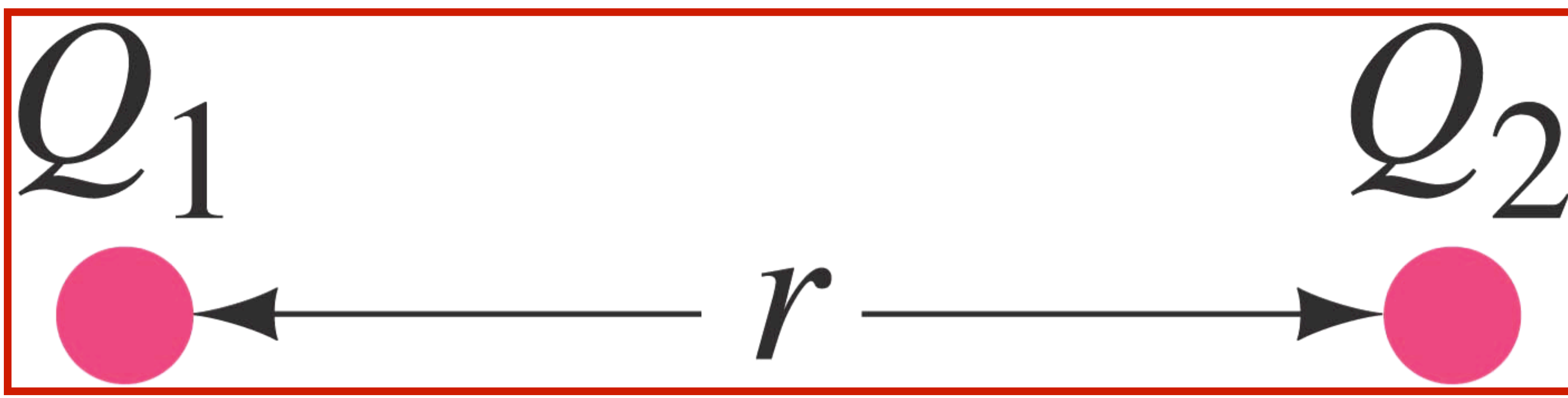
Note that:

- **The electron and proton** have charges of the same magnitude, but their masses differ by a factor of about ***1,000!***
- **The proton and the neutron** have similar masses, but their charges are very different.

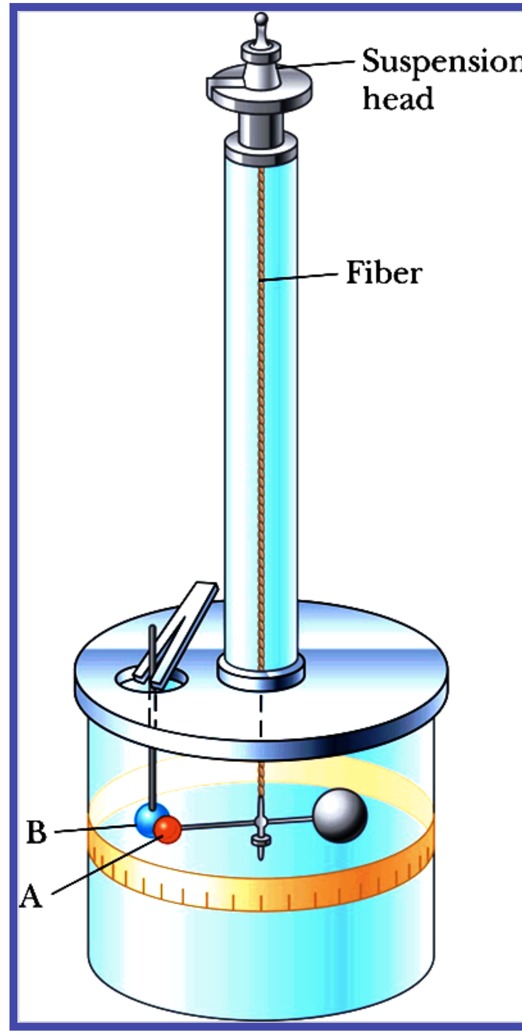
Experimental Fact

Discovered by Coulomb:

The electric force between two charges is **proportional to the product of the charges** & **inversely proportional to the square of the distance between them.**



Coulomb measured the magnitudes of electric forces between 2 small charged spheres using an apparatus similar to that in the figure.



As we just said, ***he found that***

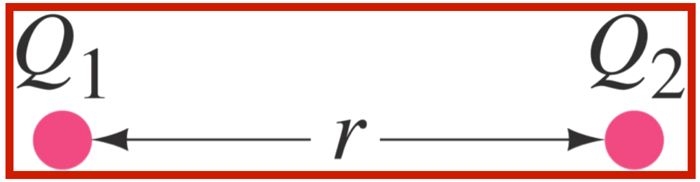
1. The force is ***inversely proportional*** to the ***square*** of the separation **r** between the charges & **directed along the line** joining them.

2. The force is ***proportional*** to the ***product*** of the charges, q_1 & q_2.

The electrical force between two stationary point charges is given by

Coulomb's Law.

Coulomb's Law



The Coulomb Force between 2 point charges **Q_1 & Q_2** has the form:

$$F = k\frac{Q_1 Q_2}{r^2}.$$

k is a universal constant. Our book calls it **k_e**.

In SI units, it has the value

$k = k_e = 8.9876 \times 10^9\ \mathrm{N \cdot m^2/C^2}$

Coulomb's Law

The Coulomb Force between 2 point charges **q_1 & q_2** has the form:

$$F_e = k_e \frac{|q_1||q_2|}{r^2}$$

k_e is called the **Coulomb Constant**

In SI units, it has the value:

$k = k_e = 8.9876 \times 10^9$ N·m²/C²

Often, it is written as **$k_e = 1/(4\pi\varepsilon_o)$**. **$\varepsilon_o$** is called

The permittivity of free space.

In SI units, ε_o has the value

$\varepsilon_o = 8.8542 \times 10^{-12}\ C^2 / N{\cdot}m^2$

Coulomb's Law

$$F_e = k_e \frac{|q_1||q_2|}{r^2}$$

- Of course the ***Coulomb Force must be consistent*** with the experimental results that it:
- Is ***attractive*** if q_1 & q_2 are of **opposite sign**.
- Is ***repulsive*** if q_1 & q_2 are of **the same sign**.
- Is a ***conservative force.***
- Satisfies ***Newton's 3rd Law***.

Relation between Gravitation and Electricity!

- Compare ***Coulomb's Law Electrostatic Force*** between 2 point charges:

$$F_e = k_e \frac{|q_1||q_2|}{r^2}$$

& ***Newton's Universal Gravitation LawForce*** between 2 point masses:

$$F_G = G\frac{m_1 m_2}{r^2}$$

- Mathematical **Similarity:**

  The two forces have ***The same*** **r** ***dependence*** **r^{-2}** **(*inverse* r-*squared*)!!**

- A huge numerical **Difference:**

  The two constants **k_e & G** are ***Orders of magnitude different in size!***

- Compare:

  $k_e = 8.9876 = 10^9$ N·m²/C² &

  $G = 6.674 = 10^{-11}$ N·m²/kg²

- Compare:

$$k_e = 8.9876 \times 10^9 \ N{\cdot}m^2/C^2 \qquad \&$$

$$G = 6.674 \times 10^{-11} \ N{\cdot}m^2/kg^2$$

- This means that

The Gravitational Force is ***orders of magnitude smaller*** than the **Coulomb Force!**

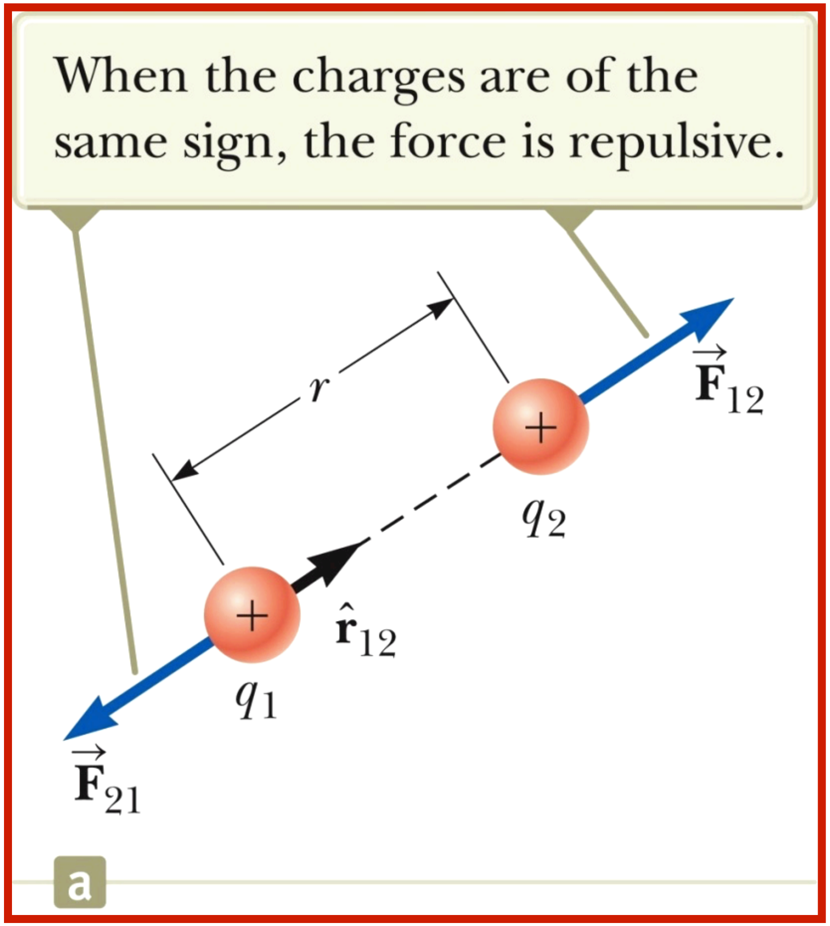
- ***Why?*** That is a philosophical question & not a physics question! It's an interesting question, but I don't know why & for physics it doesn't matter!

Vector Nature of Electric Forces

- Since it is a force, **The Coulomb Force** obviously must be a vector. In vector form, it is written:

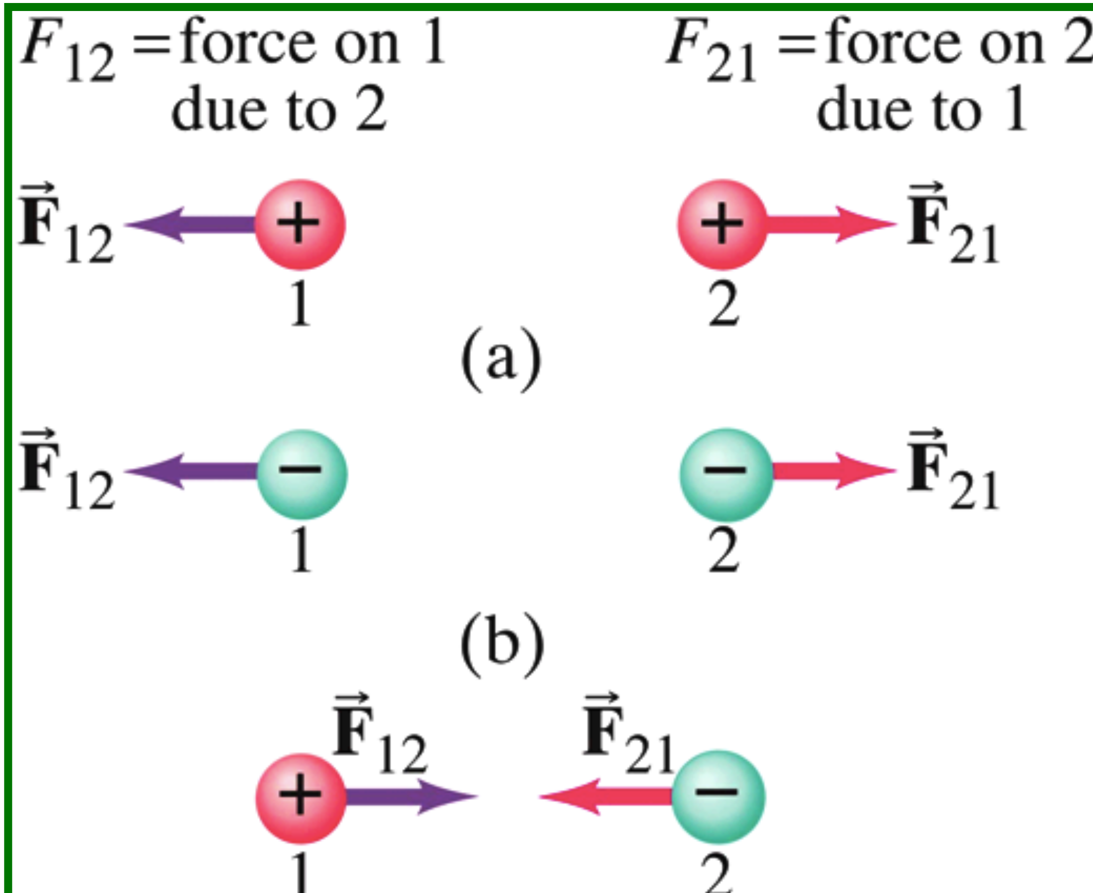
$$\vec{\mathbf{F}}_{12} = k_e \frac{q_1 q_2}{r^2} \hat{\mathbf{r}}_{12}$$

- Here, $\hat{r}_{12}$ is a unit vector directed from q_1 to q_2.
- The like charges produce a repulsive force between them.



Experimental Fact

The force is along the line connecting the charges, and is attractive if the charges are opposite, repulsive if they are the same.



Note!

F_{12} & F_{21} are ***Newton's 3rd Law Pairs***

$$F_{21} = - F_{12}$$

Conceptual Example

Which charge exerts the greater force?

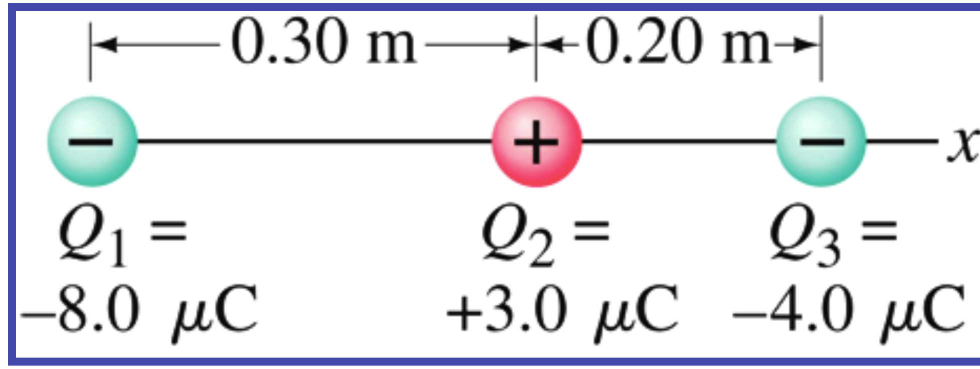
Two positive point charges, **Q_1 = 50 μC** and **Q_2 = 1 μC**, are separated by a distance, as shown. Which is larger in magnitude, the force that **Q_1** exerts on **Q_2** or the force that **Q_2** exerts on **Q_1**?

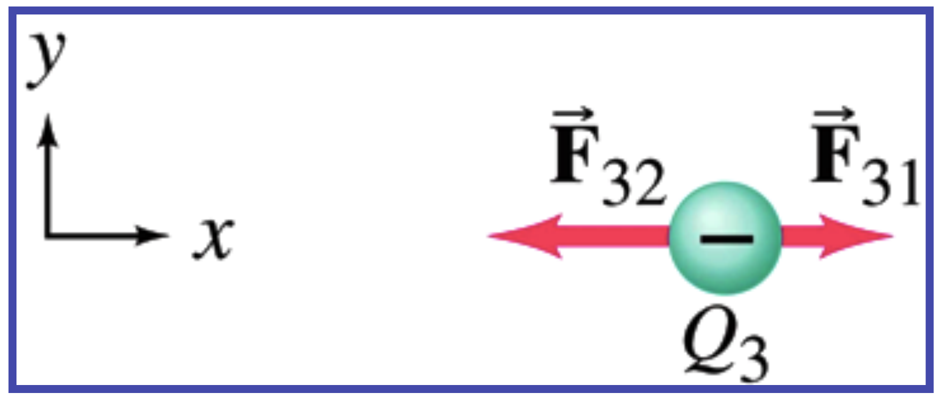
Example

Three charges in a line.

Three charged particles are arranged in a line, as shown. Calculate ***the net electrostatic force*** on particle **3** (the **- 4.0 μC** on the right) due to the other two charges.

From the book by Giancoli





Conceptual Example

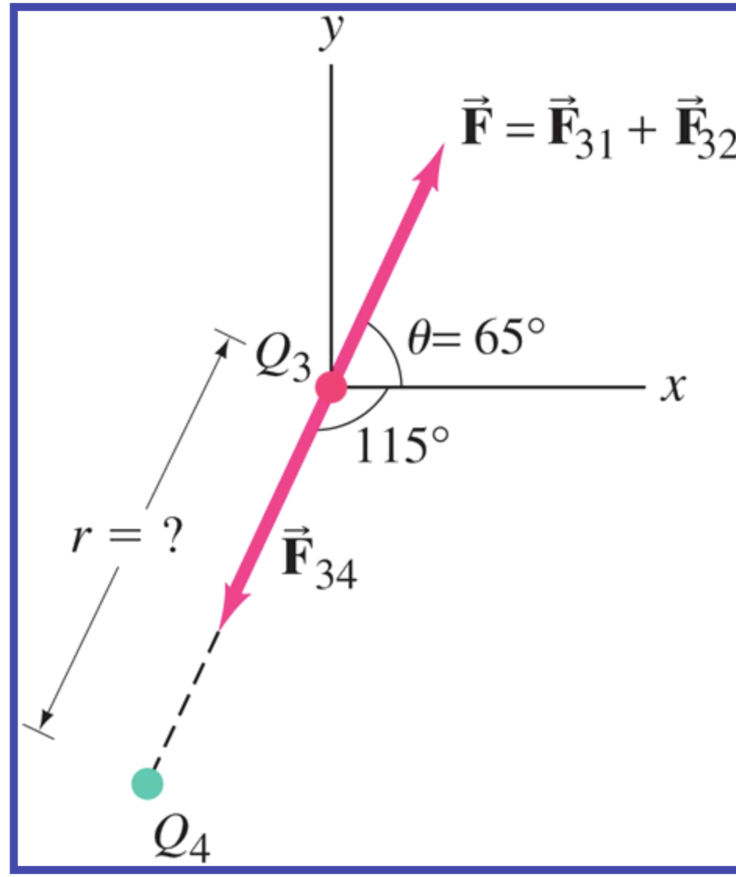
From the book by Giancoli

- In the figure, where could you place a fourth charge

  $Q_4 = -50\ \mu C$

  so that the net force on Q_3 would be zero?
- That is,

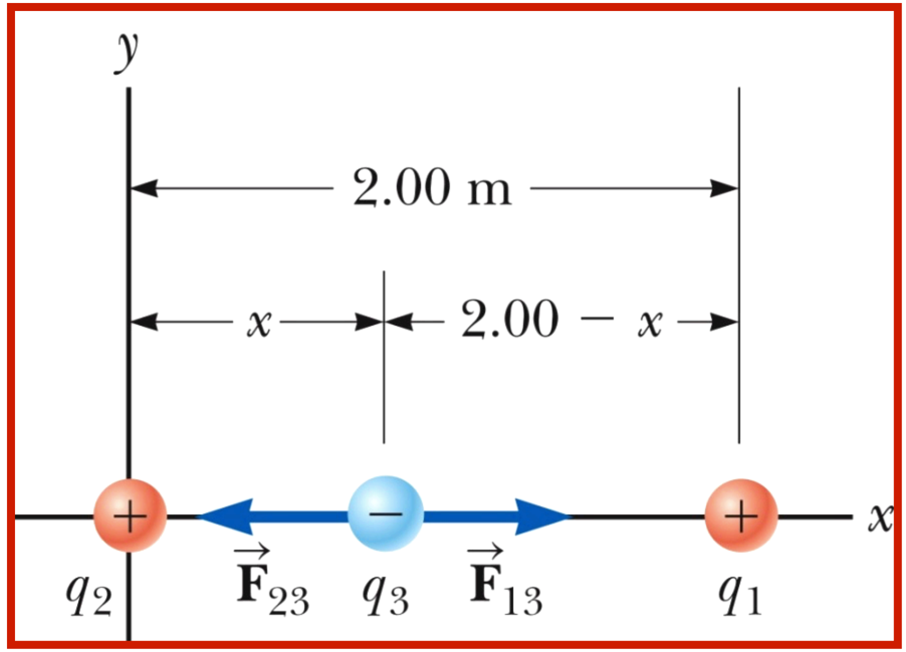
  choose r to make the force on Q_3 zero.



Another, Similar Example

Our book, Example 23.3

- ***Where*** **is the resultant force on q_3 equal to zero?** (What is x in the diagram?)
  - The magnitudes of the individual forces will be equal. Their directions will be opposite.



- **Coulombs Law** (forces on q_3):

$$F_3 = F_{23} + F_{13} \quad \textit{(vector sum!)}$$

- Choose x so that $F_3 = 0$! Get a quadratic equation for x.
- Choose the root that gives the forces in opposite directions.

Multiple Charges

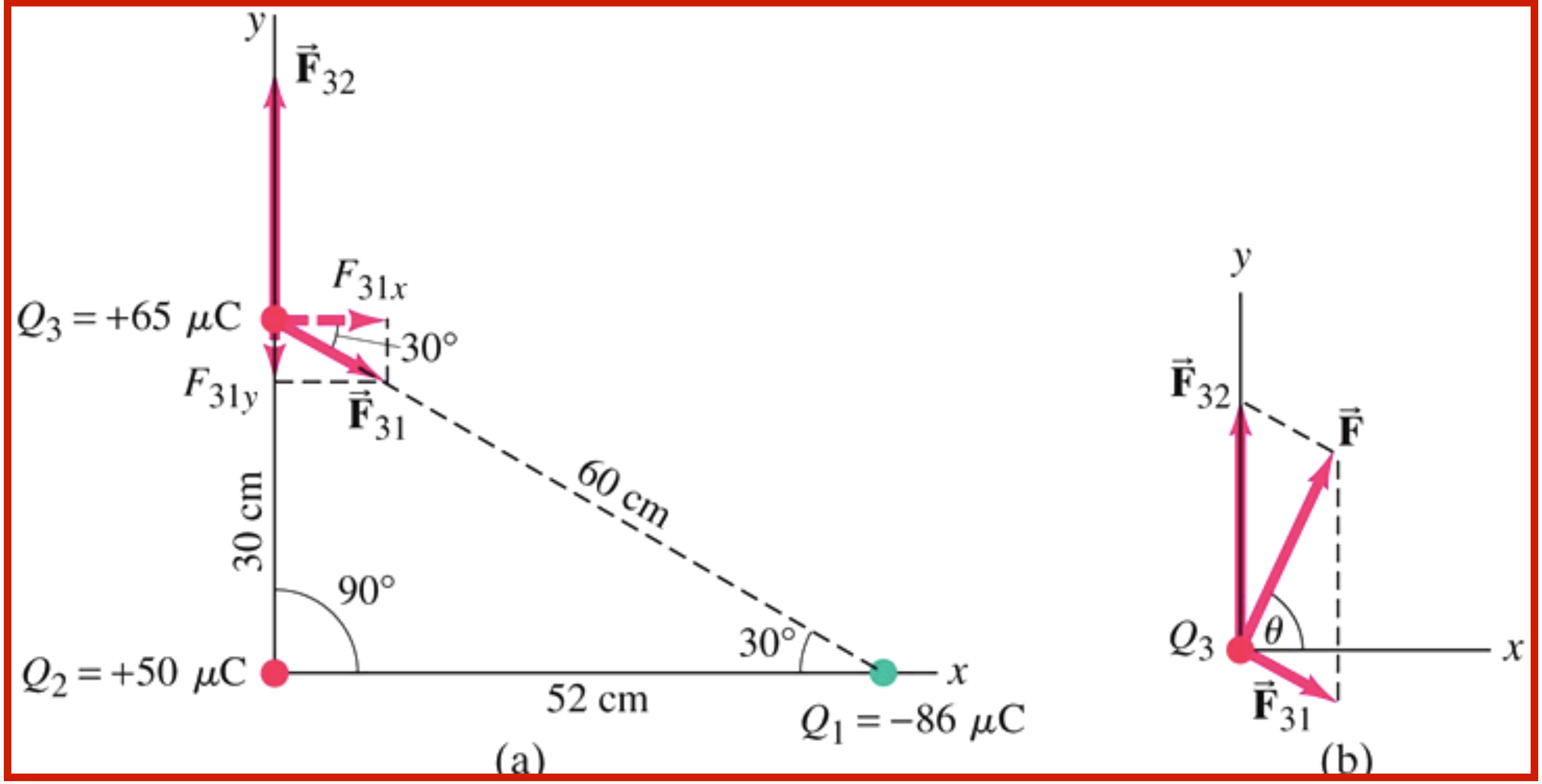
- The **Resultant Force** on any one charge equals ***the vector sum of the forces exerted by the other individual charges*** that are present.
  - Remember to ***add the forces as vectors.***
- The resultant force on charge q_1 is ***the vector sum of all forces exerted on it by other charges.***
- For example, if 4 charges are present, the resultant force on one of these equals the vector sum of the forces exerted on it by each of the other charges.

$$\vec{F}_1 = \vec{F}_{21} + \vec{F}_{31} + \vec{F}_{41}$$

Example: Our book, Example 23.2

Electric Force Using Vector Components

- Calculate the net electrostatic force on charge Q_3 shown in the figure due to the charges Q_1 and Q_2.



Example 23.4: Electric Force with Other Forces

- The spheres in the figure are ***in equilibrium.*** **Find** their charge **q.**
- **Three forces** act on them:
  1. Their **weights mg** downward.
  2. The tension **T** along the wires.
  3. The repulsive

     Coulomb Force

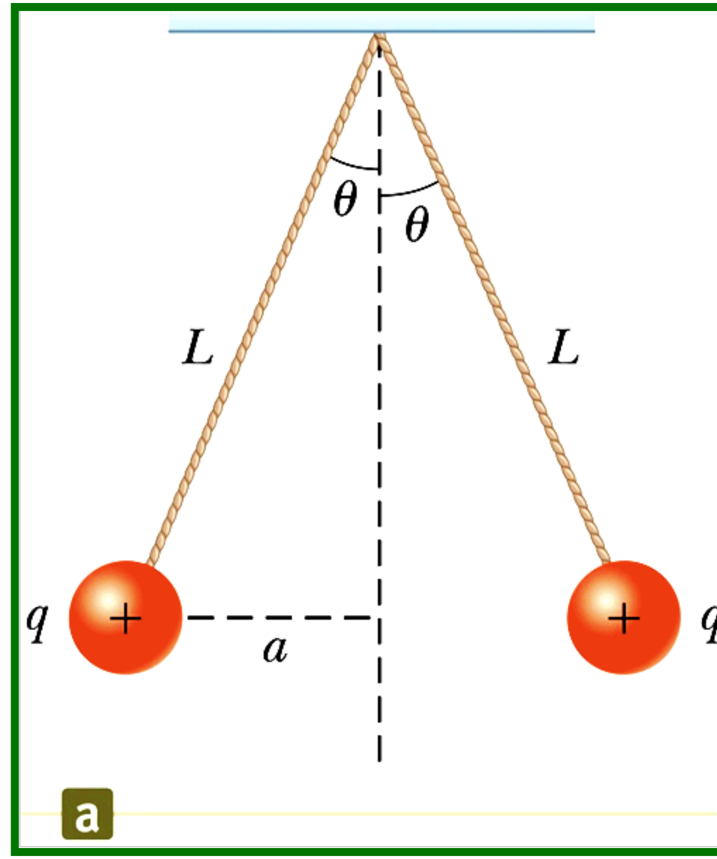
     between the two like charges.
- Proceed as usual with equilibrium problems (**ΣF = 0**) with one of the forces in the sum being

The Coulomb Force.

$m = 3 \times 10^{-2}$ kg

L = 0.15 m

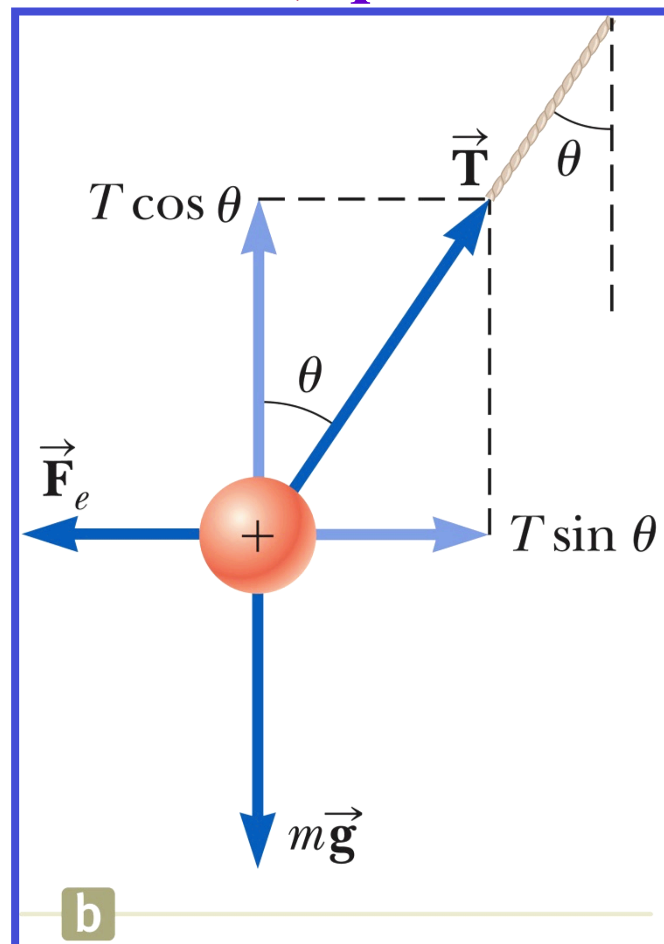
$\theta = 5^0$, q = ?



Example 23.4: Continued

- The **force diagram** includes the components the tension, the electric force, & the weight.

$m = 3 \times 10^{-2}$ kg
L = 0.15 m
$\theta = 5^0$, q = ?



Solve for |*q*|

- If the charge of the spheres is not given, you can't find the sign of **q**, only that they both have same sign.