Applied Physics

BS Software Engineering/Information Technology

1st Semester

Lecture # 2 and 3

CHAPTER 21

Coulomb's Law

Presented By

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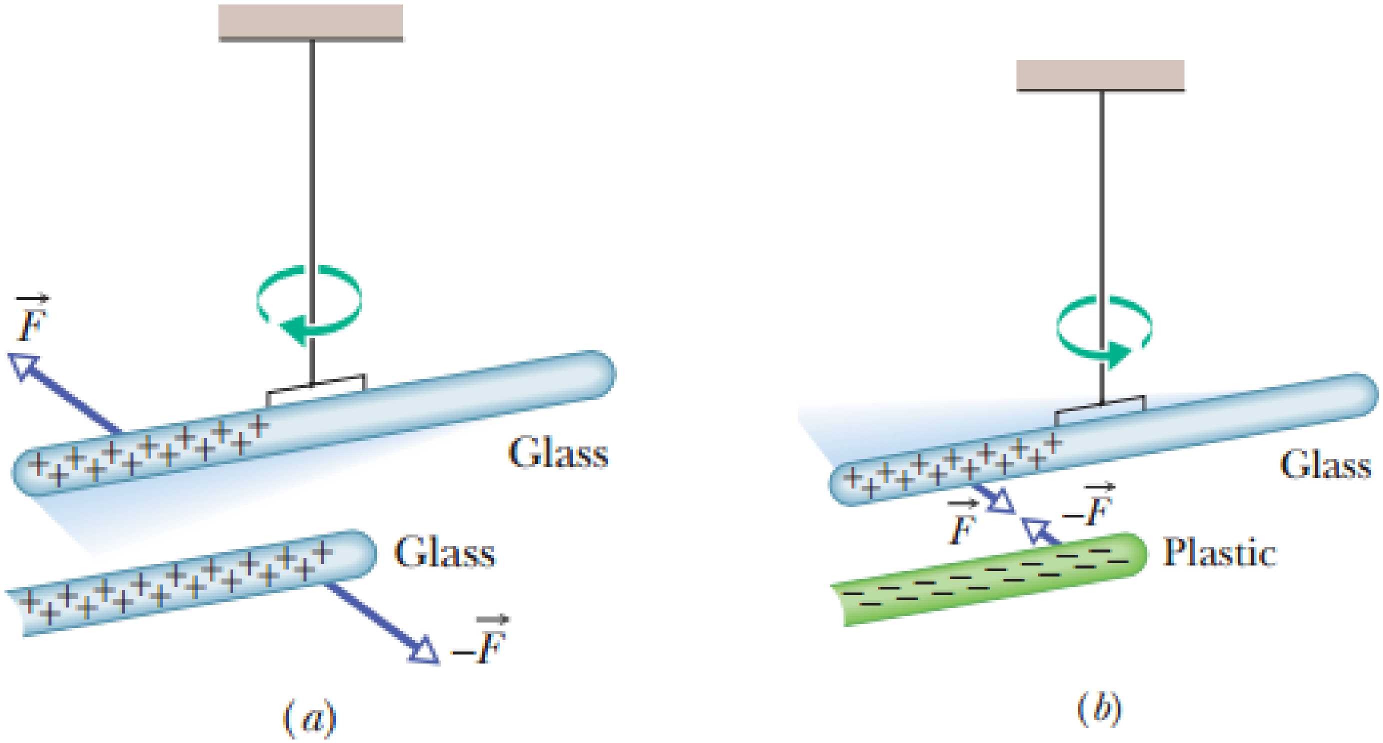
Lecture # 2 and 3

- Electric Force
- Coulomb’s Law
- Vector form of Coulomb’s Law
- Related problems
- Principle of Superposition
- Assignment # 1

CHAPTER 21

Coulomb's Law



Particles with the same sign of electrical charge repel each other, and particles with opposite signs attract each other.

Few MCQs Related to charges

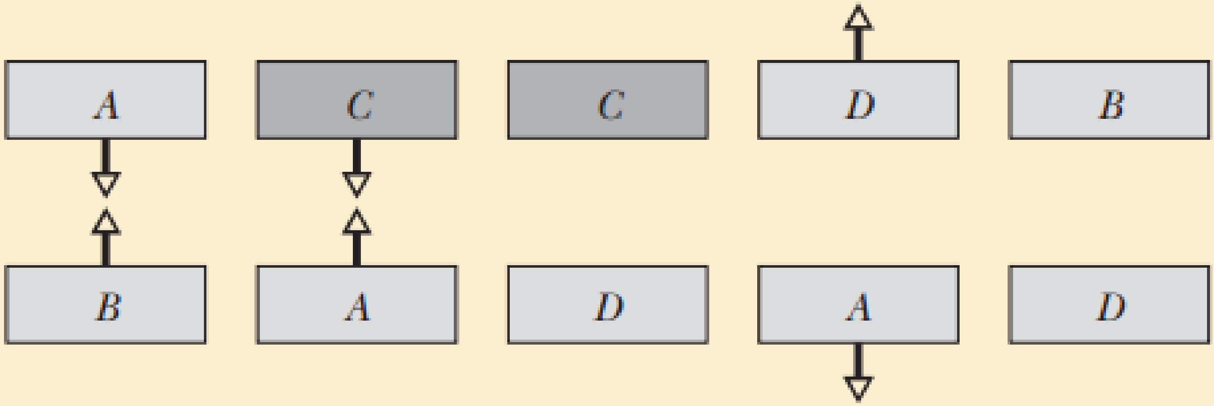
A^{+} att. B^{-}

B^{-} rpl. C^{-}

A att. C ?

Checkpoint 1

The figure shows five pairs of plates: A, B, and D are charged plastic plates and C is an electrically neutral copper plate. The electrostatic forces between the pairs of plates are shown for three of the pairs. For the remaining two pairs, do the plates repel or attract each other?



Coulomb's Law

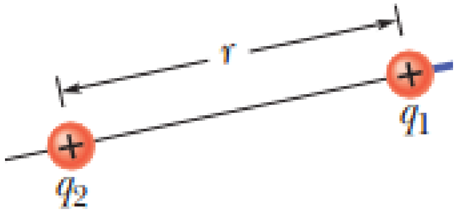
Now we come to the equation for Coulomb's law, but first a caution. This equation works for only charged particles (and a few other things that can be treated as particles). For extended objects, with charge located in many different places, we need more powerful techniques. So, here we consider just charged particles and not, say, two charged cats.

If two charged particles are brought near each other, they each exert an **electrostatic force** on the other. The direction of the force vectors depends on the signs of the charges. If the particles have the same sign of charge, they repel each other. That means that the force vector on each is directly away from the other particle (Figs. 21-5*a* and *b*). If we release the particles, they accelerate away from each other. If, instead, the particles have opposite signs of charge, they attract each other. That means that the force vector on each is directly toward the other particle (Fig. 21-5*c*). If we release the particles, they accelerate toward each other.

Coulomb's Law

Experiments due to Coulomb and his contemporaries showed that the electrical force exerted by one charged body on another depends directly on the product of the magnitudes of the two charges and inversely on the square of their separation.* That is,

$$F \propto \frac{q_1 q_2}{r^2} .$$



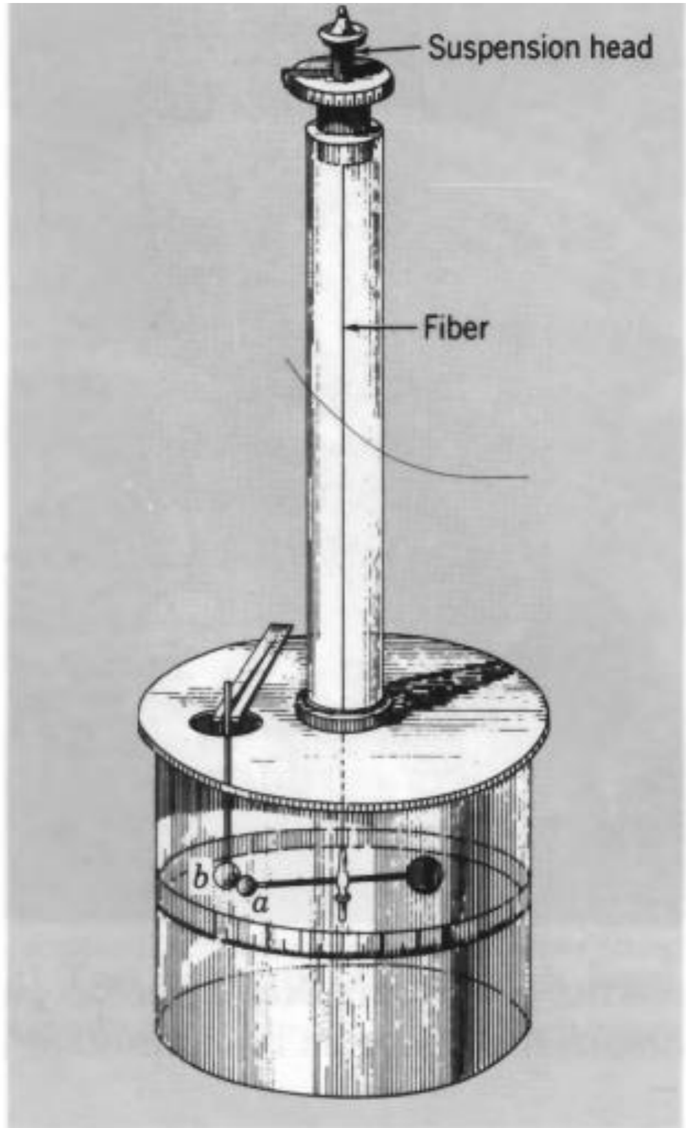
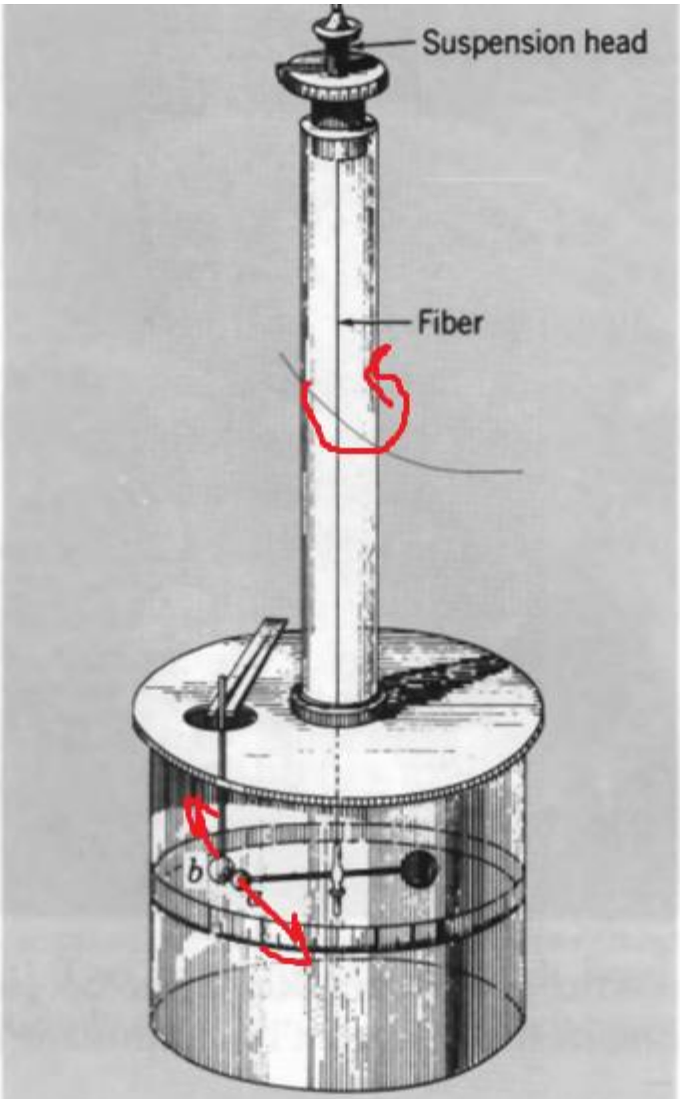
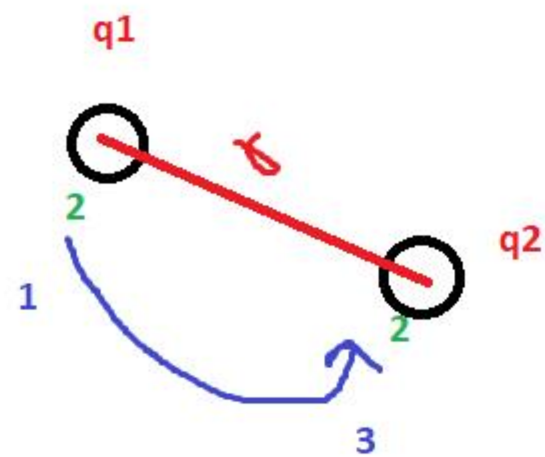


Figure 4 Coulomb's torsion balance, from his 1785 memoir to the Paris Academy of Sciences.



q1 + q2 ???

q1 . q2 ?



Sum	Prod.
4	4
4	3

$$F \propto \frac{q_1 q_2}{r^2} .$$

To turn the above proportionality into an equation, let us introduce a constant of proportionality, which we represent for now as k. We thus obtain, for the force between the charges,

$$F = k\,\frac{q_1 q_2}{r^2} . \tag{1}$$

The constant k has the corresponding value (to three significant figures)

$$k = \frac{1}{4\pi\epsilon_0} = 8.99 \times 10^9\ \mathrm{N \cdot m^2/C^2}.$$

With this choice of the constant k, Coulomb's law can be written

$$F = \frac{1}{4\pi\epsilon_0} \frac{q_1 q_2}{r^2}\ . \tag{4}$$

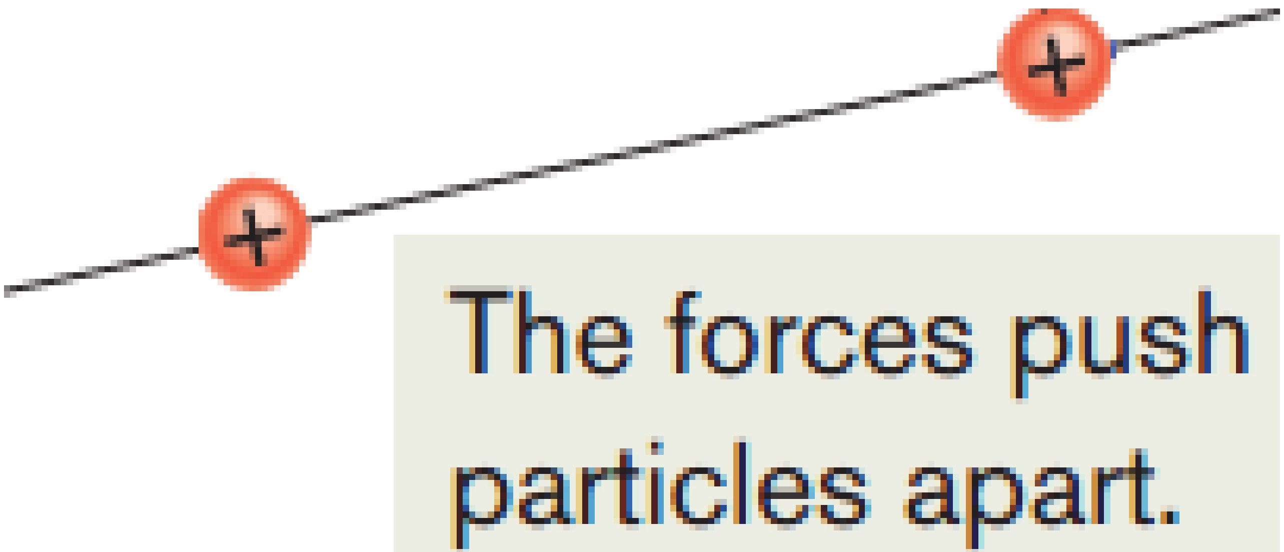
When k has the above value, expressing q in coulombs and r in meters gives the force in newtons.

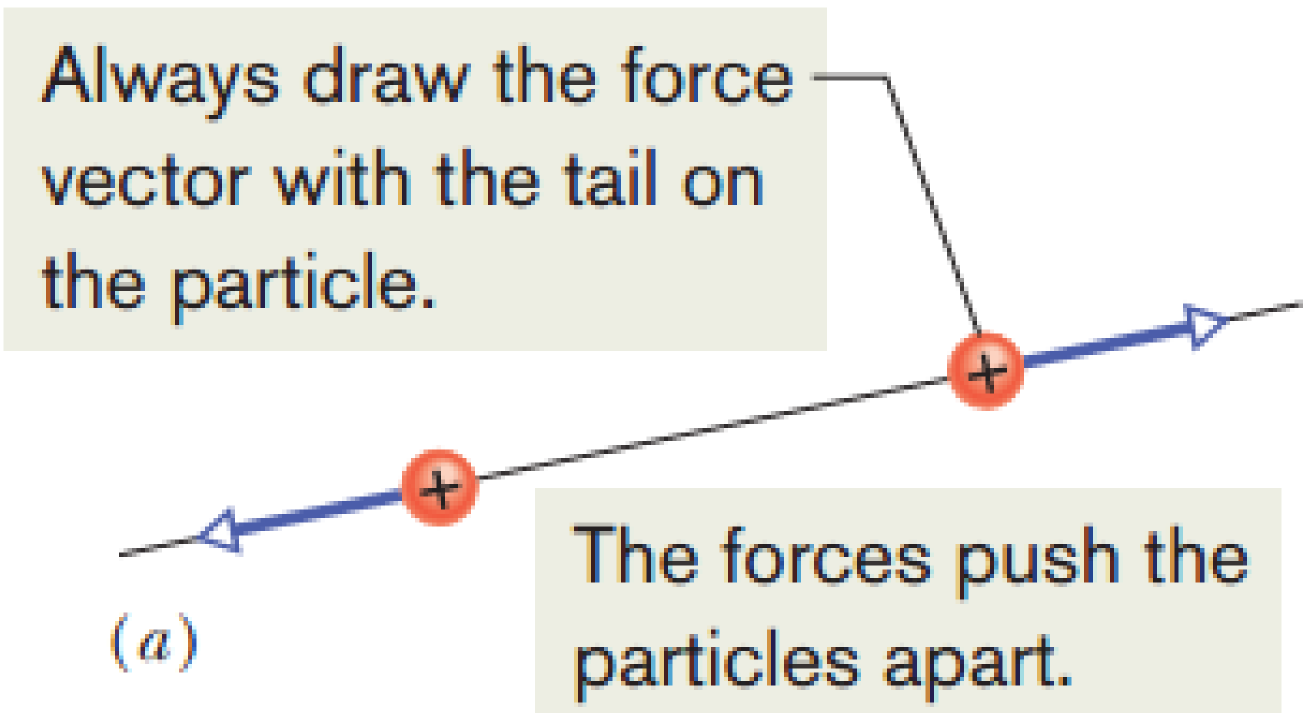
$$k = \frac{1}{4\pi\varepsilon_0} = 8.99 \times 10^9\,\mathrm{N\cdot m^2/C^2}.$$

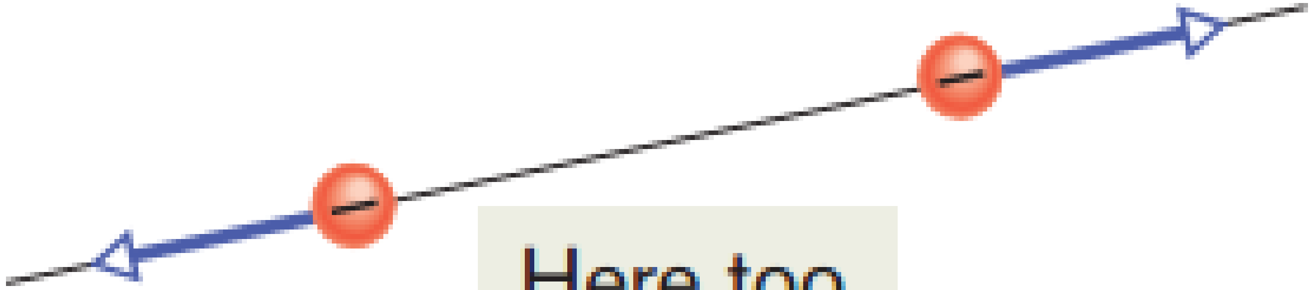
The quantity ε_0, called the **permittivity constant,** sometimes appears
equations and is

$$\varepsilon_0 = 8.85 \times 10^{-12}\,\mathrm{C^2/N\cdot m^2}.$$

Coulomb's Law: Vector Form

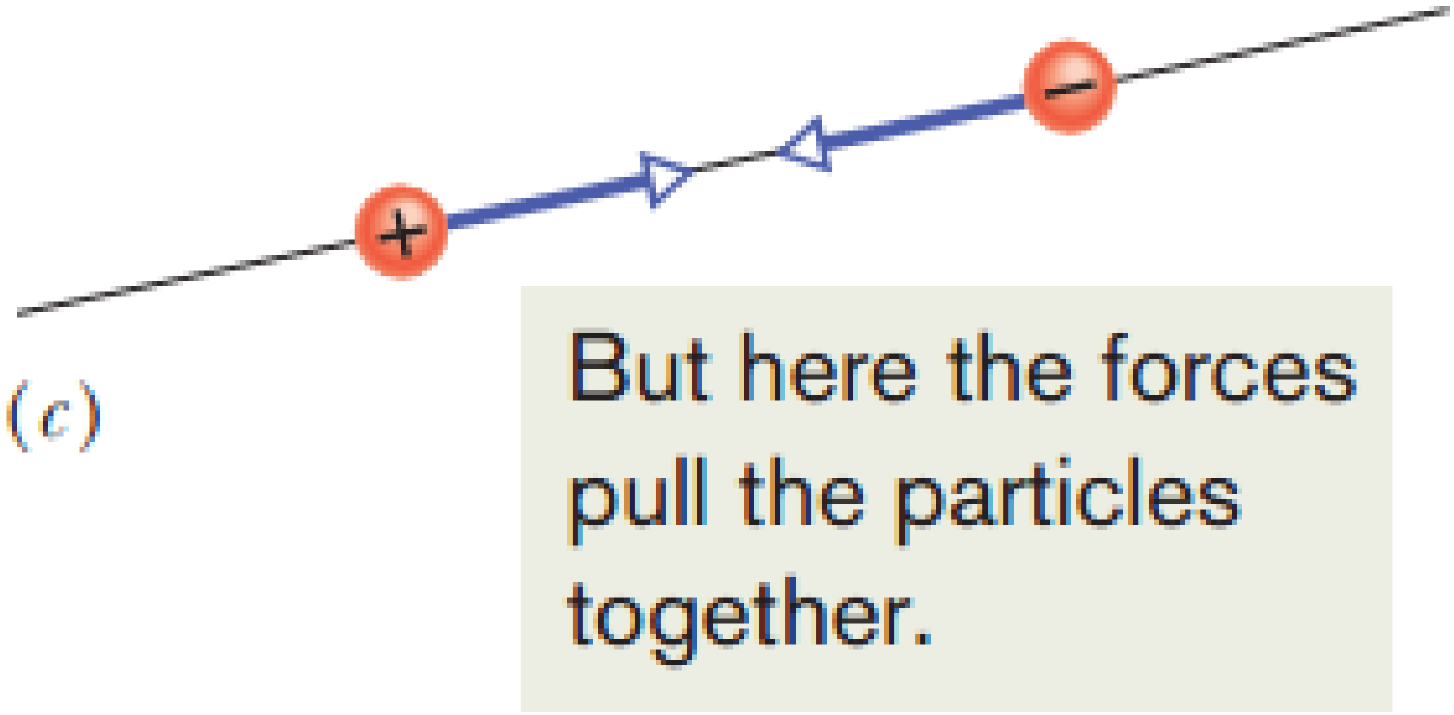

The forces push particles apart.


Always draw the force vector with the tail on the particle.
The forces push the particles apart.
(a)



(b)

Here too.


But here the forces pull the particles together.
(c)

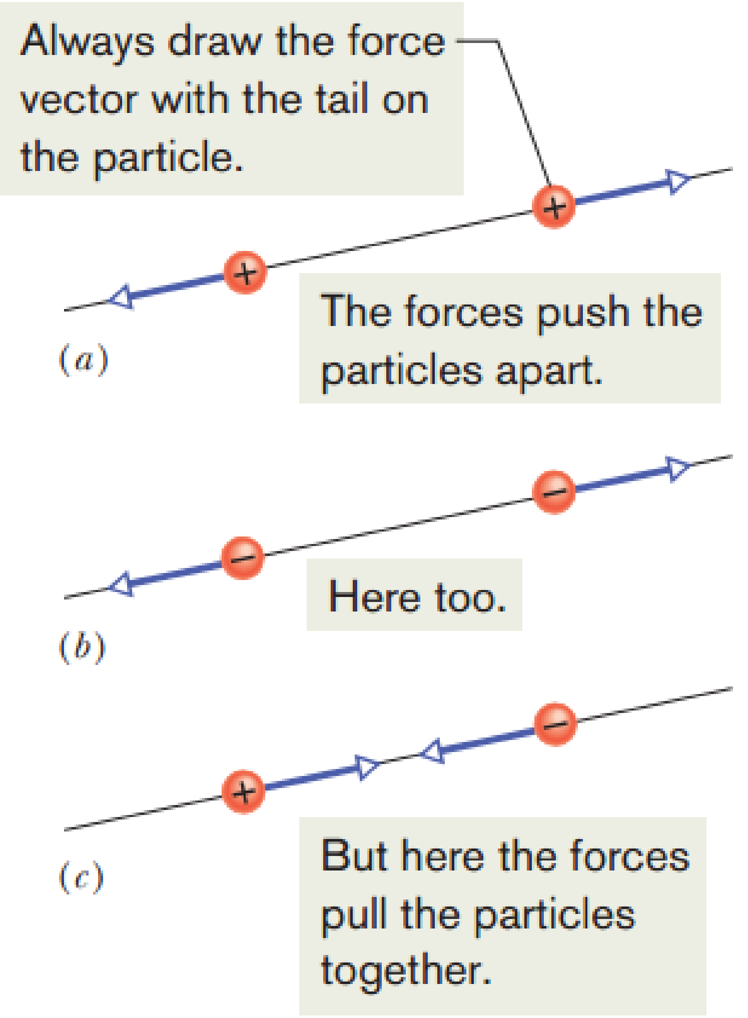
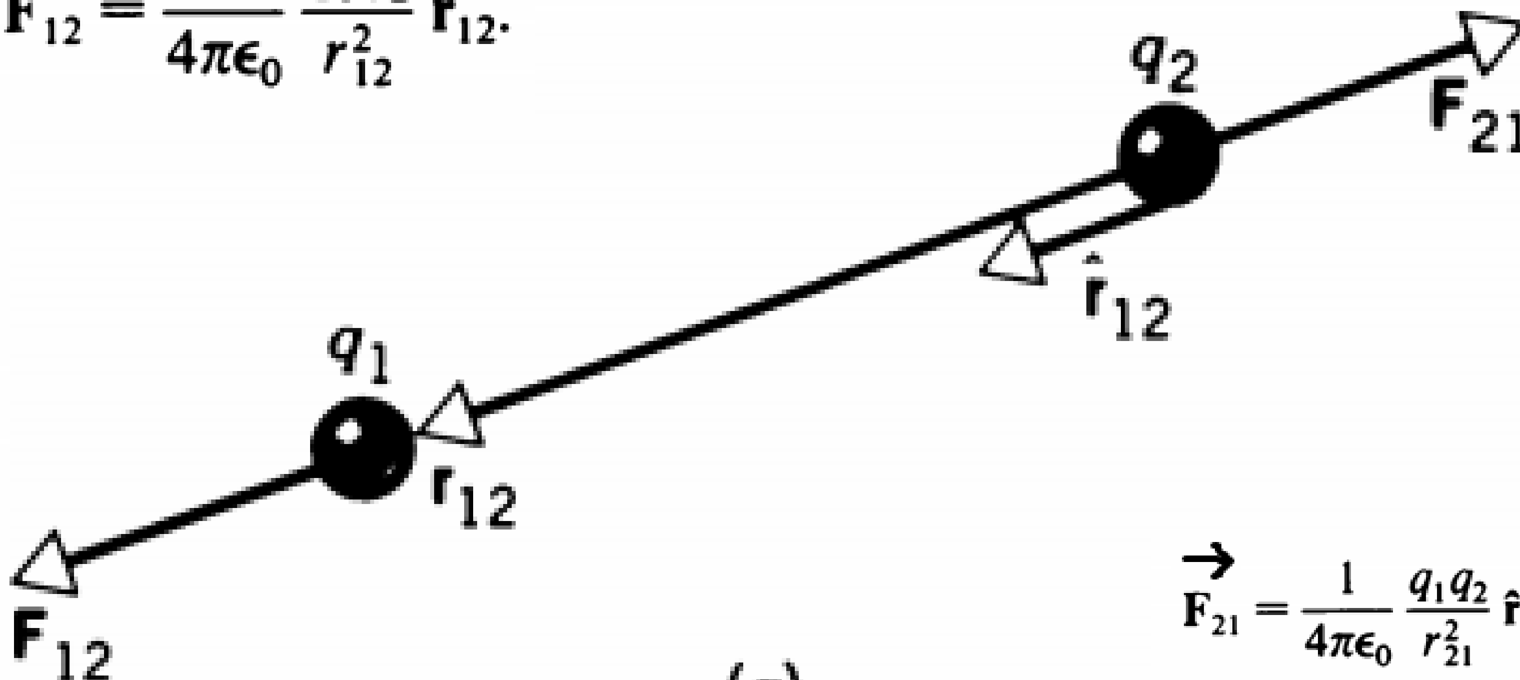


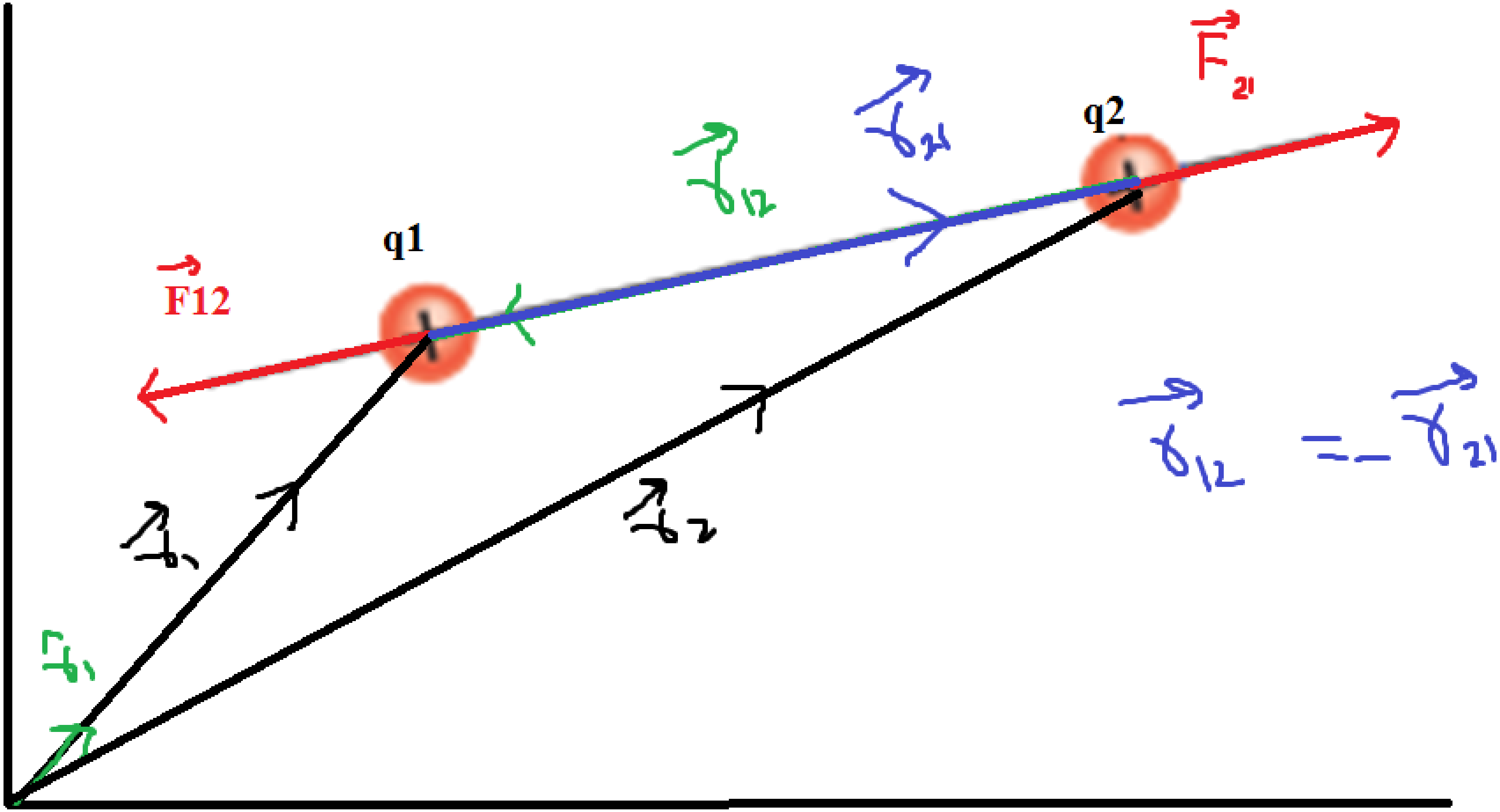
Figure 21-5 Two charged particles repel each other if they have the same sign of charge, either (*a*) both positive or (*b*) both negative. (*c*) They attract each other if they have opposite signs of charge.

$$\vec{F}_{12} = \frac{1}{4\pi\epsilon_0} \frac{q_1 q_2}{r_{12}^2} \hat{\mathbf{r}}_{12}.$$



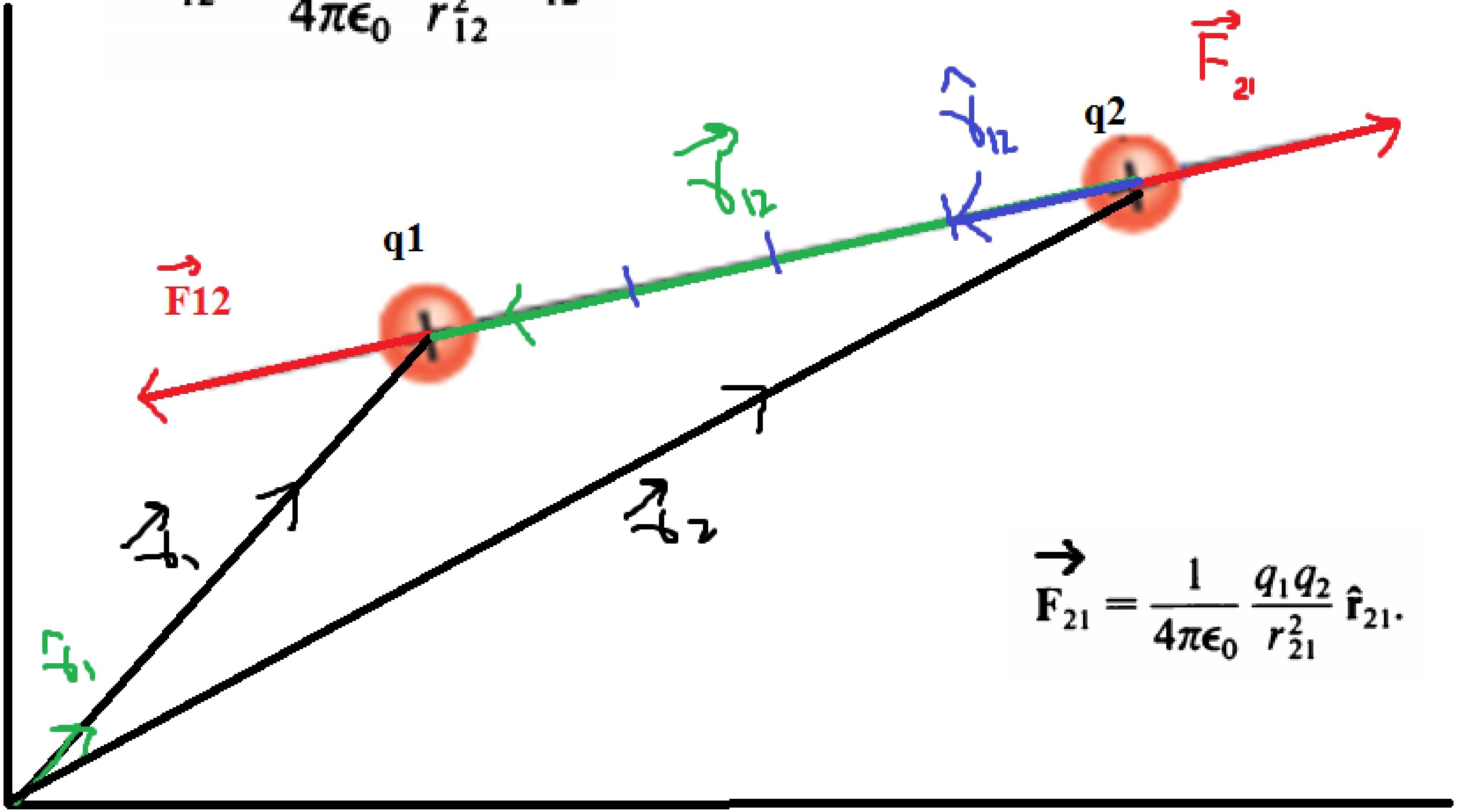
(a)

$$\vec{F}_{21} = \frac{1}{4\pi\epsilon_0} \frac{q_1 q_2}{r_{21}^2} \hat{\mathbf{r}}_{21}.$$



q1
q2
$\vec{F}12$
$\vec{F}_{21}$
$\vec{r}_{12}$
$\vec{r}_{21}$
$\vec{r}_1$
$\vec{r}_2$
$\vec{r}_1$
$\vec{r}_{12} = -\vec{r}_{21}$

$$\vec{\mathbf{F}}_{12} = \frac{1}{4\pi\epsilon_0} \frac{q_1 q_2}{r_{12}^2} \hat{\mathbf{r}}_{12}.$$



$$\vec{\mathbf{F}}_{21} = \frac{1}{4\pi\epsilon_0} \frac{q_1 q_2}{r_{21}^2} \hat{\mathbf{r}}_{21}.$$

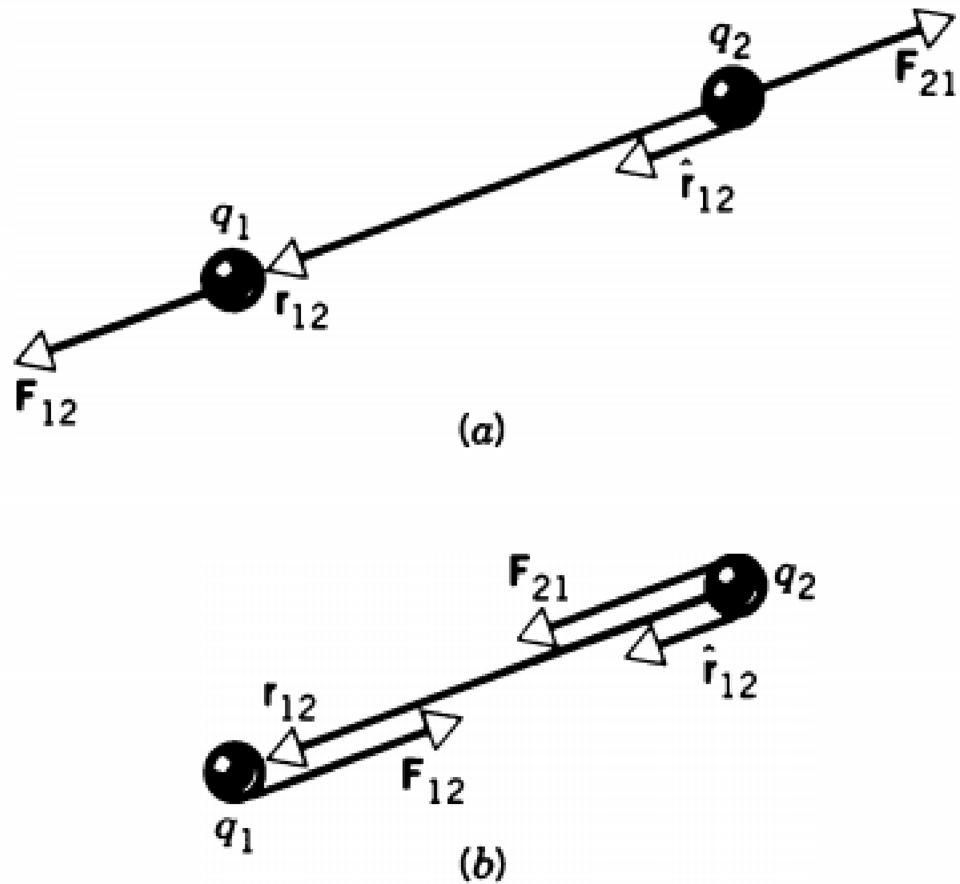


Figure 5 (*a*) Two point charges q_1 and q_2 of the same sign exert equal and opposite repulsive forces on one another. The vector $\mathbf{r}_{12}$ locates q_1 relative to q_2, and the unit vector $\hat{\mathbf{r}}_{12}$ points in the direction of $\mathbf{r}_{12}$. Note that $\mathbf{F}_{12}$ is parallel to $\mathbf{r}_{12}$. (*b*) The two charges now have opposite signs, and the force is attractive. Note that $\mathbf{F}_{12}$ is antiparallel to $\mathbf{r}_{12}$.

$$\vec{\mathbf{F}}_{12} = \frac{1}{4\pi\epsilon_0} \frac{q_1 q_2}{r_{12}^2} \hat{\mathbf{r}}_{12}.$$

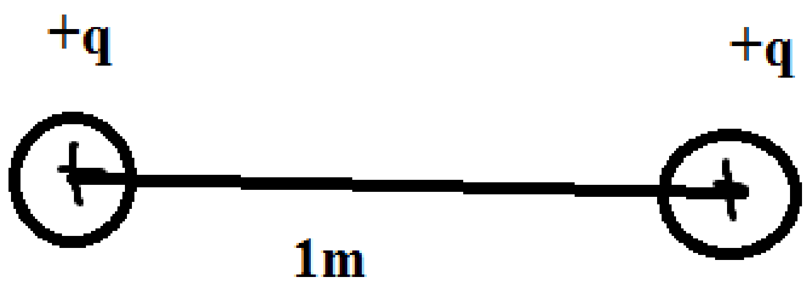
the *unit vector* in the direction of $\mathbf{r}_{12}$.

$$\hat{\mathbf{r}}_{12} = \frac{\vec{\mathbf{r}}_{12}}{r_{12}} .$$

$$\vec{\mathbf{F}}_{21} = \frac{1}{4\pi\epsilon_0} \frac{q_1 q_2}{r_{21}^2} \hat{\mathbf{r}}_{21}.$$

Few MCQs Related to Coulombs law

MCQ # 10



$$Fo = K\,q^2$$

$+q - \frac{q}{2} = \frac{q}{2}$ $\qquad$ $+q + \frac{q}{2} = \frac{3}{2}q$

$$F_o = Kq^2$$

$$F' = K\left(\frac{q}{2}\right)\left(\frac{3}{2}q\right)$$

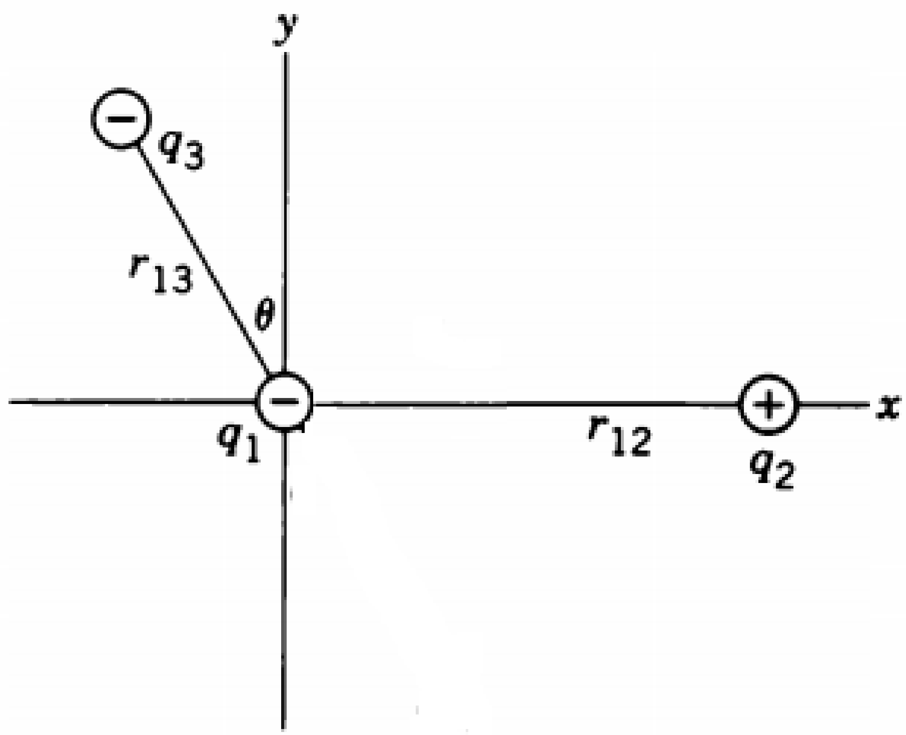
$$= \frac{3}{4} Kq^2$$

Principle of superposition applied to electric forces

Multiple Forces. As with all forces in this book, the electrostatic force obeys the principle of superposition. Suppose we have n charged particles near a chosen particle called particle 1; then the net force on particle 1 is given by the vector sum

$$\vec{F}_{1,\mathrm{net}} = \vec{F}_{12} + \vec{F}_{13} + \vec{F}_{14} + \vec{F}_{15} + \cdots + \vec{F}_{1n},$$

Sample Problem Figure 6 shows three charged particles, held in place by forces not shown. What electrostatic force, owing to the other two charges, acts on q_1? Take $q_1 = -1.2\ \mu C$, $q_2 = +3.7\ \mu C$, $q_3 = -2.3\ \mu C$, $r_{12} = 15$ cm, $r_{13} = 10$ cm, and $\theta = 32°$.



Solution This problem calls for the use of the superposition principle. We start by computing the magnitudes of the forces that q_2 and q_3 exert on q_1. We substitute the magnitudes of the charges into Eq. 5, disregarding their signs for the time being. We then have

$$F_{12} = \frac{1}{4\pi\epsilon_0}\frac{q_1 q_2}{r_{12}^2}$$

$$= \frac{(8.99 \times 10^9\ \mathrm{N \cdot m^2/C^2})(1.2 \times 10^{-6}\ \mathrm{C})(3.7 \times 10^{-6}\ \mathrm{C})}{(0.15\ \mathrm{m})^2}$$

$$= 1.77\ \mathrm{N}.$$

The charges q_1 and q_2 have opposite signs so that the force between them is attractive. Hence $\mathbf{F}_{12}$ points to the right in Fig. 6.

We also have

$$F_{13} = \frac{(8.99 \times 10^9\ \mathrm{N \cdot m^2/C^2})(1.2 \times 10^{-6}\ \mathrm{C})(2.3 \times 10^{-6}\ \mathrm{C})}{(0.10\ \mathrm{m})^2}$$

$$= 2.48\ \mathrm{N}.$$

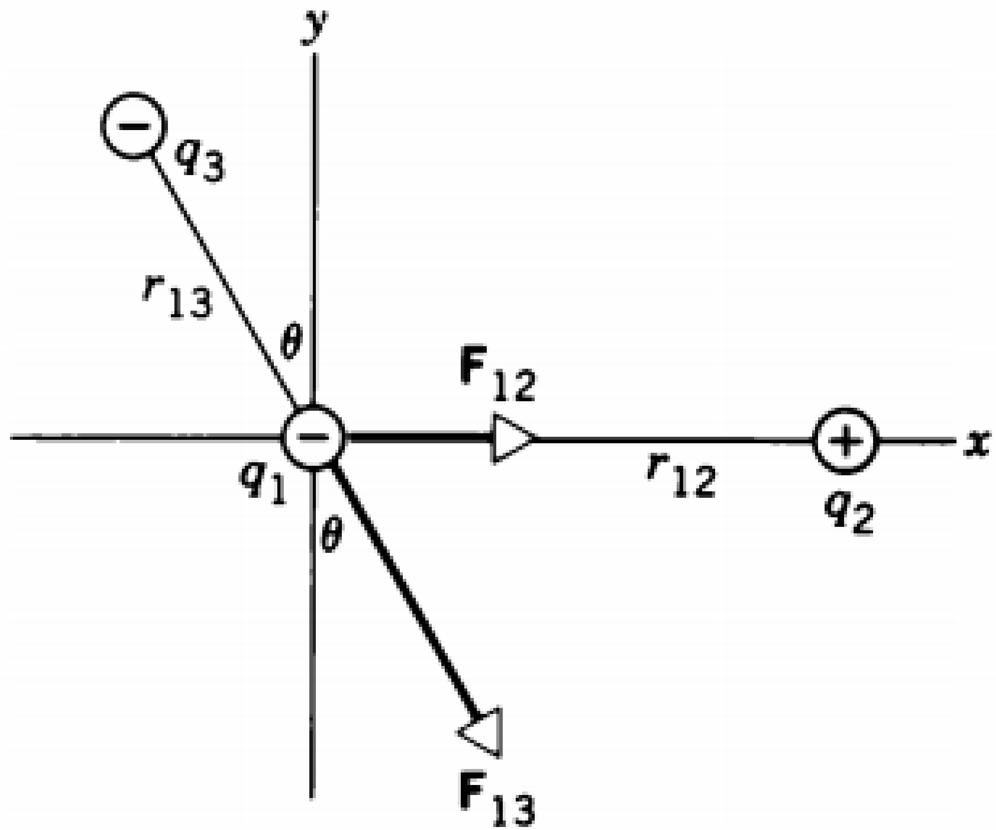
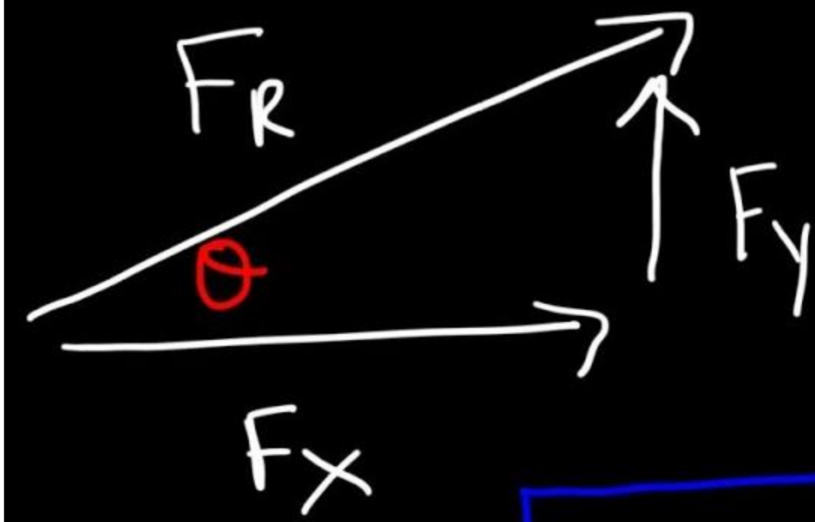


Figure 6 Sample Problem 1. The three charges exert three pairs of action–reaction forces on each other. Only the two forces acting on q_1 are shown here.



$$\boxed{\begin{aligned} F_x &= F\cos\theta \\ F_y &= F\sin\theta \end{aligned}}$$

$$\theta = \tan^{-1}\left(F_y / F_x\right)$$

$$\boxed{F_R = \sqrt{F_x^{\,2} + F_y^{\,2}}}$$

$$F_{1x} = F_{12x} + F_{13x}$$

$$F_{1y} = F_{12y} + F_{13y}$$

$$F_{1x} = F_{12x} + F_{13x}$$

$$= F_{12} + F_{13} \sin\theta$$

$$= 1.77\ \text{N} + (2.48\ \text{N})(\sin 32^\circ) = 3.08\ \text{N}$$

$$F_{1y} = F_{12y} + F_{13y}$$

$$= 0 - F_{13} \cos\theta$$

$$= -(2.48\ \text{N})(\cos 32^\circ) = -2.10\ \text{N}.$$

The components of the resultant force $\mathbf{F}_1$ acting on q_1 are determined by the corresponding components of Eq. 8, or

$$F_{1x} = F_{12x} + F_{13x} = F_{12} + F_{13} \sin \theta$$
$$= 1.77 \text{ N} + (2.48 \text{ N})(\sin 32°) = 3.08 \text{ N}$$

and

$$F_{1y} = F_{12y} + F_{13y} = 0 - F_{13} \cos \theta$$
$$= -(2.48 \text{ N})(\cos 32°) = -2.10 \text{ N}.$$

From these components, you can show that the magnitude of $\mathbf{F}_1$ is 3.73 N and that this vector makes an angle of $-34°$ with the x axis.