Lecture 1

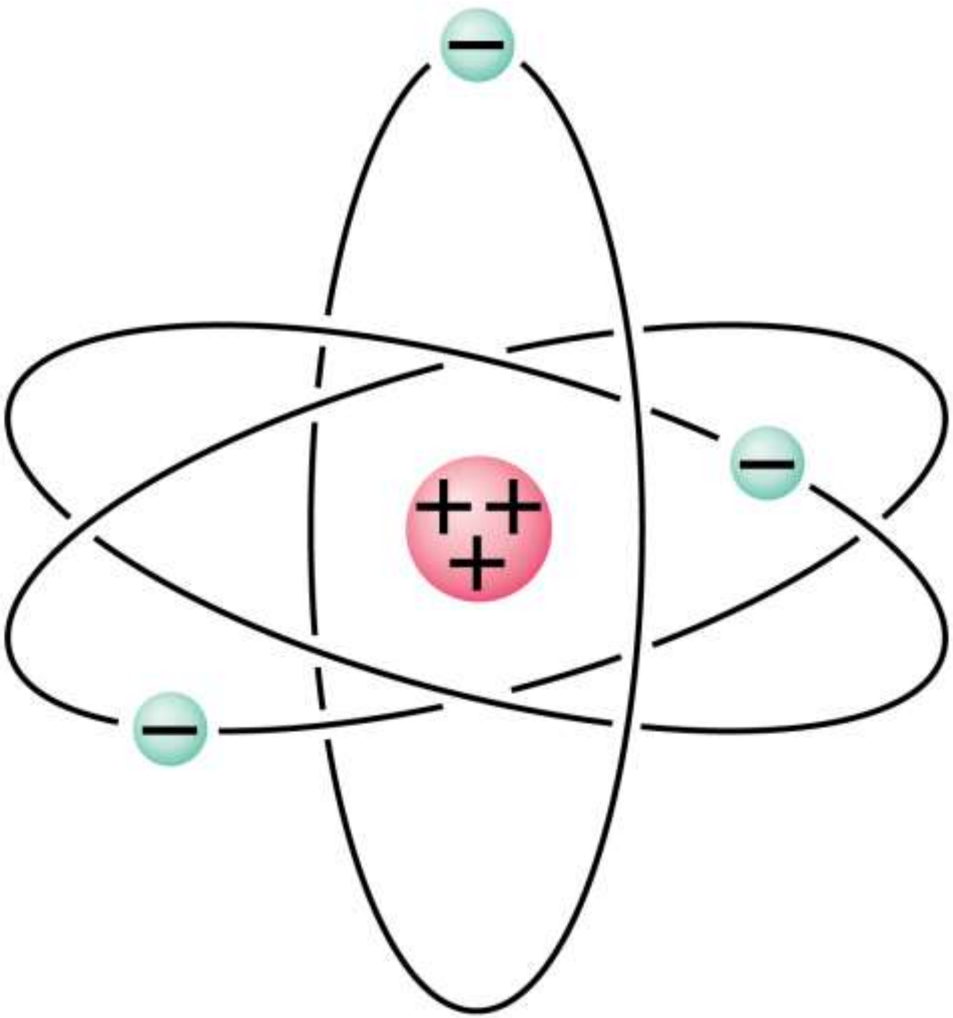
Electric Charge, Force, and Field

Electric Charge in the Atom

Atom:

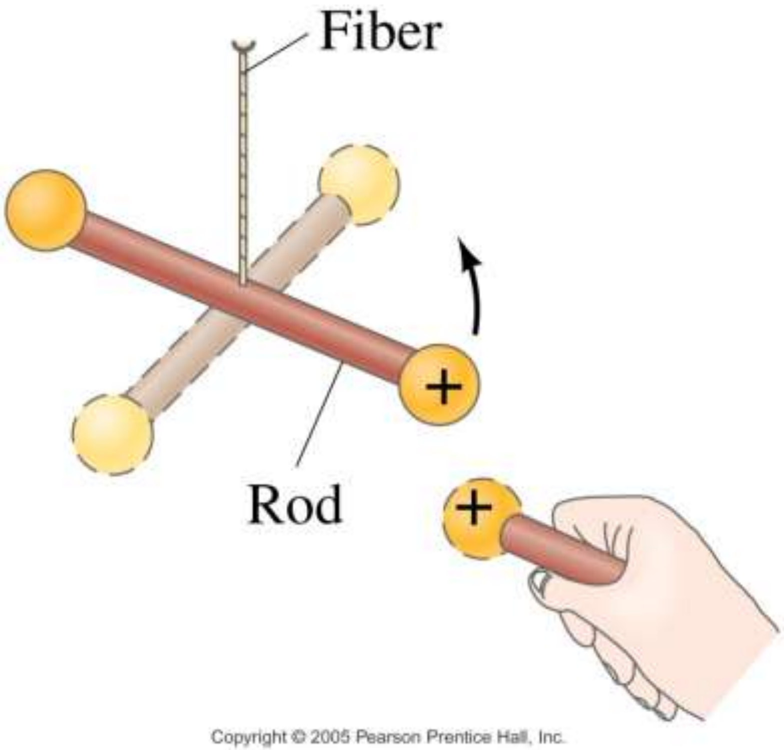
Nucleus (small, massive, positive charge) – makes up of protons and neutrons

Electron cloud (large, very low density, negative charge)



Coulomb's Law

Experiment shows that the electric force between two charges is proportional to the product of the charges and inversely proportional to the distance between them.

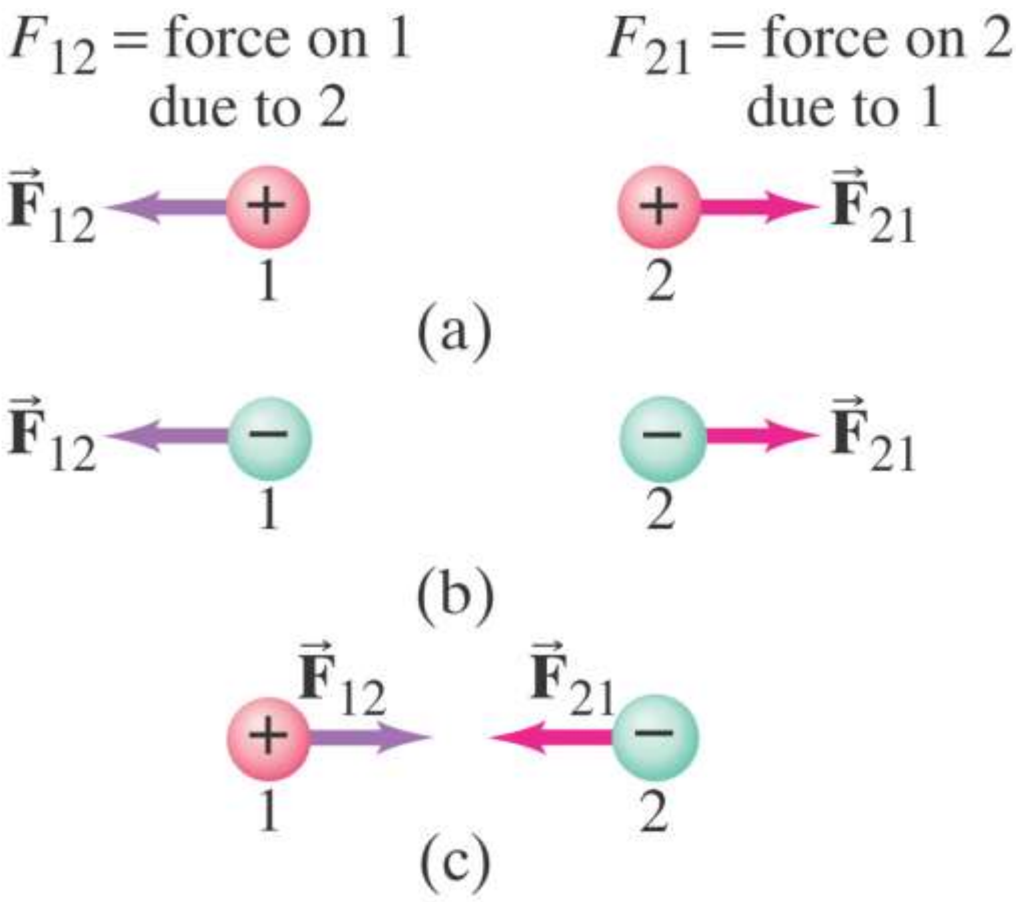


$$F = k\frac{Q_1 Q_2}{r^2}$$

This equation gives the magnitude of the force.

Coulomb's Law

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



Coulomb's Law

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

Unit of charge: coulomb, C

When charge is measured in C, the proportionality constant in Coulomb's law is then:

$$k = 8.988 \times 10^9\,\mathrm{N \cdot m^2/C^2}$$

Charges produced by rubbing are typically around a microcoulomb:

$$1\,\mu\mathrm{C} = 10^{-6}\,\mathrm{C}$$

Charge on the electron:

$$e = 1.602 \times 10^{-19}\,\mathrm{C}$$

16.5 Coulomb's Law

The proportionality constant k can also be written in terms of ϵ_0, the permittivity of free space:

$$F = \frac{1}{4\pi\epsilon_0}\frac{Q_1 Q_2}{r^2}$$

$$\epsilon_0 = \frac{1}{4\pi k} = 8.85 \times 10^{-12}\,\mathrm{C^2/N \cdot m^2} \qquad \textbf{(16-2)}$$

Eg. 1: What is the magnitude of the force between two charges of magnitude 1 Coulomb at a separation of 1 meter?

$$F = k\frac{q_1 q_1}{r^2} = 9.0\times10^9\ \frac{\mathrm{Nm}^2}{\mathrm{C}^2}\frac{(1\mathrm{C})(1\mathrm{C})}{(1\mathrm{m})^2}$$

$$= \underline{9.0\times10^9\ \mathrm{N}}$$

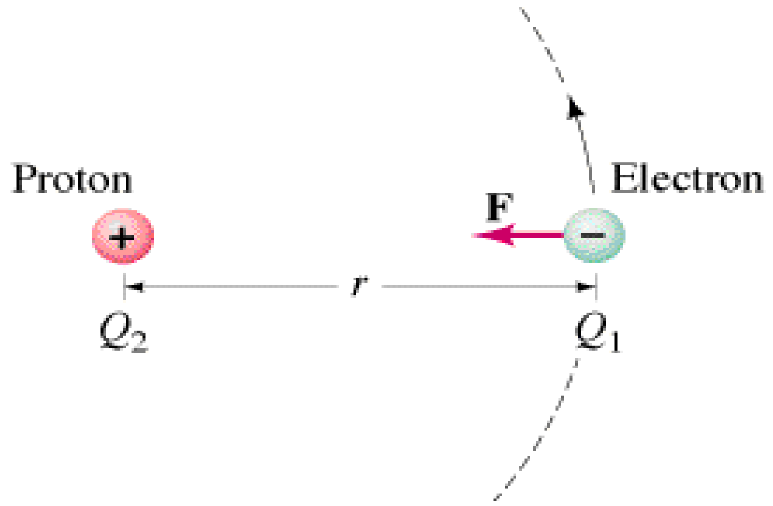
Coulomb is a very big unit!

Eg. 2: Electric & gravitational forces between electron & proton

r = 0.53 $\times 10^{-10}$m = 0.53Å

[Ångström (1814-74)]

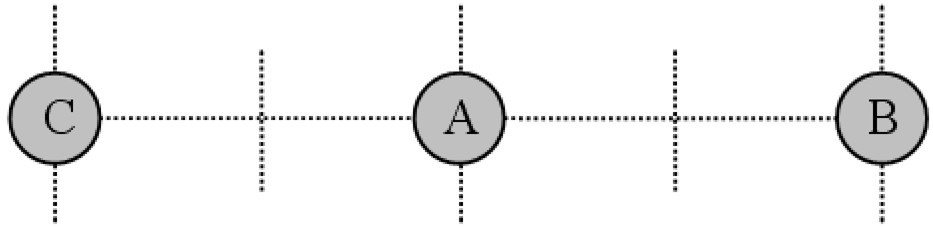
Q1 = Q2 = e = 1.6$\times 10^{-19}$C



$$F_E = \left(9.0\times10^{9}\ \frac{\text{Nm}^2}{\text{C}^2}\right)\frac{(1.6\times10^{-19}\text{C})(1.6\times10^{-19}\text{C})}{(0.53\times10^{-10}\text{m})^2} = \underline{8.2\times10^{-8}\ \text{N}}$$

$$F_G = \left(6.67\times10^{-11}\ \frac{\text{Nm}^2}{\text{kg}^2}\right)\frac{(1.7\times10^{-27}\text{kg})(9.1\times10^{-31}\text{kg})}{(0.53\times10^{-10}\text{m})^2} = \underline{3.7\times10^{-47}\ \text{N}}$$

21.4.4. A charged particle, labeled A, is located at the midpoint between two other charged particles, labeled B and C, as shown. The sign of the charges on all three particles is the same. When particle A is released, it starts drifting toward B. What can be determined from this behavior?



a) The charge on A is larger than the charge on B.

b) The charge on A is larger than the charge on C.

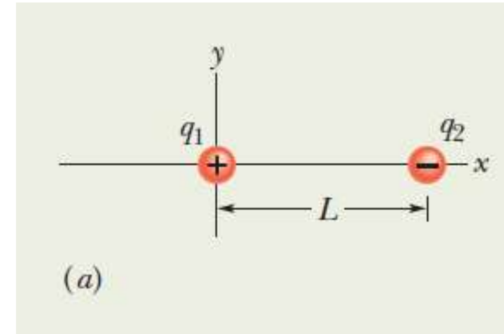
c) The charge on C is larger than the charge on B.

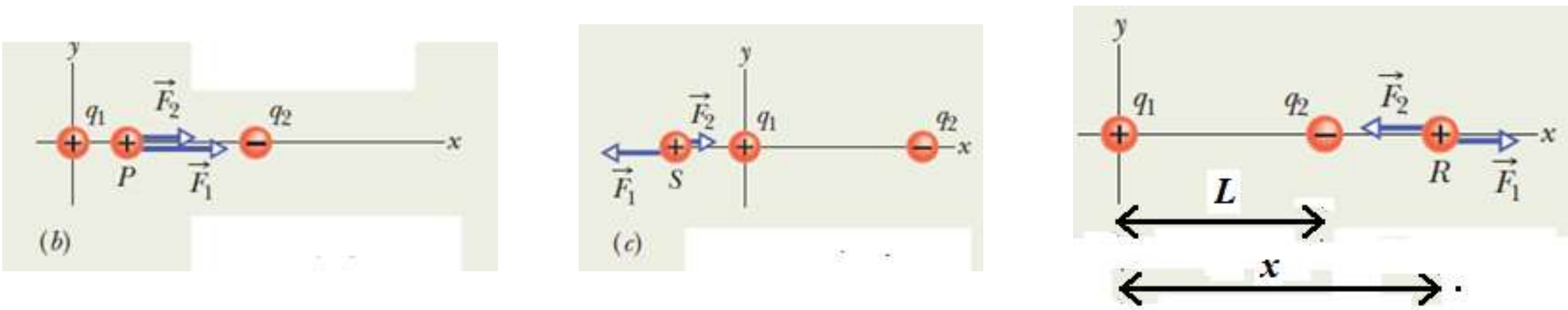
d) The charge on B is larger than the charge on A.

e) The charge on B is larger than the charge on C.

Example, Equilibrium of two forces:

Figure 21-9*a* shows two particles fixed in place: a particle of charge $q_1 = +8q$ at the origin and a particle of charge $q_2 = -2q$ at $x = L$. At what point (other than infinitely far away) can a proton be placed so that it is in *equilibrium* (the net force on it is zero)? Is that equilibrium *stable* or *unstable*? (That is, if the proton is displaced, do the forces drive it back to the point of equilibrium or drive it farther away?)





$$\frac{1}{4\pi\varepsilon_0}\frac{8qq_p}{x^2} = \frac{1}{4\pi\varepsilon_0}\frac{2qq_p}{(x-L)^2}.$$

$$\left(\frac{x-L}{x}\right)^2 = \frac{1}{4}.$$

$$\frac{x-L}{x} = \frac{1}{2},$$

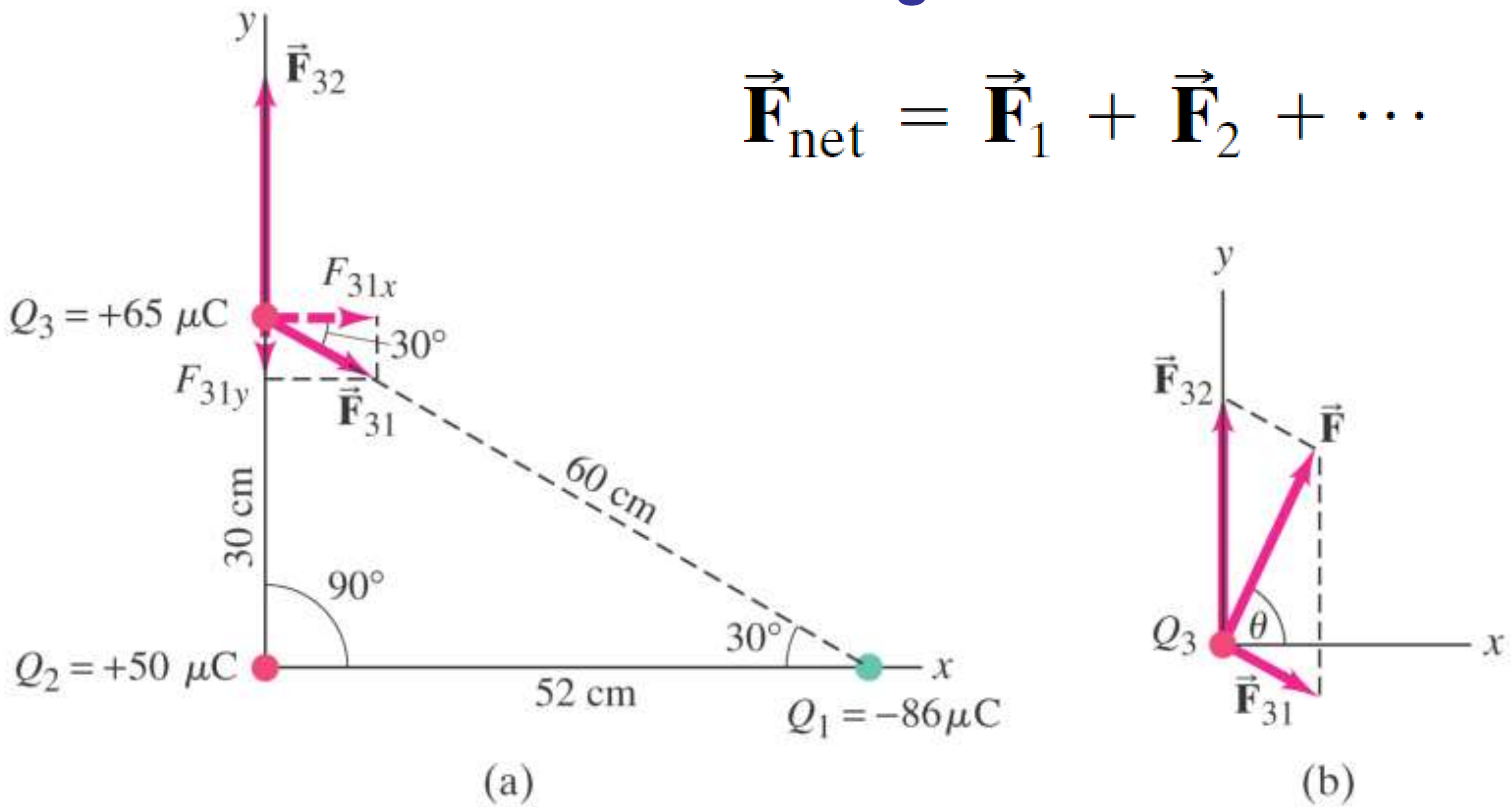
$$x = 2L.$$

Coulomb’s Law

Coulomb’s law strictly applies only to point charges.

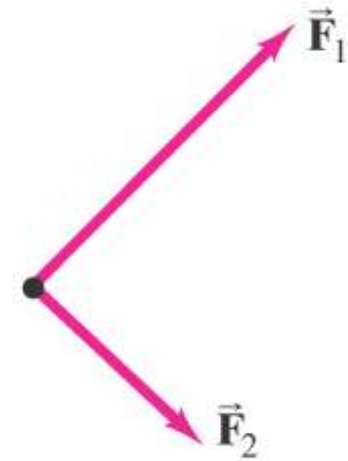
Superposition: for multiple point charges, the forces on each charge from every other charge can be calculated and then added as vectors. The net force on a charge is the vector sum of all the forces acting on it.

$$\vec{\mathbf{F}}_{\text{net}} = \vec{\mathbf{F}}_1 + \vec{\mathbf{F}}_2 + \cdots$$

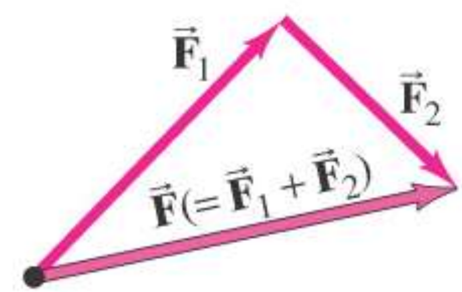


Solving Problems Involving Coulomb's Law and Vectors

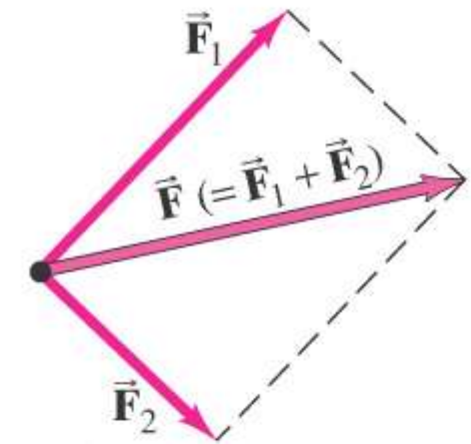
Vector addition review: 3 ways to add.



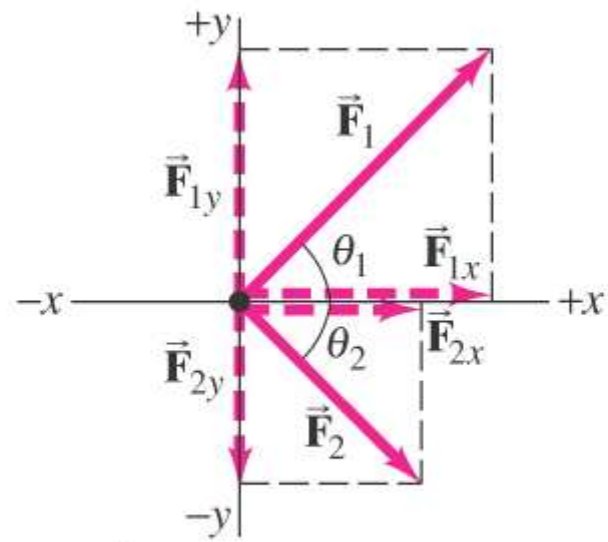
(a) Two forces acting on an object.



(b) The total, or net, force is $\vec{F} = \vec{F}_1 + \vec{F}_2$ by the tail-to-tip method of adding vectors.



(c) $\vec{F} = \vec{F}_1 + \vec{F}_2$ by the parallelogram method.



(d) $\vec{F}_1$ and $\vec{F}_2$ resolved into their x and y components.

21.2.1. Which one of the following statements concerning the electric force is true?

a) Two charged objects with identical charges will exert an attractive force on one another.

b) It is possible for a small negatively-charged particle to float above a negatively charged surface.

c) A positively-charged object is attracted toward another positively-charged object.

d) The electric force cannot alter the motion of an object.

e) Newton's third law of motion does not apply to the electrostatic force.

21.5 Charge is Quantized

- Since the days of Benjamin Franklin, our understanding of of the nature of electricity has changed from being a type of 'continuous fluid' to a collection of smaller charged particles. The total charge was found to always be a multiple of a certain elementary charge, "e":

$$q = ne, \qquad n = \pm 1, \pm 2, \pm 3, \ldots,$$

The value of this elementary charge is one of the fundamental constants of nature, and it is the magnitude of the charge of both the proton and the electron. The value of "e" is:

$$e = 1.602 \times 10^{-19}\ \mathrm{C}.$$

21.5 Charge is Quantized

Table 21-1

The Charges of Three Particles

Particle	Symbol	Charge
Electron	e or e^-	$-e$
Proton	p	$+e$
Neutron	n	0

Elementary particles either carry no charge, or carry a single elementary charge. When a physical quantity such as charge can have only discrete values, rather than any value, we say the quantity is quantized. It is possible, For example, to find a particle that has no charge at all, or a charge of +10e, or -6e, but not a particle with a charge of, say, 3.57e.

Many descriptions of electric charge use terms that might lead you to the conclusion that charge is a substance. Phrases like:

"Charge on a sphere"
"Charge transferred"
"Charge carried on the electron"

However, charge is a *property* of particles, one of many properties, such as mass.

Example, Mutual Electric Repulsion in a Nucleus:

The nucleus in an iron atom has a radius of about 4.0×10^{-15} m and contains 26 protons.

(a) What is the magnitude of the repulsive electrostatic force between two of the protons that are separated by 4.0×10^{-15} m?

KEY IDEA

The protons can be treated as charged particles, so the magnitude of the electrostatic force on one from the other is given by Coulomb's law.

Calculation: Table 21-1 tells us that the charge of a proton is $+e$. Thus, Eq. 21-4 gives us

$$F = \frac{1}{4\pi\varepsilon_0}\frac{e^2}{r^2}$$

$$= \frac{(8.99 \times 10^9\ \text{N}\cdot\text{m}^2/\text{C}^2)(1.602 \times 10^{-19}\ \text{C})^2}{(4.0 \times 10^{-15}\ \text{m})^2}$$

$$= 14\ \text{N}. \qquad \text{(Answer)}$$

No explosion: This is a small force to be acting on a macroscopic object like a cantaloupe, but an enormous force to be acting on a proton. Such forces should explode the nucleus of any element but hydrogen (which has only one proton in its nucleus). However, they don't, not even in nuclei with a great many protons. Therefore, there must be some enormous attractive force to counter this enormous repulsive electrostatic force.

(b) What is the magnitude of the gravitational force between those same two protons?

KEY IDEA

Because the protons are particles, the magnitude of the gravitational force on one from the other is given by Newton's equation for the gravitational force (Eq. 21-2).

Calculation: With m_p ($= 1.67 \times 10^{-27}$ kg) representing the mass of a proton, Eq. 21-2 gives us

$$F = G\frac{m_p^2}{r^2}$$

$$= \frac{(6.67 \times 10^{-11}\ \text{N}\cdot\text{m}^2/\text{kg}^2)(1.67 \times 10^{-27}\ \text{kg})^2}{(4.0 \times 10^{-15}\ \text{m})^2}$$

$$= 1.2 \times 10^{-35}\ \text{N}. \qquad \text{(Answer)}$$

21.6 Charge is Conserved

Hypothesis of conservation of charge has stood up under close examination.

<u>Example 1</u>: R*adioactive decay of nuclei,* in which a nucleus transforms into (becomes) a different type of nucleus.

A uranium-238 nucleus (^{238}U, 92 protons) transforms into a thorium-234 nucleus (^{234}Th, 90 protons) by emitting an *alpha particle.* An alpha particle has the same makeup as a helium-4 nucleus, it has the symbol ^{4}He (2 protons).

$$^{238}\text{U} \rightarrow {}^{234}\text{Th} + {}^{4}\text{He},$$

<u>Example 2</u>: An electron e (charge *-e)* and its antiparticle, the positron e (charge +*e),* undergo an annihilation process, transforming into two gamma rays (high-energy light):. Here the net charge is zero.

$$\text{e}^- + \text{e}^+ \rightarrow \gamma + \gamma \qquad \text{(annihilation)}.$$

Example 3: A gamma ray transforms into an electron and a positron. Here the net charge is again zero.

$$\gamma \rightarrow \text{e}^- + \text{e}^+ \qquad \text{(pair production)}.$$

21.4.1. Two positively charged particles are separated by a distance *r*. The force on particle 1 is *F* due to particle 2. The force on particle 2 is 2*F* due to particle 1. Is the previous sentence true or false? Explain why this is the case.

a) The sentence is true, if the net charge of particle 1 is twice that of particle 2.

b) The sentence is false because the forces on each of the two objects are equal in magnitude, but opposite in direction.

c) The sentence is true since the particles are separated by a distance *r*.

d) The sentence is false because two positively charged particles cannot exert a force on each other.

21.4.2. Two positively charged particles are separated by a distance *r*. Which of the following statements concerning the electrostatic force between acting on each particle due to the presence of the other is true?

a) The electrostatic force may be calculated using Faraday's law.

b) The electrostatic force depends on the masses of the two particles.

c) The electrostatic force depends on r^2.

d) The electrostatic force increases as *r* is increased.

e) The electrostatic force is on each particle is directed toward the other particle.

21.4.3. Coulomb's law is similar to Newton's law of gravitation in several ways. Which one of the statements is not a similarity between these two laws?

a) In both laws, the force is inversely proportional to the square of the distance between two particles.

b) In both laws, the force decreases with increasing distance between the two particles.

c) In both laws, the force is proportional to the product of an intrinsic property of each of the two particles.

d) In both laws, the force is always one of attraction between the two particles.

e) In both laws, there is a proportionality constant that appears.

21.6.2. When an electron (charge –1.60 × 10^{-19} C) and a positron (charge +1.60 × 10^{-19} C) come together, they annihilate one another. Two particles of light (photons) are emitted from the annihilation. This is an example of what type of physical phenomena?

a) charge quantization

b) charge separation

c) Coulomb force

d) charge density wave

e) charge conservation

21.5.1. Which one of the following values is the smallest possible amount of free charge that has been discovered?

a) 5.34×10^{-20} coulombs

b) 1.60×10^{-19} coulombs

c) 1.38×10^{-23} coulombs

d) 6.63×10^{-34} coulombs

e) 8.85×10^{-12} coulombs

21.5.2. Which one of the following statements concerning the net electric charge on an object is true?

a) An object with a net negative charge has an excess number of protons.

b) The net charge can have any value greater than 1.60×10^{-19} coulombs.

c) The net charge on an object is always a negative number.

d) Since protons are larger, a proton can carry more charge than an electron.

e) The net charge is quantized.