Sec. 7.2 - Electric Forces - Coulomb's Law

Learning Goal: By the end of today, I will be able to determine and resolve the forces created by charged point sources.

Measuring and defining charge

The unit of charge is the coulomb (abbreviated to C). Charge is a scalar quantity.

The coulomb is defined as the charge transported by a current of one ampere in one second.

A Coulomb is a bundle of electrons measuring 6.24×10^{18} in number.

A quantity of 1 C is equal to approximately 6.24×10^{18}, or 6.24 quintillion.

In terms of SI base units, the coulomb represents 1 C of unit electric charge carriers flowing past a specific point in 1 s.

Measurements show that all electrons are identical, with each one having a charge equal to -1.6×10^{-19} C; this fundamental amount of charge is known as the **electronic (or elementary) charge** and given the symbol *e*.

Charges smaller than the electronic charge are not observed in nature. (Quarks have fractional charges that appear as $\pm 1/3\, e$ or $\pm 2/3\, e$; however, they are never observed outside their nucleons.)

A coulomb is a very large unit. When a comb runs through your hair, there might be a charge of somewhere between 1 pC and 1 nC transferred to it.

Elementary Charge of an Electron

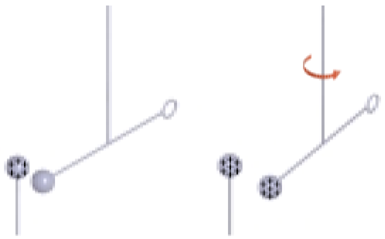
$$e = -1.602 \times 10^{-19} C \quad \text{or} \quad \frac{1}{6.24 \times 10^{18}}$$

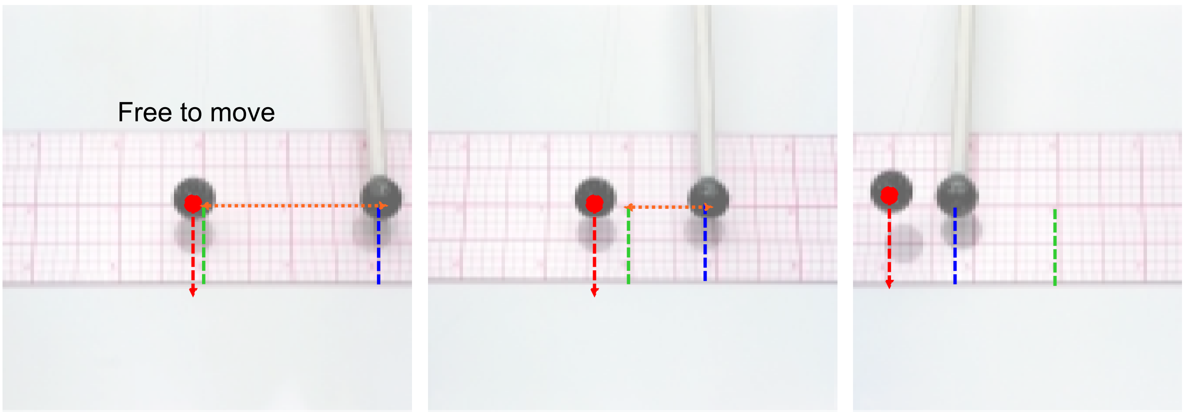
Charge of a Proton

- same magnitude as an electron, but positive
- protons have a complex structure, they are built of quarks
- quarks have charge that are $\pm\frac{1}{3}q$ or $\pm\frac{2}{3}q$
- conversation for another day

Similar to the Cavendish experiment for gravity, the Coulomb apparatus measure the tension force, the angle turned and distance between the two objects. The relationship that was discovered was as follows:

$$F_e \sim \frac{1}{r^2}$$





Left ball does not contact right ball.

Figure 2
The electrostatic force of repulsion between two identical spheres at different distances

Coulomb's Law

Coulomb's Law

The force between two point charges is inversely proportional to the square of the distance between the charges and directly proportional to the product of the charges.

$$F_E = \frac{kq_1q_2}{r^2}$$

F is force, measured in Newtons

$k = 9.0 \times 10^9$ $N{*}m^2/C^2$ (~for vacuum and air)

q_1 & q_2 are measure in Coulomb's (C)

Note: a positively and negatively charged particle would result in a negative answer, which would be attractive - two like charged particles would result in positive answer, which would be repulsive.

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Example

$$F_E = \frac{kq_1q_2}{r^2}$$

$k = 9.0 \times 10^9\ N*m^2/C^2$

What is the magnitude of the force of repulsion between two small spheres 1.0 m apart, if each has a charge of 1.0×10^{-6} C?

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Permittivity Constant - k

The equation as it stands applies only for charges that are in a vacuum. If the charges are immersed in a different medium (say, air or water) then the value of the permittivity is different. It is usual to amend the equation slightly

$$k = \frac{1}{4\pi\varepsilon} \qquad F_E = \frac{1}{4\pi\varepsilon}\frac{q_1 q_2}{r^2}$$

Material	Permittivity / $10^{-12}\ C^2\ N^{-1}\ m^{-2}$	~k value
paper	34	$2.3\text{x}10^9$
rubber	62	$1.3\text{x}10^9$
water	779	$0.1\text{x}10^9$
graphite	106	$0.6\text{x}10^9$
diamond	71	$1.1\text{x}10^9$
air	$8.85 \times 10^{-12}\ C^2\ N^{-1}\ m^{-2}$	$9.0\text{x}10^9$

As ε increases, F decreases

As ε decreases, F increases

Example

Two point charges of magnitude $+5\ \mu C$ and $+3\ \mu C$ are 1.5 m apart in a liquid that has a permittivity of $2.3 \times 10^{-11}\ C^2\ N^{-1}\ m^{-2}$.

Calculate the force between the point charges.

If the same system was moved to a vacuum, what would be the force between the point charges?

Gravity versus Coulomb

$$F_E = \frac{kq_1q_2}{r^2} \qquad F_g = \frac{Gm_1m_2}{r^2}$$

Similar:

- Both are inverse square laws that are also proportional to the product of another quantity; for gravity it is the product of two masses,and for the electric force it is the product of the two charges

- The forces act along the line joining the centres of the masses or charges

-The magnitude of the force is the same as the force that would be measured if all the mass or charge is concentrated at a point at the centre of the sphere

- can be attracted by more than one body/particle at once

Different:

- The electric force can attract or repel, depending on the charges involved, whereas the gravitational force can only attract

-The universal gravitational constant,G = 6.67×10^{-11} Nm^2/kg^2,is very small,meaning that in many cases the gravitational force can be ignored.

In contrast,Coulomb's constant, k = 9.0×10^9 Nm^2/C^2,is a very large number implying that even small charges can result in noticeable forces.

Example

Charged spheres A and B are fixed in position (**Figure 6**) and have charges $+4.0 \times 10^{-6}$ C and -2.5×10^{-7} C, respectively. Calculate the net force on sphere C, whose charge is $+6.4 \times 10^{-6}$ C.

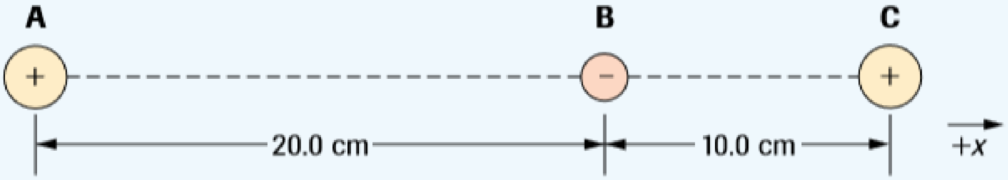


Figure 6

Solution

$q_A = +4.0 \times 10^{-6}$ C $r_{AB} = 20.0$ cm

$q_B = -2.5 \times 10^{-7}$ C $r_{BC} = 10.0$ cm

$q_C = +6.4 \times 10^{-6}$ C $\sum \vec{F}_{net} = ?$

Example

Identical spheres A, B, C, and D, each with a charge of magnitude 5.0×10^{-6} C, are situated at the corners of a square whose sides are 25 cm long. Two diagonally opposite charges are positive, the other two negative, as shown in **Figure 7**. Calculate the net force acting on each of the four spheres.

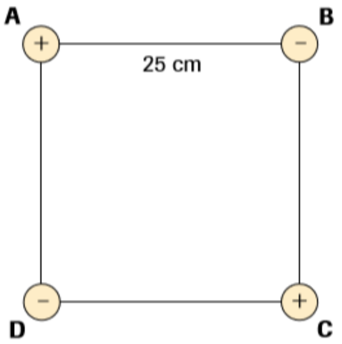
Solution

$q_A = q_B = q_C = q_D = 5.0 \times 10^{-6}$ C

$s = 25$ cm $= 0.25$ m

$r = 35$ cm $= 0.35$ m

$\sum \vec{F} = ?$



What forces act on each particle?

SUMMARY Electric Forces: Coulomb's Law

- Coulomb's law states that the force between two point charges is inversely proportional to the square of the distance between the charges and directly proportional to the product of the charges: $F_E = \frac{kq_1q_2}{r^2}$, where $k = 9.0 \times 10^9\ \text{N}\cdot\text{m}^2/\text{C}^2$.
- Coulomb's law applies when the charges on the two spheres are very small, and the two spheres are small compared to the distance between them.
- There are similarities and differences between Coulomb's law and Newton's law of universal gravitation: Both are inverse square laws that are also proportional to the product of quantities that characterize the bodies involved; the forces act along the line joining the two centres of the masses or charges; and the magnitude of the force is accurately given by the force that would be measured if all the mass or charge is concentrated at a point at the centre of the sphere. However, the gravitational force can only attract while the electric force can attract or repel. The universal gravitational constant is very small, while Coulomb's constant is very large.

Homework

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