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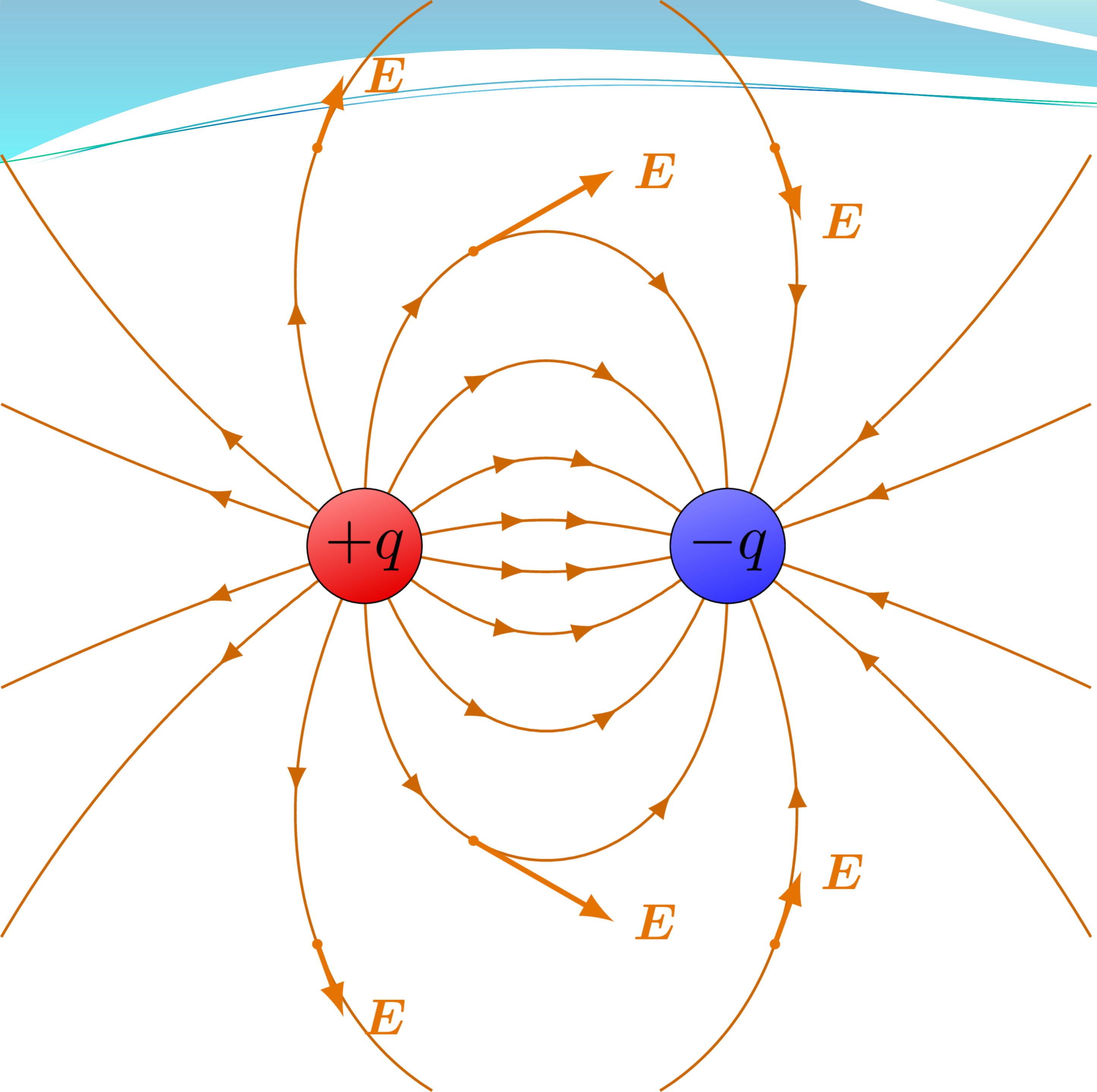


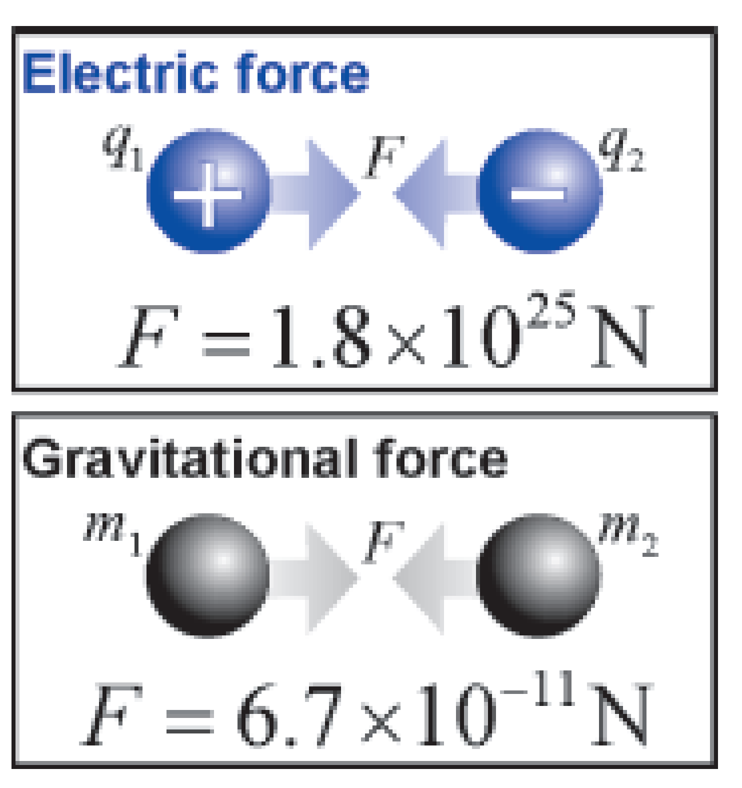
Coulomb's Law

Sagar Dutta

Electric Charge

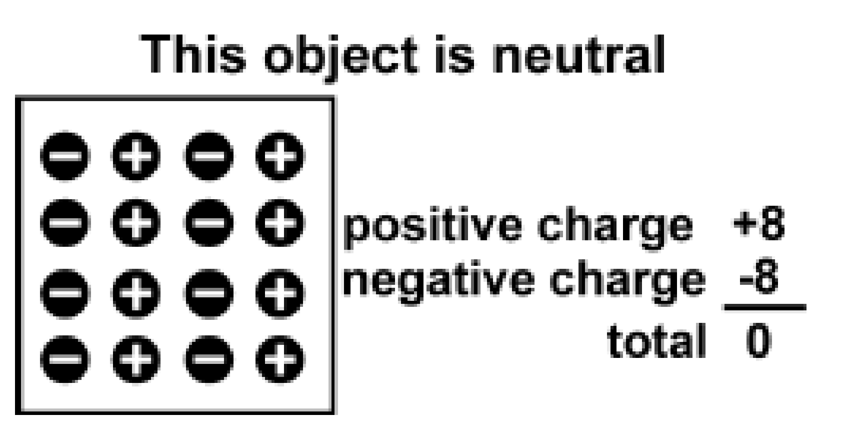
Key Question:

How do electric charges interact?



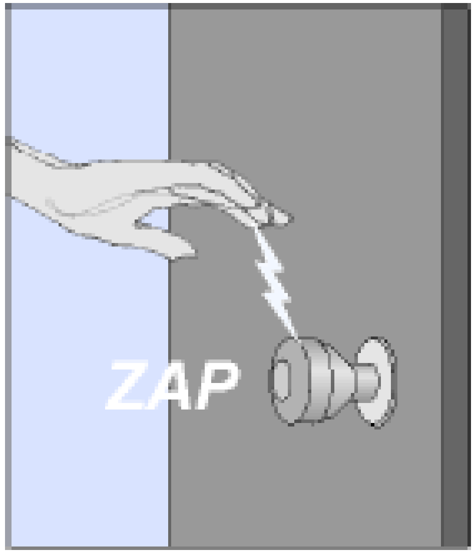
Electric Charge

- All ordinary matter contains both positive and negative charge.
- You do not usually notice the charge because most matter contains the exact same number of positive and negative charges.
- An object is electrically neutral when it has equal amounts of both types of charge.



Electric Charge

- Objects can lose or gain electric charges.
- The net charge is also sometimes called excess charge because a charged object has an excess of either positive or negative charges.
- A tiny imbalance in either positive or negative charge on an object is the cause of static electricity.

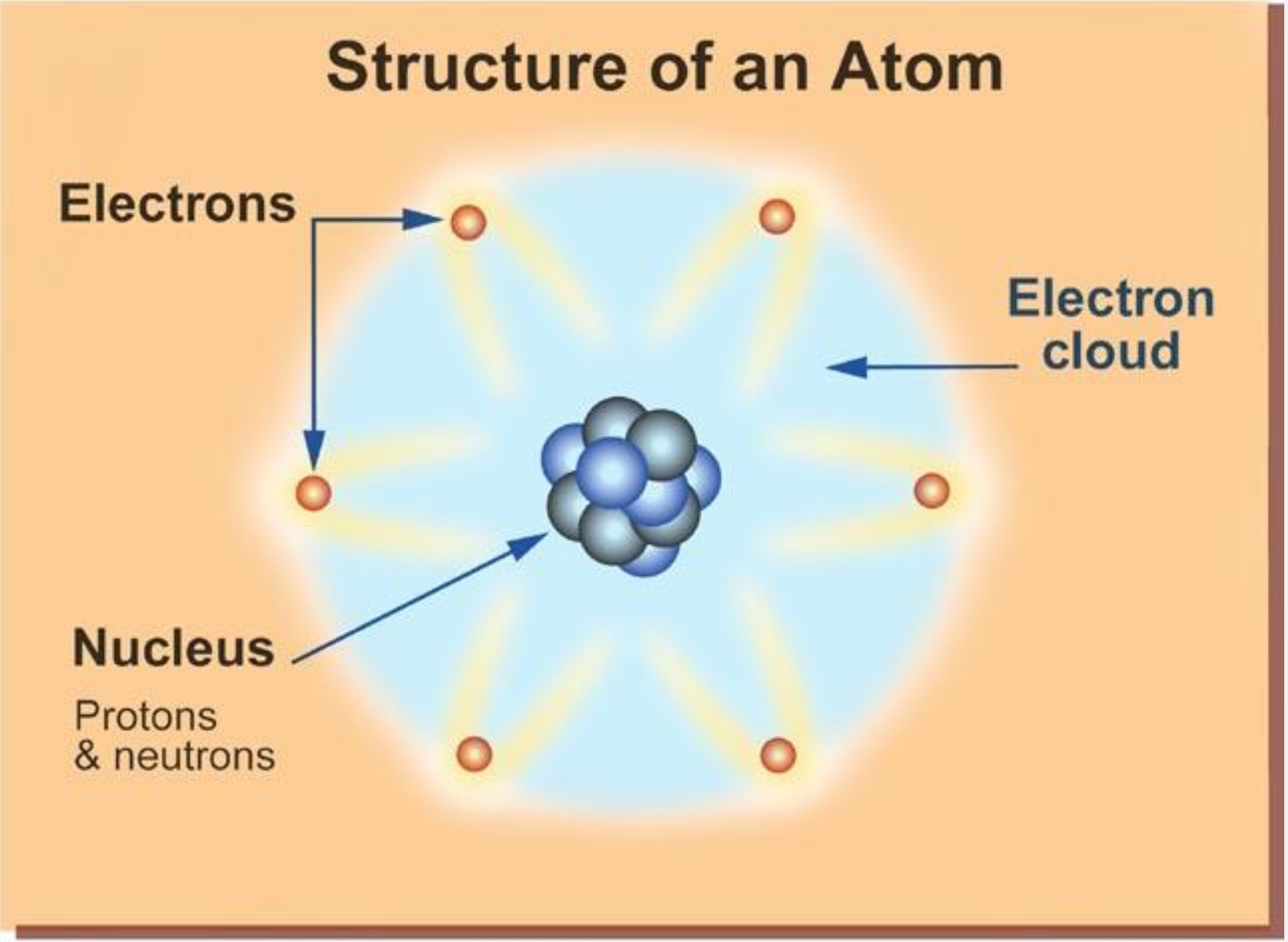


Static electricity

Electric Charge

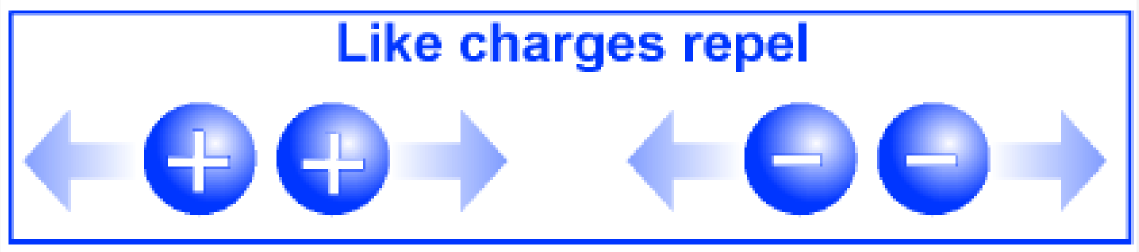
- Electric charge is a property of tiny particles in atoms.
- The unit of electric charge is the coulomb (C).
- A quantity of charge should always be identified with a positive or a negative sign.

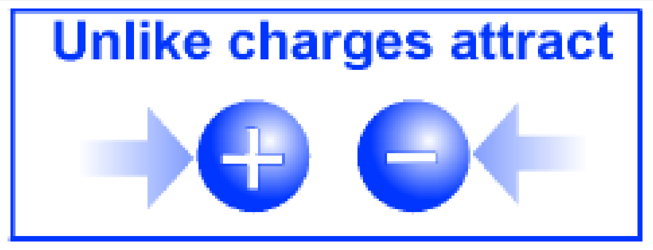
	Mass (kg)	Charge (coulombs)
Electron	9.109×10^{-31}	-1.602×10^{-19}
Proton	1.673×10^{-27}	$+1.602 \times 10^{-19}$
Neutron	1.675×10^{-27}	0


Structure of an Atom
Electrons
Electron cloud
Nucleus
Protons & neutrons

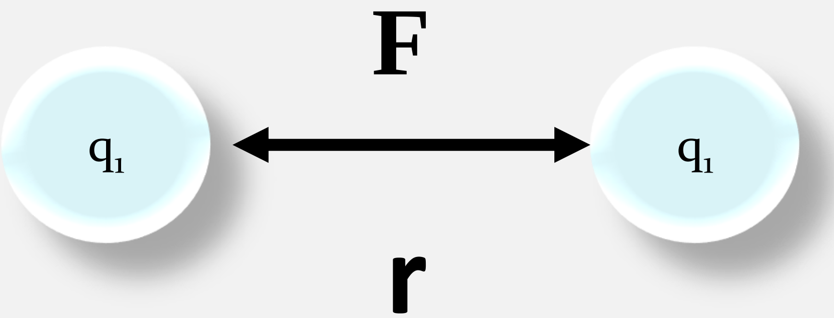
Electric forces

- Electric forces are created between all electric charges.
- Because there are two kinds of charge (positive and negative) the electrical force between charges can attract or repel.





COULOMB'S LAW



Let ,

The amount of two charges that acts here = q_1 and q_2

Electrostatic force between the two charges = **F**

Here r = distance between the two charges

$k = \frac{1}{4\pi\varepsilon o}$ = Coulombs Constant

$k = 8.987752\times10^9\ Nm^2/C^2$

$$\vec{F} = k\,\frac{q_1 q_2}{r^2}\,\hat{r} \qquad \text{(Coulomb's law)},$$

$\hat{r}$ is a unit vector along an axis extending through the two particles

Coulomb's Law

- Coulomb’s law relates the force between two single charges separated by a distance.

Constant

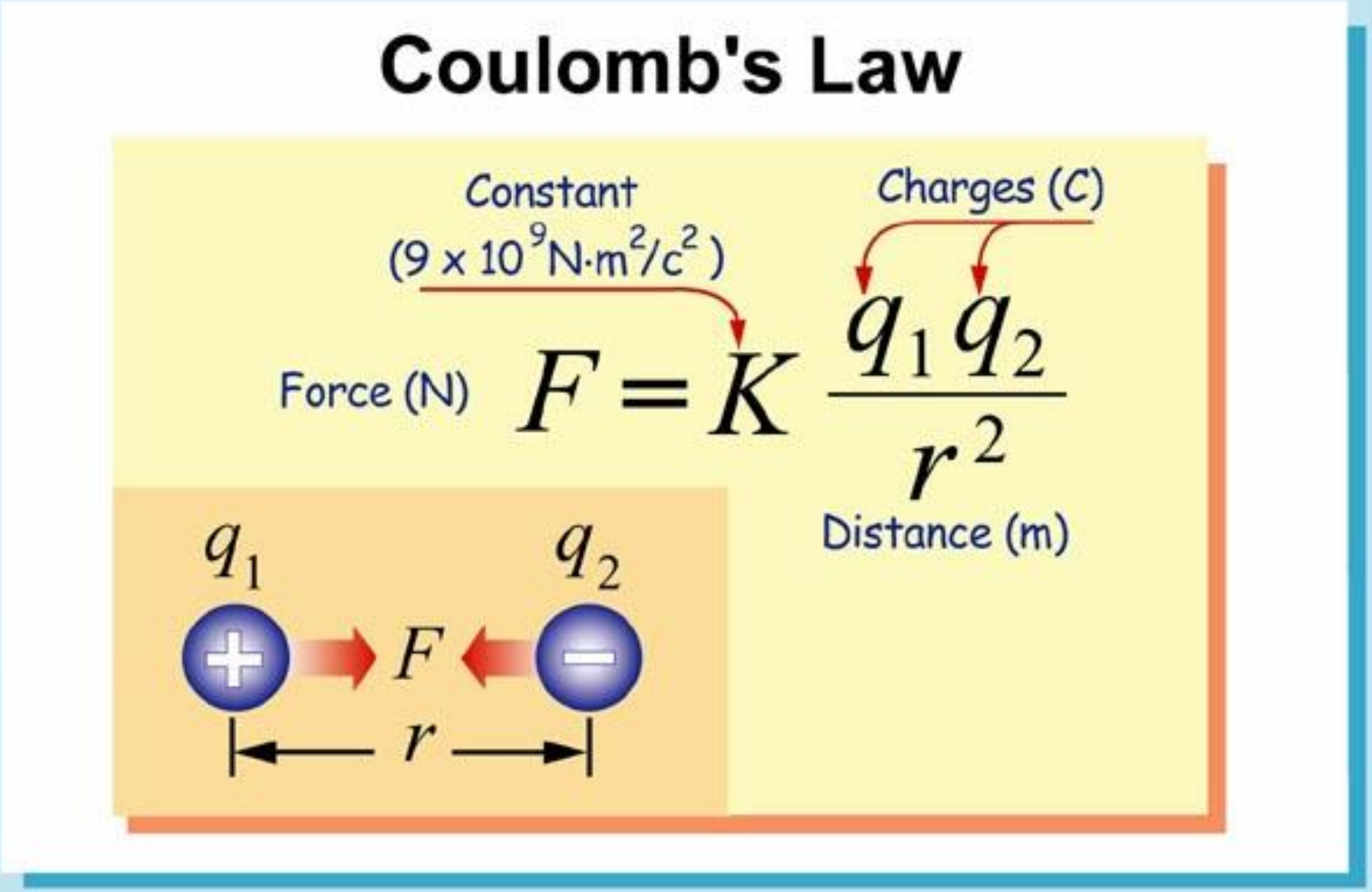
$9 \times 10^9\ N{\cdot}m^2/C^2$

Force (N)

$$F = K \frac{q_1 q_2}{r^2}$$

Charges (C)

Distance (m)


Coulomb's Law
Constant
(9 x 10^9 N·m^2/c^2)
Charges (C)
Force (N)
$F = K \frac{q_1 q_2}{r^2}$
Distance (m)
q_1
q_2
F
r

$$F = \frac{1}{4\pi\varepsilon_0} \frac{|q_1||q_2|}{r^2} \qquad \text{(Coulomb's law).} \tag{21-4}$$

The constants in Eqs. 21-1 and 21-4 have the value

$$k = \frac{1}{4\pi\varepsilon_0} = 8.99 \times 10^9 \, \mathrm{N \cdot m^2/C^2}. \tag{21-5}$$

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

$$\varepsilon_0 = 8.85 \times 10^{-12} \, \mathrm{C^2/N \cdot m^2}. \tag{21-6}$$

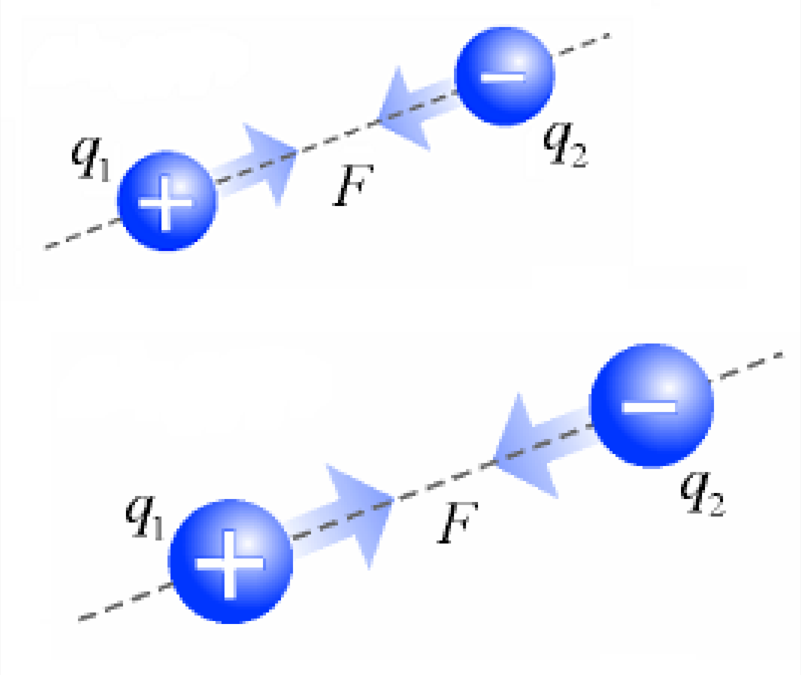
Still another parallel between the gravitational force and the electrostatic force is that both obey the principle of superposition. If we have n charged particles, they interact independently in pairs, and the force on any one of them, let us say particle 1, is given by the vector sum

$$\vec{F}_{1,\mathrm{net}} = \vec{F}_{12} + \vec{F}_{13} + \vec{F}_{14} + \vec{F}_{15} + \cdots + \vec{F}_{1n}, \tag{21-7}$$

in which, for example, $\vec{F}_{14}$ is the force acting on particle 1 due to the presence of particle 4. An identical formula holds for the gravitational force.

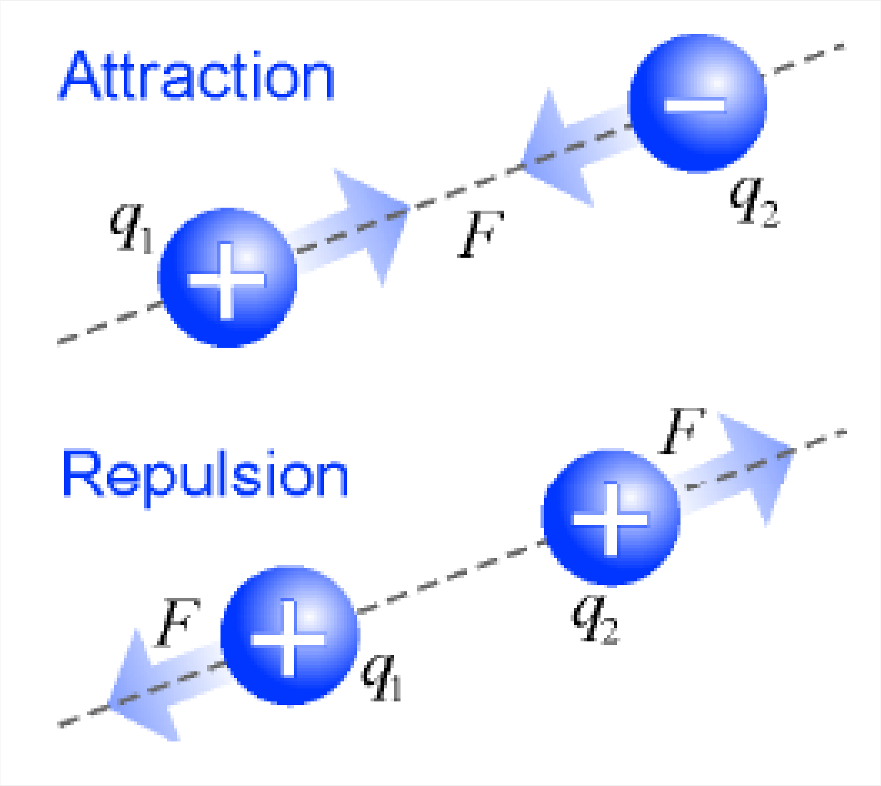
Coulomb's Law

- The force between two charges gets stronger as the charges move closer together.
- The force also gets stronger if the amount of charge becomes larger.



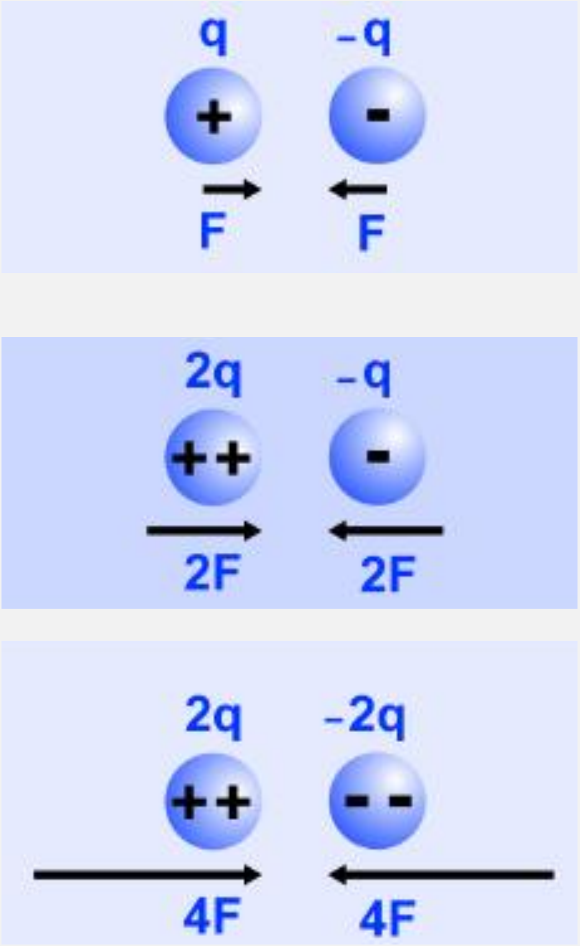
Coulomb's Law

- The force between two charges is directed along the line connecting their centers.
- Electric forces always occur in pairs according to Newton's third law, like all forces.



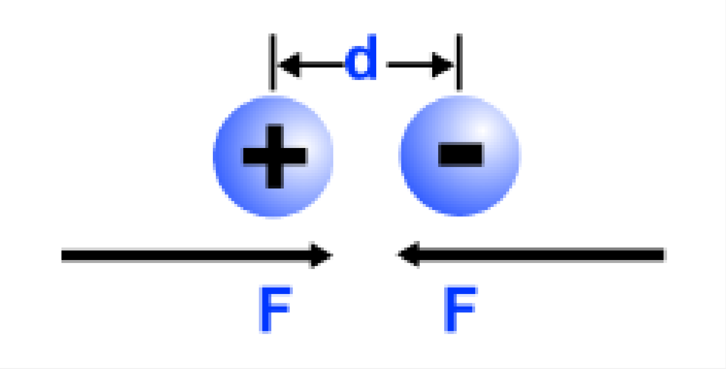
Coulomb's Law

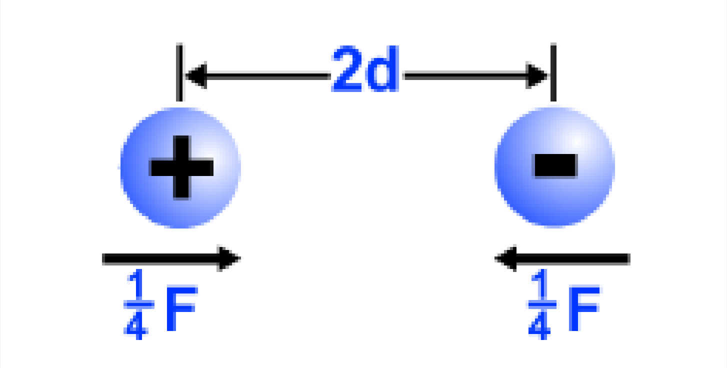
- The force between charges is directly proportional to the magnitude, or amount, of each charge.
- Doubling one charge doubles the force.
- Doubling both charges quadruples the force.



Coulomb's Law

- The force between charges is inversely proportional to the square of the distance between them.
- Doubling the distance reduces the force by a factor of $2^2 = (4)$, decreasing the force to one-fourth its original value $(1/4)$.
- This relationship is called an inverse square law because force and distance follow an inverse square relationship.





Problem 1

A positive charge of 6×10^{-6} C is 0.040m from the second positive charge of 4×10^{-6} C. Calculate the force between the charges.

$$\vec{F} = k\,\frac{q_1 q_2}{r^2}\,\hat{\mathrm{r}} \qquad \text{(Coulomb's law),}$$

Answer: $F_e = 134.85$ N

(a) Figure 21-8*a* shows two positively charged particles fixed in place on an x axis. The charges are $q_1 = 1.60 \times 10^{-19}$ C and $q_2 = 3.20 \times 10^{-19}$ C, and the particle separation is $R = 0.0200$ m. What are the magnitude and direction of the electrostatic force $\vec{F}_{12}$ on particle 1 from particle 2?

$$F_{12} = \frac{1}{4\pi\varepsilon_0}\frac{|q_1||q_2|}{R^2}$$

$$= (8.99 \times 10^9\ \mathrm{N\cdot m^2/C^2})$$

$$\times \frac{(1.60 \times 10^{-19}\ \mathrm{C})(3.20 \times 10^{-19}\ \mathrm{C})}{(0.0200\ \mathrm{m})^2}$$

$$= 1.15 \times 10^{-24}\ \mathrm{N}.$$

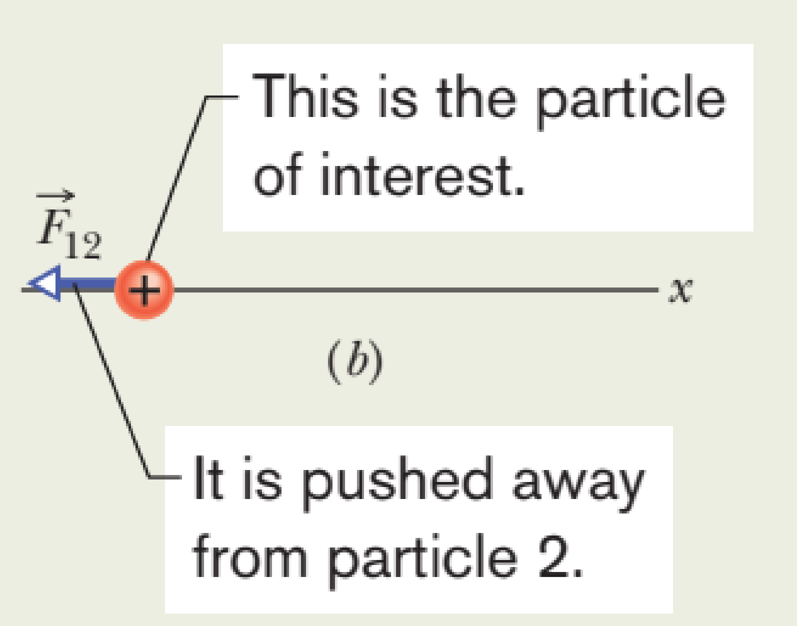
Thus, force $\vec{F}_{12}$ has the following magnitude and direction (relative to the positive direction of the x axis):

$$1.15 \times 10^{-24}\ \mathrm{N} \quad \text{and} \quad 180^\circ. \qquad \text{(Answer)}$$

We can also write $\vec{F}_{12}$ in unit-vector notation as

$$\vec{F}_{12} = -(1.15 \times 10^{-24}\ \mathrm{N})\hat{\mathrm{i}}. \qquad \text{(Answer)}$$

Problem 2



Because both particles are positively charged, particle 1 is repelled by particle 2, with a force magnitude given by Eq. 21-4. Thus, the direction of force $\vec{F}_{12}$ on particle 1 is *away from* particle 2, in the negative direction of the x axis, as indicated in the free-body diagram of Fig. 21-8*b*.

Charge Is Quantized

In Benjamin Franklin's day, electric charge was thought to be a continuous fluid—an idea that was useful for many purposes. However, we now know that fluids themselves, such as air and water, are not continuous but are made up of atoms and molecules; matter is discrete. Experiment shows that "electrical fluid" is also not continuous but is made up of multiples of a certain elementary charge. Any positive or negative charge q that can be detected can be written as

$$q = ne, \qquad n = \pm 1, \pm 2, \pm 3, \ldots, \tag{21-11}$$

in which e, the **elementary charge,** has the approximate value

$$e = 1.602 \times 10^{-19}\ \text{C}. \tag{21-12}$$

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?

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

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

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

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

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

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

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

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

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

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

Charge Is Conserved

Another example of charge conservation occurs when 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):

$$e^- + e^+ \rightarrow \gamma + \gamma \qquad \text{(annihilation)}. \tag{21-14}$$

In *pair production*, the converse of annihilation, charge is also conserved. In this process a gamma ray transforms into an electron and a positron:

$$\gamma \rightarrow e^- + e^+ \qquad \text{(pair production)}. \tag{21-15}$$

Please Practice the mathematics from the examples and also related mathematics from exercise.

Thank You