This is not a replacement for your textbook. It is essential to study from your textbook!

Objectives

Ch21: Coulomb's law

21-1 Coulomb's law

21-2 Charge is quantized

21-3 Charge is conserved

The symbol for charge is q

The SI unit for charge is the coulomb (C)

The smallest charge is that of the elementary charge e

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

All other charges are an integer multiple of e

$\Longrightarrow$ charge is quantized.

$q = 3e$ possible

$q = 3.5e$ Not possible

Charge can be negative or positive.

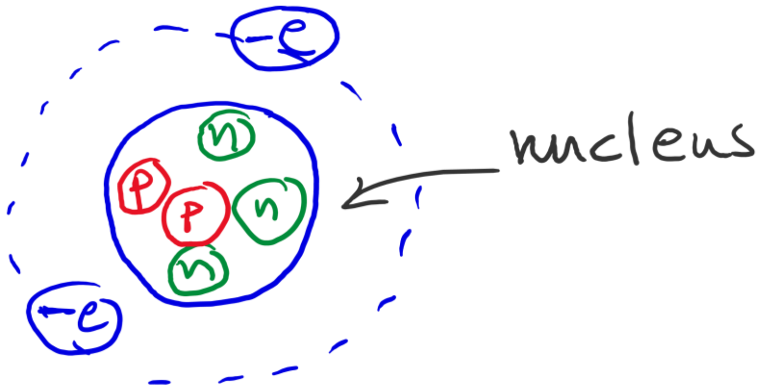
The total charge in an isolated system is conserved.

$$\boxed{\text{positive charge} + \text{negative charge} = \text{constant}}$$

	charge
electron	$-e = -1.6 \times 10^{-19}$ C
proton	$+e = +1.6 \times 10^{-19}$ C
neutron	0 has no charge

An atom is electrically neutral

number of electrons = number of protons

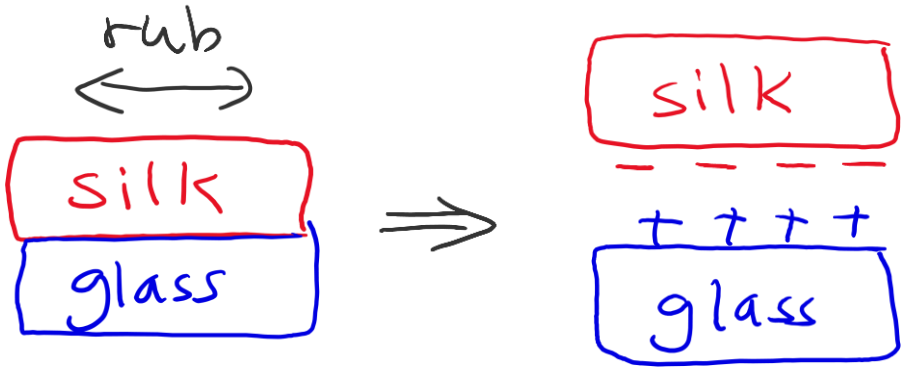


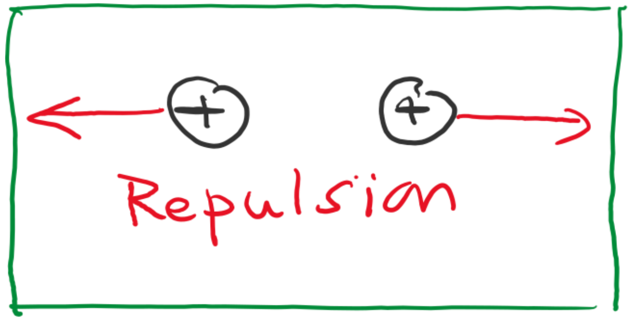
A positive ion = an atom that Lost electrons

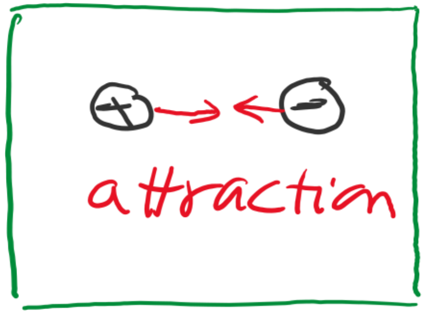
A negative ion = an atom that gained electrons

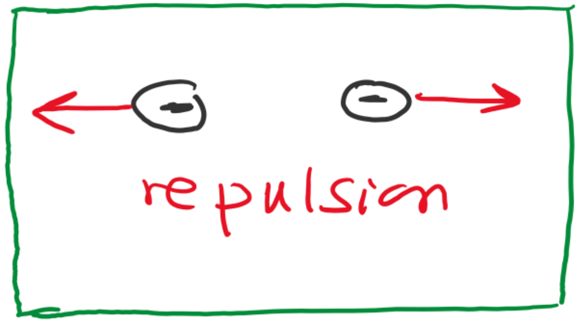
Electrostatic $\equiv$ charges are stationary or moving very slowly.

You can charge an object by rubbing









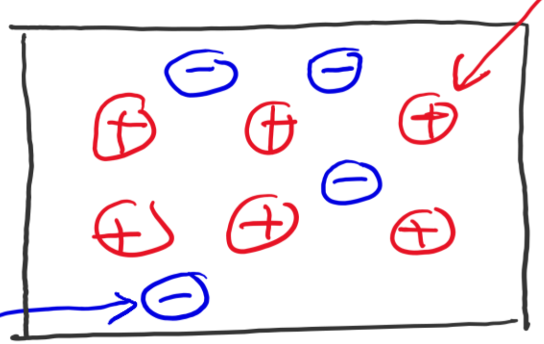
Conductors

Outermost electrons are
loosely held by the nucleus

Insulators

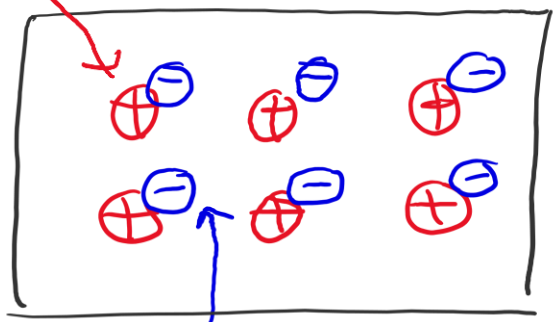
Outermost electrons are
tightly held by the nucleus

ions are fixed (solid)
move very slowly (liquid)



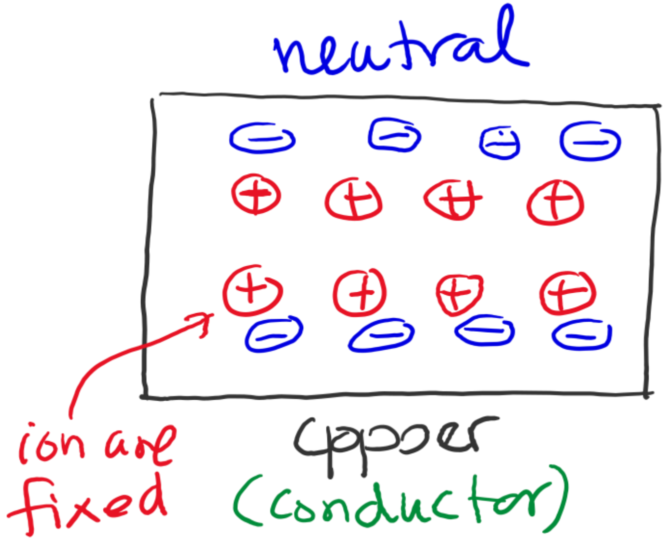
Outermost electrons can
move freely

metal
tap water
human body



Outermost electrons cannot
move

glass
pure water
plastic

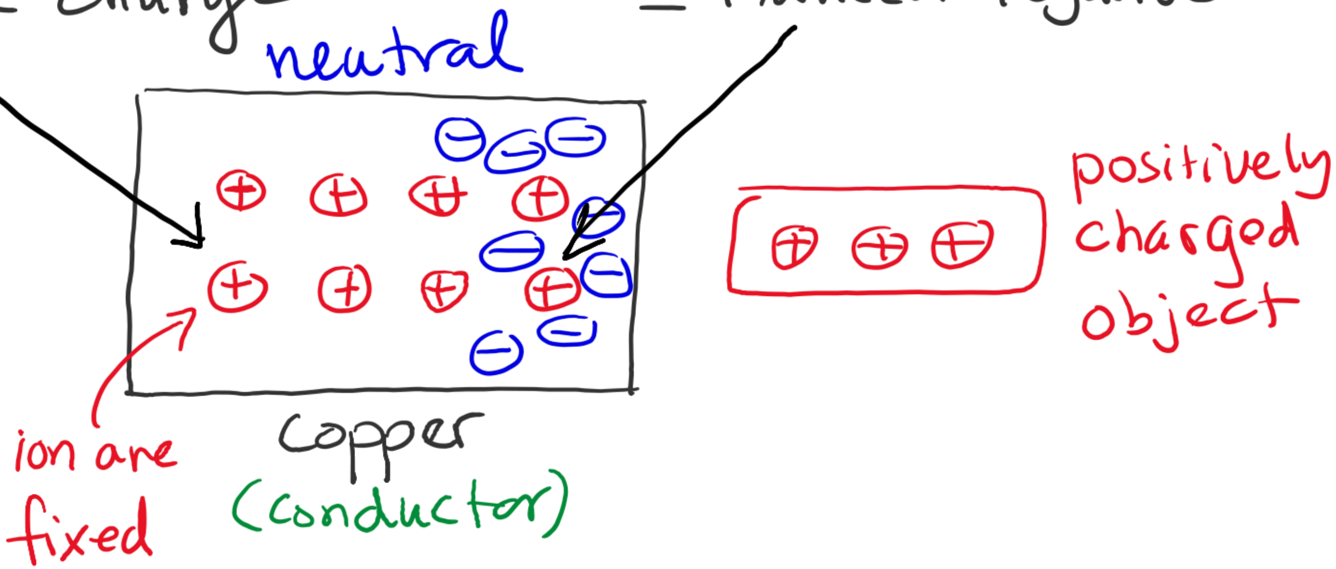


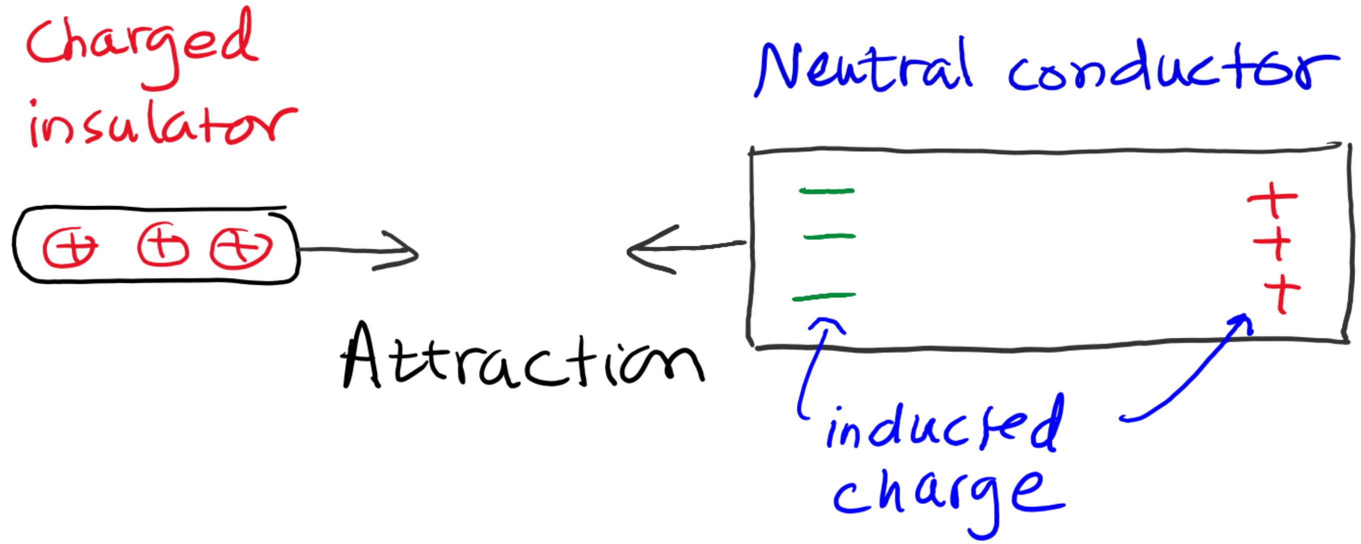
The conductor is neutral at all points.

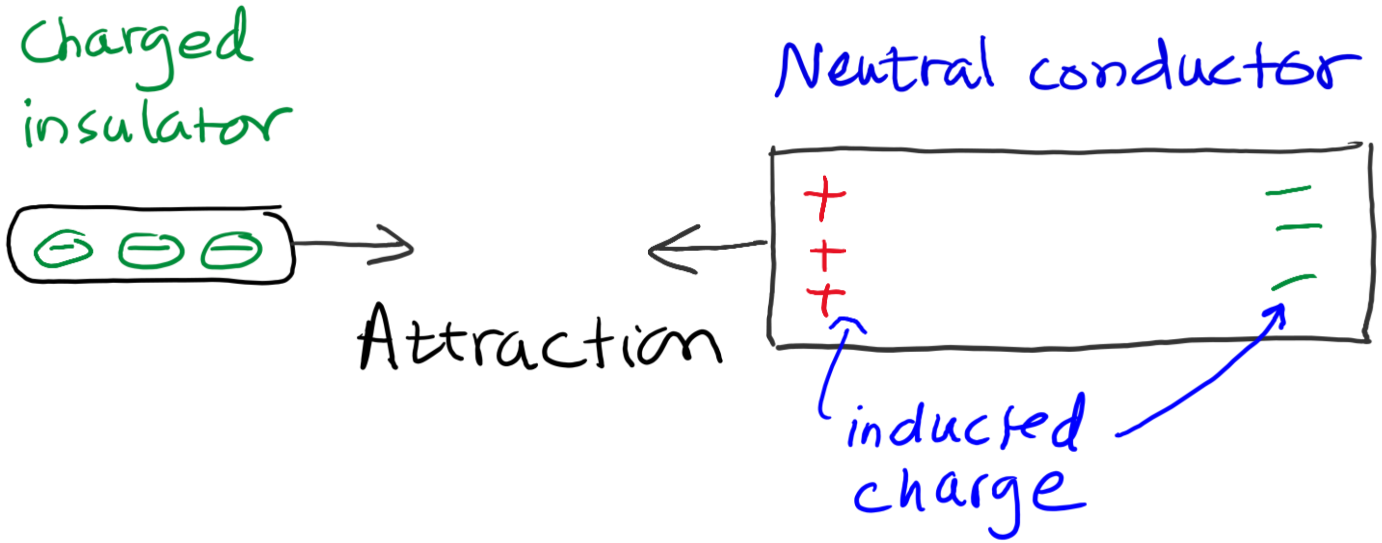
positive charge density = negative charge density

lower electron density
≡ induced positive charge

higher electron density
≡ induced negative charge




Charged insulator
Neutral conductor
Attraction
induced charge


Charged insulator
Neutral conductor
Attraction
induced charge

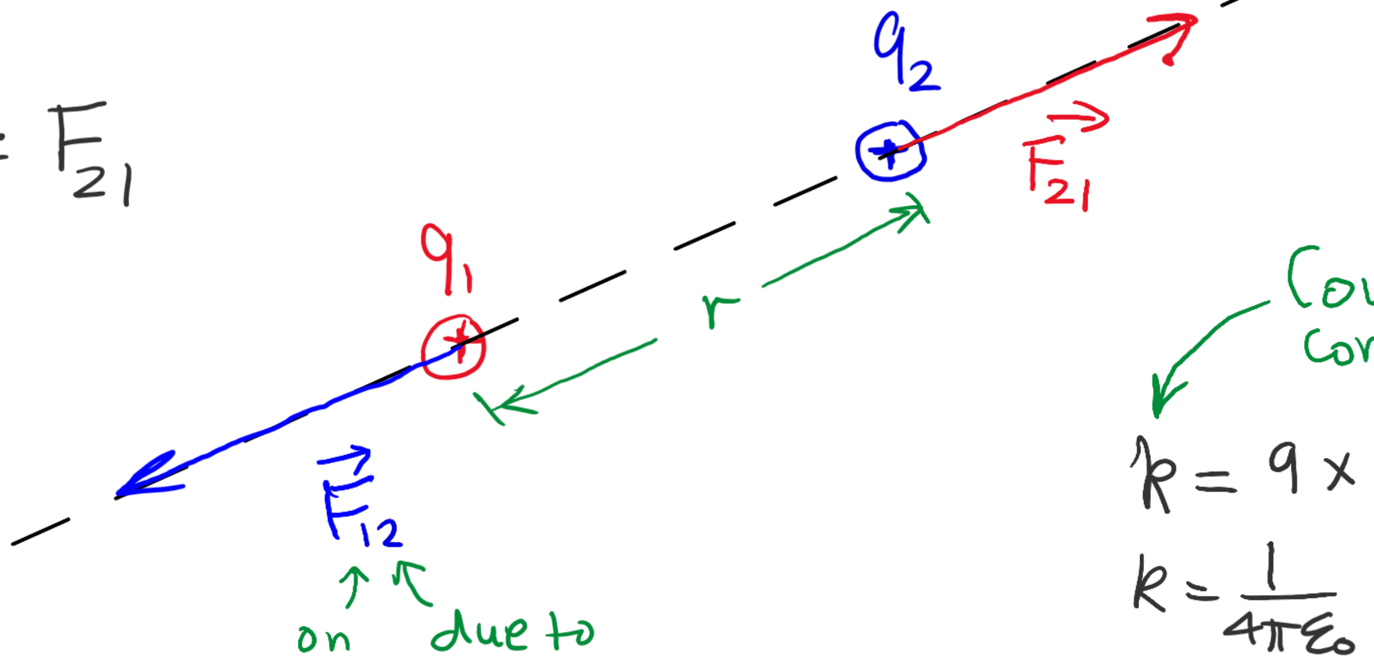
Coulomb's law

The magnitude of the electrostatic force

$$F_{12} = k\frac{|q_1||q_2|}{r^2} = F_{21}$$

on due to

$$\vec{F}_{12} = -\vec{F}_{21}$$



Coulomb constant

$$k = 9 \times 10^{9}\ \frac{Nm^2}{C^2}$$

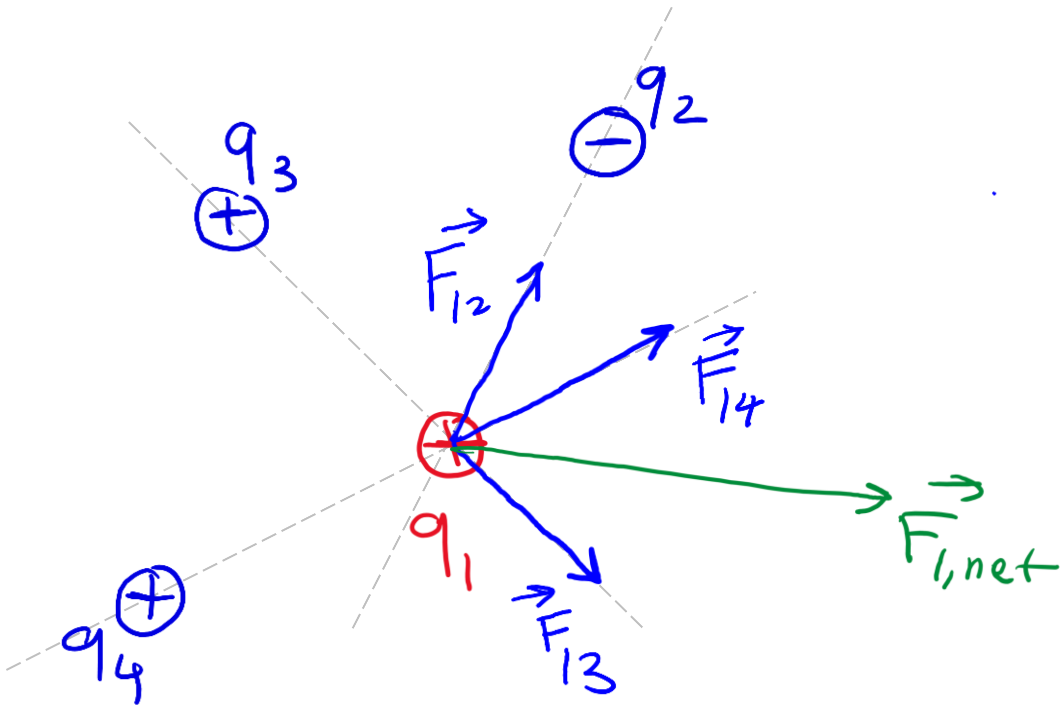
$$k = \frac{1}{4\pi\varepsilon_0}$$

permittivity constant

$$\varepsilon_0 = 8.85 \times 10^{-12}\ \frac{C^2}{Nm^2}$$

The two forces form a third-law force pair.

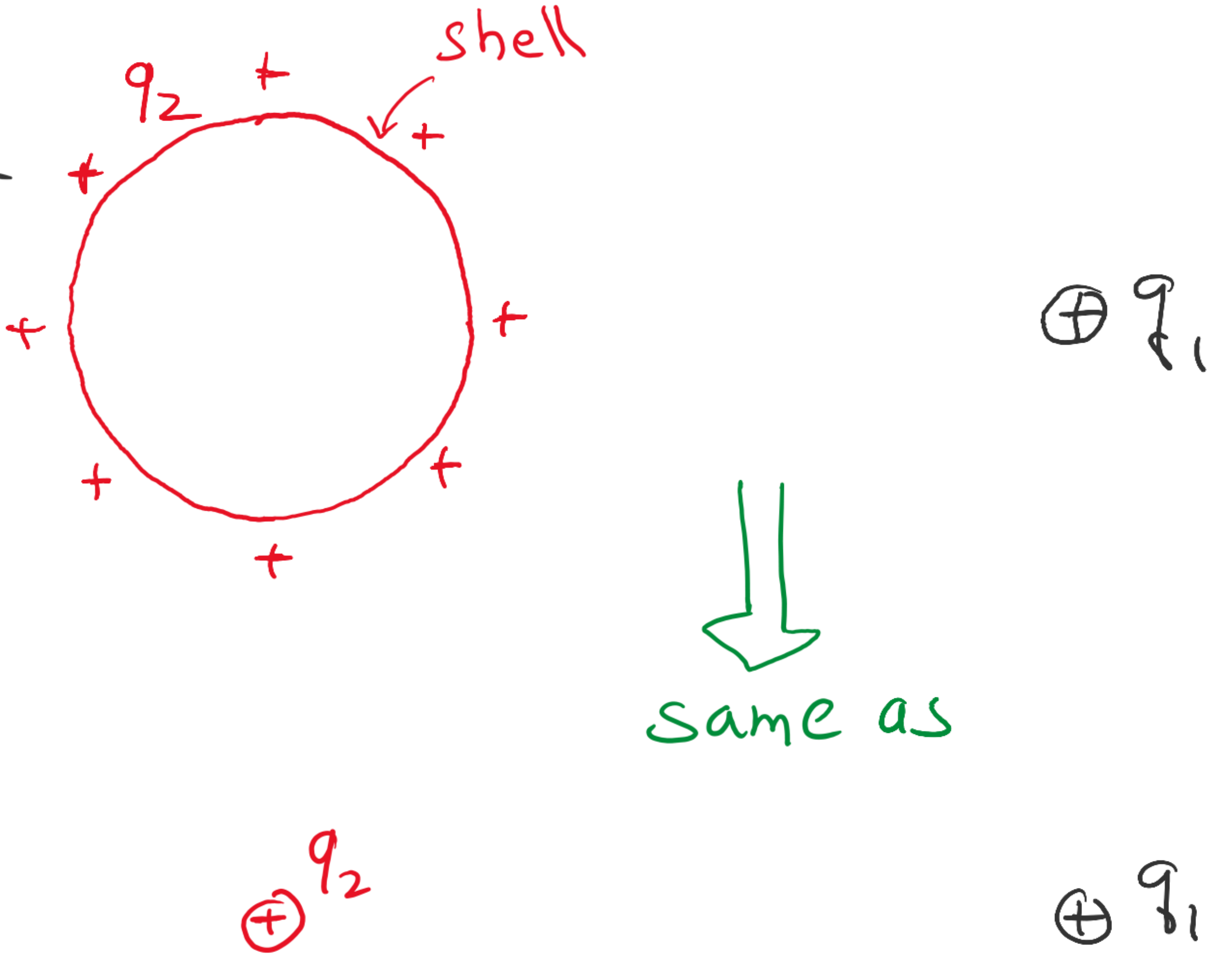
Principle of superposition



$$\vec{F}_{1,net} = \vec{F}_{12} + \vec{F}_{13} + \vec{F}_{14}$$

Shell theorem

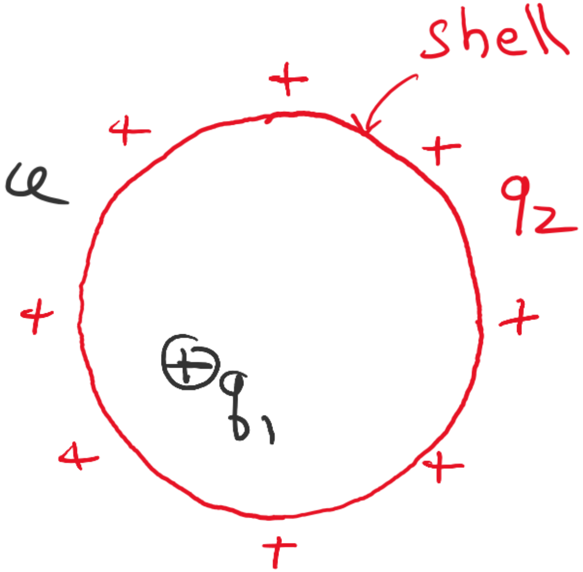
charge q_2 is uniformly distributed over the surface



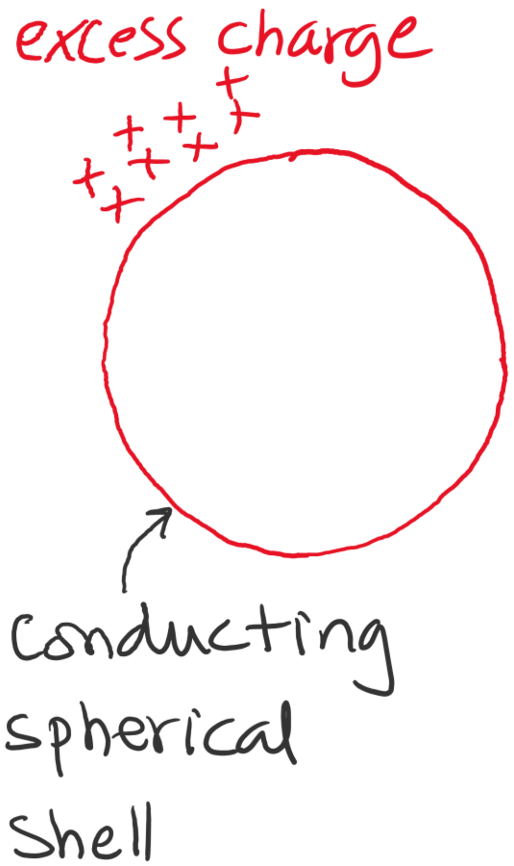
If q_1 is outside the shell, you can replace the shell with a point of charge q_2 at the center of the shell.

Shell theorem

charge q_2 is uniformly distributed over the surface

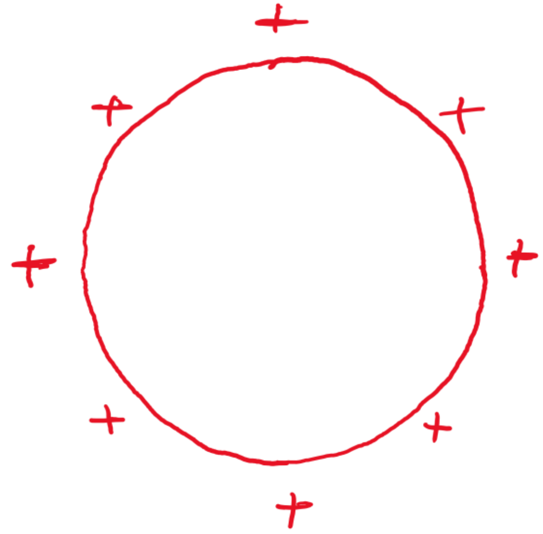


If q_1 is inside the shell, the net force on q_1 due to the shell is zero.



Free electrons in the conductor move to minimize the forces among charges

$\Longrightarrow$



$\Rightarrow$ Excess charge on a spherical conductor spreads uniformly on the surface.

Example What is the electrostatic force on q_1?

$q_1 = 1\,\mu C$
$q_2 = 4\,\mu C$
$q_3 = -4\,\mu C$

$\rightarrow \hat{i}$ unit vector

$\hat{j} \uparrow$ unit vector

$$\vec{F}_{12} = k\frac{|q_1||q_2|}{R^2}(-\hat{i}) = -9\times10^{9}\frac{1\times10^{-6}\times4\times10^{-6}}{(0.03)^2}\hat{i} = -(40\,N)\hat{i}$$

$$\vec{F}_{13} = k\frac{|q_1||q_3|}{R^2}\{\cos 60^\circ\hat{i} + \sin 60^\circ\hat{j}\} = (20\,N)\hat{i} + (35\,N)\hat{j}$$

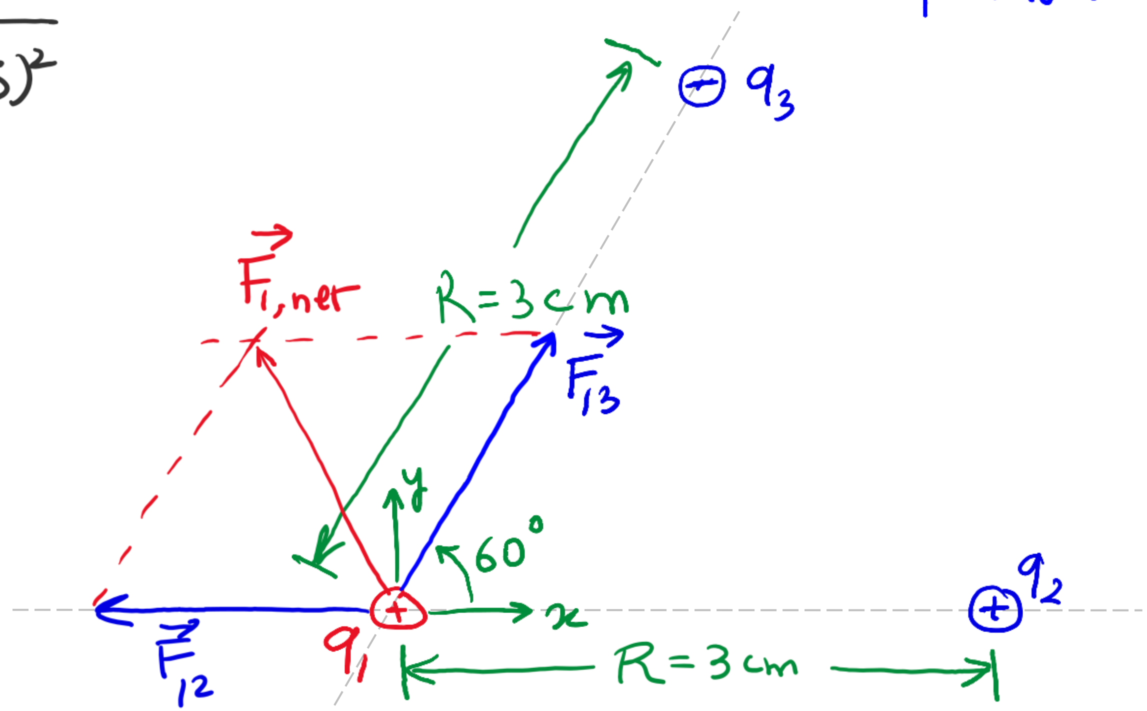
$$\vec{F}_{1,net} = \vec{F}_{12} + \vec{F}_{13} = (-40N+20N)\hat{i} + (35N)\hat{j} = -(20\,N)\hat{i} + (35\,N)\hat{j}$$

magnitude of $\vec{F}_{1,net}$ $\quad F_{1,net} = \sqrt{(-20)^2 + (35)^2}$

Angle of $\vec{F}_{1,net}$ from x-axis

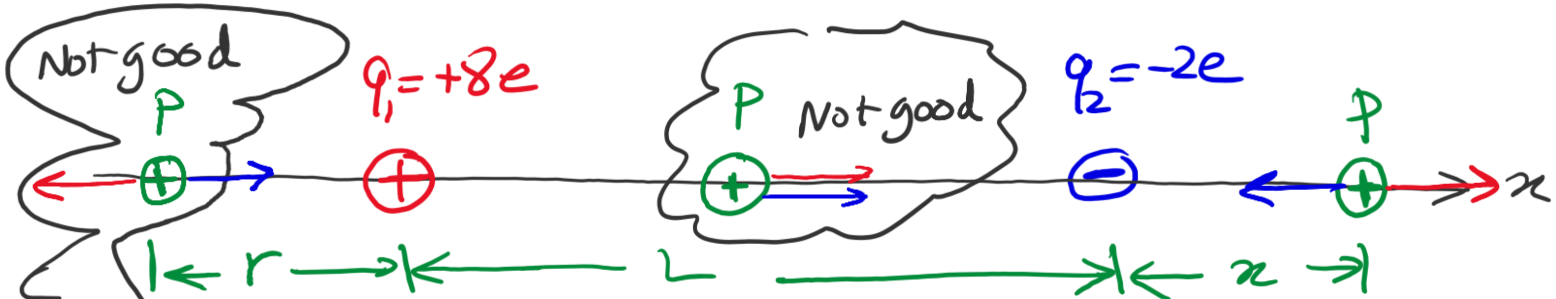
$$\theta = \tan^{-1}\frac{35}{-20} = -60^\circ + 180^\circ = 120^\circ$$

When using $\tan^{-1}$, check the angle!



Example

At what point on the x-axis a proton can be placed such that it is in equilibrium?



Not good

$$F_{p1} \overset{?}{=} F_{p2}$$

$$k\frac{e(8e)}{r^2} \overset{?}{=} k\frac{e(2e)}{(r+L)^2}$$

bigger

$$\frac{8}{r^2} > \frac{2}{(r+L)^2}$$

smaller

Equilibrium

$$\Rightarrow F_{1,net} = 0$$

$$F_{p1} \overset{?}{=} F_{p2}$$

$$k\frac{(e)(8e)}{(L+x)^2} \overset{?}{=} k\frac{(e)(2e)}{x^2}$$

$$\frac{8}{(L+x)^2} = \frac{2}{x^2}$$

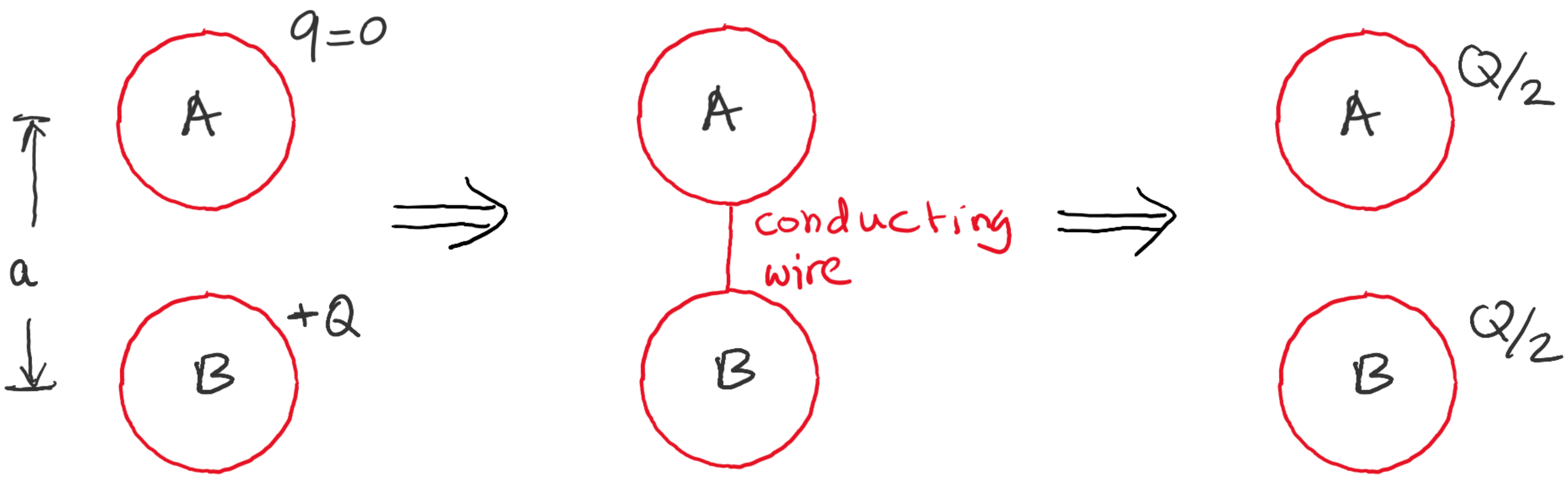
$$4x^2 = (L+x)^2$$

$$2x = L+x$$

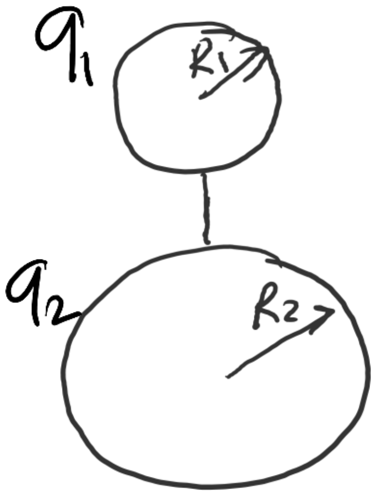
$$\Rightarrow L = x$$

The equilibrium is not stable.

Example Identical conducting spheres



$$F_{AB} = k\,\frac{\left|\frac{Q}{2}\right|\left|\frac{Q}{2}\right|}{a^2}$$

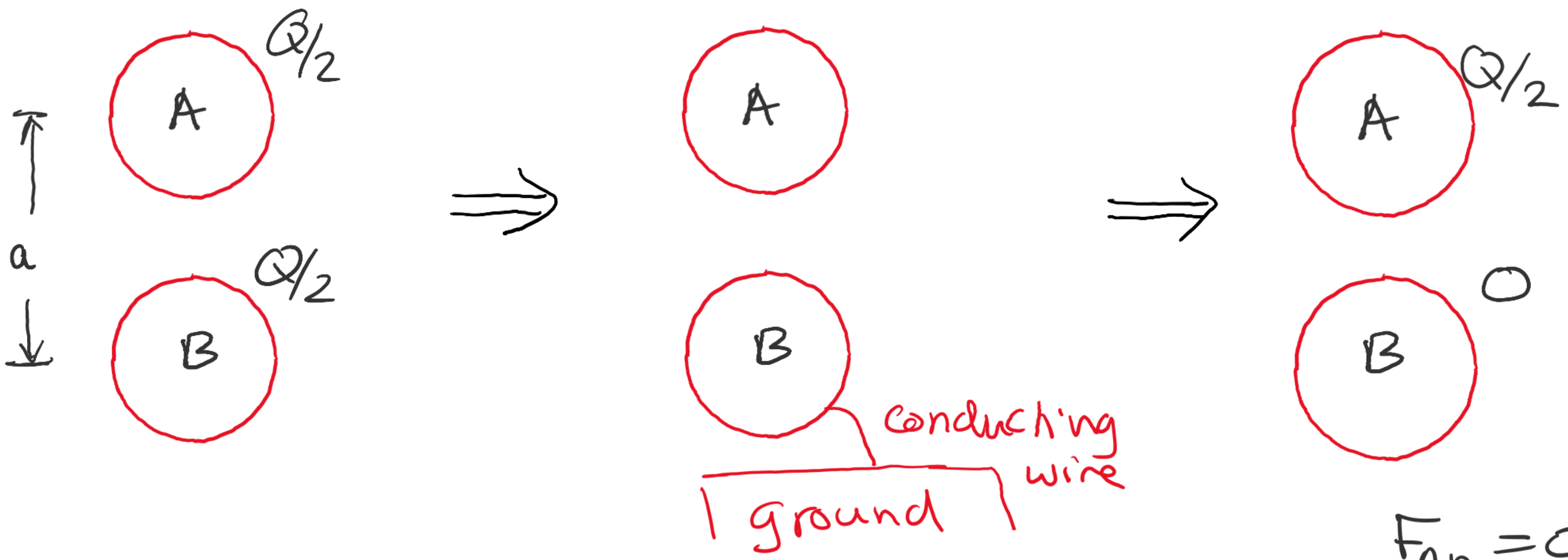


We will show later $\dfrac{q_1}{R_1} = \dfrac{q_2}{R_2} \xrightarrow{R_1 = R_2} q_1 = q_2$

$$\frac{q_1}{R_1} = \frac{q_2}{R_2} \Rightarrow q_1 = \frac{R_1}{R_2} q_2$$

$R_2 \gg R_1 \quad q_1 \approx 0$ grounding

Example Identical conducting spheres



$F_{AB} = 0$

Question Identical conducting spheres