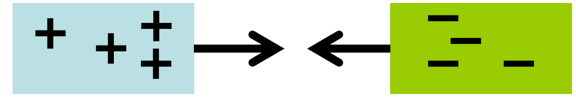
Chapter 22

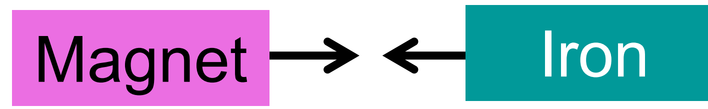
Electric Charge

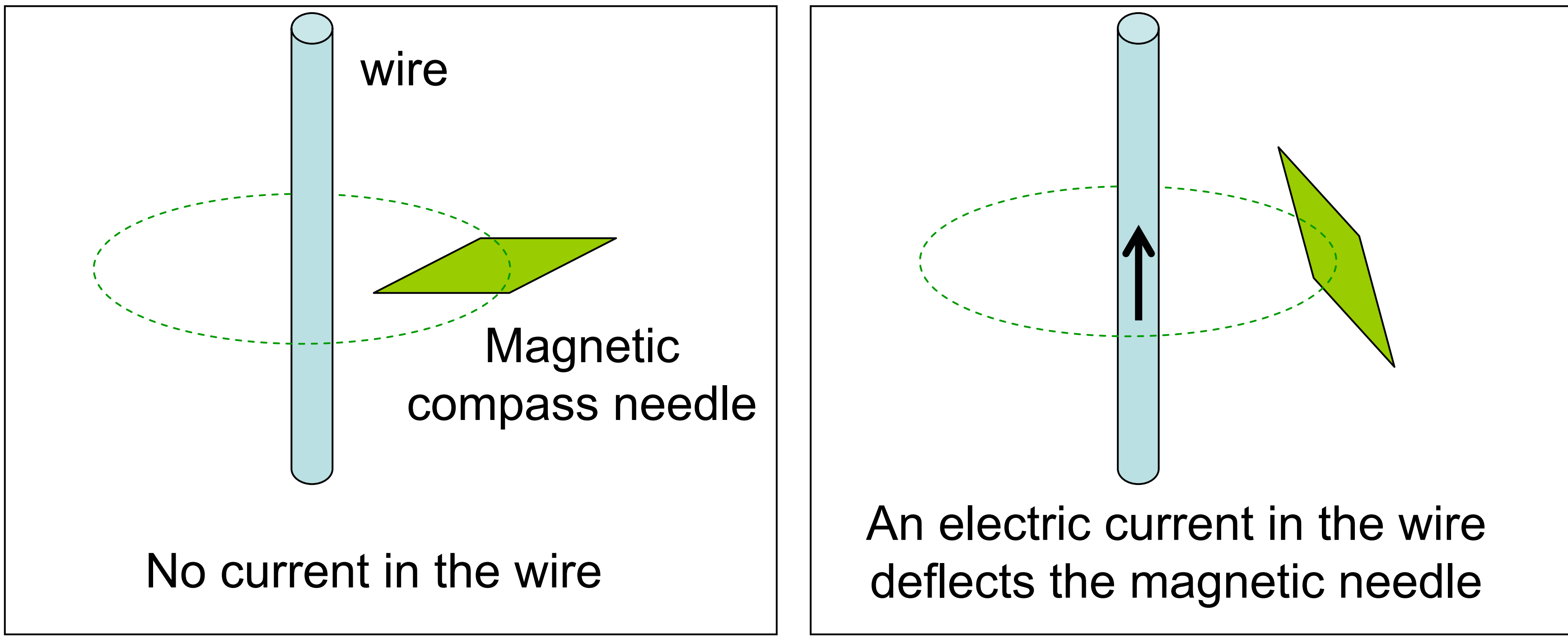
22-1 Electromagnetism

Electricity



Magnetism





Hans Oersted in 1882

Electromagnetism

22-1 Electromagnetism

Michael Faraday did a lot of experiments to study electromagnetism

Clark Maxwell, in the mid-19th century, put Faraday's ideas into four equations which fully describe electromagnetism

In the rest of phys102, we will study Maxwell's equations

Electromagnetism equations
(Maxwell's equation)

Gauss' law for electricity $$\oint \vec{E} . d\vec{A} = q_{enc}\varepsilon_0$$

Gauss' law for magnetism $$\oint \vec{B} . d\vec{A} = 0$$

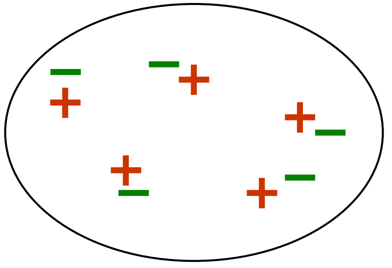
Faraday's law $$\oint \vec{E} . d\vec{s} = -\frac{d\Phi_B}{dt}$$

Ampere–Maxwell law $$\oint \vec{B} . d\vec{s} = \mu_0\varepsilon_0 \frac{d\Phi_E}{dt} + \mu_0\, i_{enc}$$

You do not need to know them now

22-2 Electric Charge

In any object, there is a huge number of positive and negative charges



If the number of positive and negative charges are equal, the object is electrically neutral

The object contains no net charge

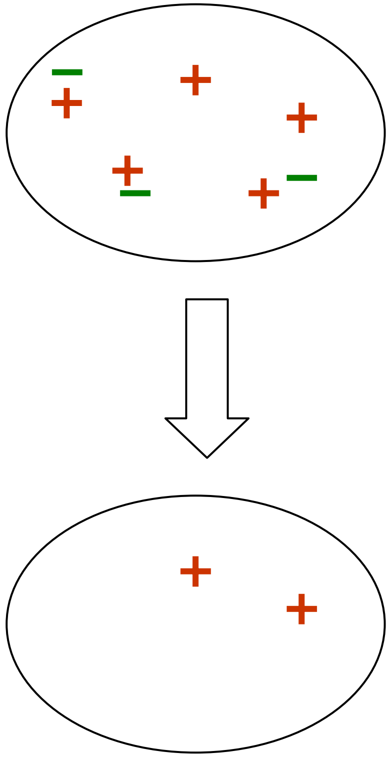
Positive and negative charges are balanced

22-2 Electric Charge

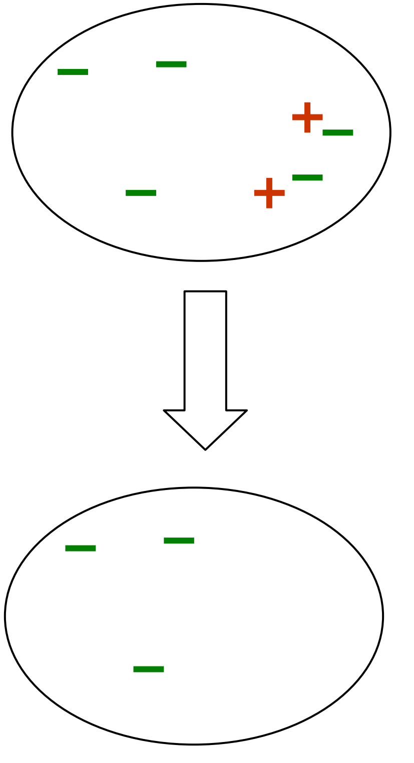
If the number of positive and negative charges are not equal, the object is charged.

The object has a net charge.

Positive and negative charges are imbalanced.

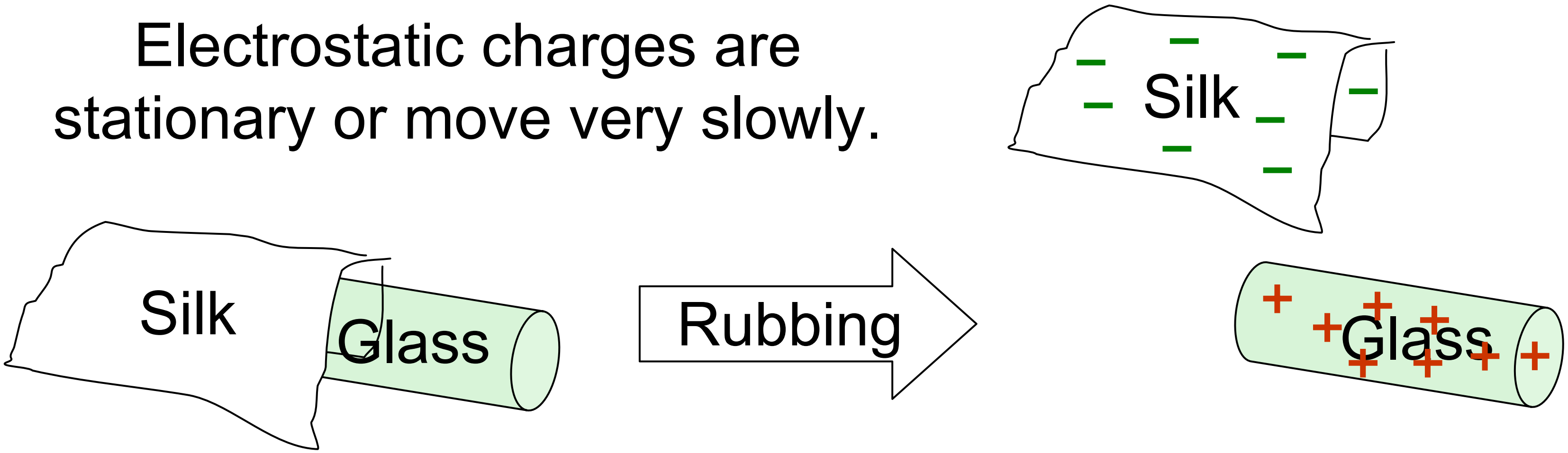


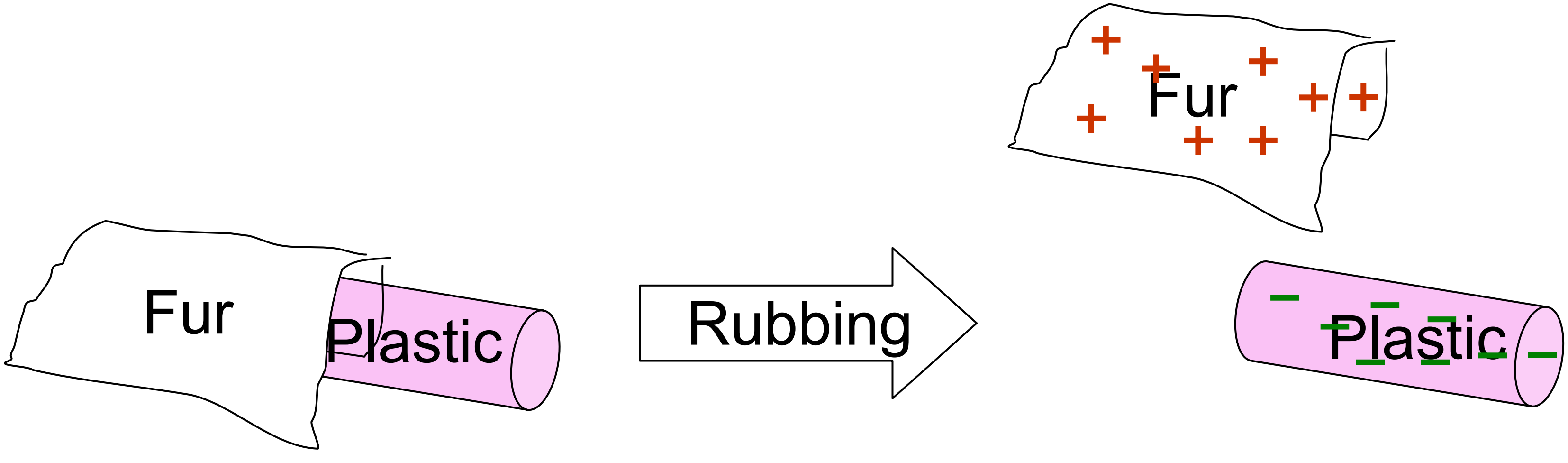
We show only the net charge.



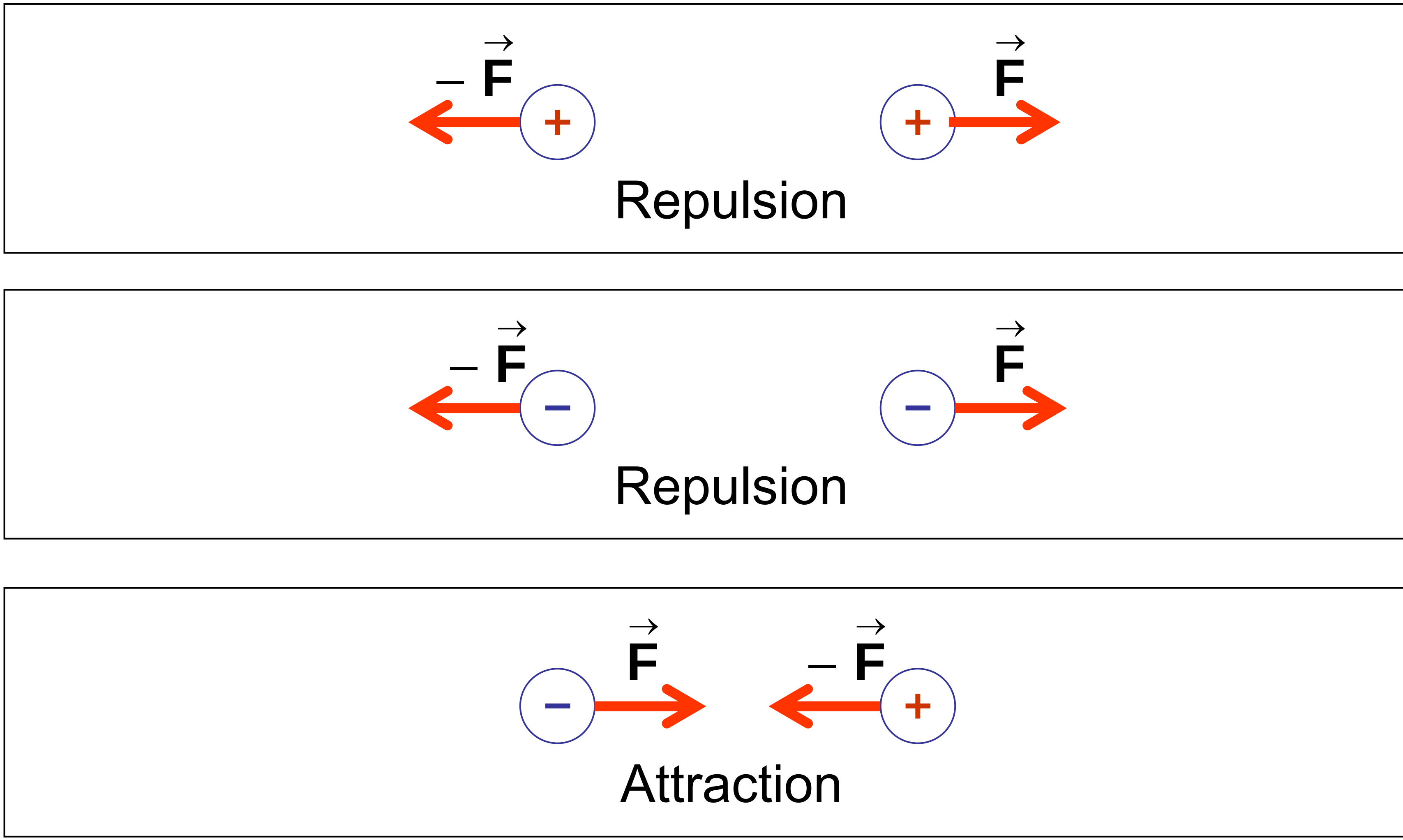
22-2 Electric Charge

Electrostatic charges are stationary or move very slowly.





22-2 Electric Charge



22-2 Electric Charge

Electric charge is measured in Coulomb

The smallest charge you can find is $e = 1.6 \times 10^{-19}$ C

All other charges are a multiple of this charge

$q = n e$ $\quad\quad n = \pm 1, \pm 2, \pm 3, \ldots$

$q = +12\,e$ or $-60\,e$ Possible

$q = +3.5\,e$ or $-5.1\,e$ Not possible

Charge cannot have any value. it has discrete values. Charge is quantized.

e is called the elementary charge.

We do not feel this discreetness in the charge because we deal with very huge number of elementary charges.

22-3 Conductors and Insulators

All matters are made of
- Protons
- neutrons
- Electrons

p — Proton is very heavy
Proton has a charge of +e

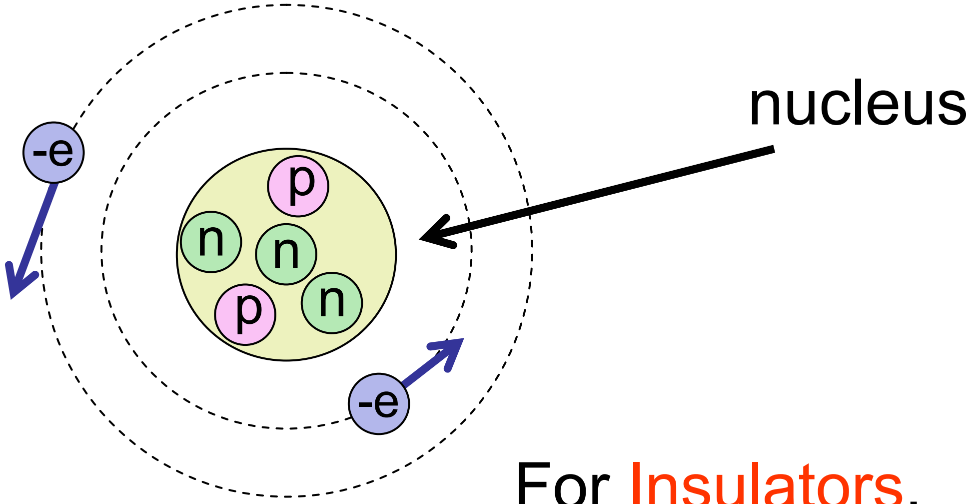
n — neutron is very heavy
neutron has no charge

-e — Electron is very light
Electron has a charge of -e

22-3 Conductors and Insulators

Atoms are electrically neutral

Atom



For conductors, outermost electrons are loosely held by nucleus

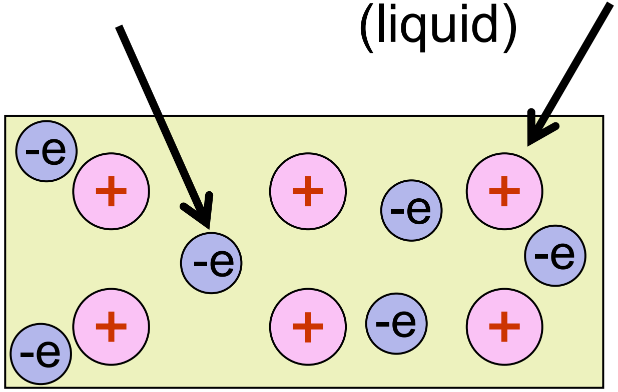
For Insulators, outermost electrons are tightly held by nucleus

An atom becomes
a positive ion when it loses electrons
and
a negative ion when it gains extra electrons.

22-3 Conductors and Insulators

Electrons can move freely

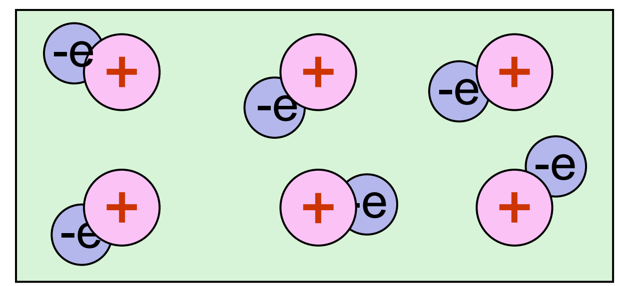
Ions are fixed (solid) or move very slowly (liquid)



Conductors

metals
human body
tap water

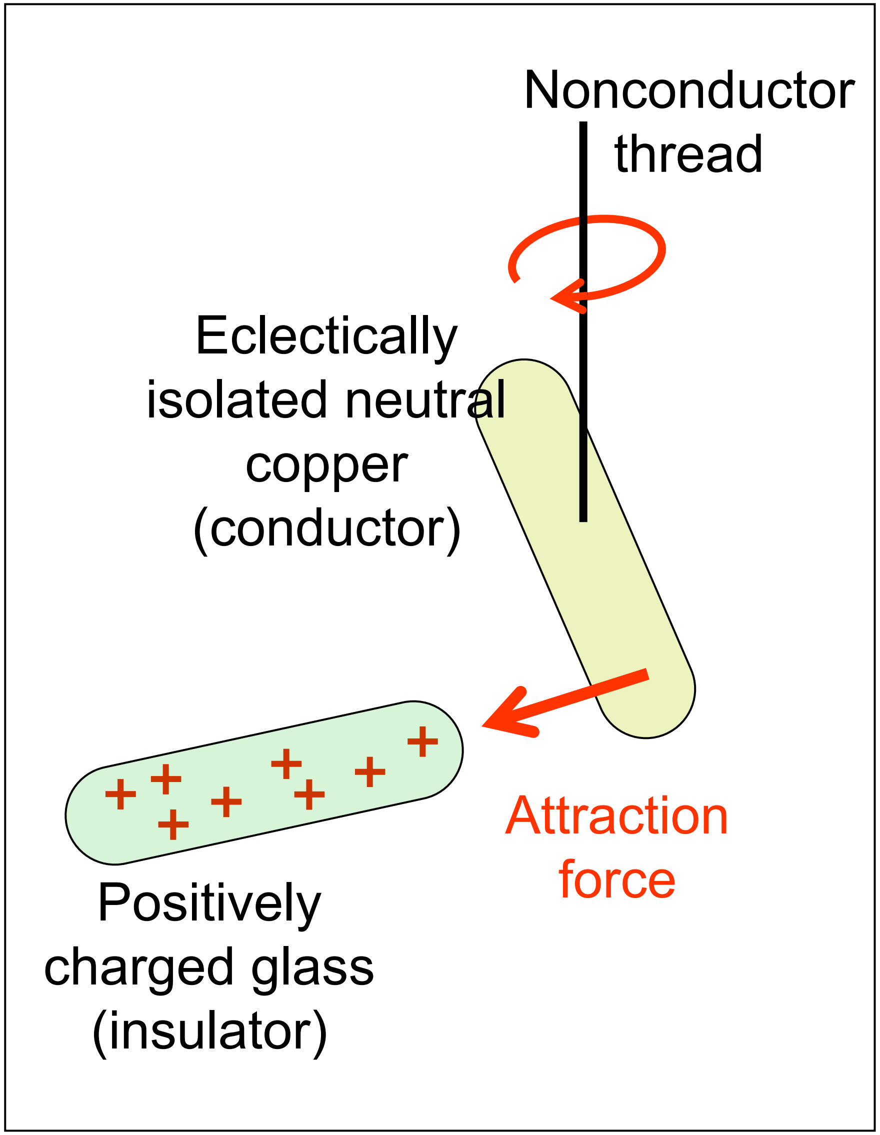
Electrons held to ions and cannot move freely

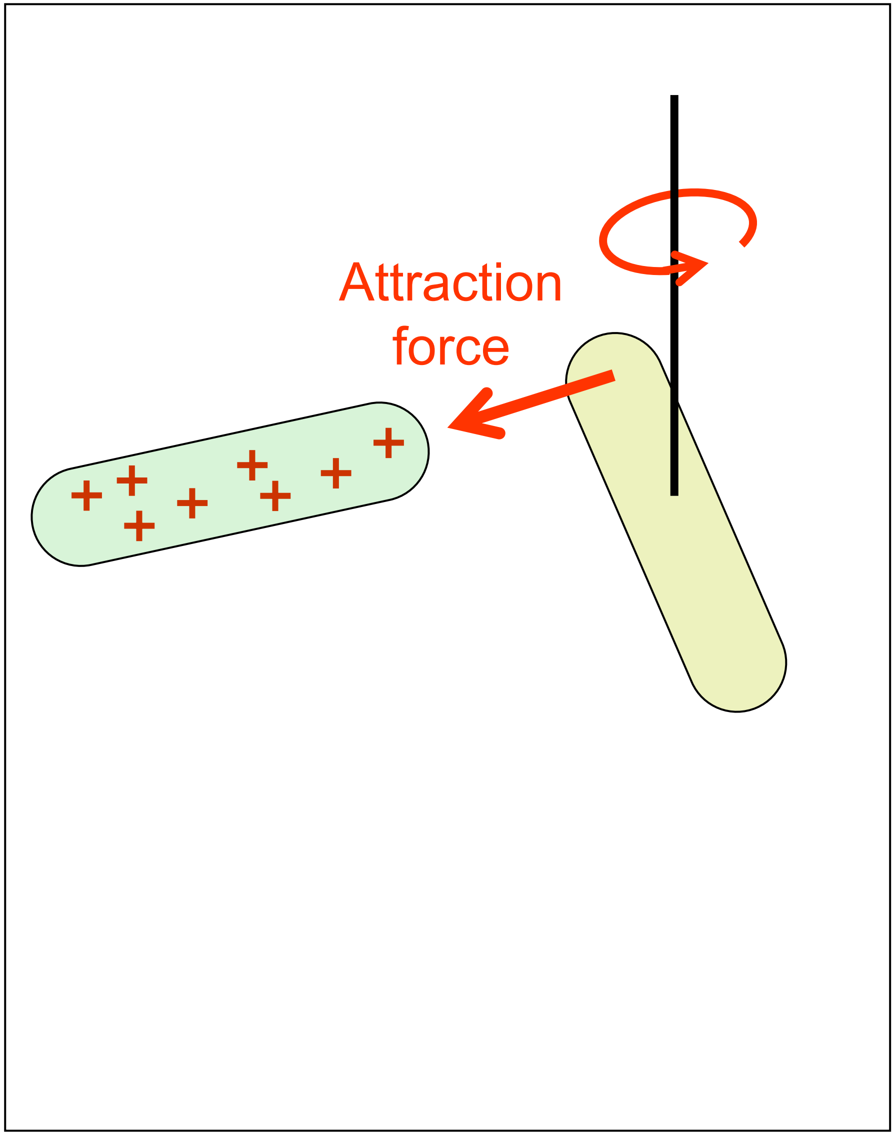


Insulators

glass
plastic
pure water

22-3 Conductors and Insulators

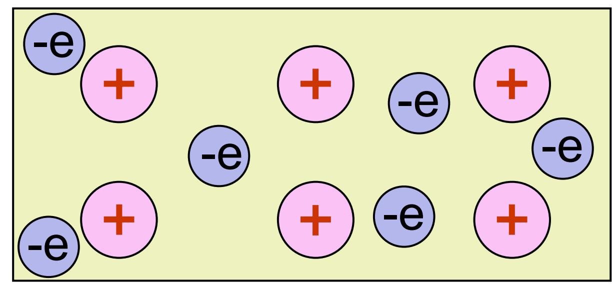




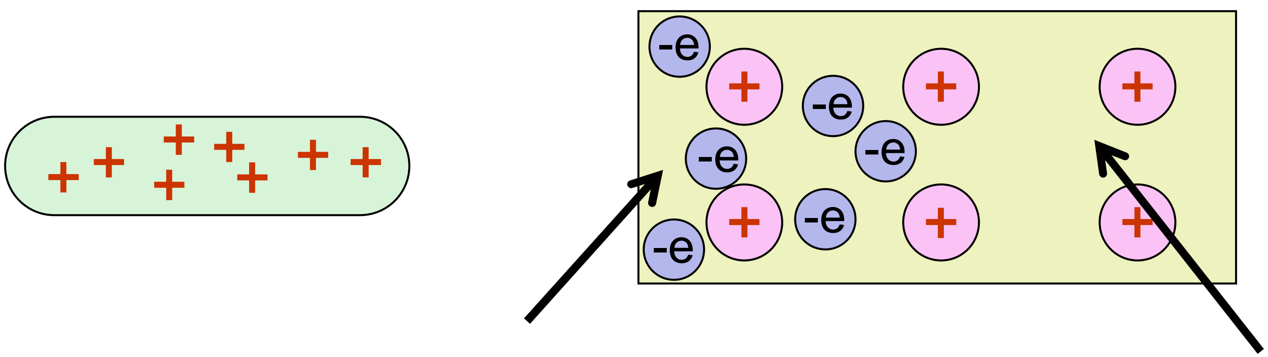
22-3 Conductors and Insulators

Charge density of fixed positive ions and free negative electrons are the same.

Conductor is neutral at all points



Conductor

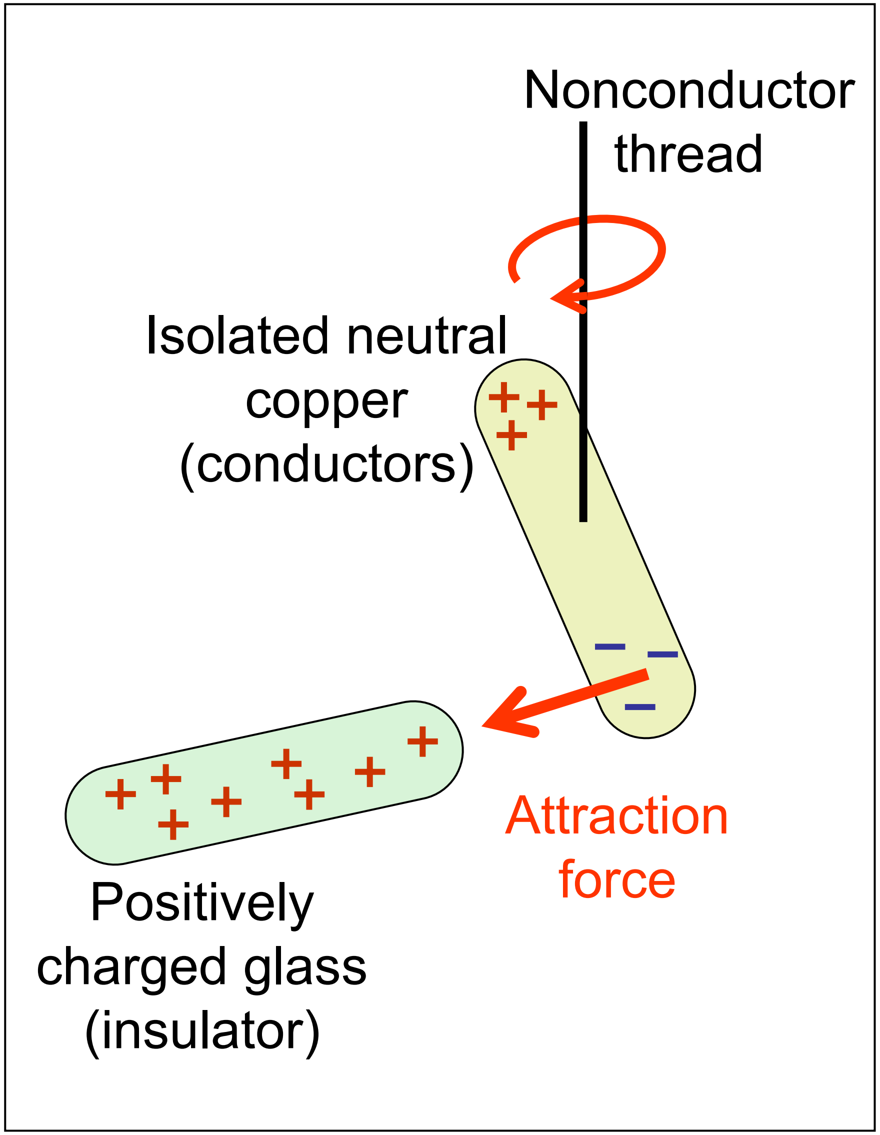


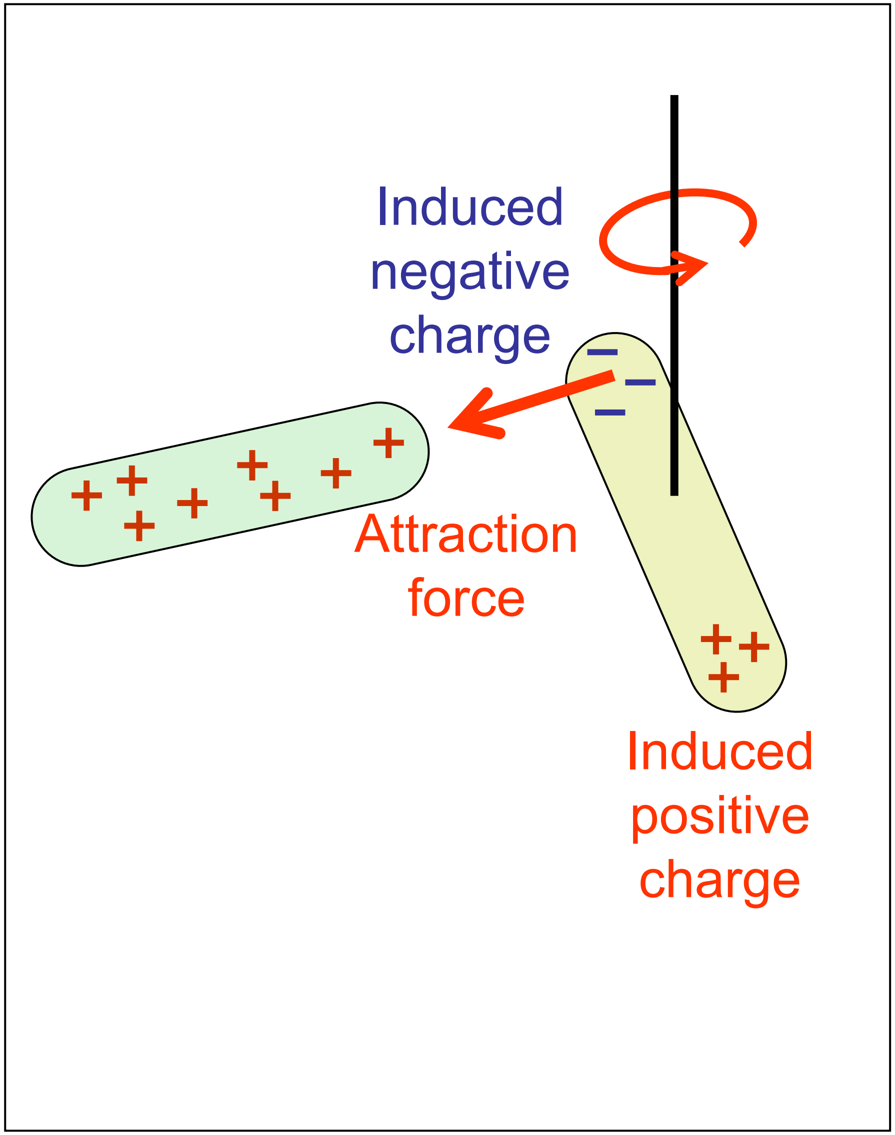
Conductor

Higher electron density.
Induced negative net charge

lower electron density.
Induced positive net charge

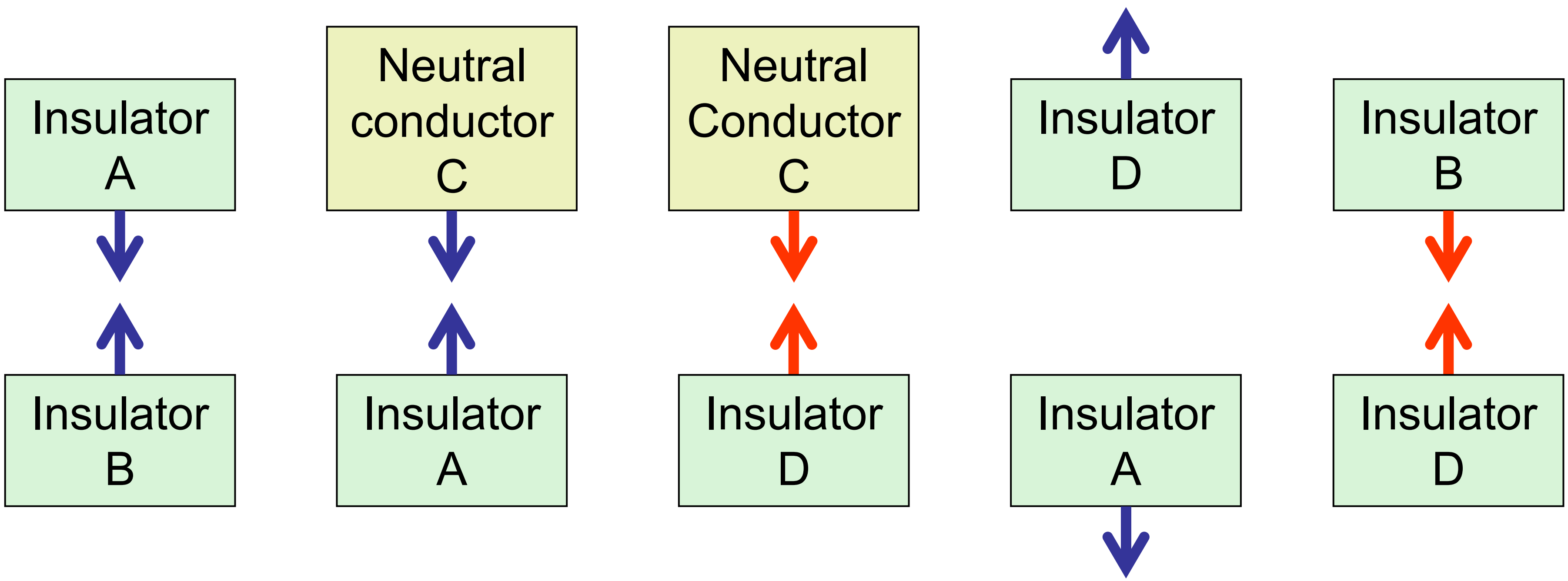
22-3 Conductors and Insulators





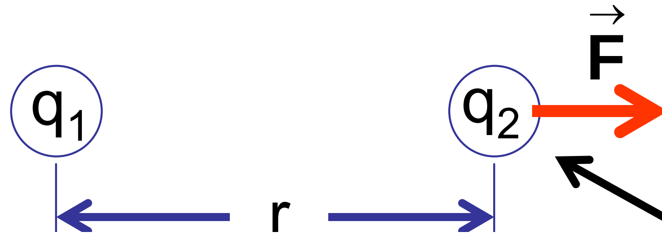
22-3 Conductors and Insulators

Checkpoint 1



22-4 Coulomb's Law

Charged particle (point charge) of magnitude $|q_1|$



Charged particle of magnitude $|q_2|$

Magnitude of electrostatic force of charged particle 1 on charged particle 2

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

constant

Coulomb's Law

22-4 Coulomb's Law

$$F = k\,\frac{|q_1||q_2|}{r^2}$$

constant

$$k = 8.99\times10^{9}\ \mathrm{N\,m^2/C^2}$$

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

permittivity constant

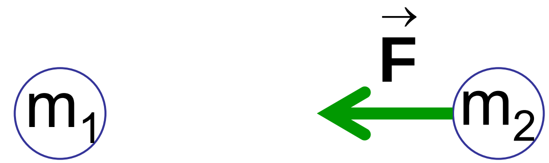
$$\varepsilon_0 = 8.85\times10^{-12}\ \mathrm{C^2/N{\cdot}m^2}$$

22-4 Coulomb’s Law

Electrostatic force

$$F=k\,\frac{|q_1||q_2|}{r^2}$$

Gravitational force



$$F=G\,\frac{m_1\,m_2}{r^2}$$

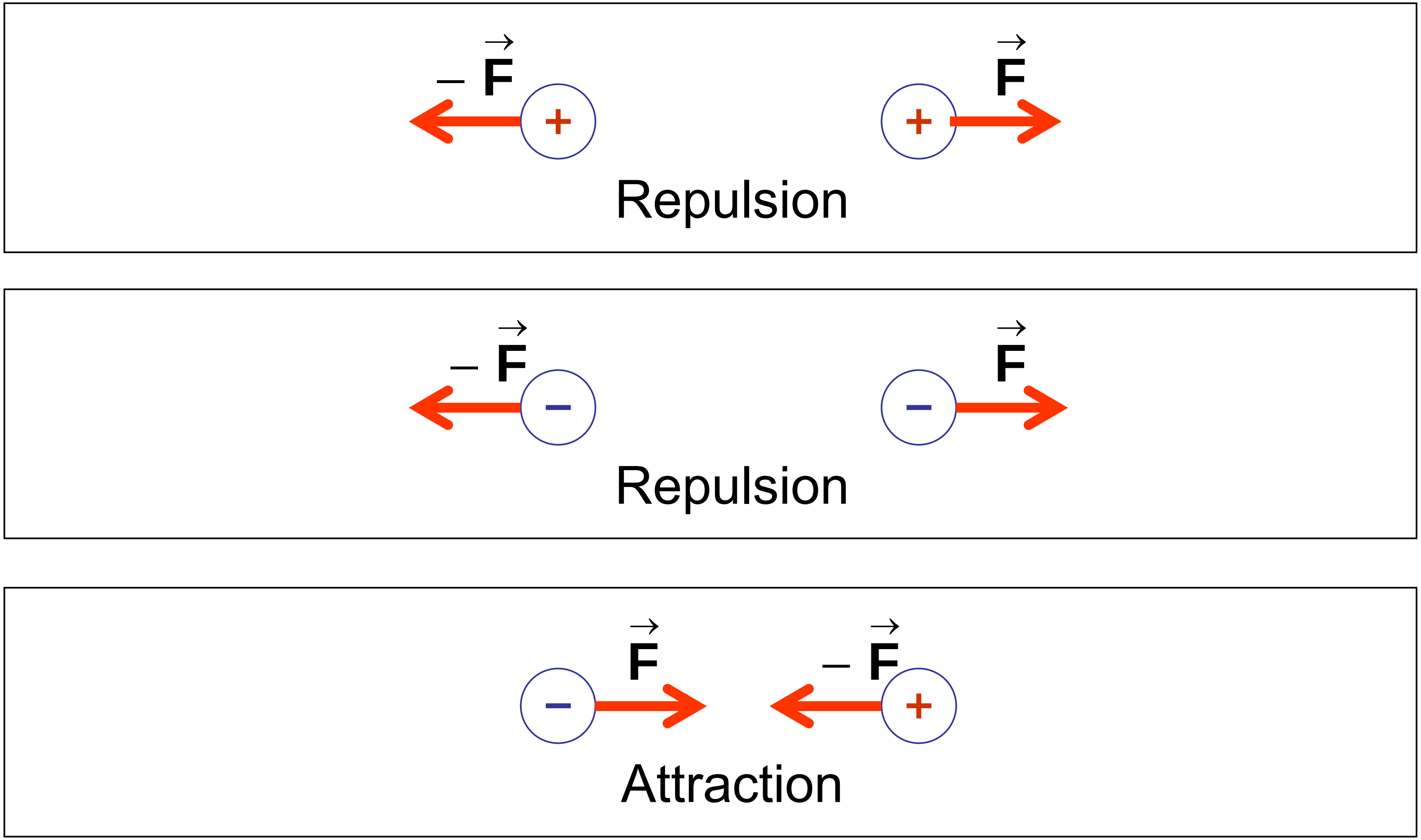
The electrostatic force has the same form as the gravitational force

22-4 Coulomb's Law

Each particle exerts a force of the same magnitude on the other

The two forces forms a third-law force pair

22-2 Electric Charge



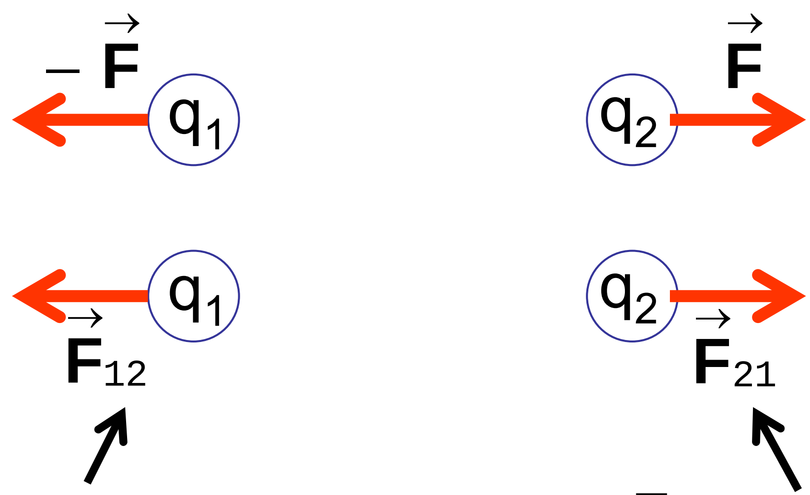
22-4 Coulomb's Law

notation

$$\vec{F}_{54}$$

On particle 5

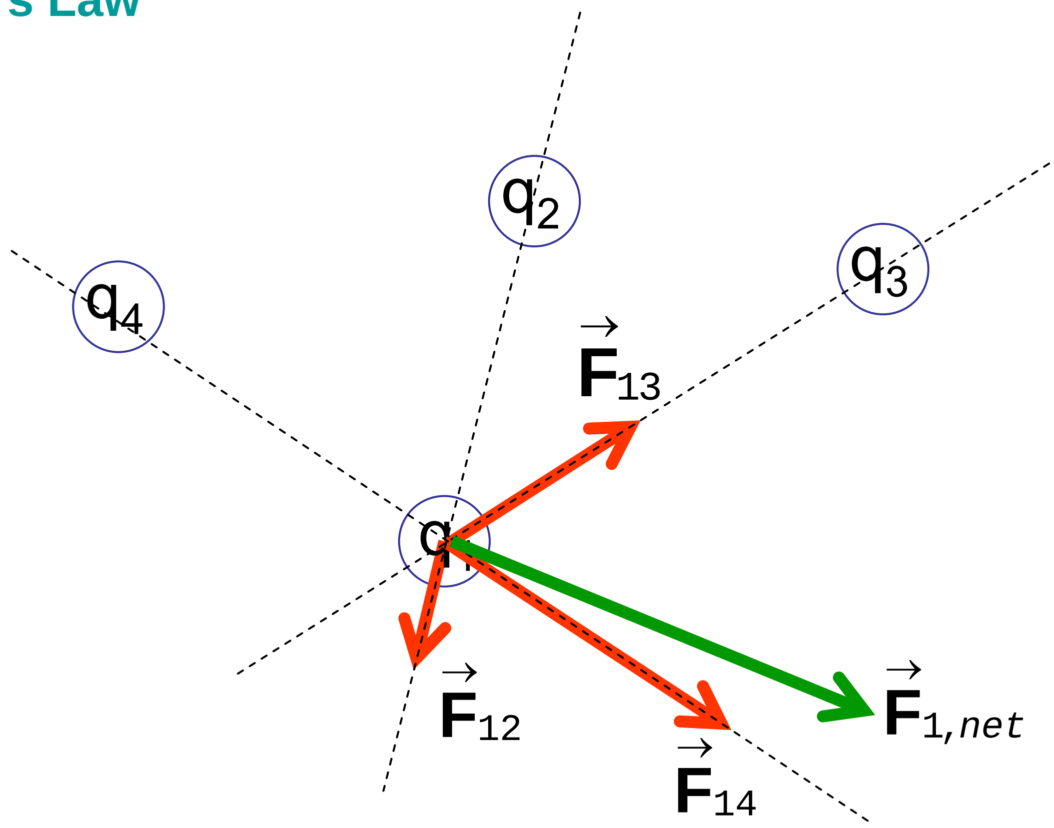
Because of (due to) particle 4



Force on charged particle 1 because of charged particle 2

Force on charged particle 2 because of charged particle 1

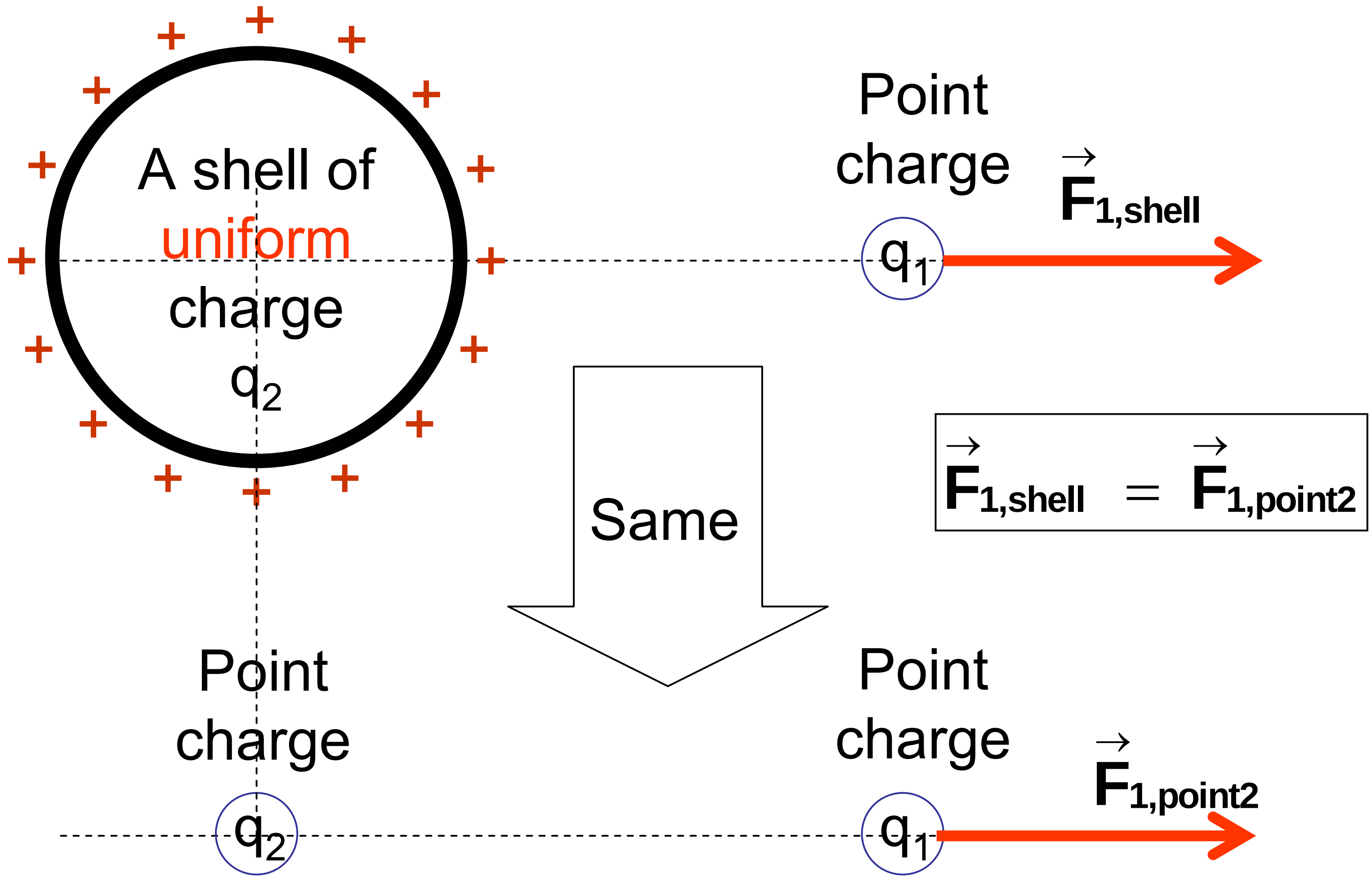
22-4 Coulomb's Law



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

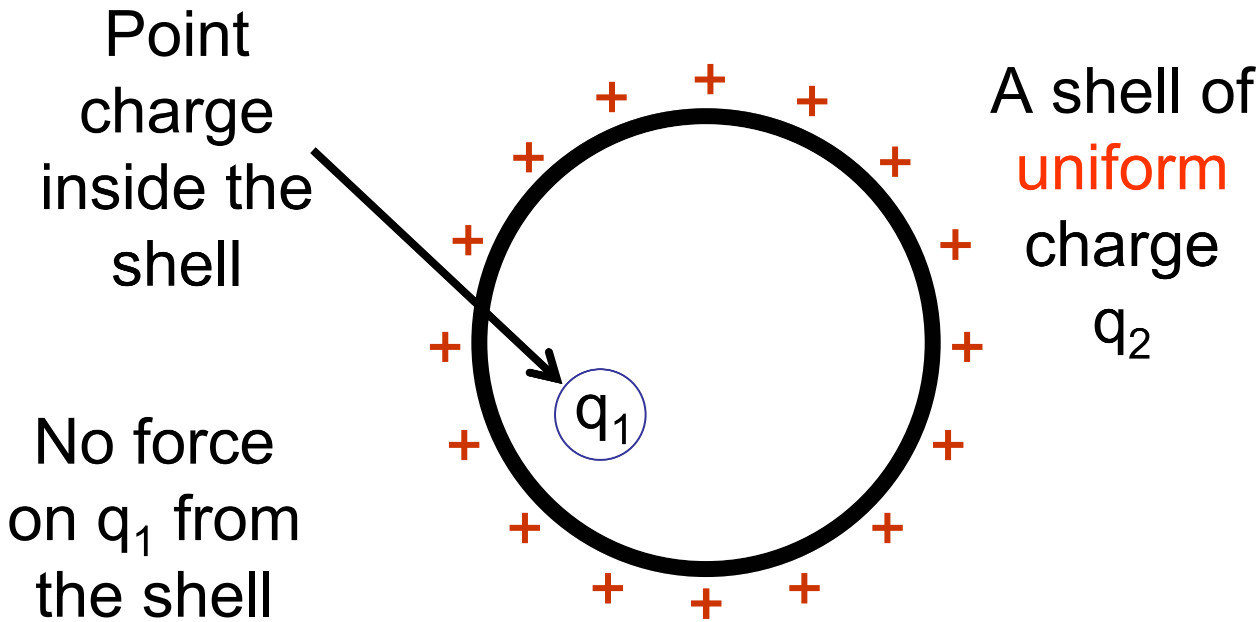
Principle of superposition: the net force acting on any particle is the vector sum of the forces acting on this particle due to individual particles

22-4 Coulomb's Law



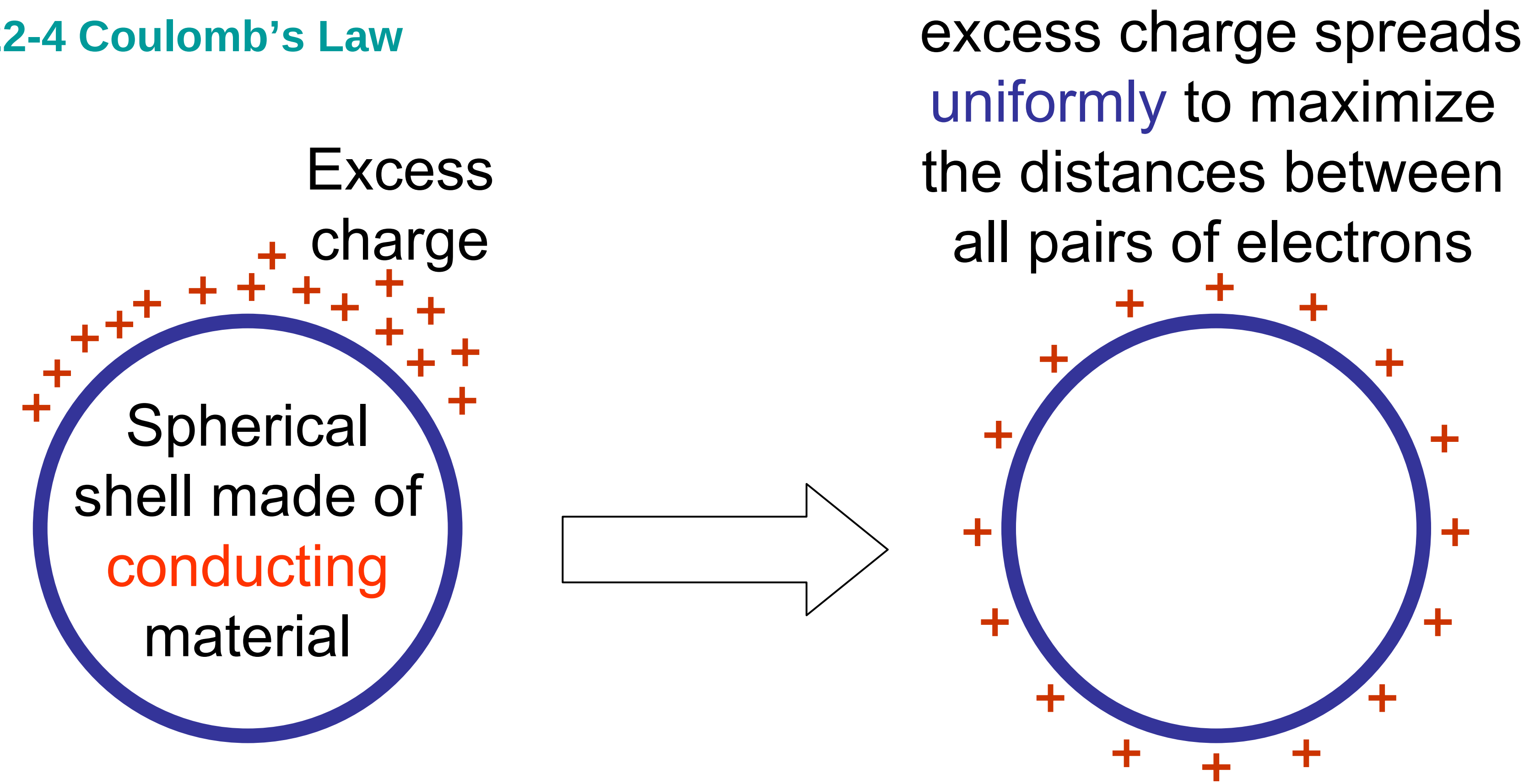
A shell of uniform charge
attracts or repels a charged particle that is outside the shell
as if all the shell's charge were concentrated at its center

22-4 Coulomb's Law



If a charged particle is located inside a shell of uniform charge, there is no net electrostatic force on the particle from the shell.

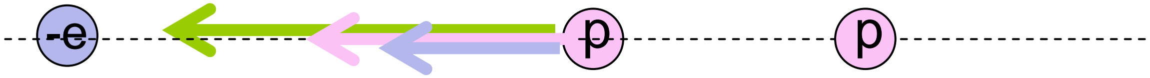
22-4 Coulomb's Law



If excess charge is placed on a spherical shell that is made of a conducting material, the excess charge spreads uniformly over the surface

22-4 Coulomb's Law

Checkpoint 2



22-4 Coulomb's Law

Sample Problem 22-1

$q_1=1.6 \times 10^{-19}$ C

$q_2=3.2 \times 10^{-19}$ C

R=0.02 m

What is the electrostatic force $\vec{F}_{12}$ on particle 1 from particle 2 ?

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

$$F_{12}=(8.99\times10^{9}\,\mathrm{N\,m^2/C^2})\frac{(1.6\times10^{-19}\mathrm{C})(3.2\times10^{-19}\mathrm{C})}{(0.02\mathrm{m})^2}=1.15\times10^{-24}\mathrm{N}$$

$$\vec{F}_{12}=-(1.15\times10^{-24}\mathrm{N})\hat{i}$$

22-4 Coulomb's Law

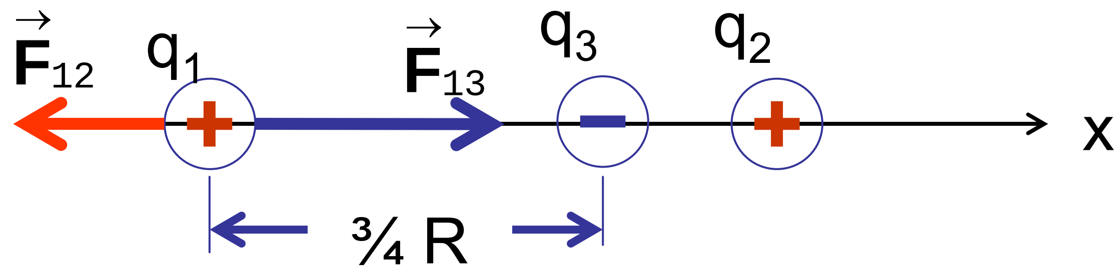
Sample Problem 22-1

$q_1 = 1.6 \times 10^{-19}$ C

$q_2 = 3.2 \times 10^{-19}$ C

$R = 0.02$ m

$q_3 = -3.2 \times 10^{-19}$ C



What is the electrostatic force $\vec{F}_{1,net}$ on particle 1 due to particles 2 and 3 ?

$$F_{13} = k \frac{|q_1||q_3|}{(3R/4)^2}$$

$$F_{13} = (8.99\times10^9 \text{N m}^2/\text{C}^2) \frac{(1.6\times10^{-19}\text{C})(3.2\times10^{-19}\text{C})}{(\frac{3}{4}\,0.02\text{m})^2} = 2.05\times10^{-24}\text{N}$$

$$\vec{F}_{13} = (2.05\times10^{-24}\text{N})\hat{i}$$

$$\vec{F}_{12} = -(1.15\times10^{-24}\text{N})\hat{i}$$

$$\vec{F}_{1,net} = \vec{F}_{12} + \vec{F}_{13} = -(1.15\times10^{-24}\text{N})\hat{i} + (2.05\times10^{-24}\text{N})\hat{i}$$

$$\vec{F}_{1,net} = (9.00\times10^{-25}\text{N})\hat{i}$$

22-4 Coulomb's Law

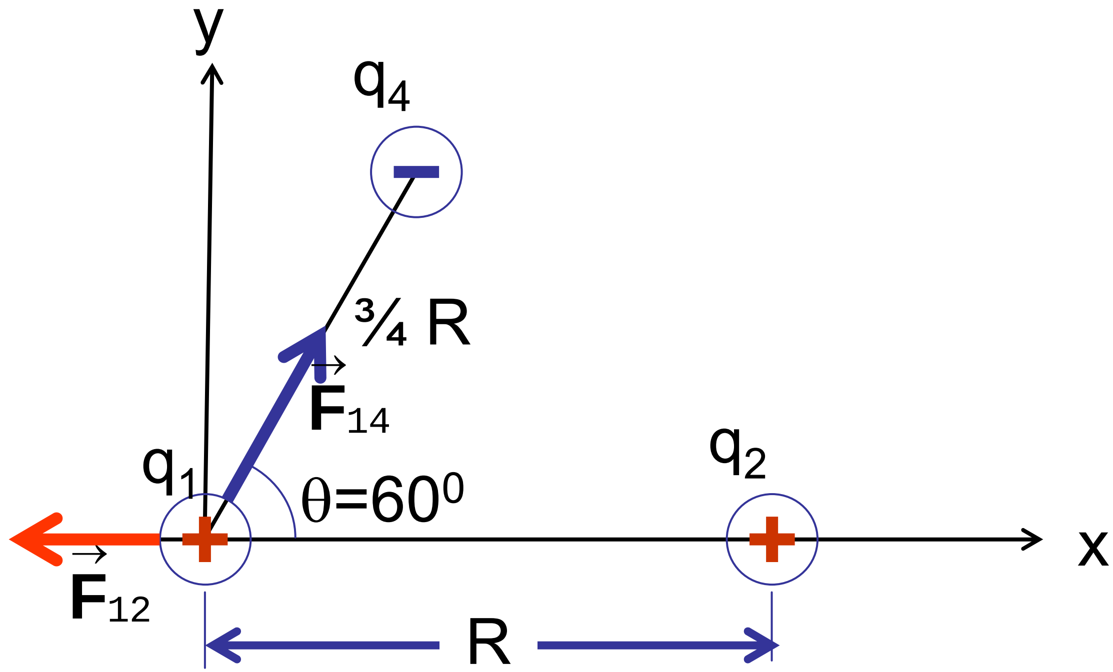
Sample Problem 22-1

$q_1=1.6 \times 10^{-19}$ C

$q_2=3.2 \times 10^{-19}$ C

R=0.02 m

$q_4= - 3.2 \times 10^{-19}$ C

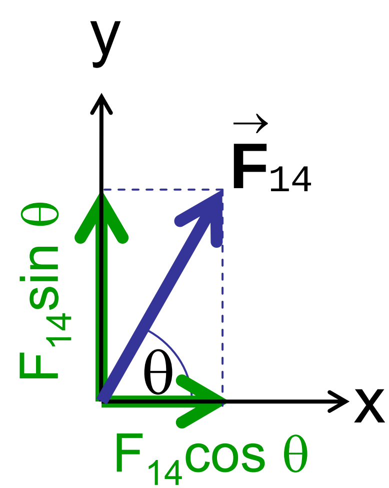


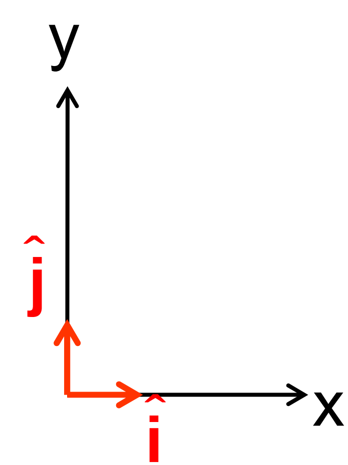
What is the electrostatic force $\vec{F}_{1,net}$ on particle 1 due to particles 2 and 4 ?

$\vec{F}_{12} = -(1.15\text{x}10^{-24}\text{N})\hat{i}$

$F_{14} = 2.05\text{x}10^{-24}\text{N}$

$\vec{F}_{14} = F_{14}\cos\theta\ \hat{i} + F_{14}\sin\theta\ \hat{j}$





22-4 Coulomb's Law

Sample Problem 22-1

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

$$\vec{F}_{14} = (1.025 \times 10^{-24} N)\hat{i} + (1.775 \times 10^{-24} N)\hat{j}$$

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

$$\vec{F}_{1,net} = -(1.15 \times 10^{-24} N)\hat{i} + (1.025 \times 10^{-24} N)\hat{i} + (1.775 \times 10^{-24} N)\hat{j}$$

$$\vec{F}_{1,net} = (-1.15 \times 10^{-24} N + 1.025 \times 10^{-24} N)\hat{i} + (1.775 \times 10^{-24} N)\hat{j}$$

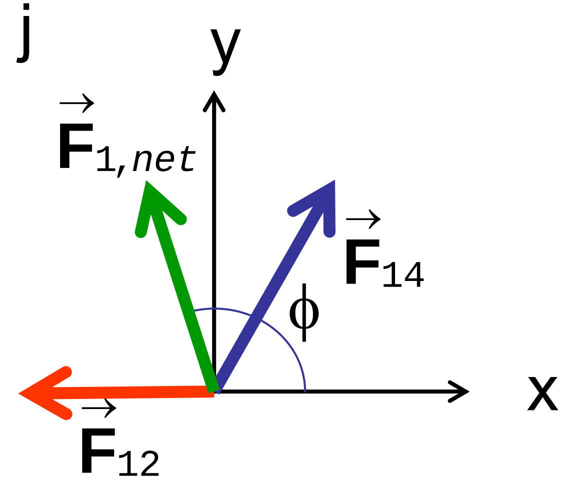
$$\vec{F}_{1,net} = (-1.55 \times 10^{-25} N)\hat{i} + (1.775 \times 10^{-24} N)\hat{j}$$

22-4 Coulomb's Law

Sample Problem 22-1

$$\vec{F}_{1,net} = (-1.55\text{x}10^{-25}\text{N})\,\hat{i} + (1.775\text{x}10^{-24}\text{N})\,\hat{j}$$

You may express this answer in terms of magnitude and the angle measured form x-axis



$$F_{1,net} = \sqrt{F^2_{1,net,x} + F^2_{1,net,y}}$$

$$F_{1,net} = \sqrt{(1.55\text{x}10^{-25})^2 + (1.775\text{x}10^{-24})^2}\ \text{N}$$

$$\phi = \tan^{-1}\left(\frac{F_{1,net,y}}{F_{1,net,x}}\right)$$

$$\phi = \tan^{-1}\left(\frac{1.775\text{x}10^{-24}}{-1.55\text{x}10^{-25}}\right) = -86.0^0$$

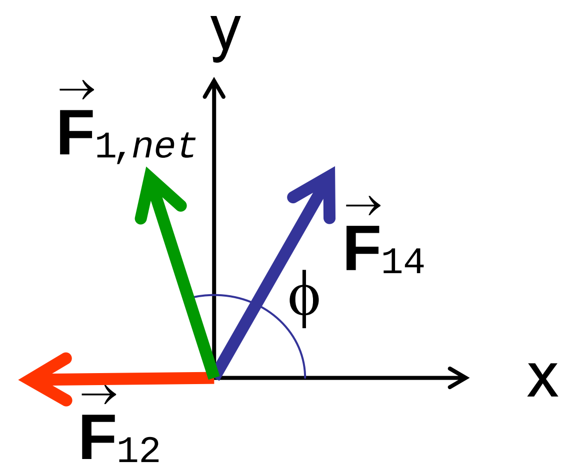
wrong answer

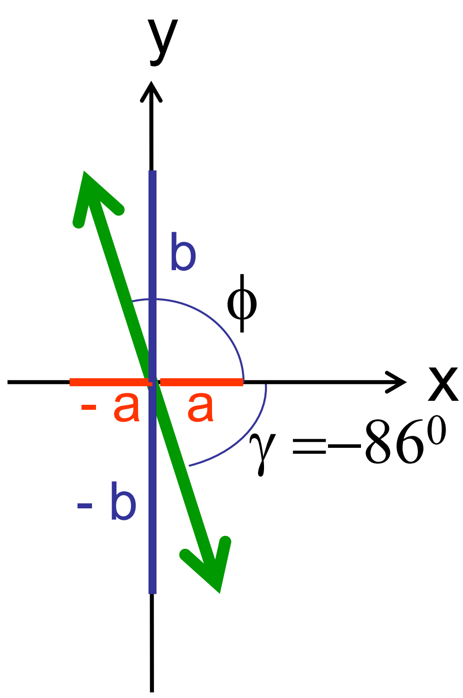
When you find an angle from an inverse trigonometric function, check the validity of your answer!

22-4 Coulomb's Law

Sample Problem 22-1

We expect the correct angle to be in the second quadrant.





$$\tan\gamma = \frac{-b}{a}$$

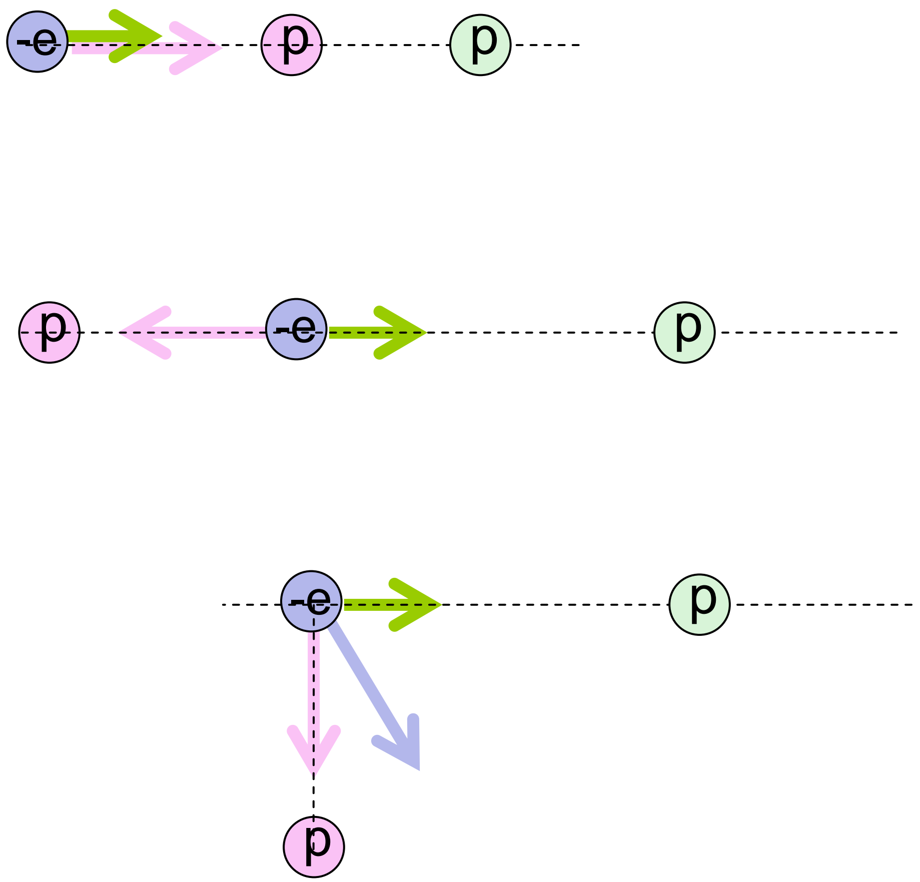
$$\tan\phi = \frac{b}{-a}$$

$$\tan\gamma = \tan\phi$$

$$\phi = -86.0^0 + 180^0 = 94.0^0$$

22-4 Coulomb's Law

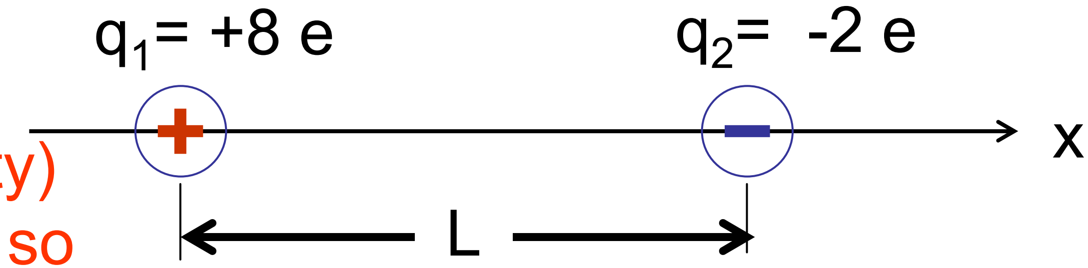
Checkpoint 3



22-4 Coulomb's Law

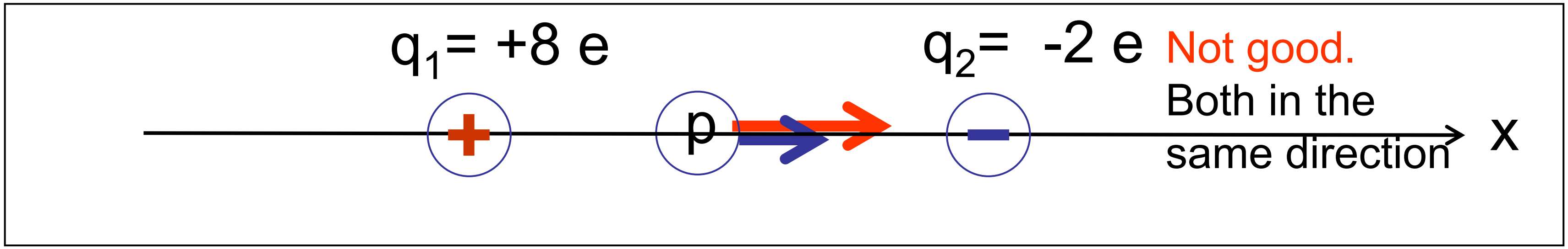
Sample Problem 22-2

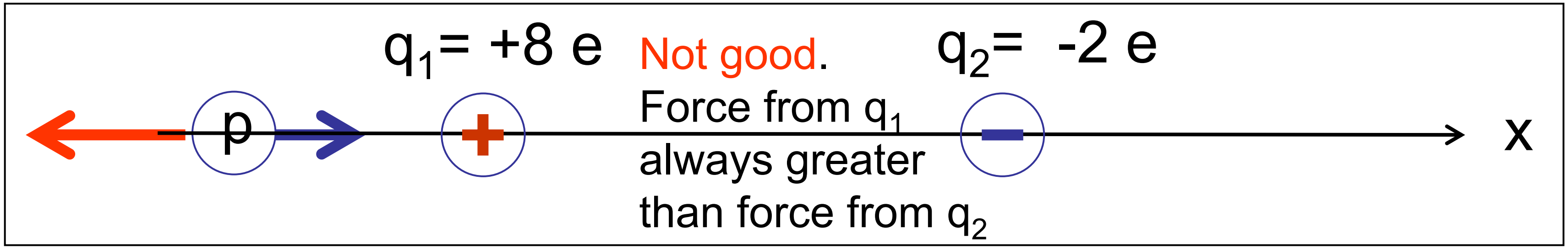
At what point (not infinity) can a proton be placed so that it's in equilibrium?

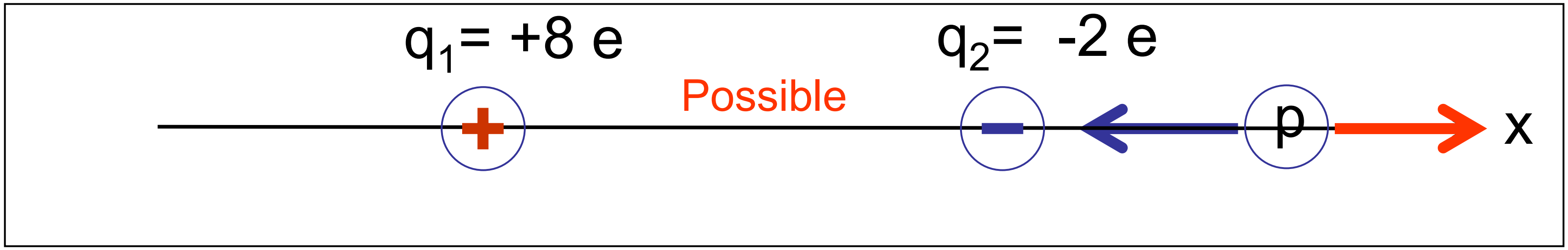


$$F_{p2} = k\,\frac{e(2e)}{r_{p2}^2}$$

$$F_{p1} = k\,\frac{e(8e)}{r_{p1}^2}$$



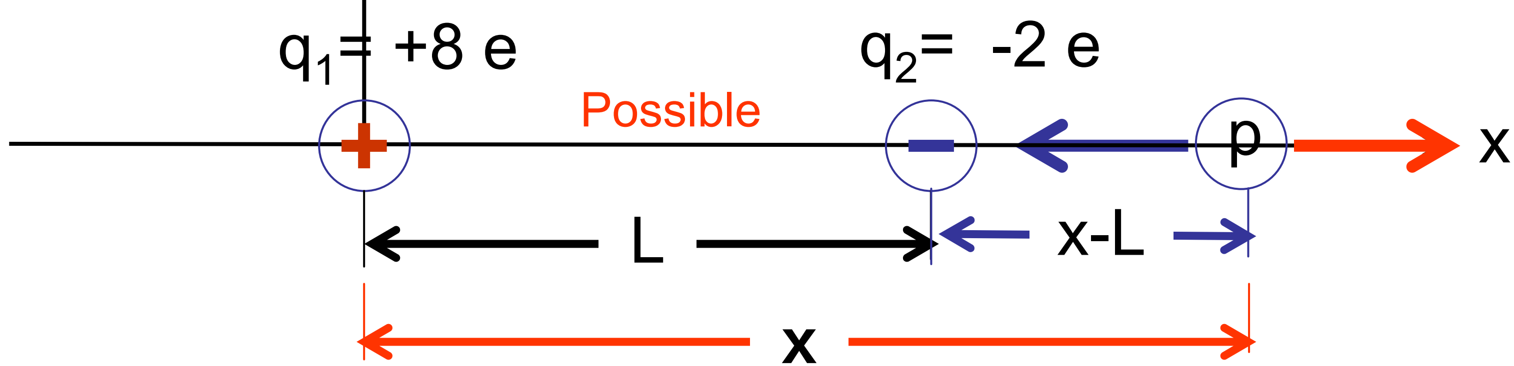




22-4 Coulomb's Law

Sample Problem 22-2

$$F_{p2} = k\frac{e(2e)}{r_{p2}^2} \qquad F_{p1} = k\frac{e(8e)}{r_{p1}^2}$$



$$F_{p1} = F_{p2}$$

$$k\frac{e(8e)}{x^2} = k\frac{e(2e)}{(x-L)^2}$$

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

$$8(x-L)^2 = 2x^2$$

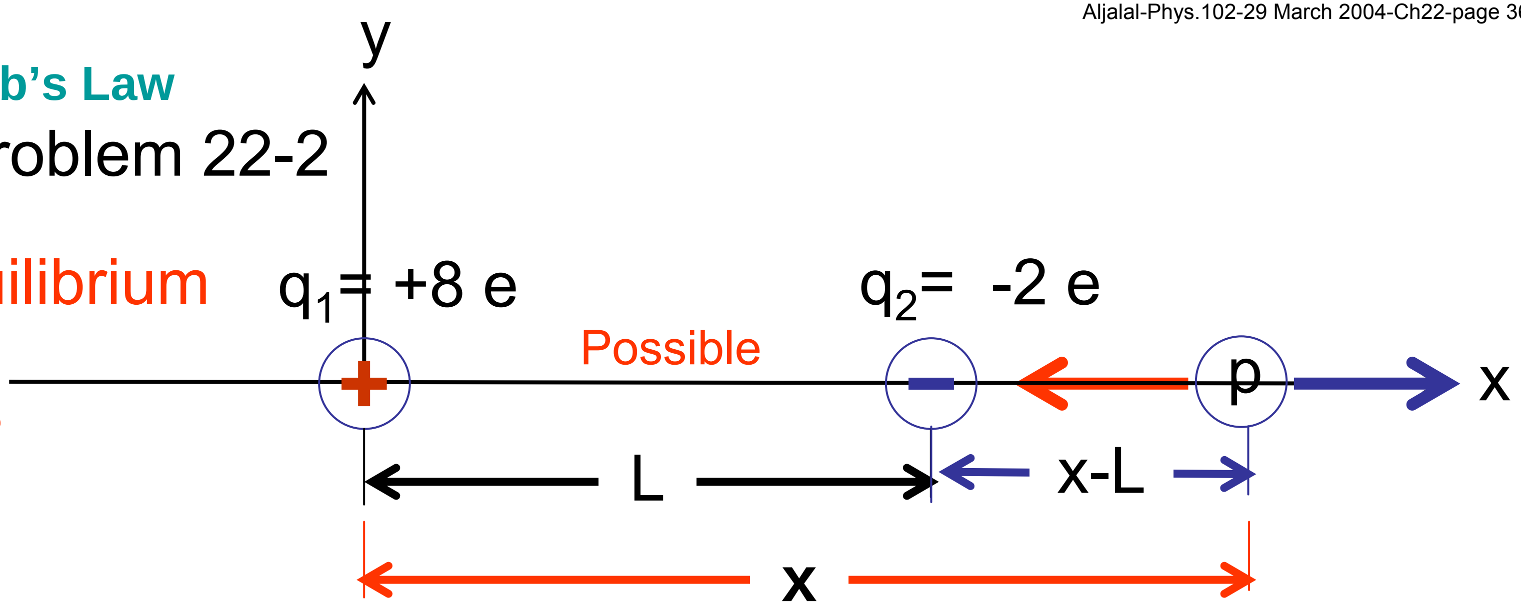
$$4(x-L)^2 = x^2$$

$$2(x-L) = x \quad \Rightarrow \quad x = 2L$$

22-4 Coulomb's Law

Sample Problem 22-2

Is the equilibrium stable or unstable?



At equilibrium

$$\vec{F} = \left(k\frac{e(8e)}{(2L)^2} - k\frac{e(2e)}{L^2}\right)\hat{i} = 0$$

If you push proton slightly to right by dx

$$\vec{F} = \left(k\frac{e(8e)}{(2L+dx)^2} - k\frac{e(2e)}{(L+dx)^2}\right)\hat{i} > 0$$

proton move to right

If you push proton slightly to left by dx

$$\vec{F} = \left(k\frac{e(8e)}{(2L-dx)^2} - k\frac{e(2e)}{(L-dx)^2}\right)\hat{i} < 0$$

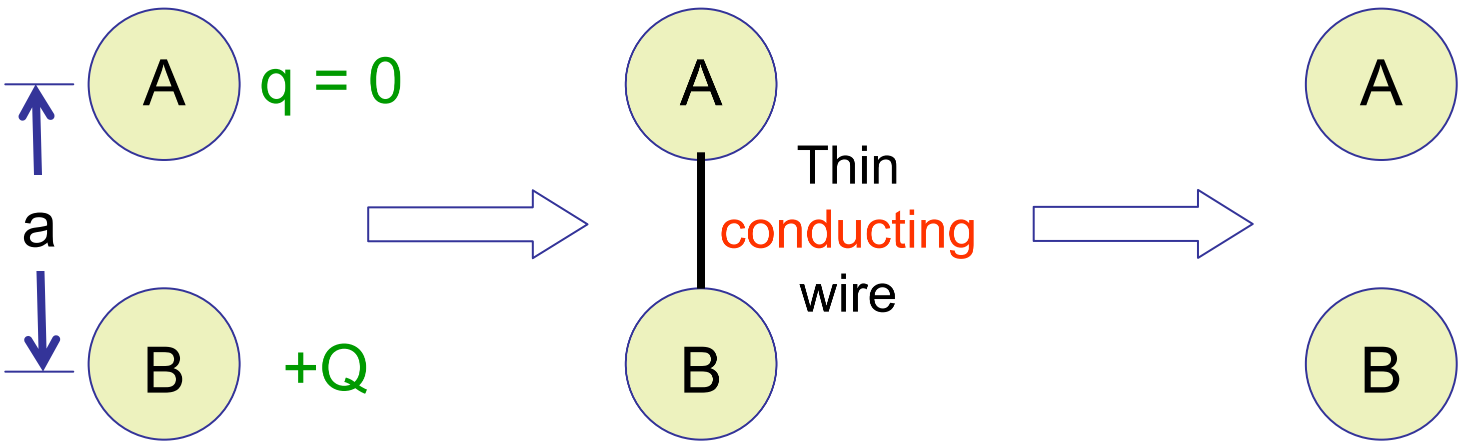
proton move to left

Equilibrium is not stable.

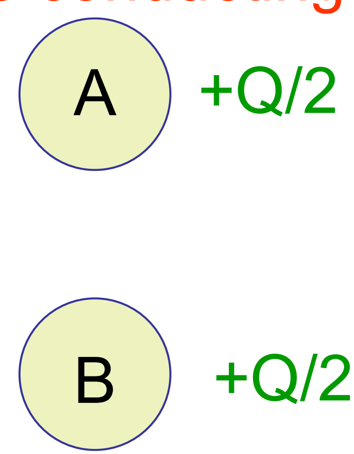
22-4 Coulomb's Law

Sample Problem 22-3

Two identical electrically isolated conducting spheres A and B



What is the magnitude of the electrostatic force between sphere A and B after removing the conducting wire. Ignore induced charges?

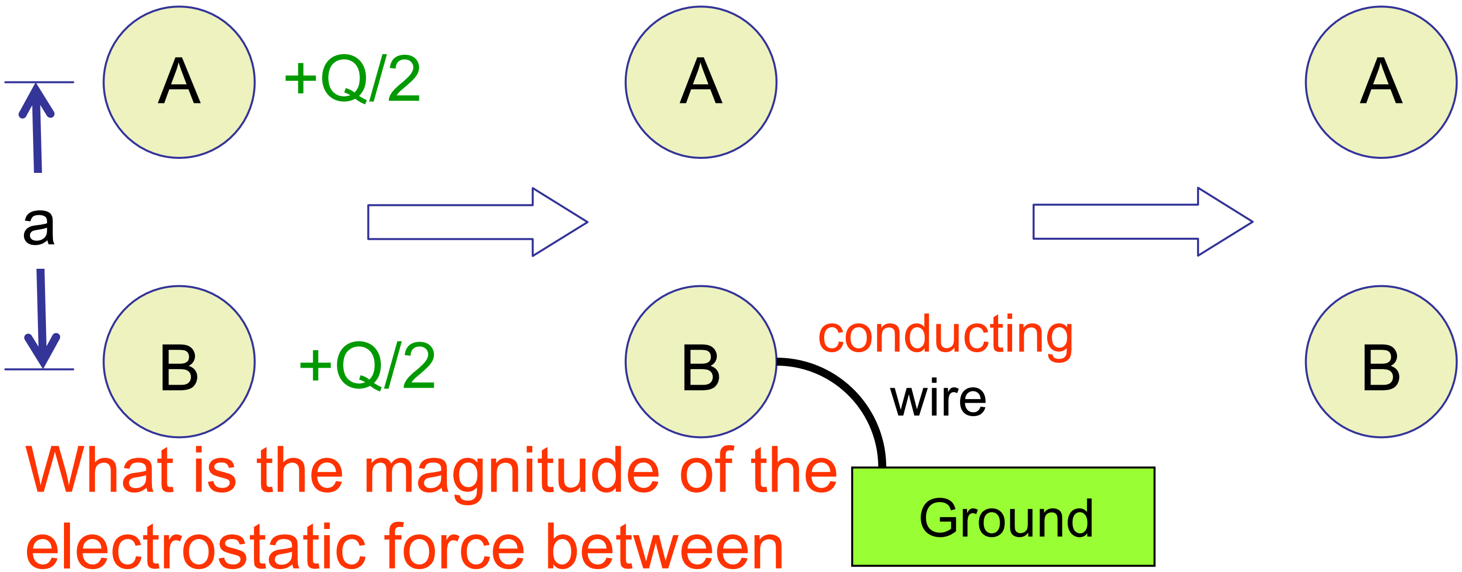


Because the spheres and wire are conductors, electrons move thought them until the charge on the two spheres are the same.

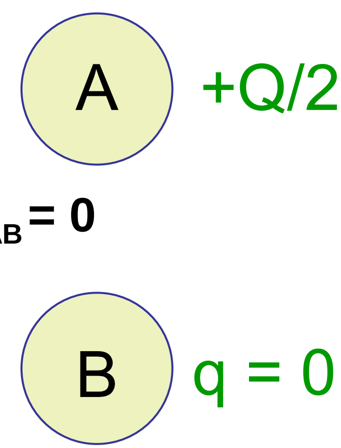
$$F_{AB} = k\frac{(Q/2)(Q/2)}{a^2}$$

22-4 Coulomb's Law

Sample Problem 22-3



What is the magnitude of the electrostatic force between sphere A and B after removing the conducting wire. Ignore induced charges?



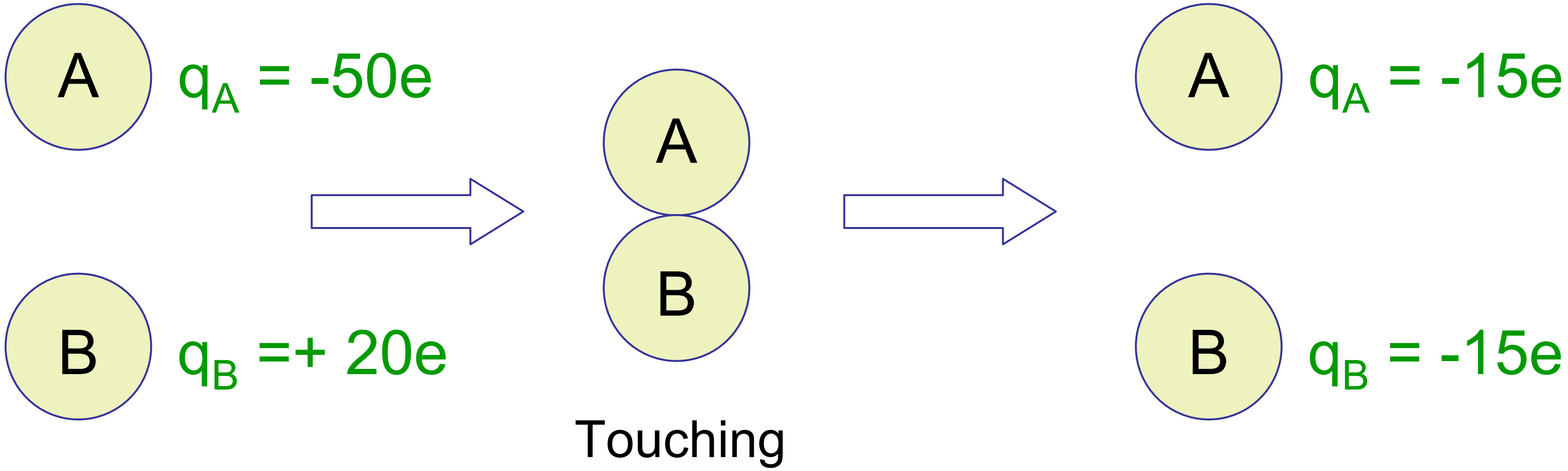
$\mathbf{F_{AB} = 0}$

The ground is a huge supply of electrons. Electrons will move from the ground to sphere B until sphere B is neutralized. Thus it contains no net charge

22-4 Coulomb's Law

Checkpoint 4

Two identical (same size) electrically isolated conducting spheres A and B



22-4 Charge is Conserved

In an isolated system,

charge is conserved.

positive charge + negative charge = constant