Physics 21900

General Physics II

Electricity, Magnetism and Optics
Lecture 2 – Chapter 14.1-4
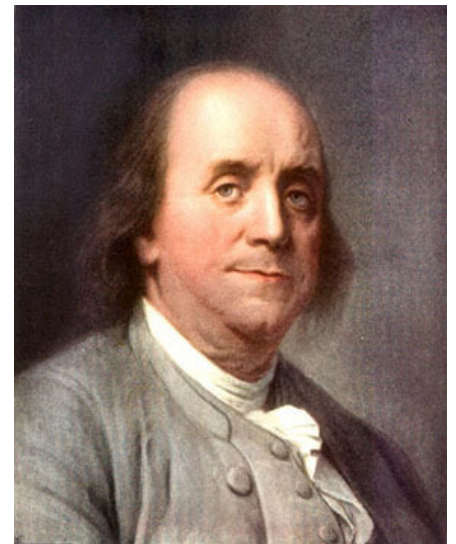
Fall 2015 Semester
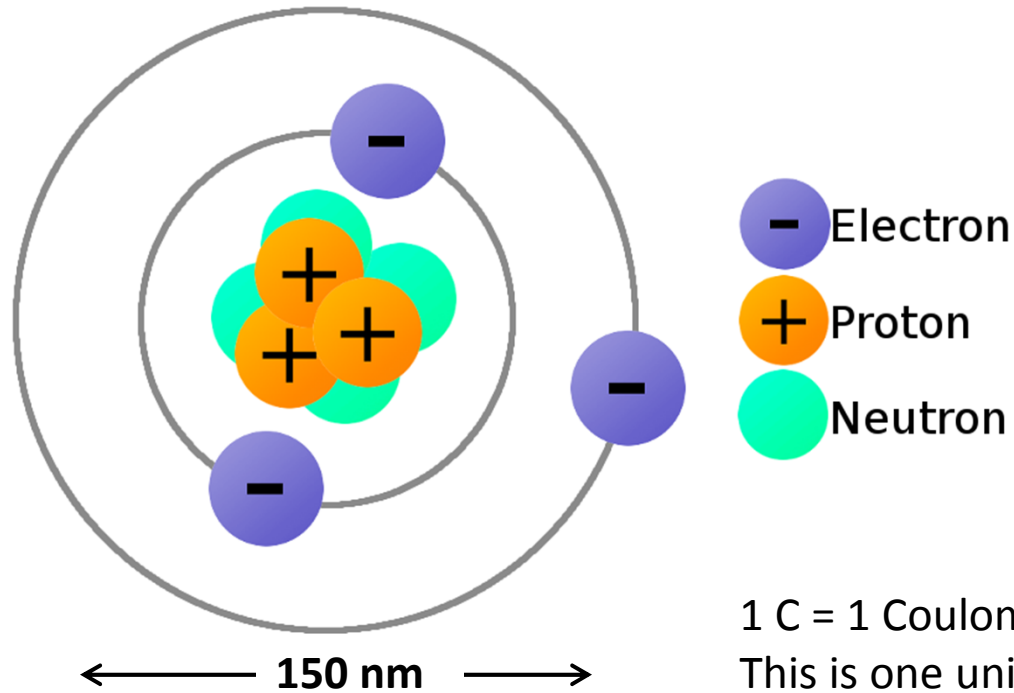
Prof. Matthew Jones

Electrostatics

- Electrostatics is concerned with the properties of charges that are not moving.
  - For example, forces on charged objects
- Most objects have no, or very small net electric charge so we don't notice these forces.
  - They are small compared with gravity
- In the 1700's, people began the systematic study of these forces induced by static electricity.
- But what is electric charge?

Observing Electric Charge

- *Electric charges exert **forces** on each other.*

- Charles DuFay classified types of charge (*vitreous/resinous*).

- Ben Franklin proposed that there was only one type of charge but that objects could have too much (+) or too little (-).

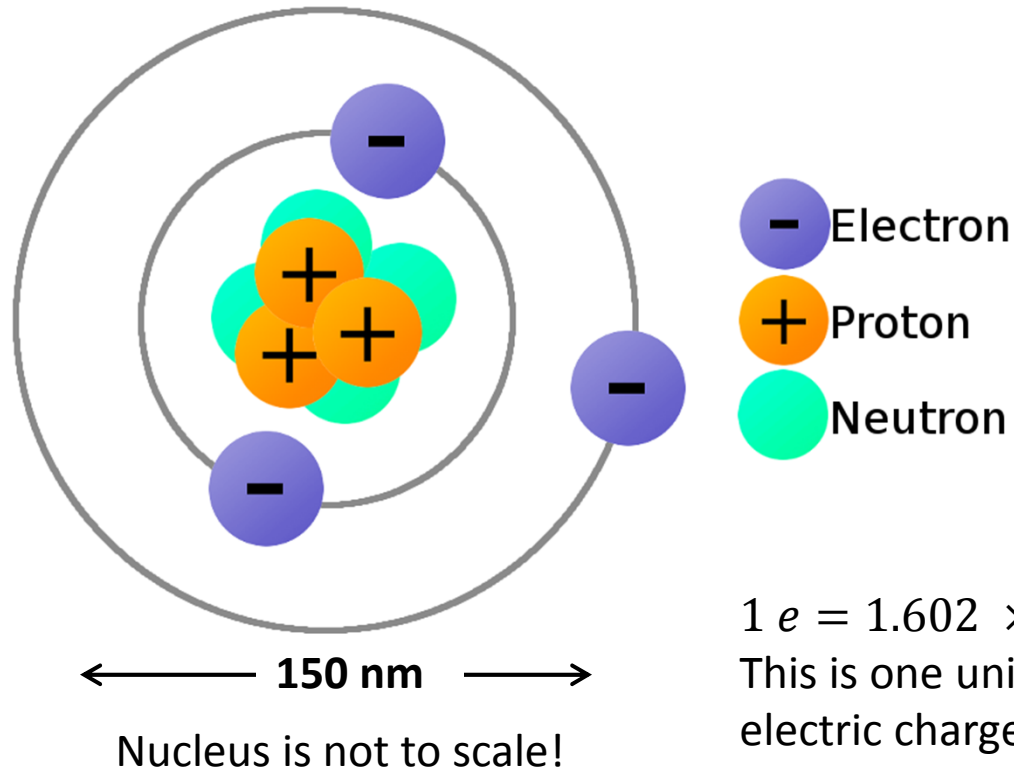- Thought of charge as a fluid and electric forces cause it to move…

Atomic Theory of Mater

← **150 nm** →

Nucleus is not to scale!

- Electron
+ Proton
Neutron

1 C = 1 Coulomb
This is one unit of electric charge.

	Proton	Neutron	Electron
Symbol	p	n	e^-
Charge	$+1.6 \times 10^{-19}\ C$	0	$-1.6 \times 10^{-19}\ C$
Mass	$1.675 \times 10^{-27}\ kg$	$1.673 \times 10^{-27}\ kg$	$9.11 \times 10^{-31}\ kg$

Atomic Theory of Mater

150 nm

Nucleus is not to scale!

$1\ e = 1.602\ \times 10^{-19}$ Coulomb
This is one unit of elementary electric charge.

	Proton	Neutron	Electron
Symbol	p	n	e^-
Charge	$+e$	0	$-e$
Mass	$1.675 \times 10^{-27}\ kg$	$1.673 \times 10^{-27}\ kg$	$9.11 \times 10^{-31}\ kg$

More Realistic Picture

Example 1 : Carbon atom
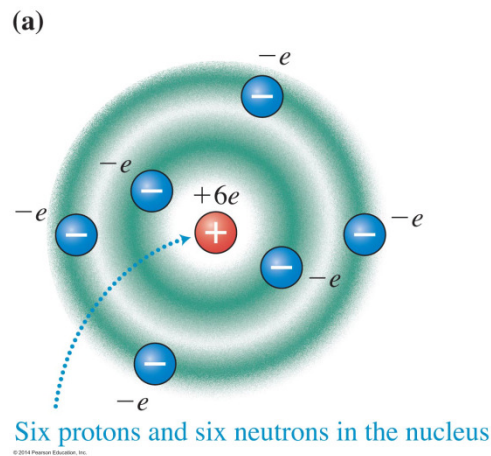
The sodium ion Na^+ has 10 negative electrons and a nucleus with charge $+11e$ (11 protons and 12 neutrons).

(a)

$-e$

$-e$

$-e$

$-e$ $+6e$ $-e$

$-e$

$-e$

Six protons and six neutrons in the nucleus

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$-e$ $-e$

$-e$

$-e$ $-e$

$+11e$

$-e$

$-e$ $-e$

$-e$

$-e$ $-e$

$-e$

Free electron

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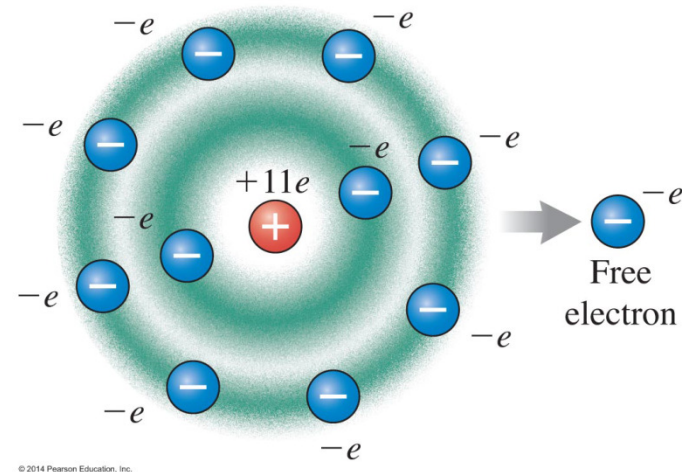
Net charge = 0

Net charge = +e

TIP Electric charge is completely defined by the effects it produces. You cannot see electric charge; it does not correspond to any amount of mass, color, length, width, or any other physical quantity.

Electric Charge

- An electron (or a proton) has a measured charge of _magnitude_ $e = \mathbf{1.602 \times 10^{-19}}$ **Coulombs**.

- This means that there are approximately $1/e = 6.25 \times 10^{18}$ electrons or protons in one Coulomb (1 C) of charge.

- Macroscopic materials contain a very large number of protons and electrons.

  - Avagadro's number: $N_A = 6.02 \times 10^{23}$

  - Example: 12 grams of Carbon-12 contains N_A atoms.

- When an object has an equal number of electrons and protons, it is _electrically neutral_.

Electric Charge

- How do objects become electrically charged?
- The ***addition*** or ***removal*** of electrons creates ***negatively*** or ***positively*** charged objects.
- Except under extreme conditions, protons stay in place and electrons are moved or transferred.
- Example:

- $= 1\, e^-$
+ $= 1\, p$

Net electric charge: 0
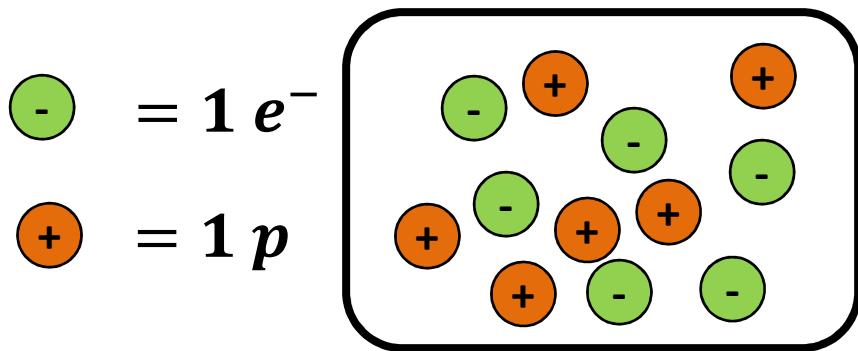
Net electric charge:
$$3\, e = 3\,(1.6 \times 10^{-19}\, C)$$
$$= 4.8 \times 10^{-19}\, C$$

Key Points

✓ Charge is said to be *quantized* – it is always observed as an integer multiple of *e*, the magnitude of the charge of **one** electron or **one** proton.

✓ Charge can be redistributed, but cannot be created or destroyed.

✓ An object is charged when it has an imbalance between electrons and protons.

Conservation of Charge

- Electric charge is conserved. The <u>net charge</u> of an ***isolated system*** can be positive, negative or zero. Charge can move between objects in a system, but the net charge of an ***isolated system*** remains unchanged.

- **CONDUCTOR**: an object or material in which charge can flow freely (eg. metals)

- **INSULATOR**: an object or material in which charge does not move freely – also called dielectrics (eg. glass or plastic)

- **GROUND**: a name given to a ***large***, conducting reservoir of charge. Its properties do not change when charge is added or removed.
  - An object that gets connected to ground is no longer an isolated system.
  - The charge of the object changes as it flows to/from ground.

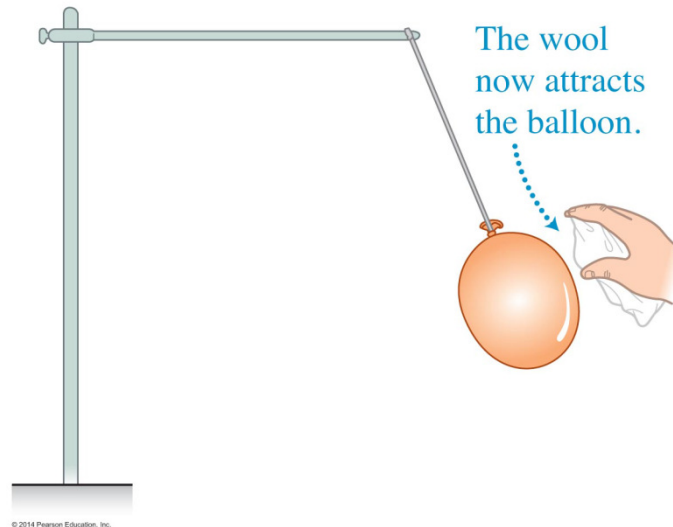# Charging by Friction
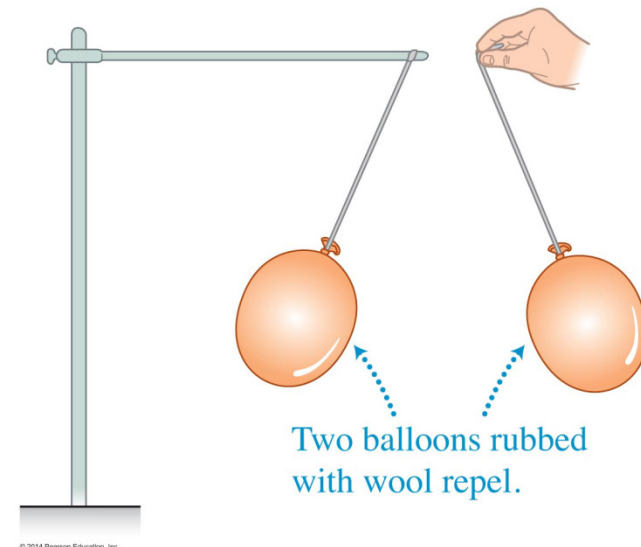
(a)

Rubbing a balloon with wool.

Balloon
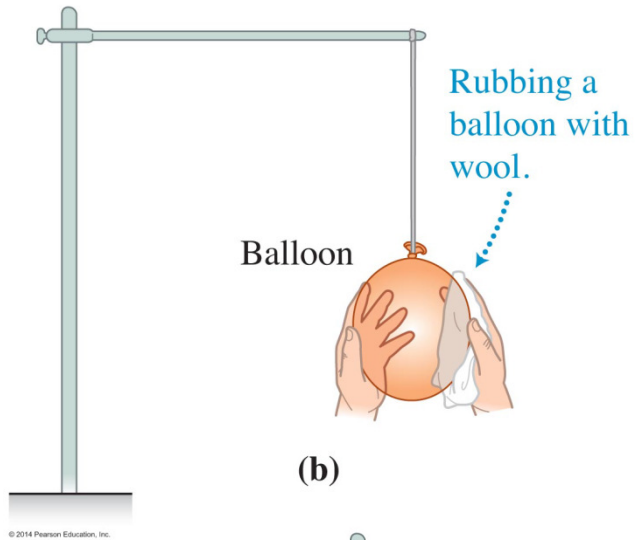
When objects rub together, molecular fragments are transferred from one surface to the other surface.

When molecules (eg, polymers) are broken, the charge is not (on average) equally distributed on the two parts.
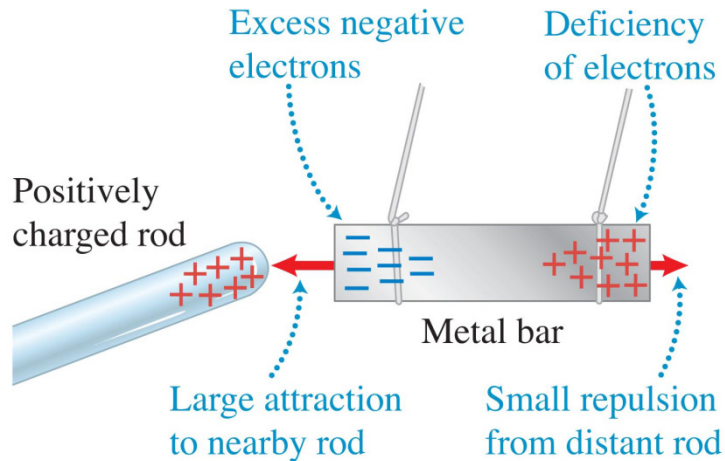
(b)

The wool now attracts the balloon.

(c)

Two balloons rubbed with wool repel.

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Charging by Friction

Triboelectric Series

Positive
+

Air
Human body
Glass
Nylon
Wool
Lead
Cotton
Aluminum
Paper
Steel
Wood
Gelatin
Nickel, copper
Gold, platinum
Natural rubber
Sulfur
Acetate
Polyester
Celluloid
Urethane
Polyethylene
Vinyl
Silicon
Teflon

Negative
−

When an object that is *higher* on the triboelectric series is rubbed with a material that is *lower* on the series, it will lose electrons and become more positive.
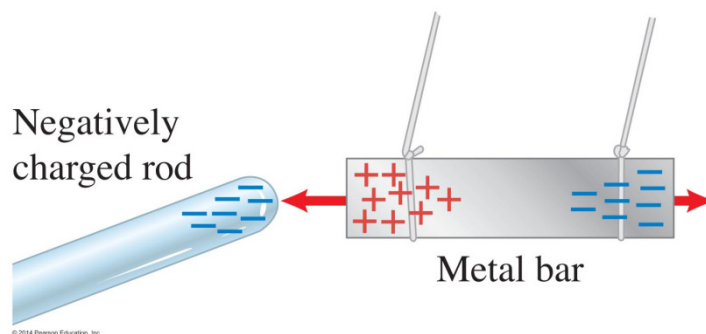
Teflon   Rabbit's Fur   Glass   Silk

50cm

Inducing an Electric Charge *without* direct contact

(a)

Excess negative electrons

Deficiency of electrons

Positively charged rod

Metal bar

Large attraction to nearby rod

Small repulsion from distant rod

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(b)

Negatively charged rod

Metal bar

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- In a metal, electrons can move freely.

- Electrons are attracted to a positively charged rod.

- Electrons are repelled from a negatively charged rod.

- The metal bar remains electrically neutral.

- The charged rod and the metal are attracted in both cases.

Inducing an Electric Charge _without_ direct contact

(a)

Neutral atoms with charge uniformly distributed

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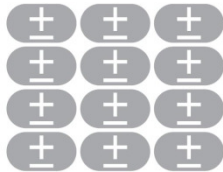
When the positively charged object is brought near the dielectric material, its atoms and molecules become polarized.
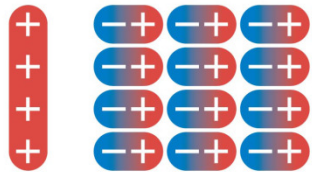
There is now a weak attraction between the charged object and the dielectric material.

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(c)

A similar thing happens if we bring a negatively charged object near a non-conducting material.

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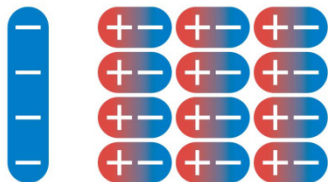
- In an insulator, the electrons cannot move freely.
- A charged object will **_polarize_** the molecules in the insulator.
- The negative ends will be attracted to a positive charge
- The negative ends will be repelled by a negative charge.

What are the consequences of net charge?

- Charges exert forces on other charges
- Opposite-sign charges experience an attractive force
- Same-sign charges experience a repulsive force.

Like charges   Unlike charges

F ←(+)   (+)→ F

F ←(−)   (−)→ F

(+)→ F   F ←(−)
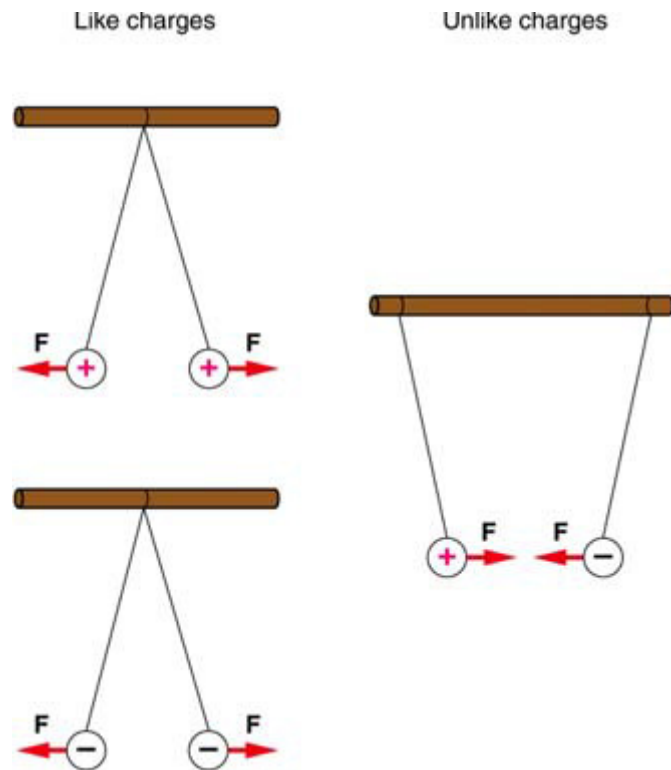
In general, this force will cause the charges to move until they are balanced by other mechanical forces in the system.

When the charges stop moving, they are said to be in *electrostatic equilibrium*.

Mechanics Question

- Does a static charge configuration imply that there are no forces acting on them?

- Not necessarily!

- There can be several forces:
  - Electrostatic force
  - Mechanical forces, eg. tension in a string
  - Gravity

- The forces must cancel each other so that the **_net_** force is zero.

- Remember that forces are vectors – they have both *magnitude* and *direction*

A Force is a Push or a Pull. We prefer to measure force in Newtons.

- Both gravity and the electrostatic force are non-contact forces. They act on objects that do not touch each other.

Gravitational Force	Electrostatic Force
$$\left\|F_g\right\| \propto \frac{m_1 m_2}{r^2}$$ $$\left\|F_g\right\| \equiv G\,\frac{m_1 m_2}{r^2}$$ $$G = 6.67 \times 10^{-11}\ N \cdot m^2/kg^2$$	$$\left\|F_e\right\| \propto \frac{\|q_1\|\|q_2\|}{r^2}$$ $$\left\|F_e\right\| \equiv k\,\frac{\|q_1\|\|q_2\|}{r^2}$$ $$k = 9.0 \times 10^9\ N \cdot m^2/C^2$$

The Electrostatic Force: Coulomb's Law
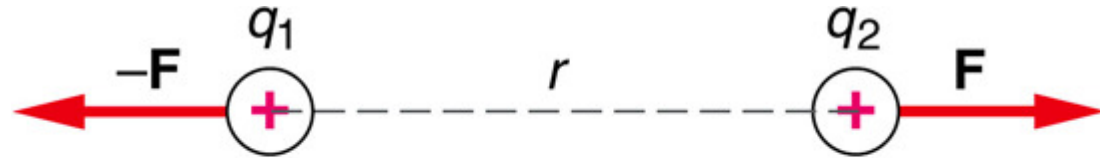
$$F = \frac{kq_1 q_2}{r^2}$$

- Only applies to *point charges*!
- We assume that the charges are stuck down and can't move.
  - If they moved, then r would change, F would be a function of time and we would need calculus!
- Force is a vector – it has a direction.
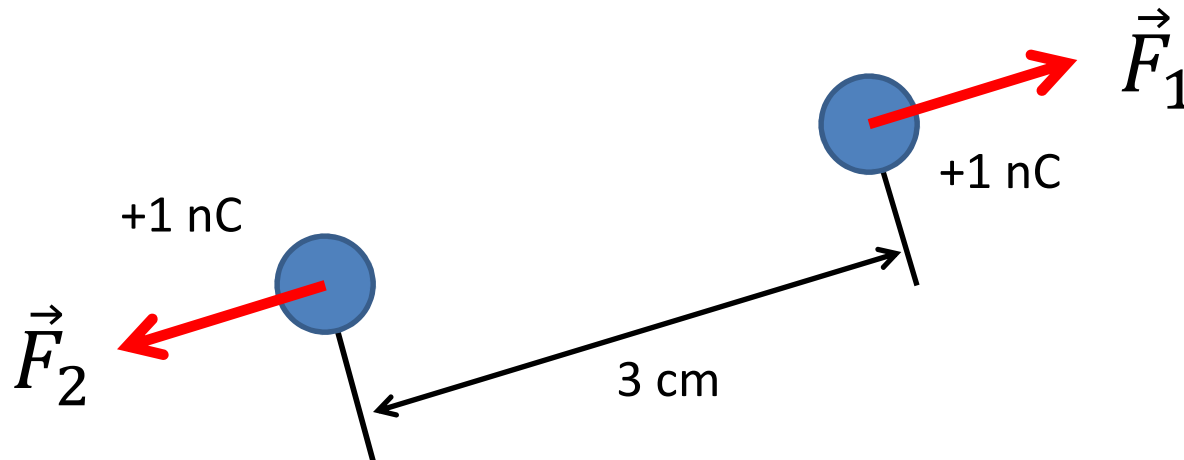 - We need to define a coordinate system.

Example

Two pieces of lint have a charge of +1 nC. If they are located 3 cm apart, what is the electrostatic force they exert on each other?
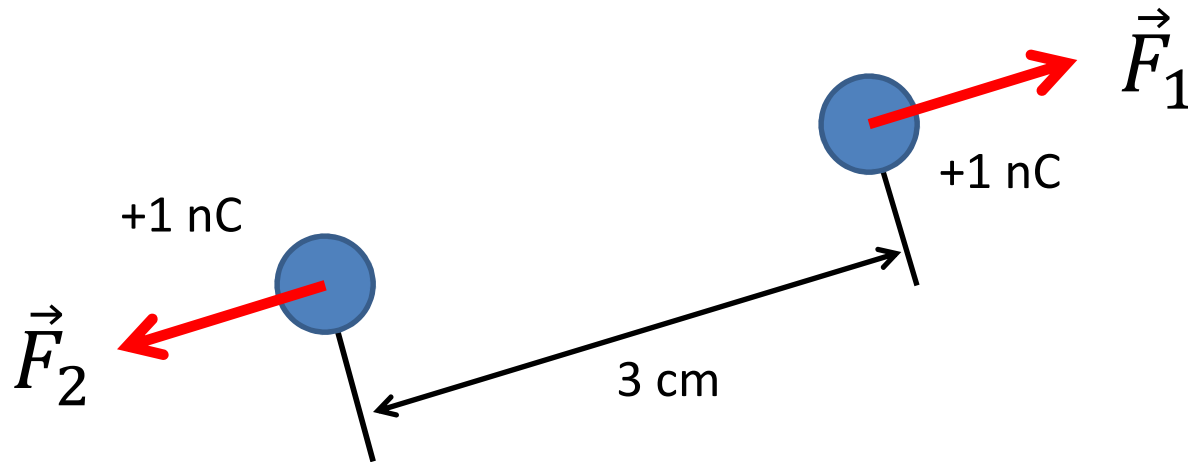

The force will be along the line joining the two point charges.

The magnitude will be equal.

The directions will be opposite.

Example

Two pieces of lint have a charge of +1 nC. If they are located 3 cm apart, what is the electrostatic force they exert on each other?

Coulomb's law:

$$\left|\vec{F}_1\right| = \left|\vec{F}_2\right| = k\,\frac{q_1 q_2}{r^2}$$

Example

Two pieces of lint have a charge of +1 nC. If they are located 3 cm apart, what is the electrostatic force they exert on each other?


+1 nC

+1 nC

$\vec{F}_1$

$\vec{F}_2$

3 cm=0.03 m
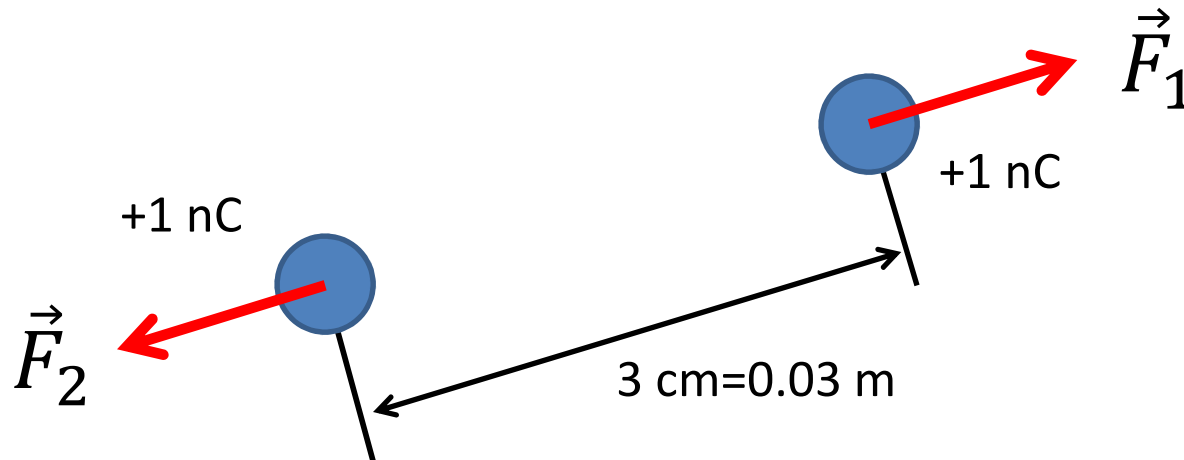
$$|\vec{F}_1| = |\vec{F}_2| = \left(9.0 \times 10^9 \ N \cdot \frac{m^2}{C^2}\right) \frac{(1.0 \times 10^{-9} \ C)^2}{(0.03 \ m)^2}$$

$$= 1.0 \times 10^{-5} \ N$$

Example

Two pieces of lint have a charge of +1 nC. If they are located 3 cm apart, what is the electrostatic force they exert on each other?

$\vec{F_1}$

+1 nC

+1 nC

$\vec{F_2}$

3 cm
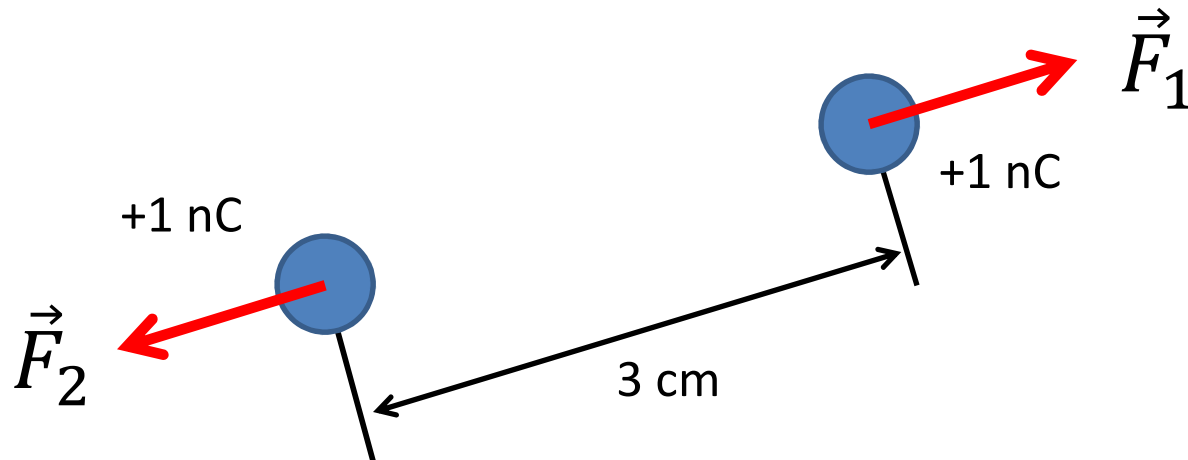
$$|\vec{F_1}| = |\vec{F_2}| = 1.0 \times 10^{-5} \, N$$

If each piece of lint had a mass m, what would the acceleration be? ➔ $\vec{F} = m\,\vec{a}$

More than two charges

- Principle of superposition:
  - Calculate the force on one charge due to each of the other charges using Coulomb's law
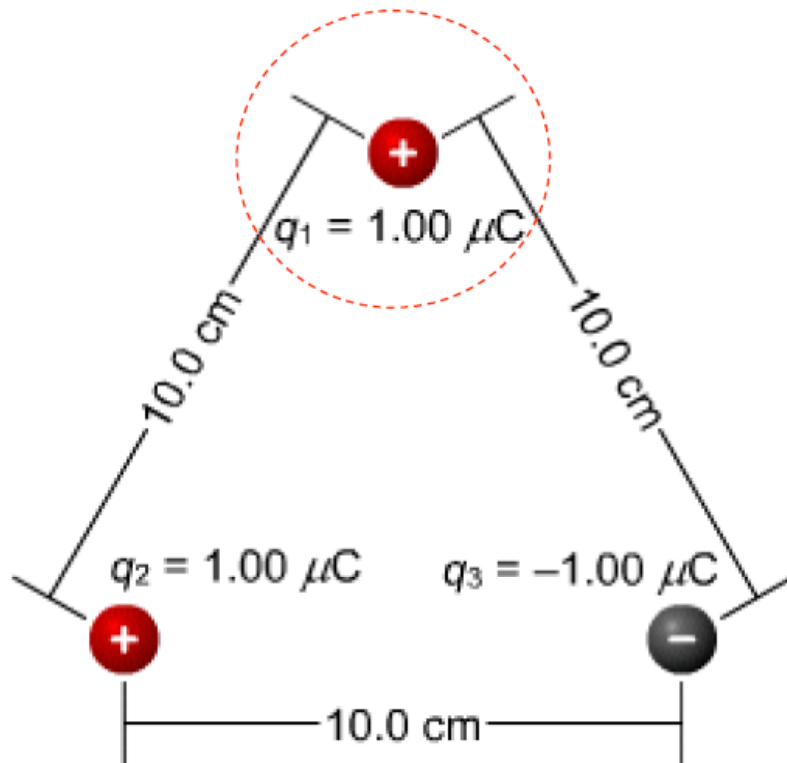 - The __net__ force is the **vector sum** of the individual forces.
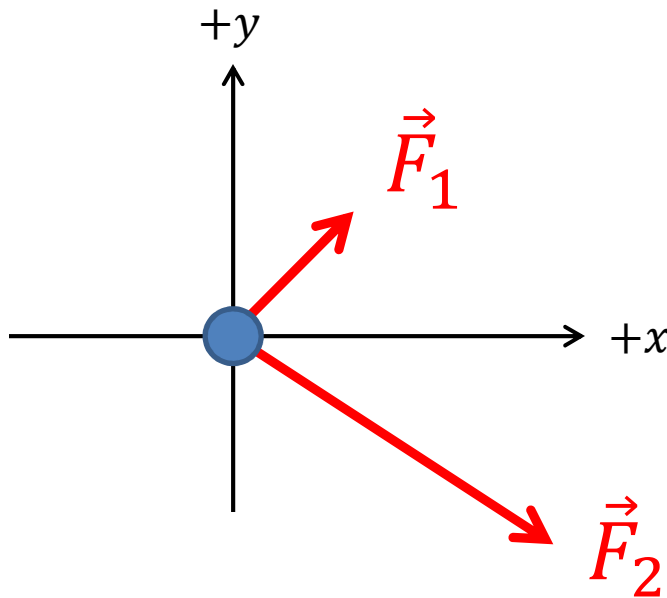
More than two charges

- Vector addition:
  - Graphical: join the vectors head-to-tail
  - Numerical: resolve vectors into components along the x and y axes and add them up.
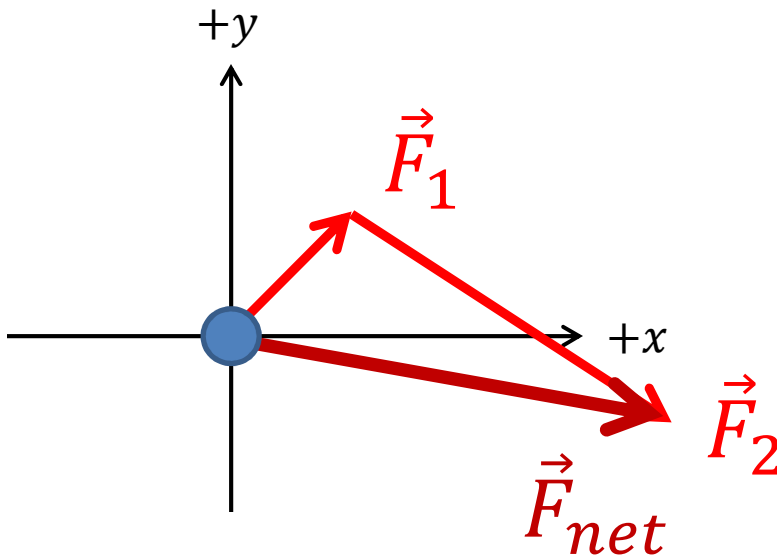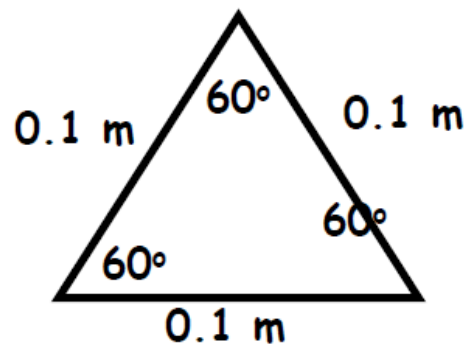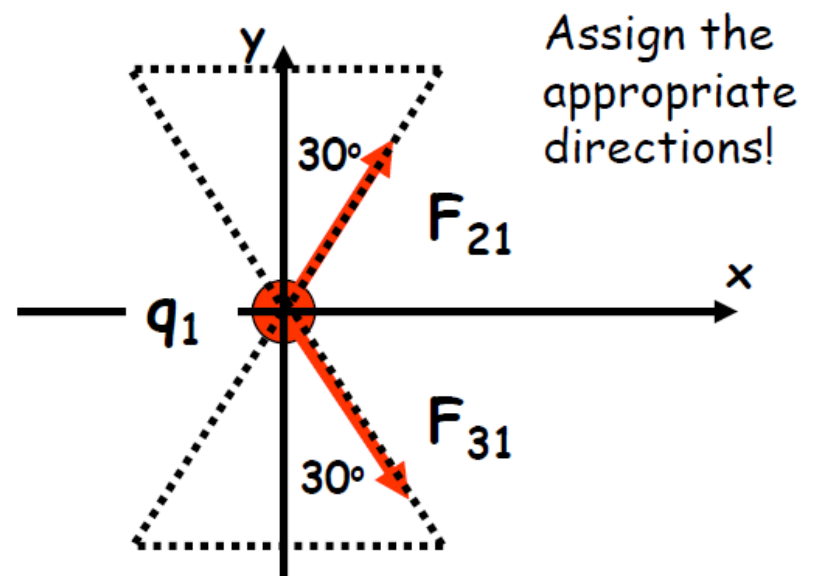
Example: What is force on q_1? (six steps)

$q_1 = 1.00\ \mu C$

10.0 cm

10.0 cm

$q_2 = 1.00\ \mu C$ $q_3 = -1.00\ \mu C$

10.0 cm

A. Units:

10 cm = 0.1 m

$1.00\ \mu C = 1.00 \times 10^{-6}\ C$

C. Force Diagram

Assign the appropriate directions!

Y

30°

F_{21}

x

q_1

F_{31}

30°

B. Geometry

0.1 m   60°   0.1 m

60°

60°

0.1 m

D. Vector Components
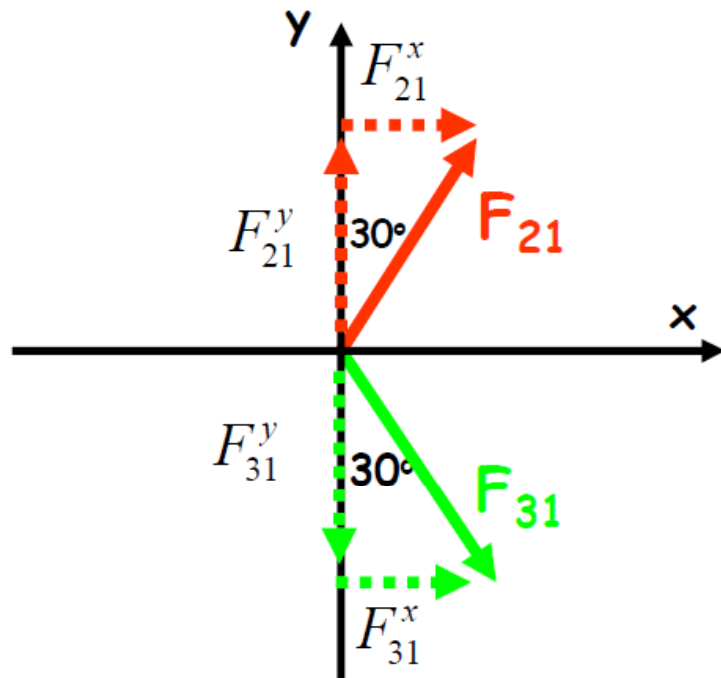
$$F_{21}^x = F_{21}\sin(30^o); +x$$

$$F_{21}^y = F_{21}\cos(30^o); +y$$

$$F_{31}^x = F_{31}\sin(30^o); +x$$

$$F_{31}^y = F_{31}\cos(30^o); -y$$

E. Arithmetic

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

$$= 9\times10^9\frac{1\times10^{-6}\bullet1\times10^{-6}}{(0.1)^2} = 0.9\,N$$

$$\left|F_{31}\right| = k\frac{|q_1||q_3|}{r^2}$$

$$= 9\times10^9\frac{1\times10^{-6}\bullet1\times10^{-6}}{(0.1)^2} = 0.9\,N$$

F. Final Answer

$$F_{net}^x = F_{21}^x + F_{31}^x$$

$$= 0.9N\sin(30^o) + 0.9N\sin(30^o)$$

$$= 0.90N \text{ in +x direction}$$

$$F_{net}^y = F_{21}^y - F_{31}^y$$

$$= 0.9N\cos(30^o) - 0.9N\cos(30^o)$$

$$= 0.00N \text{ in } y \text{ direction}$$