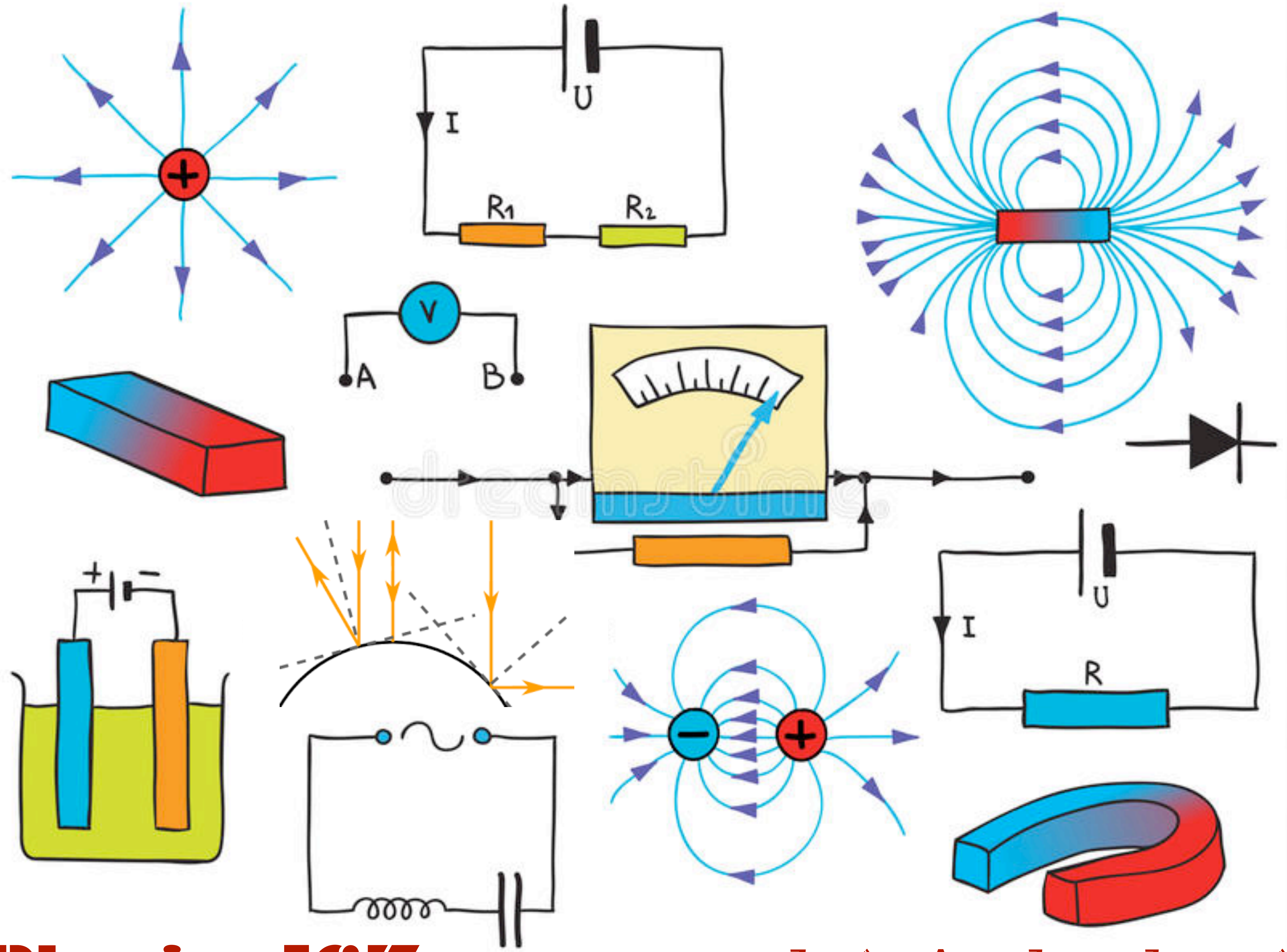


Physics 167

Luis Anchordoqui

Electric Charge

- ➢ If you rub a balloon across your hair on a dry day the balloon and your hair become charged and attract each other
- ➢ Two charged balloons, on the other hand, repel each other

The two balloons must have the same kind of charge because each became charged in the same way

Because two charged balloons repel one another we see that like charges repel

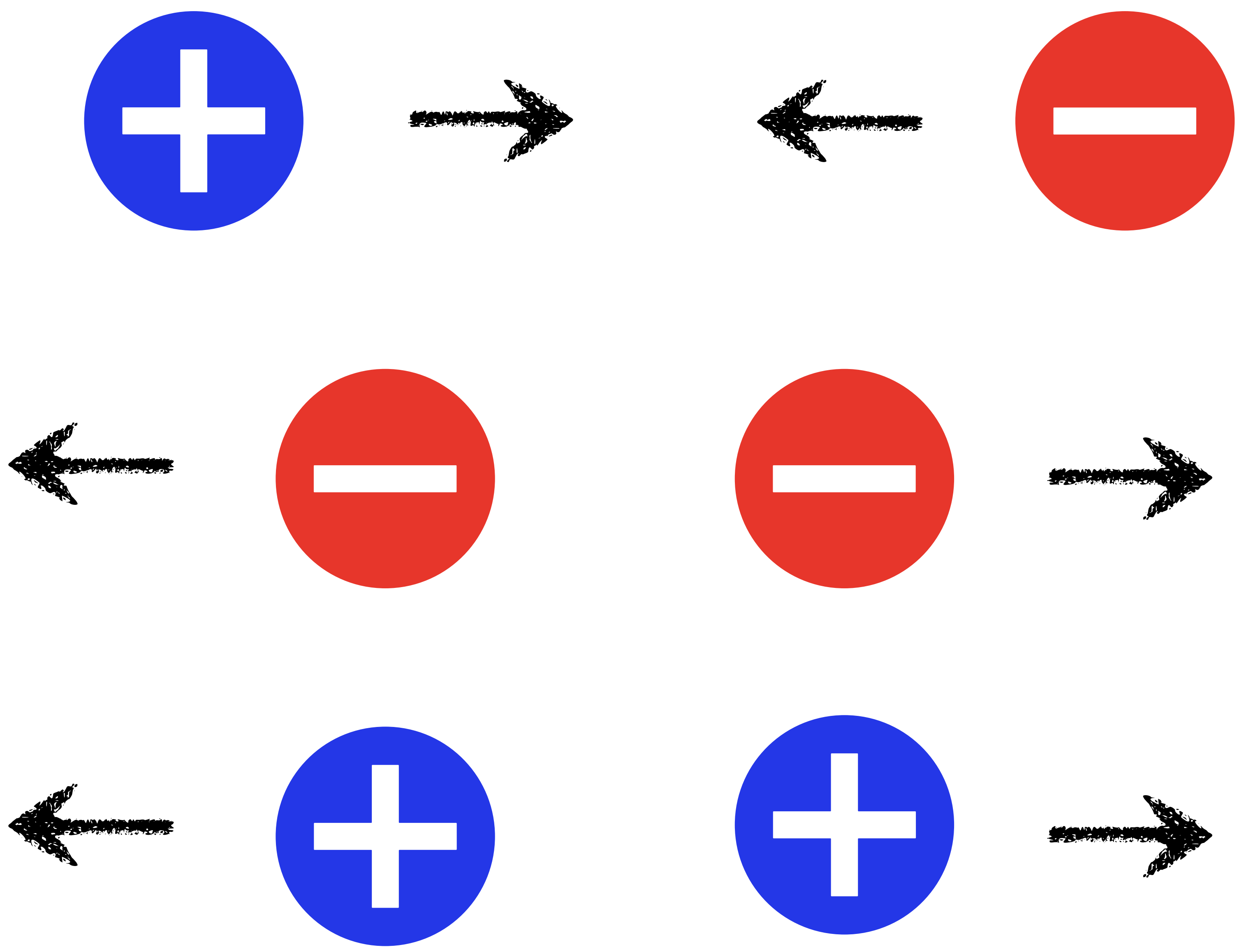
Conversely ☞ a rubbed balloon and your hair which do not have the same kind of charge are attracted to one another

☞ unlike charges attract

Electric Charge

Charge is an intrinsic property of matter

- ➢ Two types of charges name by Ben Franklin
- ➢ How charges interact
  - * Opposite charges attract
  - * Like charges repel



Net Charge

- ➢ Net Charge ☞ the total amount of charge on an object
- ➢ For **most** objects positive and negative charges balance out or **net** charge = zero
  - ✱ They are said to be electrically neutral
- ➢ " Charged" means
  - ✱ Having **more** of one kind of charge (+ or -)
- ➢ Charges can be separated
- ➢ The **net charge in an isolated system cannot change**
  - ✱ This means that the sum of the negative and positive charges in any system remains constant
- ➢ You can **move charges around** but you cannot create or destroy charge!

What is charge ?

- ➢ Mechanics never really tell us what mass is ☞ but just how it behaves: how it moves, etc.

LIKEWISE

- ➢ Classical Electromagnetism does not tell us what charge is exactly ☞ but only how it behaves !

↓

Electricity and magnetism

Atomic Structure

- All matter is composed of atoms
- All atoms are composed of three subatomic particles

  Protons: positively charged (made out of quarks & gluons)

  Electrons: negatively charged (elementary particles)

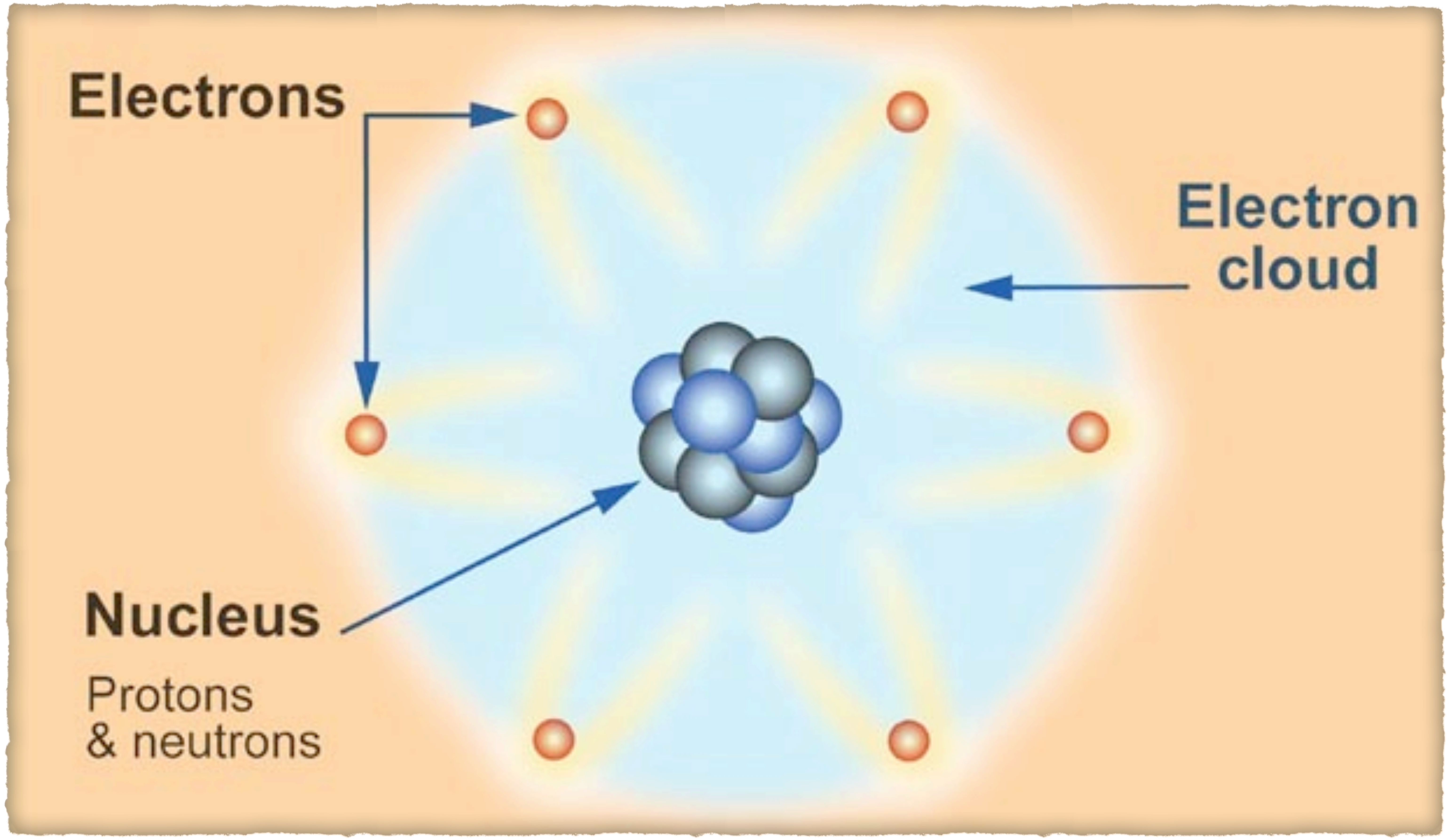
  Neutrons: uncharged (made out of quarks & gluons)

Atomic Structure

- ➢ Protons and neutrons have almost equal masses
- ➢ Electrons are about 2,000 times less massive than protons and neutrons
  - ✱ Electron mass = 9.11×10^{-31} kg
  - ✱ Proton mass = 1.673×10^{-27} kg
  - ✱ Neutron mass = 1.675×10^{-27} kg
- ➢ Protons and neutrons make up the nucleus of an atom with its electrons moving about the nucleus some distance away
- ➢ Atoms are mostly ... empty ☞ we live in almost empty space

Structure of an Atom

A schematic diagram (not to scale) of the most common type of carbon atom, which has six protons, six neutrons, and six electrons



Charge is Conserved and Quantized

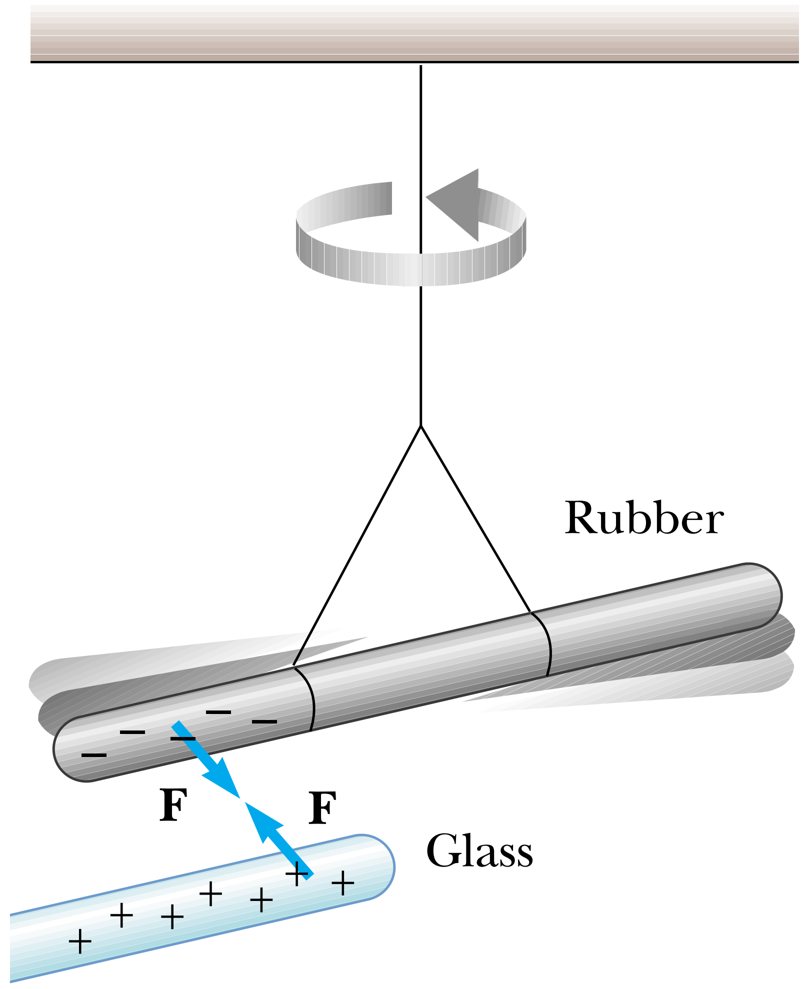
When a glass rod is rubbed with silk electrons are transferred from the glass to the silk

Because of conservation of charge each electron adds negative charge to the silk

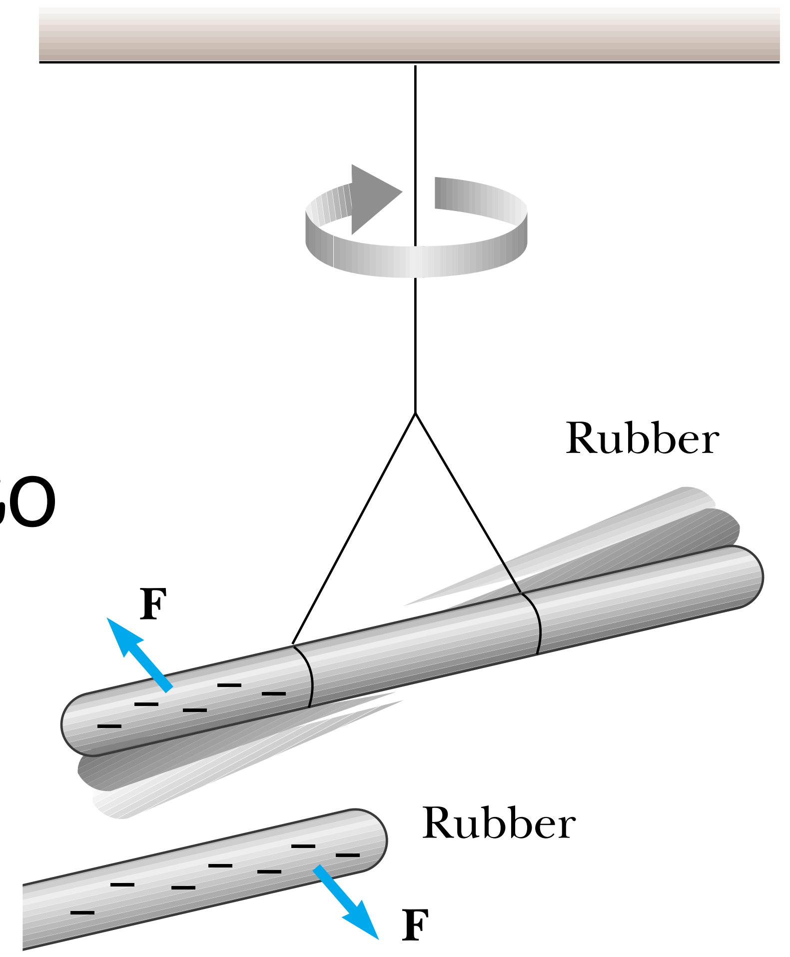
and an equal positive charge is left behind on the rod

Also ☛ because charges are transferred in discrete bundles

charges on the two objects are $\pm e, \pm 2e, \pm 3e, \cdots$



A negatively charged rubber rod suspended by a thread is attracted to a positively charged glass rod



A negatively charged rubber rod is repelled by another negatively charged rubber rod

Measuring Charge

- The unit of electric charge is Coulomb (C)
- Electrons carry the smallest "piece" of negative charge

(-) 1.6×10^{-19} Coulombs of charge

- Protons carry an equal amount of positive charge

(+) 1.6×10^{-19} Coulombs of charge

- Electric charges is not continuous but occur in multiples of basic unit charge in nature

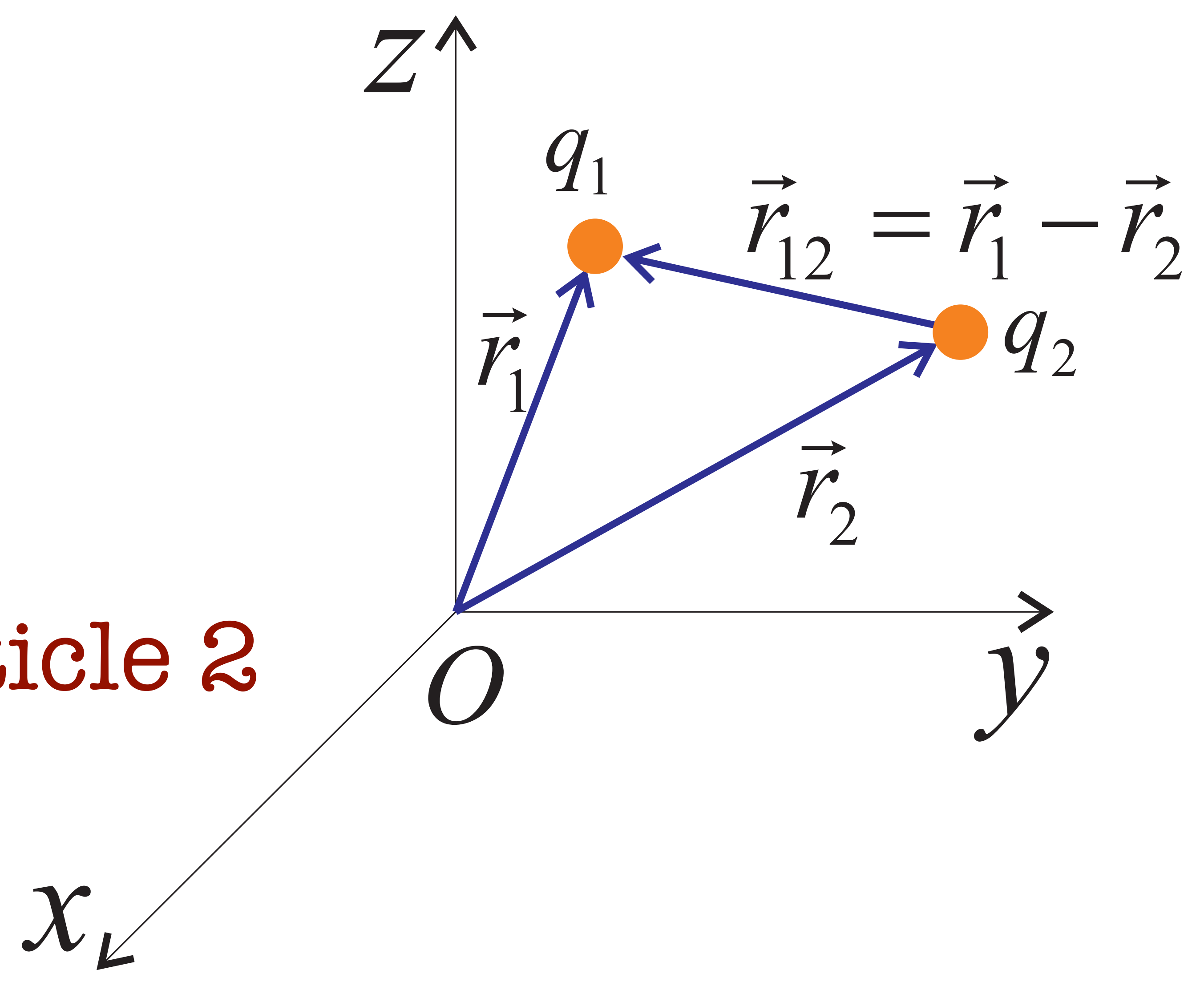
$$\pm e = \pm 1.6 \times 10^{-19}\ C$$

Electric Force

Electric force between two charges q_1 and q_2 described by ☛ Coulomb's Law

$\vec{F}_{12}$ = Force q_1 on exerted by q_2

$$\vec{F}_{12} = \frac{1}{4\pi\epsilon_0} \cdot \frac{q_1 q_2}{r_{12}^2} \cdot \hat{r}_{12}$$



$\hat{r}_{12} = \dfrac{\vec{r}_{12}}{|\vec{r}_{12}|}$ ☛ unit vector which locates particle 1 relative to particle 2

i.e $\vec{r}_{12} = \vec{r}_1 - \vec{r}_2$

- q_1, q_2 are electrical charges in units of Coulomb (C)
- Charge is quantized ☛ electron carries 1.602×10^{-19} C
- Permittivity of free space $\epsilon_0 = 8.85 \times 10^{-12}\ \mathrm{C^2/Nm^2}$ ☛ $k = \dfrac{1}{4\pi\epsilon_0}$

Coulomb's Law

(1) q_1, q_2 can be either positive or negative

(2) If q_1, q_2 are of same sign

force experienced by q_2 is in direction away from q_1 i.e. ☞ repulsive

(3) Force on q_2 exerted by q_1:

$$\vec{F}_{21} = \frac{1}{4\pi\epsilon_0} \cdot \frac{q_2 q_1}{r_{21}^2} \cdot \hat{r}_{21}$$

BUT

$$r_{12} = r_{21} = \text{distance between } q_1, q_2$$

$$\hat{r}_{21} = \frac{\vec{r}_{21}}{r_{21}} = \frac{\vec{r}_2 - \vec{r}_1}{r_{21}} = \frac{-\vec{r}_{12}}{r_{12}} = -\hat{r}_{12}$$

$$\vec{F}_{21} = -\vec{F}_{12}$$ **Newton's 3rd Law**

Coulomb's Law

Example 1

What is the magnitude of the force on the proton due to the electron in hydrogen?

Coulomb's Law

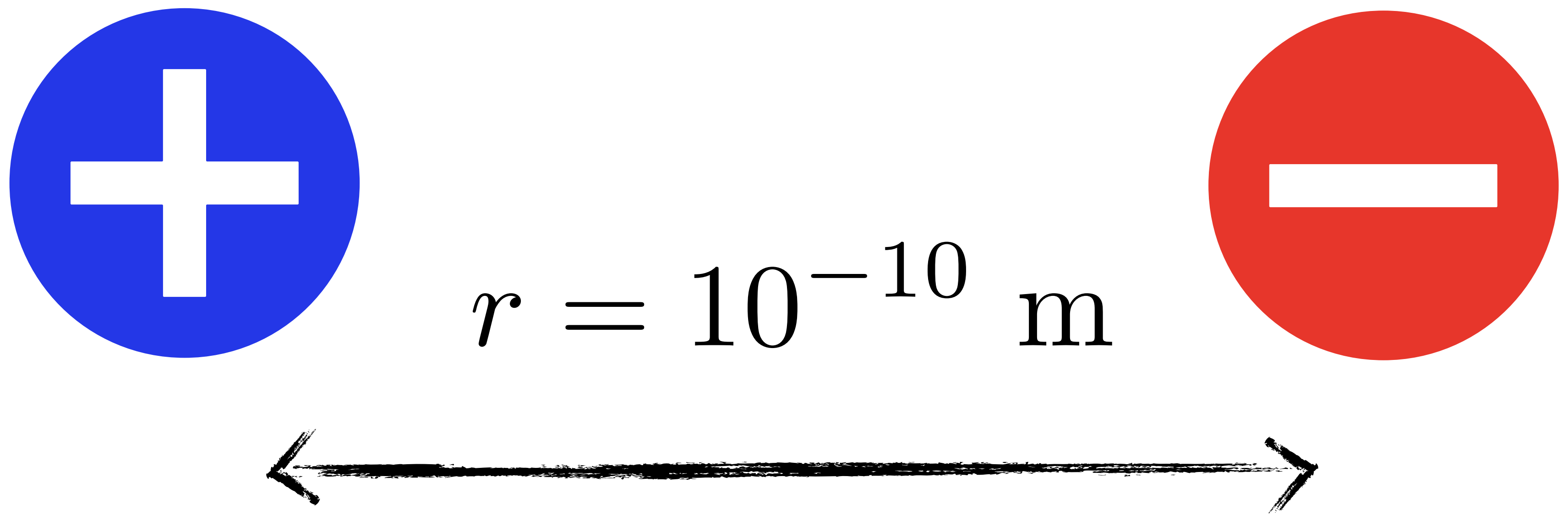
Example 1

What is the magnitude of the force on the proton due to the electron in hydrogen?

$$F = kq_pq_e/r^2$$

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

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



$$r = 10^{-10} \ \text{m}$$

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

$$F = 9 \times 10^9 \ \frac{\text{Nm}^2}{\text{C}^2} \ \frac{(1.6 \times 10^{-19} \ \text{C})(1.6 \times 10^{-19} \ \text{C})}{(10^{-10} \ \text{m})^2} = 2.3 \times 10^{-8} \ \text{N}$$

Coulomb's Law

Example 1

What is the direction of the force on the proton due to the electron?

(A) Left

(B) Right

(C) Zero

Coulomb's Law

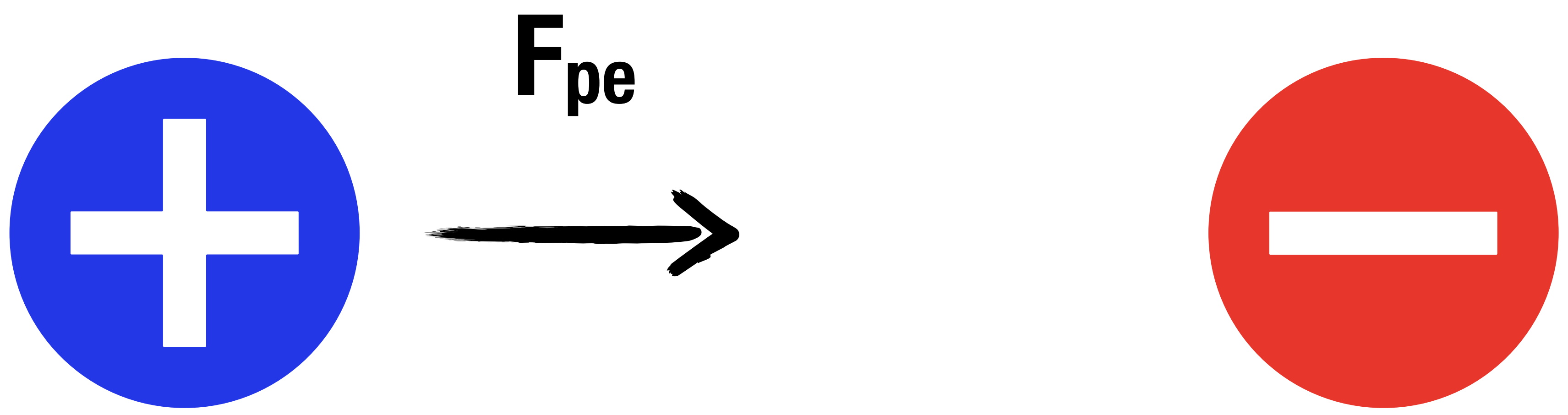
Example 1

What is the direction of the force on the proton due to the electron?

(A) Left

(B) Right ✓

(C) Zero



Coulomb's Law

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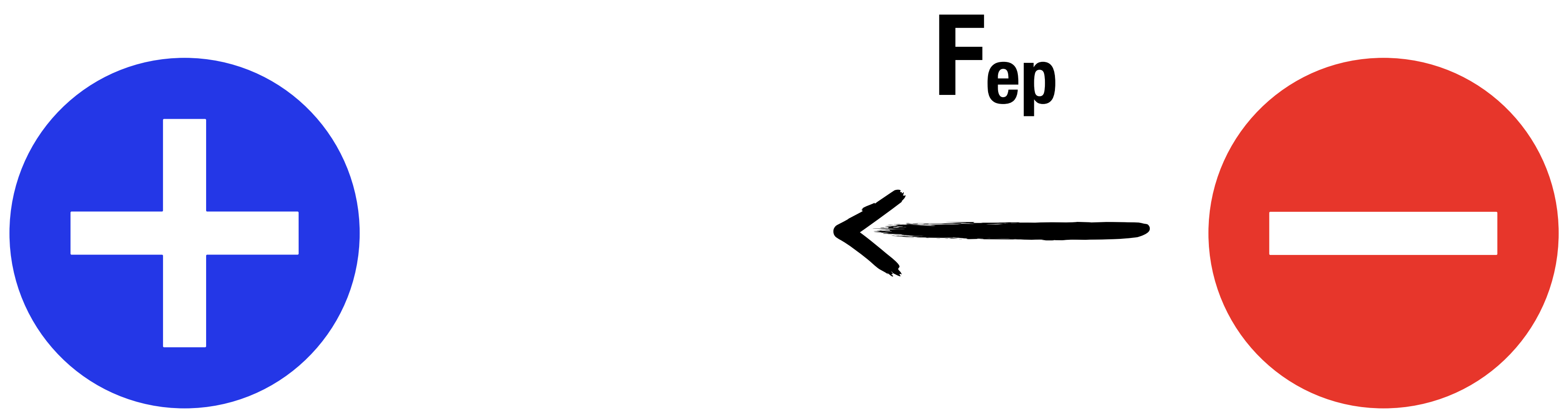


Coulomb's Law

Example 2

The hydrogen atom, the simplest of all, consists of a single proton as its nucleus, with an electron an average of 5.3×10^{-11} m away.

(i) Compare the electric and gravitational forces between the proton and the electron in this atom

(ii) Would life be different if the electron were positively charged and the proton were negatively charged?

Does the choice of signs have any bearing on physical and chemical interactions? Explain

Coulomb's Law

Example 2

Solution (i)

* Take the ratio of the electric force divided by the gravitational force, that is

$$\frac{F_E}{F_G} = \left(\frac{q_1 q_2}{4\pi\epsilon_0\ r^2}\right) / \left(\frac{G\, m_1 m_2}{r^2}\right) = \frac{8.99 \times 10^9\ \mathrm{N \cdot m^2/C^2}\ (1.602 \times 10^{-19}\ \mathrm{C})^2}{6.67 \times 10^{-11}\ \mathrm{N \cdot m^2/kg^2}\, 9.11 \times 10^{-31}\ \mathrm{kg}\, 1.67 \times 10^{-27}\ \mathrm{kg}} \simeq 2.3 \times 10^{39}$$

* The electric force is about 2.3 x 10^{39} times stronger than the gravitational force for the given scenario.

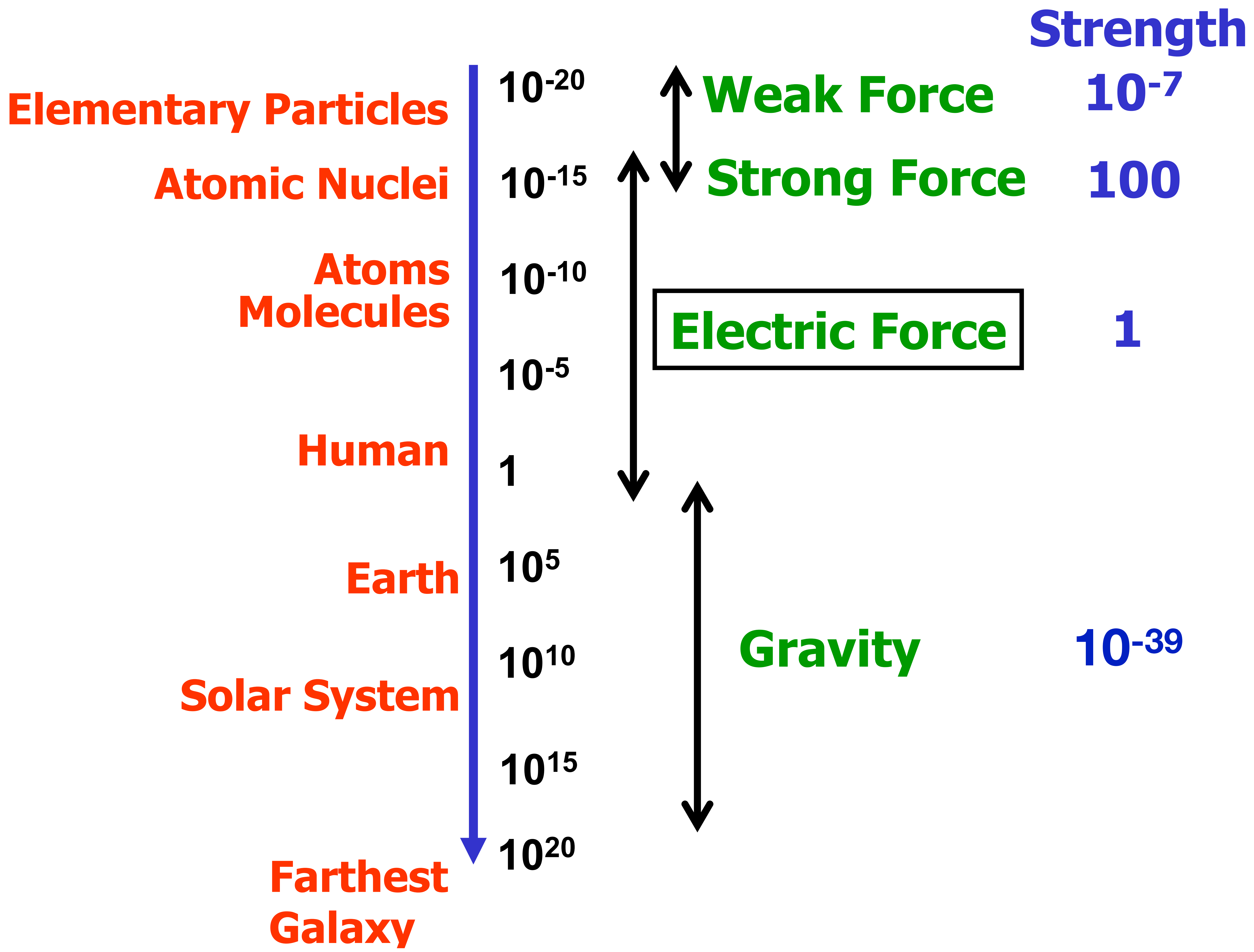
Solution (ii)

* No.
* Life would be no different if electrons were positively charged and protons were negatively charged.
* Opposite charges would still attract, and like charges would still repel.
* The designation of charges as positive and negative is merely a definition.

Fundamental Forces

- How does the Electric force compare to the other fundamental forces?
  - Gravity
  - Strong force (atomic nucleus)
  - Weak force (radioactivity, star “fuel”)
- How strong?
- What range?

Fundamental Forces



Modern View (>1930)

- ➢ Interactions 'mediated' by exchange of particles ('gauge bosons')

* Weak interaction: Vector bosons (m large)
* Strong interaction: Gluons (m=0)
* Electric Force: Photons (m=0)
* Gravity: Graviton (m=0)

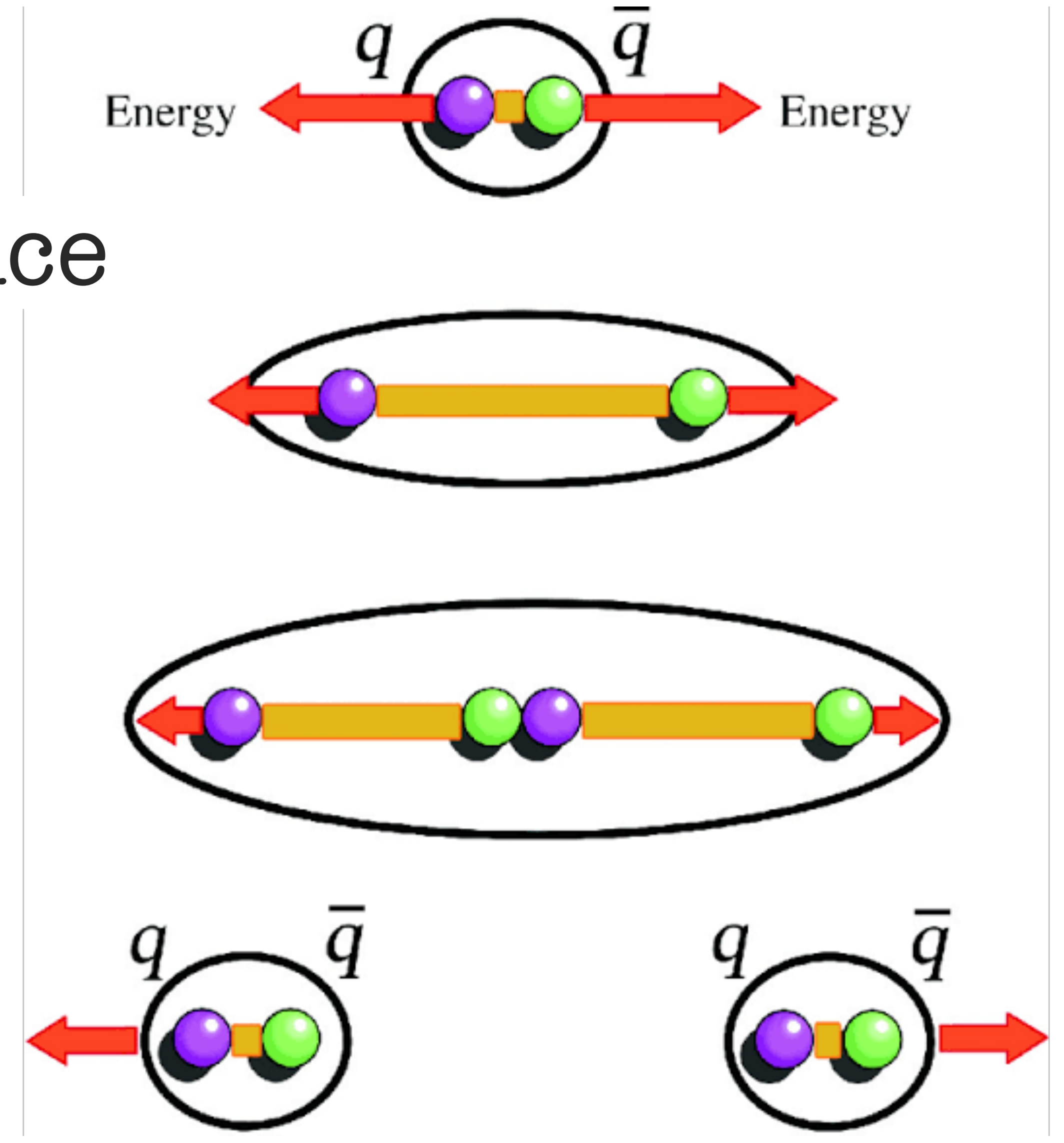
- ➢ For infinite range ☞ exchanged particle must be massless!
- ➢ Weak force: short range ☞ but why does strong force also have short range?

Why does the strong force have a short range despite a massless boson?

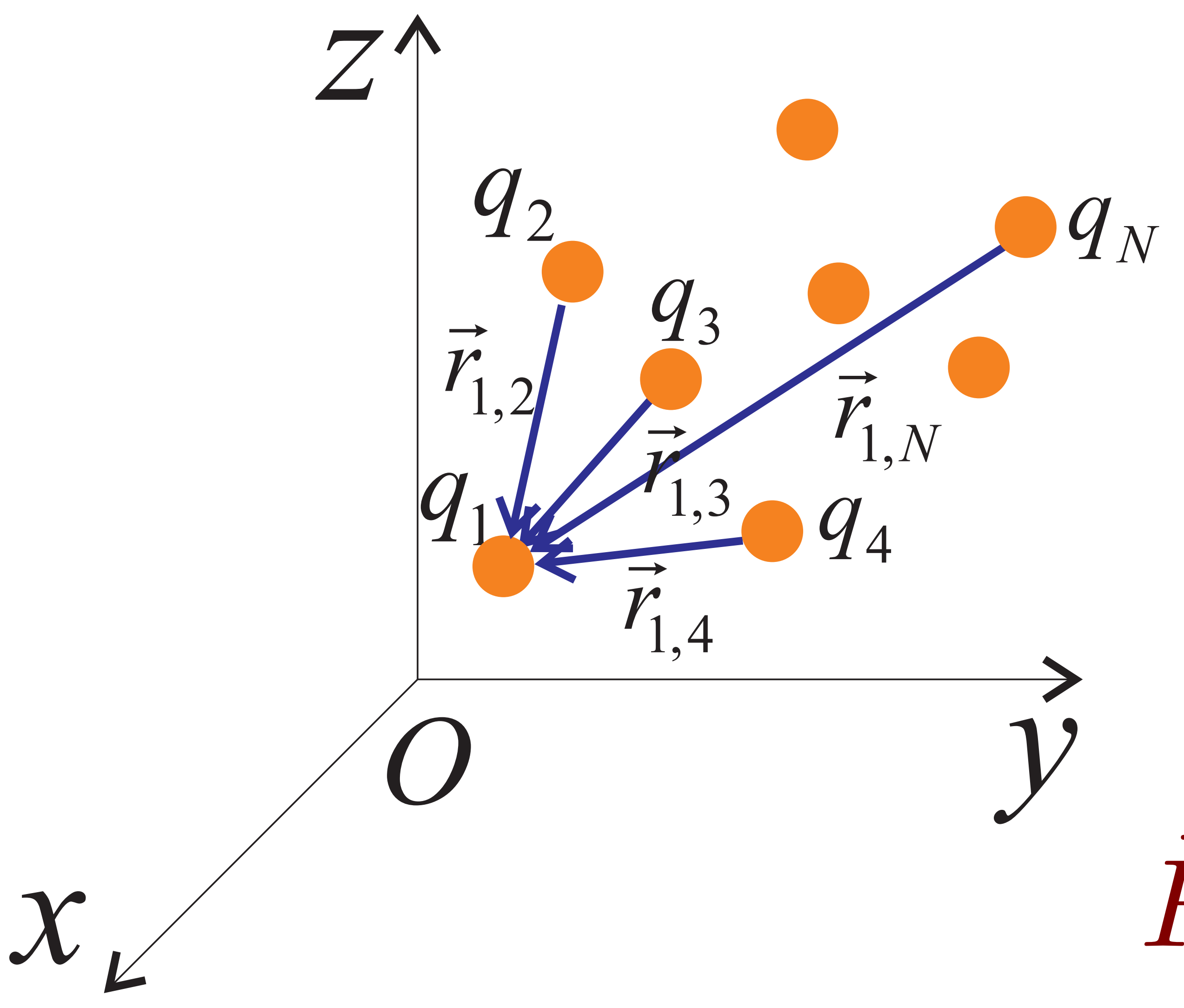
- ➢ Fundamental reason is that "gluons" strongly attract each other unlike photons or gravitons
- ➢ So when they extend out to large distances they tend to bundle up into narrow cable-like structures

  ↓ generally called "strings"
- ➢ These cables mean that the force does not decrease with an inverse square law (which is what you would expect from typical massless particle exchange)

  ☞ but rather (to first approximation) give a force that is constant with distance
- ➢ Strong force tends to keep particles very close
- ➢ If the cable extends very far ☞ it breaks and creates quark-antiquark pairs
- ➢ This limits the range of the string splitting distance



System with many charges



Total force experienced by charge q_1

vector sum of forces on q_1 exerted by other charges

$\vec{F}_1$ = Force experienced by q_1

$$= \vec{F}_{1,2} + \vec{F}_{1,3} + \vec{F}_{1,4} + \cdots + \vec{F}_{1,N}$$

PRINCIPLE OF SUPERPOSITION $\vec{F}_1 = \sum_{j=2}^{N} \vec{F}_{1,j}$

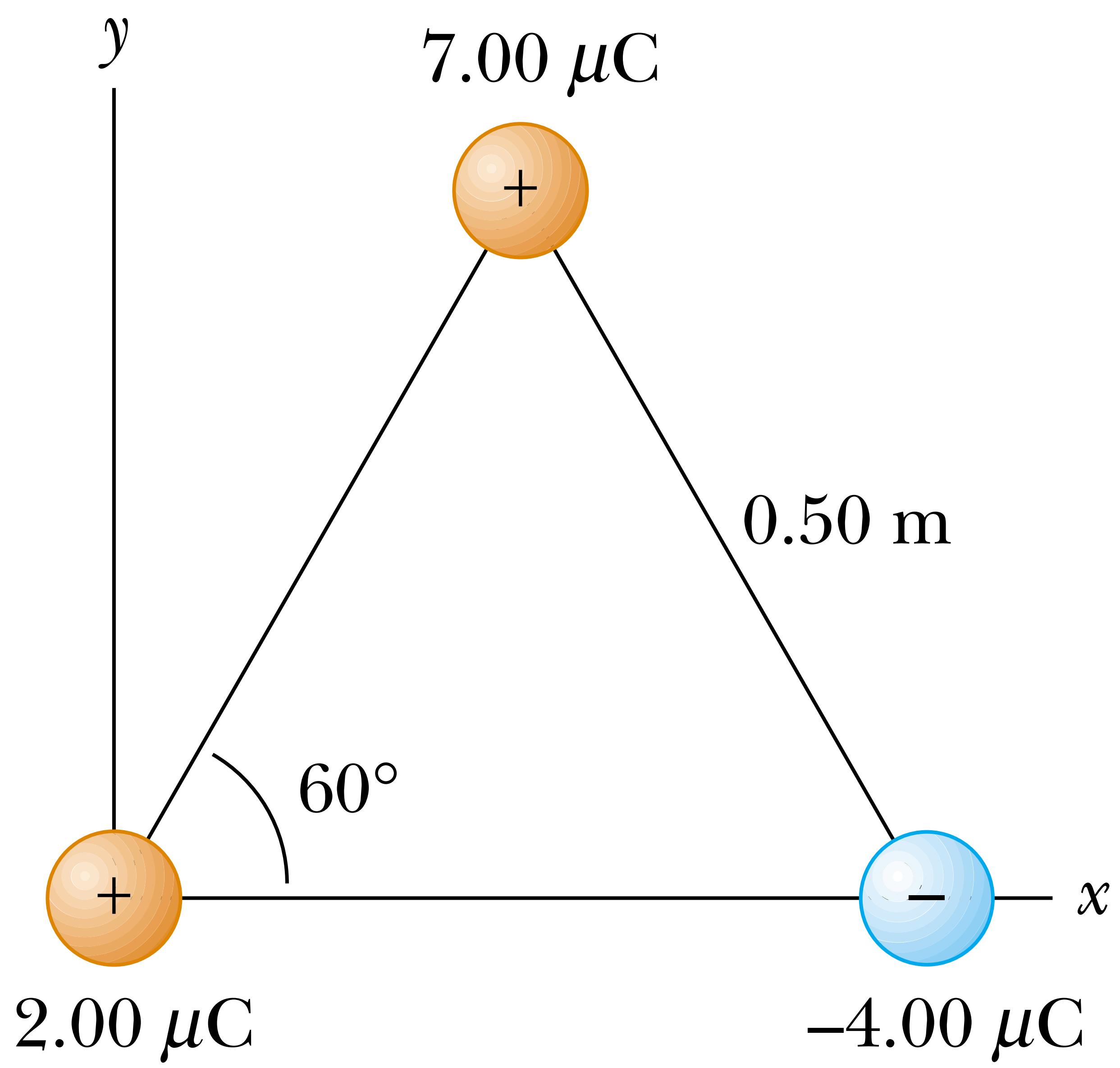
Coulomb's Law

Example 3

Three charged particles are placed at the corners of an equilateral triangle of side 0.500 m.

The charges are +7.00 µC, +2.00 µC, and –4.00 µC.

Calculate the magnitude and direction of the net force on the 7.00 µC charge.



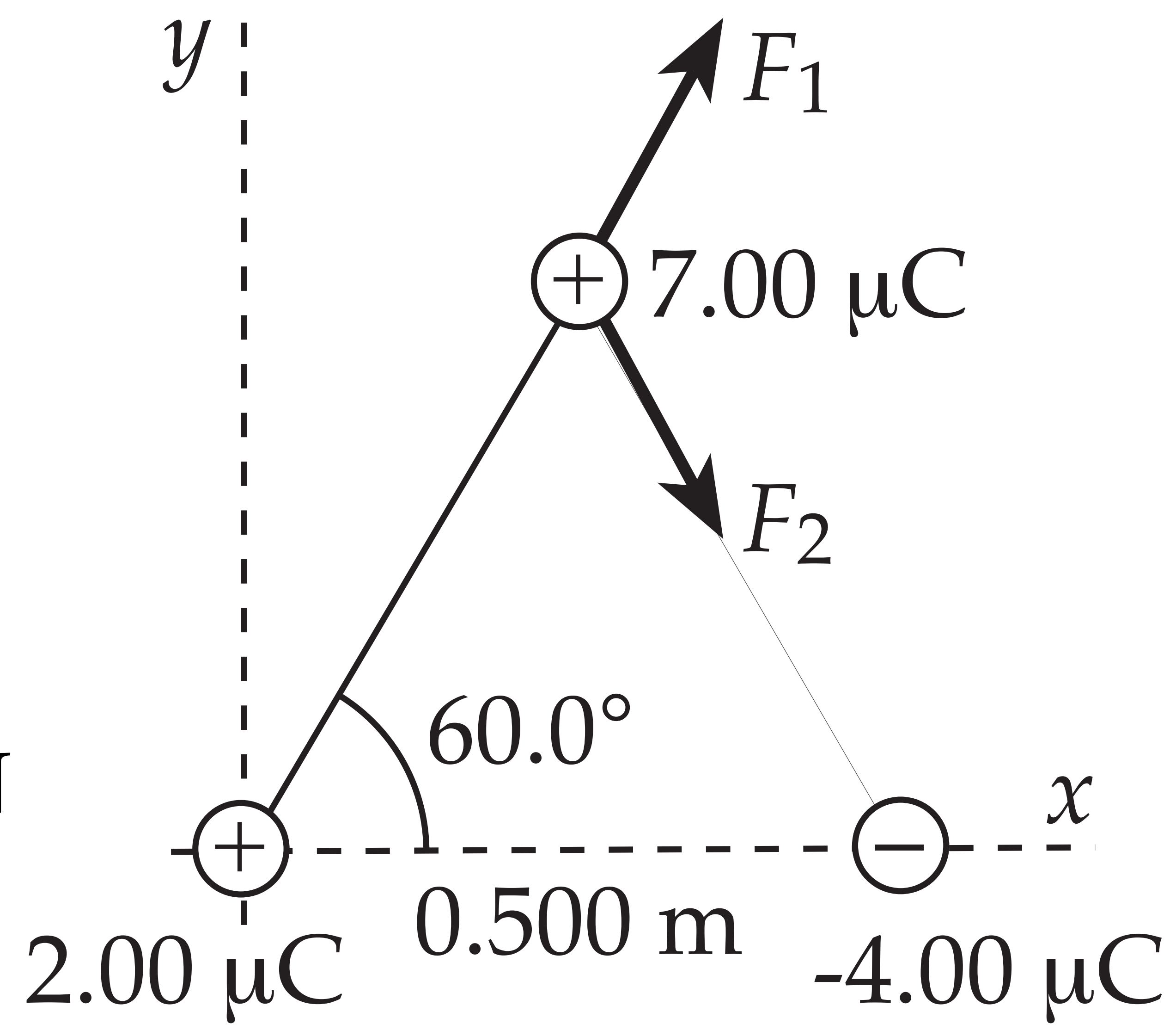
2.

Coulomb's Law

Example 3

Applying Coulombs law to calculate each force, we get $\vec{F}_1 = 8.99 \times 10^9 \frac{\mathrm{N} \cdot \mathrm{m}^2}{\mathrm{C}^2} \frac{7.00 \times 10^{-6}\ \mathrm{C} \cdot 2.00 \times 10^{-6}\ \mathrm{C}}{(0.500\ \mathrm{m})^2} = 0.503\ \mathrm{N}$

and $\vec{F}_2 = 8.99 \times 10^9 \frac{\mathrm{N} \cdot \mathrm{m}^2}{\mathrm{C}^2} \frac{7.00 \times 10^{-6}\ \mathrm{C} \cdot 4.00 \times 10^{-6}\ \mathrm{C}}{(0.500\ \mathrm{m})^2} = 1.01\ \mathrm{N}$



From the superposition principle, we know $\sum F_x = (\vec{F}_1 + \vec{F}_2) \cos 60^\circ = 0.755\ \mathrm{N}$

and $\sum F_y = (\vec{F}_1 + \vec{F}_2) \sin 60^\circ = -0.436\ \mathrm{N}$

So the resultant force on the 7.00 µC charge is $F_R = \sqrt{(\sum F_x)^2 + (\sum F_y)^2} = 0.872\ \mathrm{N}$

at $\theta = \tan^{-1}(\sum F_y / \sum F_x) = -30^\circ$

History of Electromagnetism

* Circa B.C. 500: Greeks discover that rubbed amber attracts small pieces of stuff

  (Note the Greek word for amber: "$\eta\lambda\epsilon\kappa\tau\rho o\nu$", or "electron")

* They also discover that certain iron rich rocks from the region of $M\alpha\gamma\nu\eta\sigma\iota\alpha$ (Magnesia) attract other pieces of iron

Summary of today's class

* 1730: Charles Francois du Fay noted that electrification seemed to come in two "flavors": vitreous (now known as positive; example, rubbing glass with silk) and resinous (negative; rubbing resin with fur)

* 1740: Ben Franklin suggested the "one fluid" hypothesis: "positive" things have more charge than "negative" things Suggested an experiment to Priestley to indirectly measure the inverse square law...

* 1766: Joseph Priestley did the suggested experiment, indirectly proving $1/r^2$ form of the force law

* 1773: Henry Cavendish did Priestley's experiment accurately

$$F = k\frac{q_1 q_2}{r^{2+\delta}} \qquad |\delta| < \frac{1}{50}$$

* 1786: Charles-Augustin de Coulomb measured the electrostatic force and directly verified the inverse square law
* By late 1800s, Maxwell was able to show that $|\delta| < 1/21600$
* By 1936 Plimpton and Lawton were able to show $|\delta| < 2 \times 10^{-9}$

History of Electromagnetism

Looking ahead

* 1800: Count Alessandro Giuseppe Antonio Anastasio Volta invented the electric battery
* 1820: Hans Chrstian Oersted and André-Marie Ampère established connection between magnetic fields and electric currents
* 1831: Michael Faraday discovered magnetic induction
* 1873: James Clerk Maxwell unified electricity and magnetism into electromagnetism
* 1887: Heinrich Hertz confirms the connection between electromagnetism and radiation
* 1905: Albert Einstein formulates the special theory of relativity, which (among other things) clarifies the inter-relationship between electric and magnetic fields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