Announcements

- Please use only your ucalgary email address when registering for WileyPLUS and TopHat.
- Assignment 0 (Intro to WileyPLUS) is not for marks. Please do it in order to familiarize yourself with the homework platform.
- Assignment 1 (Math Review) IS for marks.

Today’s Lecture

- The language of science and the importance of being specific
- What is a physical theory? How do we know it is correct?
- Forces in nature, electromagnetism
- Introduction to electric charge. What is it? (Hard question to answer!)
- Atomic structure

The Language of Science:

Words in science have precise meanings that are different from their everyday usage:

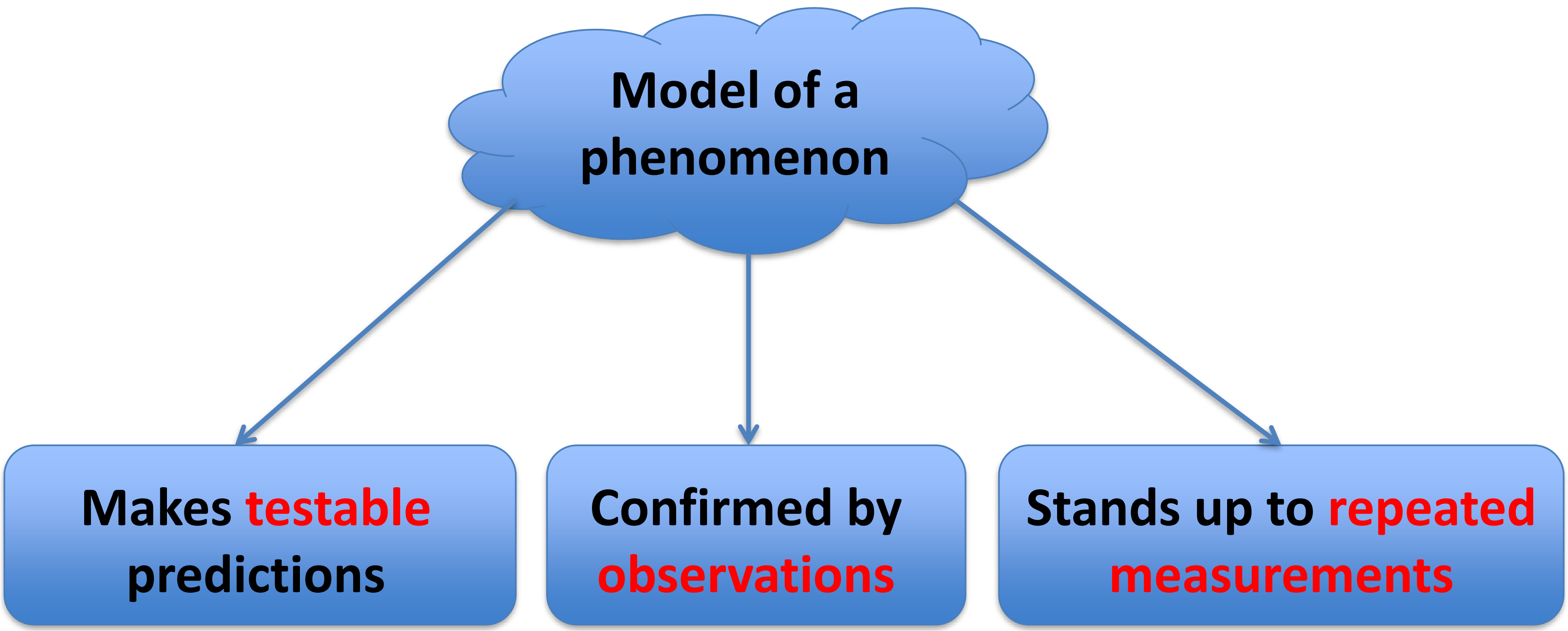
Energy: “you’re giving off good energy”, practically anything in the New Age movement (energy crystals, energy alignment, etc)

Theory: “I’ve got a theory about that…”, “evolution is just a theory” (colloquially used in place of “hypothesis”)

A fun other example:

“I will <u>decimate</u> that ant colony” does not mean you will destroy it.

What is a physical theory?



Lectures

Labatorials

Fundamental characteristics of particles

All fundamental particles can be classified according to two observable parameters: mass and charge.

This simplified model of the Universe is incredibly effective at explaining a wide range of physical phenomena.

All models are wrong, but some are useful. - G. Box

A model is a representation of reality and not reality itself.

Forces in nature

There are 4 fundamental forces in nature (that we know of):

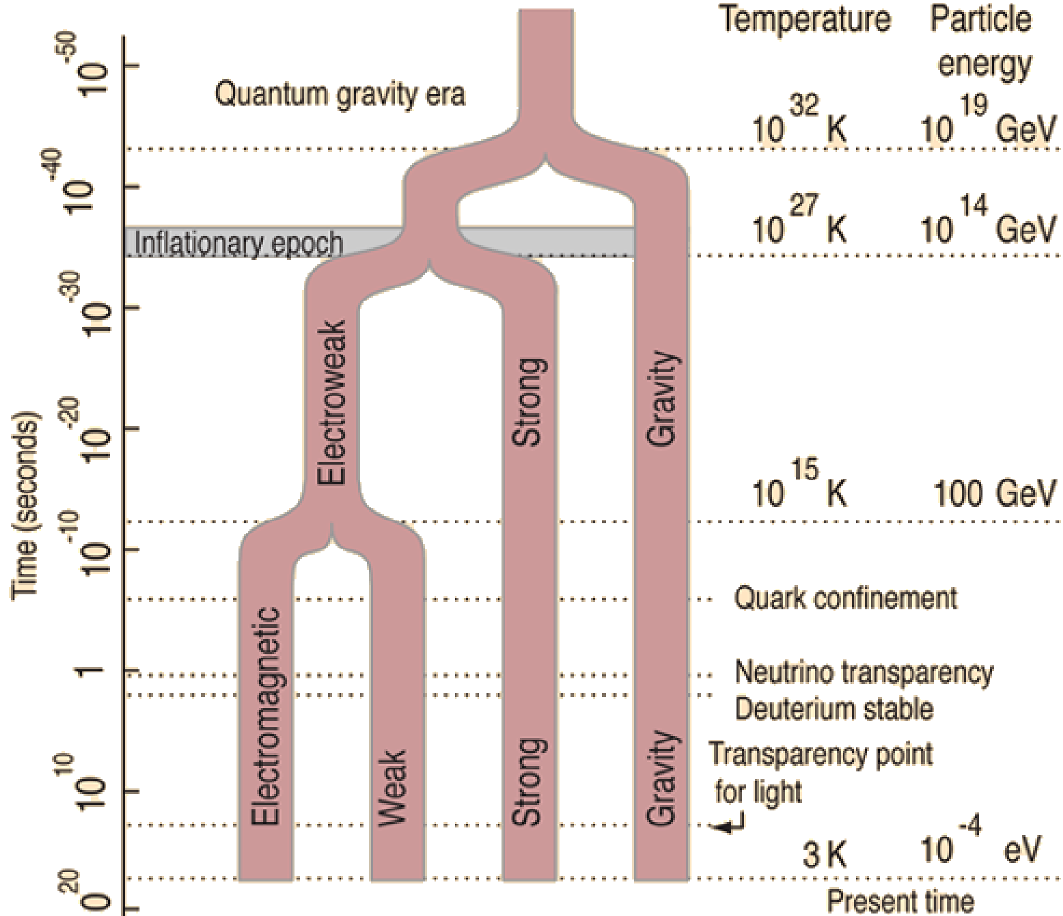
1. Strong Nuclear Force: responsible for holding together protons and neutrons, as well as holding atomic nuclei together. Very short-range (~ 10^{-15} m)

2. Weak Nuclear Force: Responsible for radioactive decay and fusion reactions in the sun. Very short-range (~ 10^{-17} m)

3. Electromagnetic Force: Responsible for nearly everything we observe! Extremely important force to understand. Long range

4. Gravitational Force: Responsible for planetary orbits, holding together galaxies, maintaining an atmosphere. Long range (also not really a force in reality)

Forces in nature



http://hyperphysics.phy-astr.gsu.edu/hbase/Astro/unify.html

Forces are vector!

- Scalar vs Vector
  - What are the properties?

- Scalar: are quantities that are fully described by a magnitude
- e.g.: Temperature, speed, mass, and volume are examples of scalars.

- Vector: are quantities that are fully described by both a magnitude and a direction.
- e.g.: displacement, velocity, acceleration and force

Vectors!

- Vectors are equal if they have the same magnitude and direction.
- Vectors must have the same units in order for them to be added or subtracted.
- The negative of a vector has the same magnitude but opposite direction.
- Subtraction of a vector is defined by adding a negative vector:

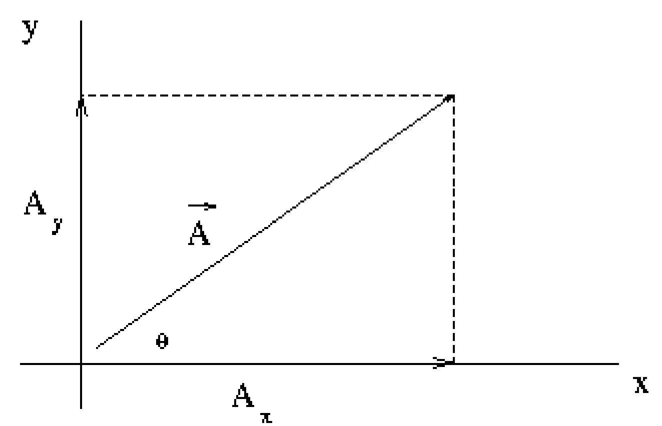
$$\vec{A} - \vec{B} = \vec{A} + (-\vec{B})$$

Vectors!

- Multiplication or division of a vector by a scalar results in a vector for which
  - (a) only the magnitude changes if the scalar is positive
  - (b) the magnitude changes and the direction is reversed if the scalar is negative.
- The projections of a vector along the axes of a rectangular co-ordinate system are called the **components** of the vector. The components of a vector completely define the vector.

$$A = |\vec{A}| = \sqrt{A_x^2 + A_y^2}$$

$$\tan\theta = \frac{A_y}{A_x}$$

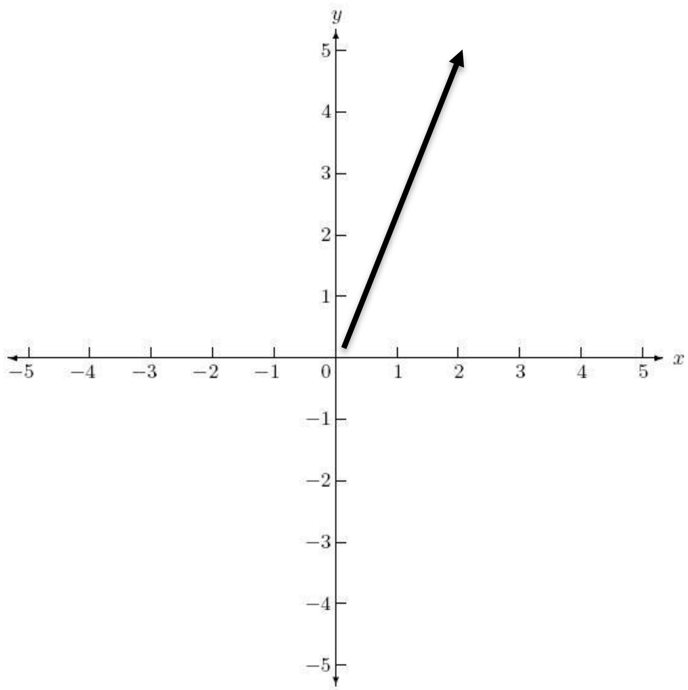


Vectors!

- To add vectors by components:
  $\vec{K} = \vec{A} + \vec{B} + \vec{C} + \ldots$
  - Find the components of all vectors to be added.
  - Add all x components to get $K_x = A_x + B_x + C_x + \ldots$
  - Add all y components to get $K_y = A_y + B_y + C_y + ..$
- $\vec{K} = K_x\,\hat{\imath} + K_y\,\hat{\jmath}$

TopHat question!

- Represent the following vector in components:



- A = 5.24
- Θ = 66.37º

Last time

- The language of science and the importance of being specific
- Forces in nature, electromagnetism
- Vectors
- Introduction to electric charge. What is it?
- Maxwell was so awesome!

Comin'_Through_the_Rye.ogg

Gin a body meet a body

Flyin' through the air.
Gin a body hit a body,
Will it fly? And where?

This time

- More about vectors!
- Atomic structure: insulators and conductors
- Charging macroscopic objects via friction
- The electrostatic force: Coulomb's Law

Unity Vector

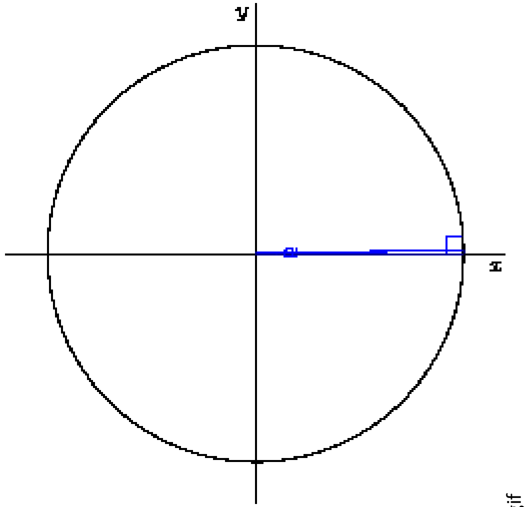
- The **normalized vector** or $\hat{r}$ of a non-zero vector $\vec{\boldsymbol{r}}$ is the unit vector in the direction of **r:**
  - $\hat{r} = \dfrac{\vec{\boldsymbol{r}}}{|\boldsymbol{r}|}$
- **Coordinate systems:**
  - ✓ **Cartesian coordinates**
    - $\hat{\boldsymbol{\imath}} = \begin{bmatrix} \mathbf{1} \\ \mathbf{0} \\ \mathbf{0} \end{bmatrix}, \quad \hat{\boldsymbol{\jmath}} = \begin{bmatrix} \mathbf{0} \\ \mathbf{1} \\ \mathbf{0} \end{bmatrix}, \quad \hat{\boldsymbol{k}} = \begin{bmatrix} \mathbf{0} \\ \mathbf{0} \\ \mathbf{1} \end{bmatrix}$
  - ➢ **Cylindrical Coordinates**
  - ➢ **Spherical Coordinates**

More info can be found here:
https://en.wikipedia.org/wiki/Unit_vector

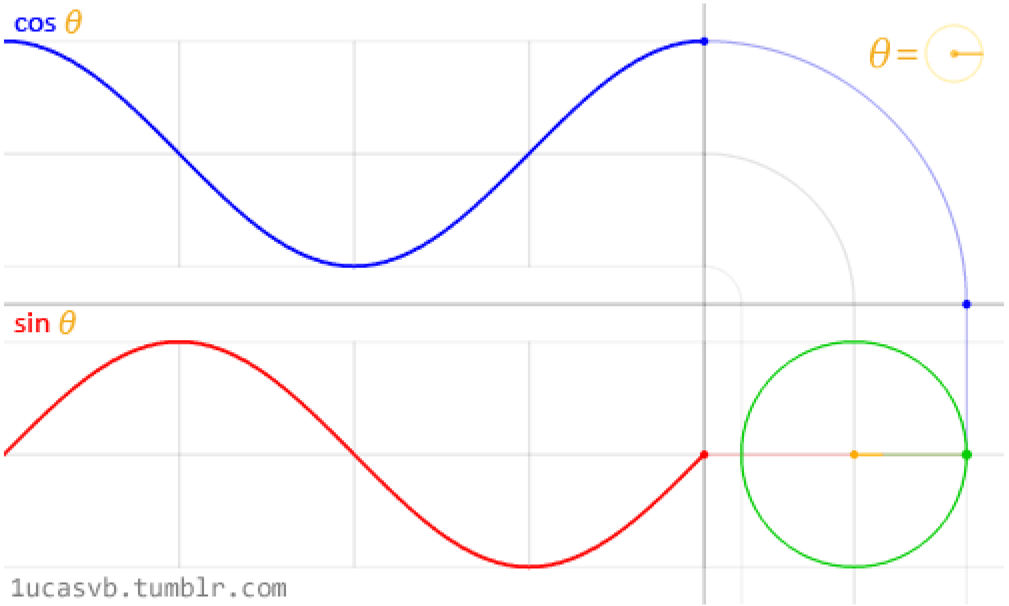
WIKIPEDIA
The Free Encyclopedia

Unity Circle

https://commons.wikimedia.org/wiki/File:Trigo-unitcircle-animation.gif



https://commons.wikimedia.org/wiki/File:Circle_cos_sin.gif



TOPHAT Q2

What is electromagnetism?

- Electric forces between objects carrying an electric charge.
- Chemical bonds between atoms:
  - Ionic bond is when one atom gives another atom an electron, creating two oppositely charged ions that stick together.
  - Covalent bond is when two atoms share electrons.
- Currents flowing through wires that power electronic devices.
- Magnetic forces between objects carrying electric currents.
- The force responsible for keeping me from falling through the floor.
- Much, much more.

Key concepts

Matter is composed of charged particles and charge is conserved.

Charges can produce electric forces (Coulomb's Law) or electric fields (Gauss's law).

Electric forces or fields can move charges and produce currents (Ohm's law).

Currents can produce magnetic fields (Biot-Savart law, Ampere's law).

Changes in magnetic fields can produce electric fields (Faraday's law).

Maxwell's equations

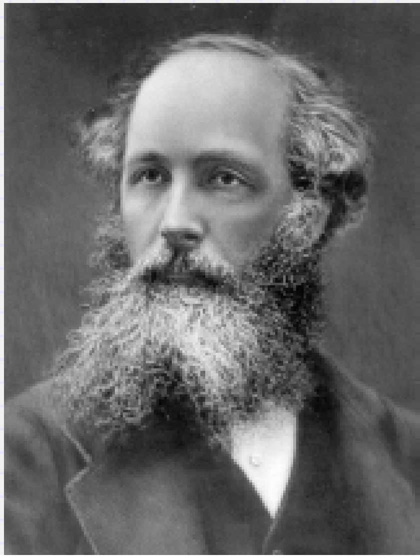
$$\oiint \vec{E} \cdot d\vec{A} = \frac{Q_{enclosed}}{\epsilon_0}$$ Gauss's law for electricity

$$\oiint \vec{B} \cdot d\vec{A} = 0$$ Gauss's law for magnetism

$$\oint \vec{B} \cdot d\vec{l} = \mu_0\left(i_c + \epsilon_0 \frac{d\Phi_E}{dt}\right)$$ Ampere's law

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

James Clerk Maxwell
1831-1879



What is an electric charge?

- Hard to fundamentally define at this stage. Try it! Think, Pair, Share (TPS) exercise.

Step 1: Write something down by yourself without talking to a neighbour.

Step 2: Discuss your answer with a neighbour and come to a consensus.

Step 3: Share what you have so we can come to a consensus as a class

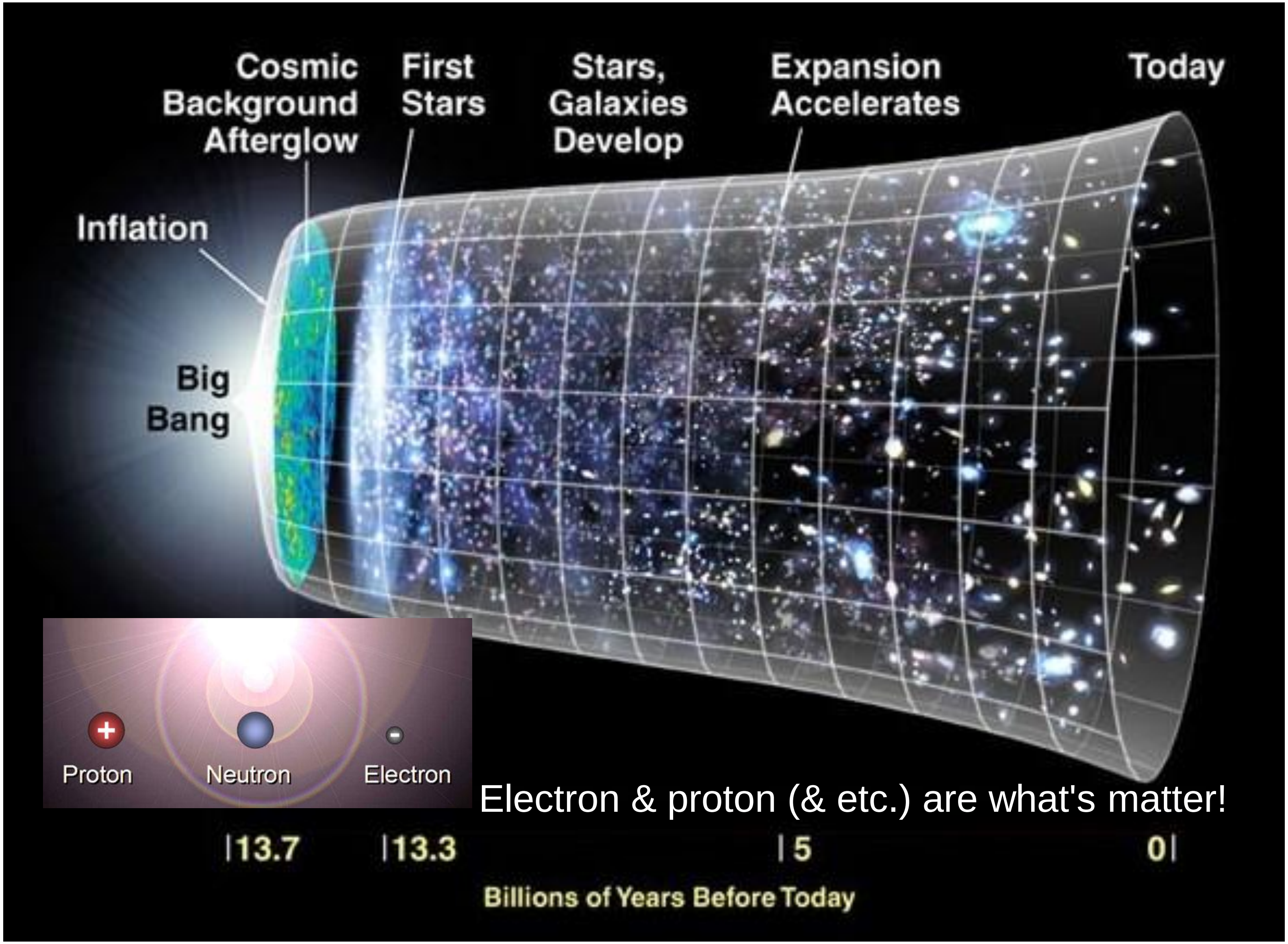
What is an electric charge?

- An intrinsic property of particles: electrons (–) and protons (+)
- A quantity that determines the strength of the electric force between two objects.
- Can't be created or destroyed*
- Can transfer from one object to another
- Like charges repel, opposites attract

Where does charge come from? In reality, there is a symmetry in the equations of quantum electrodynamics. A symmetry always implies that something is conserved!

Tophat Q3

Atoms and Electricity



Source: HETDEX: http://hetdex.org/dark_energy/index.php

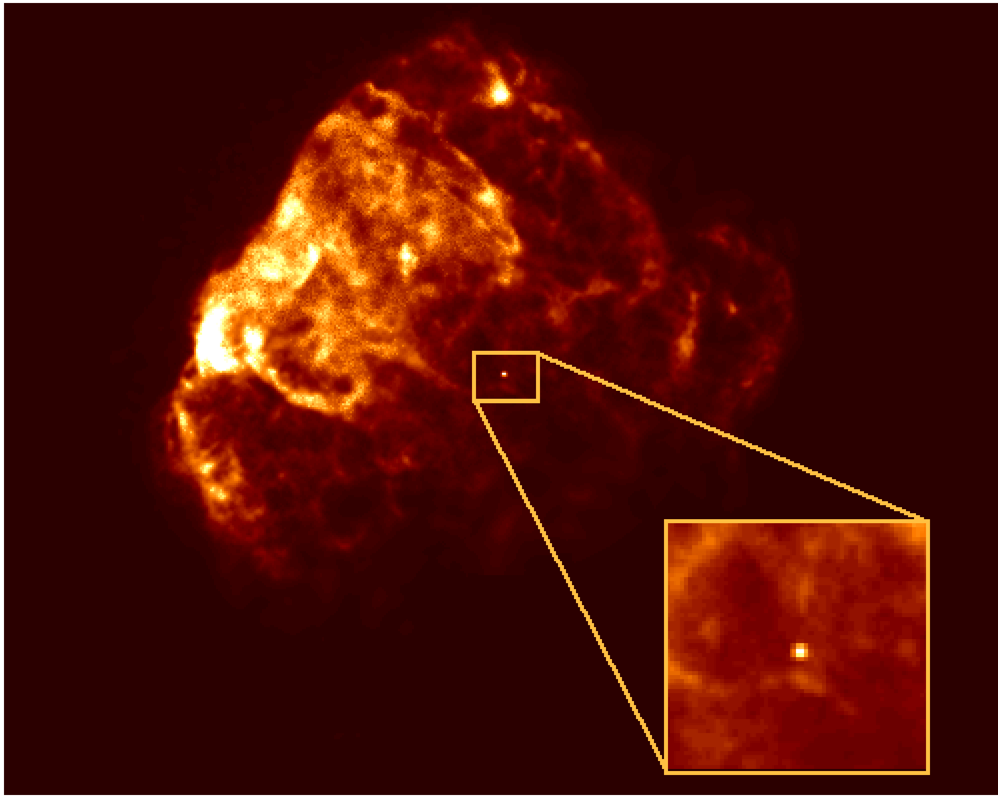
Atoms and Electricity

- An atom consists of a very small and dense *nucleus* surrounded by much less massive orbiting *electrons.*
- The nucleus is a composite structure consisting of *protons,* positively charged particles, and neutral *neutrons.*
- The atom is held together by the attractive electric force between the positive nucleus and the negative electrons.
- Electrons and protons have charges of opposite sign but *exactly* equal magnitude.

Atomic Density

If you could fill a 4L milk jug with material as dense as an atomic nucleus, it would have the mass of Mount Everest

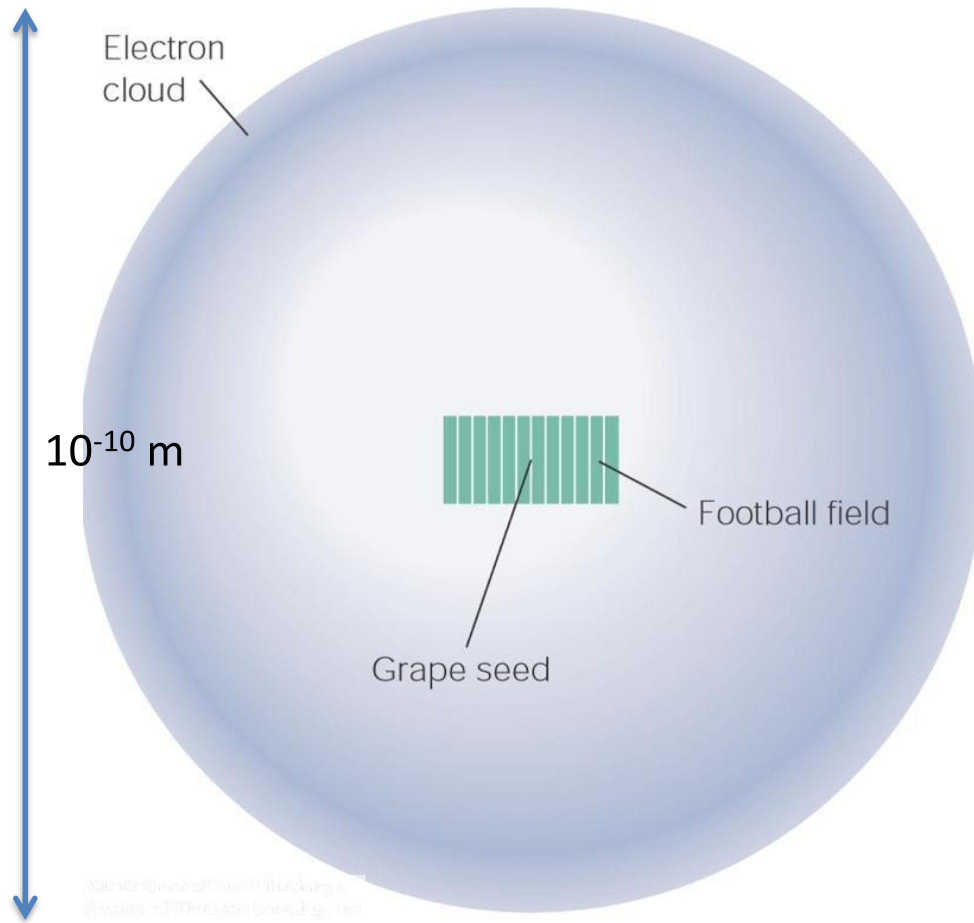
- Neutron Stars are the end point of a massive star's life.
- When a massive star runs out of nuclear fuel in its core, the core begins to collapse under gravity. When the core collapses the entire star collapses. The surface of the star falls down until it hits the now incredibly dense core. It then bounces off the core and blows apart in a supernova.
- All that remains is the collapsed core, a Neutron Star or sometimes a Black Hole, in case a very massive star.



Atomic Structure

An atom consists of an *atomic nucleus* (protons and neutrons) and a cloud of electrons surrounding it.

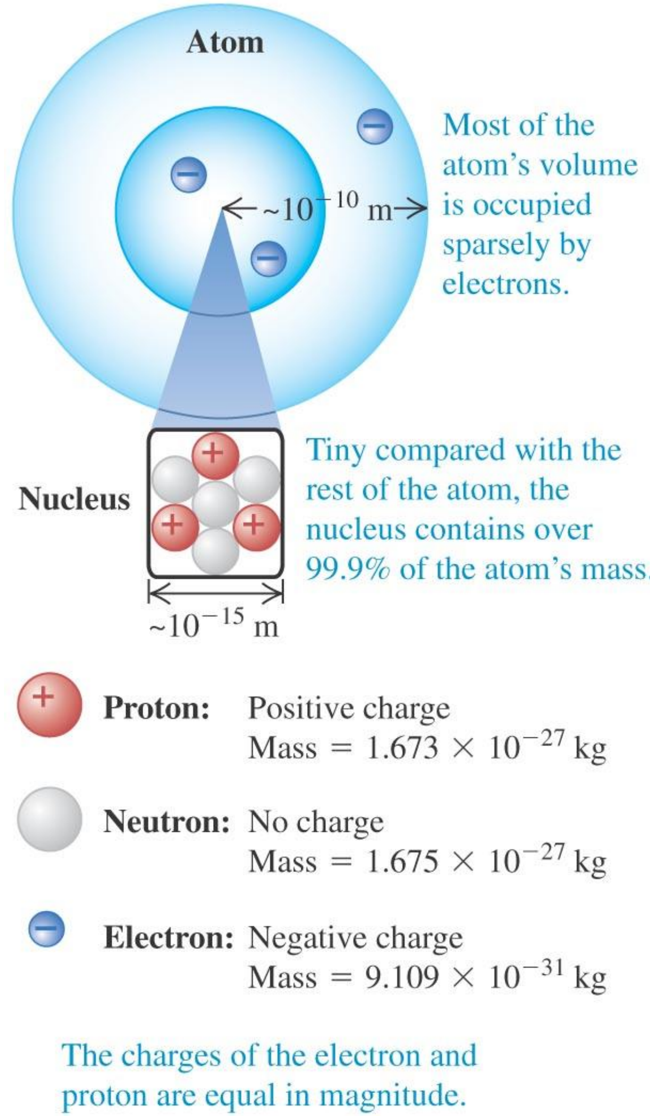
Almost all of the mass is contained in the nucleus, while almost all of the space is occupied by the electron cloud.



The diameter of a nucleus is much smaller than the diameter of the atom, by a factor of about 23,000 (uranium) to about 145,000 (hydrogen).

Electric charge and the structure of matter

- Atoms are made up of the negative *electrons*, the positive *protons*, and the uncharged *neutrons*.
- Protons and neutrons make up the tiny dense nucleus which is surrounded by electrons.
- The electric attraction between protons and electrons holds the atom together.

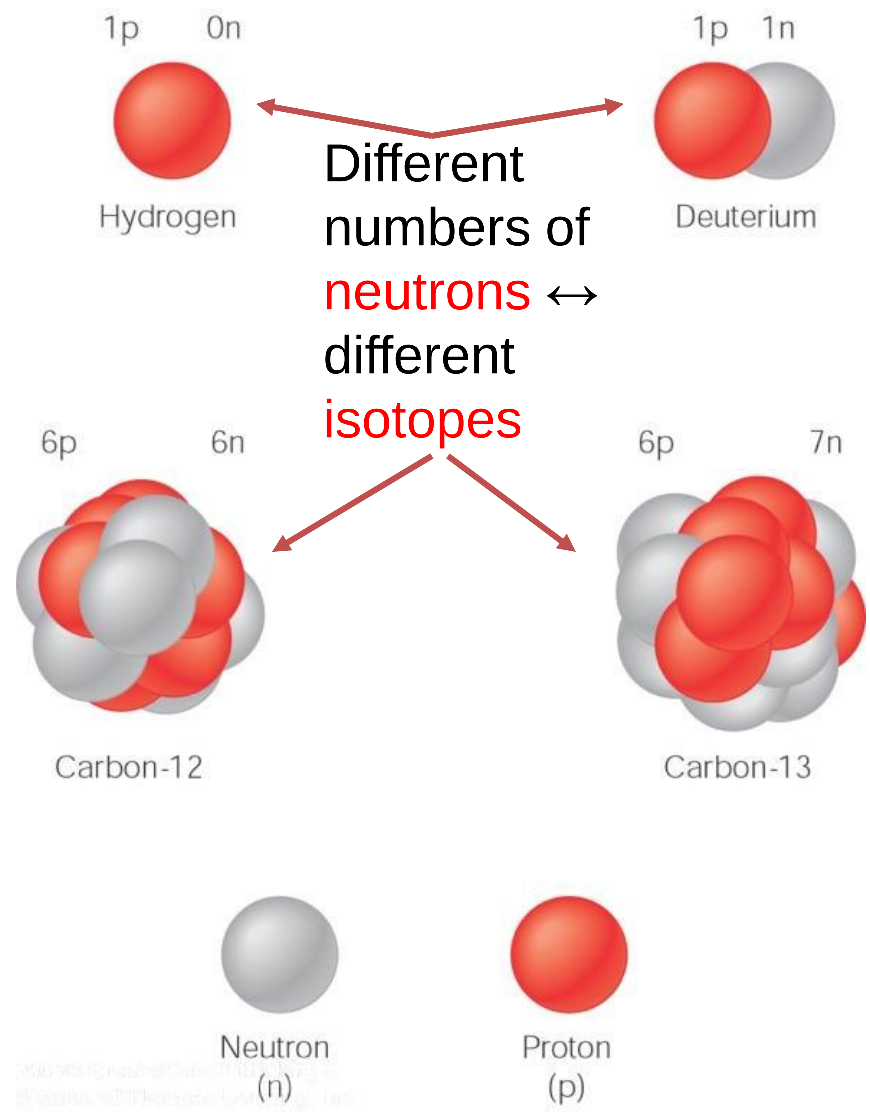


Different Kinds of Atoms

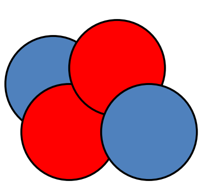
The kind of atom depends on the number of protons in the nucleus.

Most abundant (74% of the known universe):
Hydrogen (H), with one proton (+ 1 electron).

Second most abundant (24%)
Helium (He), with 2 protons (and 2 neutrons + 2 electrons.).



Different numbers of neutrons ↔ different isotopes



The nucleus of Helium 4 is called α particle.

Quantization of electric charge

Electric charge is *quantized*.

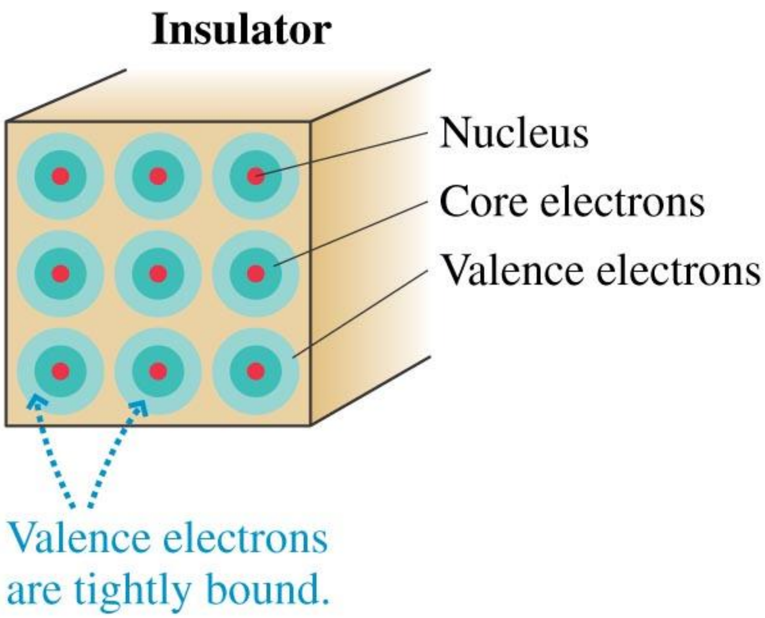
Charge always comes in some integral multiple of some fundamental charge e, which is the charge of electron.

Electric charge comes in discrete packets.

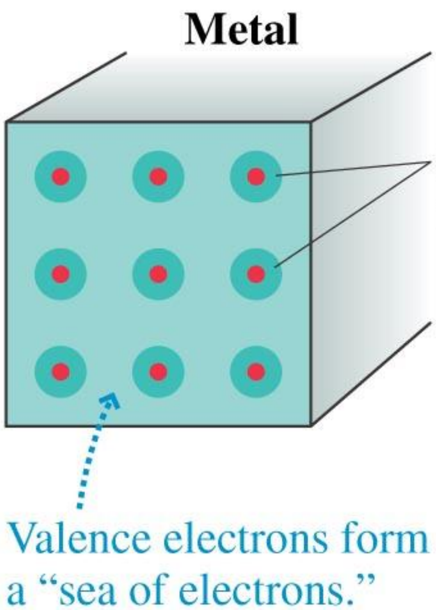
Light comes in discrete packets too, photons.

$$E = h\nu$$

Insulators do not conduct electricity, because the electrons are **not** free to move.



Conductors do conduct electricity, because the electrons **are** free to move.



PERIODIC TABLE OF THE ELEMENTS

http://www.periodni.com

Metal	Semimetal	Nonmetal	
Alkali metal	Chalcogens element		
Alkaline earth metal	Halogens element		
Transition metals	Noble gas		
Lanthanide			
Actinide			

STANDARD STATE (25 °C; 101 kPa)

Ne - gas Fe - solid
Hg - liquid Tc - synthetic

RELATIVE ATOMIC MASS (1)
GROUP IUPAC 13 — GROUP CAS IIIA
ATOMIC NUMBER 5 — 10.811
SYMBOL B
ELEMENT NAME BORON

PERIOD \ GROUP	1 IA	2 IIA	3 IIIB	4 IVB	5 VB	6 VIB	7 VIIB	8 VIIIB	9 VIIIB	10 VIIIB	11 IB	12 IIB	13 IIIA	14 IVA	15 VA	16 VIA	17 VIIA	18 VIIIA
1	1 1.0079 H HYDROGEN																	2 4.0026 He HELIUM
2	3 6.941 Li LITHIUM	4 9.0122 Be BERYLLIUM											5 10.811 B BORON	6 12.011 C CARBON	7 14.007 N NITROGEN	8 15.999 O OXYGEN	9 18.998 F FLUORINE	10 20.180 Ne NEON
3	11 22.990 Na SODIUM	12 24.305 Mg MAGNESIUM											13 26.982 Al ALUMINIUM	14 28.086 Si SILICON	15 30.974 P PHOSPHORUS	16 32.065 S SULPHUR	17 35.453 Cl CHLORINE	18 39.948 Ar ARGON
4	19 39.098 K POTASSIUM	20 40.078 Ca CALCIUM	21 44.956 Sc SCANDIUM	22 47.867 Ti TITANIUM	23 50.942 V VANADIUM	24 51.996 Cr CHROMIUM	25 54.938 Mn MANGANESE	26 55.845 Fe IRON	27 58.933 Co COBALT	28 58.693 Ni NICKEL	29 63.546 Cu COPPER	30 65.38 Zn ZINC	31 69.723 Ga GALLIUM	32 72.64 Ge GERMANIUM	33 74.922 As ARSENIC	34 78.96 Se SELENIUM	35 79.904 Br BROMINE	36 83.798 Kr KRYPTON
5	37 85.468 Rb RUBIDIUM	38 87.62 Sr STRONTIUM	39 88.906 Y YTTRIUM	40 91.224 Zr ZIRCONIUM	41 92.906 Nb NIOBIUM	42 95.96 Mo MOLYBDENUM	43 (98) Tc TECHNETIUM	44 101.07 Ru RUTHENIUM	45 102.91 Rh RHODIUM	46 106.42 Pd PALLADIUM	47 107.87 Ag SILVER	48 112.41 Cd CADMIUM	49 114.82 In INDIUM	50 118.71 Sn TIN	51 121.76 Sb ANTIMONY	52 127.60 Te TELLURIUM	53 126.90 I IODINE	54 131.29 Xe XENON
6	55 132.91 Cs CAESIUM	56 137.33 Ba BARIUM	57-71 La-Lu Lanthanide	72 178.49 Hf HAFNIUM	73 180.95 Ta TANTALUM	74 183.84 W TUNGSTEN	75 186.21 Re RHENIUM	76 190.23 Os OSMIUM	77 192.22 Ir IRIDIUM	78 195.08 Pt PLATINUM	79 196.97 Au GOLD	80 200.59 Hg MERCURY	81 204.38 Tl THALLIUM	82 207.2 Pb LEAD	83 208.98 Bi BISMUTH	84 (209) Po POLONIUM	85 (210) At ASTATINE	86 (222) Rn RADON
7	87 (223) Fr FRANCIUM	88 (226) Ra RADIUM	89-103 Ac-Lr Actinide	104 (267) Rf RUTHERFORDIUM	105 (268) Db DUBNIUM	106 (271) Sg SEABORGIUM	107 (272) Bh BOHRIUM	108 (277) Hs HASSIUM	109 (276) Mt MEITNERIUM	110 (281) Ds DARMSTADTIUM	111 (280) Rg ROENTGENIUM	112 (285) Cn COPERNICIUM	113 (...) Uut UNUNTRIUM	114 (287) Fl FLEROVIUM	115 (...) Uup UNUNPENTIUM	116 (291) Lv LIVERMORIUM	117 (...) Uus UNUNSEPTIUM	118 (...) Uuo UNUNOCTIUM

LANTHANIDE

57 138.91 La LANTHANUM	58 140.12 Ce CERIUM	59 140.91 Pr PRASEODYMIUM	60 144.24 Nd NEODYMIUM	61 (145) Pm PROMETHIUM	62 150.36 Sm SAMARIUM	63 151.96 Eu EUROPIUM	64 157.25 Gd GADOLINIUM	65 158.93 Tb TERBIUM	66 162.50 Dy DYSPROSIUM	67 164.93 Ho HOLMIUM	68 167.26 Er ERBIUM	69 168.93 Tm THULIUM	70 173.05 Yb YTTERBIUM	71 174.97 Lu LUTETIUM

ACTINIDE

89 (227) Ac ACTINIUM	90 232.04 Th THORIUM	91 231.04 Pa PROTACTINIUM	92 238.03 U URANIUM	93 (237) Np NEPTUNIUM	94 (244) Pu PLUTONIUM	95 (243) Am AMERICIUM	96 (247) Cm CURIUM	97 (247) Bk BERKELIUM	98 (251) Cf CALIFORNIUM	99 (252) Es EINSTEINIUM	100 (257) Fm FERMIUM	101 (258) Md MENDELEVIUM	102 (259) No NOBELIUM	103 (262) Lr LAWRENCIUM

(1) Pure Appl. Chem., **81**, No. 11, 2131-2156 (2009)
Relative atomic masses are expressed with five significant figures. For elements that have no stable nuclides, the value enclosed in brackets indicates the mass number of the longest-lived isotope of the element. However three such elements (Th, Pa and U) do have a characteristic terrestrial isotopic composition, and for these an atomic weight is tabulated.

Last time

- Unit Vectors, Unity Circle
- Atomic Structures → (Never trust them,) they make up everything!
- Insulator & Conductors!

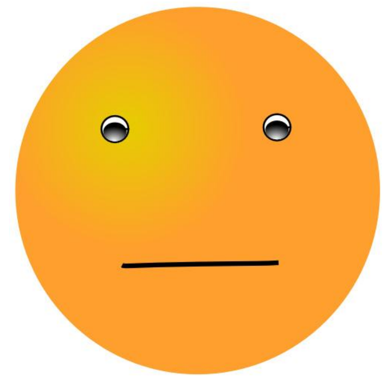
This time

- Charging macroscopic objects via friction
- The electrostatic force: Coulomb's Law

I am proton

I am electron

I am neutron



I am positive!

I am negative!

Whatever!

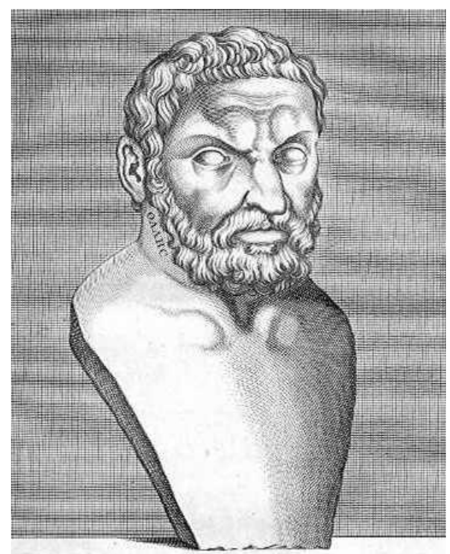
Responsible for mostly
all charge transfers!

Generating electric charge

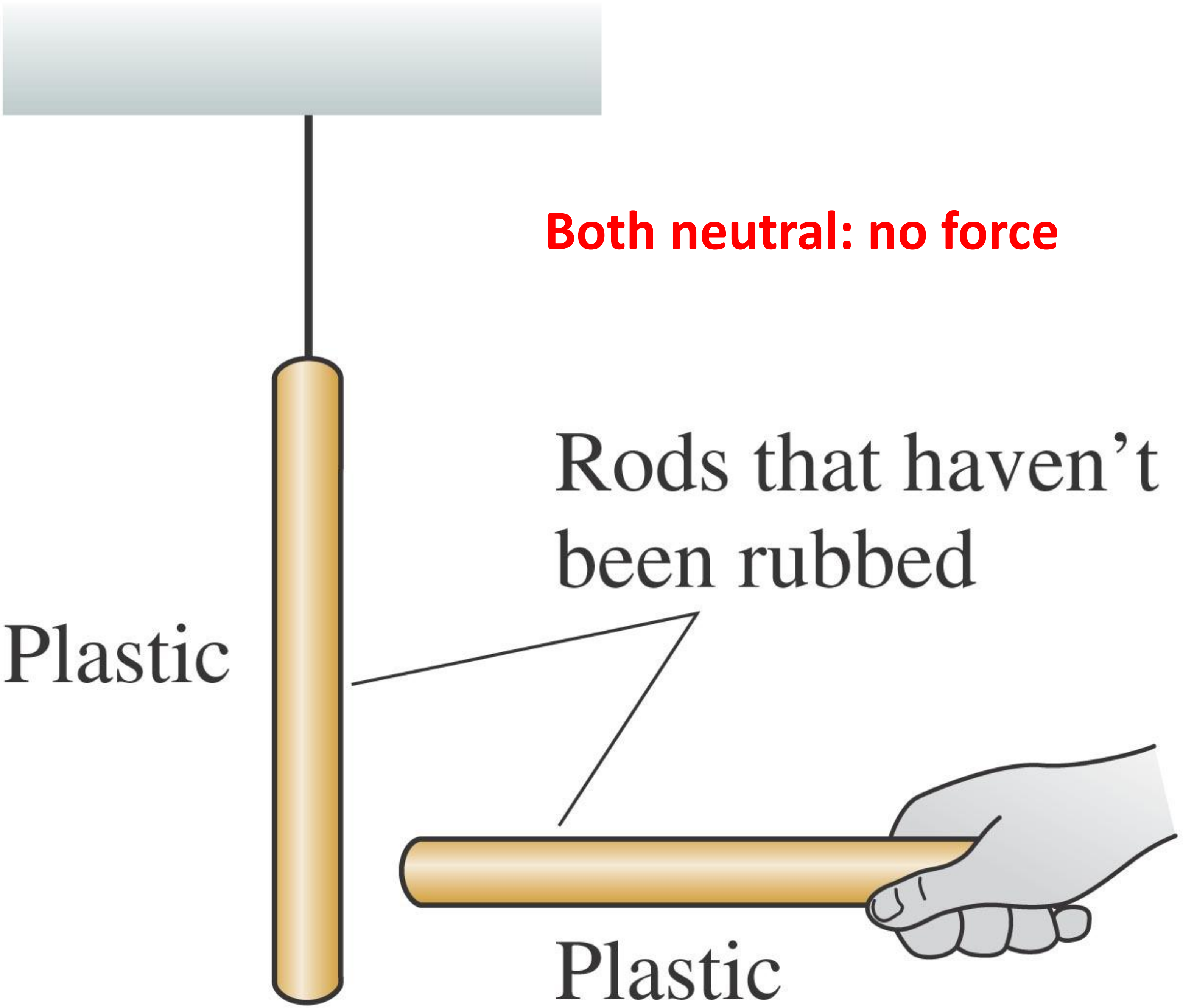
Because friction is due to bonds between the atoms of two surfaces, when those bonds are broken charges can be transferred from one surface to another.

The word “electricity” comes from the Greek word for amber: ἤλεκτρον (elektron)

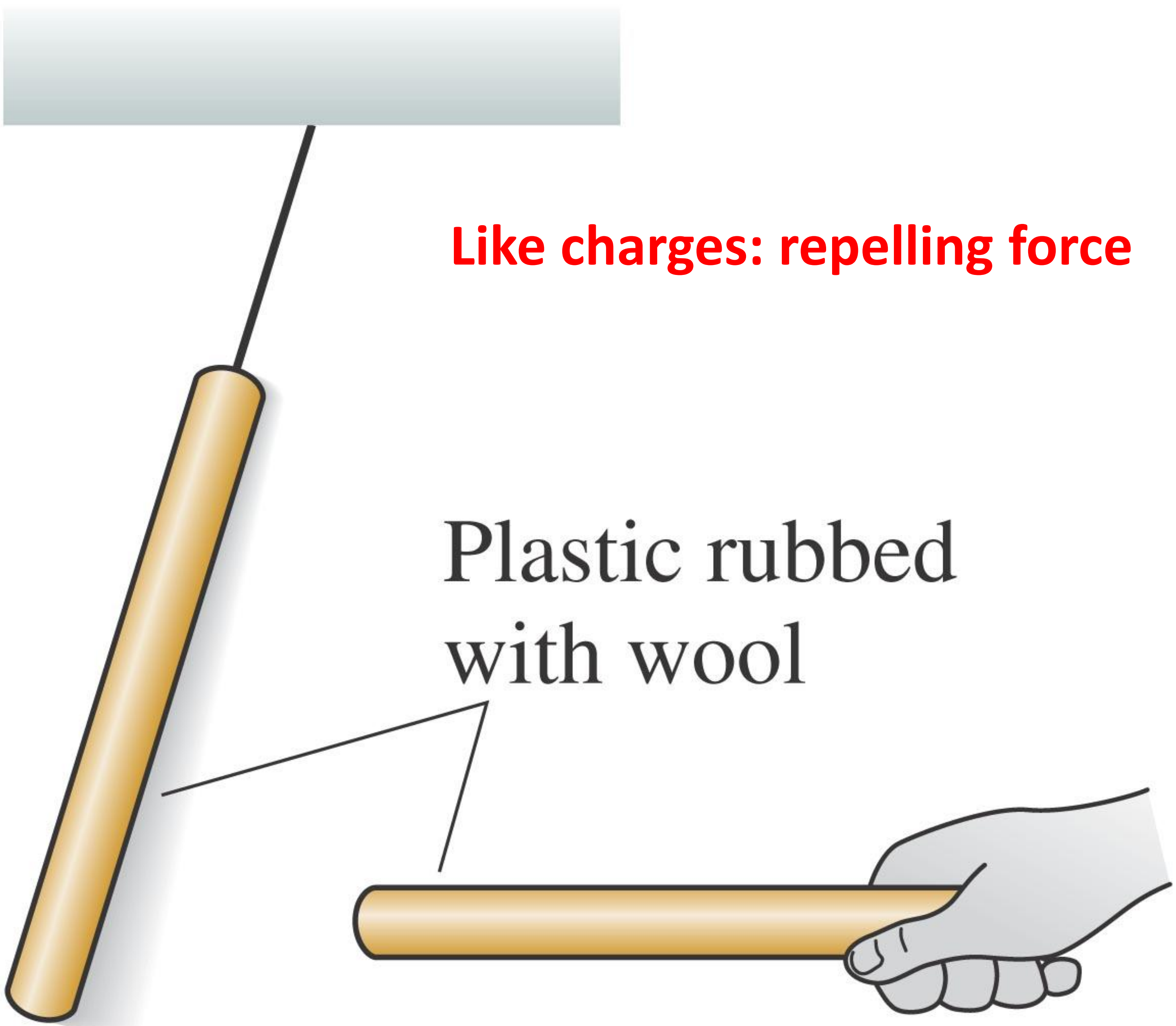
Thales of Miletus 600 BCE



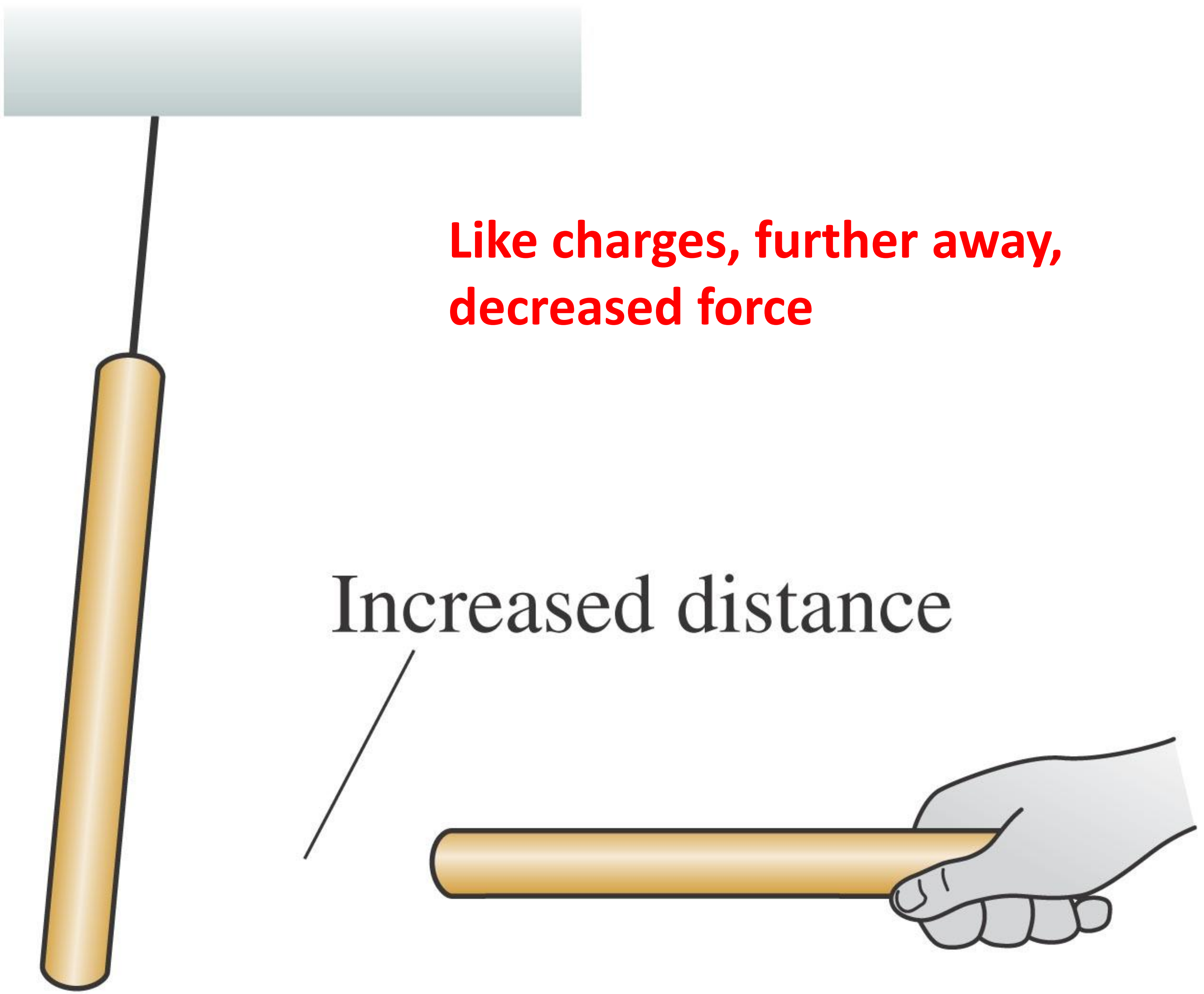
Both neutral: no force



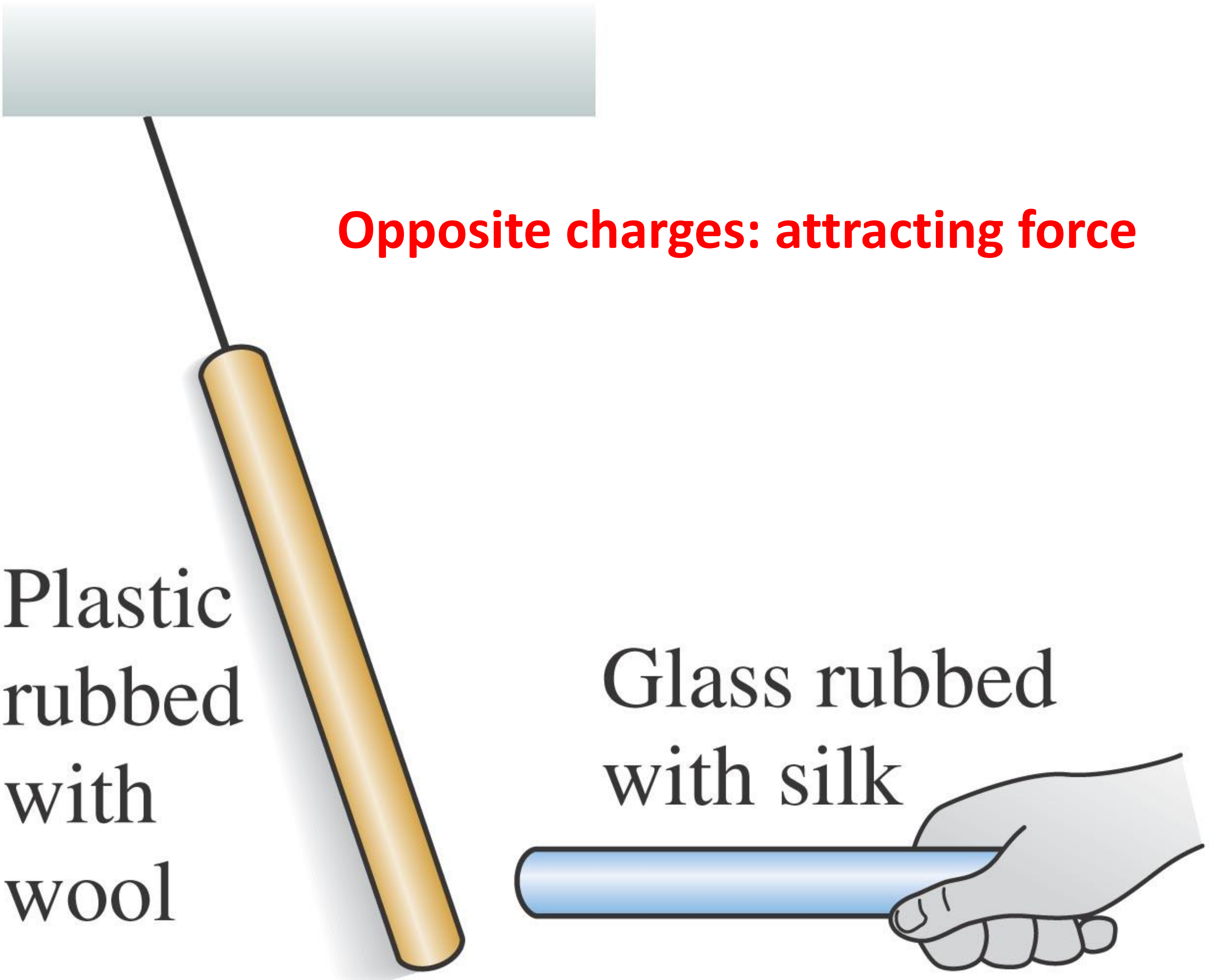
Like charges: repelling force



Like charges, further away, decreased force



Opposite charges: attracting force



Balloon demo
(Yay! Everyone loves balloons!)

Doesn't love balloons

image from http://scienceblogs.org/startswithabang

image from http://everylifeeveryday.blogspot.ca

What is going on in these two cases?

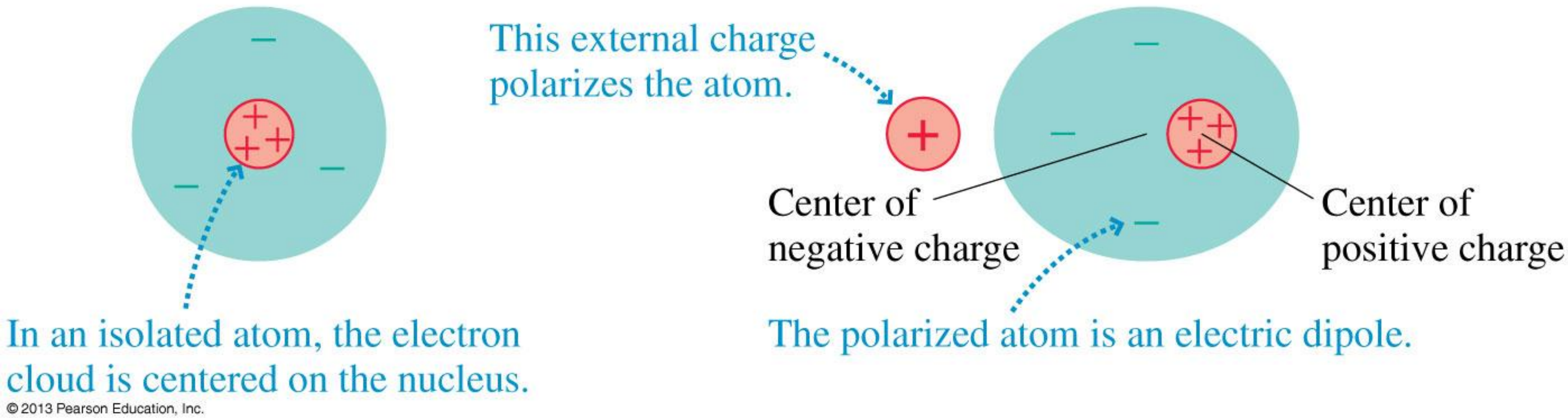
Balloon on hair: easy! Balloon and hair rub together, become oppositely charged, attract each other.

Balloon on wall: is the wall charged?

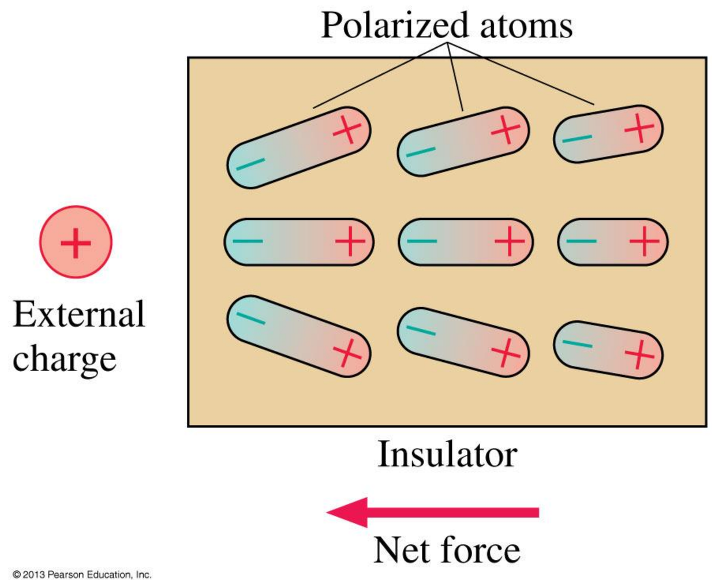
NO!

So why does the balloon stick to the wall?

Charge Polarization

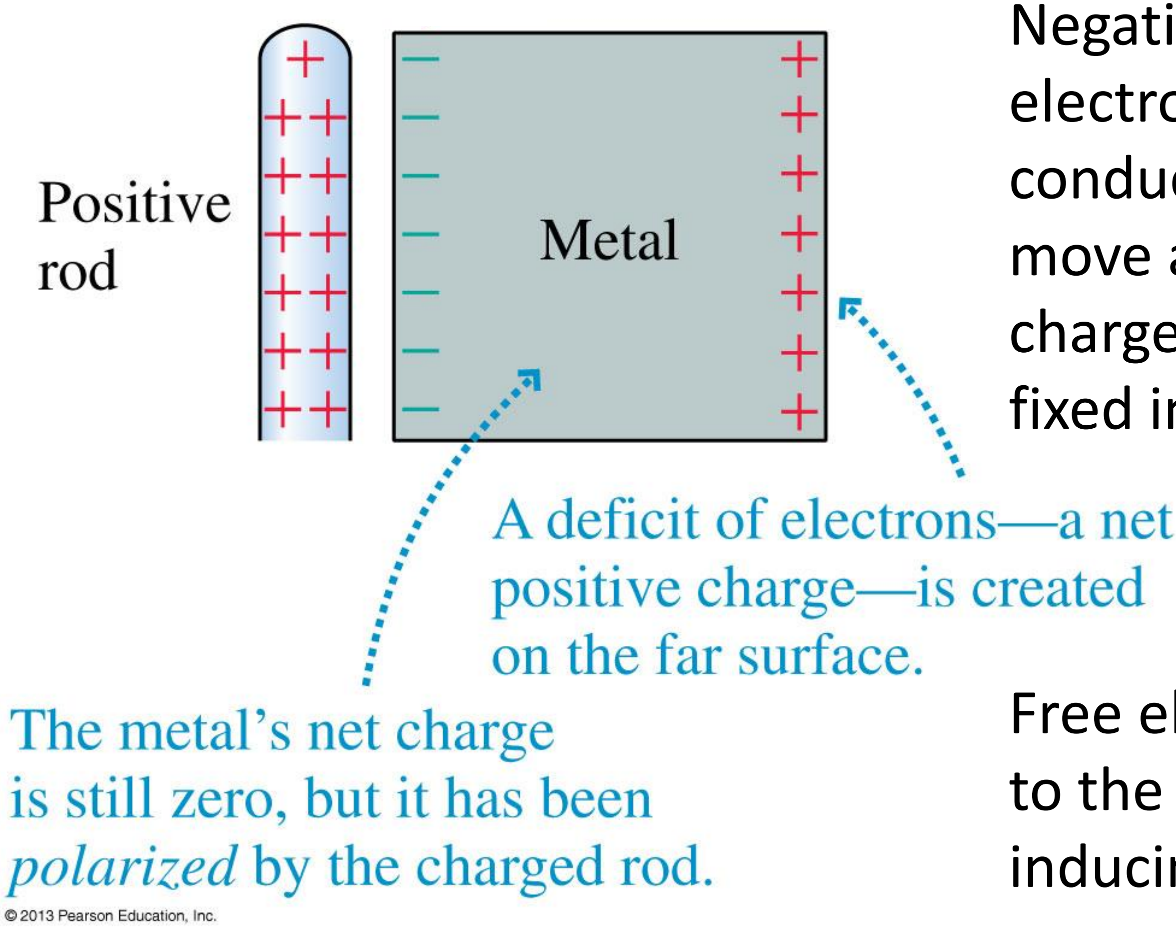


Balloon



Wall

What happens with conductors?



Negatively charged valence electrons inside the conductor are able to freely move around. The positively charged atomic cores are fixed in place.

Free electrons are attracted to the positively charged rod, inducing a polarization.

What we know

- There are positive and negative charges
- Like charges repel each other
- Opposite charges attract each other
- The force between charged objects varies with distance
- The force between charged objects depends on the amount of charge

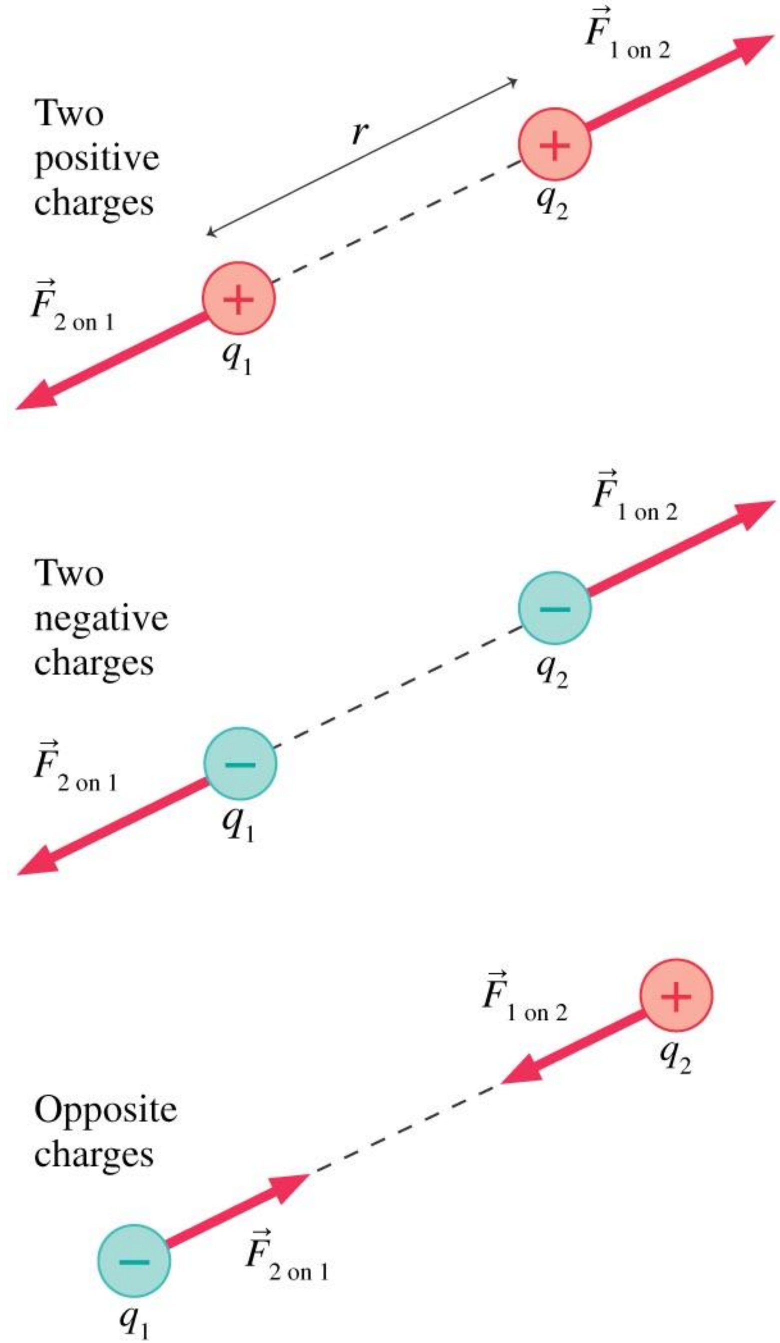
HOW CAN WE QUANTIFY THIS?

Coulomb’s Law

Describes the forces that charged **particles** exert on each other:

point charges

The forces always act along the line joining the charges.



Last time

- Coulomb's law
- Group Activity

This time

- More Coulomb's law
- Electric Charge leaking & Van de Graaf Generator Experiment

- Dedicated to her …

“**Education** is the most powerful weapon which you can use to change the world.”

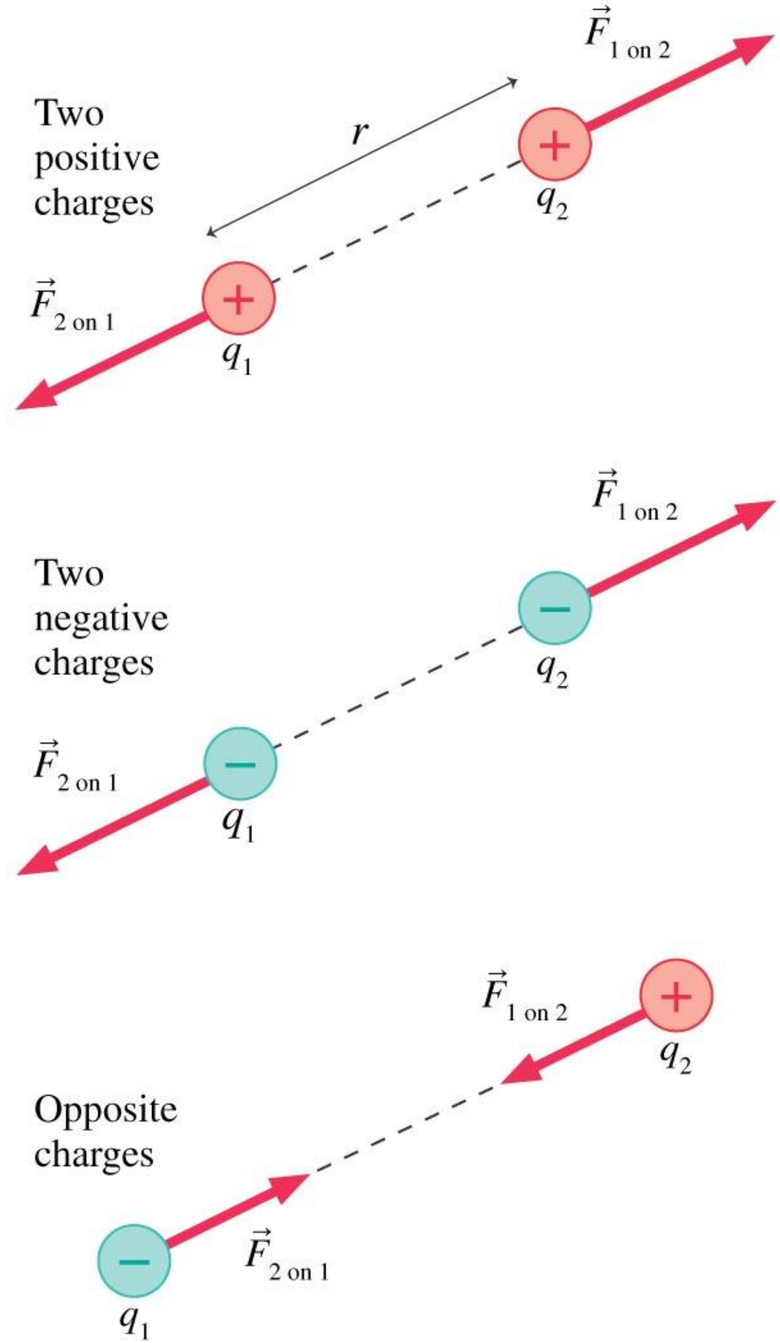
Coulomb's Law

There are only two kinds of charges:

positive and **negative**.

Charges of the **same** sign **repel** each other.

Charges of **opposite** sign **attract** each other.



TopHat Q4

Two Ways of Writing Coulomb's Law

$$\boxed{F_{1\,on\,2} = F_{2\,on\,1} = K\frac{|q_1||q_2|}{r^2}}$$

K = electrostatic constant

$$K = 8.99\times10^{9}\,\frac{N\cdot m^2}{C^2}$$

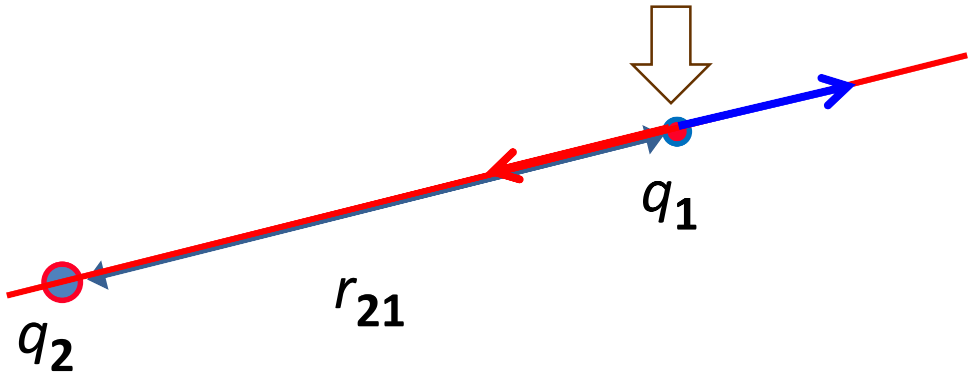
$$\boxed{F_{1\,on\,2} = F_{2\,on\,1} = \frac{1}{4\pi\varepsilon_0}\frac{|q_1||q_2|}{r^2}}$$

ε_0 = permittivity of free space

$$\varepsilon_0 = \frac{1}{4\pi K} = 8.85\times10^{-12}\,\frac{C^2}{N\cdot m^2}$$

Coulomb's Law

How to compute the magnitude and direction properly.



$$\left|\vec{F}_{21}\right| = K\frac{|q_1||q_2|}{r_{21}^2}$$

1) Find the distance between the charges.

2) Draw a line passing through the two charges.

3) The force on q_1 due to q_2 has its tail at location 1 and points either towards q_2 or away from q_2.

4) Pick the direction according to basic rule of charges:

Like charges repel, Opposite charges attract

SI unit of charge: the **coulomb** (C)

Fundamental charge:

the smallest possible amount of free charge

= charge of one proton: $\boxed{e = 1.60 \times 10^{-19}\, C}$

Then 1 C is approximately **6.25 x 10^18 protons**.

1 C is **BIG!!**

$$\boxed{\begin{aligned} 1\,\mu C &= 1\ \text{microcoulomb} = 10^{-6}\, C \\ 1\,nC &= 1\ \text{nanocoulomb} = 10^{-9}\, C \end{aligned}}$$

Small, medium, or large?

The fundamental units in the MKS system all correspond to reasonable scales

2 metres = a very tall person
1 kilogram = a very large hamburger
60 seconds = just a minute

as do some of the commonly encountered combinations

30 metres/second = major league fastball
10 Newtons = gravity acting on a very large hamburger

What about electricity and magnetism?

12 volts = car battery
0.1 amperes = cell phone recharger
140,000 coulombs = all the electrons in a copper penny

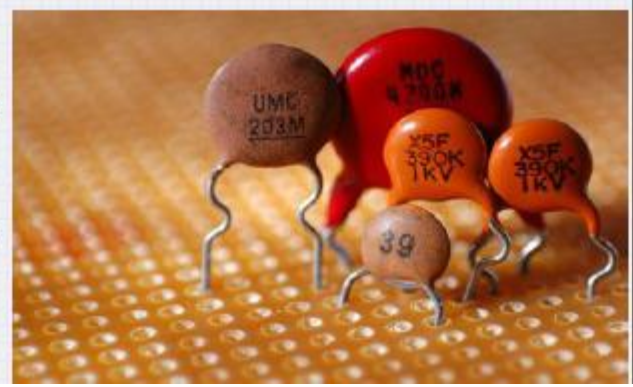
1 Coulomb is a great deal of charge

An average bolt of lightning

charge = 5 Coulombs
current = 50,000 Amperes
power = 500,000,000 Joules

so all the electrons in a copper penny have a total charge equivalent to 30,000 lightning bolts.

A single electron has 1.6E-19 Coulombs of charge.

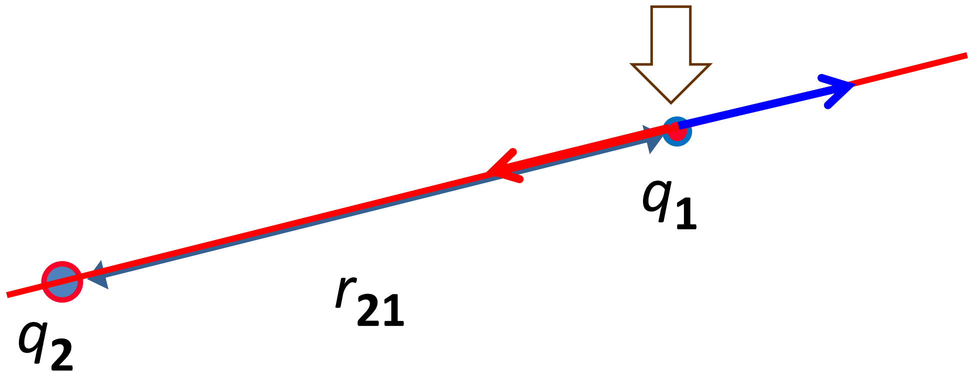


Capacitors in circuits typically hold charges on the order of 10E-9 to 10E-3 Coulombs.

All materials contain very large numbers of charges, but they are usually in nearly perfect balance ($N_+ = N_-$).

Coulomb's Law

How to compute the magnitude and direction properly.



$$\left|\vec{F}_{21}\right| = K\frac{|q_1||q_2|}{r_{21}^2}$$

1) Find the distance between the charges.

2) Draw a line passing through the two charges.

3) The force on q_1 due to q_2 has its tail at location 1 and points either towards q_2 or away from q_2.

4) Pick the direction according to basic rule of charges:

Like charges repel, Opposite charges attract

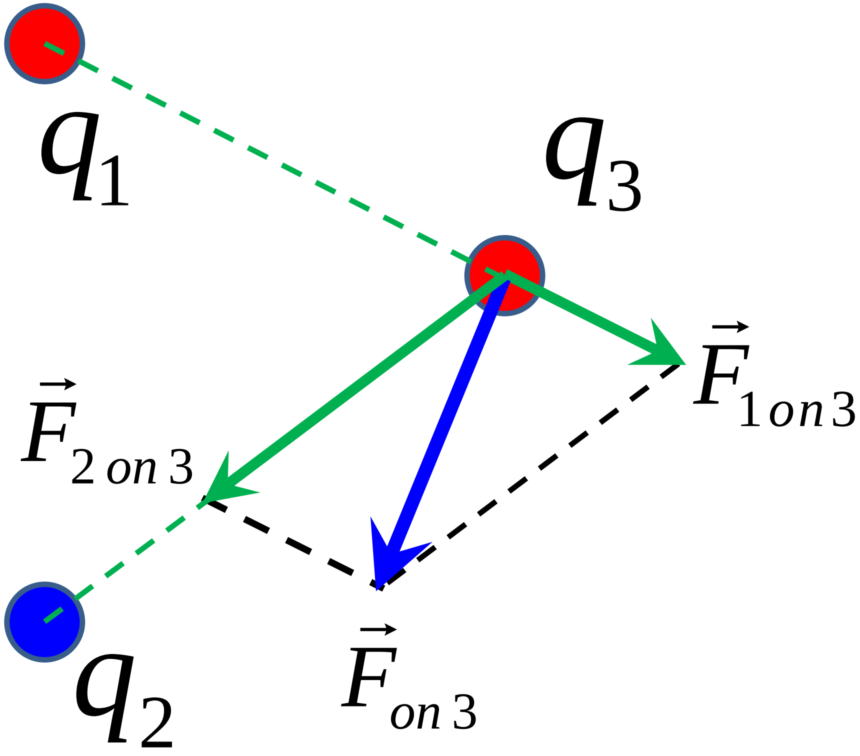
Superposition Principle

q_1 exerts a force $\vec{F}_{1\,on\,3}$ on q_3.

q_2 exerts a force $\vec{F}_{2\,on\,3}$ on q_3.

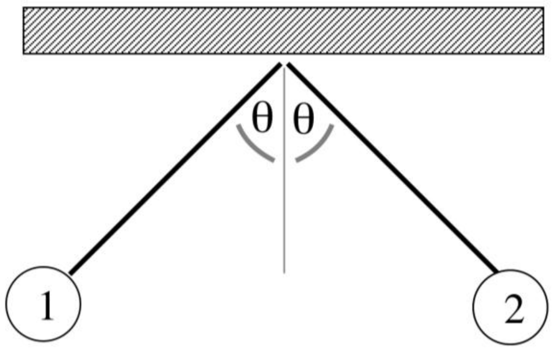
The total force on q_3 is the vector sum of the individual forces:

$$\vec{F}_{on\,3} = \vec{F}_{1\,on\,3} + \vec{F}_{2\,on\,3}$$



TopHat Question: **JOIN CODE: 524259**

Two small **equal mass**, **insulating** balls are charged and hang on strings as shown:

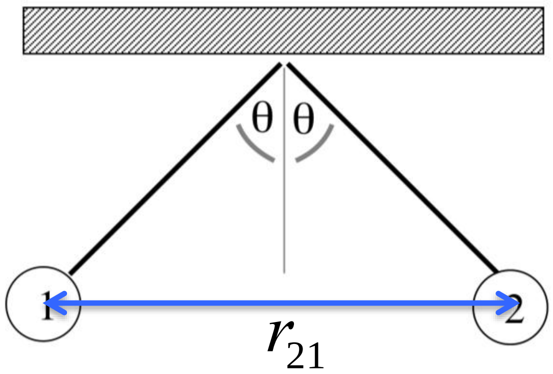


What can you say about the **signs** of the charges Q1 and Q2 on the two balls?

(A) Both charges are "**+**"
(B) Both charges are "**–**"
(C) Both charges must have opposite signs but we can't tell which is "**+**" and which is "**–**"
(D) Both charges must have the same sign but we can't tell if they're both "**+**", or both "**–**"

TopHat Question: **JOIN CODE: 524259**

Two small **equal mass**, **insulating** balls are charged and hang on strings as shown:



$$\left|\vec{F}_{21}\right| = K\frac{|Q_1||Q_2|}{r_{21}^2} = \left|\vec{F}_{12}\right|$$

What can you say about the **magnitudes** of the charges Q1 and Q2 on the two balls?

A: Q1 must equal Q2

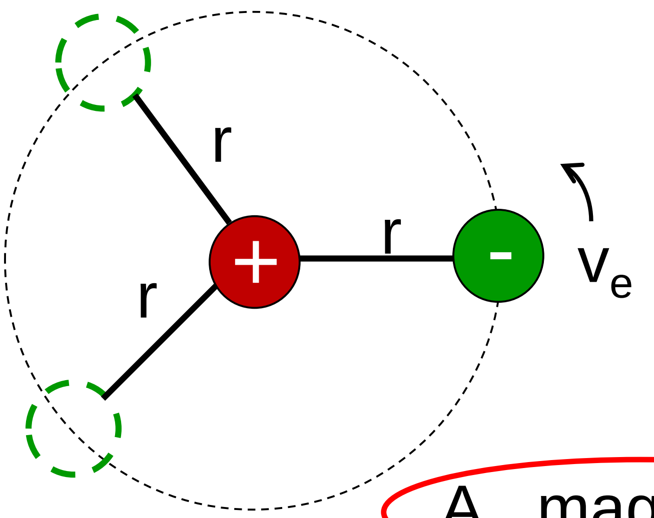
B: Q1 cannot equal Q2

C: Can't decide/not enough information.

TopHat Question: **JOIN CODE: 524259**

A negative point charge moves along a circular orbit around a positive point charge

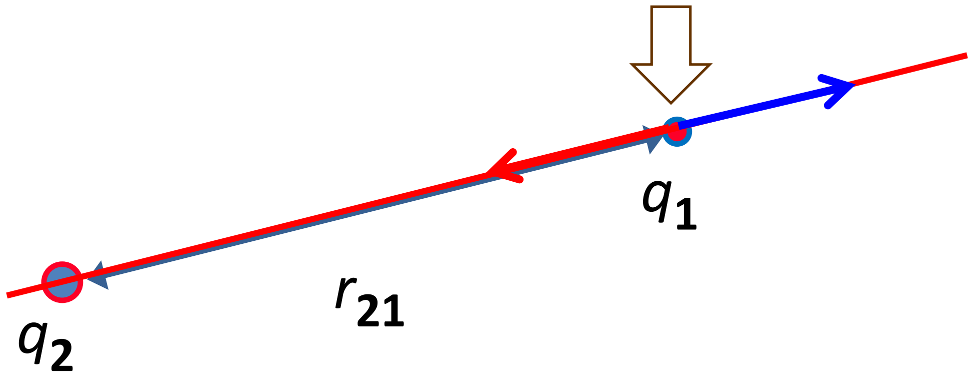
Which aspect(s) of the electric force on the negative point charge will **remain constant** as it moves



A. magnitude
B. direction
C. magnitude and direction
D. neither magnitude nor direction

Last Time

How to compute the magnitude and direction properly.



$$\left|\vec{F}_{21}\right| = K\frac{|q_1||q_2|}{r_{21}^2}$$

1) Find the distance between the charges.

2) Draw a line passing through the two charges.

3) The force on q_1 due to q_2 has its tail at location 1 and points either towards q_2 or away from q_2.

4) Pick the direction according to basic rule of charges:

Like charges repel, Opposite charges attract

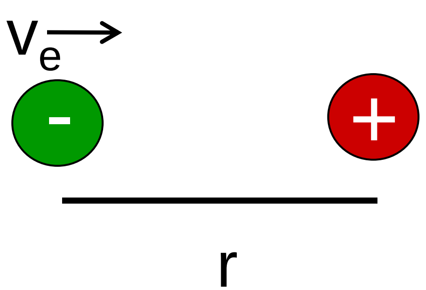
This time

- Coulomb’s law example!
- More about the vector!

TopHat Question: **JOIN CODE: 524259**

A negative point charge moves along a straight-line path directly toward a stationary positive point charge.

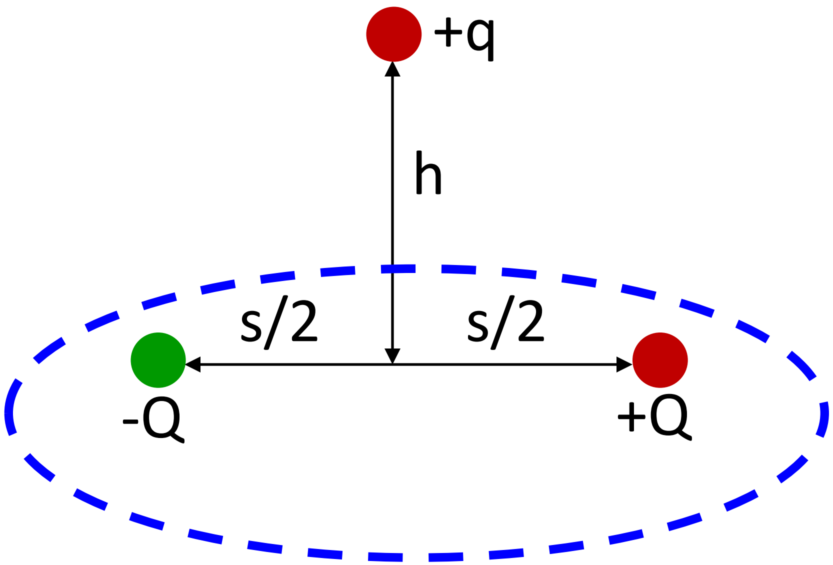
Which aspect(s) of the electric force on the negative point charge will **remain constant** as it moves

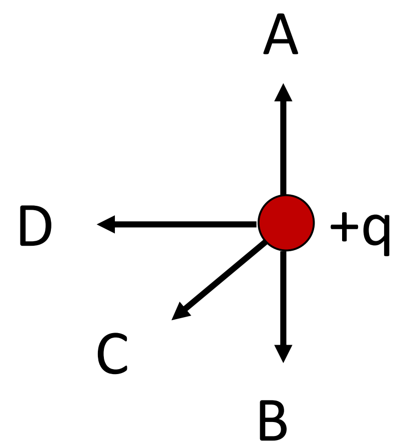


A. magnitude
B. direction
C. magnitude and direction
D. neither magnitude nor direction

TopHat Question: **JOIN CODE: 524259**

The three charges +q, -Q and +Q are fixed in space as shown below. What happens to the +q charge if it is free to move?(consider only the instant it is released)



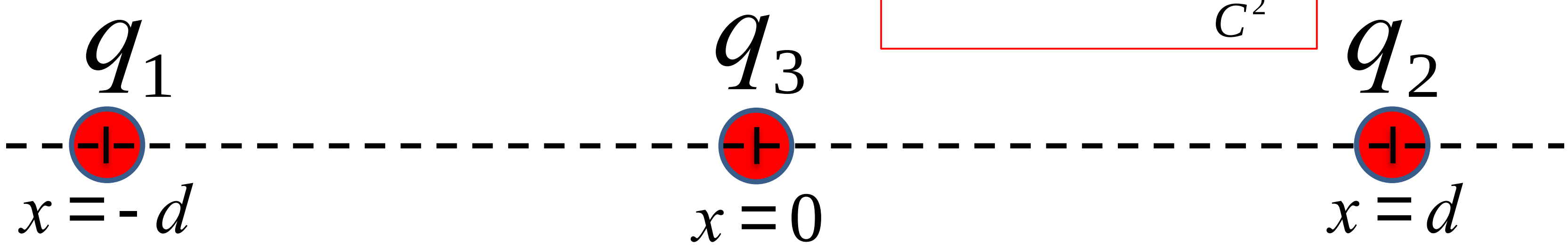


A. +q will accelerate along direction A
B. +q will accelerate along direction B
C. +q will accelerate along direction C
D. +q will accelerate along direction D
E. +q will experience no acceleration

Group Activity #1 (practice)

Three point charges, q_1, q_2, and q_3, are placed in a line at x=–d, x=d, and x=0 respectively, as shown below.

$$K = 8.99\times10^{9}\ \frac{N\cdot m^2}{C^2}$$

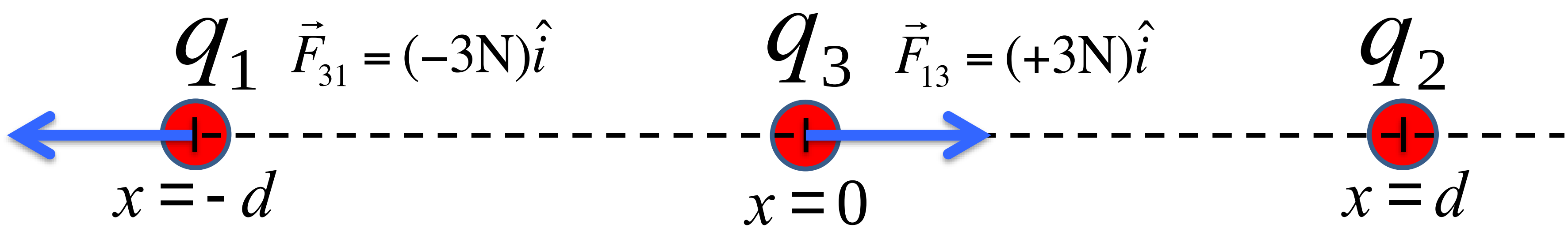


1. If the force of q_1 on q_3 is $\mathbf{F}_{13}$ = +3.0 N $\hat{\mathbf{i}}$ (i.e., in the +x direction), and the force of q_3 on q_1 is $\mathbf{F}_{31} = F_{31}\,\hat{\mathbf{i}}$, what is the component F_{31} in N?

2. If q_1=+1.0 nC, q_2=–1.0 nC, and q_3=+1.0 nC, what is the total electric force on q_1 in N? Note: nC = 10^{-9} C, and take d=1.0 m.

3. If q_1=+1.0 nC and the total electric force on q_3 is exactly zero, what is the value of q_2 in nC?

Group Activity #1 (solution)



1. If the force of q_1 on q_3 is $\vec{F}_{13} = (+3\text{N})\hat{i}$ (i.e., in the +x direction), and the force of q_3 on q_1 is $\vec{F}_{31} = F_{31}\hat{i}$, what is the component F_{31}?

$$\boxed{F_{31} = -3\text{N}}$$

Two ways to think about this:

Newton's Third Law

$$\vec{F}_{13} = -\vec{F}_{31}$$

Forces are equal and opposite

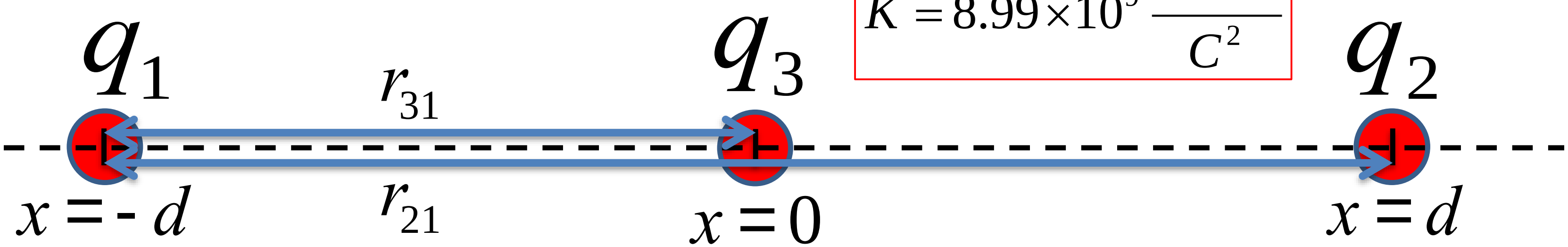
Coulomb's Law

$$\left|\vec{F}_{13}\right| = \left|\vec{F}_{31}\right|$$

Pick direction using charge rules.

Group Activity #1 (solution)

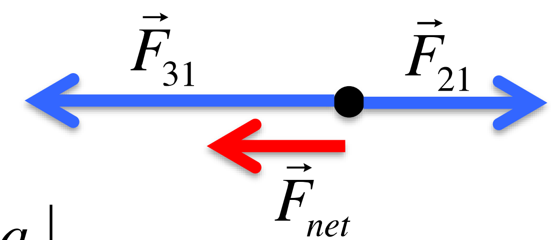
$$K = 8.99\times10^{9}\ \frac{N\cdot m^2}{C^2}$$



2. If q_1=+1.0 nC, q_2=–1.0 nC, and q_3=+1.0 nC, what is the total electric force on q_1? Note: nC = 10^{-9} C, and take d=1.0 m.

$$\boxed{\vec{F}_{net} = \left(-6.74\times10^{-9}\ \mathrm{N}\right)\hat{i}}$$

Free Body Diagram:



$$\left|\vec{F}_{31}\right| = \frac{K|q_3||q_1|}{r_{31}^2}$$

$$\left|\vec{F}_{31}\right| = \frac{(8.99\times10^{9}\ \mathrm{N\,m^2/C^2})(1.0\times10^{-9}\ \mathrm{C})^2}{(1.0\ \mathrm{m})^2}$$

$$\left|\vec{F}_{31}\right| = 8.99\times10^{-9}\ \mathrm{N}$$

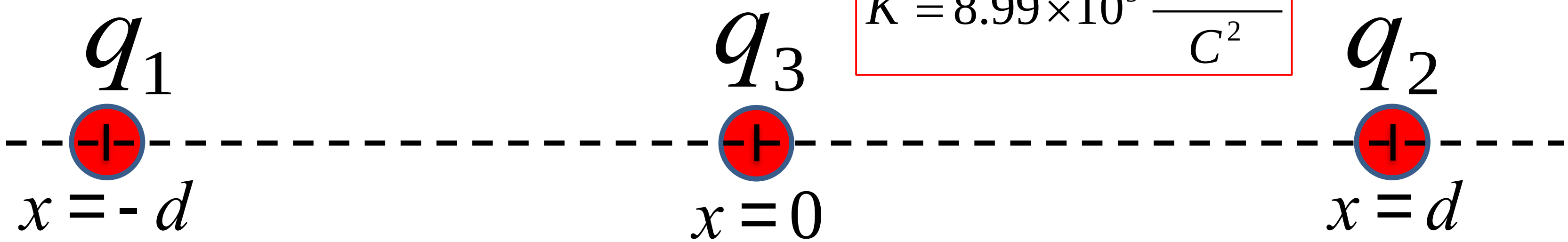
$$\left|\vec{F}_{21}\right| = \frac{K|q_2||q_1|}{r_{21}^2}$$

$$\left|\vec{F}_{31}\right| = \frac{(8.99\times10^{9}\ \mathrm{N\,m^2/C^2})(1.0\times10^{-9}\ \mathrm{C})^2}{(2.0\ \mathrm{m})^2}$$

$$\left|\vec{F}_{31}\right| = 2.25\times10^{-9}\ \mathrm{N}$$

Group Activity #1 (solution)

$$K = 8.99 \times 10^9 \frac{N \cdot m^2}{C^2}$$



3. If q_1=+1.0 nC and the total electric force on q_3 is exactly zero, what is the value of q_2 in nC?

Simple symmetry argument:

$\boxed{q_2 = +1.0 \text{ nC}}$

q_3 can be either positive or negative and this will work. Choose +:

q_1 pushes q_3 to the right, so q_2 must push to the left: q_2 is +

Distances are the same, so $|q_1 q_3| = |q_2 q_3|$, i.e., $|q_1| = |q_2|$

Scalars *vs.* Vectors

A **scalar** is any physical quantity that can be described by a single number.

- The temperature in the room is 20°C.

A **vector** is a physical quantity has both a magnitude and a direction.

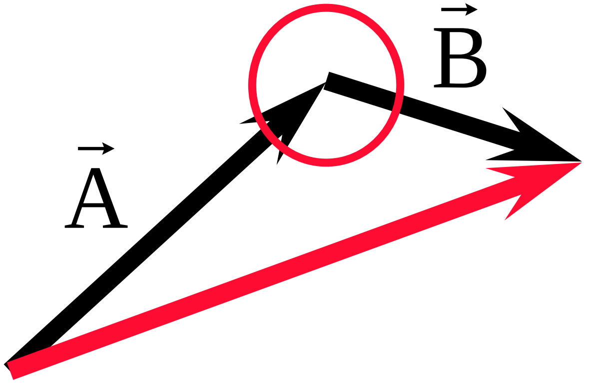
- Edmonton is 300 km north of Calgary.

Vector Addition

Adding vectors requires taking not only their magnitudes into account, but also their directions.

To find the sum of two vectors:

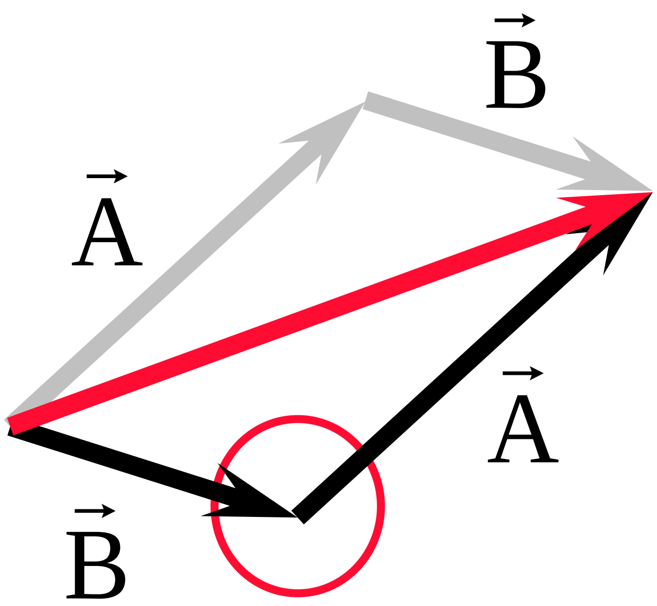
- Draw the first vector.
- Draw the second vector with the tail starting where the tip of the first vector ended.
- Draw a final vector from the tail of the first vector to the tip of the second vector.



$$\vec{C} = \vec{A} + \vec{B}$$

Vector Addition

We could also have done it the other way around:



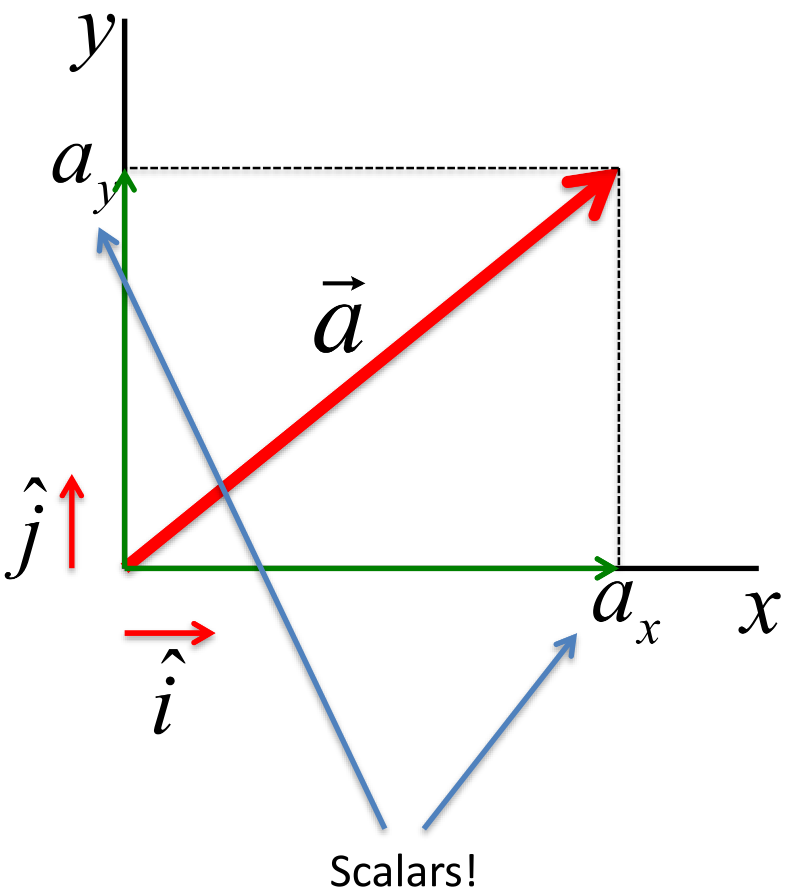
$$\vec{C} = \vec{A} + \vec{B} = \vec{B} + \vec{A}$$

The order of adding does not matter.

Notice the parallelogram

Vector Components

Scalars are usually easier to use than vectors. So let's replace our vectors with scalar quantities called vector components.



$$\vec{a} = a_x \hat{i} + a_y \hat{j}$$

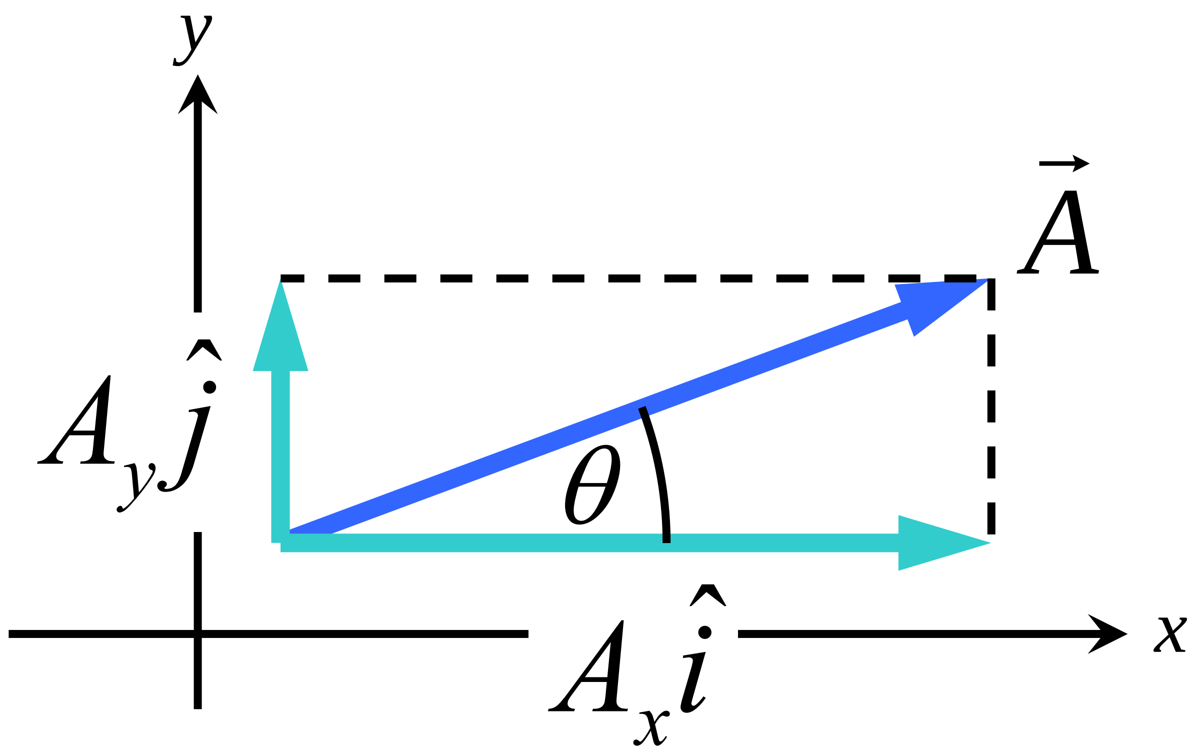
x-component

y-component

$$|\vec{a}| = \sqrt{a_x^2 + a_y^2}$$

magnitude is always positive

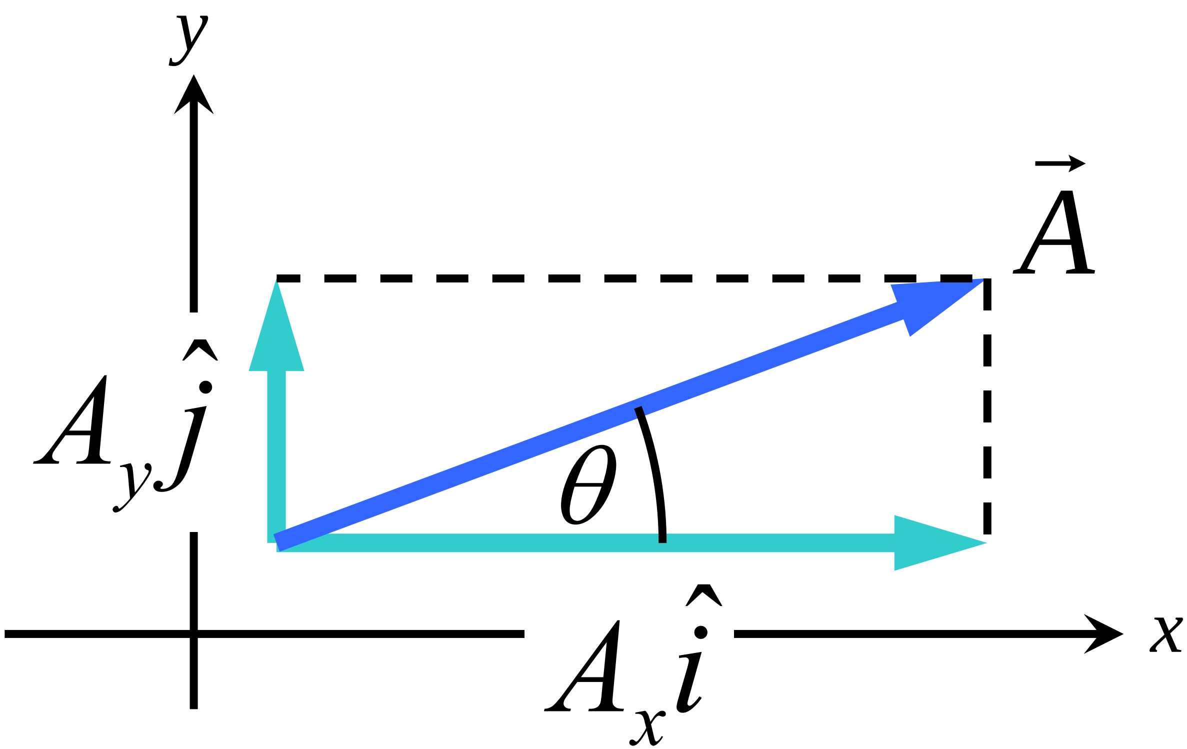
Finding Components of Vectors



$$A_x = A\cos q \qquad A_y = A\sin q$$

The direction tells us the sign.

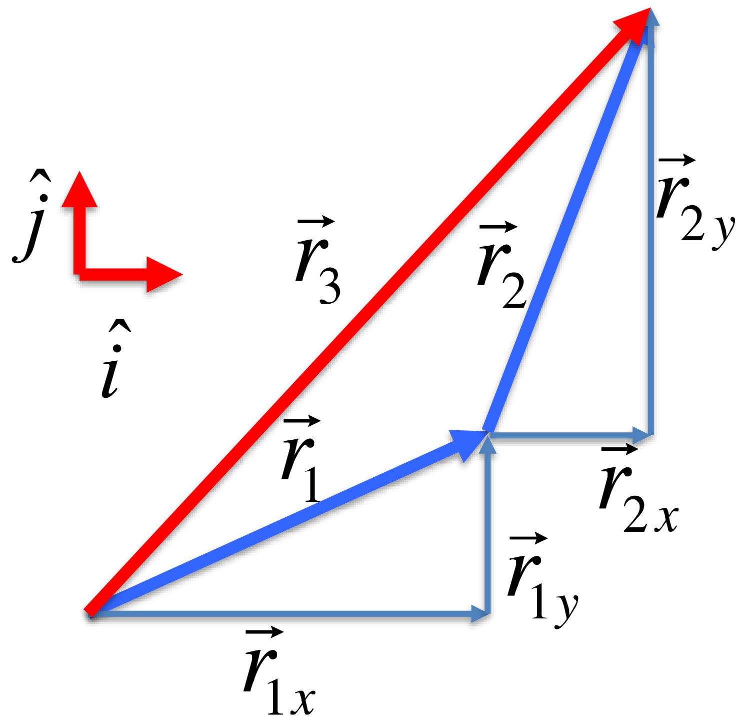
What if we already know the components?



$$A^2 = A_x^2 + A_y^2 \qquad \theta = \tan^{-1}\left|\frac{A_y}{A_x}\right|$$

Vector Addition using Components

$$\boxed{\vec{r}_3 = \vec{r}_1 + \vec{r}_2}$$



$$\vec{r}_1 = r_{1x}\hat{i} + r_{1y}\hat{j}$$

$$\vec{r}_2 = r_{2x}\hat{i} + r_{2y}\hat{j}$$

$$\vec{r}_3 = \left(r_{1x} + r_{2x}\right)\hat{i} + \left(r_{1y} + r_{2y}\right)\hat{j}$$

Dot Product of Two Vectors

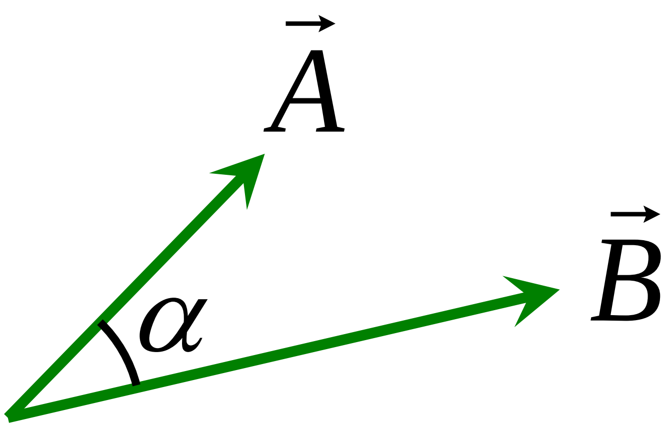
$$W = \int_{s=s_i}^{s_f} F_s \, ds = F_s \Delta s$$

Work is a scalar.

Force is a vector.

Displacement is a vector.

So really we are multiplying two vectors to get a scalar.



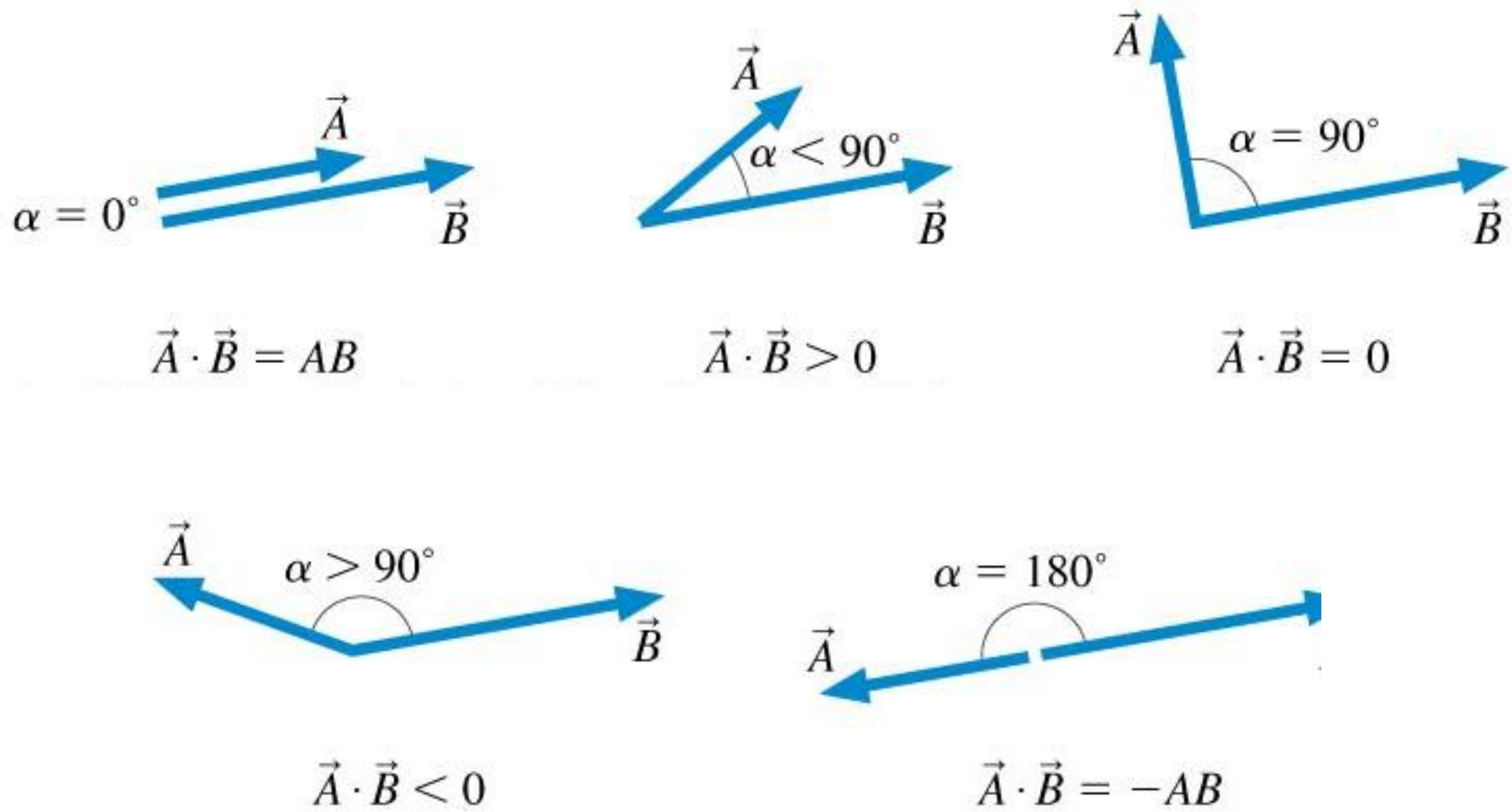
$$\boxed{\vec{A}\cdot\vec{B} = AB\cos\alpha}$$

$$\underbrace{AB\cos\alpha}_{\text{SCALAR}}$$

Dot product.

Dot Product of Two Vectors

$$\vec{A} \cdot \vec{B} = AB \cos\alpha$$

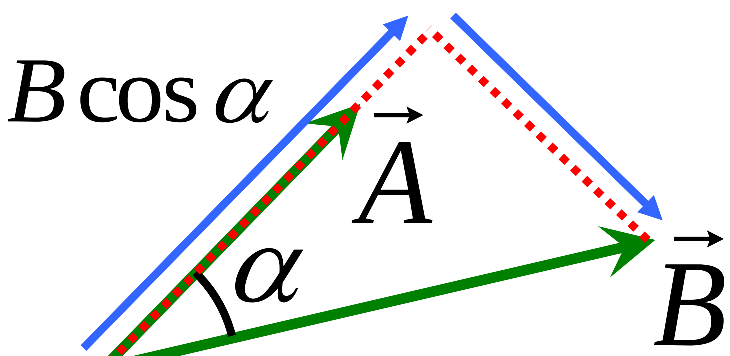


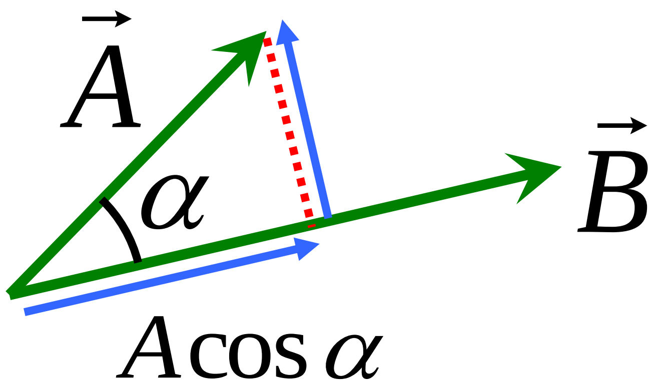
Dot Product of Two Vectors

$$\vec{A}\cdot\vec{B} = A\underbrace{\left(B\cos\alpha\right)} = B\underbrace{\left(A\cos\alpha\right)}$$

Component of B along the direction of A.

Component of A along the direction of B.

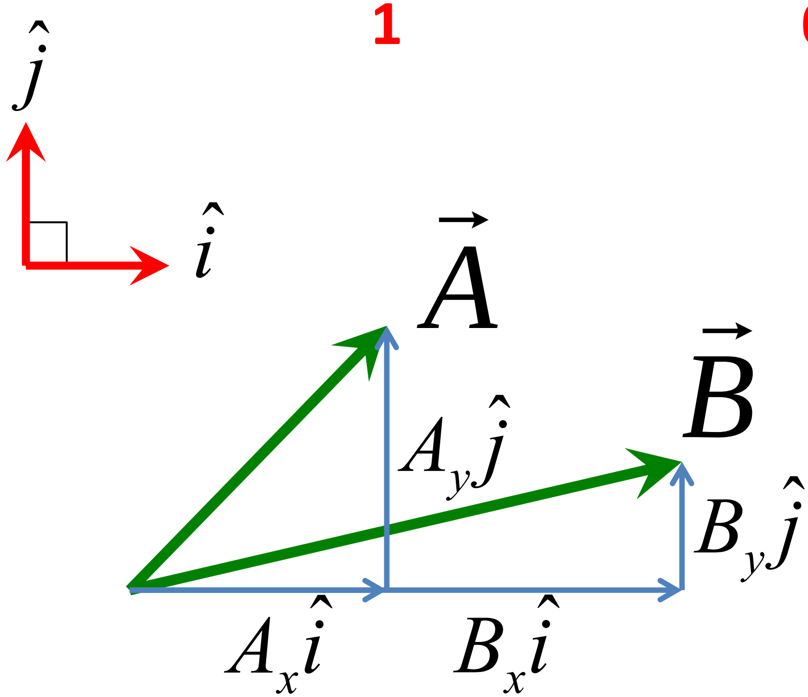




Dot Product of Two Vectors

$$\vec{A}\cdot\vec{B} = \left(A_x\hat{i} + A_y\hat{j}\right)\cdot\left(B_x\hat{i} + B_y\hat{j}\right)$$

$$= A_xB_x\underbrace{\hat{i}\cdot\hat{i}}_{1} + A_xB_y\underbrace{\hat{i}\cdot\hat{j}}_{0} + A_yB_x\underbrace{\hat{j}\cdot\hat{i}}_{0} + A_yB_y\underbrace{\hat{j}\cdot\hat{j}}_{1}$$



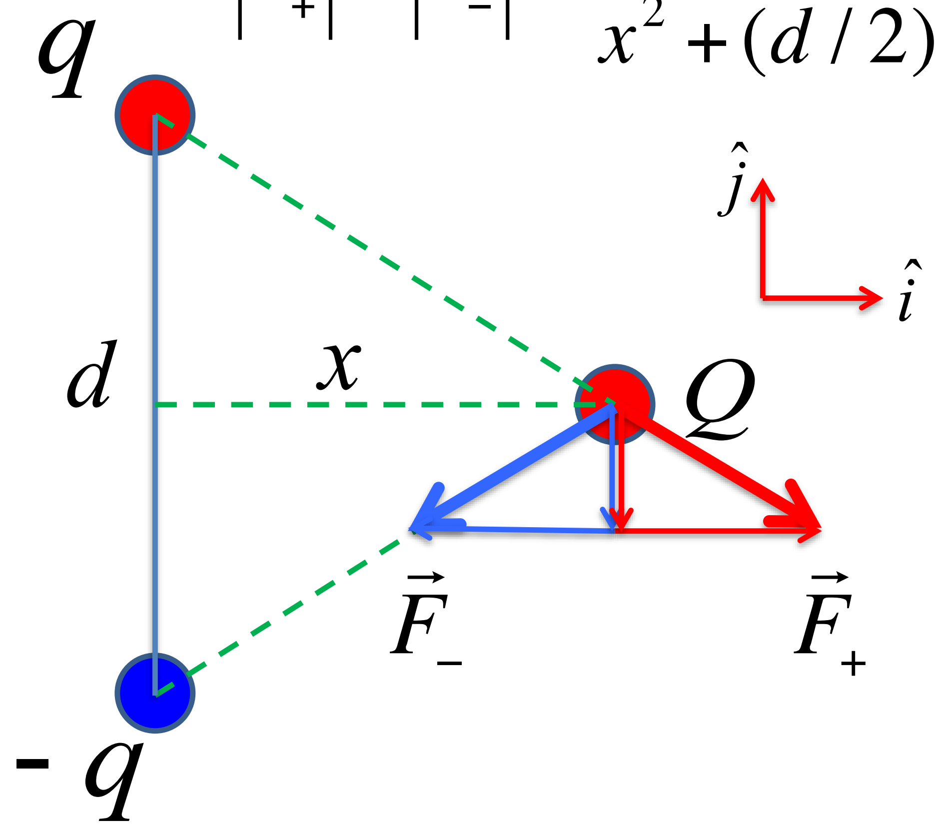
$$\boxed{\vec{A}\cdot\vec{B} = A_xB_x + A_yB_y}$$

Example: force due to a dipole

A charge Q sits at a distance x on the axis perpendicular to the dipole. What is the force (magnitude and direction) it experiences?

$$\left|\vec{F}_+\right| = \left|\vec{F}_-\right| = \frac{KqQ}{x^2 + (d/2)^2}$$

FBD:



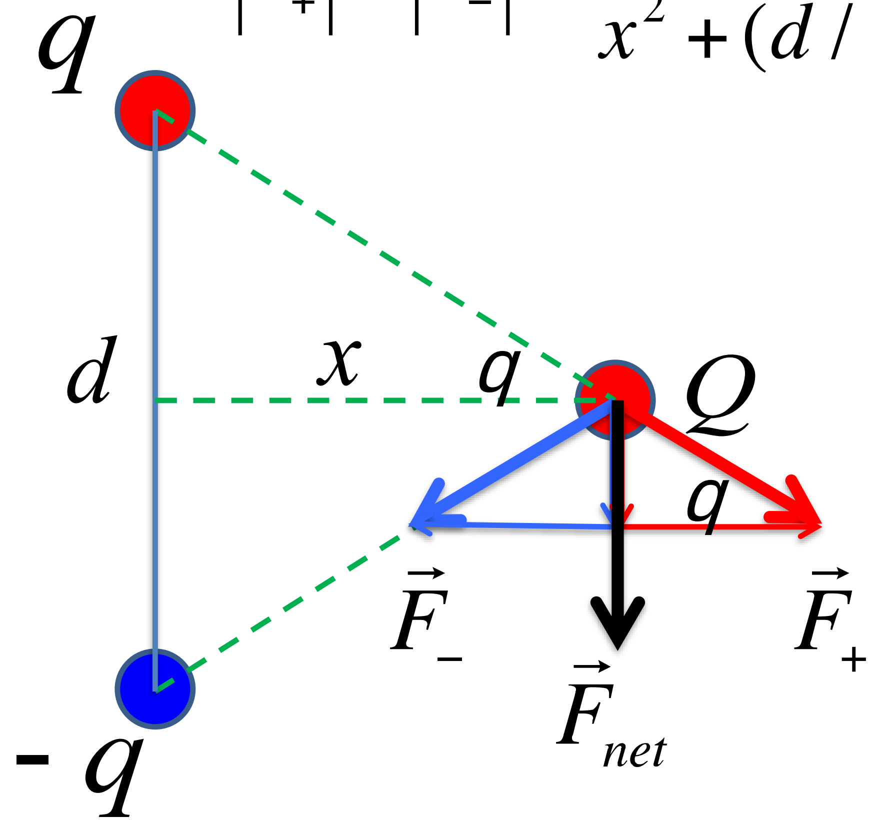
Horizontal components cancel.
Vertical components add.
SYMMETRY!

Example: force due to a dipole

$$\left|\vec{F}_{net}\right| = 2\left(\frac{KqQ}{x^2+(d/2)^2}\right)\sin\theta$$

$$\left|\vec{F}_{+}\right| = \left|\vec{F}_{-}\right| = \frac{KqQ}{x^2+(d/2)^2}$$

$$\sin q = \frac{d/2}{\sqrt{x^2+(d/2)^2}}$$



$$\left|\vec{F}_{net}\right| = \frac{KqQd}{\left(x^2+(d/2)^2\right)^{3/2}}$$

Direction: **downward**

Last time

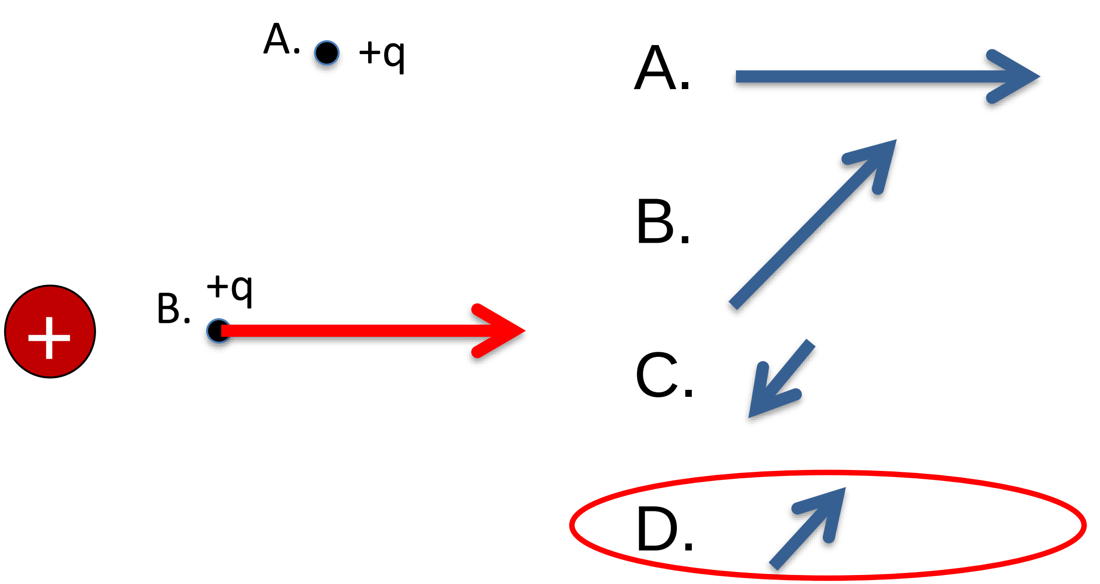
- Brief review of scalars vs vectors, vector notation, etc.
- Example: calculating force from electric dipole

This time

- Coulomb’s Law as a fundamental building block
- Electric force due to a charged ring (on the white board)
- Electric force due to a charged wire (on the white board)

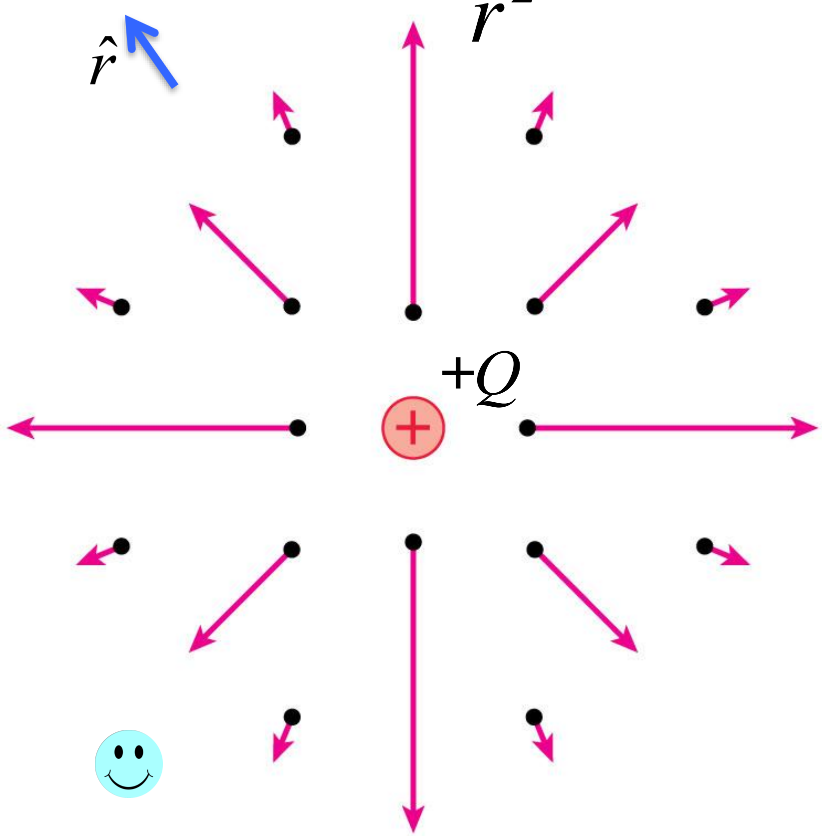
TopHat Question: **JOIN CODE: 524259**

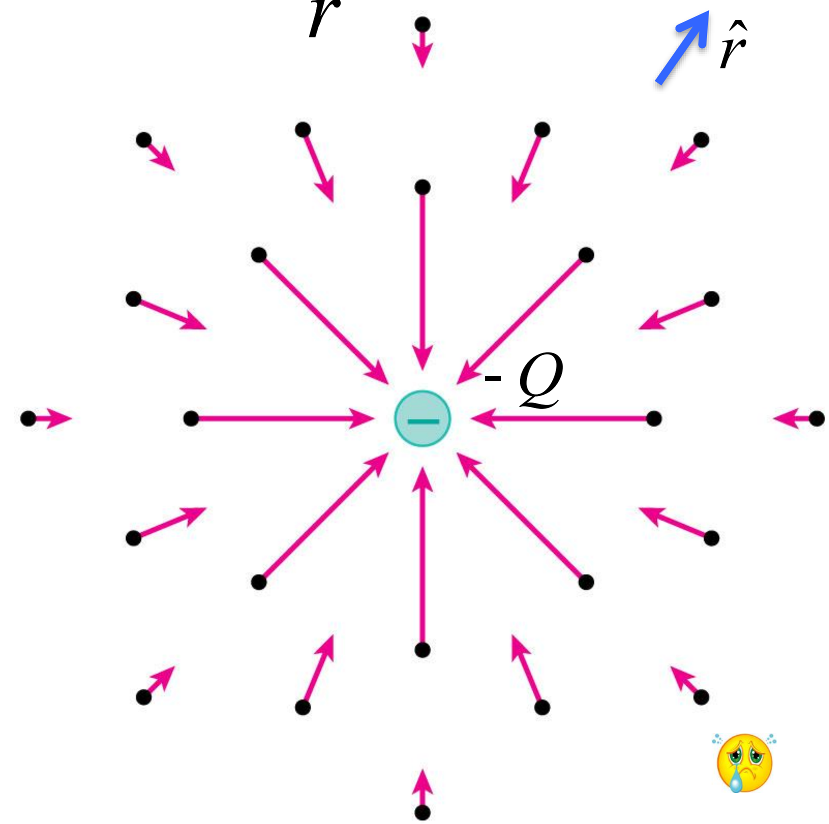
Which one represent best, the direction and size of the force at point A? Assume the red arrow shows the force at point B.



Building blocks of electric force

$$\vec{F} = \frac{KQq}{r^2}\hat{r} \qquad \vec{F} = \frac{-KQq}{r^2}\hat{r}$$

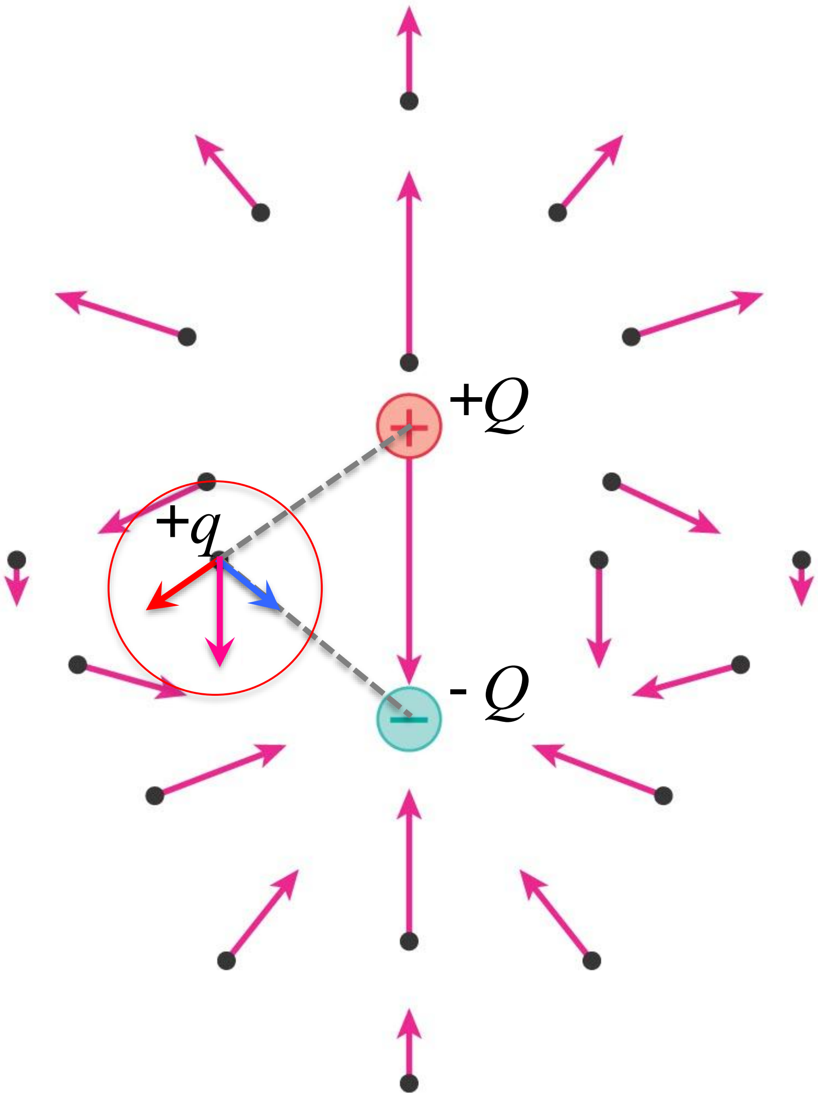




● = positive charge *q* at the position indicated

Superposition with Building Blocks

The vector represents the magnitude and direction of the electric force on the charge q **at that point**. It comes from superposition of the individual forces from +Q and –Q.



Step 1: draw the lines connecting the charge pairs

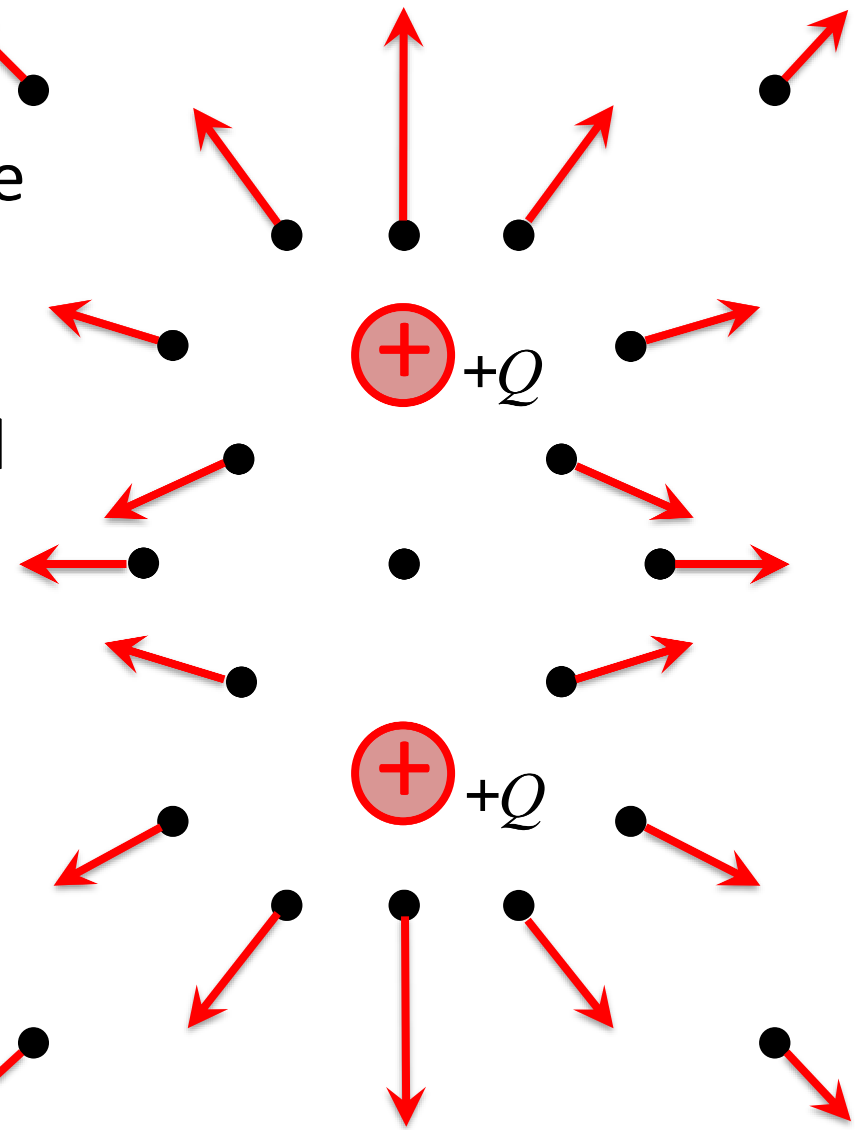
Step 2: draw the force vector for each charge pair

Step 3: sum all forces to find net force

Superposition with Building Blocks

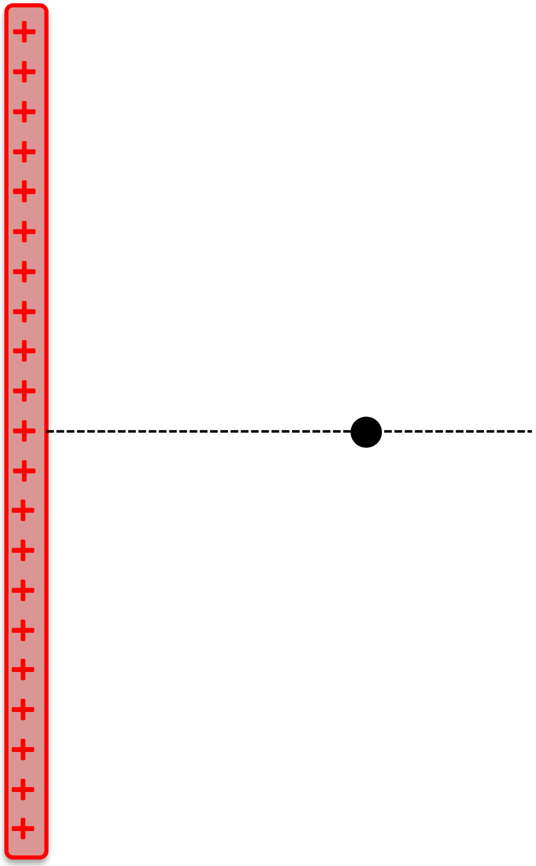
The vector represents the magnitude and direction of the electric force on the charge q **at that point**. It comes from superposition of the individual forces from +Q and +Q.

Direction again comes from superposition! Same steps as previous apply here too.

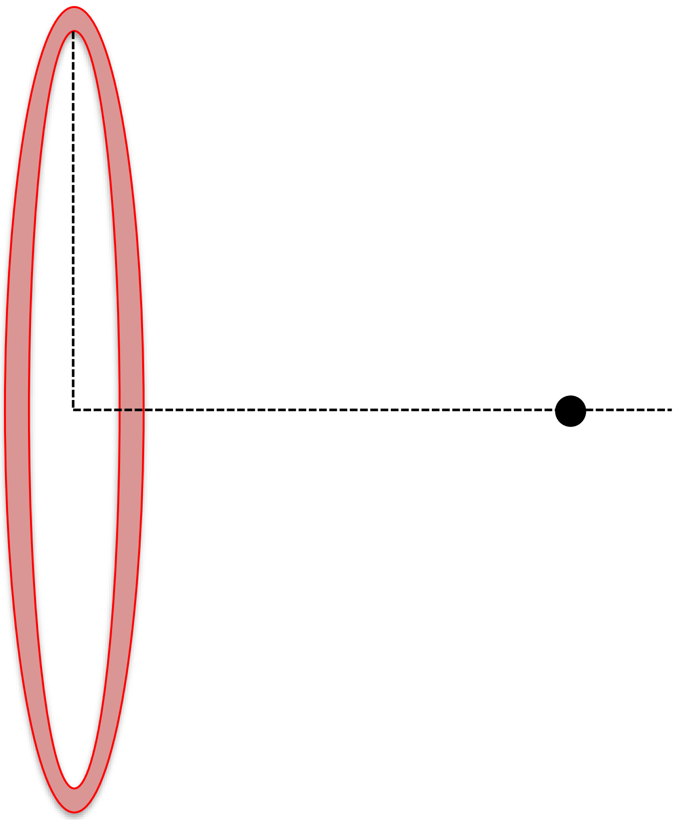


Superposition with Building Blocks

1. Force from a line of charge



2. Force from a ring of charge



Why should we care? Applications:

Attractor plate in 2D plotter

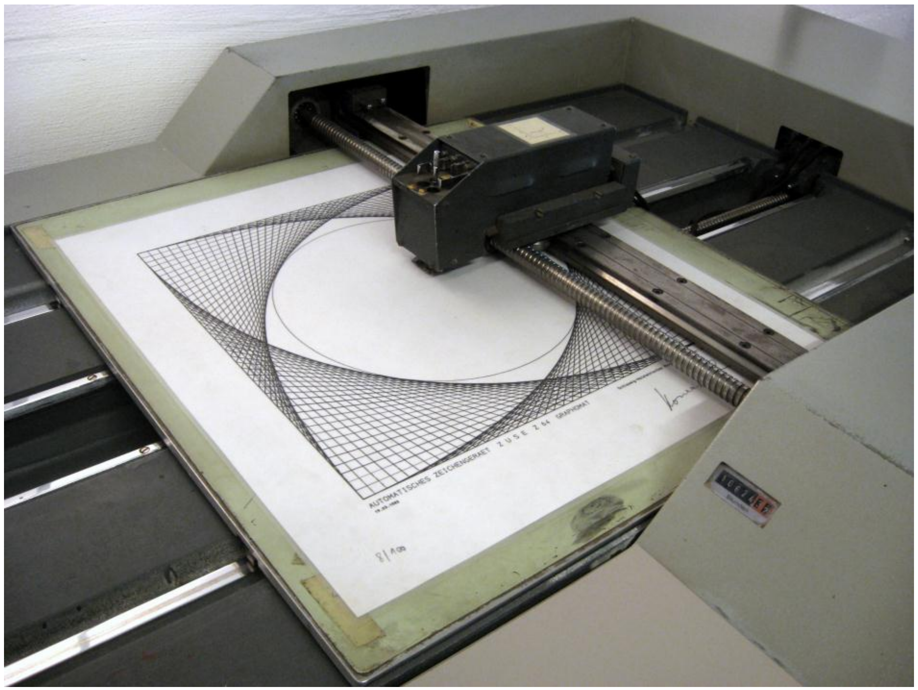


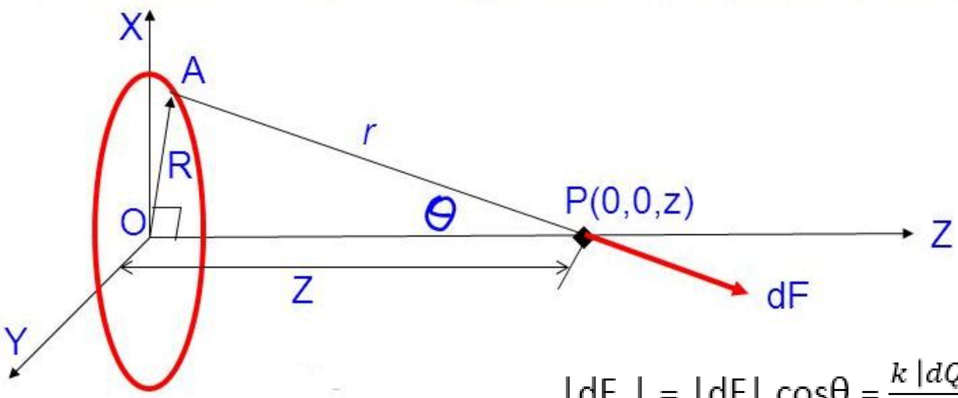
Photo taken from https://en.wikipedia.org/wiki/Plotter

Ring antenna (very directional)

Photo taken from https://en.wikipedia.org/wiki/Loop_antenna

Look at notes called: Jan_Appendix_Chapter21&22

TopHat Question: **JOIN CODE: 524259**



$$|dF_z| = |dF| \cos\theta = \frac{k\,|dQ||q|}{R^2+Z^2} \cos\theta$$

What is $|dF_z|$?

A. $|dF_z| = |dF| \cos\theta = \frac{k\,|dQ||q|}{R^2+Z^2} \frac{z}{\sqrt{R^2+Z^2}}$

B. $|dF_z| = |dF| \cos\theta = \frac{k\,|dQ||q|}{R^2+Z^2} \frac{R}{\sqrt{R^2+Z^2}}$

C. $|dF_z| = |dF| \cos\theta = \frac{k\,|dQ||q|}{R^2+Z^2} \frac{Z^2}{\sqrt{R^2+Z^2}}$

D. $|dF_z| = |dF| \cos\theta = \frac{k\,|dQ||q|}{R^2+Z^2} \frac{R^2}{\sqrt{R^2+Z^2}}$

Last time

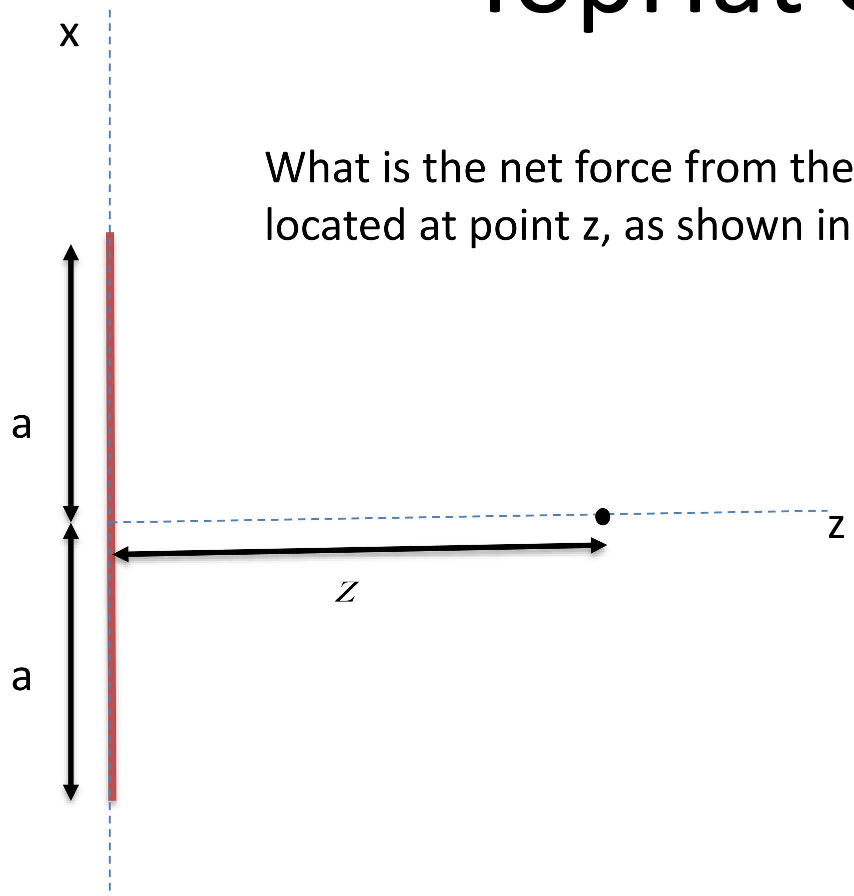
- Coulomb's Law as a fundamental building block
- Electric force due to a charged wire (slowly on doc camera)
- Electric force due to a charged ring (slowly on doc camera)

This time

- The electric field: conceptually difficult but much more useful
- TopHat questions related to E-field
- Finishing up Coloumb's Law: Group Activity

Quote of the day: "The true sign of intelligence is not knowledge but imagination."
~ Albert Einstein

TopHat Question



What is the net force from the wire with charge density of λ, on a +q charge located at point z, as shown in the figure?

A. $\int_{-a}^{+a} \frac{k\lambda z dx}{(x^2+z^2)^{3/2}}$

B. $\int_{-a}^{+a} \frac{k\lambda z x dx}{(x^2+z^2)^{3/2}}$

C. $\int_{-a}^{+a} \frac{k\lambda z dx}{(x^2+z^2)}$

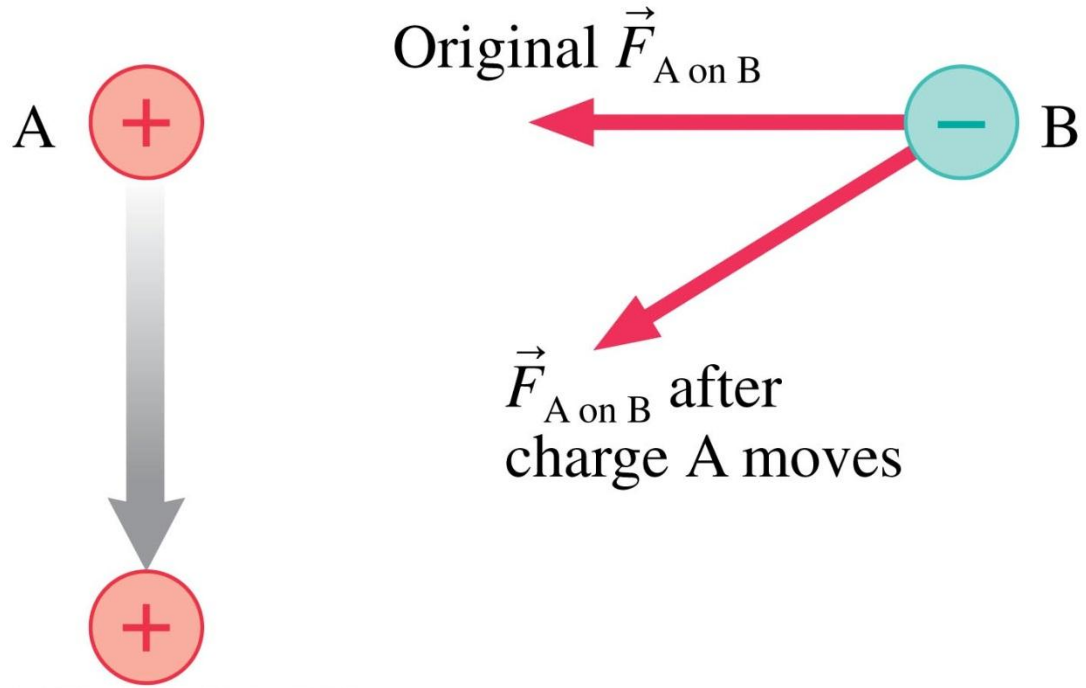
D. $\int_{-a}^{+a} \frac{k\lambda z x dx}{(x^2+z^2)}$

Action-at-a-Distance Forces

A exerts a force on **B** through empty space.

- No contact.
- No apparent **mechanism**.

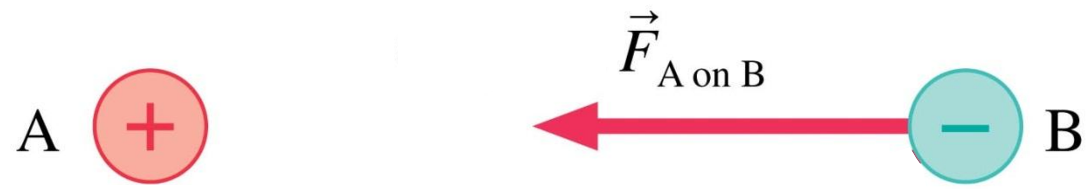
If **A** suddenly moves to a new position, the force on **B** varies to match. **How?**



Action-at-a-Distance Forces

A exerts a force on **B** through empty space.

- No contact.
- No apparent **mechanism**.



What if B wasn't there?

If B is not there, the other charge still "does something" to the **surrounding space**. We can quantify this by using the concept of an **electric field**. Start with a single charge:

Coulomb's Law rewritten:

$$\vec{F}_e = \left(\frac{Kq}{r^2}\hat{r}\right)q' = \vec{E}q'$$

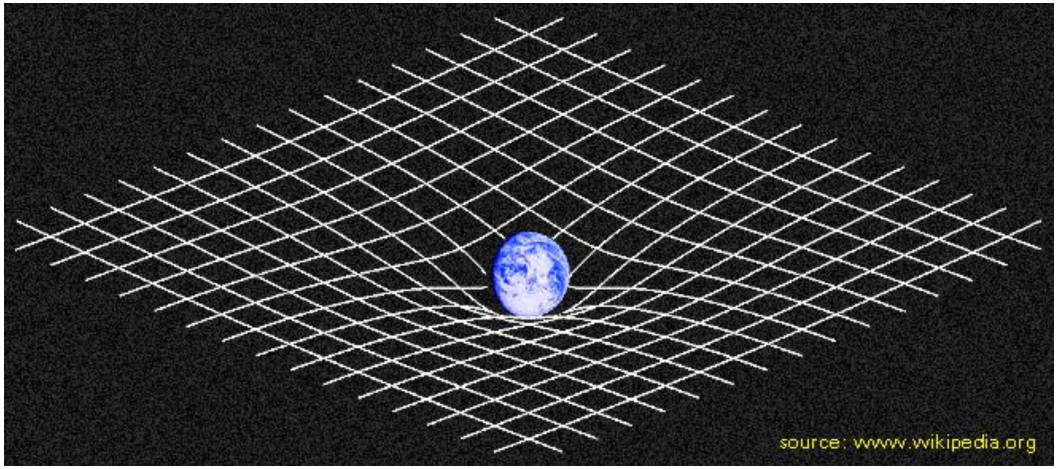
Electric field

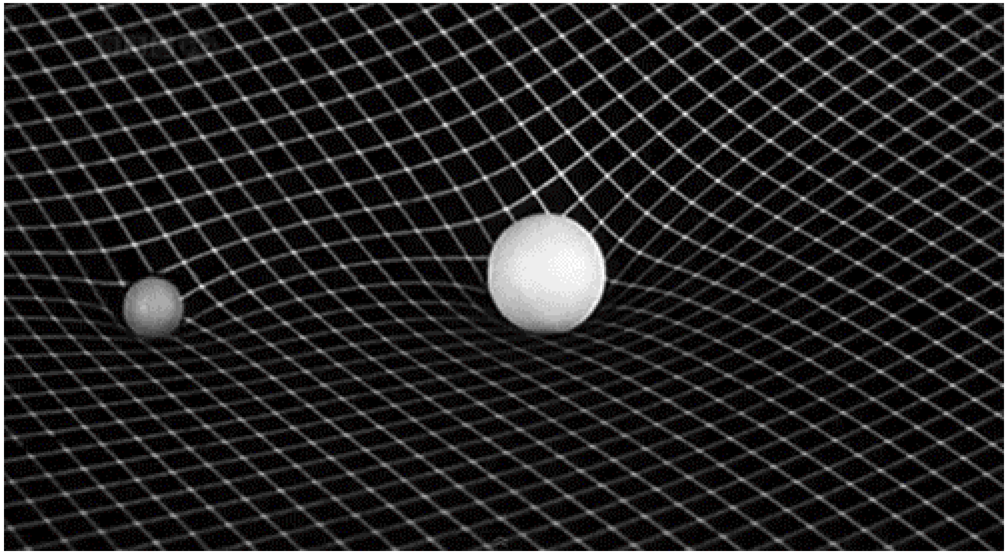
Universal gravity rewritten:

$$\vec{F}_G = \left(\frac{-GM}{r^2}\hat{r}\right)m = \vec{g}m$$

Gravitational field

Gravitational Field

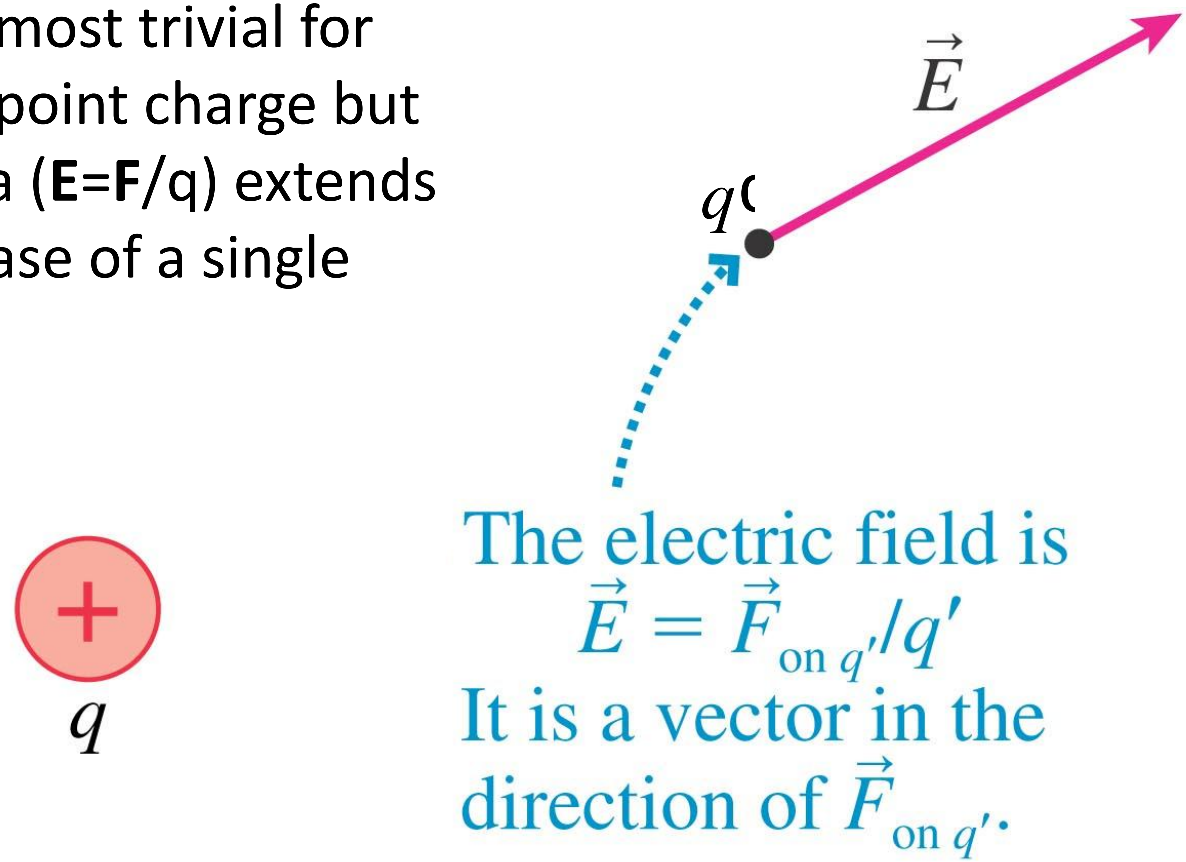




https://metaphysicien.wordpress.com/2014/09/24/whats-wrong-with-gravity/

How do we calculate Electric field?

This seems almost trivial for the field of a point charge but the same idea (**E**=**F**/q) extends beyond the case of a single point charge

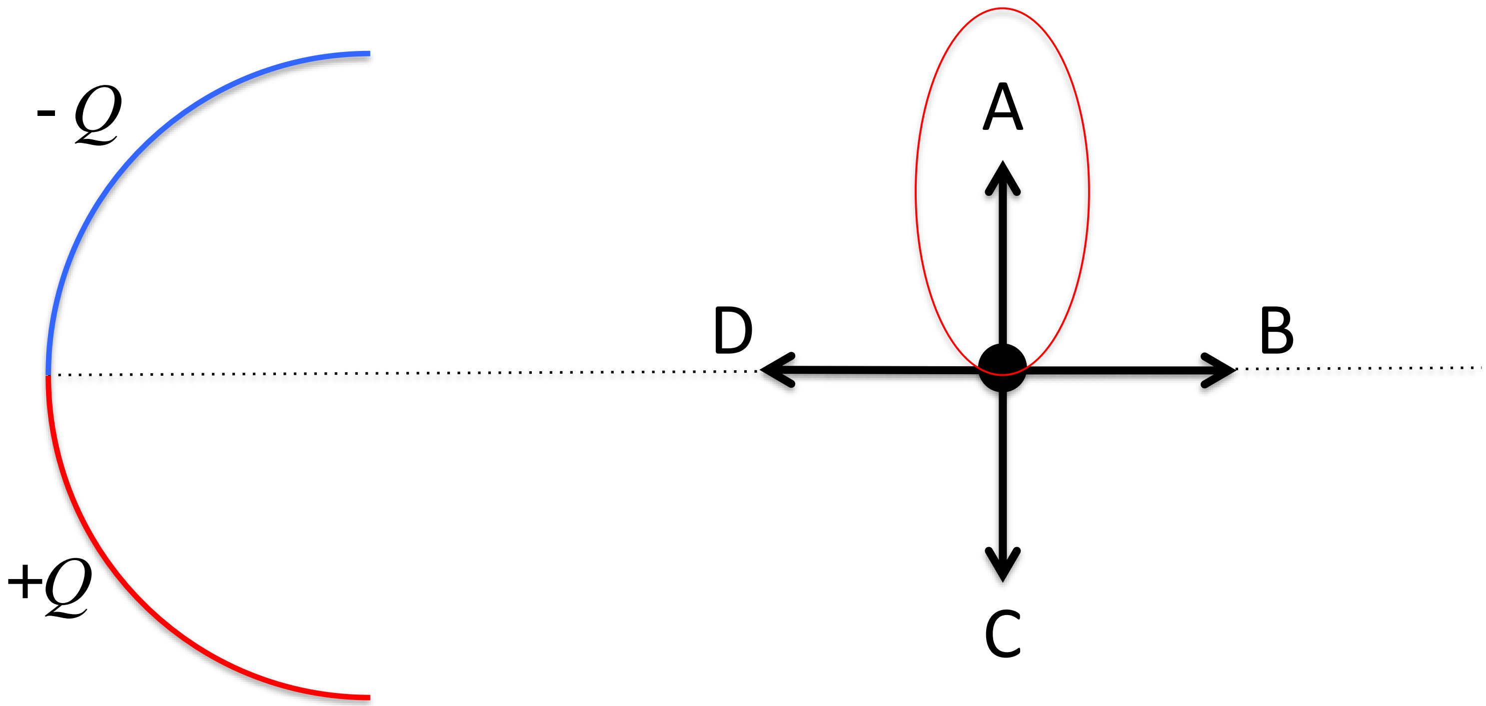


Charge q is the source of the field.

q' is a small + charge that we used to probe the field.

Practice Yourself Question!

What is the direction of the electric field at the point indicated?



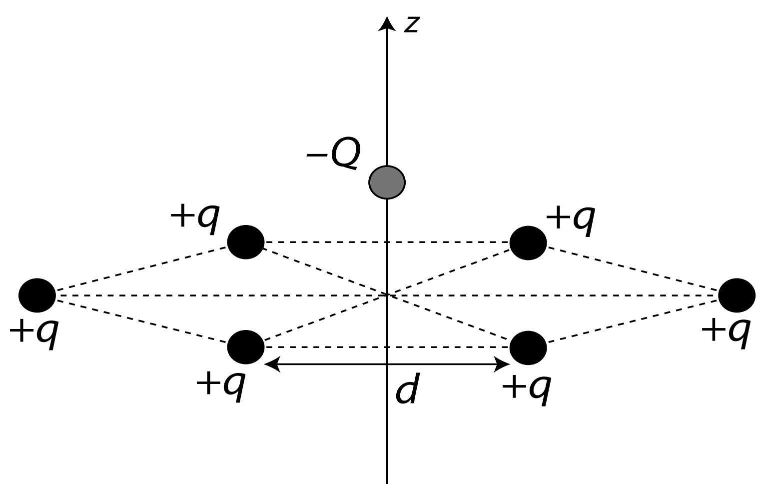
Crystalline solids have their atoms arranged in highly symmetric arrays called lattices. The triangular lattice structure of a particular solid is shown in the diagram below: there are six positive charges arranged in a hexagon with side length *d* and the solid is doped with an atom carrying a negative charge $-Q$ at the middle site whose height above the lattice plane is *h*.

a) Choose two charges that are diametrically opposite each other: which components of the electrostatic force on $-Q$ will cancel and which components will add together? Hint: this is a 2-dimensional problem.

b) What is the magnitude and direction of the force on $-Q$ due only to these two charges?

c) What is the magnitude and direction of the **net force** acting on $-Q$ from all six charges?

d) What is the net force on $-Q$ when $h \ll d$? ~~What about when $h \gg d$?~~



Top view