Wednesday Jan 11, 2017
part 2

Last time

- The language of science and the importance of being specific
- Forces in nature, electromagnetism
- Introduction to electric charge. What is it?
- Recent developments in physics (neutrinos)

This time

- Atomic structure: insulators and conductors
- Charging macroscopic objects via friction
- Balloon demo
- The electrostatic force: Coulomb's Law

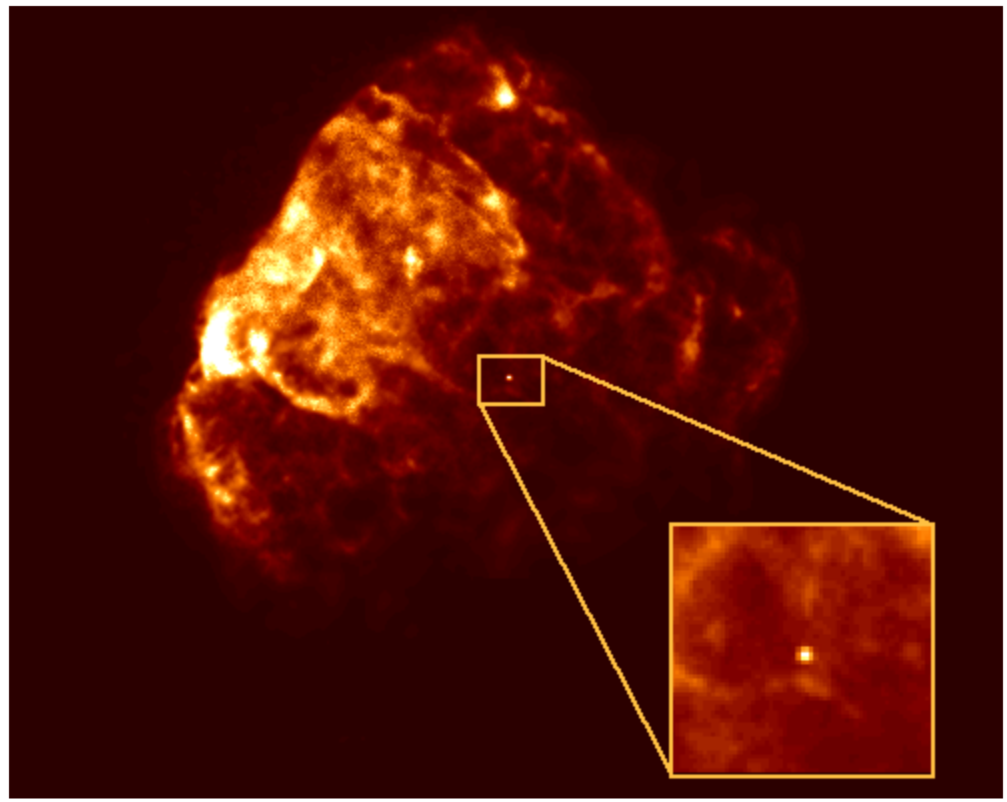
Atoms and Electricity

- 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

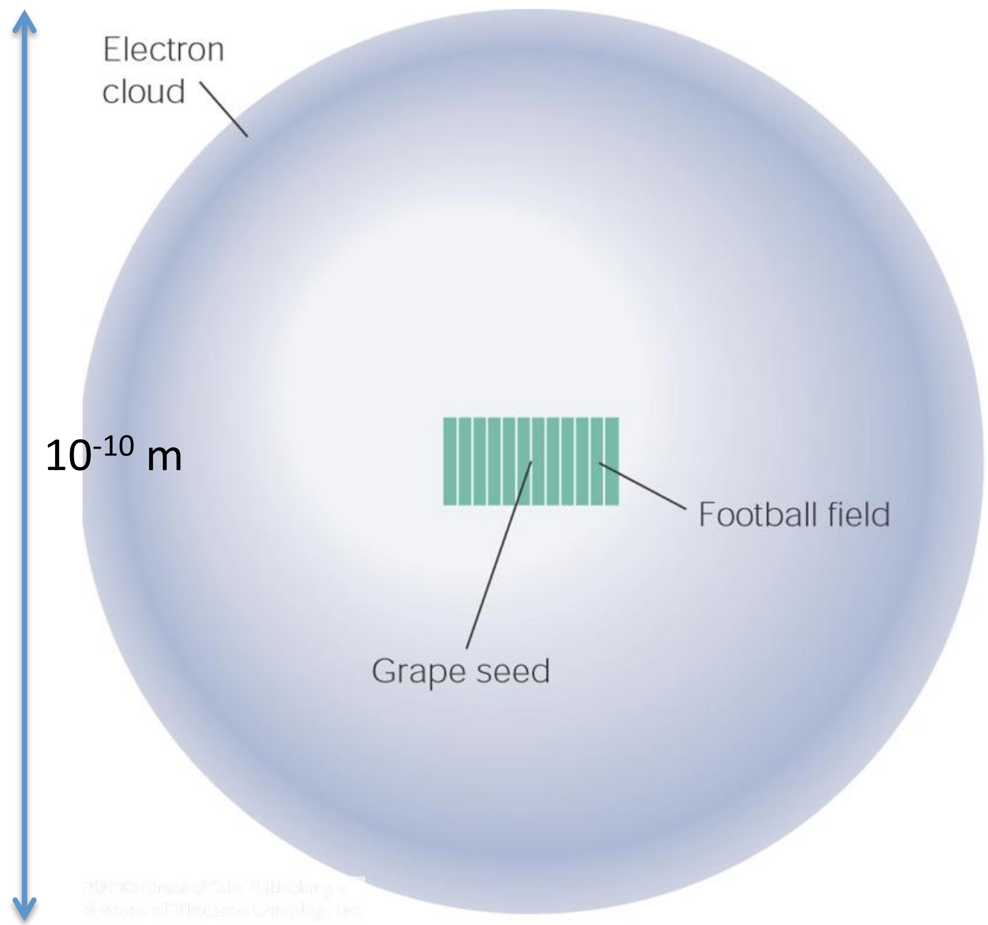
- Neutron Stars are the end point of a massive star's life.
- When a massive star runs out of nuclear fuel in its core, the core begins to collapse under gravity. When the core collapses the entire star collapses. The surface of the star falls down until it hits the now incredibly dense core. It then 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.

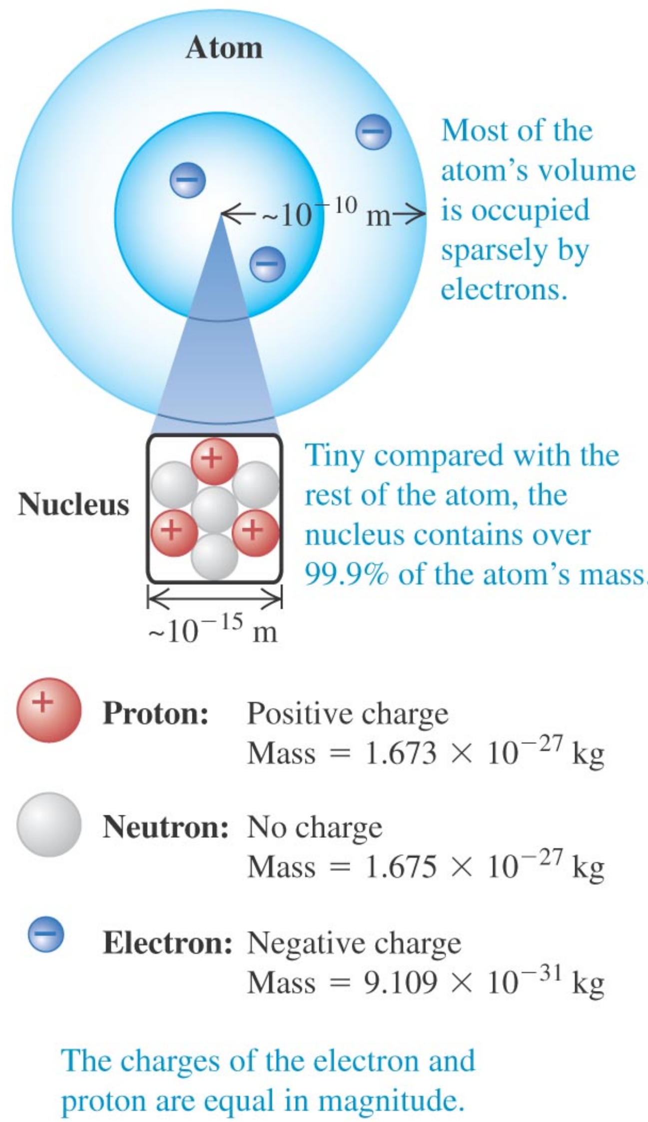
Almost all of the mass is contained in the nucleus, while almost all of the space is occupied by the electron cloud.



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.

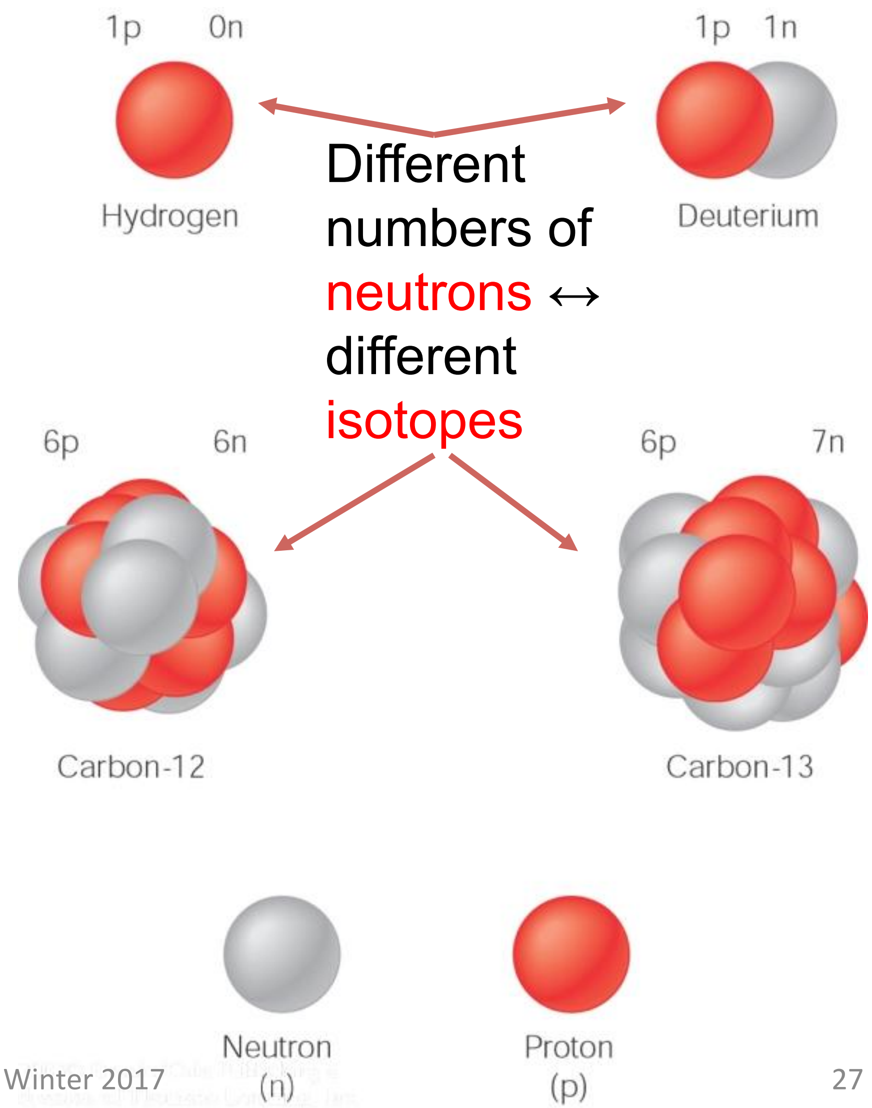


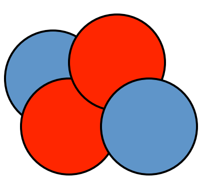
Different Kinds of Atoms

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.).





The nucleus of Helium 4 is called α particle.

Quantization of electric charge

Electric charge is *quantized*.

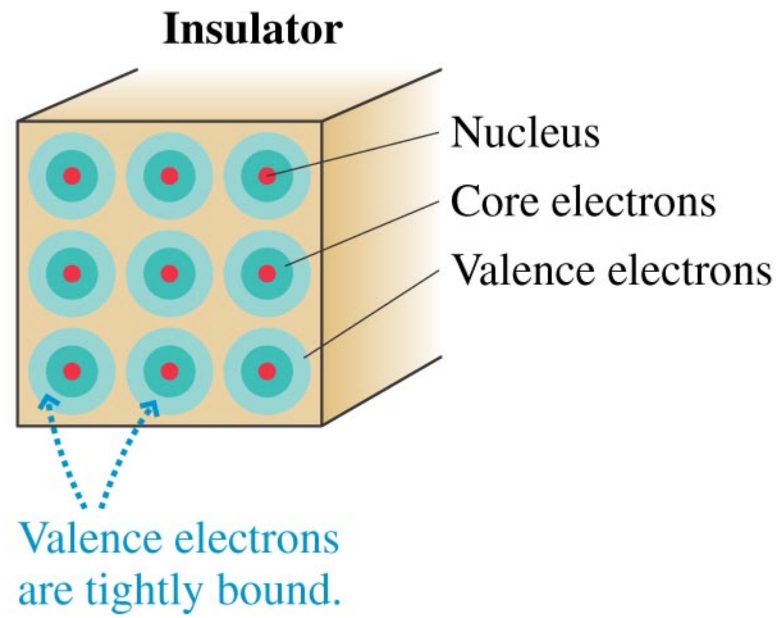
Charge always comes in some integer multiple of some fundamental charge e, which is the charge of electron.

Electric charge comes in discrete packets.

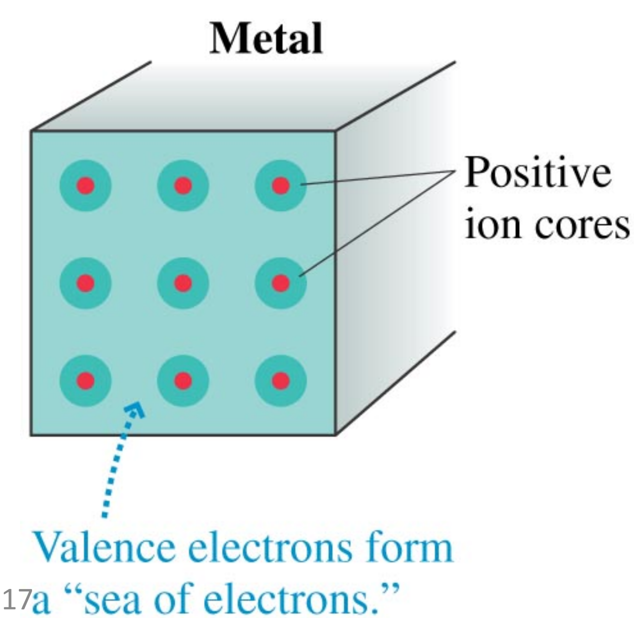
Light comes in discrete packets too, photons.

$$E = hf$$

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



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



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PERIODIC TABLE OF THE ELEMENTS

http://www.periodni.com

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

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

STANDARD STATE (25 °C; 101 kPa)
Ne - gas · Fe - solid
Hg - liquid · Tc - synthetic

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

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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

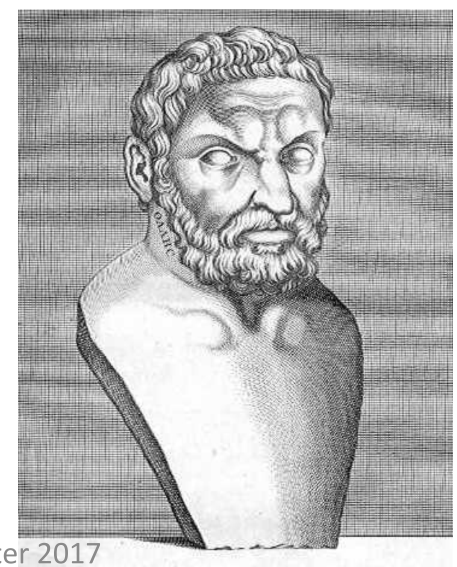
(1) Pure Appl. Chem., **81**, No. 11, 2131-2156 (2009)
Relative atomic masses are expressed with five significant figures. For elements that have no stable nuclides, the value enclosed in brackets indicates the mass number of the longest-lived isotope of the element. However three such elements (Th,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

Generating electric charge

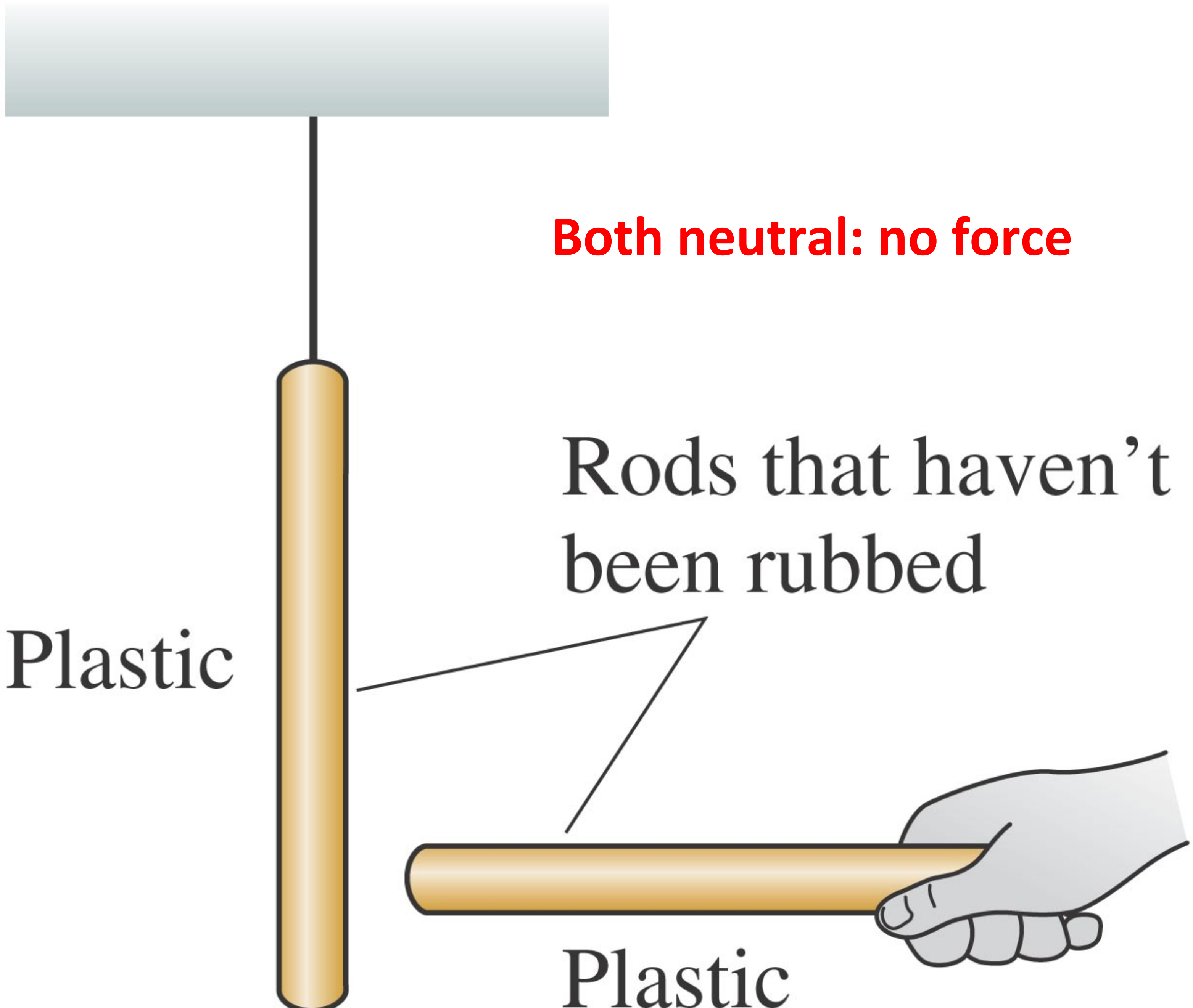
Because friction is due to bonds between the atoms of two surfaces, when those bonds are broken charges can be transferred from one surface to another.

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

Thales of Miletus 600 BCE



Both neutral: no force



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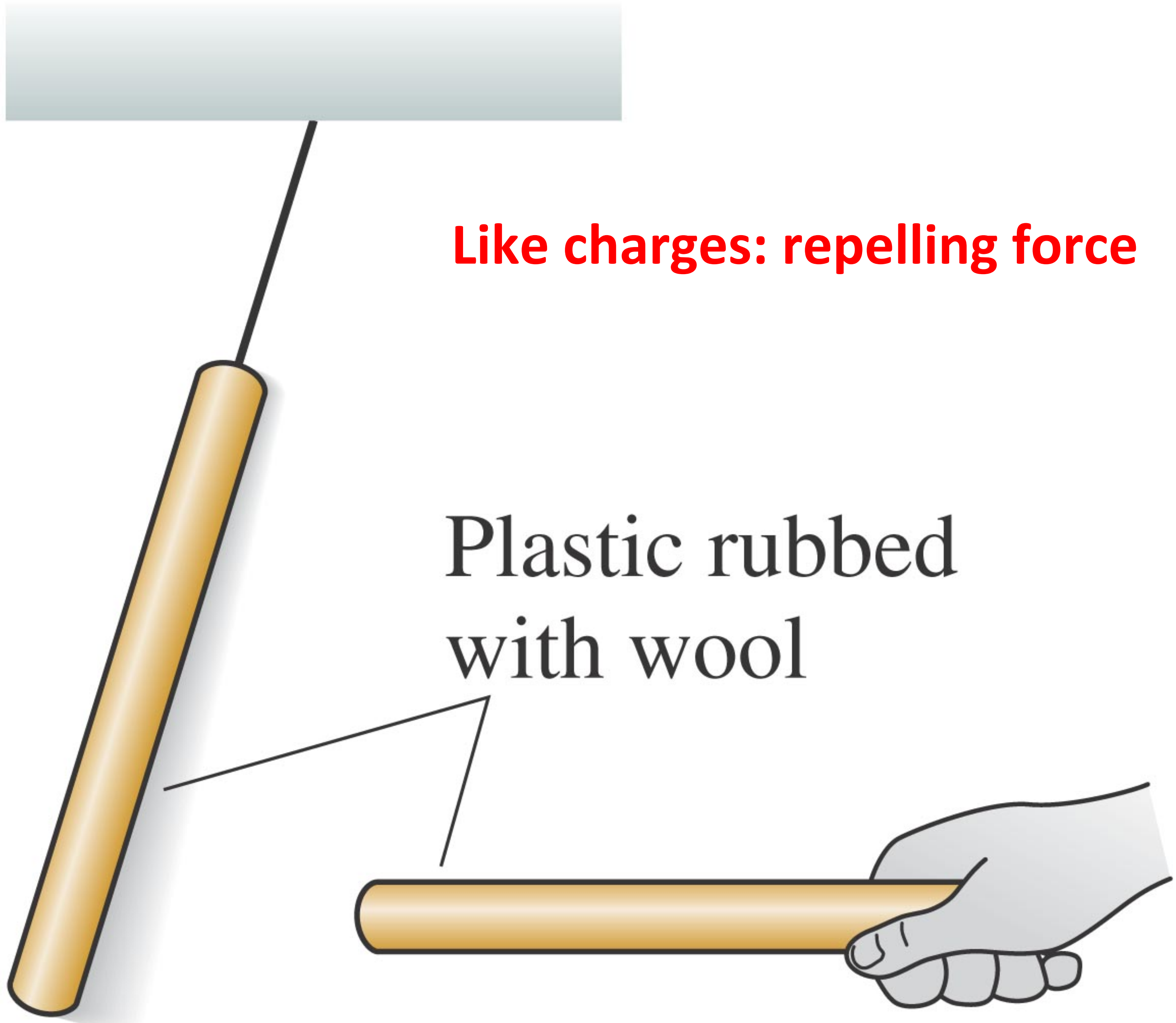
Like charges: repelling force



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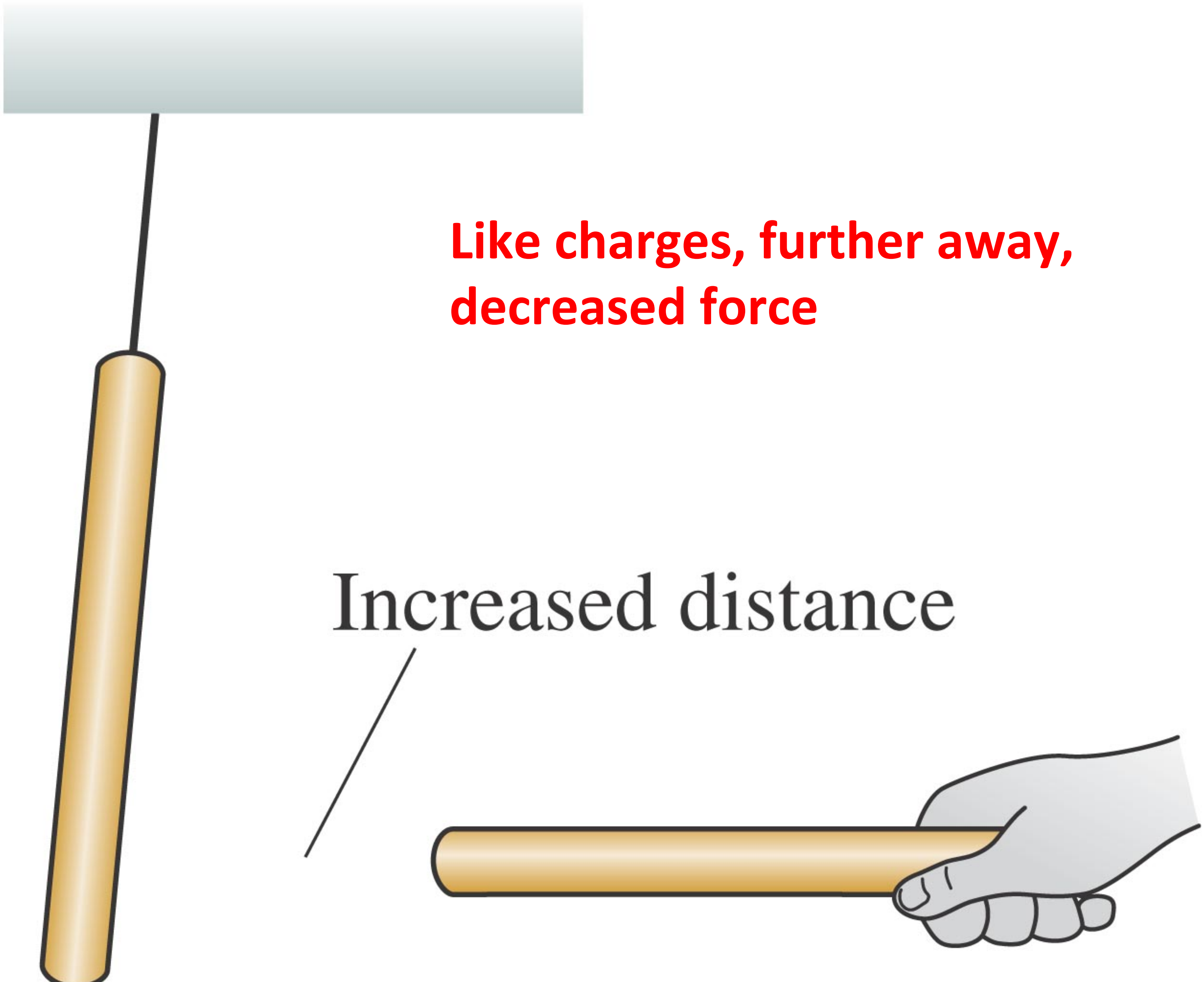
Like charges, further away, decreased force



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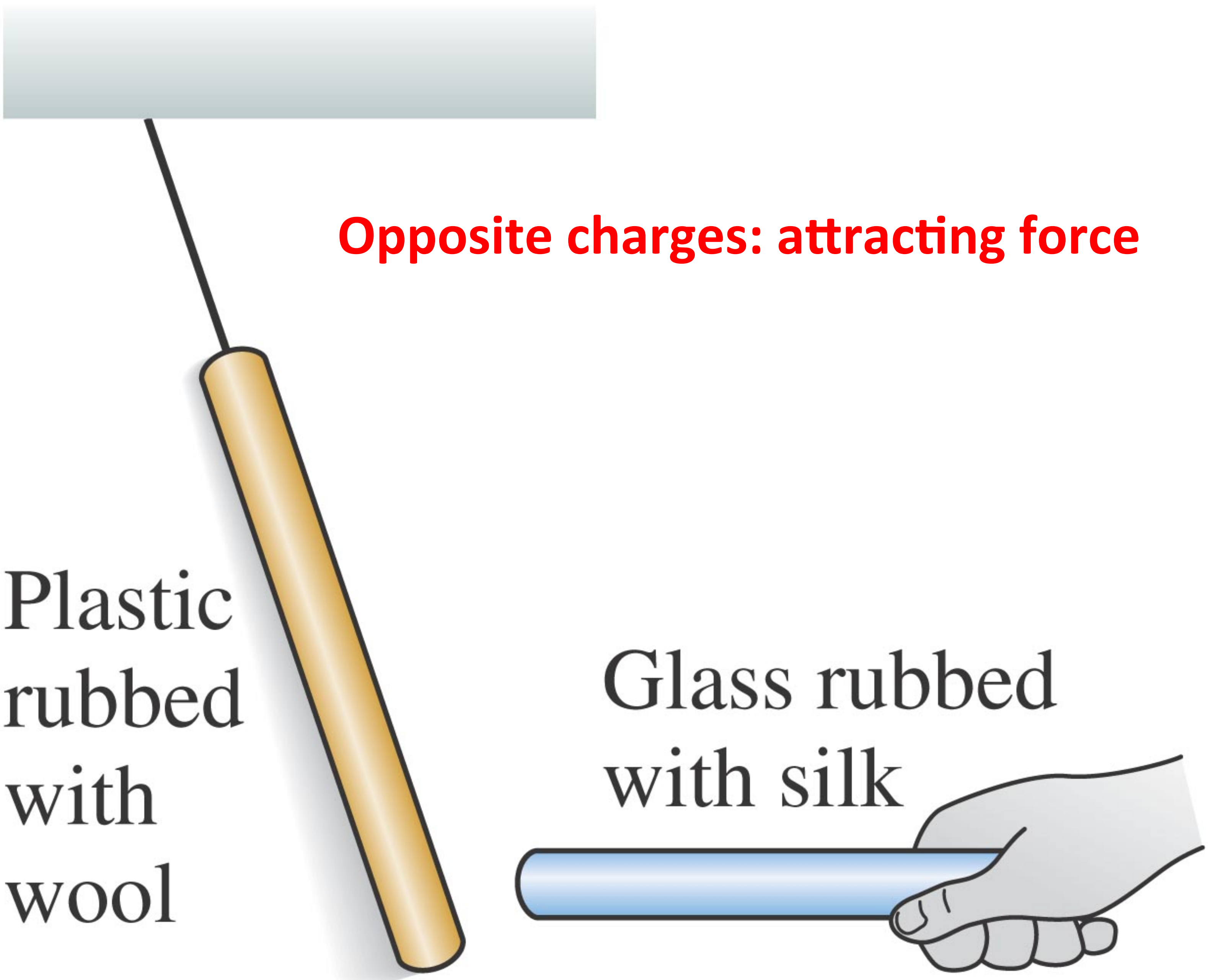
Opposite charges: attracting force



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Balloon demo
(Yay! Everyone loves balloons!)

Doesn't love balloons

What is going on in these two cases?

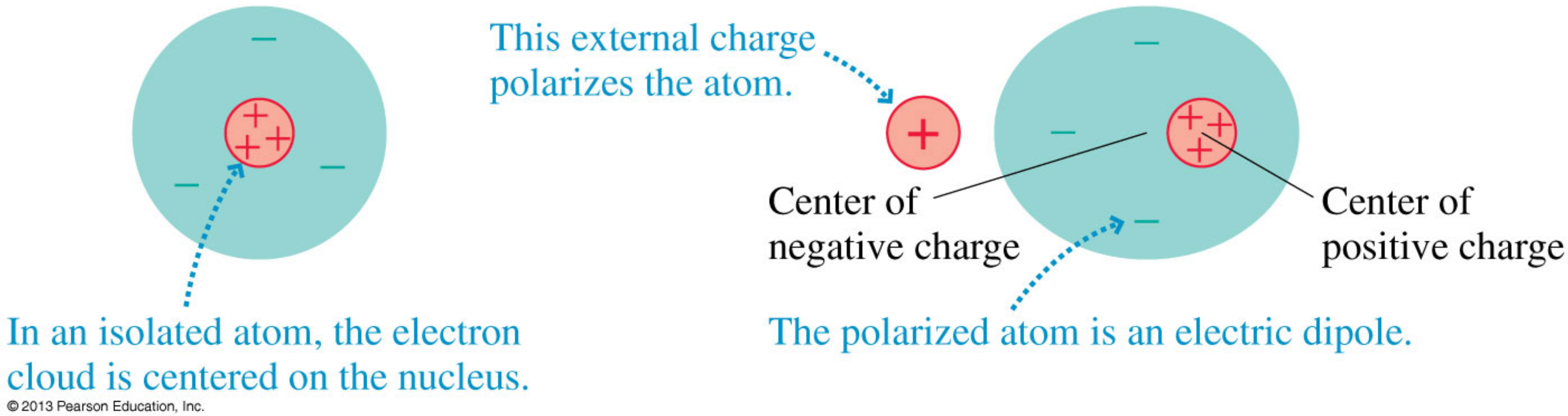
Balloon on hair: easy! Balloon and hair rub together, become oppositely charged, attract each other.

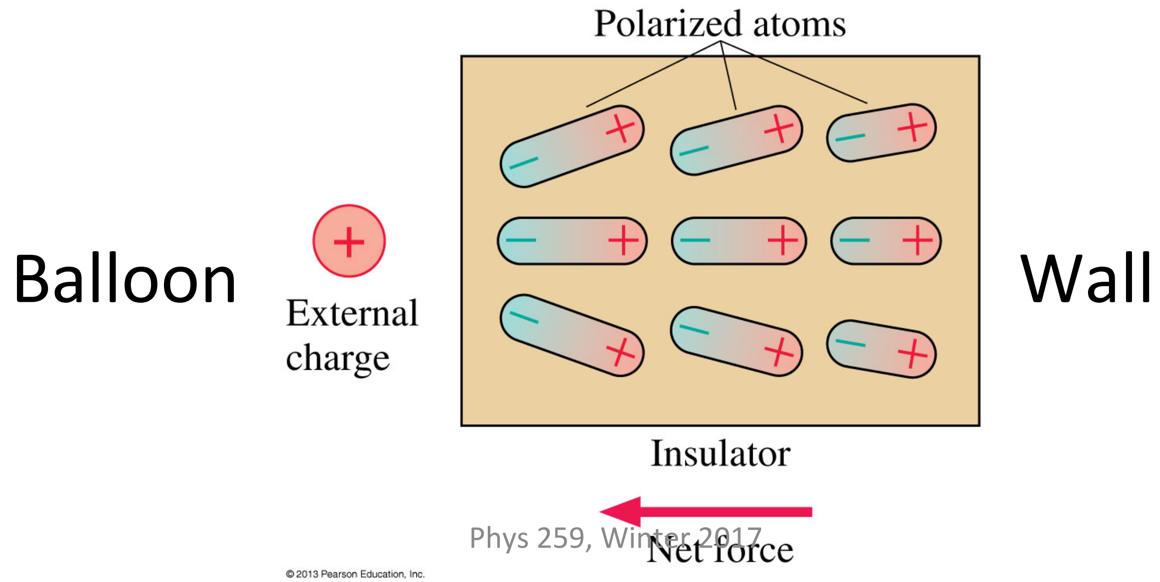
Balloon on wall: is the wall charged?

NO!

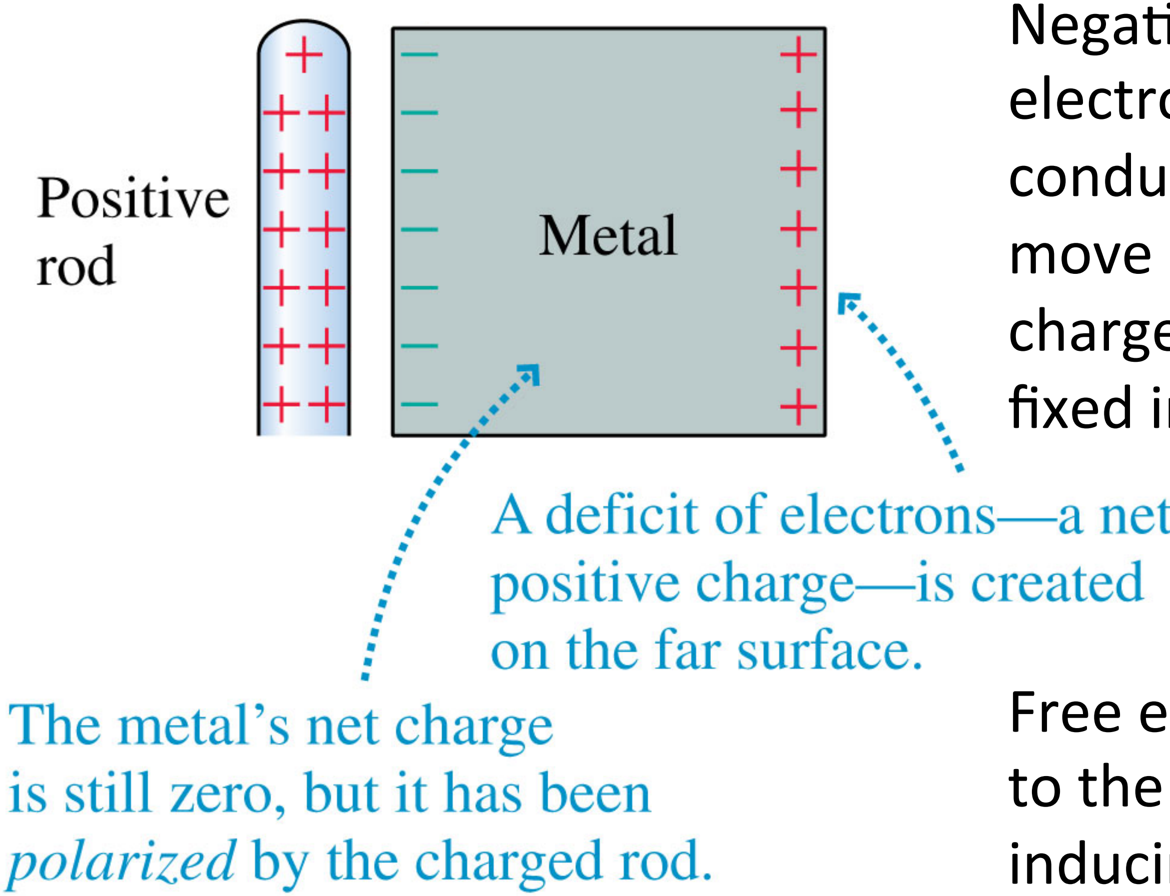
So why does the balloon stick to the wall?

Charge Polarization





What happens with conductors?



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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

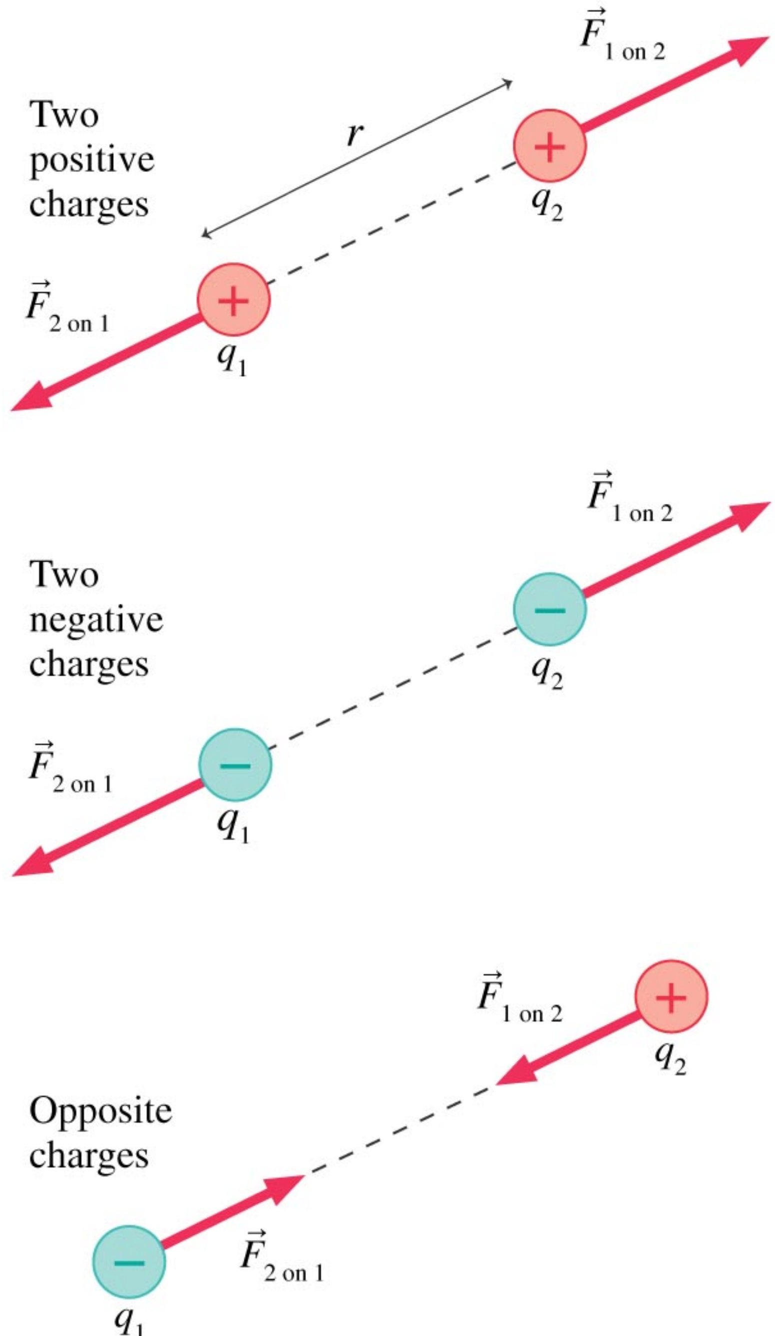
HOW CAN WE QUANTIFY THIS?

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.



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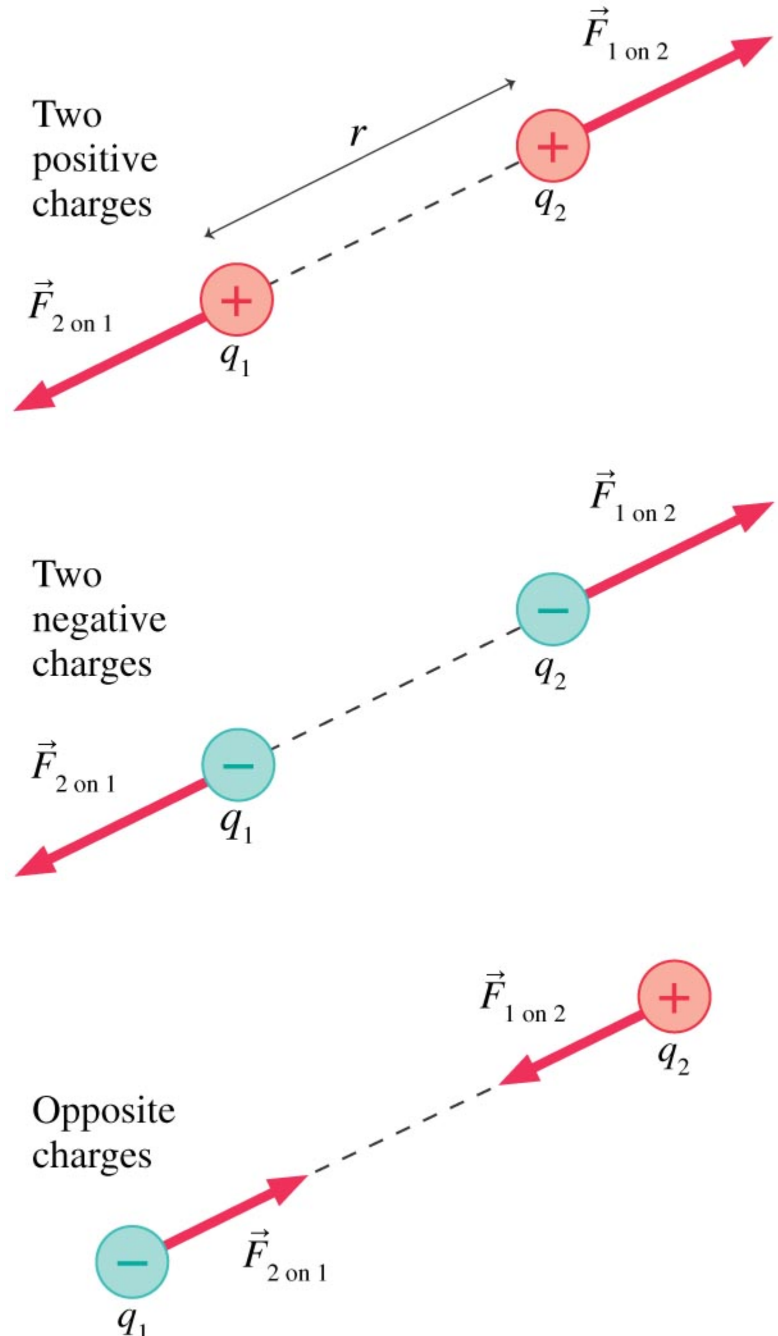
Coulomb's Law

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.



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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

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

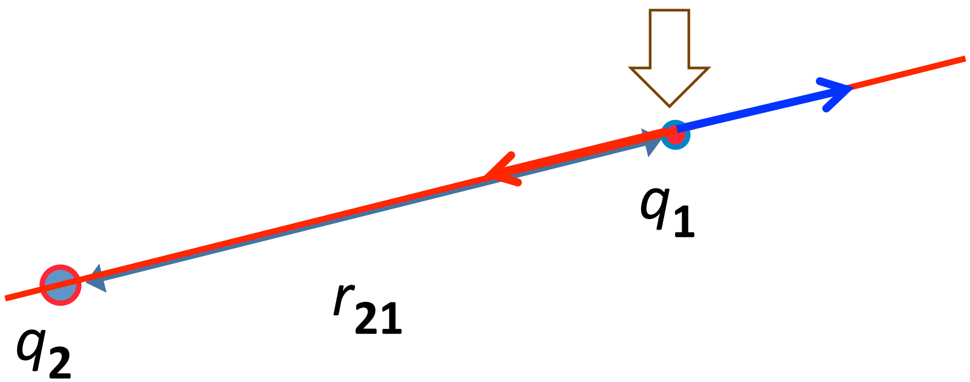
$$\boxed{F_{1\,on\,2} = F_{2\,on\,1} = \frac{1}{4\pi\varepsilon_0}\frac{|q_1||q_2|}{r^2}}$$

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!!**

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

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

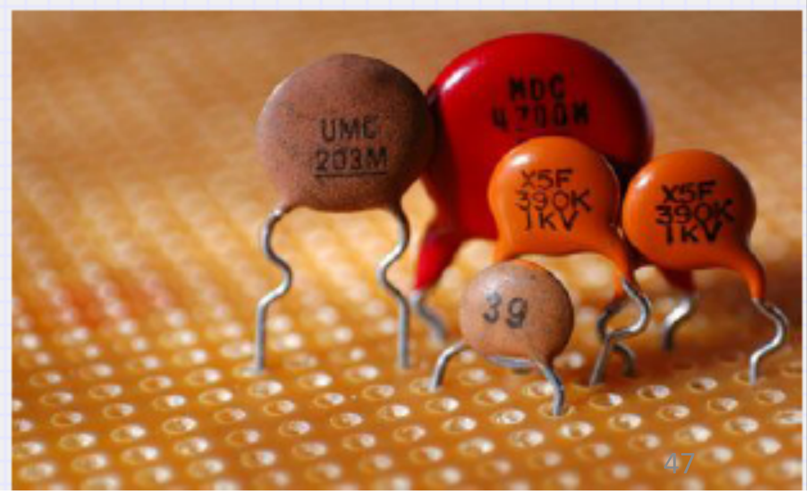
An average bolt of lightning

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 ($N_+ = N_-$).