Lecture 03: 01/23/2024

- Announcements
  Recitation – Do written HW #1
  Clickers – Count beginning today
  Written HW due Thursday midnight
  Make your exam reference while doing homeworks

- Homework challenges and exams
- Electrostatics
  - Types of charge
  - Tribocharging
  - Insulators and Conductors
  - Coulomb's Law
    Superposition

iClicker

- We will start using iClicker cloud today.
- Go to www.iclicker.com and "Create an account"
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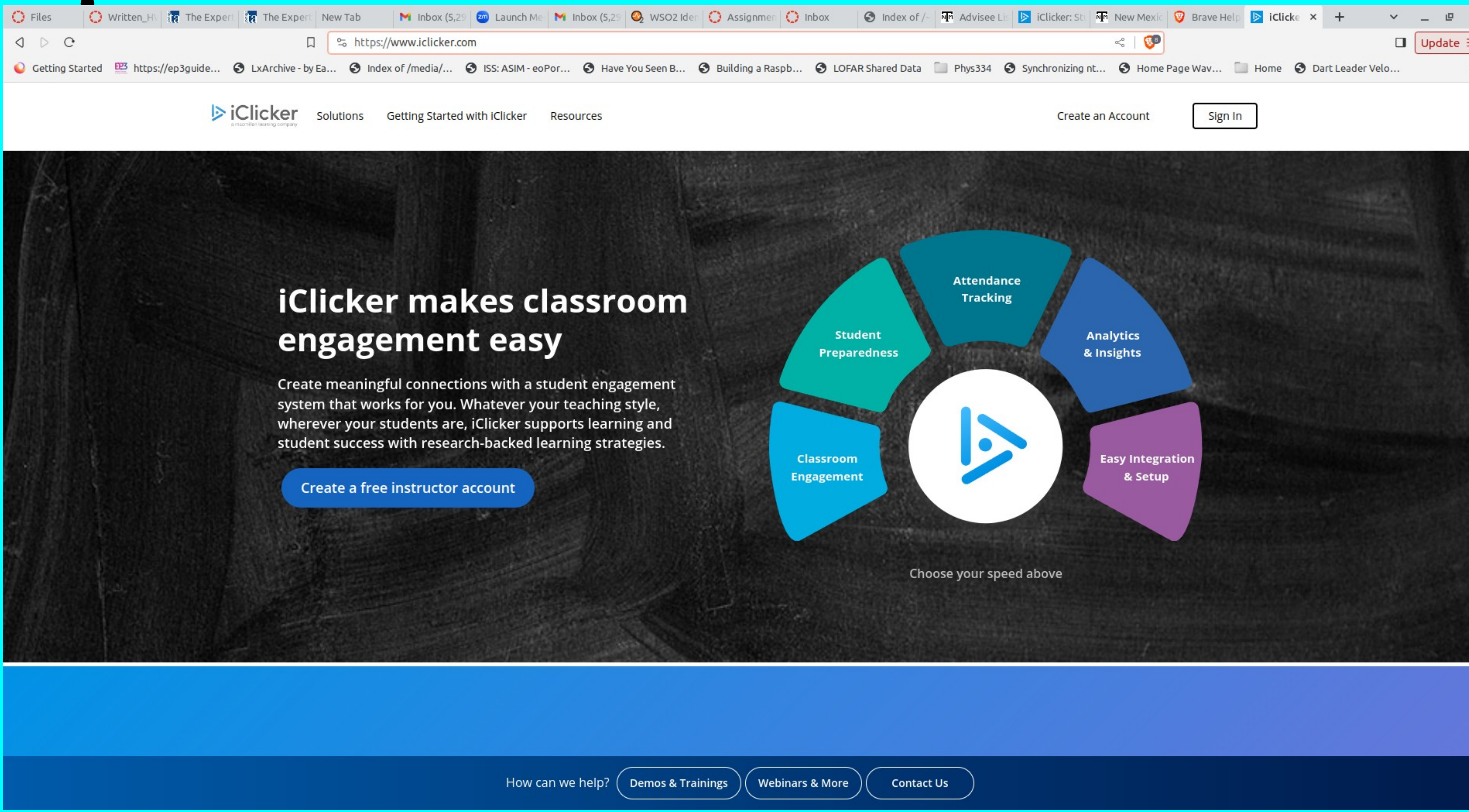


Key Equations

Wave speed	$v = \frac{\lambda}{T} = \lambda f$
Linear mass density	$\mu = \frac{\text{mass of the string}}{\text{length of the string}}$
Speed of a wave or pulse on a string under tension	$\lvert v \rvert = \sqrt{\frac{F_T}{\mu}}$
Speed of a compression wave in a fluid	$v = \sqrt{\frac{B}{\rho}}$
Resultant wave from superposition of two sinusoidal waves that are identical except for a phase shift	$y_R(x,t) = \left[2A\cos\left(\frac{\phi}{2}\right)\right]\sin\left(kx - \omega t + \frac{\phi}{2}\right)$
Wave number	$k \equiv \frac{2\pi}{\lambda}$
Wave speed	$v = \frac{\omega}{k}$

A periodic wave	$y(x,t) = A\sin(kx \mp \omega t + \phi)$
Phase of a wave	$kx \mp \omega t + \phi$
The linear wave equation	$\frac{\partial^2 y(x,t)}{\partial x^2} = \frac{1}{v_w^2}\frac{\partial^2 y(x,t)}{\partial t^2}$
Power averaged over a wavelength	$P_{\text{ave}} = \frac{E_\lambda}{T} = \frac{1}{2}\mu A^2\omega^2\frac{\lambda}{T} = \frac{1}{2}\mu A^2\omega^2 v$
Intensity	$I = \frac{P}{A}$
Intensity for a spherical wave	$I = \frac{P}{4\pi r^2}$
Equation of a standing wave	$y(x,t) = [2A\sin(kx)]\cos(\omega t)$
Wavelength for symmetric boundary conditions	$\lambda_n = \frac{2}{n}L, \quad n = 1,2,3,4,5\ldots$
Frequency for symmetric boundary conditions	$f_n = n\frac{v}{2L} = nf_1, \quad n = 1,2,3,4,5\ldots$

Summary

A possible exam problem: (similar to online #9)

Problem requires that two formulae be put together

A guitar string of length 0.900 m is under a tension of 120.0 N. The string is made of steel. The radius of the string is 1.00 mm. What is the velocity of a transverse wave on the string?

$v = \sqrt{\frac{T}{\mu}}$ $T = 200 N$

$L = .9 m$ $T = 120 N$

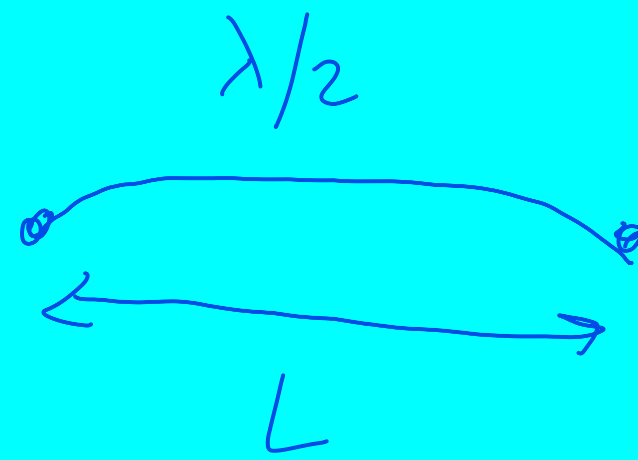
$r = 1.00 mm$ $v = f\lambda$ $v = \frac{\omega}{k}$

A harder exam problem: (similar to online #9)

Problem requires that three formulae be put together

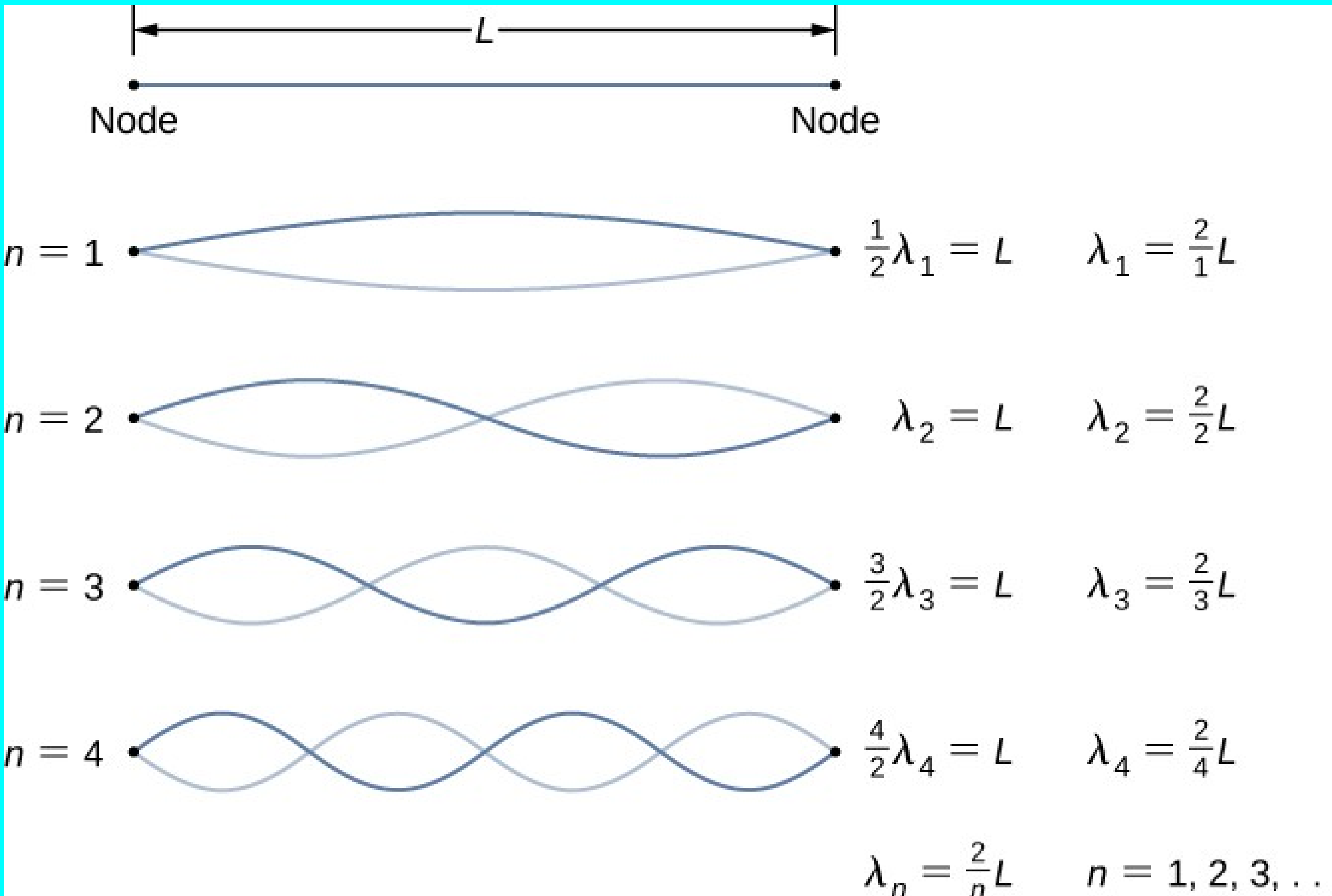
A guitar string of length 0.900 m is under a tension of 120.0 N. The string is made of steel. The radius of the string is 1.00 mm. What is the frequency of the fundamental tone?

$v = f\lambda$ $\qquad$ $v = \sqrt{\frac{T}{\mu}}$

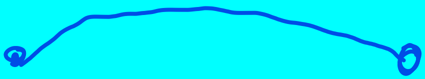


Standing Waves

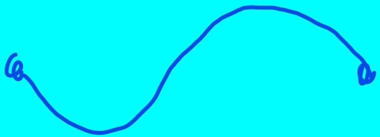
If you create a wave with fixed ends, it can only have certain wavelengths



$\lambda/2$



L

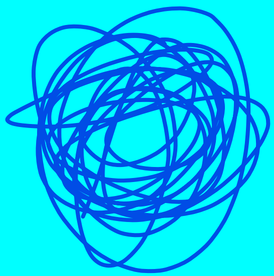


$\lambda = L$

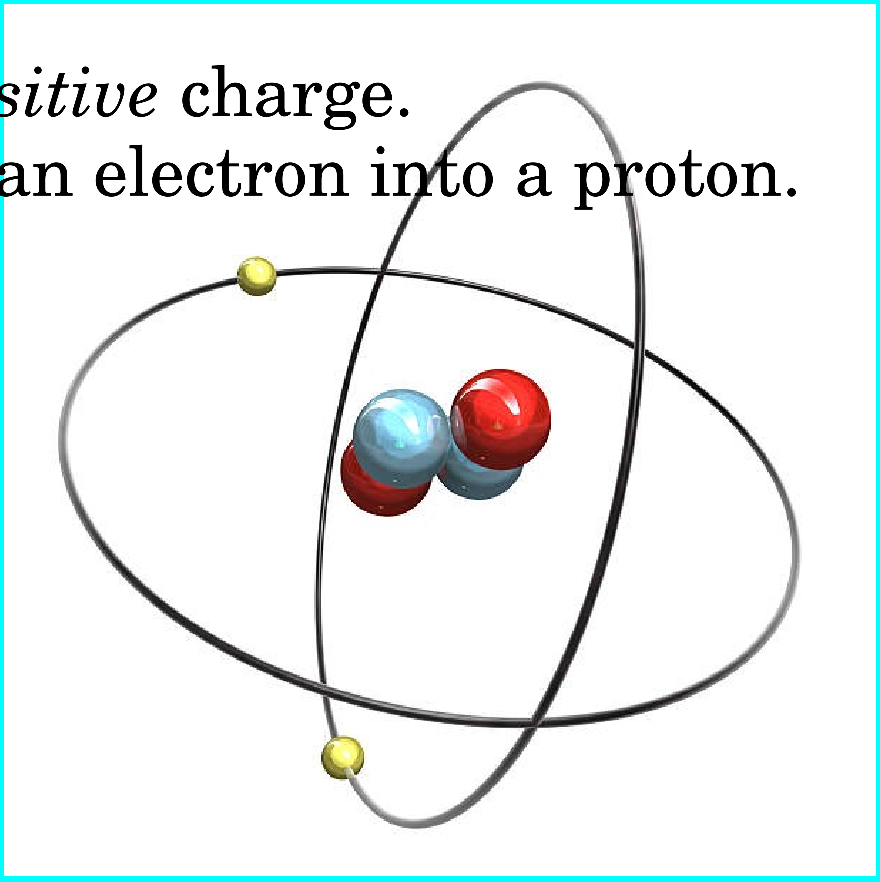
Charge!

An electron carries the smallest possible charge.
Called “fundamental charge”
also q_e or just 'e'

$|e| = 1.602 \times 10^{-19}$ Coulombs



Electrons carry *negative* charge.
Protons carry the exact same *positive* charge.
Neutrons are made by crashing an electron into a proton.



Why do protons have the exact same charge as electrons?

Units1 – The SI unit of force is the:

[A] Pound

[B] gram

[C] Dyne

[D] kilogram

[E] Newton

Units2 – The SI unit of mass is the:

[A] Pound

[B] gram

[C] Dyne

[D] kilogram

[E] Newton

Units3 – The SI unit of charge is the:

[A] Volt

[B] Coulomb

[C] Ampere

[D] electron volt (eV)

[E] gram

You have 10,000 protons. How many Coulombs is this?

[A] 1 mole

[B] 10,000

q_e [C] $1.602 \times 10^{-19} = e$

[D] 1.602×10^{-15}

[E] an Ampere-second

You can transfer charge to an insulator
by rubbing it. (Rubbing glass with
silk makes it "positive")

You can rub a charged insulator on a
Conductor to transfer charge to it.

You can charge a conductor by "induction"

You can create a force on a neutral
object by polarization.

Triboseries

THESE CHARGE POSITIVE

acrylic (lucite, plexiglas)
glass
wool
silk
nylon
cotton
amber
hard rubber
saran-wrap
Teflon

THESE CHARGE NEGATIVE
(When rubbed on something higher)

Amber, or "Elektrum" from which we get "Electron" and "Electricity"

DEMOS!

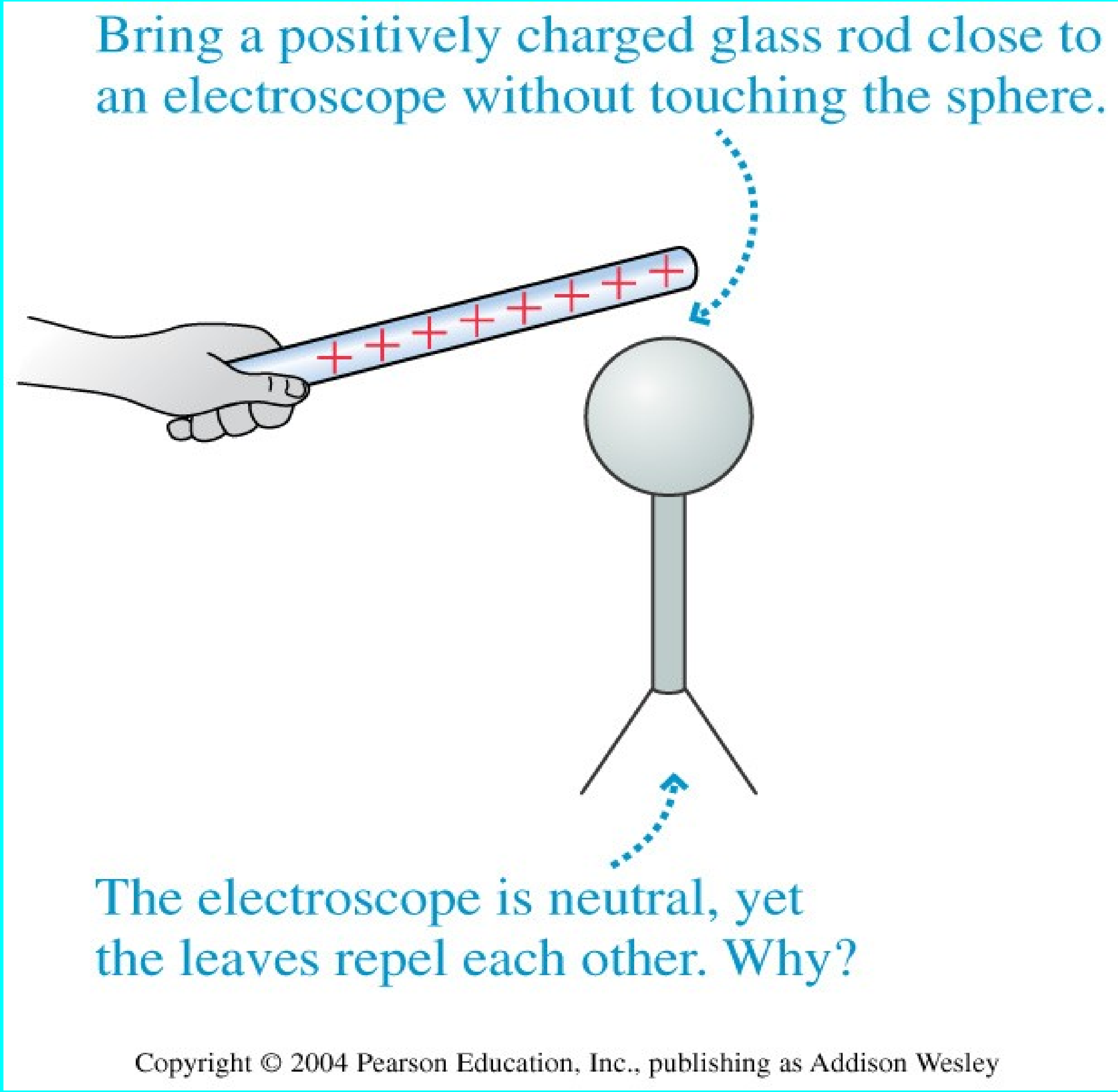
DEMOS!

Soda can magic

Electroscope two types of charge

Induced Charge

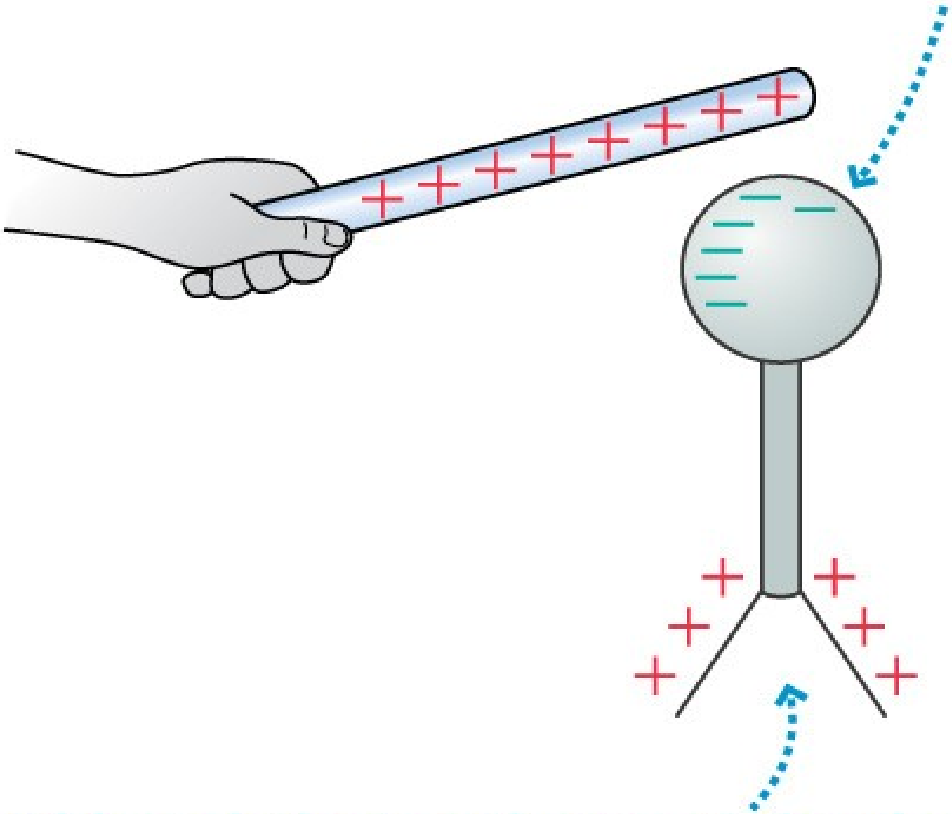
Electric Forces on Metals - I



Electric Forces on Metals - II

(b)

The electroscope is polarized by the charged rod. The sea of electrons shifts toward the rod.



Although the net charge on the electroscope is still zero, the leaves have excess positive charge and repel each other.

Modern Electricity

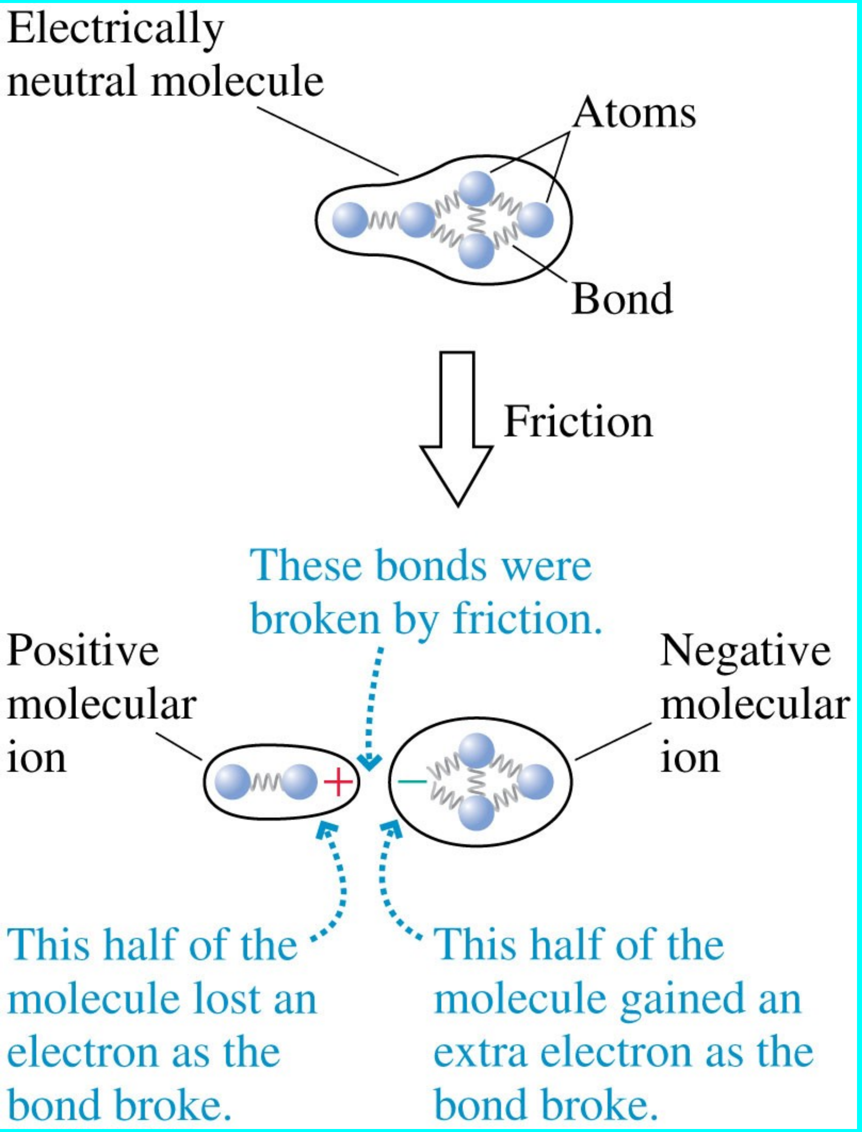
You can transfer charge to an insulator by spraying ions generated by a large electric field. (photocopiers / laser printers)

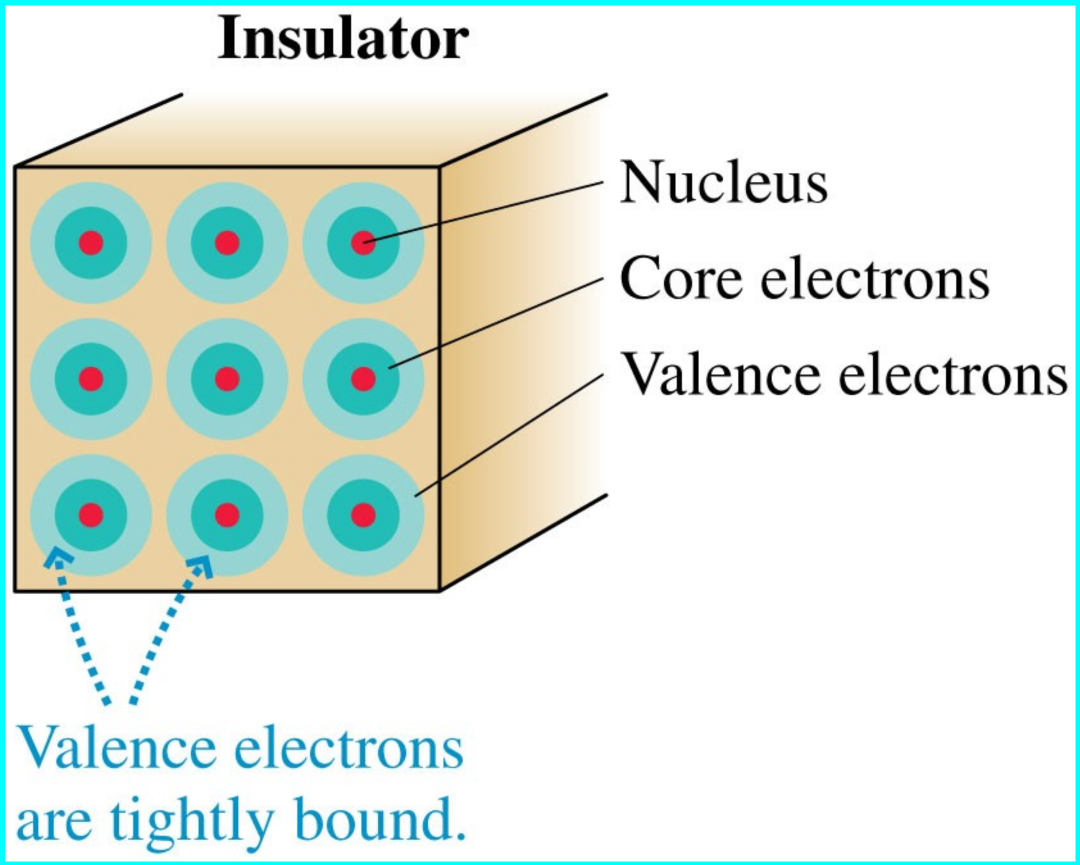
You can transfer charge
to a conductor by connecting it to another conductor at higher voltage.
(battery or power supply)

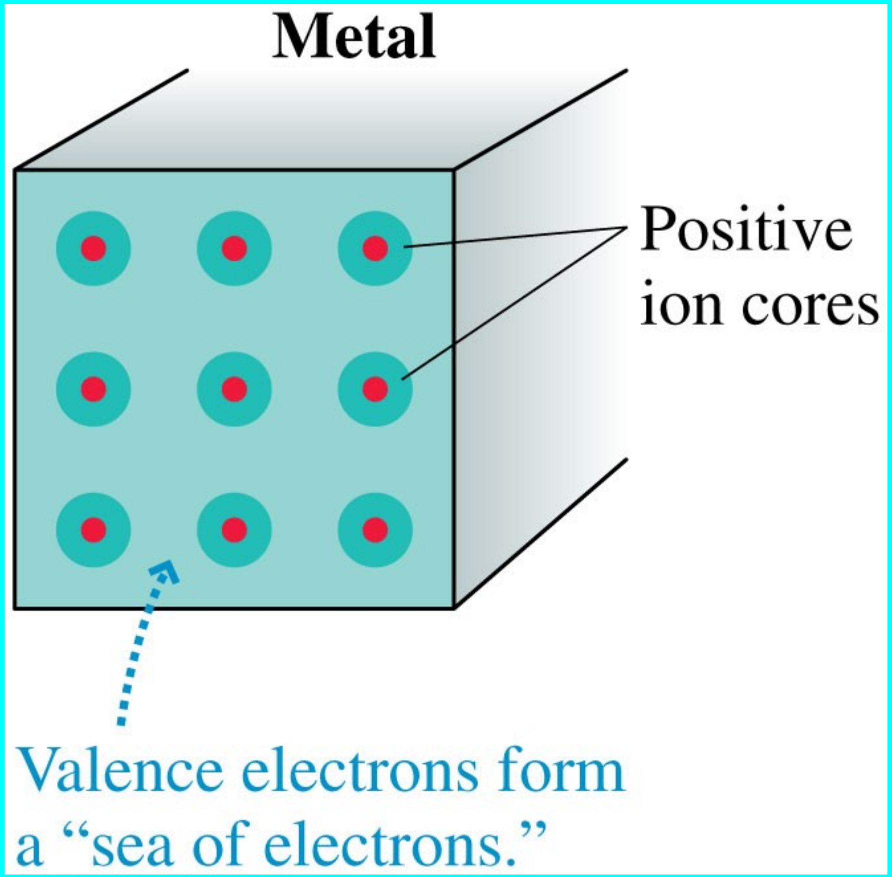
You can still do Ben Franklin things … rubbing breaks molecular bonds

How Tribocharging Works

- *Molecular ions* can be created when one of the bonds in a large molecule is broken.
- This is the way in which a plastic rod is charged by rubbing with wool or a comb is charged by passing through your hair.

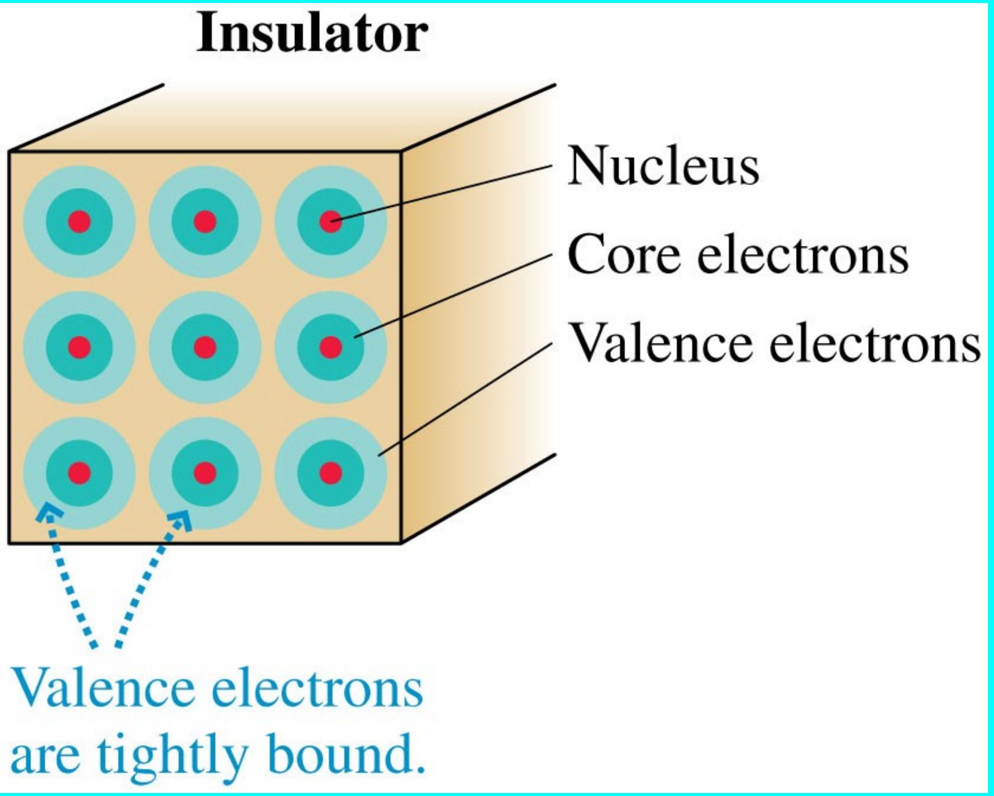



Insulator
Nucleus
Core electrons
Valence electrons
Valence electrons
are tightly bound.


Metal
Positive
ion cores
Valence electrons form
a "sea of electrons."

Insulators

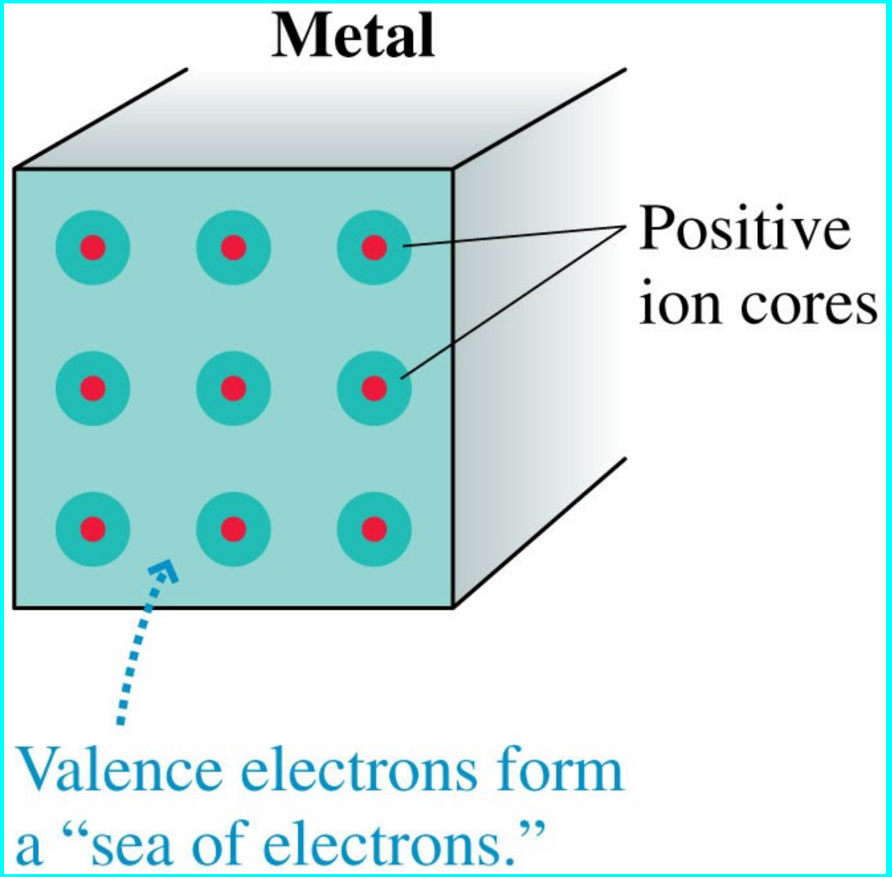
- The electrons in an **insulator** are all tightly bound to the positive nuclei and **not free** to move around.
- Charging an insulator by friction leaves patches of molecular ions on the surface, but these patches are immobile.



Conductors

- In metals, the outer atomic electrons are only weakly bound to the nuclei.

- These outer electrons become detached from their parent nuclei and are free to wander about through the entire solid.



- The solid *as a whole* remains electrically neutral, but the electrons are now like a negatively charged liquid permeating an array of positively charged **ion cores**.

You rub a teflon with rabbits fur and make it negatively charged.

[A] The negatively charged teflon rod weighs slightly more than in did before it was rubbed and the rabbits fur a bit less.

[B] Neither material changes its weight.

[C] Both materials are lighter than before

[D] The teflon is lighter than it was

[E] Don’t be silly, any weight change would be indetectable.

Which is correct?

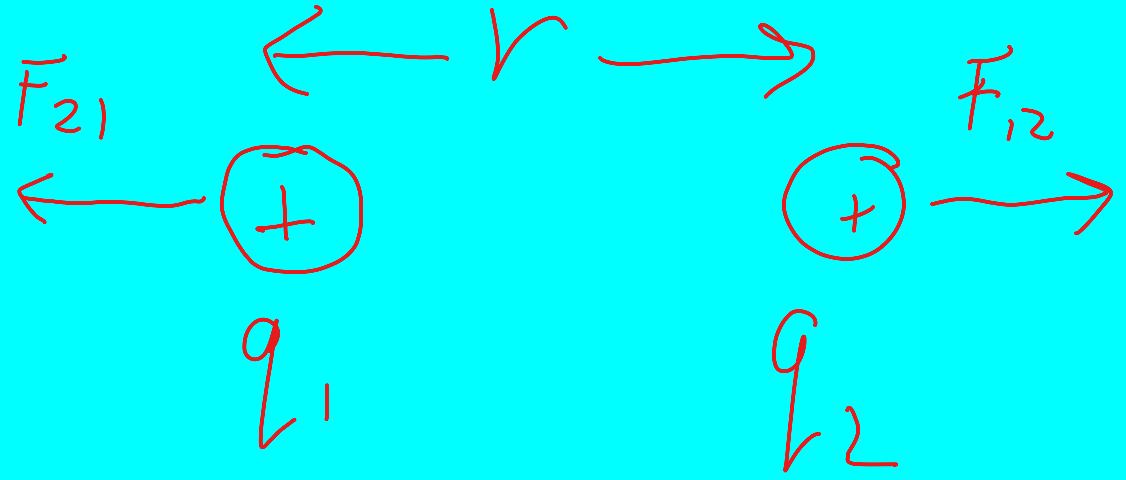
[A] Only electrical conductors may be charged

[B] Only electrical insulators may be charged

[C] Both conductors and insulators may be charged

[D] You can't charge anything, only polarize it.

Coulomb's Law



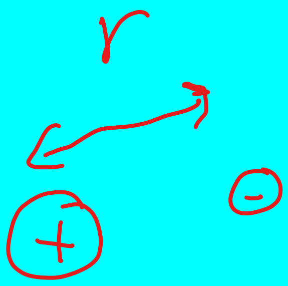
$$F = k\frac{q_1 q_2}{r^2}$$

$$k = 8.99 \times 10^9 \frac{N\,m^2}{C^2}$$

$$F = \frac{1}{4\pi\epsilon_0}\frac{q_1 q_2}{r^2}$$

k

What is force between electron & Proton in hydrogen?



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

$$F = (9.00\times10^{9})\frac{(1.6\times10^{-19})(1.6\times10^{-19})}{(5.0\times10^{-11}\,m)^2}$$

$$= \frac{(9)(1.6)^2}{25}\cdot\frac{(10^{9})(10^{-38})}{10^{-22}} \cong 1\times10^{-7}\,N$$

What other law is most similar to Coulomb's Law?

(**A**) Ideal gas Law

(**B**) Newton's 2nd Law

(**C**) Hooke's Law

(**D**) Murphy's Law

(**E**) Newton's Law of Gravitation

Coulomb's Law and Gravitation

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

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

$$k = 8.99 \times 10^9 \frac{N\,m^2}{C^2}$$

$$G = 6.674 \times 10^{-11} N\,m^2/kg^2$$

Why do masses attract?

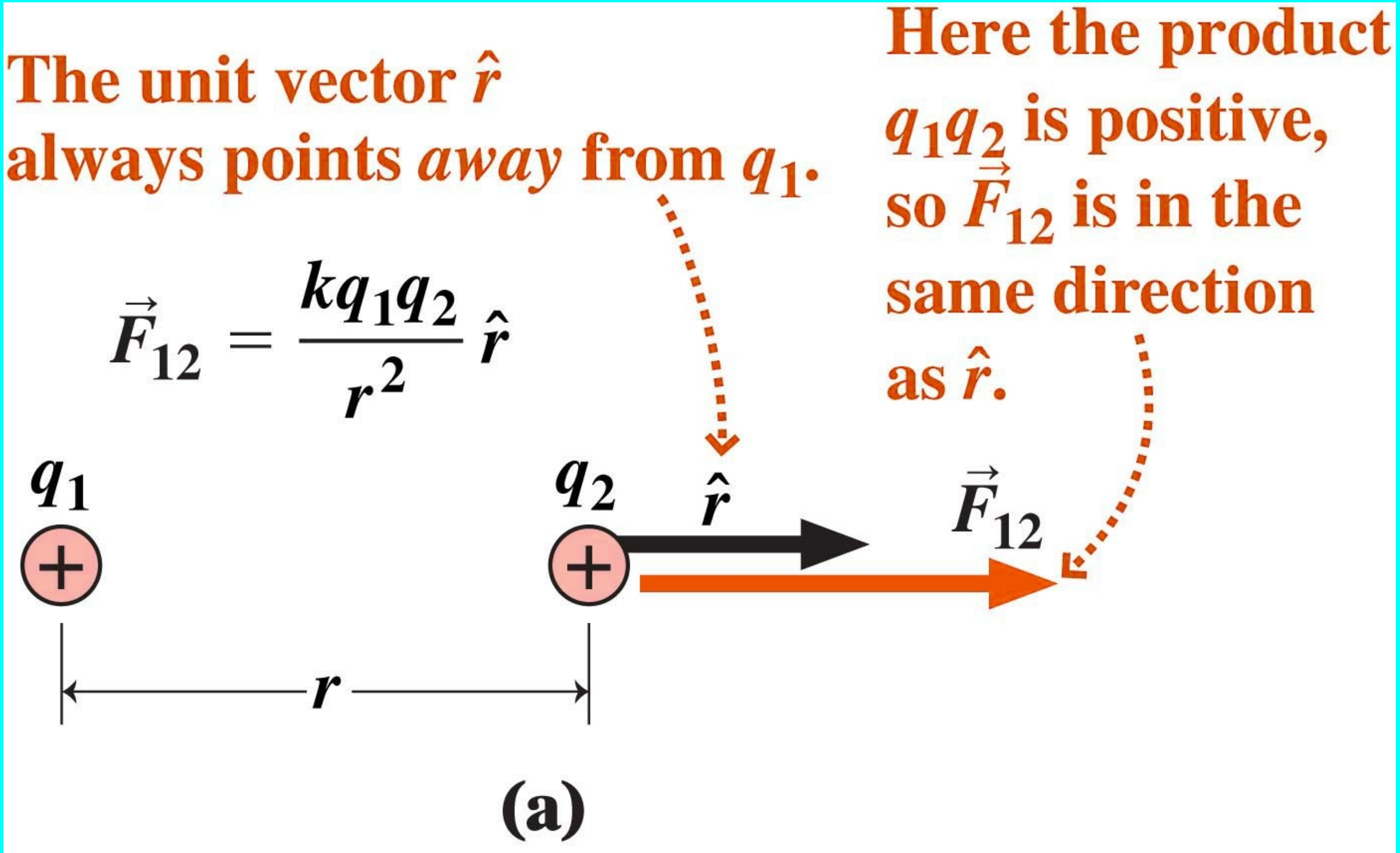
Why do charges attract/repel?

Coulomb's Law, Vector Form

Forces in Hydrogen atom

A hydrogen atom is composed of a proton and an electron with equal charges. The proton has roughly 1800 X the electron mass.
Compare the forces on electron and proton.

(A) The electron feels a greater force because it orbits the nucleus.
(B) The proton feels a greater force because it is larger and has a larger surface area.
(C) Depends on whether the atom is in a molecule.
(D) The electron and proton feel the same force because coulomb's law is symmetrical.


The unit vector $\hat{r}$ always points *away* from q_1.
Here the product $q_1 q_2$ is positive, so $\vec{F}_{12}$ is in the same direction as $\hat{r}$.
$\vec{F}_{12} = \frac{k q_1 q_2}{r^2} \hat{r}$
q_1
q_2
$\hat{r}$
$\vec{F}_{12}$
r
(a)

"Superposition"

Steps to solve a superposition problem

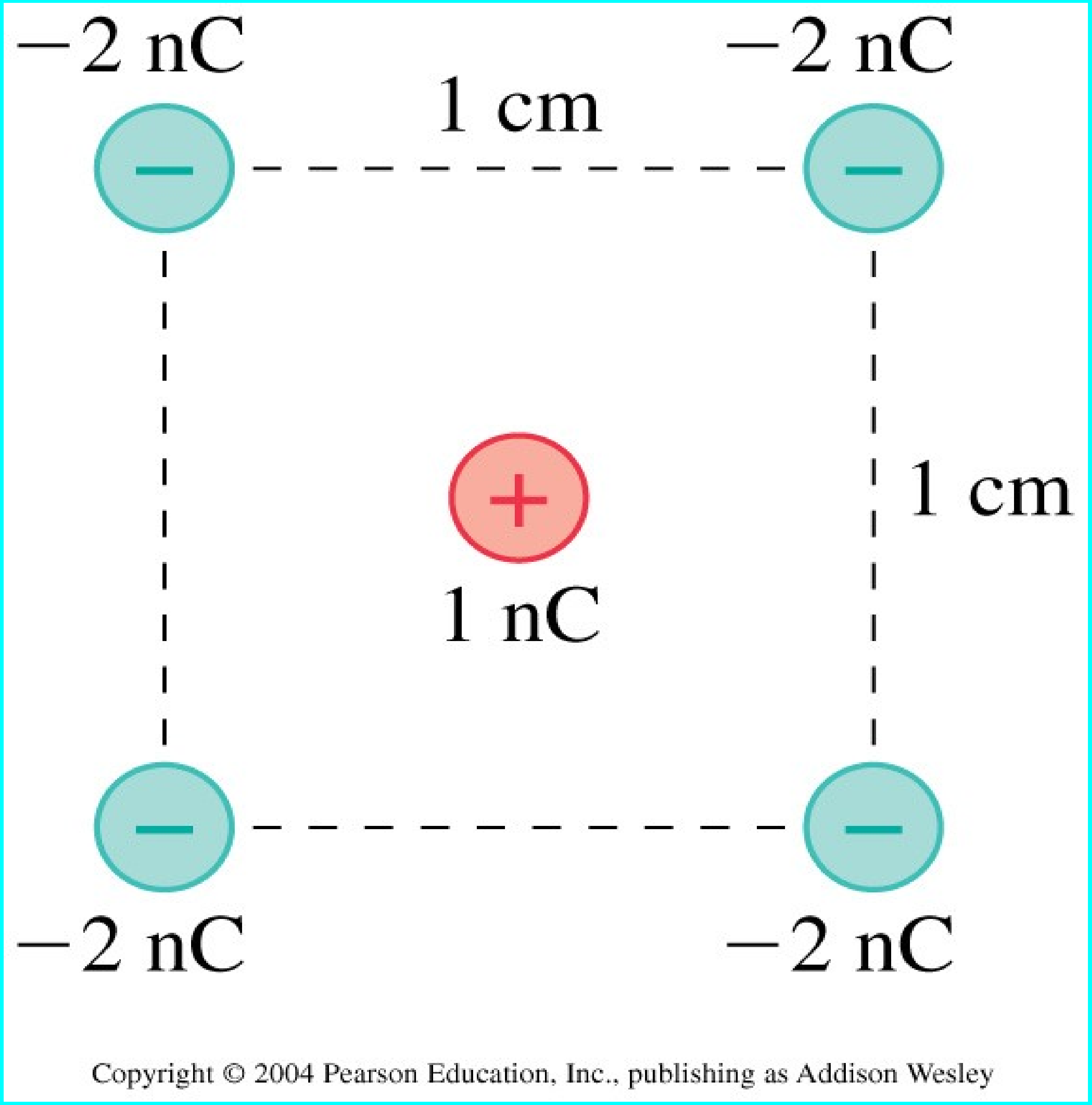
1) Identify the charge (or point P) at which you want to calculate the force (or field).

2) Draw an arrow (a vector) representing the Force Vector (or Field Vector) at the charge along a line joining it with each of the other charges.

3) Make the length of the vectors proportional to the force between the charges (shorter arrows for more distant charges)

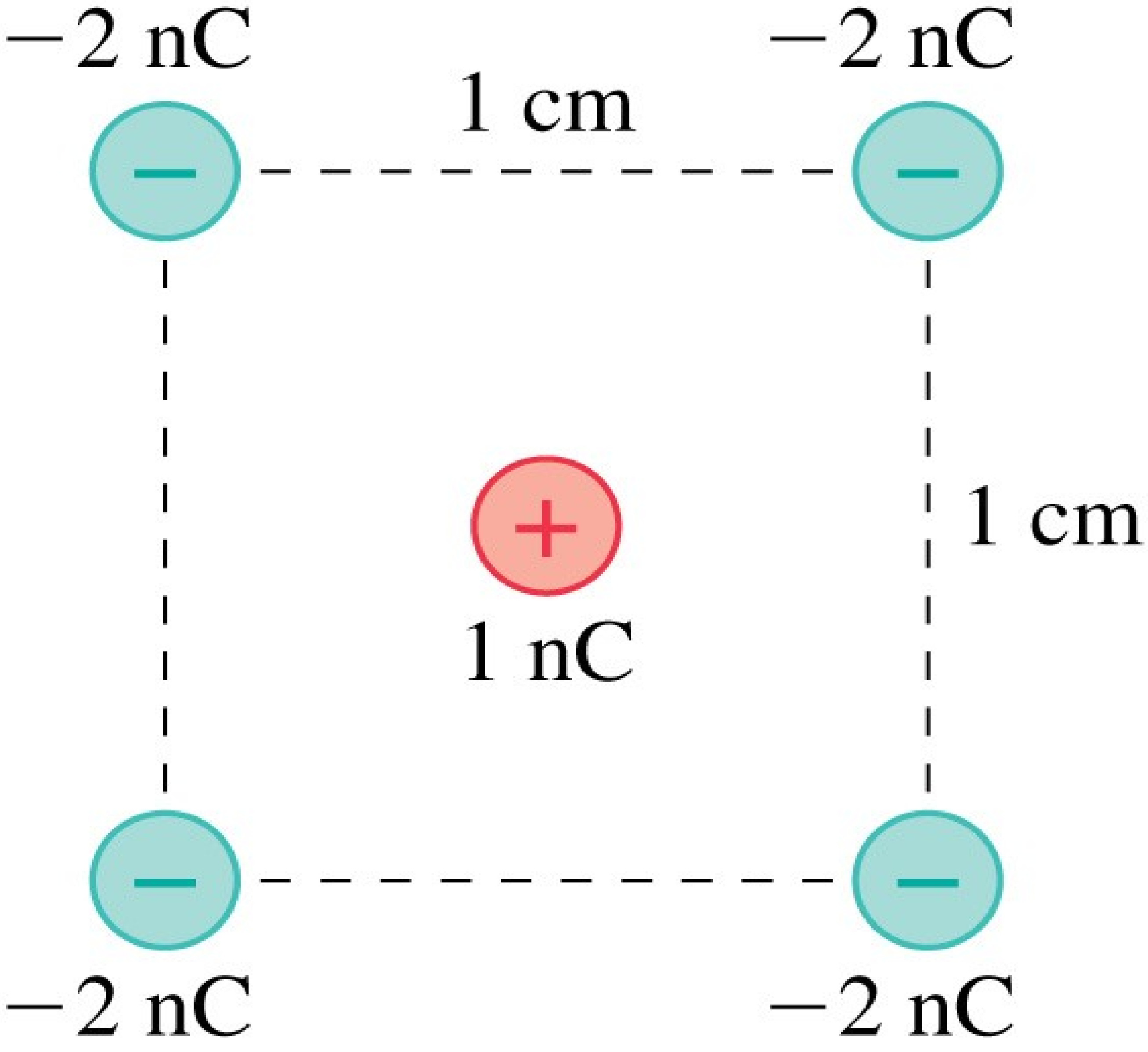
4) Add the vectors using the tip to tail method to find the *resultant*.

Superposition problem #1



Estimate the direction and magnitude of the NET force on the central charge due to the other four charges.

Superposition problem #1



Key Equations

Coulomb's law	$\vec{\mathbf{F}}_{12}(r) = \frac{1}{4\pi\varepsilon_0} \frac{q_1 q_2}{r_{12}^2} \hat{\mathbf{r}}_{12}$
Superposition of electric forces	$\vec{\mathbf{F}}(r) = \frac{1}{4\pi\varepsilon_0} Q \sum_{i=1}^{N} \frac{q_i}{r_i^2} \hat{\mathbf{r}}_i$
Electric force due to an electric field	$\vec{\mathbf{F}} = Q\vec{\mathbf{E}}$
Electric field at point P	$\vec{\mathbf{E}}(P) \equiv \frac{1}{4\pi\varepsilon_0} \sum_{i=1}^{N} \frac{q_i}{r_i^2} \hat{\mathbf{r}}_i$
Field of an infinite wire	$\vec{\mathbf{E}}(z) = \frac{1}{4\pi\varepsilon_0} \frac{2\lambda}{z} \hat{\mathbf{k}}$
Field of an infinite plane	$\vec{\mathbf{E}} = \frac{\sigma}{2\varepsilon_0} \hat{\mathbf{k}}$
Dipole moment	$\vec{\mathbf{p}} = q\vec{\mathbf{d}}$

Next Class:

More on Coulomb's law and introducing electric field