Fall 2004 Physics 3
Tu-Th Section

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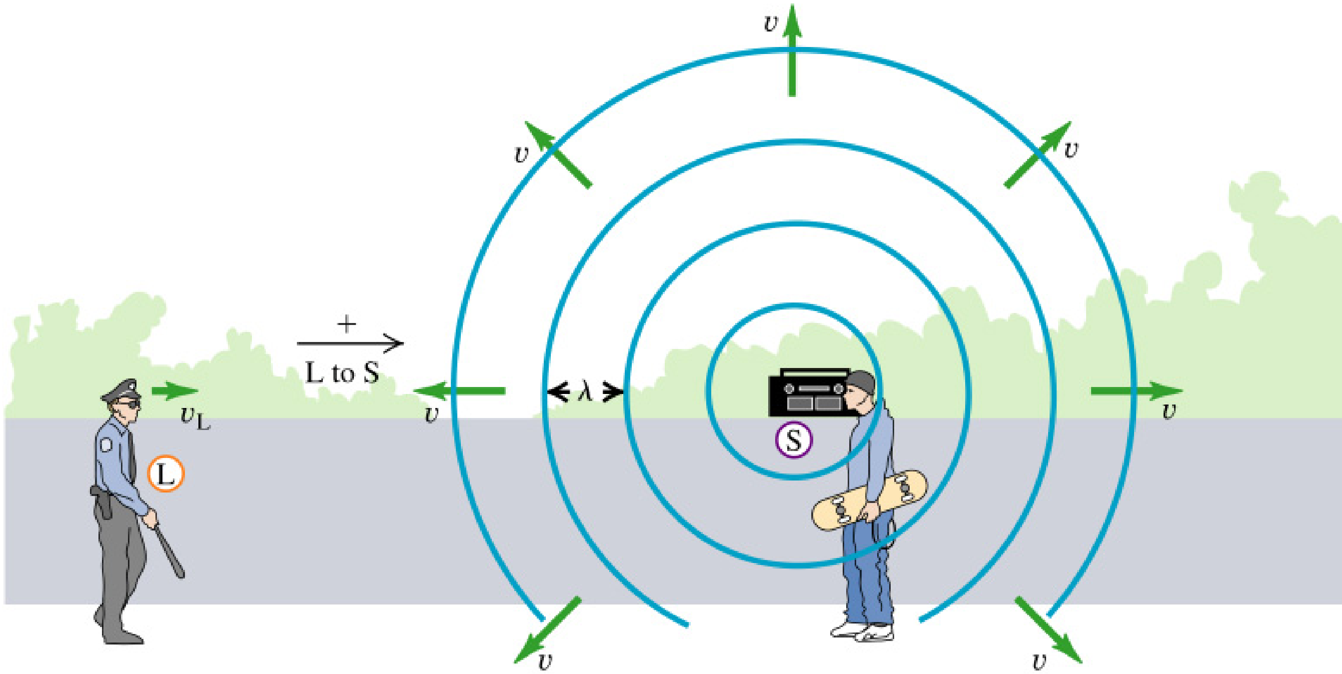
Lecture 5: 7 Oct. 2004

Web page:
http://hep.ucsb.edu/people/claudio/ph3-04/

Doppler Effect

- When a car goes past you, the pitch of the engine sound that you hear changes.
- Why is that?
- This must have something to do with the velocity of the car with respect to you (towards you vs. away from you).
  - Unless it is because the driver is doing something "funny" like accelerating to try to run you over ☺

Consider listener moving towards sound sorce:

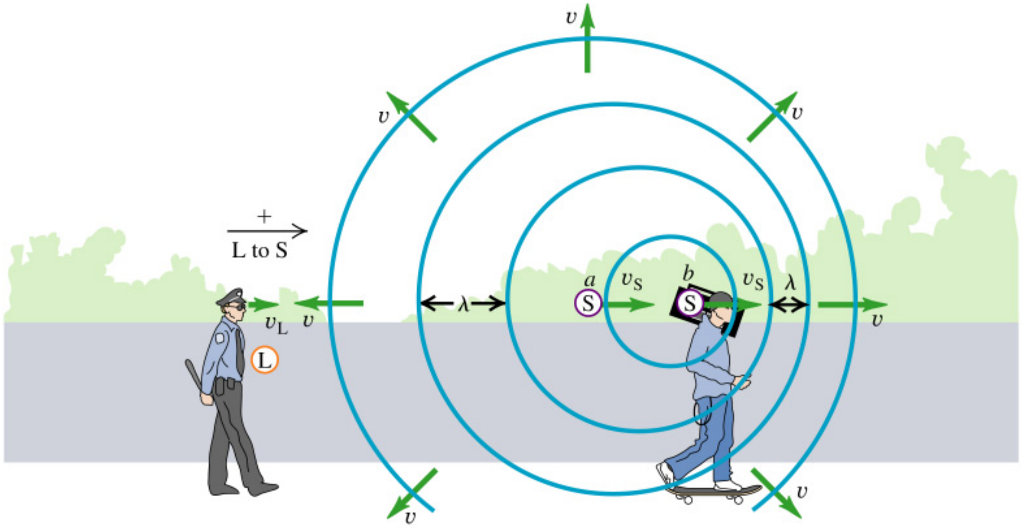


- Sound from source: velocity v, frequency f_s, wavelength λ, and $v=\lambda f_s$.
- The listener sees the wave crests approaching with velocity $v+v_L$.
- Therefore the wave crests arrive at the listener with frequency:

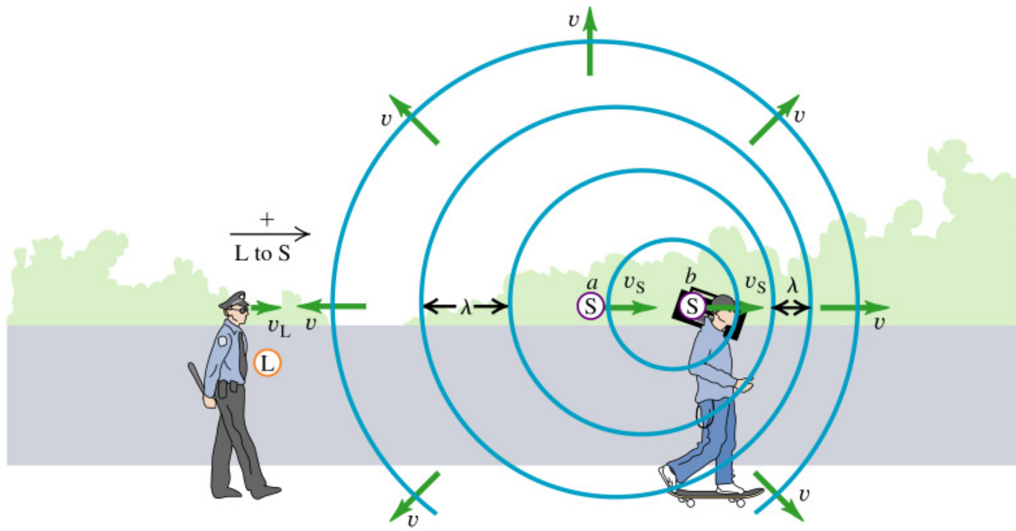
$$f_L = \frac{v+v_L}{\lambda} = \frac{v+v_L}{v} f_S = \left(1 + \frac{v_L}{v}\right) f_S$$

→ The listener "perceives" a different frequency (Doppler shift)

Now imagine that the source is also moving:



- The wave speed relative to the air is still the same (v).
- The time between emissions of subsequent crests is the period $T=1/f_s$.
- Consider the crests in the direction of motion of the source (to the right)
  - ➢ A crest emitted at time t=0 will have travelled a distance vT at t=T
  - ➢ In the same time, the source has travelled a distance v_sT.
  - ➢ At t=T the subsequent crest is emitted, and this crest is at the source.
  - ➢ So the distance between crests is $vT-v_sT=(v-v_s)T$.
  - ➢ But the distance between crests is the wavelength
    - ❖ $\lambda = (v-v_s)T$
  - ➢ But $T=1/f_s$ → $\lambda = (v-v_s)/f_s$ (in front of the source)



- $\lambda = (v-v_s)/f_s$ (in front of the source)
- Clearly, behind the source $\lambda = (v+v_s)/f_s$
- For the listener, $f_L=(v+v_L)/\lambda$
  - ➢ Since he sees crests arriving with velocity $v+v_L$

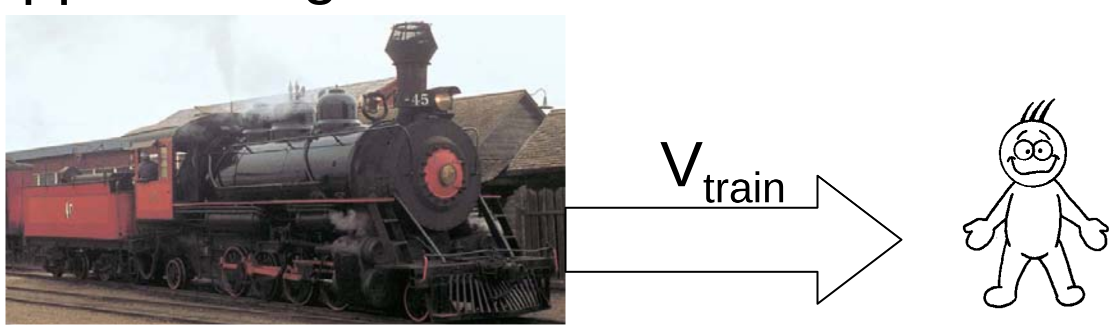
$$\rightarrow \quad f_L = \frac{v+v_L}{v+v_S} f_S$$

Sample problem

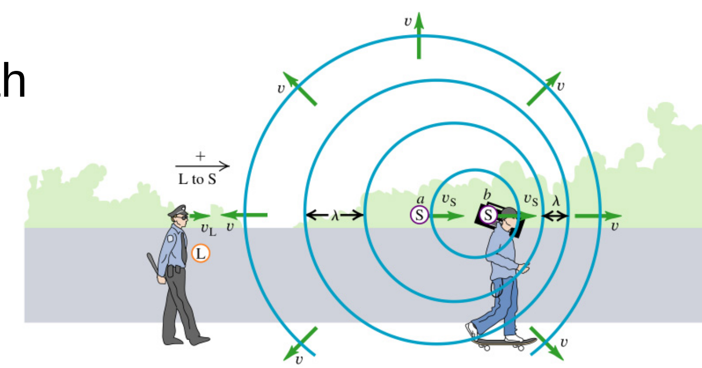
- A train passes a station at a speed of 40 m/sec. The train horn sounds with f=320 Hz. The speed of sound is v=340 m/sec.

  What is the change in frequency detected by a person on the platform as the train goes by.

Approaching train:



Compare with



$$f_L = \frac{v + v_L}{v + v_S} f_S$$

In our case v_L=0 (the listener is at rest) and the source (train) is mowing towards rather than away from the listener.

→ I must switch the sign of v_S

$$f_L = \frac{v+v_L}{v+v_S} f_S$$ becomes $$f_{L1} = \frac{v}{v-v_{\text{train}}} f$$

When the train moves away:

Clearly I need to switch the sign of v_{train}: $$f_{L2} = \frac{v}{v+v_{\text{train}}} f$$

$$\Delta f = f_{L1} - f_{L2} = \text{.. (algebra) ..} = -2\frac{v v_{\text{train}}}{v^2 - v_{\text{train}}^2} f = 76 \text{ Hz}$$

Electricity & Magnetism (Electromagnetism)

Four fundamental interactions in physics

1. Electromagnetism
2. Gravity
3. Strong Interaction
   - Responsible for holding the nucleus together
4. Weak Interaction
   - Responsible for some forms of radioactive nuclear decay, e.g. β decay

(Items 3 and 4:) **Felt only at subatomic level**

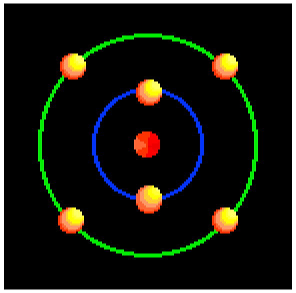
Electromagnetism and gravity are the interactions responsible for all phenomena that we experience in our daily life

Electric Charge

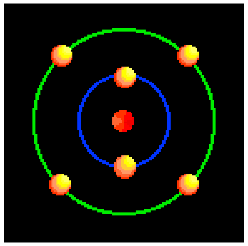
- All electric and magnetic phenomena are caused by electric charges
- What is the electric charge?
- www.dictionary.com:

  "The intrinsic property of matter responsible for all electric phenomena, in particular for the force of the electromagnetic interaction, occurring in two forms arbitrarily designated *negative* and *positive*".

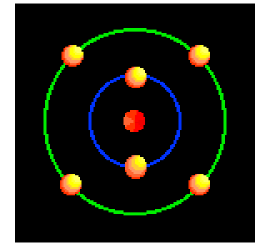
Microscopic picture of electric charge



- Atom: electrons orbiting a nucleus
- Charge is an <u>intrinsic property</u> of the electrons and of the protons in the nucleus
  - An intrinsic property like mass
- Electrons have <u>negative charge</u>
- Protons have <u>positive charge</u>
- This seems like an arbitrary definition. It is useful to account for the fact that
  - like charges (++ or --) repel
  - unlike charges (+-) attract
- The attraction between the nucleus (+) and the electrons (-) is what keeps the atom together



The atom (cont.)



- The magnitude of the charge of an electron and a proton is the same
- What does it mean?
  - The force between two charges depends on the magnitude of the charges.
  - The force between two electrons (repulsive) or two protons (repulsive) or a proton and an electron (attractive) is the same in magnitude
- Normally an atom has the same number of electrons and protons
  - It is electrically neutral
- An atom with an excess or deficit of electrons has a net charge and is said to be ionized

Quantization of charge

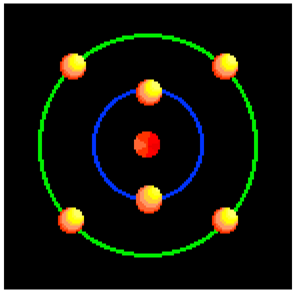
- Because the charge (Q) of an object is the sum of the charges of all its protons and electrons, Q can only take on a set of discrete values
- e = absolute value of electron charge
- $Q_{object} = (N_{protons} - N_{electrons}) \cdot e$

Conservation of charge

- The sum of all charges in a closed system is constant
- Thinking about the number of protons and electrons, this makes sense:
  - If you keep the same number of protons and electrons, the total charge stays the same regardless of what else happens to these particles
- But the principle of conservation of charge is much broader
  - It applies also to processes where protons or electrons are created, like in an high energy accelerator experiment ($E=mc^2$)

Aside (1)

This picture is very misleading:



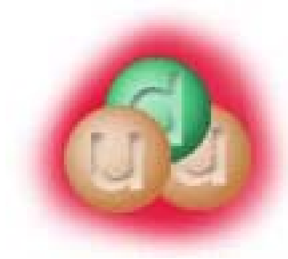
Atoms are mostly empty space !!

e.g. Hydrogen, one electron orbiting one proton:

$$R_{proton} \sim 10^{-15}\ \mathrm{m}$$

$$R_{electron\ orbit} \sim \tfrac{1}{2}\ 10^{-10}\ \mathrm{m}$$

Aside (2)



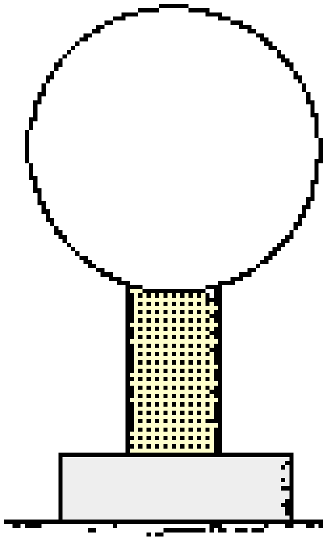
- The proton is actually made of more fundamental particle called *quarks*
- Proton = 2 up-quarks + 1 down-quark
  - ➢ up-quark has charge + 2/3 e
  - ➢ down-quark has charge - 1/3 e
- But we can never find a quark by itself!
  - ➢ Quarks only exist in "bound states"
    - up-up-down bound state: proton!
    - up-down-down bound state: neutron!
  - ➢ Because the "strong" force between quark is very peculiar
    - Almost no force when they are very close
    - Very large (tends to infinite) force as they are pulled apart → It takes an infinite amount of energy to pull a single quark out of a proton

David Gross Nobel Prize this week!

Conductors vs. Insulators

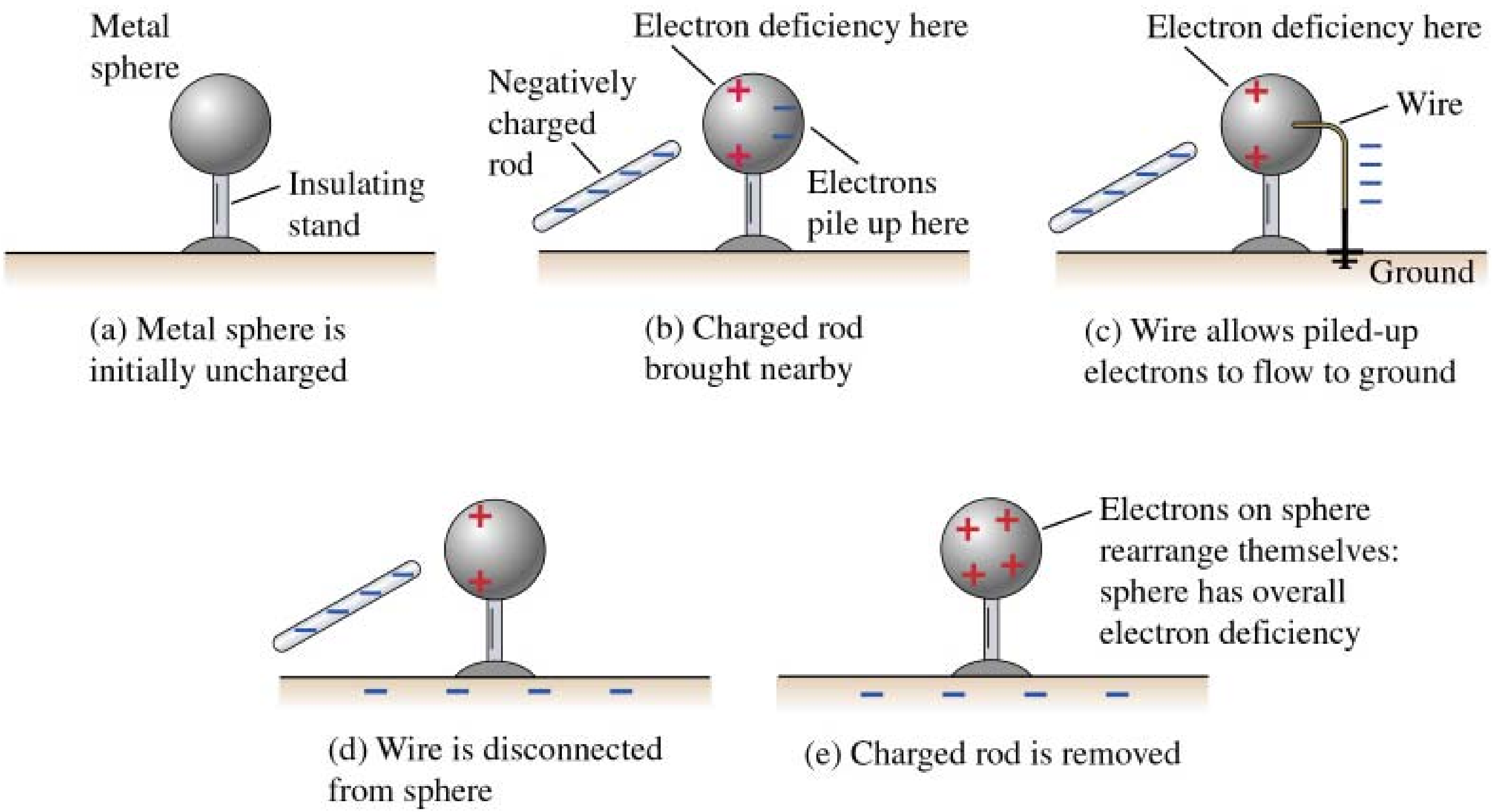
- Some materials allow the electric charge within the material to move easily from one region to the another → conductors
- Otherwise → insulators
- Most metals are conductors
- Most other materials are insulators
- Semi-conductors, e.g. silicon, are somewhere in between
- In a conductor some electrons in the outer orbits (shells) become detached and can move freely in the material

Induction



A negatively charged object is brought near to a neutral, conducting sphere. Electrons in the sphere are forced from the left side of the sphere to the right side.

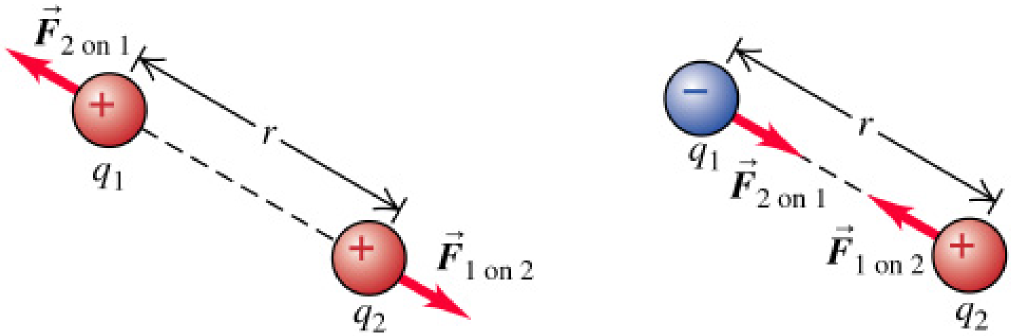
Induction



Metal sphere
Insulating stand
(a) Metal sphere is initially uncharged
Electron deficiency here
Negatively charged rod
Electrons pile up here
(b) Charged rod brought nearby
Electron deficiency here
Wire
Ground
(c) Wire allows piled-up electrons to flow to ground
(d) Wire is disconnected from sphere
Electrons on sphere rearrange themselves: sphere has overall electron deficiency
(e) Charged rod is removed

Coulomb's Law

Force between two charges q_1 and q_2 separated by a distance r



It is directed along the line joining q_1 and q_2

and:

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

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

Proportional to the product of the charges
Inversely proportional to square of distance
k = 8.987551787 x 10^9 N m^2/C^2.

C = Coulomb is the unit of charge
electron charge e = - 1.6 10^{-19} C

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

Is often written as:

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

With $4\pi\varepsilon_0 = (1/k)$ and

$\varepsilon_0 = 8.854 \times 10^{-12}\ C^2/N\ m^2$

Nothing fundamental.

A different way of writing the same thing.

Looks more complicated now

But will make things easier later!

Example

What is the force exerted by q_1 on q_2?

The two forces are equal and opposite

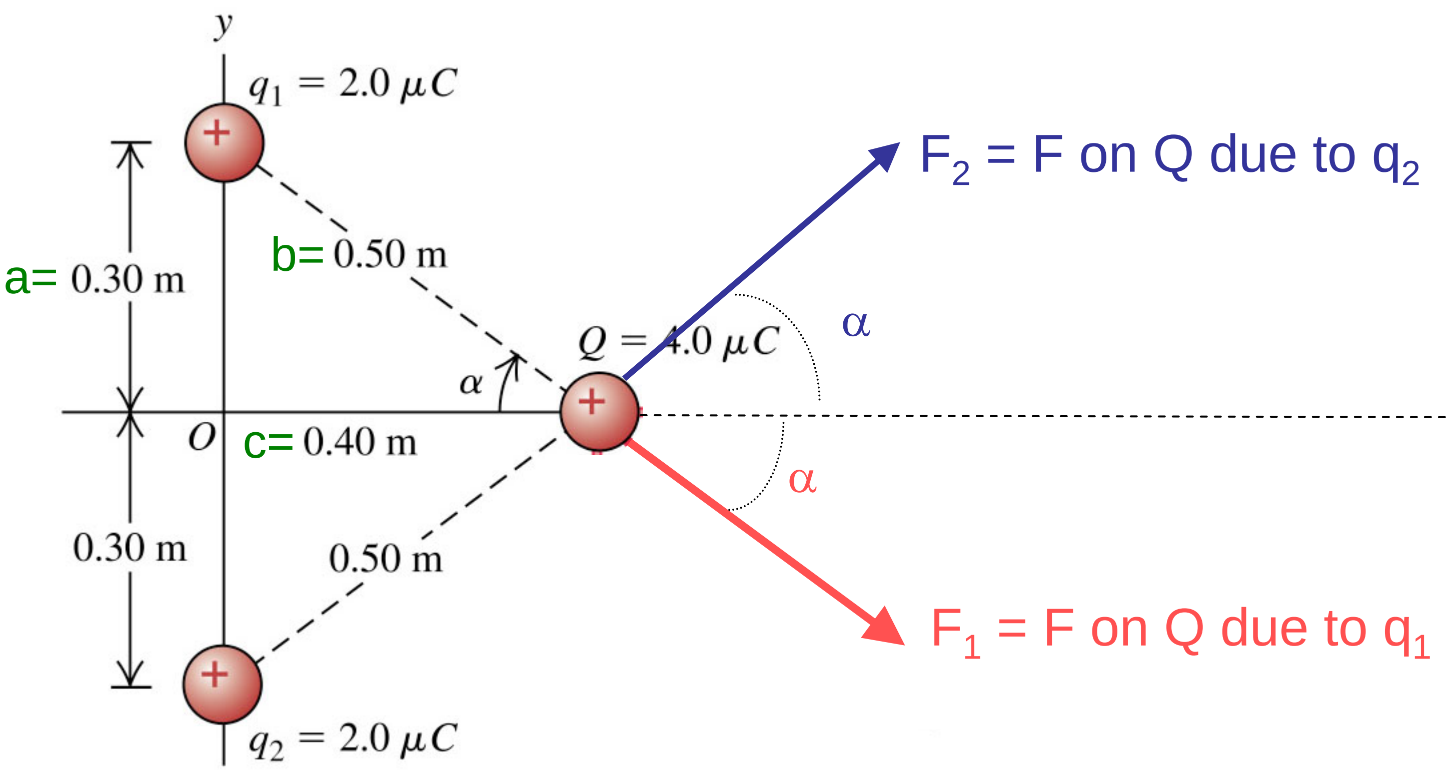
Same-sign charges → repulsive force

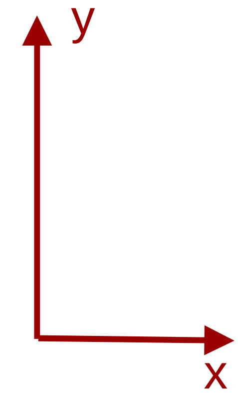
$$F = k\frac{|q_1 q_2|}{r^2}$$

$$F = (9 \cdot 10^9)\ \frac{|(-3{\cdot}10^{-9}){\cdot}(-2{\cdot}10^{-9})|}{(10^{-1})^2}\ \mathrm{N}$$

$$F = 5.4 \times 10^{-6}\ \mathrm{N}$$

Another Example

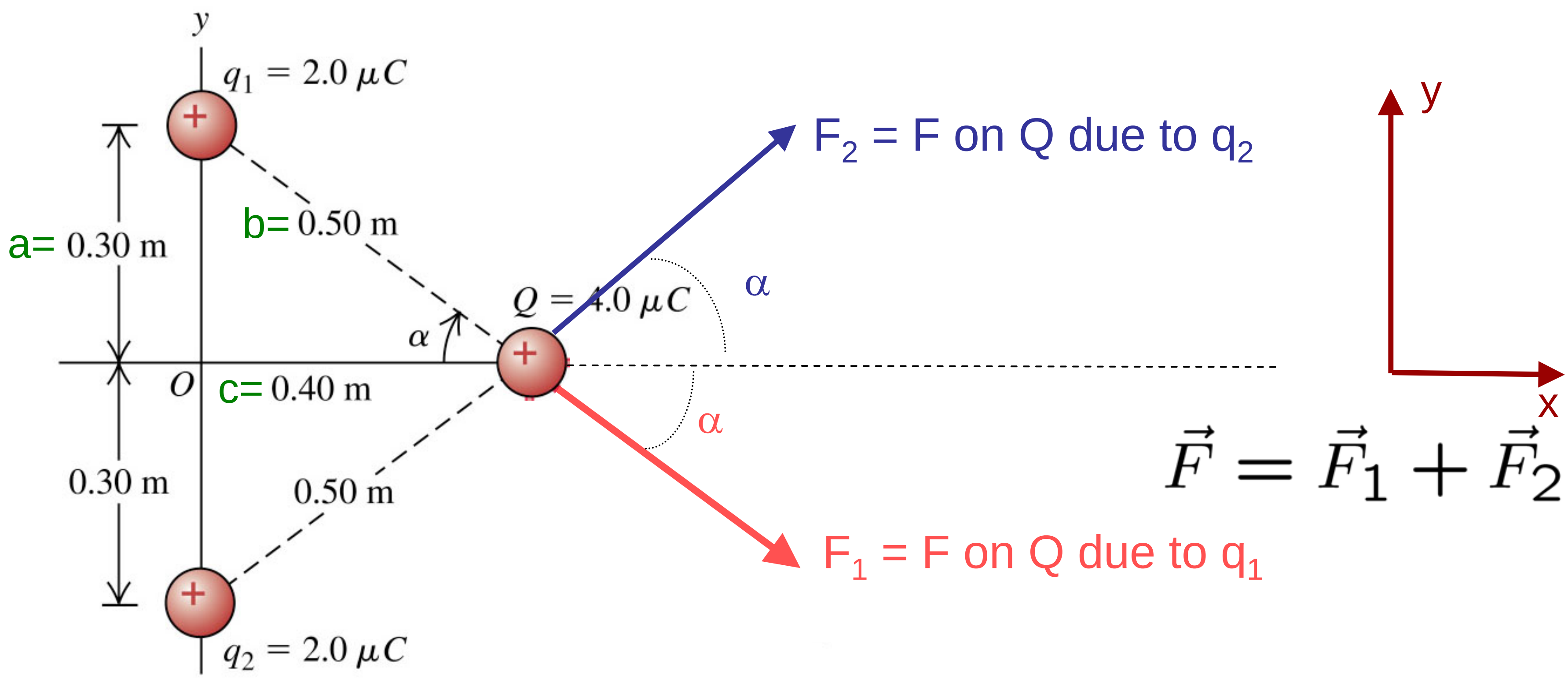




What is the force, magnitude & direction on Q ?

- Draw the forces
- Label the distances
- Pick a coordinate system

$$\vec{F} = \vec{F}_1 + \vec{F}_2$$



$$\vec{F} = \vec{F}_1 + \vec{F}_2$$

By symmetry, $F_1 = F_2$ (in magnitude, not direction!)

Also: $F_{1x} = F_{2x}$ and $F_{1y} = -F_{2y}$

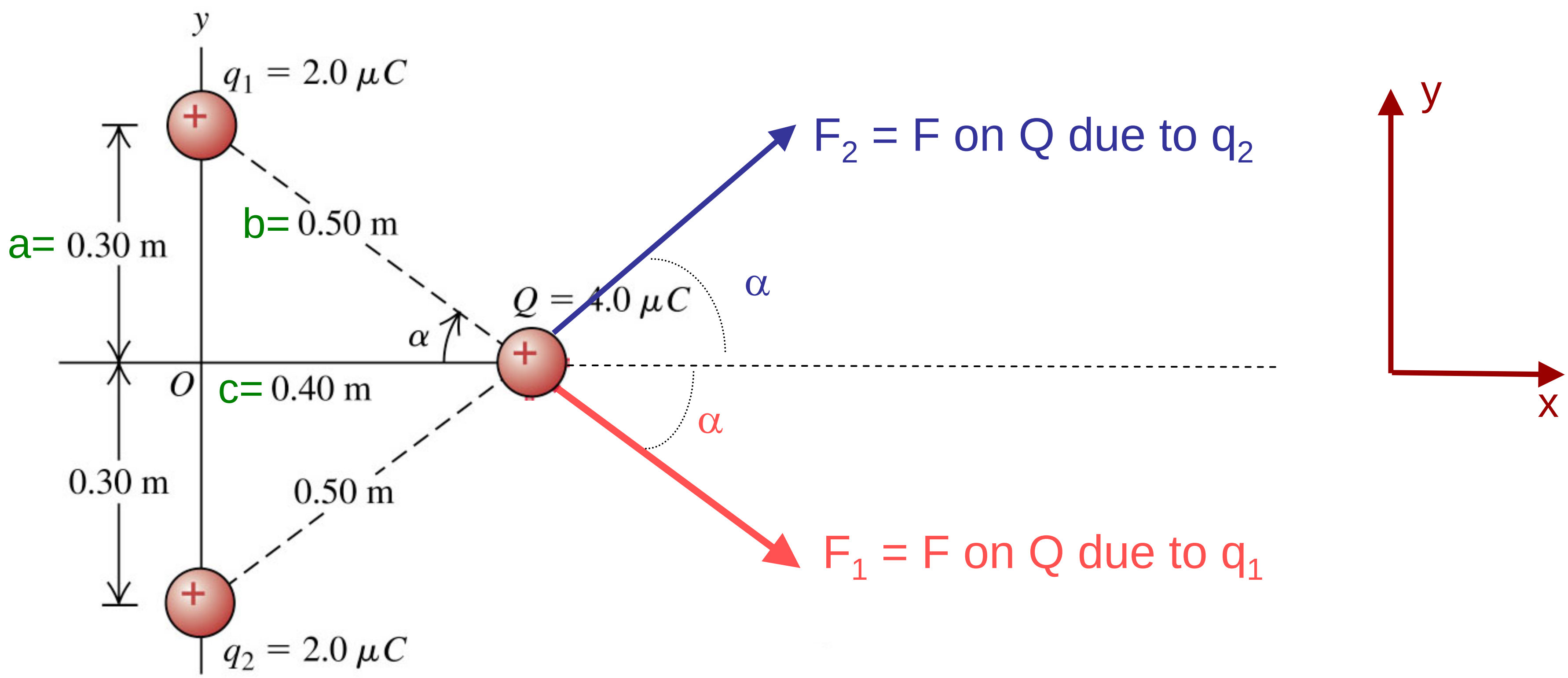
→The total force is in the x-direction and in magnitude $F = 2F_{1x}$.

$F_{1x} = F_1 \cos\alpha$ → $F = 2F_1 \cos\alpha$

But $c = b \cos\alpha$ → $\cos\alpha = c/b$

→ $F = 2F_1(c/b)$

But $F_1 = k\ q_1 Q/b^2$ → $F = 2kcq_1 Q/b^3$

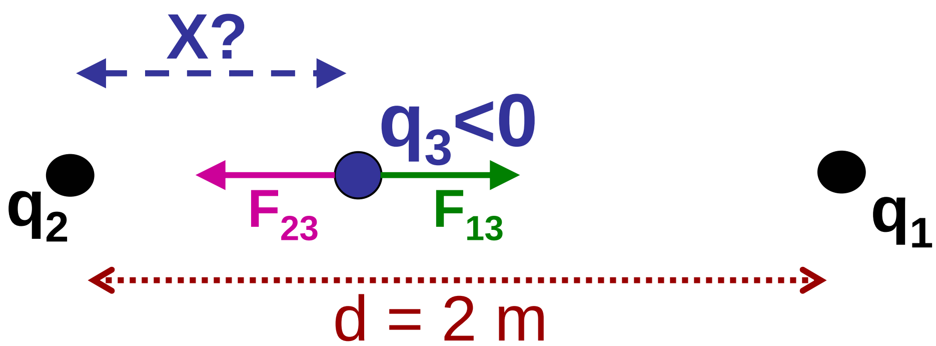


$$F = 2k\frac{cq_1Q}{b^3}$$

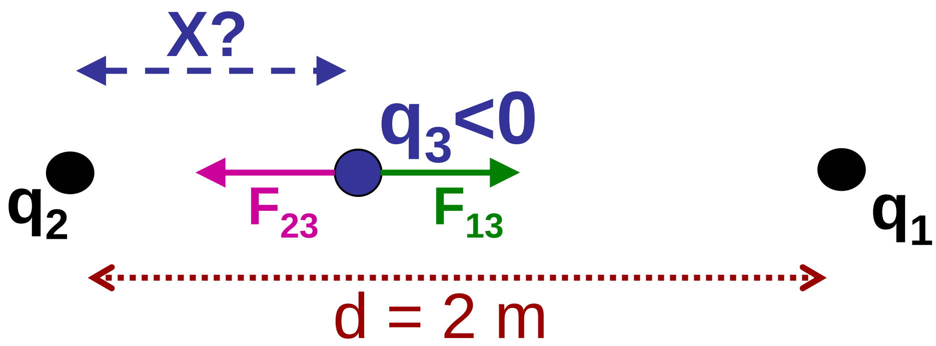
$$F = 2(9\times10^9)\frac{0.4(2\times10^{-6})(4\times10^{-6})}{(0.5)^3}$$

F = 0.46 N (in the x-direction)

(Yet) Another Example



- q_2 = + 6 μC q_1=+15μC
- Where in between the two charges would a charge $q_3 < 0$ be in equilibrium?
- q_3 has opposite sign from q_1 and q_2
- F_{23} = force on q_3 due to q_2
- F_{13} = force on q_3 due to q_1
- Equilibrium: $F_{13} = F_{23}$ (<u>in magnitude</u>)



$F_{13} = F_{23}$

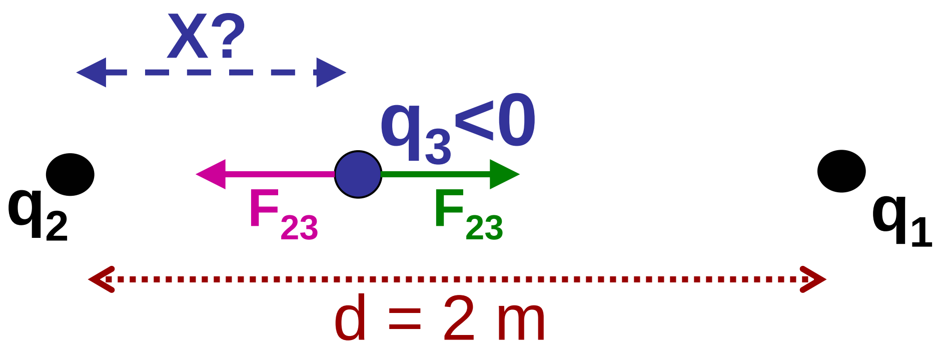
$$F_{13} = k\frac{q_1 q_3}{(d-x)^2}$$

$$F_{23} = k\frac{q_2 q_3}{x^2}$$

$$\rightarrow \frac{q_1}{(d-x)^2} = \frac{q_2}{x^2}$$

$$q_1 x^2 = q_2 d^2 - 2q_2 xd + q_2 x^2$$

$$(q_2 - q_1)x^2 - 2q_2 xd + q_2 d^2 = 0$$



$$(q_2 - q_1)x^2 - 2q_2xd + q_2d^2 = 0$$

$$9x^2 + 24x - 24 = 0 \quad (x \text{ in meters})$$

$$x = 0.8 \text{ m OR } x = -3.4\text{m}$$

Are they both OK?

NO. Only the solution with <u>*x* > 0</u> makes sense!