From last time…

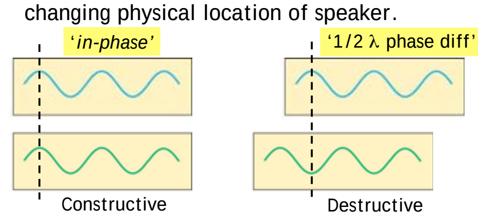
Wavelength, frequency, and velocity are all related.

Waves can add up, either giving a wave of larger amplitude, or one of smaller amplitude.

HW#4: Chapter 8: Conceptual: # 19, Problems: # 2, 7
Chapter 9: Conceptual: # 4, 10 Problems: # 2, 4, 8

Interference of sound waves

- Interference arises when waves change their 'phase relationship'.
- Can vary phase relationship of two waves by changing physical location of speaker.



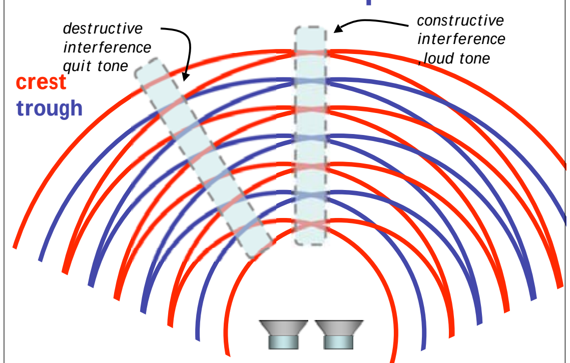
Superimposing sound waves

- Depending on your *relative* distance from two identical sound sources, the sound intensity can vary.
- Important aspect is relative distance from each source in wavelengths!

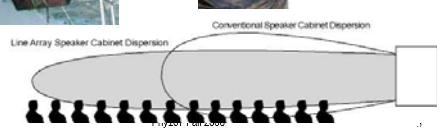
Destructive interference for 1 half wavelength, also for 3 half wavelengths, 5 half-wavelengths, etc.

Constructive interference also occurs at differences of 2 whole wavelengths, 3 whole wavelengths

Interference of 2 speakers



Interference engineering

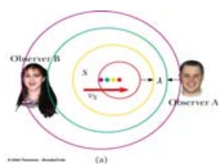


Doppler Effect

- A Doppler effect is experienced whenever there is relative motion between a source of waves and an observer.
- For instance, a fire engine or train passing you.
  - When the source and the observer are moving toward each other, the observer hears a higher frequency
  - When the source and the observer are moving away from each other, the observer hears a lower frequency
- Although the Doppler Effect is commonly experienced with sound waves, it is a phenomena common to all waves

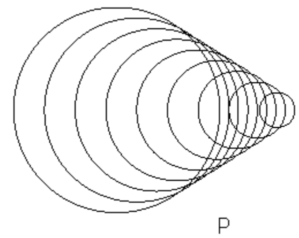
Doppler Effect for a moving source

- As the source moves toward the observer (A), the wavelength appears shorter and the frequency increases
- As the source moves away from the observer (B), the wavelength appears longer and the frequency appears to be lower



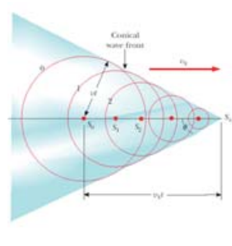
Shock Waves and Sonic Booms

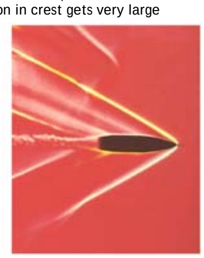
- A shock wave results when the source velocity exceeds the speed of the wave itself
- The circles represent the wave fronts emitted by the source



Sonic Boom

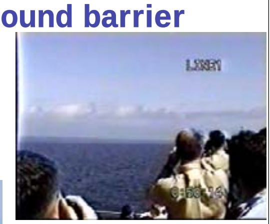
- Source of sound approaching the listener is equal to or faster than the speed of sound
  - Each successive wave is superimposed on the previous one
  - Shock wave results as air compression in crest gets very large





Breaking the sound barrier

- No sound received till after the source passes the listener - then a sonic boom - followed by normal sound from the source
- Conical bow wake from condensed water vapor at high pressure shock wave front.



Breaking the 'sound' barrier in a canoe!

If the canoe moves faster than the water wave velocity, shock wave also builds up where all the crests line up.

For water wave velocity ~1 m/s, so Mach 2 is 2 m/s = 4.5 mph !!

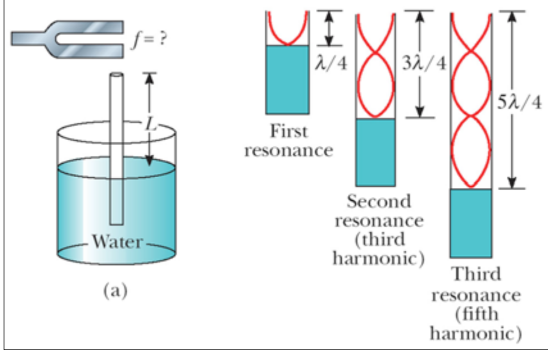
Resonance

- So far have been talking about waves traveling in media that extend in all directions.
- In a finite object, the boundaries cause reflections.
- The reflected wave interferes with rest of wave, causing destructive or constructive interference.
- For destructive interference, the wave tends to die away.
- But for constructive interference, the wave builds up.
- Which one happens depends on wavelength.

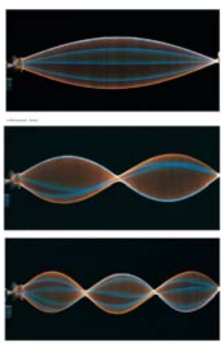
Most objects resonate

- But even complicated objects have some natural frequency of oscillation
- Pendulum
- Wine glass
- Musical instruments
- Natural frequency has to do with size and materials properties of object.

Closed tube resonance



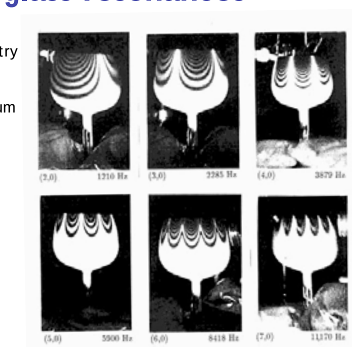
Resonance on string



- First three natural vibrational modes of a string fixed at both ends (e.g. a guitar string).
- A normal pluck excites primarily the first vibrational mode.

Wine glass resonances

Holographic interferometry showing contour map of vibration for different modes. Points of maximum motion appear as bull's eyes.



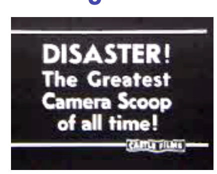
Driving at resonance

- Can tune a speaker to the fundamental resonant frequency of the wine glass (here 1210 Hz).
- More and more energy poured into glass - the glass vibrates with larger and larger amplitude.
- The glass shatters as the vibration amplitude becomes too large.

Stroboscopic movie of fundamental vibration mode of a wineglass.

Tacoma Narrows Bridge

- Even a non-resonant drive can transfer energy.
- Driven by 40 mph wind
- Causes vibration of bridge at its natural (resonant) frequency.

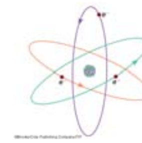


Movie of bridge torsional vibrations

Electricity and Magnetism

- Electric charge and electric forces
- Magnetic forces
- Unification of electric and magnetic forces
  - Understanding how they combine together
  - Electromagnetic waves

Electrical Charge



- Charge: intrinsic property of matter
- Two types:
  - Positive Charge: Protons
  - Negative Charge: electrons
  - Opposites Attract! (likes repel)
- Atoms are neutral
  - Positively charged central nucleus r~10^{-15} m
  - Negatively charged electrons orbit r~10^{-10} m
- Charge is quantized(one electron or proton)

Electrical charge

- Electrons carry electrical charge, and can be moved from one material to another.
- The electrons have a **negative** charge.
- The unit of electric charge is the Coulomb
- One electron carries only a tiny amount of charge

Charge on 1 electron = 1.6 x 10^{-19} Coulomb

Transferring 1 Coulomb of charge means that 6,250,000,000,000,000,000 electrons have moved!

Positive and negative seperated

- Triboelectric – friction
- Conduction – contact
- Induction
  - Proximity/ground
- Polarization

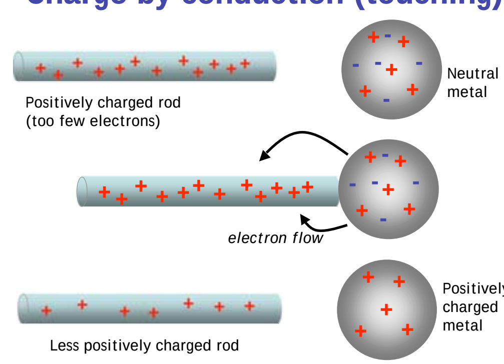
Separating charge

Rod becomes positively charged after rubbing with fur.

Electrons (negative charges) have been transferred from rod to fur.

- Positively charged rod can then be used to transfer electrons from other objects.

Charge by conduction (touching)



Pith ball demo

Interactions between charges

Why did the electrons flow?

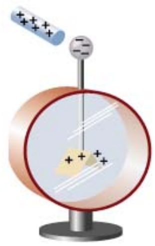
attractive force between positive and negative charges.

repulsive force between two positive or two negative charge

The positively charged rod attracts negative charges to the top of the electroscope.

This leaves positive charges on the leaves.

The like-charges on the leaves repel each other.

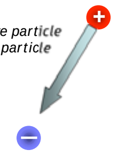


Force between charges

Opposite charges attract
Like charges repel.

- Other than the polarity, they interact much like masses interact gravitationally.
- Force is along the line joining the particles.

Force on positive particle due to negative particle

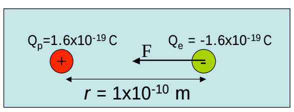


Electrostatic force: $F_E = k\,Q_1 Q_2 / r^2$, $k = 9\text{x}10^9\ \text{Nm}^2/\text{C}^2$

Gravitational force: $F_G = GM_1M_2 / r^2$, $G = 6.7\text{x}10^{-11}\ \text{Nm}^2/\text{kg}^2$

Electrostatic force is strong

- Electrostatic force between proton and electron in a hydrogen atom



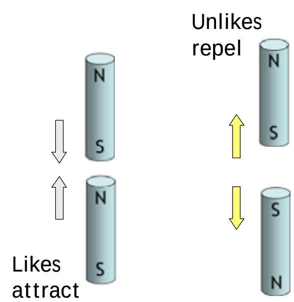
$F_E = (9\text{x}10^9)(1.6\text{x}10^{-19})(1.6\text{x}10^{-19})/(10^{-10})^2 = 2.3\text{x}10^{-8}$ N

- Gravitational force between proton and electron

$F_G = (6.7\text{x}10^{-11})(1.7\text{x}10^{-27})(9.1\text{x}10^{-31})/(10^{-10})^2 = 2.3\text{x}10^{-28}$ N

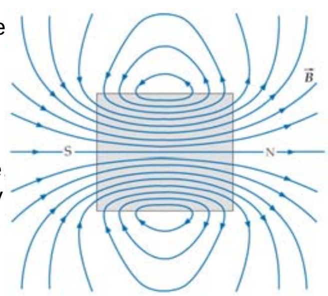
Magnetism: Permanent magnets

- North Pole and South Pole
- This is the elementary magnetic particle
- Called magnetic dipole (North pole and south pole)
- There are no magnetic 'charges'

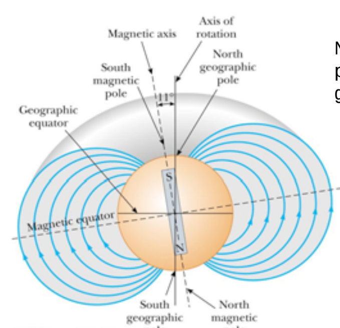


Field lines of a magnet

- Field lines indicate direction of force
- Density indicates strength of force
- Similar to electrostatic force but force is felt by magnetic dipole



The Earth is a Magnet!



North magnetic pole ~ at south geographic pole

A compass is a magnet

Compass needle aligns with local Earth field