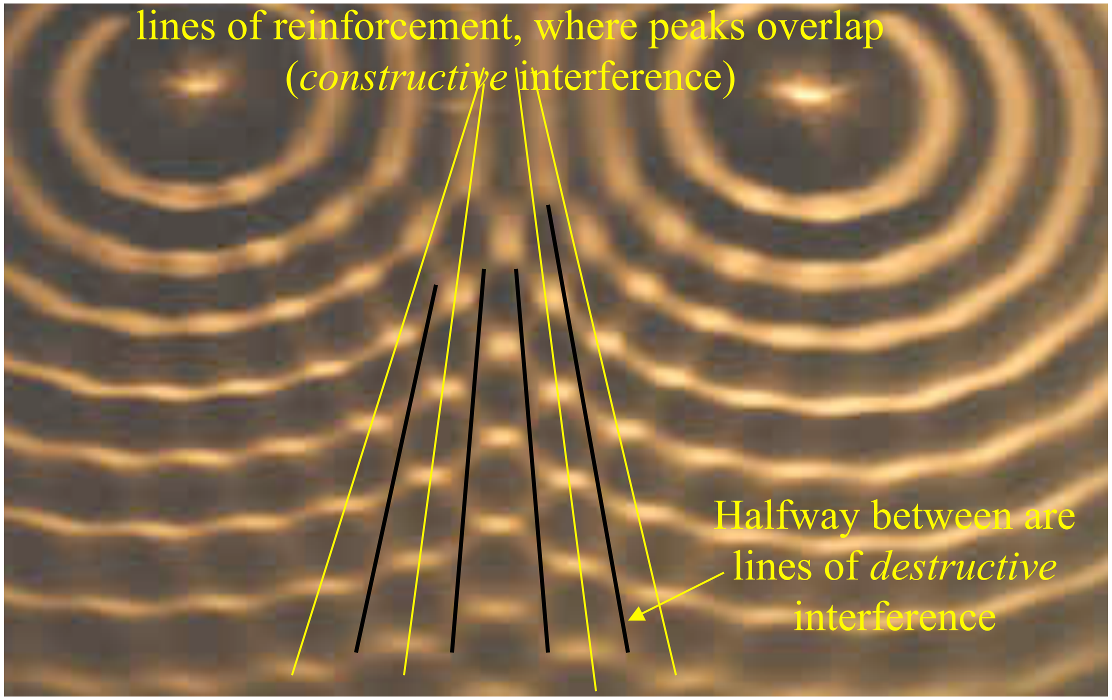
# Physics 116

## Lecture 8
# Interference
Oct 11, 2011

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# Announcements

- Exam 1 is Monday, 10/17
  - All multiple choice, similar to HW problems
    - YOU must bring a standard mark-sense (bubble) sheet
  - Closed book/notes, formula page provided
  - You provide: bubble sheet, pencils, calculator, brain
- Covers material in Ch.13 and 14 (through Thursday's class)
  - Damped/driven oscillators will NOT be on test
  - Friday's class: review, and example questions

- TA Kyle Armour's regular office hour on Thursdays: time changed to 10:30-11:30 (in B442).
- Kyle will hold a special office hour 11:30-12:30 on Monday 10/17 in room B442.

# Lecture Schedule
## (up to exam 1)

| *date* | *day* | *Session* | *Topic* | *Readings* |
|---|---|---|---|---|
| 9/29/11 | Thurs | 1 | Periodic motion and oscillations | 13.1 |
| 9/30/11 | Fri | 2 | Simple harmonic motion and circular motion | 13.2 –13.4 |
| 10/3/11 | Mon | 3 | Mass-spring system, energy conservation in SHM | 13.5 –13.6 |
| 10/4/11 | Tues | 4 | The pendulum; damped and driven oscillations | 13.7 –13.8 |
| 10/6/11 | Thurs | 5 | Types of waves; waves on a string; harmonic functions [HW 1 due] | 14.1 –14.3 |
| 10/7/11 | Fri | 6 | Sound | 14.4 –5 |
| 10/10/11 | Mon | 7 | Doppler shift; interference | 14.6 |
| 10/11/11 | Tues | 8 | Superposition | 14.7 |
| 10/13/11 | Thurs | 9 | Standing Waves & Beats [HW 2 due] | 14.8 - 14.9 |
| 10/14/11 | Fri | 10 | Review | |
| 10/17/11 | Mon | 11 | EXAM 1 (covers Chs. 13-14) | |

**Today**

# Doppler effect:

If sound source and observer are in relative motion, observed frequency will differ from source's frequency

- Sound waves require a material medium to propagate
- Recall: **Galilean relativity**
  - If two coordinate systems differ only by a constant v, not by an acceleration, we can simply add velocity vectors to get apparent v in either
  - Standard example: rowboat in a river that is flowing with speed *v*
    - rower has speed *u* relative to water,
    - water has speed *v* relative to earth,
    - so rower's speed relative to earth is *u* + *v*

    *u* is + if same direction as river (rowing downstream), negative if opposite (upstream)
- Coordinate system of medium (air, water, etc) is "special" for sound waves
  - Sound waves have speed c, and f and l are related by $c = \lambda f$
- For an observer moving relative to medium with speed u, apparent propagation speed c' will be different: $c' = c \pm u$ (sign depends on relative direction of *u* )
  - Wavelength cannot change – it's a constant length in the medium, and same length in moving coordinate system (motion does not change lengths)
  - Observed frequency has to change, to match apparent speed and fixed wavelength: $f' = \frac{c'}{\lambda}$

## Doppler effect:

- So if observer is moving (speed $u$) relative to source at rest in medium, then apparent frequency $f'$ is:

$$f' = \frac{c'}{\lambda} = \frac{(c+u)}{(c/f)} = \frac{(c+u)f}{c} = f\left(1+\frac{u}{c}\right)$$

+ sign if u is toward source,
Minus sign if away from source

- However, if source is moving (speed $u$) relative to observer at rest in medium, then
  - Frequency remains constant (same time interval between wavefront emissions)
  - But source now chases its own waves (or runs away from them): wavelength in the medium is shorter or longer
    - Wave speed = $c$
    - Time between successive peaks = $T$
    - Distance between peaks = $cT - uT$ = wavelength
    - Frequency of wave in medium (and for observer):

$$f' = \frac{c}{\lambda'} = \frac{c}{(c-u)T} = \frac{c}{(c-u)}f = f\left(\frac{1}{1-u/c}\right)$$

minus sign if toward observer,
+ sign if away from observer.
Notice: different f for observers on opposite sides of the source!

Notice the central role of the medium in both cases

# Doppler effect:

- General case
  - For either source or observer (or both) moving relative to medium,

$$f' = f\frac{\left(1 \pm \frac{u_{OBS}}{c}\right)}{\left(1 \mp \frac{u_{SRC}}{c}\right)}$$

c = speed of sound in medium
u = speed of source/observer in the medium
(both are unsigned = always taken as positive)

Use upper sign if source and observer move toward each other,

lower sign if source and observer move away from each other

## Examples

- Car moving with u=18 m/s sounds horn with f=550 Hz, in still air at 20C.

What f' is heard by observer on sidewalk?

Moving source, observer at rest in air:

$$f' = f\left(\frac{1}{1-u/c}\right) = 550\,Hz\left(\frac{1}{1-\left(18\text{m/s}/343\text{m/s}\right)}\right) = 550\,Hz\,(1.055) = 580\,Hz$$

Car toots again while at stop sign. What f' is heard by bicyclist with u=7.2 m/s toward the car? Moving observer, source at rest in air:

$$f' = f\left(1+\frac{u}{c}\right) = 550\,Hz\left(1+\frac{7.2\text{m/s}}{343\text{m/s}}\right) = 550\,Hz\,(1.02) = 562\,Hz$$

Road-raging driver toots horn yet again, when car is again moving with u=18 m/s. Now what f' is heard by bicyclist?

Source and observer both in motion relative to air, approaching each other

$$f' = f\frac{\left(1+\frac{u_{OBS}}{c}\right)}{\left(1-\frac{u_{SRC}}{c}\right)} = 550\,Hz\frac{\left(1+\left(7.2\text{m/s}/343\text{m/s}\right)\right)}{\left(1-\left(18\text{m/s}/343\text{m/s}\right)\right)} = 550\,Hz\,(1.07) = 590\,Hz$$

# Pop Quiz 2

- Mr. A is on a train moving **toward** me at 100 m/s
- I am at rest on the ground next to the track
- Mr. A aims a horn at me and toots it

His horn toots at 256 Hz. The frequency that **I** hear is:

**A. Higher than 256 Hz**

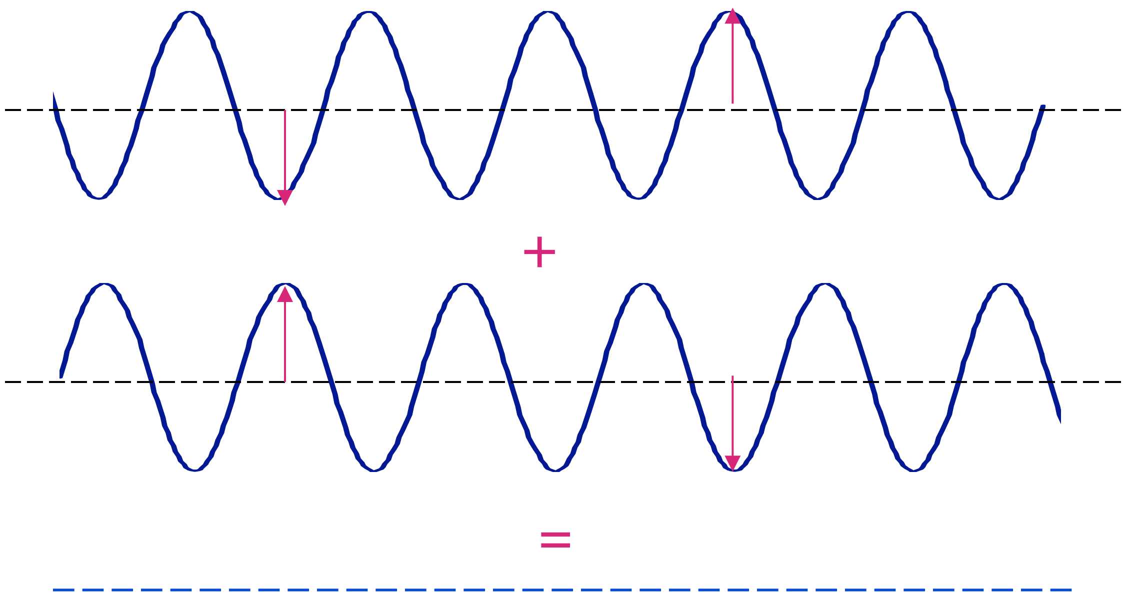
**B. 256 Hz (same frequency as he observes, on the train)**

**C. Lower than 256 Hz**

**D. (it is impossible to predict what the observer would find)**

# Interference

- Important properties of waves:
  - They can *add* to each other (*superposition* ), because of which…
  - They can *interfere* with each other
    - Superpose 2 waves (colliding water waves, merging sound waves, etc) have same l and their *amplitudes add*
      - If one is going down while the other is going up, result = 0 !



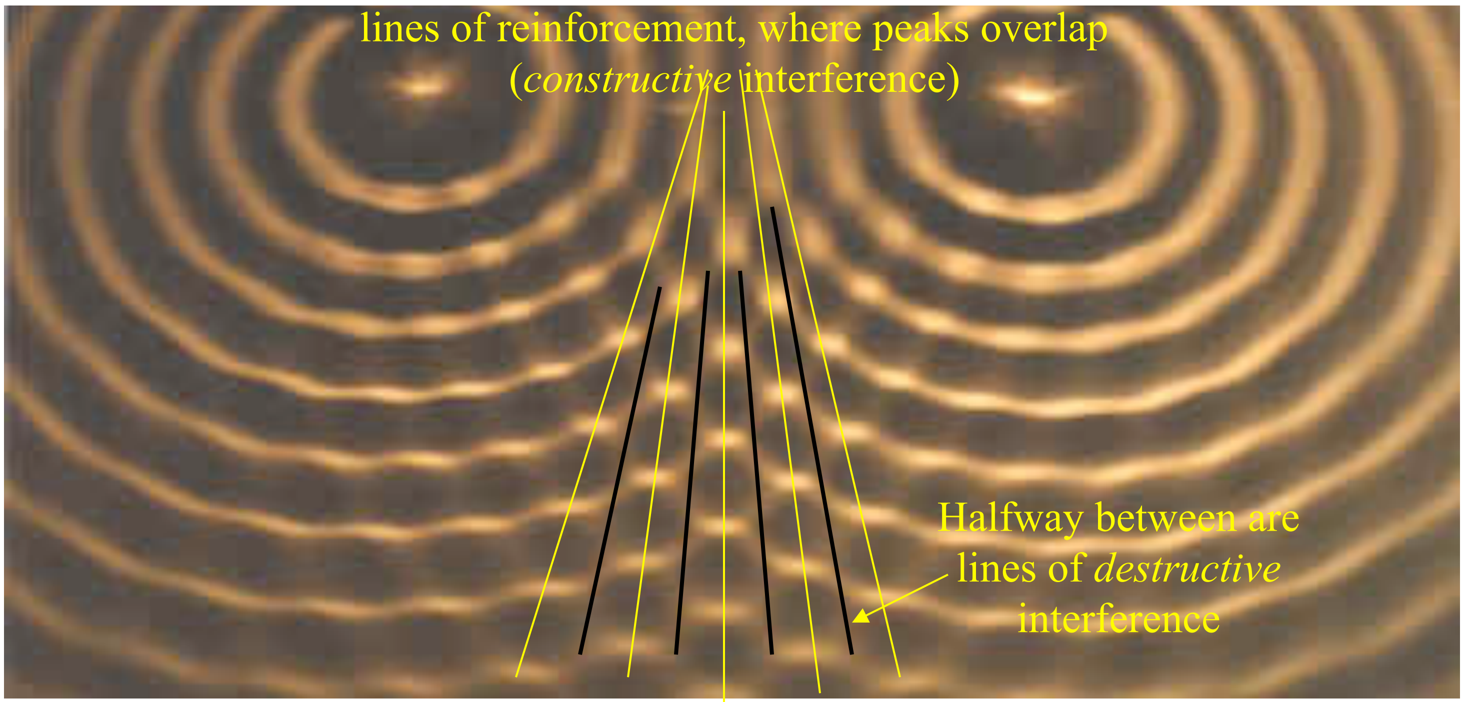

At each point along the waves, they add up to zero:
We say they are "out of phase"

Note: doesn't matter if the horizontal axis is time or space…

OR: if they *add* to each other, they are "in phase": result = wave with 2X amplitude

# Interference patterns

- Imagine two kids paddling their hands in a pond *in unison*
- Waves (ripples) propagate outward, and overlap
- There will be lines of *reinforcement*, and lines of *cancellation* (*constructive* and *destructive* interference)




  - We'll come back to this soon, when we talk about optics…

# Interference = defining property of waves

- If you see interference effects, you are looking at waves !

  Case study: Isaac Newton thought light was a stream of particles

    Newton's "Opticks" (1687) explained all observations at the time

  Thomas Young (120 years later) observed interference effects with light

  **Only waves could do that…**

    Wave theory of light replaced Newton's particle theory

- Interference depends on phase relationship of overlapping waves
- Phase relationship depends on distance from source

  Recall: Phase at distance D from source = 2p (D/l)

  but sin/cos repeat every cycle, so all that matters is where we are relative to start of latest cycle: fraction of a cycle

  Phase at distance D from source = 2p [ fractional part of (D/l) ]

  Example: fractional part of 5.678 is 0.678

# Phase relationships

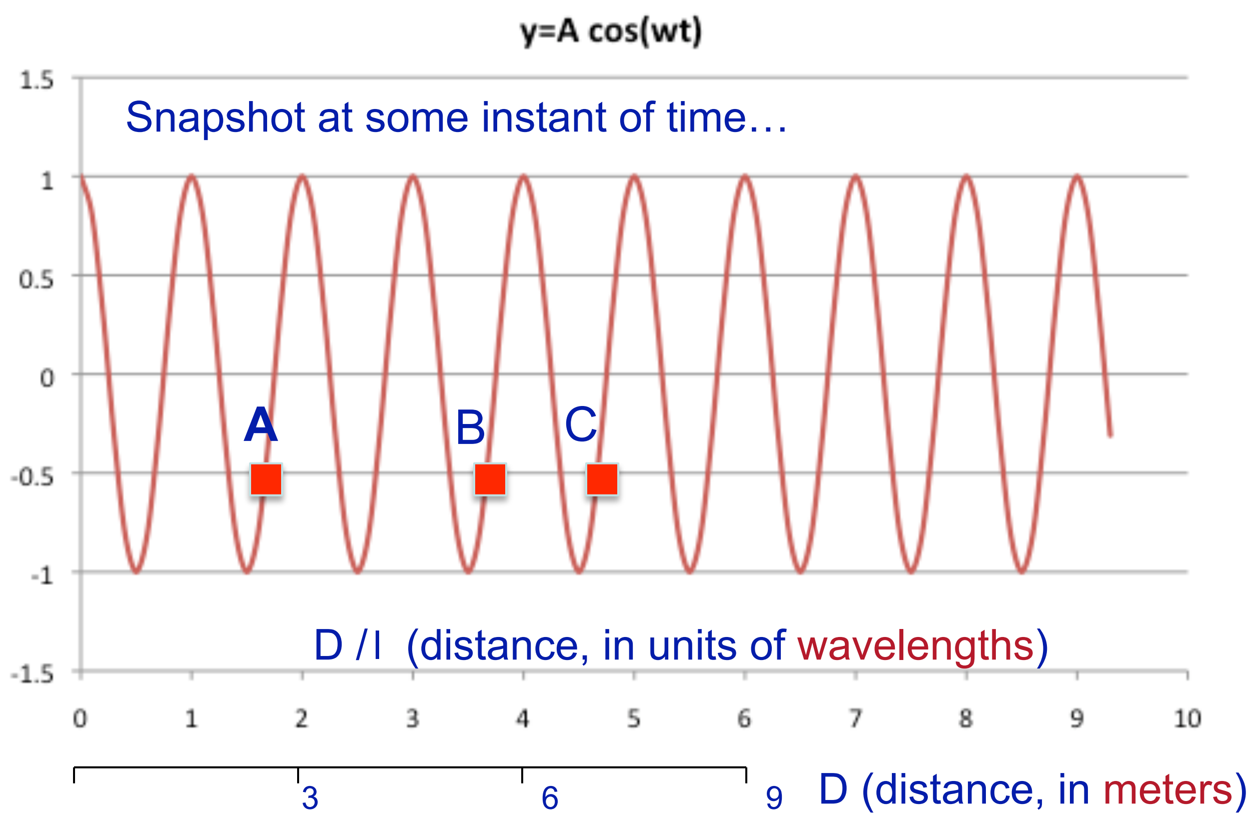
Example: source of sound has l=1.5m

Point A is 2.5 m away, B is 5.5 m away, C is 7 m away

Phase values are

$$\Phi_A = 2\pi\left(\frac{D}{\lambda}\right) = 2\pi\left(\frac{2.5m}{1.5m}\right) = 2\pi(1.66)$$

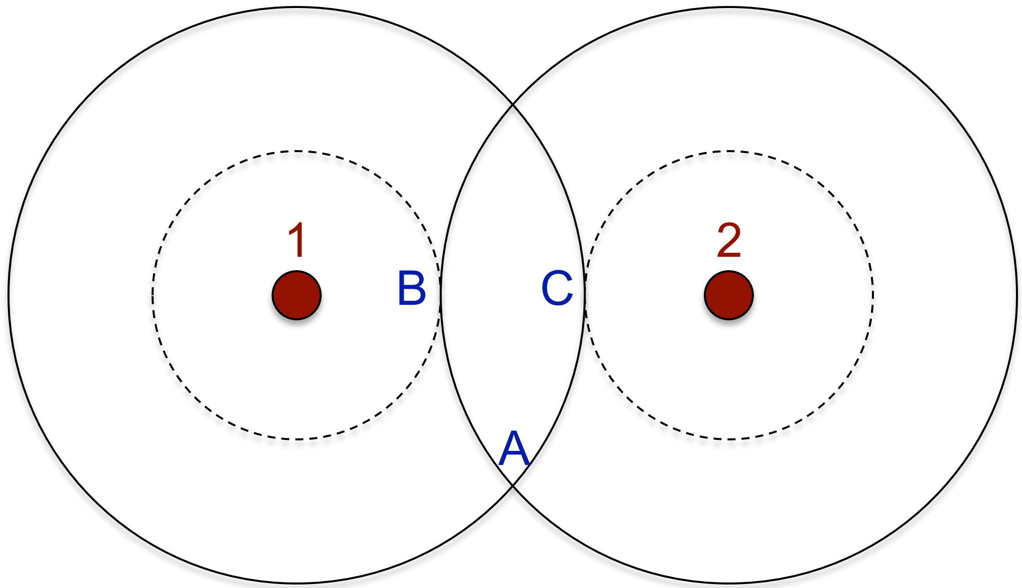
$$\Phi_B = 2\pi\left(\frac{5.5m}{1.5m}\right) = 2\pi(3.66), \quad \Phi_C = 2\pi\left(\frac{7m}{1.5m}\right) = 2\pi(4.66),$$




A, B, C are all 2/3 along a cycle, so sound waves have the same phase at all these points at all times

# Example: 2 sound sources with same f

Solid line: R = one wavelength, dashed R= ½ wavelength




Point A: sources 1 and 2 are in phase, so we get constructive interference

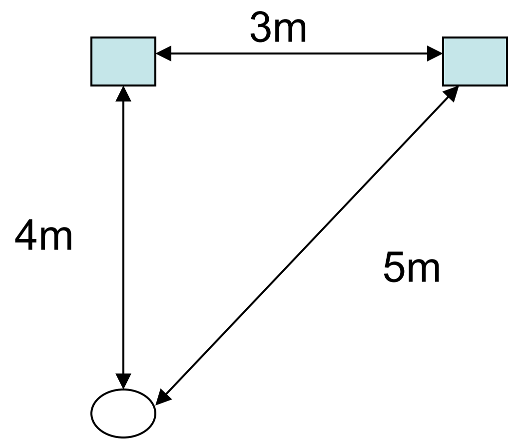
Points B and C: 1 and 2 are “180 deg out of phase”, so destructive interference

# Examples

- R and L channel loudspeakers, spaced 3m apart, are in phase: both speaker cones move forward or backward in sync together

Observer 4m away, parallel to L speaker hears constructive interference.

What f sound is being played?




$$D_1 = 4m \qquad D_2 = \sqrt{(3m)^2 + (4m)^2} = 5m$$

$$D_2 - D_1 = n\lambda$$

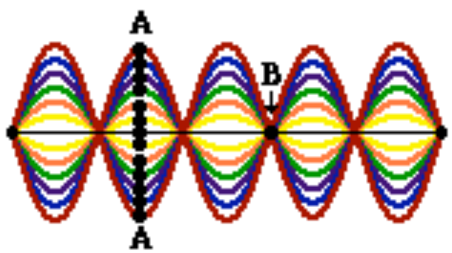
$$for \quad n = 1, \quad \lambda = D_2 - D_1 = 1m$$

$$f = \frac{c}{\lambda} = \frac{343\ m/s}{1m} = 343Hz$$

Any integer multiple of this f will also produce constructive interference at the observer's location

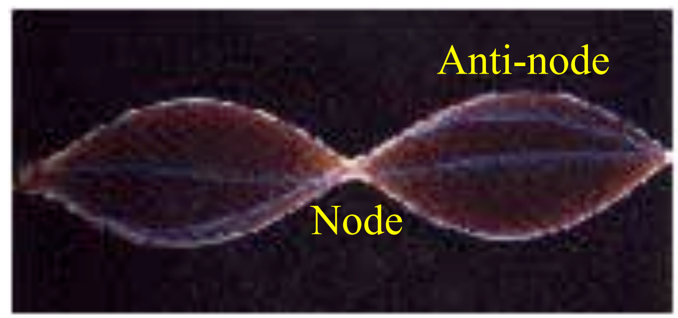
# Self-interference: "standing waves"

- If I wiggle the rope at *just* the right f
  - Waves reflected from the end *interfere constructively* with new waves I am making
  - Result: looks as if some points stand still: standing waves
    - Example of *resonance:* rope length L = multiple of l/2




Point A moves with big amplitude

Point B has amplitude ~0




Nodes = stationary points; anti-nodes=maxima

- Same thing happens in *musical instruments*
  - Structure favors waves which have L = multiple of l/2
    - Guitar, violin strings: both ends must be *nodes*

  - Organ pipes, wind instruments: one end must be node, other antinode