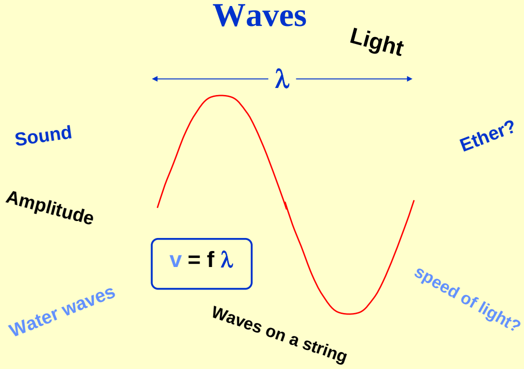
Lecture 11 Waves and Interference

The Final Piece of Classical Physics: Waves



Announcements

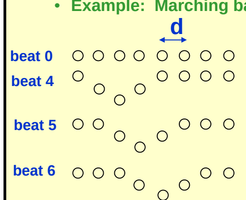
- Today: Waves and Light
- Final part of Classical Mechanics
- Many Kinds of Waves - light, sound, strings, ...
  - March (Ch 7)
- Next Time: The beginning of a new scientific revolution
  - Idea of time and space? What is light? Does the earth move? The Michelson-Morley Experiment
  - Lightman (ch 3); March (Ch 8)

Introduction

- In the last lecture we discussed electromagnetic waves
- Travel at speed of light
- Described by Maxwell's equations
- Today we will continue our study with a discussion of some of the properties of waves.
- Examples
  - Waves on a string, water, sound
- Key Property of Waves: interference
- Interference clearly shows the wave property of light

Waves

- What are waves??
  - Patterns in motion.
  - Example: Dominoes fall... what moved as dominoes fell?
  - Example: Marching band (March, figure 7-2.)



Rule: Do whatever the person on your right does one beat later.

Result: The pattern moves to the right a distance = separation of band members in a time equal that of one beat. This is then the characteristic velocity of the wave!!

If time per beat is T, and distance between people is d,

the speed of the wave is $v = d/T$

Waves

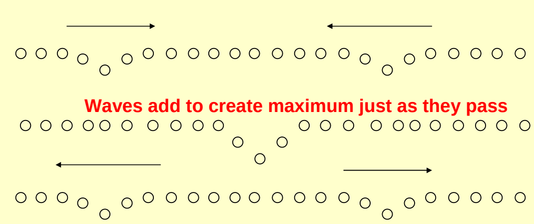
- The previous example of the "marching band wave" illustrates one very important property of waves:
  - A wave is a pattern in motion
  - The velocity of a wave depends upon the type of wave and the medium through which it is transmitted.
- The other property of waves which we will need to understand is the Principle of Superposition:
  - The displacement produced by two waves at the same point is merely the sum of the displacements produced by each wave alone.

Leads to Interference

Demonstrations with a "slinky spring"

Interference - 1

- Principle of Superposition
  - The displacement produced by two waves at the same point is the sum of the displacements produced by each wave alone.
- Example of "Constructive Interference"



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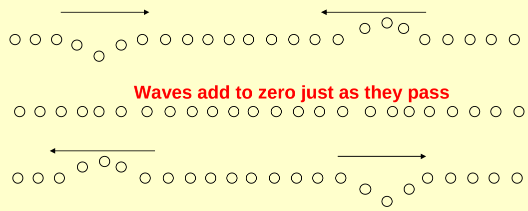
Interference - 2

- Principle of Superposition
  - The displacement produced by two waves at the same point is the sum of the displacements produced by each wave alone.
- Example of "Destructive Interference"



Waves

- Important example: Periodic waves
  - Repeated identical waves:

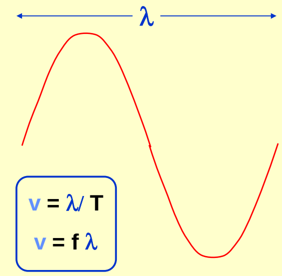
λ = wavelength = distance it takes for pattern to repeat

f = frequency = number of times a given point reaches maximum each second

f = 1/T, T = period = time between maxima

v = velocity of wave

Amplitude = max to min variation



$v = \lambda / T$

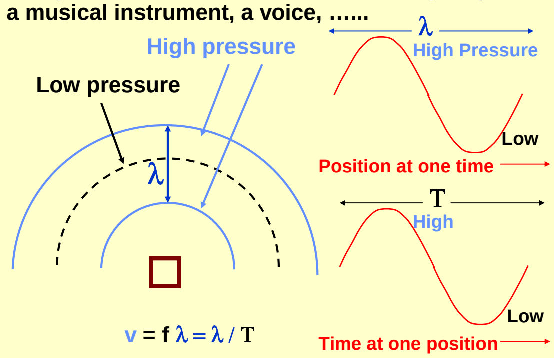
$v = f \lambda$

Examples of Waves

- The velocity of a wave is determined by the type of wave and the medium through which it is transmitted.
- Sound waves
  - Speed of sound is about 340m/s in dry air
  - About 1500 m/s in water
- Speed of light in vacuum
  - $c = 300{,}000{,}000$ m/s $= 3.0 \times 10^8$ m/s
- Surface water waves (e.g. at a beach)
  - depends upon depth of water

Sound Waves

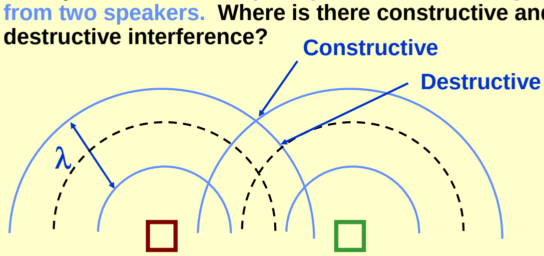
- Compression Waves in the air emitted by a speaker, a musical instrument, a voice, ……



$v = f \lambda = \lambda / T$

Interference of Sound Waves

- When two periodic waves meet, their amplitudes add (by principle of superposition) and the resulting disturbance can be either reinforced (constructive interference) or eliminated (destructive interference)
- Example: The same frequency emitted coherently from two speakers. Where is there constructive and destructive interference?

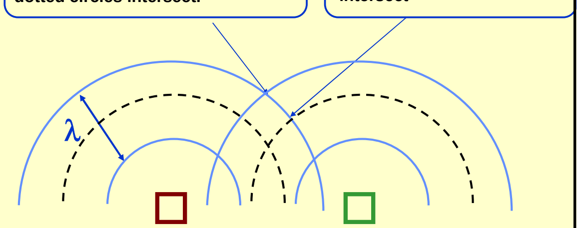


Interference of Sound Waves

- Conditions for Constructive and destructive interference

Constructive: Path lengths from each speaker differ by an integral number of wavelengths - where the blue circles intersect or the black dotted circles intersect.

Destructive: Path lengths from each speaker differ by λ/2, 3 λ/2, 5 λ/2 etc. - where the blue and black circles intersect



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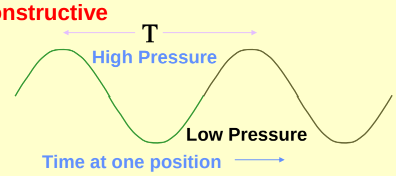
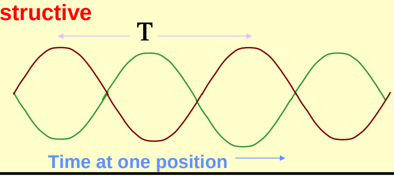
Interference of Sound Waves

- Interference of waves from the two speakers at one position as a function of time - add amplitudes
- Position of Constructive interference

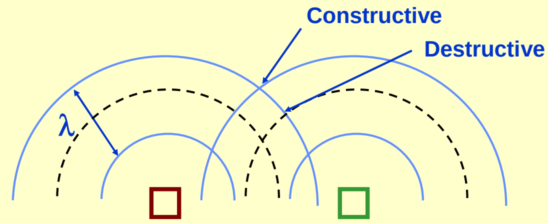


- Position of Destructive interference



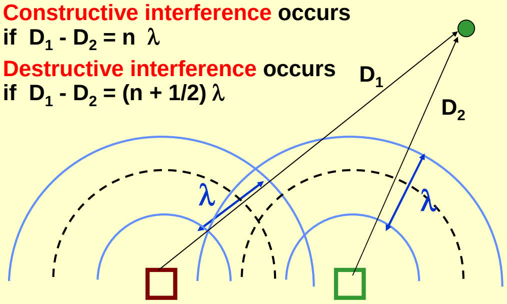
Demo: Interference of Sound Waves

- Two speakers emit sound “in phase”, I.e, the highs and lows are emitted simultaneously
- Move your head and hear the changes in sound intensity - Interference !



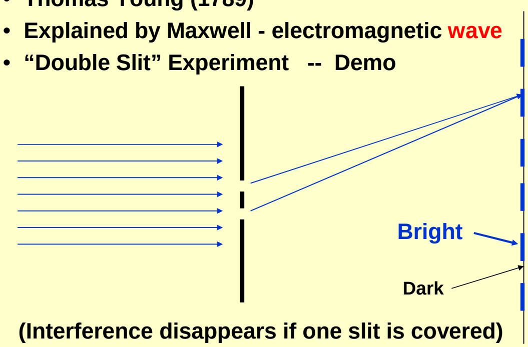
Conditions for Interference of Waves

- If any type of wave is emitted from two sources “in phase”, i.e, the highs and lows are emitted simultaneously
- Constructive interference occurs if $D_1 - D_2 = n\ \lambda$
- Destructive interference occurs if $D_1 - D_2 = (n + 1/2)\ \lambda$



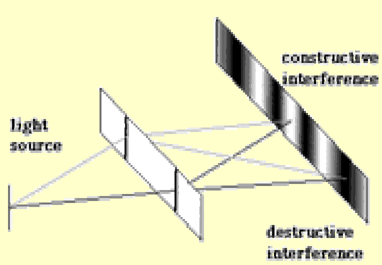
Demo - Light shows interference! Light is a Wave!

- Thomas Young (1789)
- Explained by Maxwell - electromagnetic wave
- “Double Slit” Experiment -- Demo



(Interference disappears if one slit is covered)

Another view of interference Light is a wave!



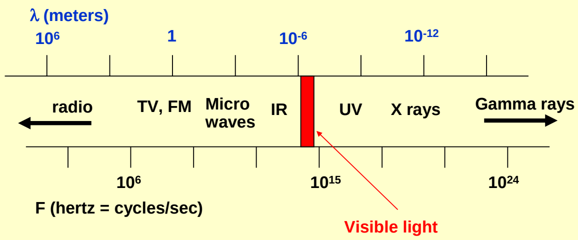
What kind of wave is light?

- Maxwell showed it is an electromagnetic wave
- But what does it travel through?
- Other waves we know are moving patterns in some material
  - Sound in air
  - Surface waves on water
  - Waves on a string
- What is the medium that transmits light?
- Maxwell proposed the ether - mysterious substance in all space invented to carry light
- Yet somehow the earth could move through it with no resistance!
- Not a satisfactory state of affairs!

Lecture 11 Waves and Interference

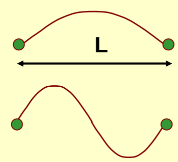
The range of electromagnetic waves

- All waves have velocity given by $v = f\lambda$
- Electromagnetic waves have velocity $v = c$ in vacuum
- Therefore $c = f\lambda$ or $f = c/\lambda$ or $\lambda = c/f$



Standing Waves

- Waves with boundary conditions.. e.g. hold both ends of a string fixed as in a guitar.
  - velocity of any wave produced (by plucking the string) is determined by the medium.. in this case the type of the string.
  - For a fixed length of string, only waves with certain wavelengths can be standing waves... namely those wavelengths which have zeroes at the ends of the string.
  - Therefore only certain frequencies will be heard.. namely those which correspond to the definite wavelengths via $f = v/\lambda$.



$L = \lambda/2$ fundamental: lowest frequency

$L = \lambda$ first harmonic: higher frequency

Summary

- Waves: Moving patterns
  - Water waves (height), Vibration of string: (displacement)
  - Sound: pressure wave
  - Light: Electromagnetic wave (also radio, x-rays, ...)
- Waves described by:
  - Amplitude A, Frequency ν, Wavelength λ
  - Velocity $v = \lambda\nu$
- Velocity of waves:
  - determined by the medium through which it is transmitted
  - Sound in air, around 340 m/s
  - Light in vacuum, around 3×10^8 m/s
- Interference is a key general property of waves
- Contrast with particles - objects with mass. In classical physics they are completely different - never show interference