Tues: Warm Up 12

Weds: Review III

Thurs: Exam III Covers Ch 29, 30, 31 (parts) Lecture 20-31 HW 7-9

Previous exams: 2018 Class 3 All Q

2017 Class 2 . Q 5-8

Class 3 Q 1-3

## Interference of waves or light

Electromagnetic theory predicts that electromagnetic waves travel at the speed of light. Thus we could envision light as a wave. However, when we observe optical effects via intensities or polarization, we do not access wave aspects of light. In order to demonstrate wave features of light we will use a characteristic property of waves - interference of waves

Interference (or superposition) is a process by which two or more waves on the same medium combine to produce a superposition.

Demo: PhET W.o.a.S.

- loose end
- damping = 0
- tension = low

manual observe

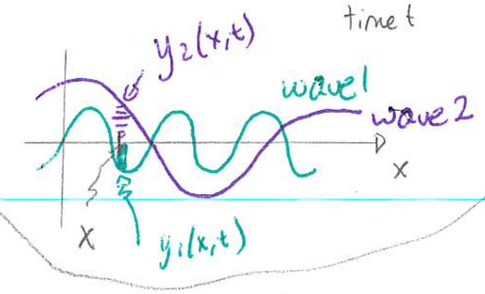
We observe:

1) The pulses eventually pass through each other as though they had never interacted.

2) While the pulses interact, they form a "combined" superposition.

The general scheme for determining the profile of the superposition is:

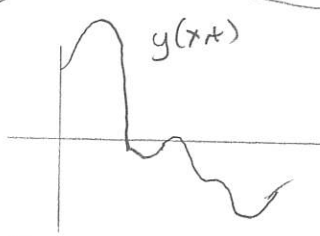
Consider each wave separately




→ At any instant in time, t, the overall displacement of the superposition at location x is

$$y(x,t) = y_1(x,t) + y_2(x,t)$$

where $y_i(x,t)$ is the displacement of wave $i$




Add two wave profiles

Demo: Zona Land.

Demo: Slide 1, Slide 2 → one round each.

Quiz 1, ~100% Quiz 2 ~100%

The same method applies to continuous waves.

Demo: Slides 3, 4, 5, 6, 7.

We see that these superpositions result from two shifted sinusoidal waves with the same amplitude but variable phase shifts.

$$\left.\begin{aligned} y_1 &= A\sin(kx) \\ y_2 &= A\sin(kx+\phi) \end{aligned}\right\} \rightarrow y(x,t) = A\sin(kx) + A\sin(kx+\phi)$$

The amplitude of the superposition depends on the phase shift. Two extremes are:

1) <u>constructive interference</u> – crests coincide, – troughs " } → wave of larger amplitude

2) <u>destructive interference</u> – crest of one meets trough of other } → wave of zero amplitude / cancel.

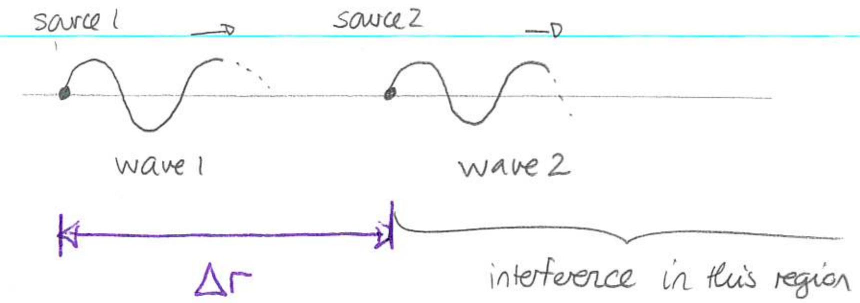
We would like to obtain rules for when these extremes occur.

In optics the two interfering waves will be produced by two sources:

- each source produces waves via an oscillation. The oscillations are always in step with each other (coherent/in phase)
- the sources are separated by a position shift $\Delta r$

When will constructive or destructive interference occur?

Slides, 8,9,10




These, and a relatively straightforward mathematical derivation, indicate:

| | |
|---|---|
| Constructive interference occurs when | $\Delta r = 0, \lambda, 2\lambda, 3\lambda, \ldots, n\lambda, \ldots$ |
| | (any integer number of wavelengths) |
| Destructive interference occurs when | $\Delta r = \lambda/2, \frac{3\lambda}{2}, \ldots \frac{2n-1}{2}\lambda, \ldots$ |
| | (odd half integer number of wavelengths) |

~~Quiz~~ Quiz 3 - 90%

~~Quiz 3~~ Quiz 4 - 90%

Thus we can observe wave properties by producing two or more overlapping waves on a medium. We can then try to observe constructive and destructive interference.

## 199 Adding sinusoidal waves

Two sources separated by distance $\Delta r$ produce one dimensional sinusoidal traveling waves. These are described by

$$y_1(x,t) = A\sin(kx - \omega t)$$
$$y_2(x,t) = A\sin(k(x - \Delta r) - \omega t).$$

In the following note that

$$\sin A + \sin B = 2\cos\left(\frac{A-B}{2}\right)\sin\left(\frac{A+B}{2}\right)$$

a) Show that the superposition is represented by

$$y(x,t) = \sout{B}\ C \sin(kx - \omega t + \phi)$$

where ~~B~~ C is independent of location and time and $\phi$ a phase constant. Find an expression for ~~B~~ C.

b) Use the previous part to determine conditions where constructive interference occurs.

c) Use the previous part to determine conditions where destructive interference occurs.

Answer: a) $y(x,t) = y_1(x,t) + y_2(x,t)$

$$= A\left[\sin(kx-\omega t) + \sin(kx - k\Delta r - \omega t)\right]$$

$$= 2A\cos\left[\frac{kx-\omega t - (kx - k\Delta r - \omega t)}{2}\right]\sin\left[\frac{kx-\omega t + kx - \omega t - k\Delta r}{2}\right]$$

$$= 2A\cos\left[\frac{k\Delta r}{2}\right]\sin\left[kx - \omega t - \frac{k\Delta r}{2}\right]$$

This matches with $C = 2A\cos\left(\frac{k\Delta r}{2}\right)$ $\phi = -\frac{k\Delta r}{2}$.

b) Need $|B|$ to be a max $(\pm 1)$ $\Rightarrow \frac{k\Delta r}{2} = n\pi \Rightarrow \frac{2\pi}{\lambda}\frac{\Delta r}{2} = n\pi$

$= \boxed{\Delta r = n\lambda}$

c) Need $|B|$ to be a min $(0)$ $\Rightarrow \frac{k\Delta r}{2} = \left(\frac{2n-1}{2}\right)\pi$

$\Rightarrow \frac{2\pi}{\lambda 2}\Delta r = \frac{2n-1}{2}\pi \Rightarrow \boxed{\Delta r = \frac{2n-1}{2}\lambda}$

# Observations of interference

In general we observe interference of waves that propagate in two dimensions. These provide interference patterns. We can illustrate these with an animation

PhET Wave Interference

- Interference - water waves

We see that, in two dimensions:

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| constructive | interference | occurs | along | entire | lines | - these | are | antinodal lines |
| destructive | " | " | " | " | " | - " | " | nodal lines |

The location of these lines depends on:

1) separation of sources
2) wavelength of waves.

Demo show with PhET:

We can actually observe these with

1) water waves - Loyola Univ video ~ 0:30
2) sound waves - Two tuning forks.