PHY385-H1F Introductory Optics

Fall 2011

- What is light?

- Light is an electromagnetic wave – and is highly useful in our everyday life!

- How does light travel in a vacuum?

- How does light travel through a transparent medium?

- What neat tricks can we do with light in the laboratory to help us do physics research?

Today

- Introduction to course and Harlow
- History of the Theories of Optics – Chapter 1 of Hecht
- Starting Chapter 2:
- One dimensional waves
- Harmonic Waves

PHY385-H1F Introductory Optics

- The prerequisites for this course are PHY250-H1 (or PHY251) and PHY254-H1 (or PHY255).

- Required Text: “Optics” 4th Edition (Copyright 2002) by Eugene Hecht. This course covers Chapters 2-5 and 8, and sections 9.1, 10.1, 10.2 and 13.1. Chapter 1 is also recommended reading.

- I am Jason Harlow. I’m a Senior Lecturer. I have been a teaching stream faculty at U of T for 7 years.

- My PhD is in observational stellar astronomy. As part of my thesis I designed, built and commissioned an optical fibre-fed spectrograph for an 11-metre telescope in Texas.

- I was an Assistant Professor for 6 years at the University of the Pacific in California, where I taught the upper-year Optics course.

Phototherapy

My daughter, Zainab Harlow, July 29, 2011

History of Light

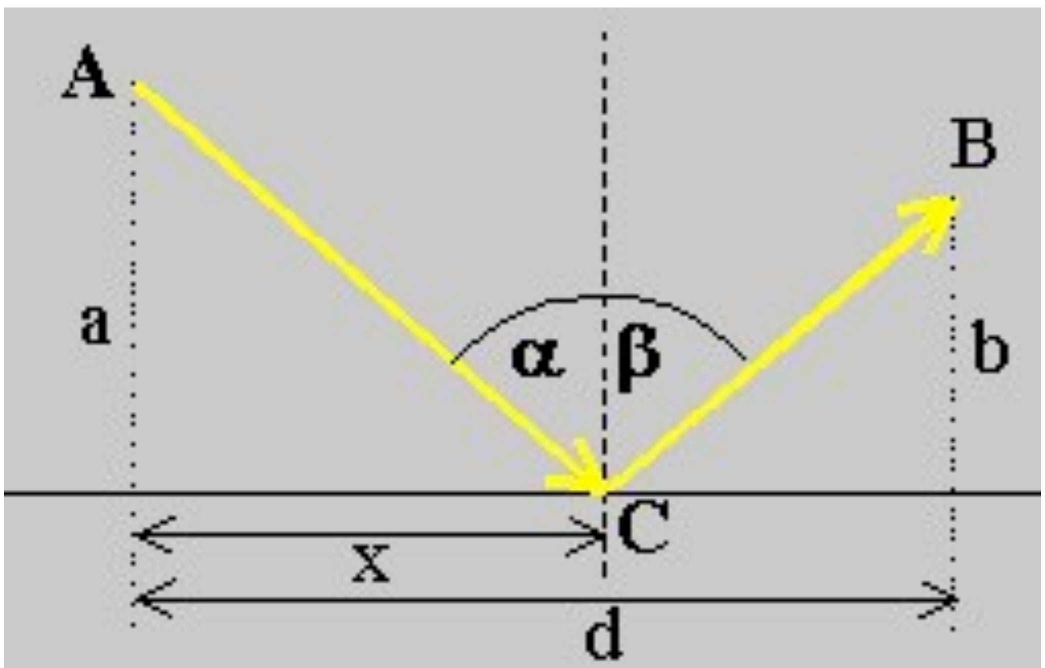
- 300 B.C. – **Euclid** of Alexandria noted that light travels in straight lines, and wrote down the Law of Reflection for plane mirrors.

$$\theta_1 = \theta_2$$

- Unfortunately, Euclid believed that vision was due to our eyes emitting rays of light.

History of Light

- 50 A.D. – **Hero** of Alexandria explained Euclid's Law of Reflection by proposing that light always takes the shortest path between two points.



History of Light

- 1000 A.D. – **Alhazen** of Basra considered the law of reflection in 3-D, noting that the angles of incidence and reflection are in the same plane normal to the interface.

- Alhazen proved experimentally that vision is due to light proceeding to our eyes, from each point on an object. He also investigated refraction, pinhole cameras, and lenses.

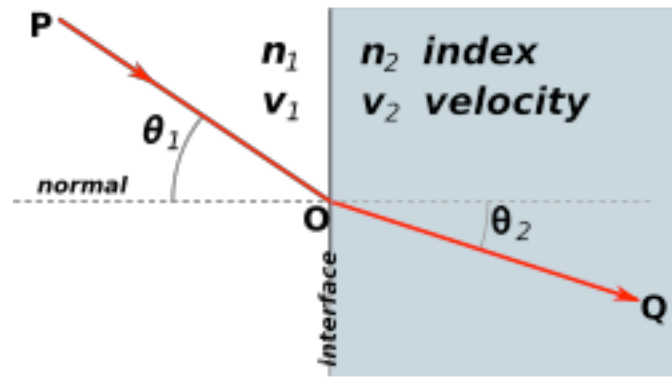
History of Light

- 1611 – **Johannes Kepler** discovered total internal reflection, and, in 1621, **Willebrord Snel** wrote down the Law of Refraction (Snell's Law).

Kepler

Snel

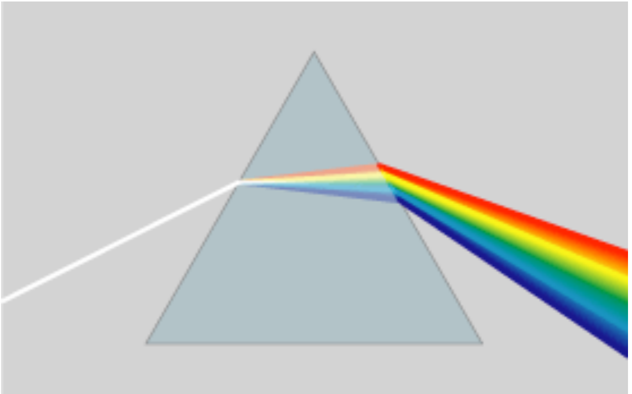
Fermat



- 1657 – **Pierre de Fermat** derived the law of reflection using the principle of least *time*.

History of Light

- 1665 – **Isaac Newton** used a glass prism to disperse light and create a rainbow. He concluded that white light was composed of a mixture of a whole range of colours.



- Unfortunately, Newton advocated the idea that light was a stream of particles, not a wave phenomenon.

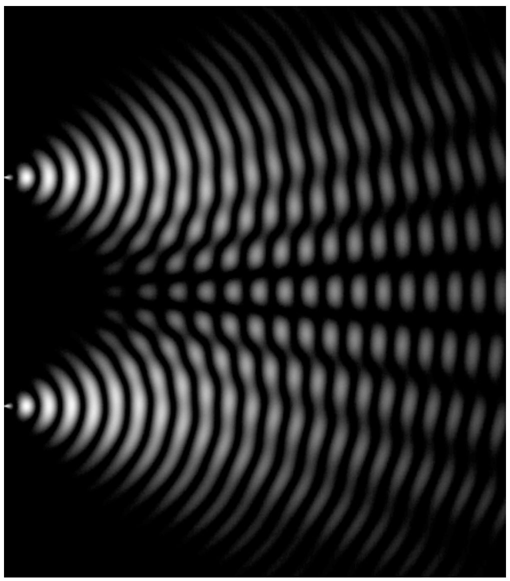
History of Light

- 1670 – **Christiaan Huygens** used the wave theory of light to explain how it can travel in straight lines.

- Huygens correctly applied Fermat's principle to derive Snell's Law using a wave theory.

History of Light

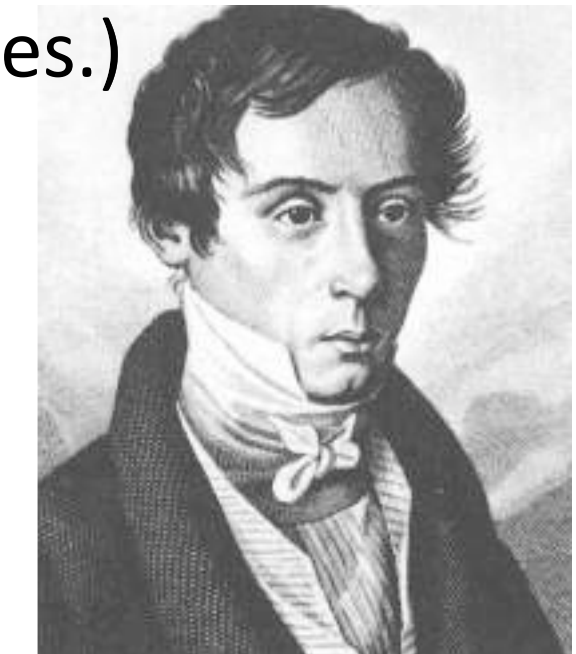
- 1801 – **Thomas Young** wrote down the Principle of Interference (superposition) and made the first derivations of the wavelength of light based on Newton's observations of fringes from thin films.



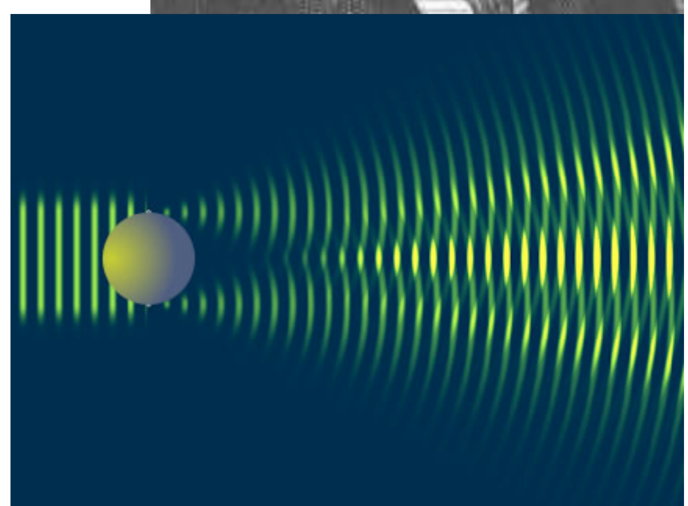
- Young also suggested that light was a transverse wave (oscillations perpendicular to direction of wave motion) and that it therefore could be polarized.

History of Light

- 1814 – **Jean Fresnel** elaborated Huygens's wave theory to explain diffraction effects (bending of light around obstacles.)

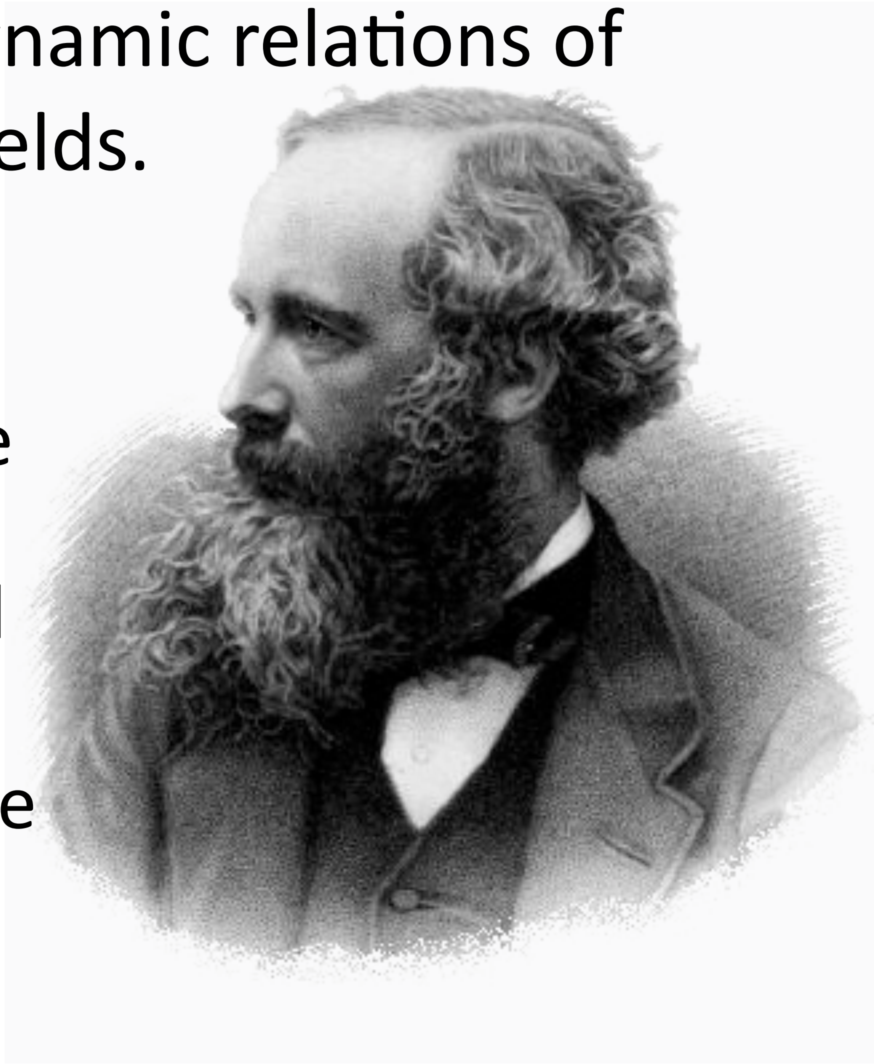


- Fresnel used the idea of polarization to predict amplitudes of reflected and transmitted light from glass interfaces.
- These successes *finally* convinced the scientific community that light was a wave phenomenon, not a stream of particles.



History of Light

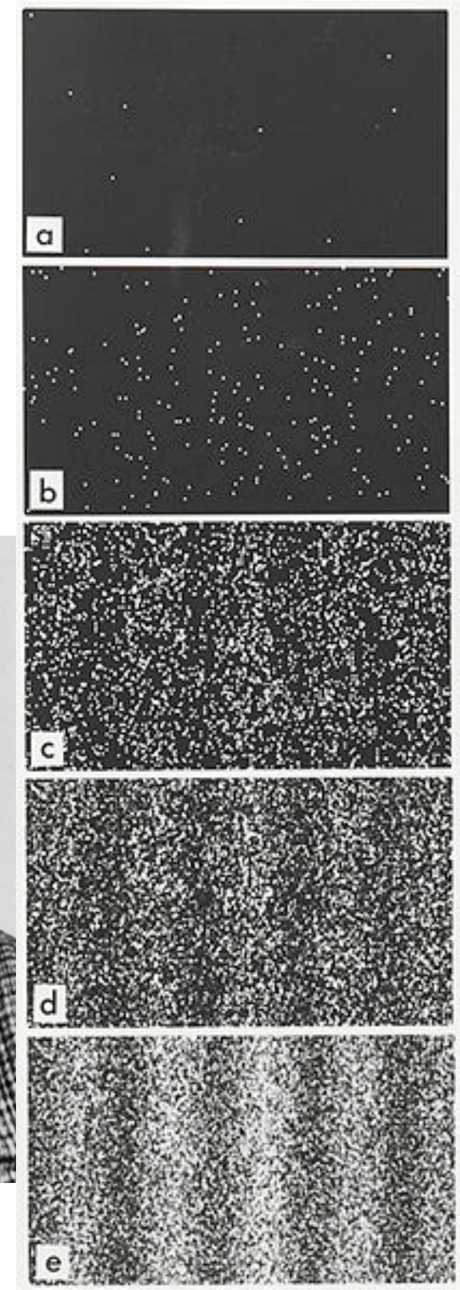
- 1864 – **James Clerk Maxwell** published his equations describing the dynamic relations of the electric and magnetic fields.



- Maxwell showed that disturbances in the electric and magnetic fields could propagate as a transverse wave, and he solved for the theoretical speed of this wave.
- This speed was very close to the current experimental value, justifying his theory that light was an electromagnetic wave.

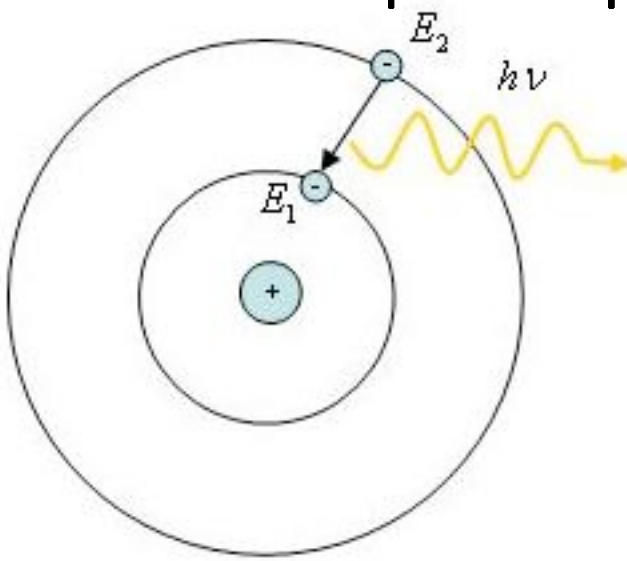
History of Light

- 1905 – **Albert Einstein** explained the photoelectric effect by proposing that light could only be delivered in globs or “particles” of energy (photons).
- This lead to the theory of Quantum Mechanics, which states that every particle moves according to a wave equation which gives the probability density of its future location.
- Thus, light is correctly understood as a stream of particles.



History of Light

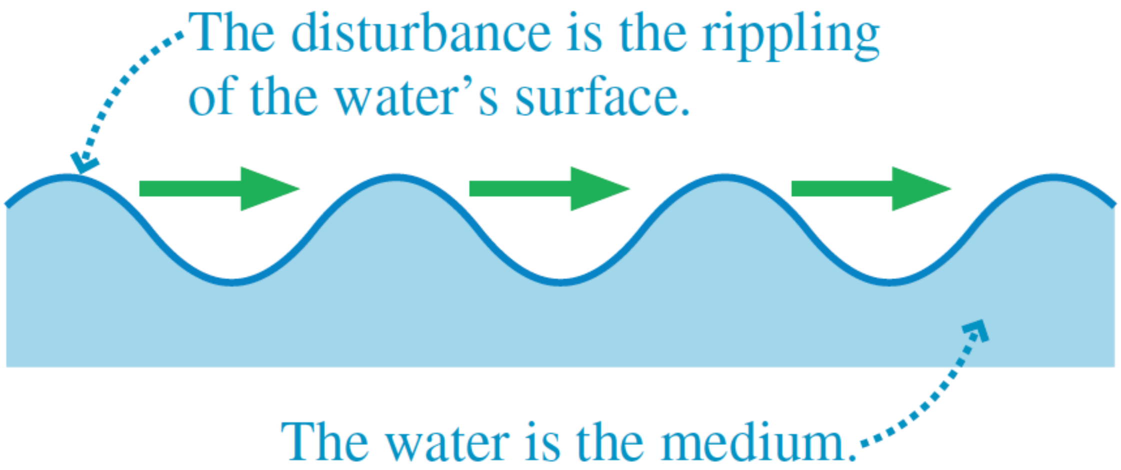
- 1913 - **Niels Bohr** modelled the electron orbits of a Hydrogen atom to explain the wavelengths of emission and absorption spectra of Hydrogen gas.



- This was then applied to many other elements to begin the study of atomic and molecular chemistry.

The Wave Model

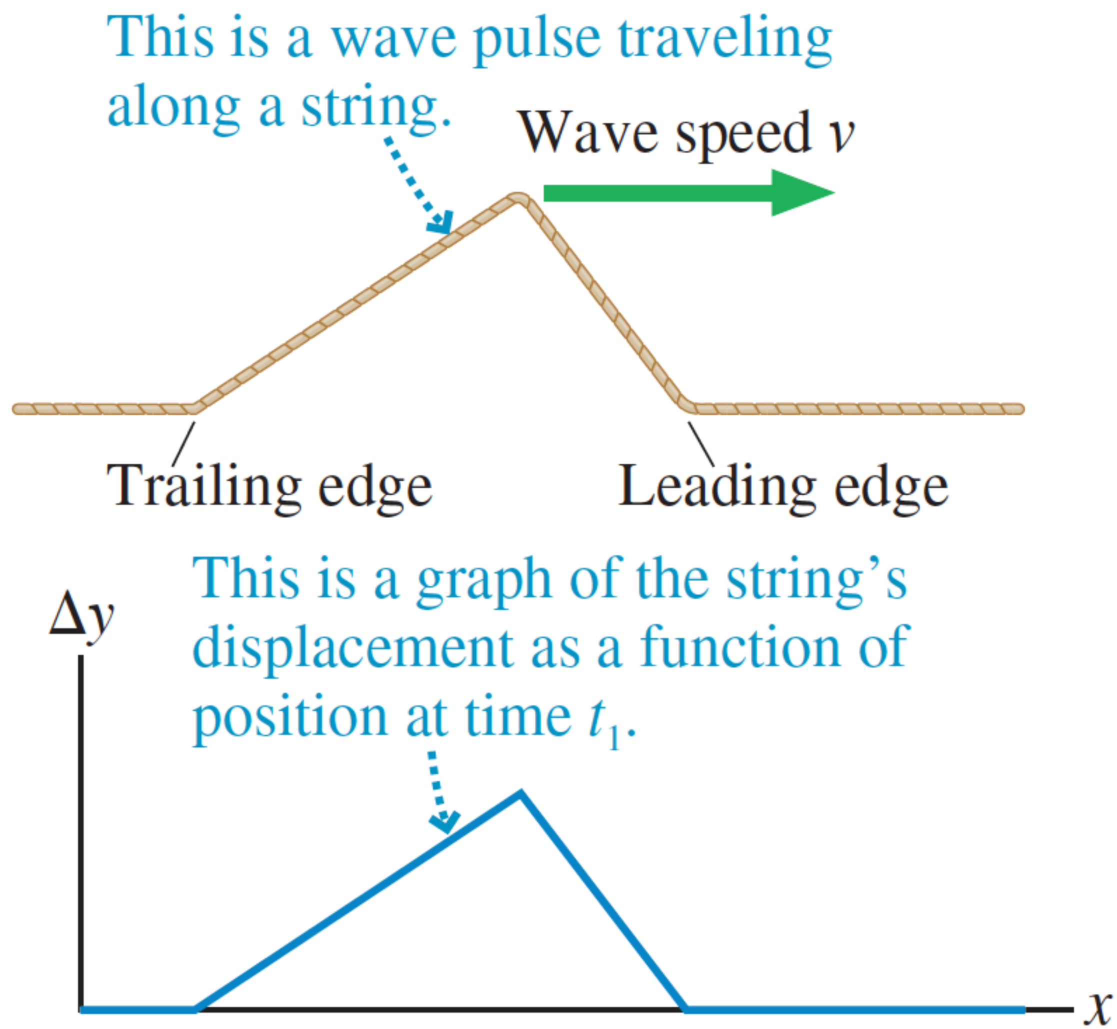
- The wave model is built around the idea of a **traveling wave**, which is an organized disturbance traveling with a well-defined wave speed
- The **medium** of a mechanical wave is the substance through or along which the wave moves



Snapshot Graph

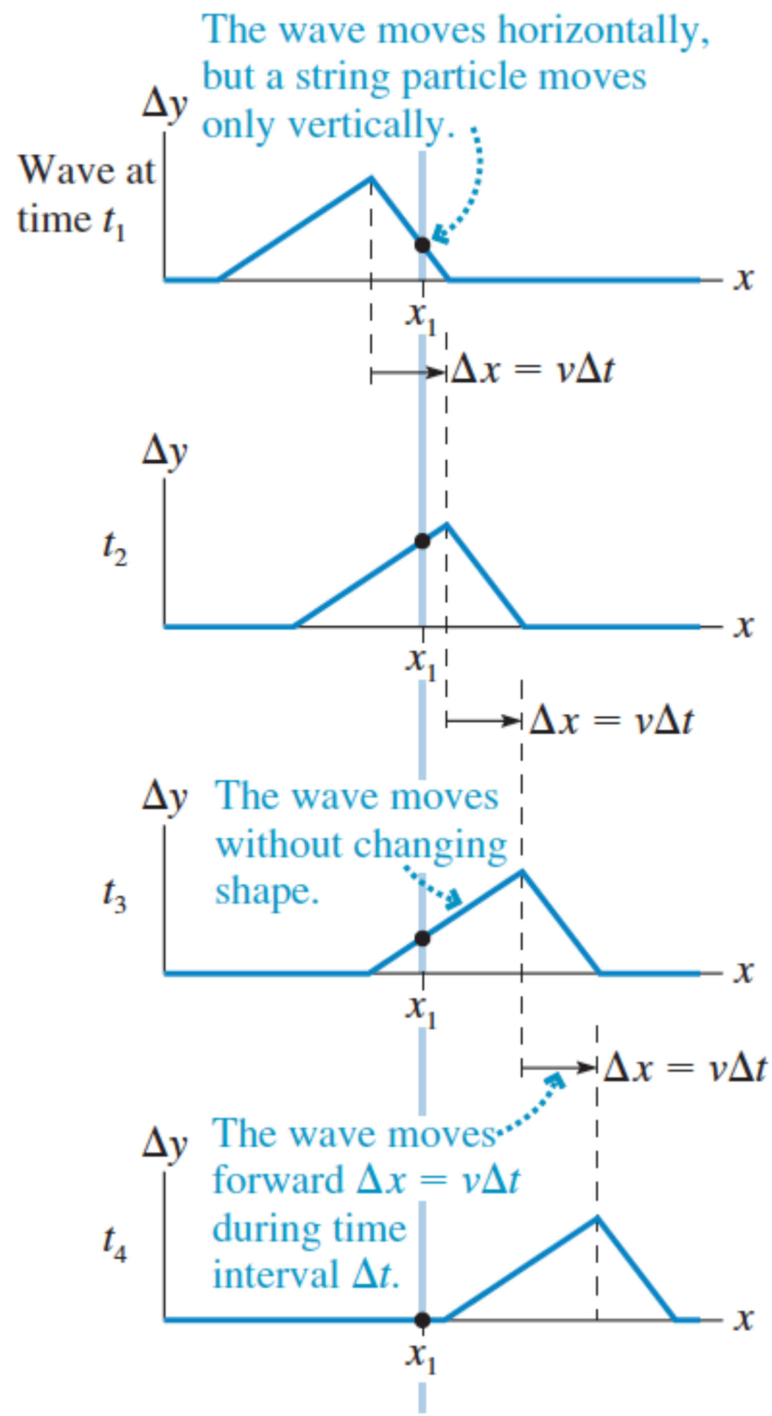
- A graph that shows the wave's displacement as a function of position at a single instant of time is called a **snapshot graph**

- For a wave on a string, a snapshot graph is literally a picture of the wave at this instant.



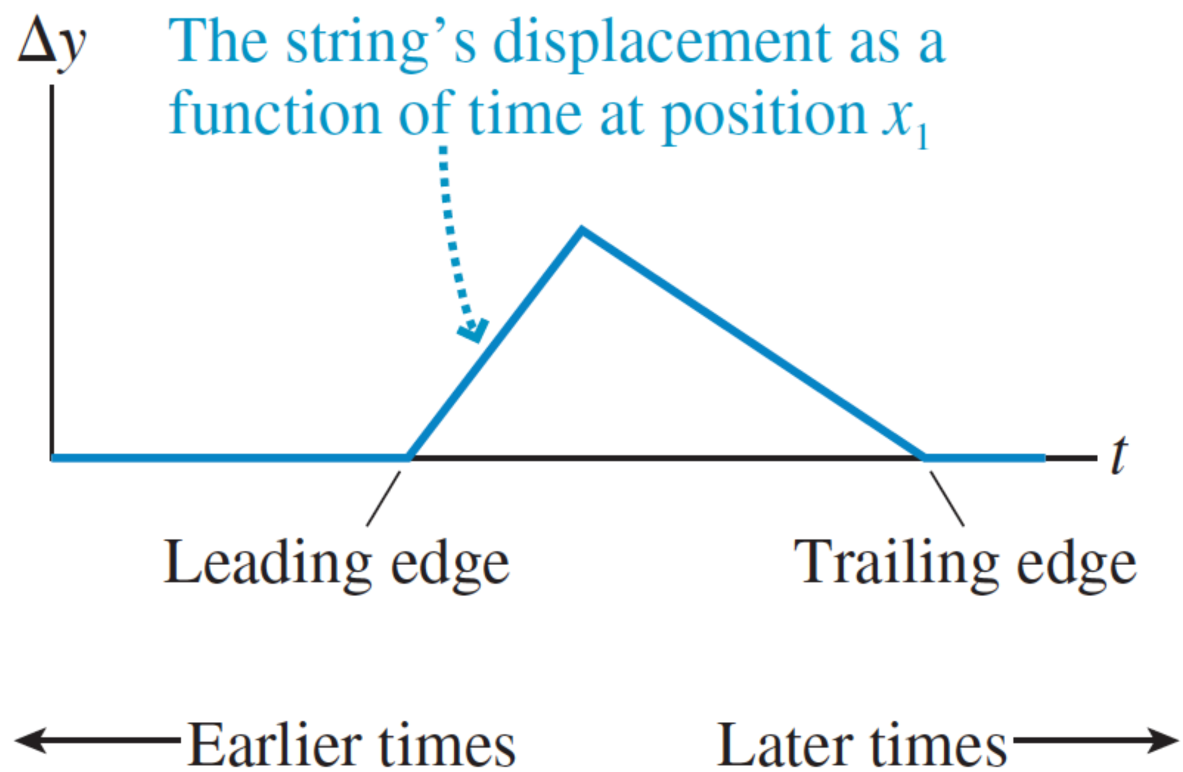
One-Dimensional Waves

- The figure shows a sequence of snapshot graphs as a wave pulse moves
- These are like successive frames from a movie
- Notice that the wave pulse moves forward distance $\Delta x = v\Delta t$ during the time interval Δt
- That is, the wave moves with *constant speed*



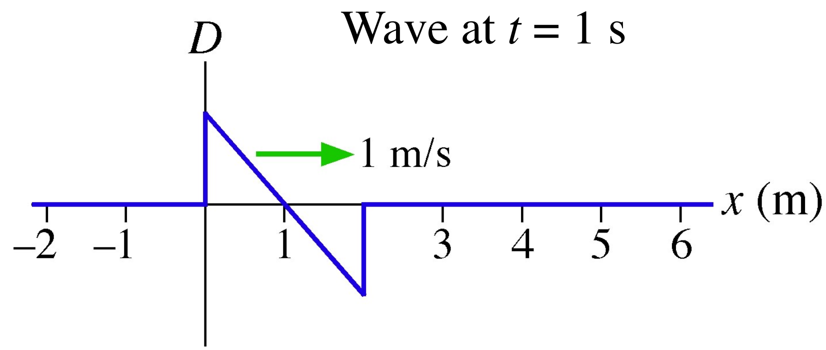
History Graph

- A graph that shows the wave's displacement as a function of time at a single position in space is called a **history graph**
- This graph tells the history of that particular point in the medium
- Note that for a wave moving from left to right, the shape of the history graph is *reversed* compared to the snapshot graph

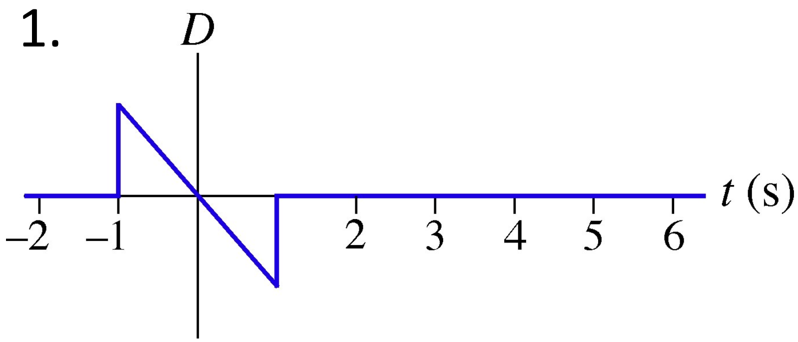


Finger Vote!!!

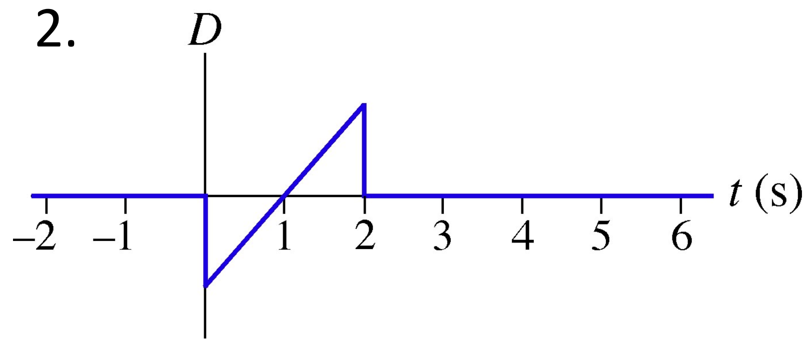
This is a snapshot graph at t = 1 s of a wave pulse traveling to the right at 1 m/s. Which graph below shows the history graph at x = 1 m?



1.



2.



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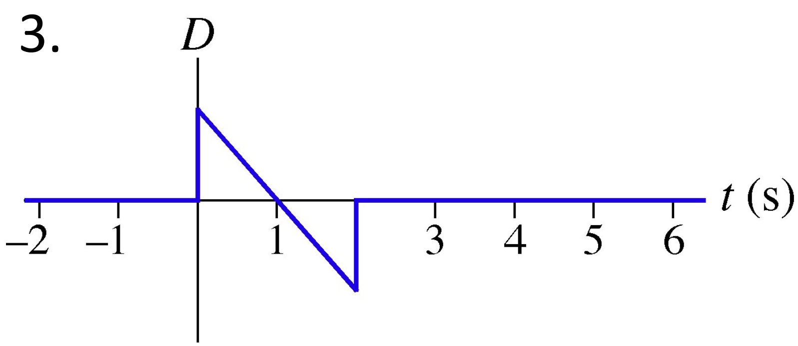

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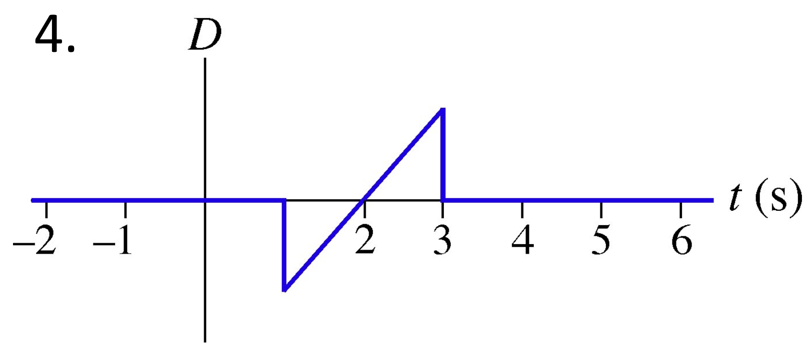

Finger Vote!!!

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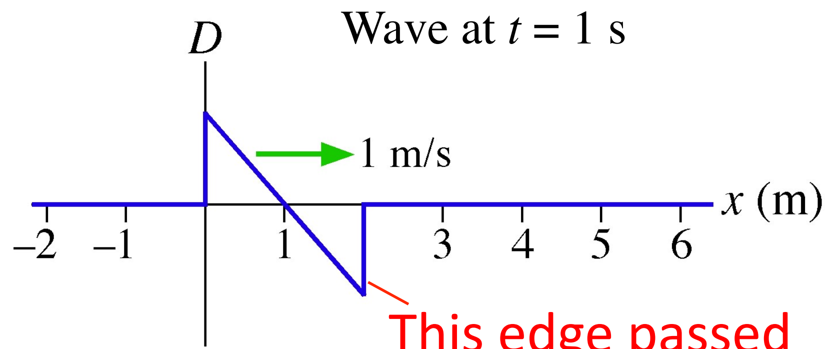
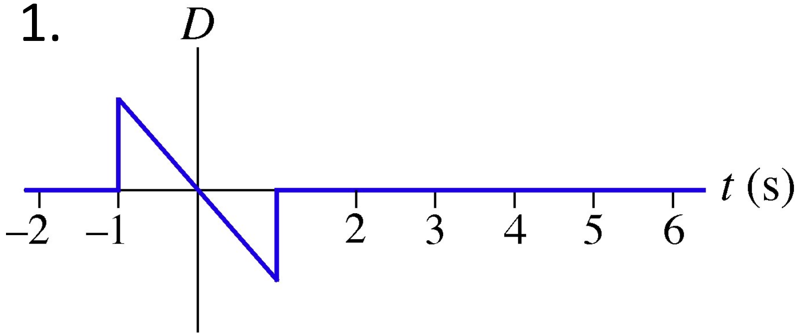


This edge passed x = 1 m 1 s ago, at t = 0 s.

1.



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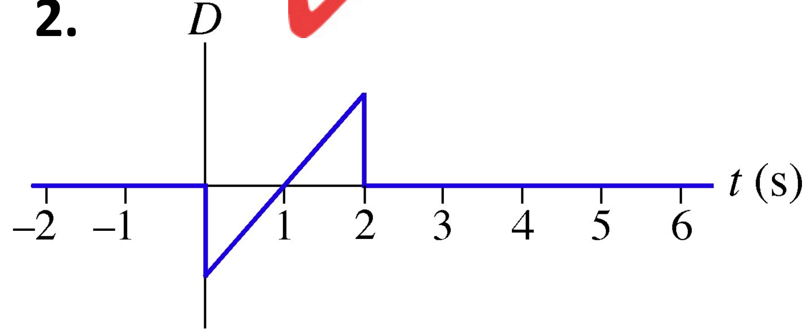

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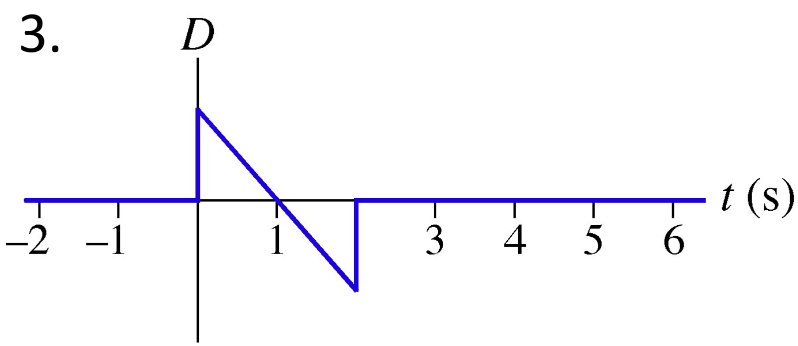

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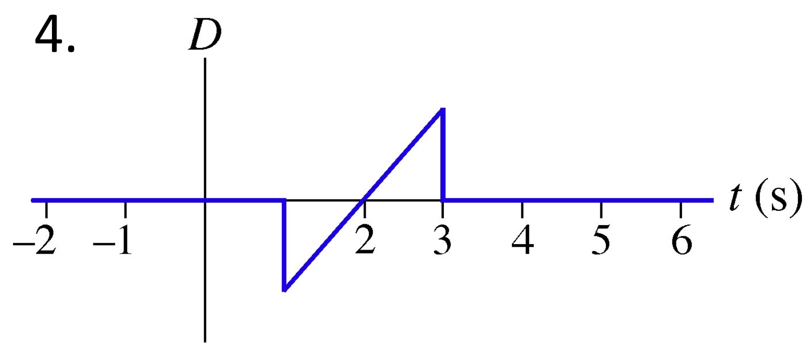
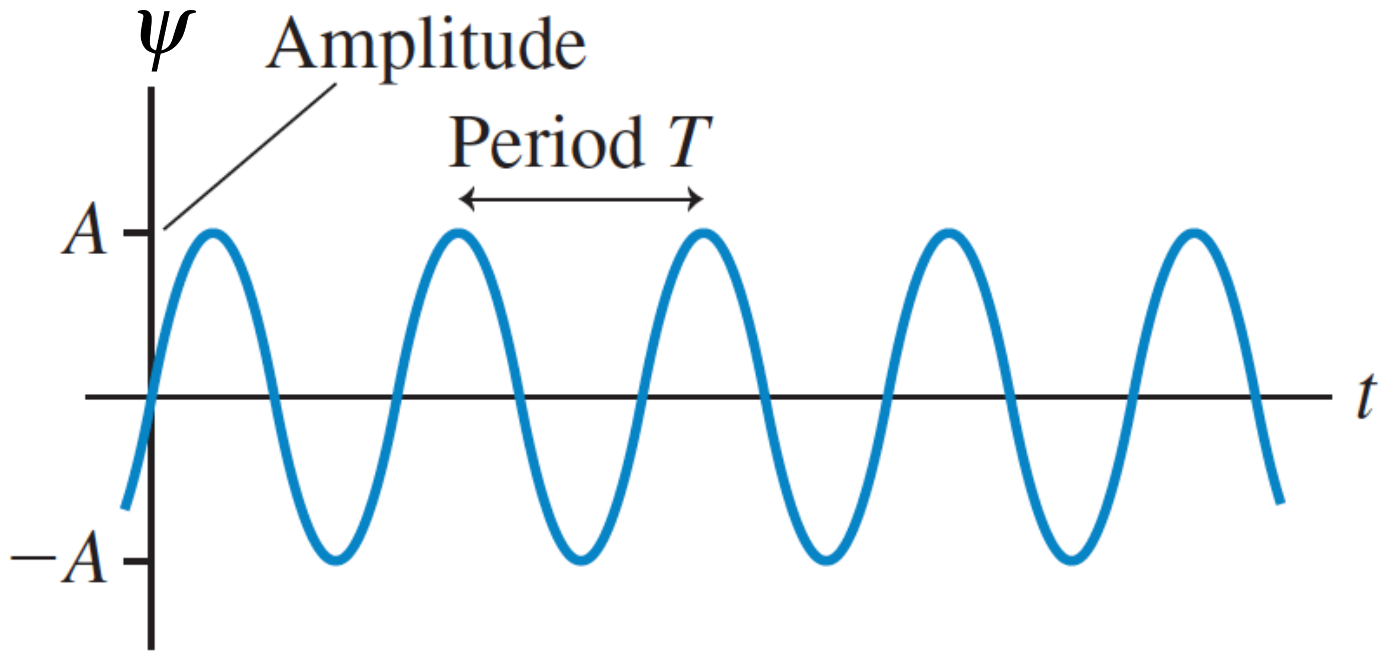


The Wavefunction

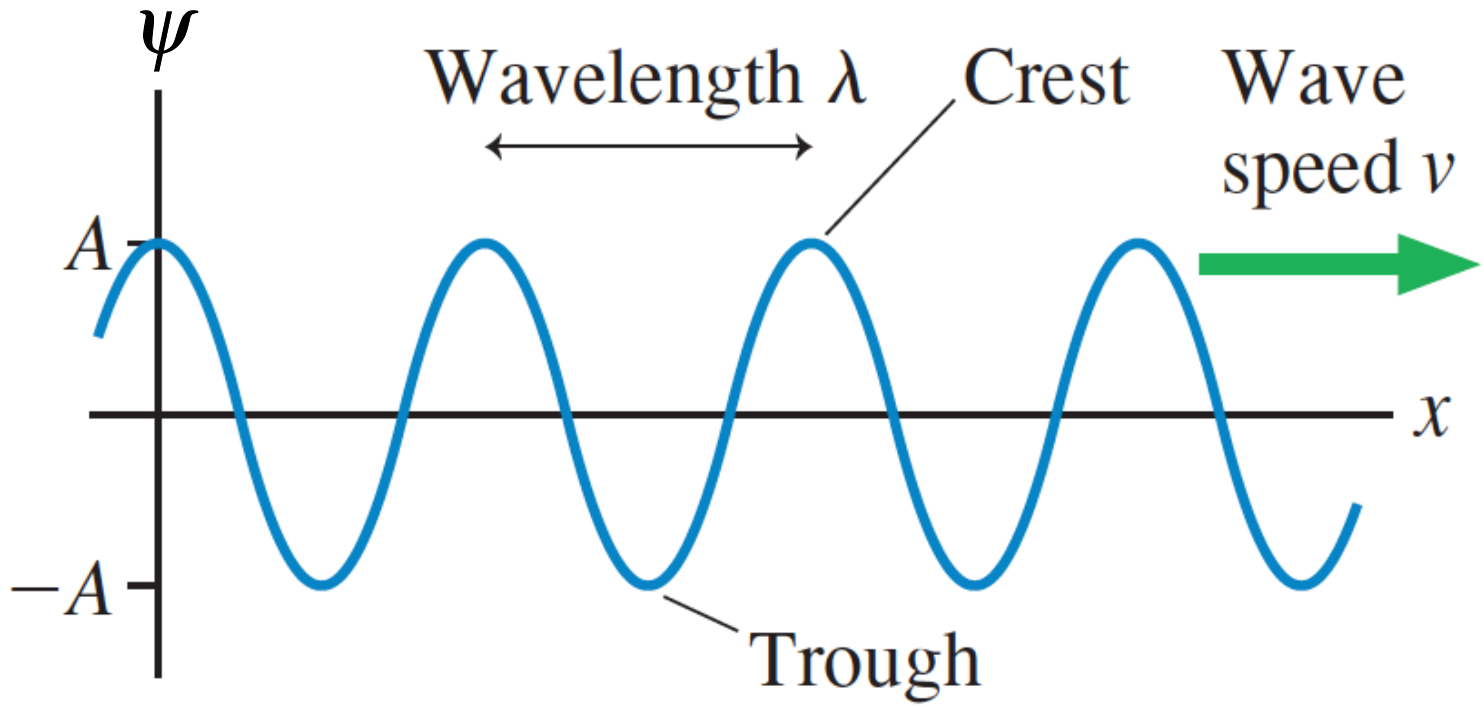
- In “the wave” at the Rogers Centre, the wave moves around the stadium, but the particles (people) undergo small displacements from their equilibrium positions
- When describing a wave mathematically, we’ll use the generic symbol ψ to stand for the *wavefunction* of a wave of any type
- $\psi\ (x, t)$ = the wavefunction at time t of a particle at position x

Harmonic Waves



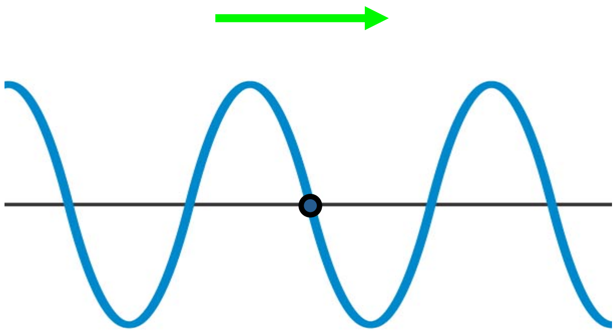
- Above is a history graph for a harmonic wave, showing the displacement of the medium at one point in space
- Each particle in the medium undergoes simple harmonic motion with frequency f, where $f = 1/T$
- The **amplitude** A of the wave is the maximum value of the displacement

Harmonic Waves



- Above is a snapshot graph for a harmonic wave, showing the wave stretched out in space, moving to the right with speed *v*
- The distance spanned by one cycle of the motion is called the wavelength *λ* of the wave

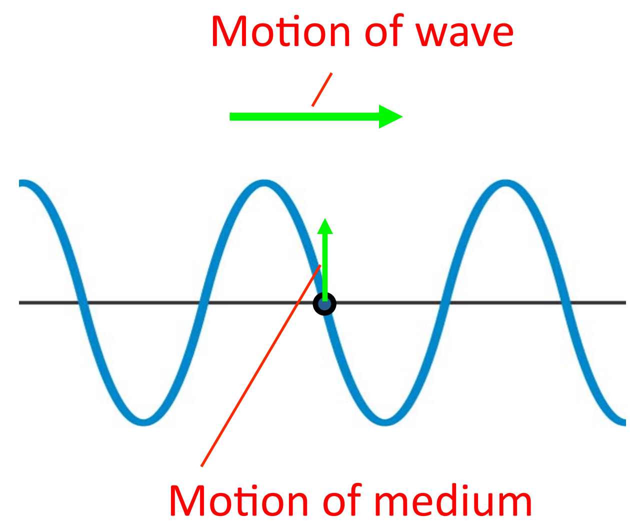
Finger Vote!!! 



A wave on a string is traveling to the right. At this instant, the motion of the piece of string marked with a dot is

1. up.
2. down.
3. right.
4. left.
5. zero. Instantaneously at rest.

Finger Vote!!! 

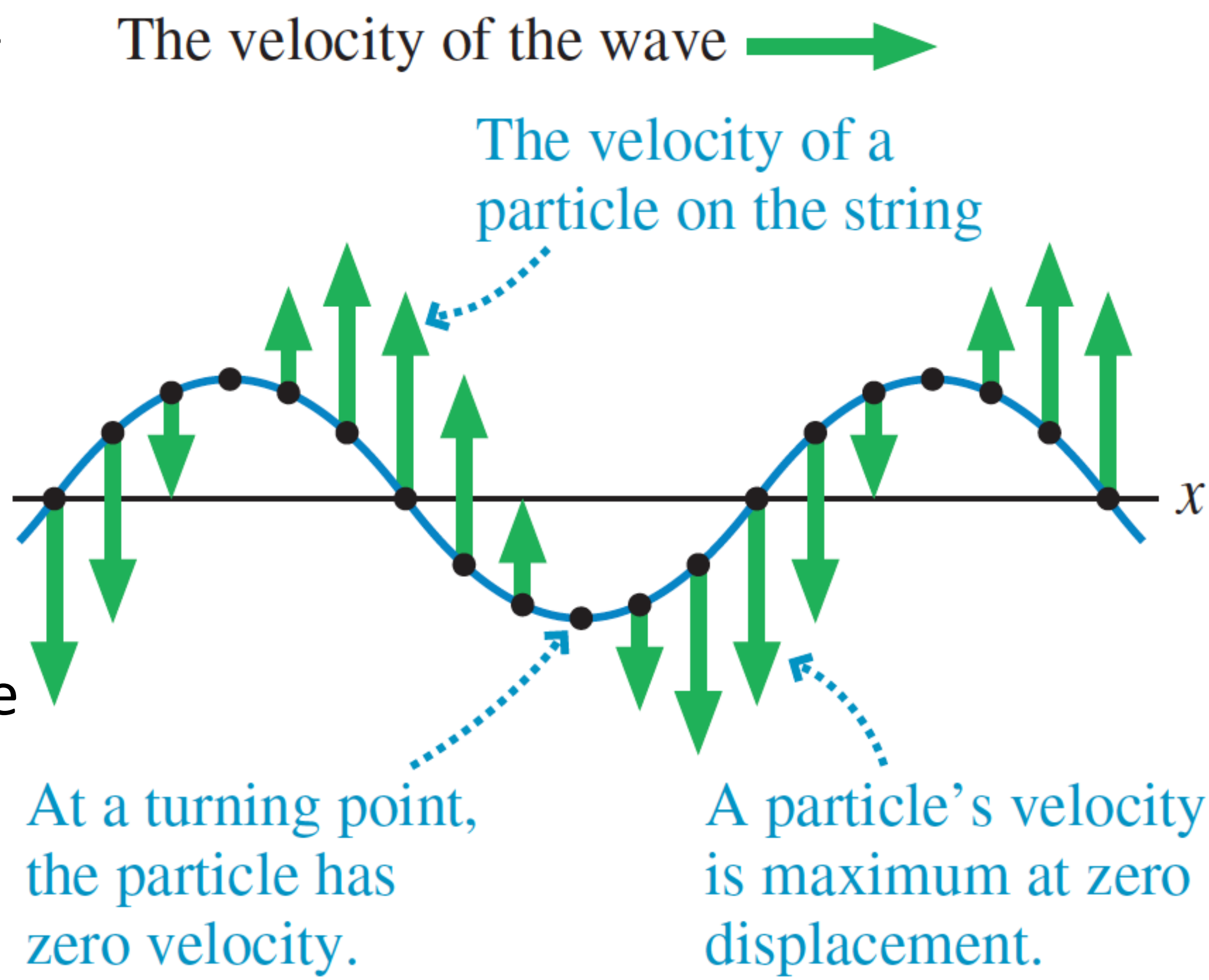


A wave on a string is traveling to the right. At this instant, the motion of the piece of string marked with a dot is

1. **up.**
2. down.
3. right.
4. left.
5. zero. Instantaneously at rest.

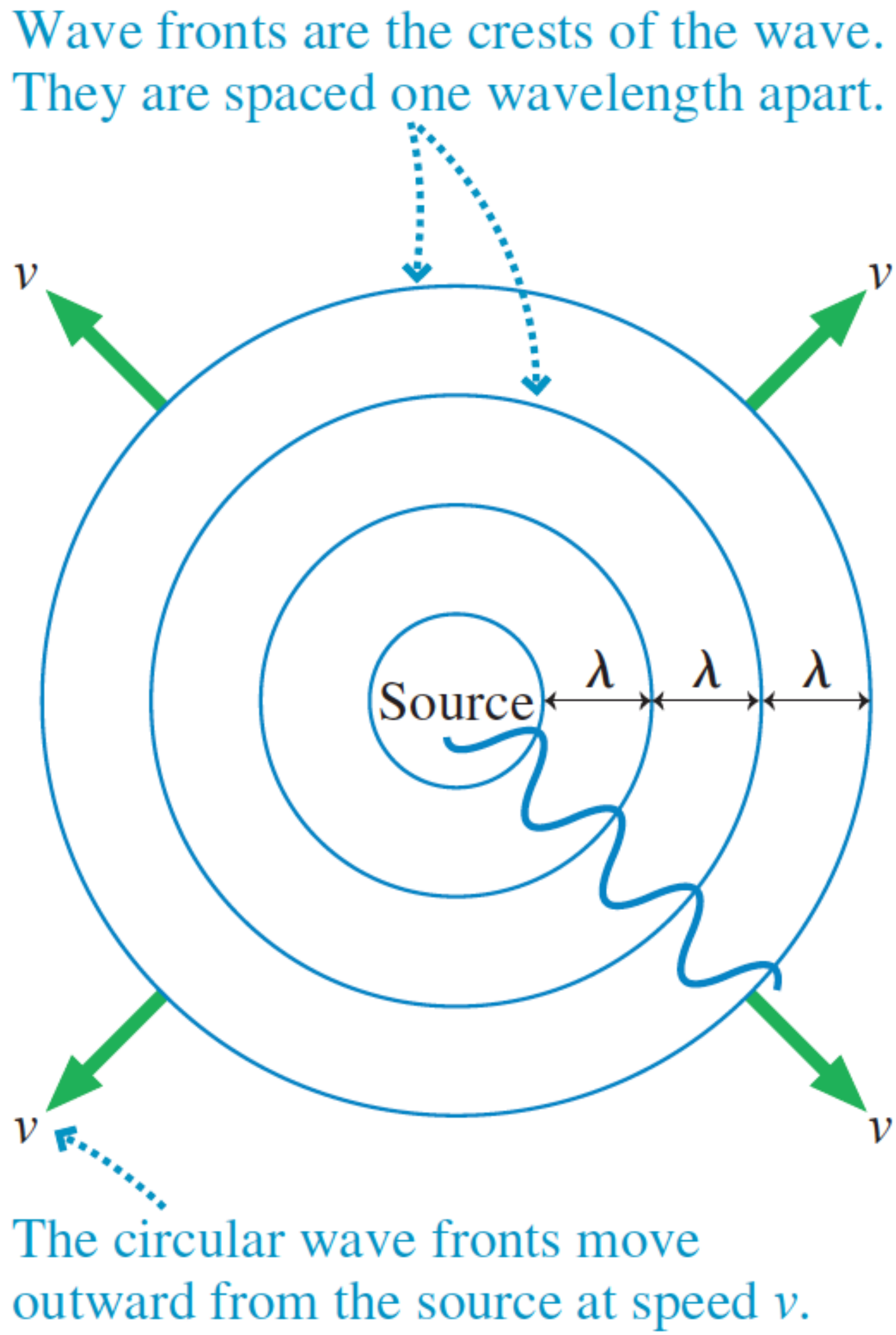
Wave Motion on a String

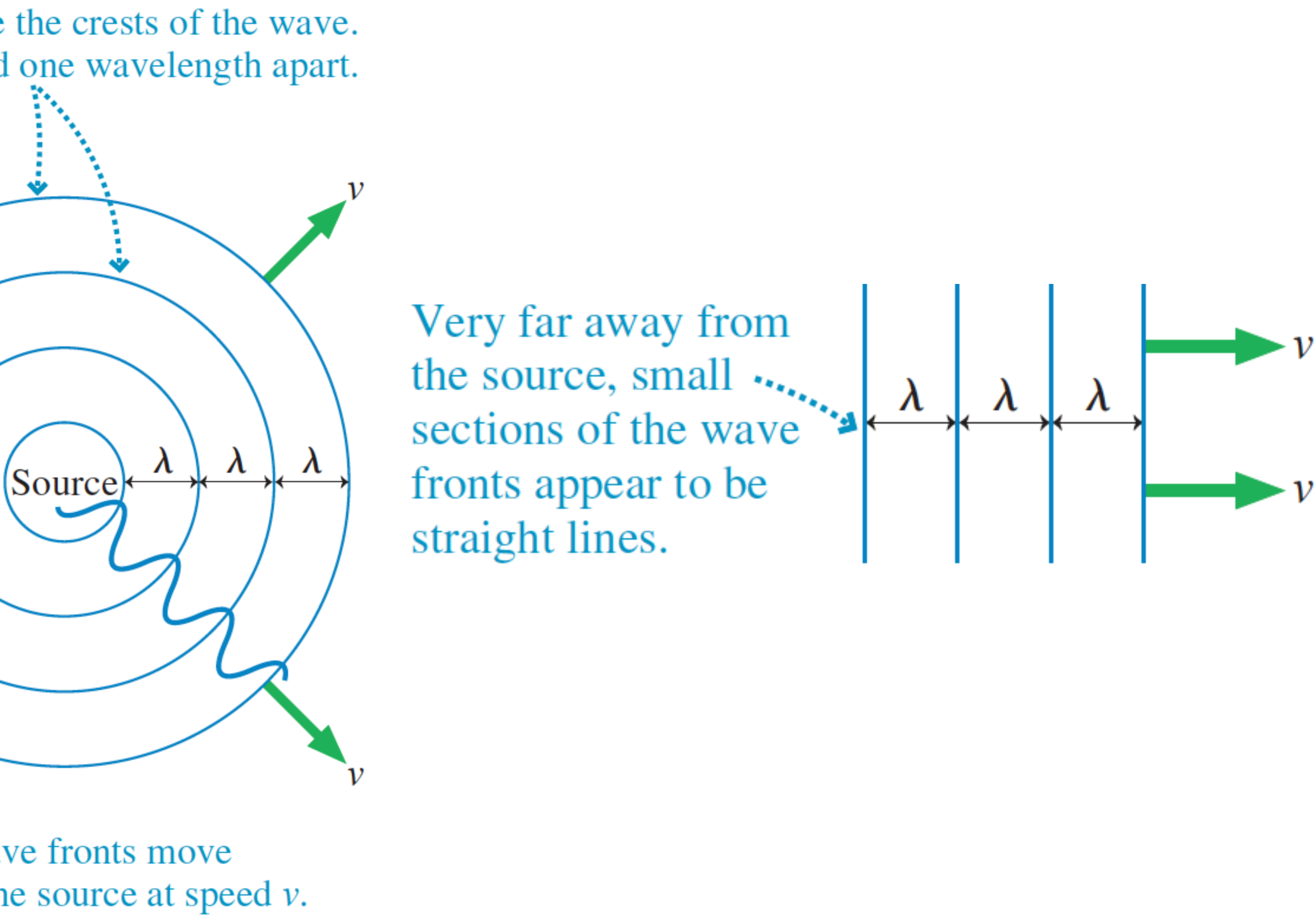
- Shown is a snapshot graph of a wave on a string with vectors showing the velocity of the string at various points
- As the wave moves along *x*, the velocity of a particle on the string is in the *y*-direction



Waves in Two and Three Dimensions

- Consider circular ripples spreading on a pond
- The lines that locate the crests are called **wave fronts**

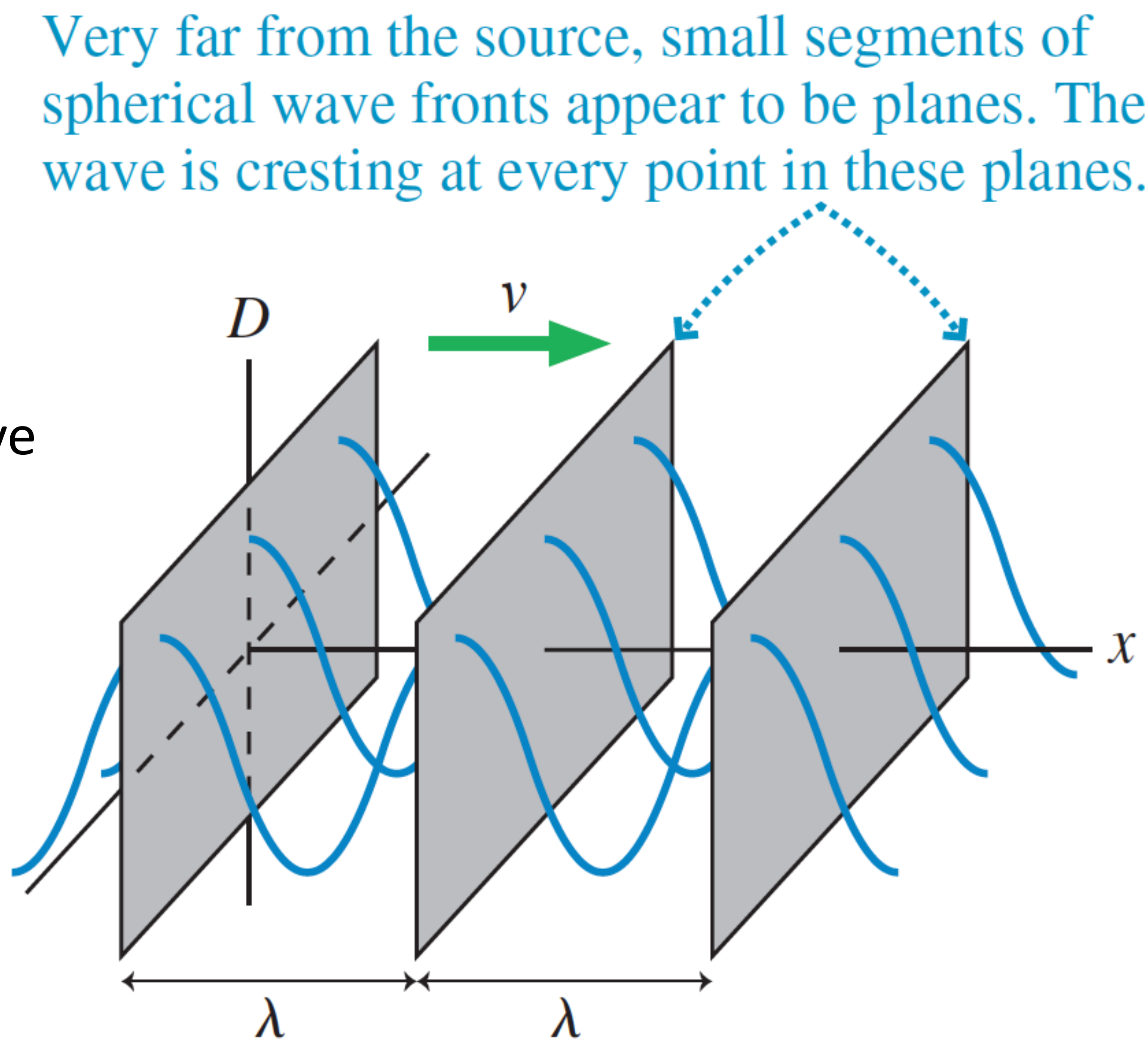




e the crests of the wave.
d one wavelength apart.
v
Source
λ
λ
λ
v
ve fronts move
he source at speed v.
Very far away from the source, small sections of the wave fronts appear to be straight lines.
λ
λ
λ
v
v

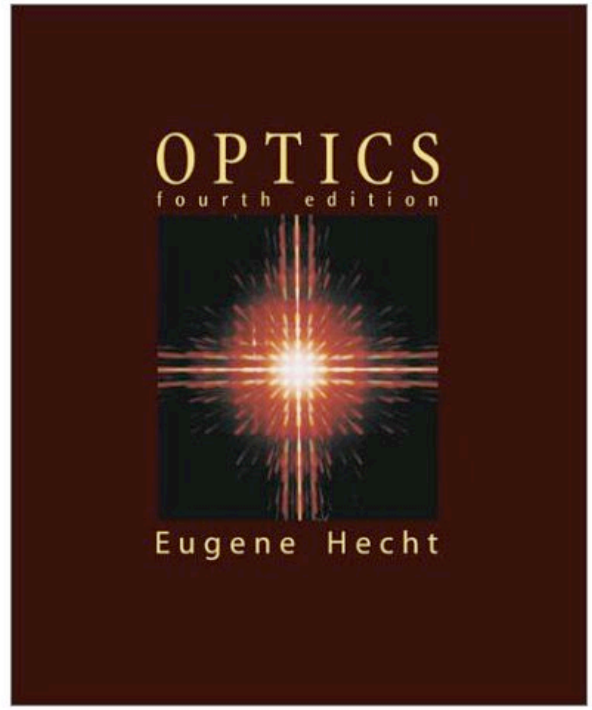
Waves in Two and Three Dimensions

- Loudspeakers and lightbulbs emit **spherical waves**
- That is, the crests of the wave form a series of concentric spherical shells
- Far from the source this is a **plane wave**



PHY385-H1F Introductory Optics

- Don't forget the 3 hand-outs today:
  - Syllabus
  - Problem Set 0
  - Problem Set 1
- Just before class today I saw 3 used Hechts at the Campus Bookstore College & St.George
- At the Campus Bookstore it is $167 for a new book, $125 for a used book



- New on amazon.com for $127, plus $24 for shipping and wait 8-16 days
- New on chapters.indigo.ca for $165 and wait 3-9 days
- See you on Thursday!!