Engineering Optics

Lecture 2

by

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Course Content

Module 1: Wave Optics

- **Interference**- Introduction to waves, Coherence (Spatial and Temporal), Principle of Superposition, Young's double slit experiment, Interference by wave front division and by amplitude division and examples.
- **Diffraction**- Fresnel and Fraunhofer diffraction, Fraunhofer diffraction due to double slit. Diffraction grating and its applications.
- **Polarization**- Introduction, Malus' law, Polarization by reflection and Brewster's law and applications.

Module 2: Laser Basics

- Laser operation, Absorption, Spontaneous Emission and Stimulated Emission, Population & Inversion, Three- and Four Level Laser Systems, Laser Characteristics- Types of Lasers: Solid-State Lasers, Gas Lasers, Semiconductor Lasers.

Module 3: Applications

- **Interferometers:** Michelson interferometer, Fabry-Perot interferometer, Mach-Zehnder interferometer, Sagnac interferometer.
- **Fiber optics:** Fermat's principle and Snell's law, optical fiber: principle and construction, acceptance cone, numerical aperture, types of fibers, Applications.

Books: 1. **A. Ghatak, Optics (4th edition), Tata Mcgraw Hill (2009) and 2.** Eugene Hecht, Optics (5th edition), Pearson (2019) and

Why Engineering optics?

- knowledge of optics to engineering problems
- to acquire the basic principles of optics

Course → Physical intuition and engineering design

Optics in

- *Everyday life*
- *Space-science*
- *Materials science*
- *Medical science*

Applications

- *Imaging: Microscope, Telescope*
- *Mobile, Internet → optical fibers*
- *Lasers for surgery*
- *Industry: LASER cutting and wielding*
- *Computer chips → optical lithography*

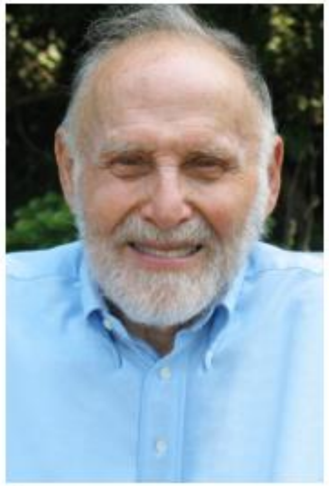
Nobel prizes in optics

- **Ashkin → optical tweezers** that use laser light to trap microscopic objects such as particles, atoms, and viruses. **Optical tweezers are now used to capture and study living bacteria**.

- **Mourou and Strickland developed chirped pulse amplification (CPA),** a method of generating high-intensity, ultra-short pulses. The scheme allows creation of powerful laser pulses that would otherwise damage the optical materials in the amplifiers. higher-intensity, ultra-sharp laser beams now **used in millions of corrective eye surgeries.**

https://www.aps.org/publications/apsnews/201811/nobel18.cfm

The Nobel Prize in Physics 2018



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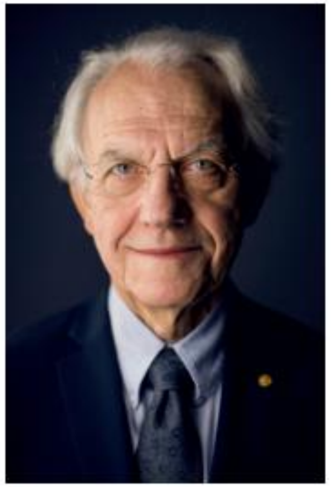
Prize share: 1/2



© Nobel Media AB. Photo: A. Mahmoud
Gérard Mourou
Prize share: 1/4

© Nobel Media AB. Photo: A. Mahmoud
Donna Strickland
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The Nobel Prize in Physics 2018 was awarded "for groundbreaking inventions in the field of laser physics" with one half to Arthur Ashkin "for the optical tweezers and their application to biological systems", the other half jointly to Gérard Mourou and Donna Strickland "for their method of generating high-intensity, ultra-short optical pulses"

Nobel prizes in optics

- ***Glowing proteins – a guiding star for biochemistry***
- first observed in the beautiful jellyfish→ Since then one of th most important tools in contemporary bioscience.
- watch processes that were previously invisible: development c nerve cells in the brain or how cancer cells spread.
- Checking protein machinery malfunctions→ illness and diseas often follow. That is why it has been imperative for bioscience t map the role of different proteins in the body.

The Nobel Prize in Chemistry 2008

© The Nobel Foundation. Photo: U. Montan
Osamu Shimomura
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© The Nobel Foundation. Photo: U. Montan
Martin Chalfie
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Roger Y. Tsien
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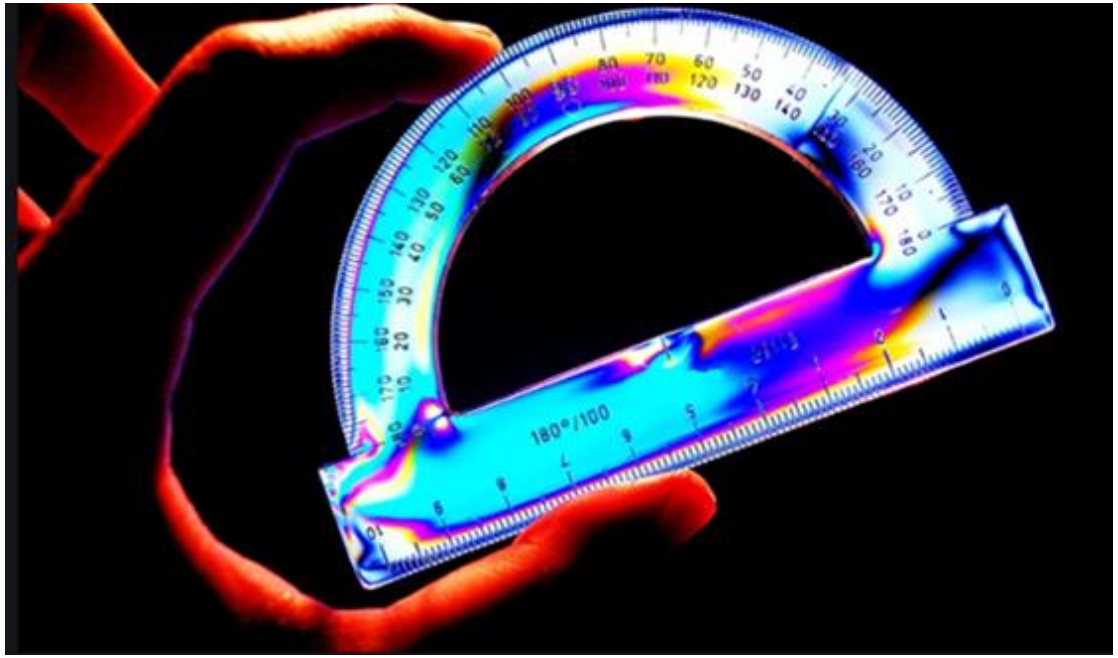
The Nobel Prize in Chemistry 2008 was awarded jointly to Osamu Shimomura, Martin Chalfie and Roger Y. Tsien "for the discovery and development of the green fluorescent protein, GFP"

Photoelasticity

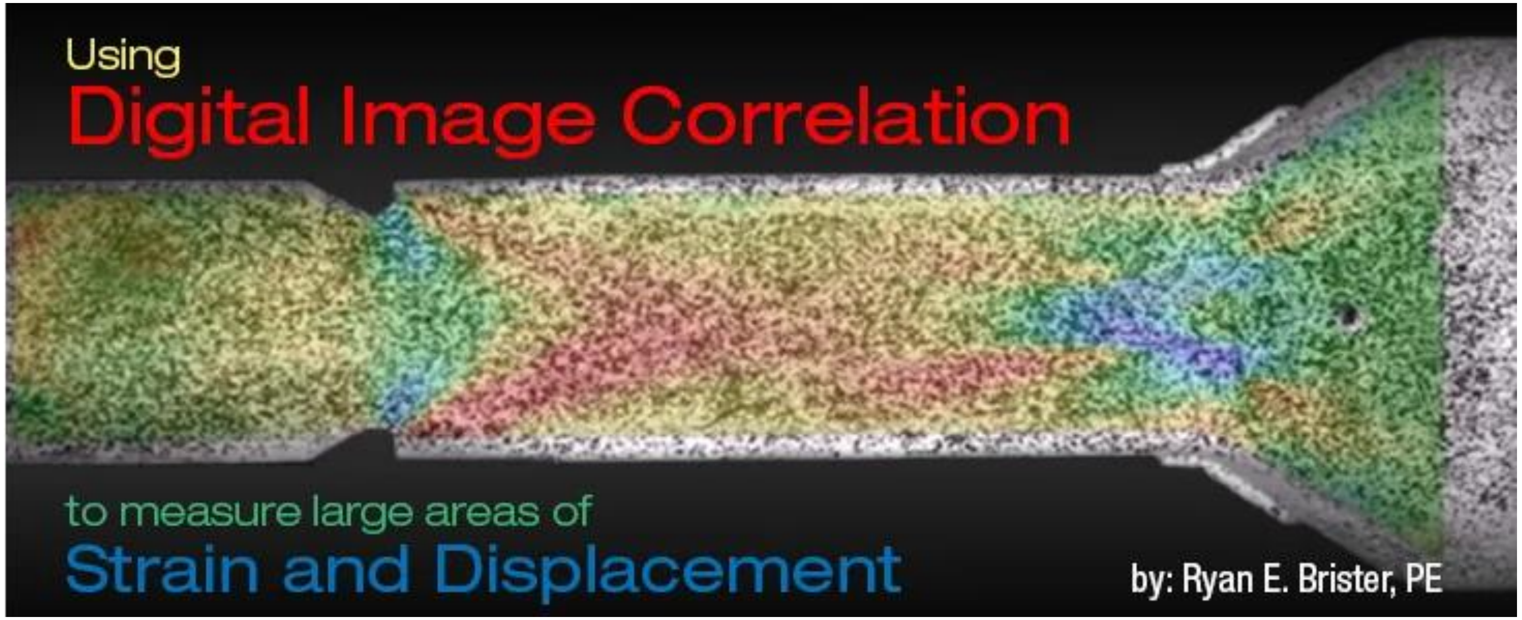
a whole-field technique for measuring and visualizing stresses and strains in structures→ Change in a material’s optical properties when it undergoes mechanical deformation.



https://www.azosensors.com/article.aspx?ArticleID=428

Digital Image Correlation (DIC)

- The Digital Image Correlation (DIC) is a state of art technique that can be used for accurate strain measurement. Because of its capability for fast data acquisition, this technique is well suited for the characterization of material properties both in the elastic and plastic ranges.



https://www.stress.com/dic-to-measure-large-areas-of-strain-displacement/

Optical coherence tomography (OCT)

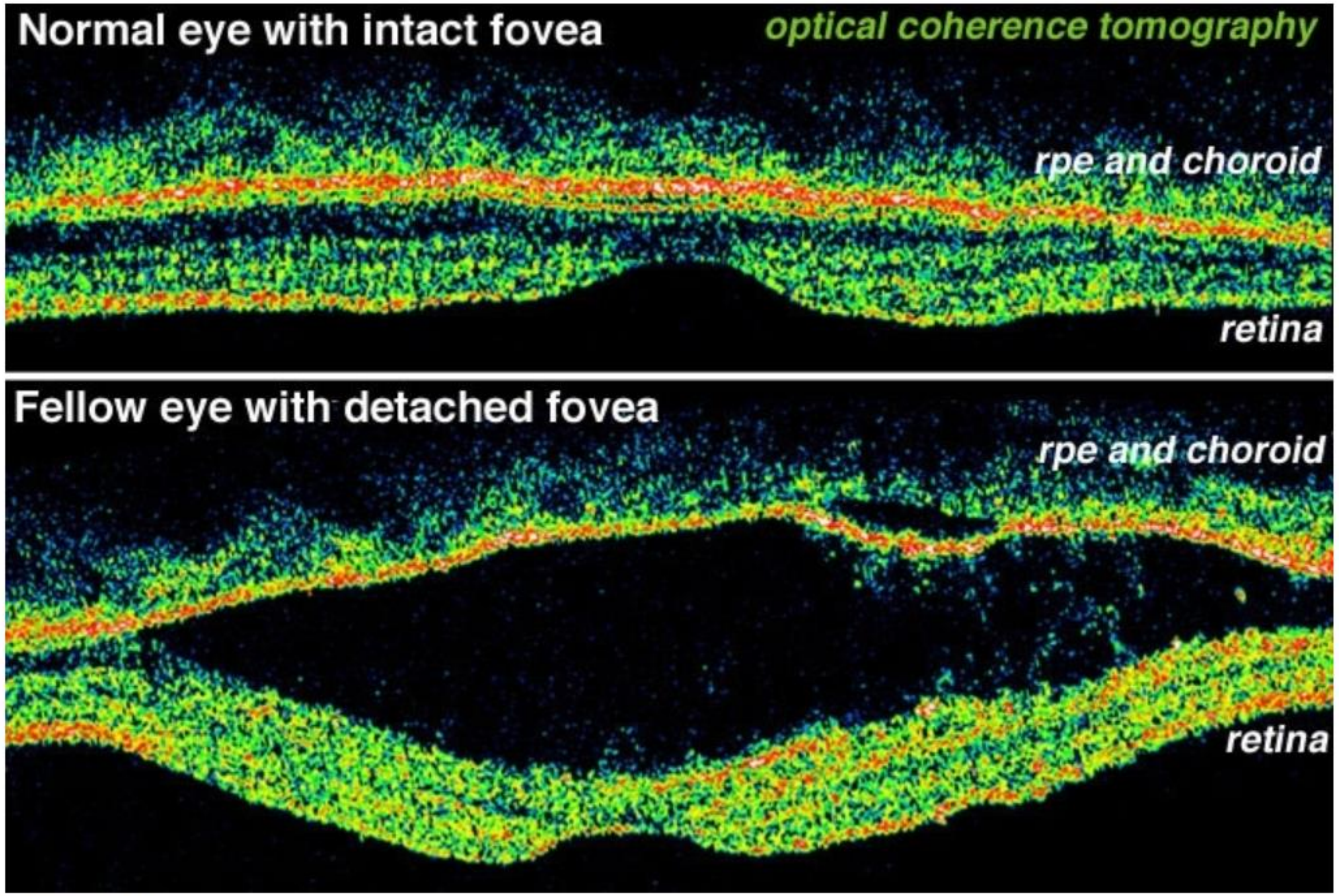


Figure 31b

Optical coherence tomography (OCT) images of the patient's normal macula and of the retina in the other eye with the macular detachment.

https://www.ncbi.nlm.nih.gov/books/NBK11553/figure/ch36clinicalerg.F31b/

Optical Sensors

- Optical sensors : broadly classified into – (1) intensity sensors, (2) *diffraction-based* sensor, (3) *interferometric* sensors and (4) *polarization* sensors (https://www.ndt.net/article/v08n09/asundi/asundi.htm)
- Function→ based on the optical property altered by the measurand
- Final display is the intensity but the information it provides varies with the sensor used

Course Structure

- Module 1: Wave Optics (L17+T8)
  - Interference
  - Diffraction
  - Polarization
- Module 2: Laser Basics (L8+T3)
- Module 3: Applications (L16+T3)
  - Interferometers
  - Fiber optics

Optics fundamental & *applications* in detail

History of *optics*

- Ancient Greeks (~5-3 century BC): rays emerge from the eyes → 'simulacra'(m)
- Lens invented → northern Italy, ~12th century AD
- Descartes, Gallileo, Kepler → geometrical optics, construction of optical instruments (~15th century AD)
- Newton and Huygens → Particle theory *vs* wave theory → Particle theory prevailed
- Experimental evidence (interference) of wave nature

History of *optics continued*

- Fresnel, Young (18^{th} –19^{th} centuries) experimentally observe diffraction → justification for wave theory
- Maxwell formulates electro-magnetic equations
- Quantum theory explains wave-particle duality
- Optical applications and Invention → holography, laser, communications, in science, engineering, surgeries etc.

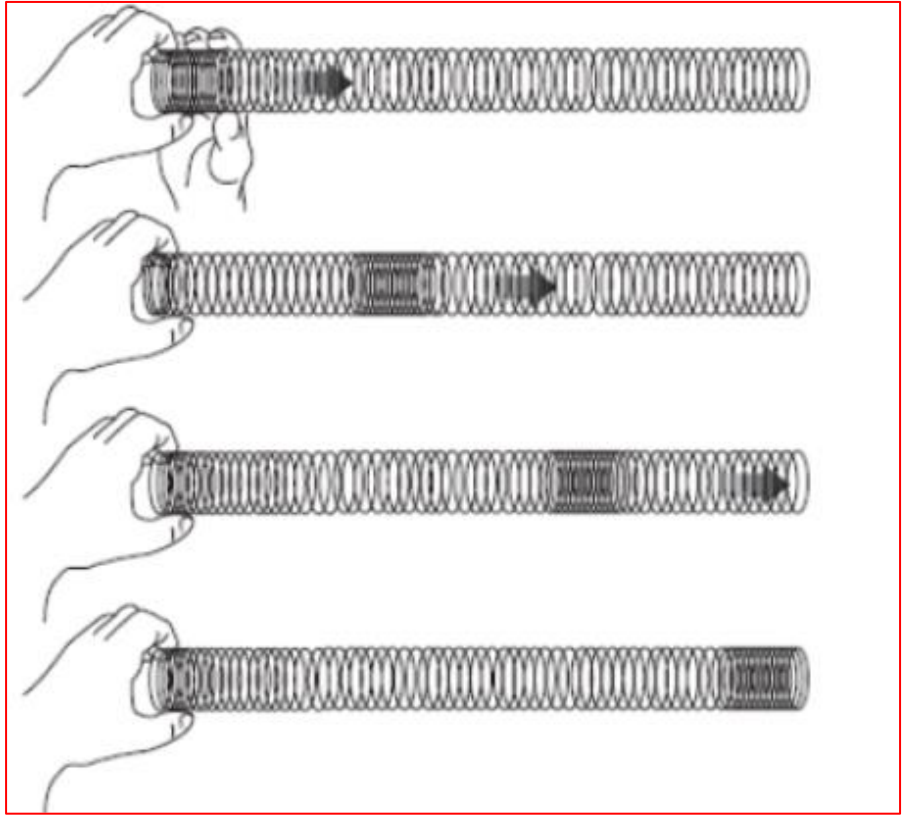
What is light

- Particle phenomenon or wave phenomenon? *Localized vs non-localized*
  - Envision a particle→ what about the field?→ impossible to separate
- Particle side: photons → energy
  - Q.O. → bunch of bullets carrying energy
  - Energy =hv = hc/λ → need the wave nature of light to describe energy

Introduction to waves

Types of Waves

Wave type-1

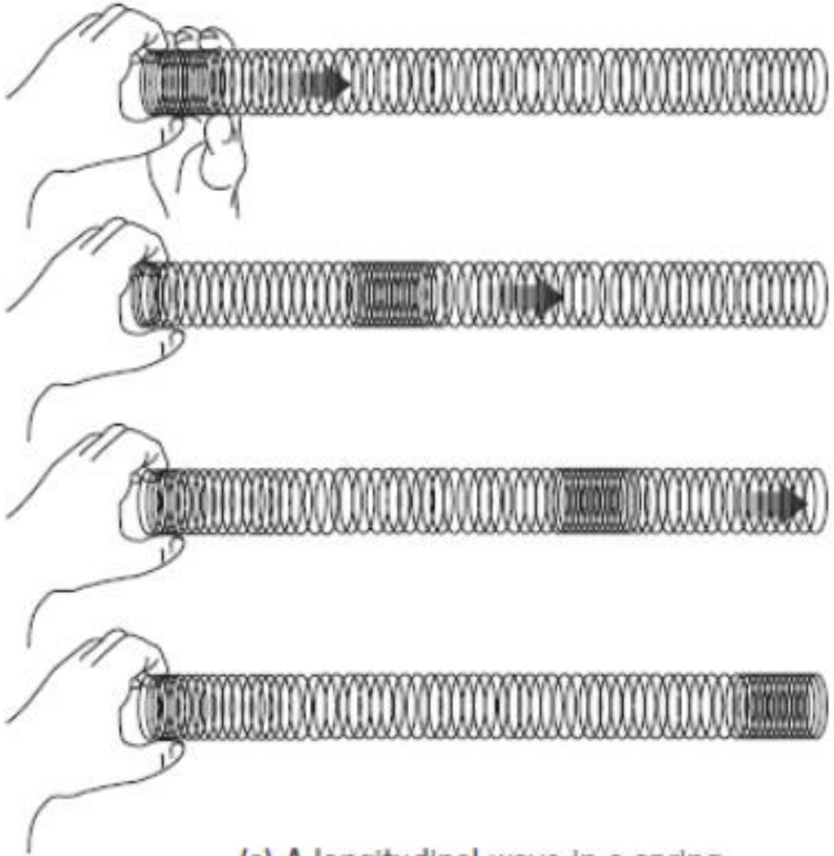


Q: What kind of wave it is?

Q: Medium is displaced in which direction?

Optics, Hecht

Longitudinal wave



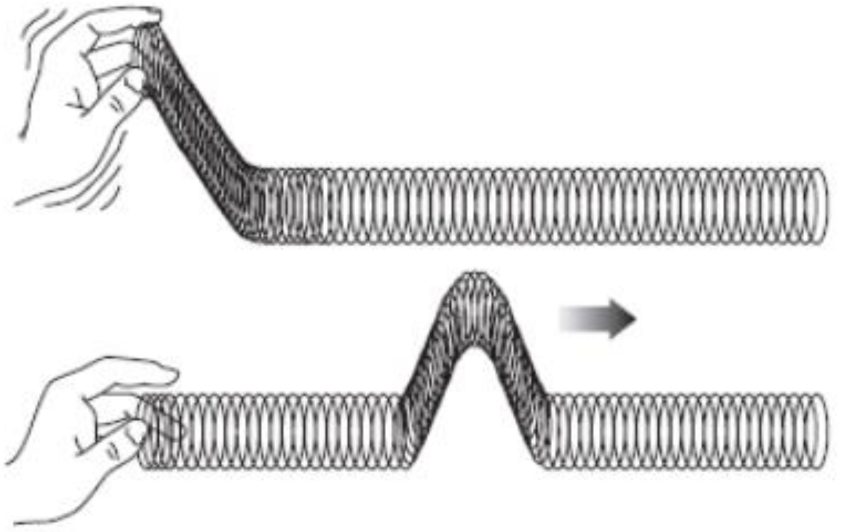
(a) A longitudinal wave in a spring.

The medium is displaced in the direction of motion of the wave

Q: any other example?

Optics, Hecht

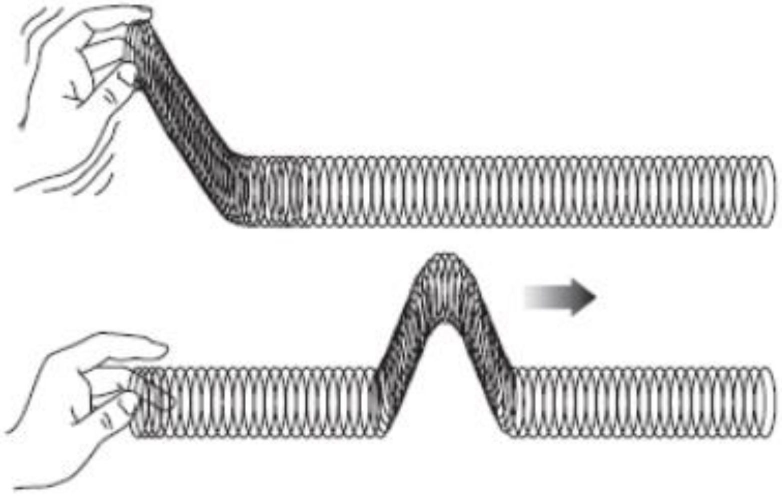
Wave type-2



Q: What kind of wave it is?

Q: Medium is displaced in which direction?

Wave type-2



(b) A transverse wave

Q: any other example?

Medium is displaced in a direction perpendicular to that of the motion of the wave

Optics, Hecht

A few points to note

- Which one moves→ disturbance or atoms/medium?
- Or the disturbance and medium both move in the direction of wave propagation?

A few points to note

- In all cases, the energy-carrying disturbance advances through the medium

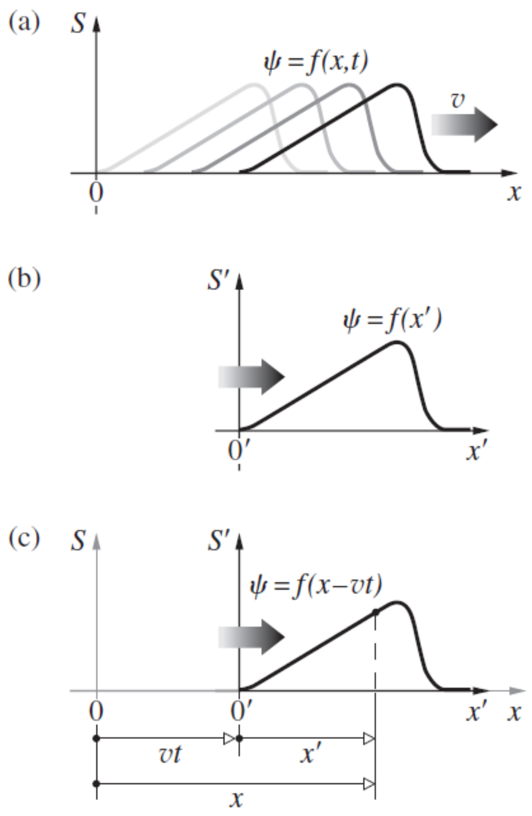
  NOT the individual participating atoms → remain in the vicinity of their equilibrium positions

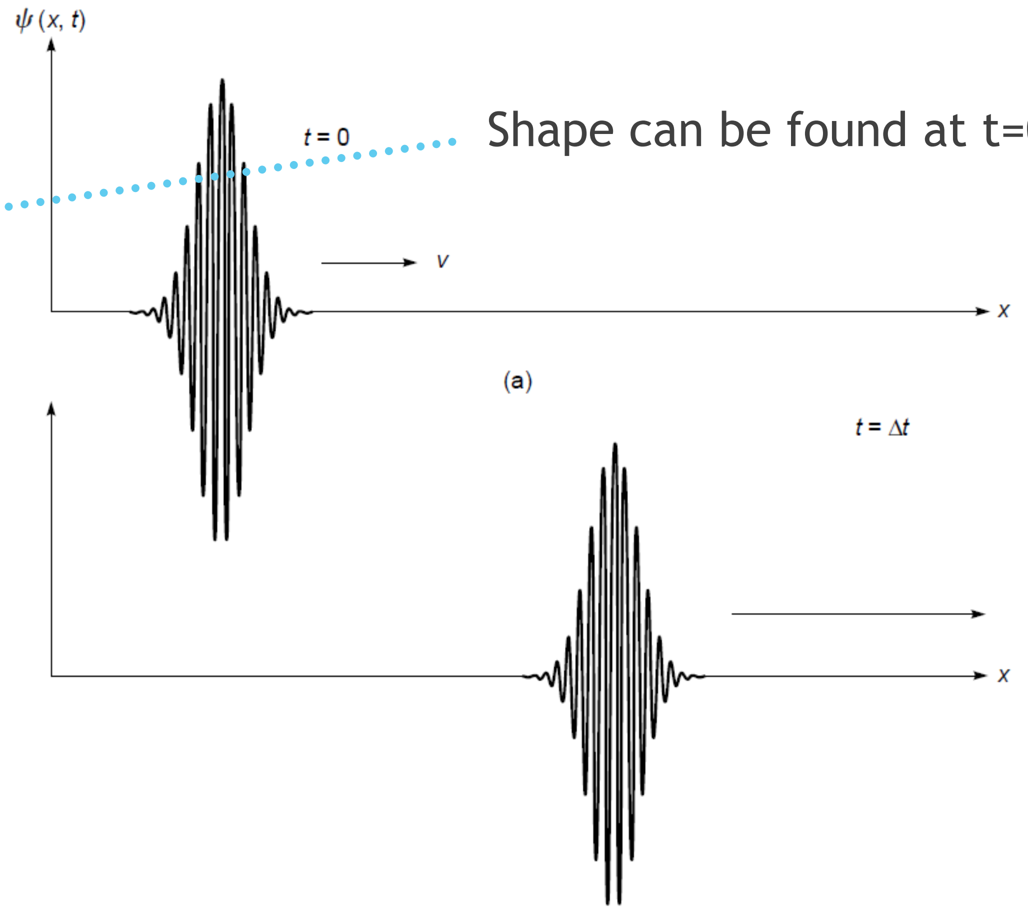
- disturbance advances, not the material medium.

- That’s one of several crucial features of a wave that distinguishes it from a stream of particles.

1D Wave

As disturbance moves: $\psi(x, t) = f(x, t)$ [$f(x, t)$ → *specific function or wave shape*]





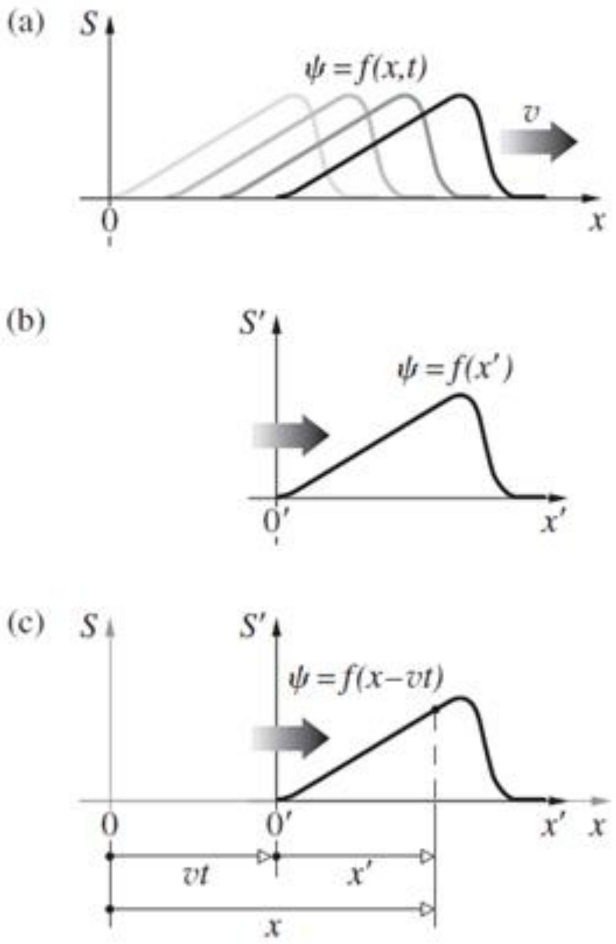
Shape can be found at t=0

The disturbance at t in S' = at $t = 0$ in S. *So, x' to be replaced by x-vt* → $\psi(x, t) = f(x-vt)$

Optics, Hecht; Ghatak

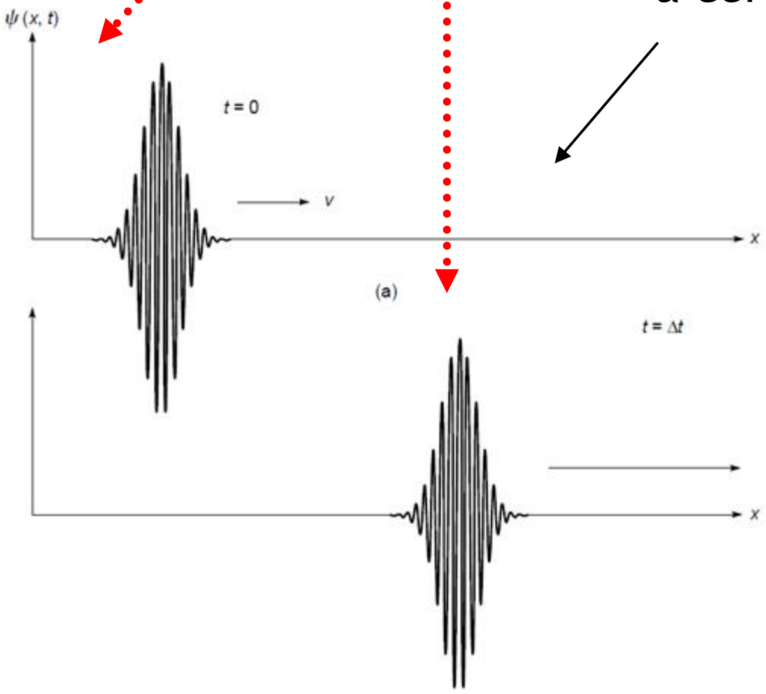
1D Wave

Shape can be found at t=0→ wavefunction



Shapes→ diff.?

disturbance has traveled through a certain distance= ?



if the equation describing the rope at t = 0 is y(x),
then the equation at a later instant t is ?

for a disturbance propagating in the –x direction, equation of the curve is ?

Optics, Hecht; Ghatak

Thank You