

Nanotechnology



Width of DNA
Nanometer (10^{-9}m)

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Thickness of skin
Millimeter (10^{-3}m)

Images of skin and standing human removed due to copyright restrictions.



Diameter of Hair
Micrometer (10^{-6}m)

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Height of Humans
Meter

Have you ever heard of **nanoscience** or **nanotechnology**? If so, where?

What are 3 things that nanotechnology brings to mind for you?

The Costs of Nanofabrication

Cleanroom Facilities



- A very small dust-free cleanroom about this size (10'x10') would cost **~\$10,000**



Fabrication Equipment



- A photolithography aligner for making small patterns: **>\$100,000**
- A spin-coater to apply photosensitive films: **\$3,000**
- An evaporator for depositing metals: **~\$60,000**
- A fumehood to suck up toxic fumes: **\$10,000**

Materials



- Silicon wafers: **~\$5/piece**
 - Photoresist : **~\$2,000/Liter**
 - Developer: **~\$200/Liter**
 - Metals:
 - Aluminum: **\$1/lb**
 - Chrome: **\$2/lb**
 - Gold: **\$24,000/lb**
- \$1.50 for a 100nm Au film on a 5" dia. wafer

The point: it is very easy to spend **>\$200,000** even for very simple fabrication...(not counting waste management, deionized water, and building renovation)

The Goal this Class: DIY Research

Spin-coater: \$3,000

Plasma etcher: \$50,000

Spectrometer: \$2,000



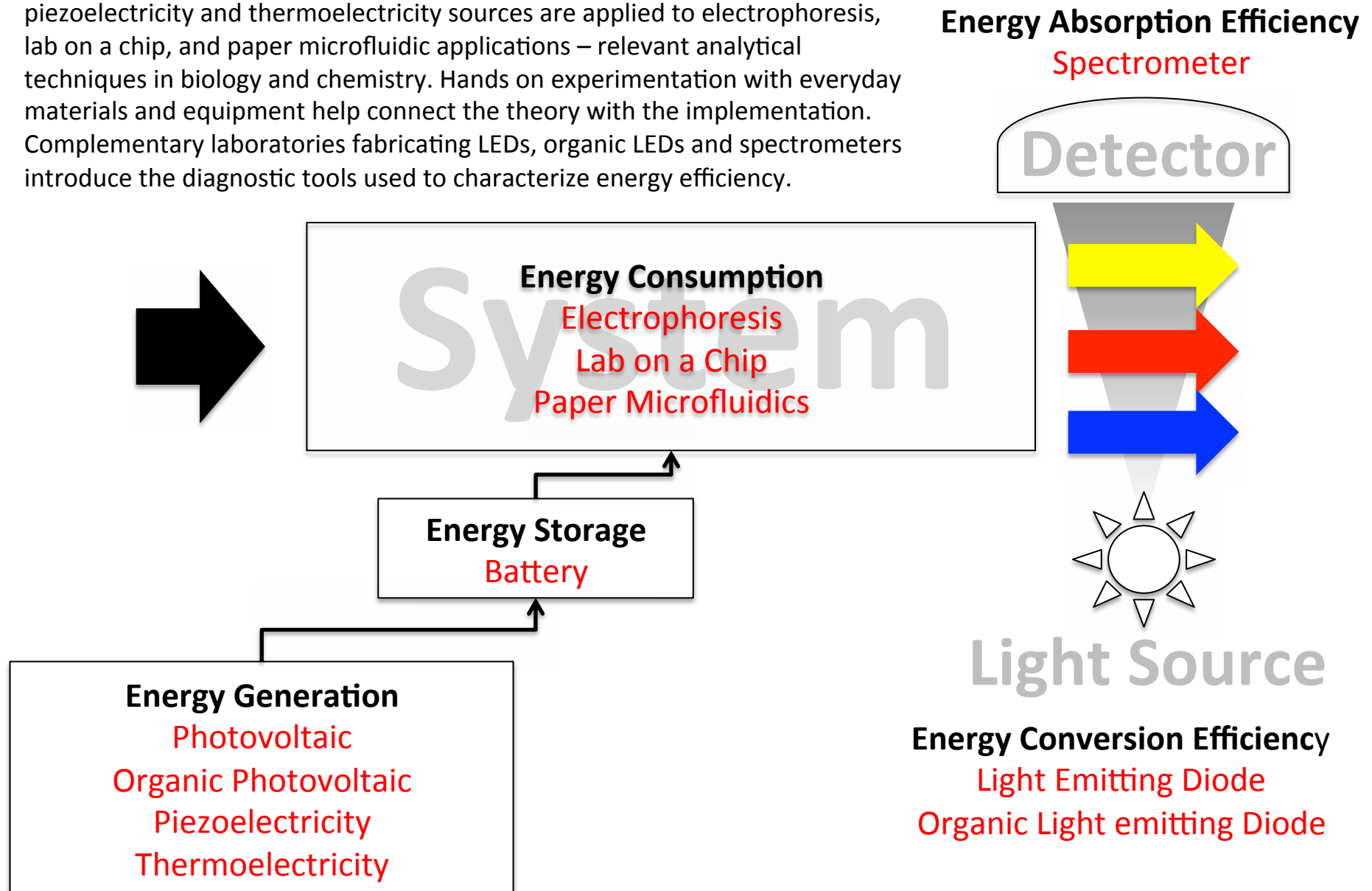
Computer fan: \$5

Microwave oven: \$50

CD-R: \$0.15

Real science using off-the-shelf, consumer equipment

This class links clean energy sources and storage technology to energy consumption case studies to give students a concept of the full circle of production and consumption. Specifically, photovoltaic, organic photovoltaic, piezoelectricity and thermoelectricity sources are applied to electrophoresis, lab on a chip, and paper microfluidic applications – relevant analytical techniques in biology and chemistry. Hands on experimentation with everyday materials and equipment help connect the theory with the implementation. Complementary laboratories fabricating LEDs, organic LEDs and spectrometers introduce the diagnostic tools used to characterize energy efficiency.



Questions About the Class?

Lecture: T4 Lab: Th2-5

Pre-lab Assignment: 20%

Measurement Sheet: 40%

Final: 40%

Pre-lab Assignment - due **Thursday at 2pm**

Measurement Sheet - due the following **Tuesday at 4pm**

Nanomaker

Lab #1: Spectrometry



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Particles or Waves
Double-Slit Experiment
Thin Film Interference
Birefringence Interference
Applications

Light

Is light a particle?

Particles travel along a single path in one direction
(like a ball that's been kicked).



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Is light a wave?

Waves move spread out in many directions.

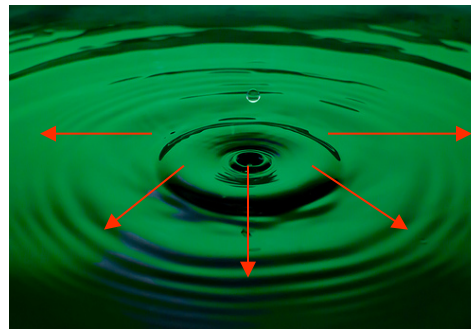
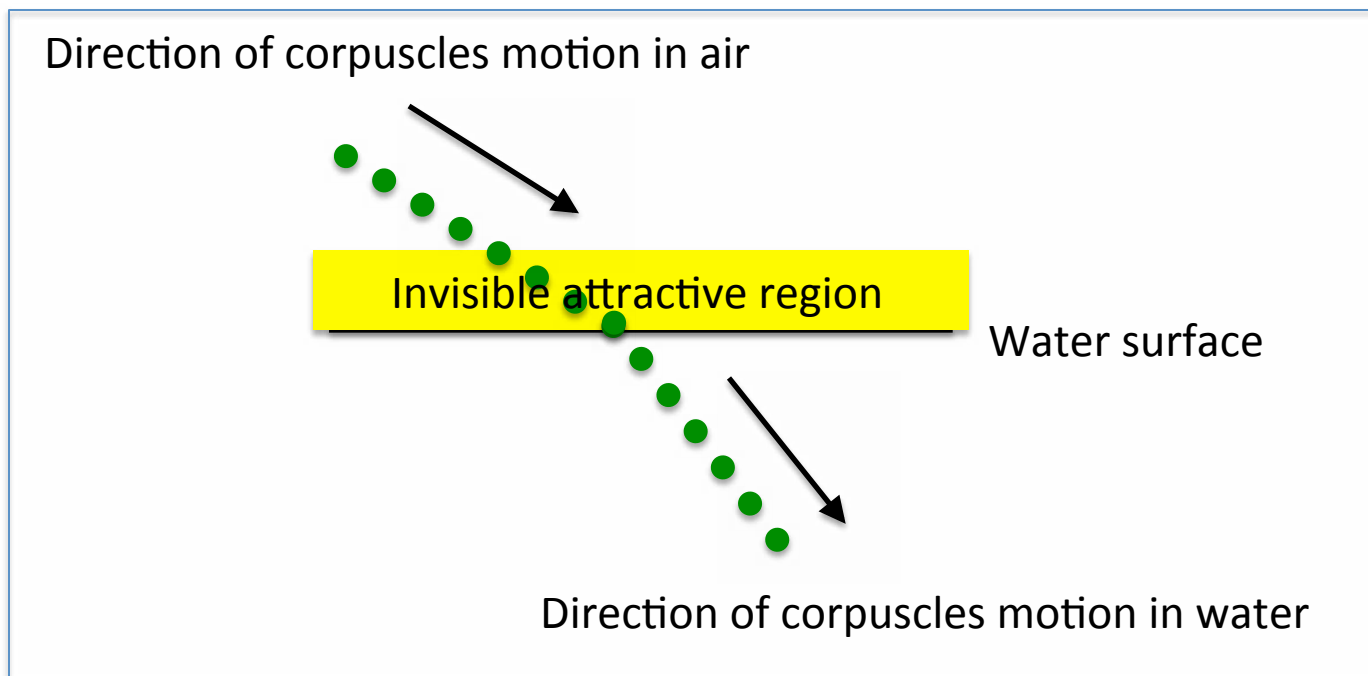


Photo courtesy of [May Wong](#) on Flickr.

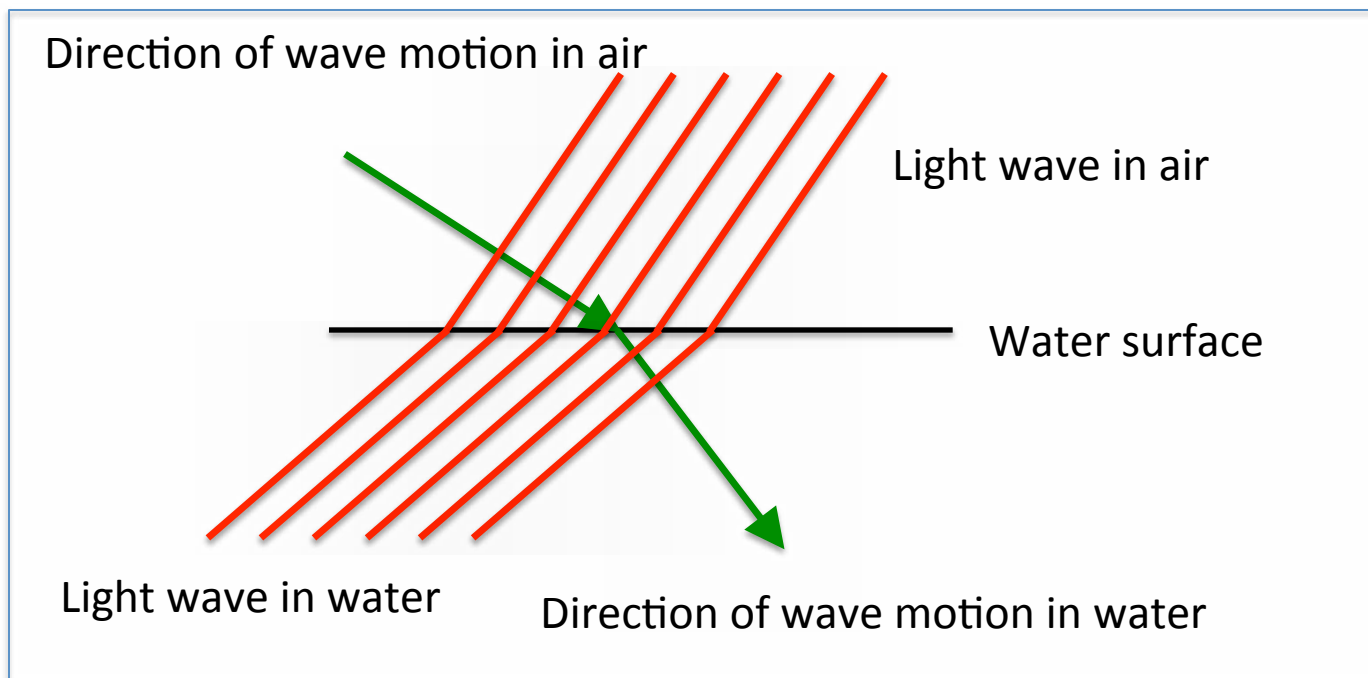
Newton's Corpuscular Theory

- Light is made up of small discrete particles called "corpuscles" (little particles) which travel in a straight line with a finite velocity and possess kinetic energy.
- They obey the same laws of physics as other masses like baseballs.
- They are tiny so the particles in two intersecting beams do not scatter off each other.



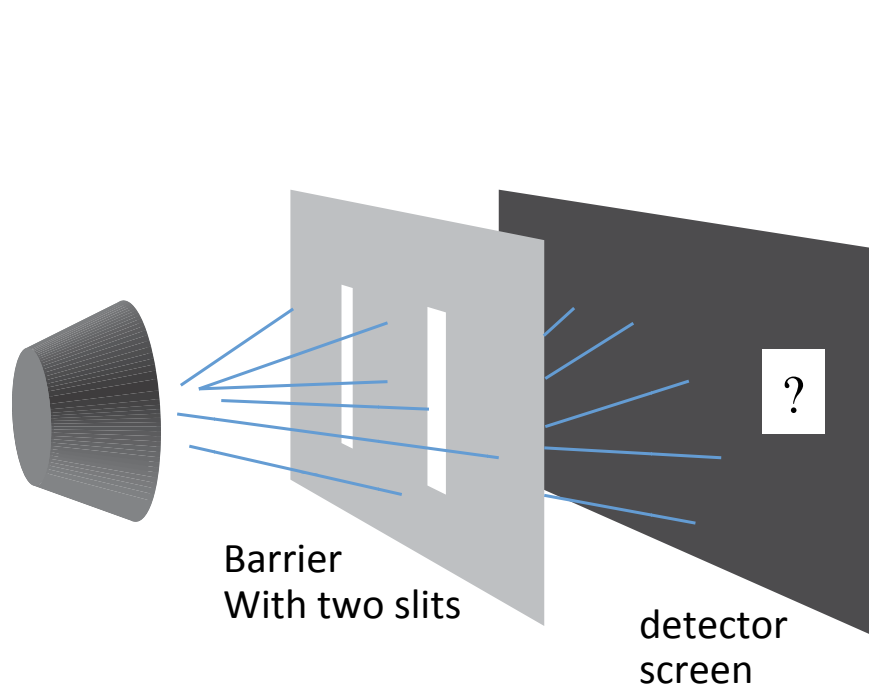
Huygen's Principle

- Huygen assumed that light is a form of wave motion.
- A geometric construction for determining the position of a new wave at some point based on the knowledge of the wave front that preceded it.
- All points on a given wave front are taken as point sources for the production of spherical secondary wavers, called wavelets.



Particles or Waves
Double-Slit Experiment
Thin Film Interference
Birefringence Interference
Applications

Particles or Waves?

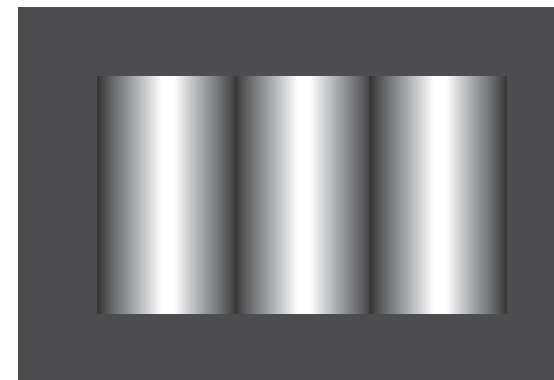


What should we see on the detector screen ?

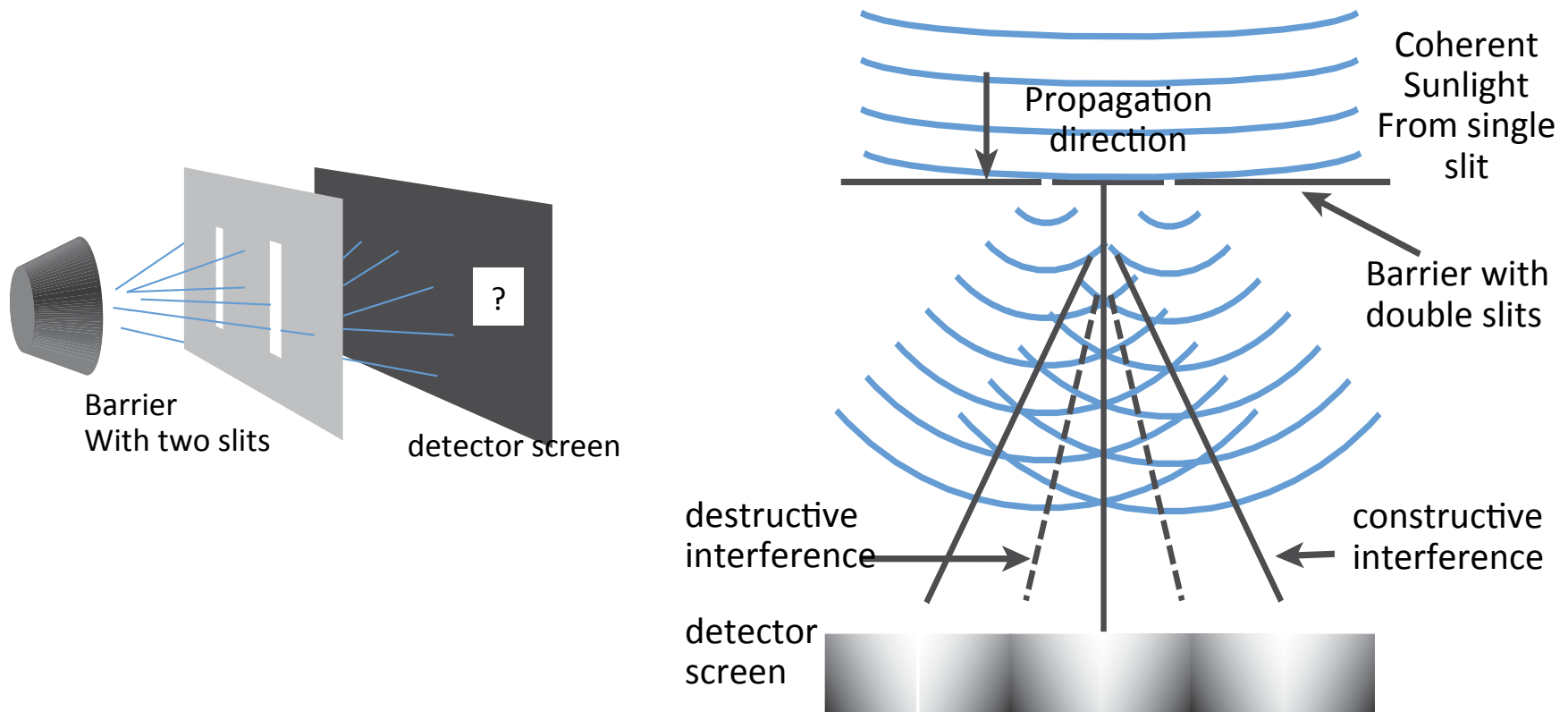
particles



waves

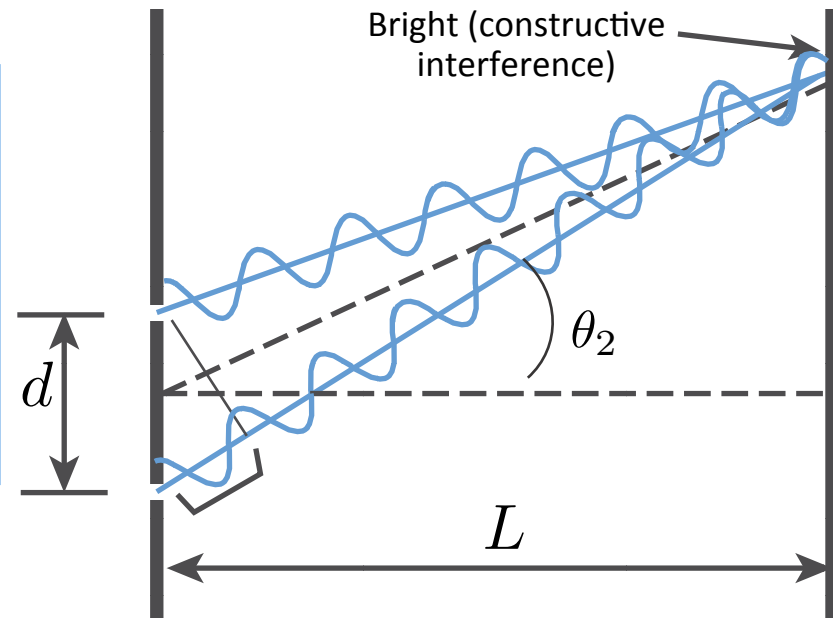
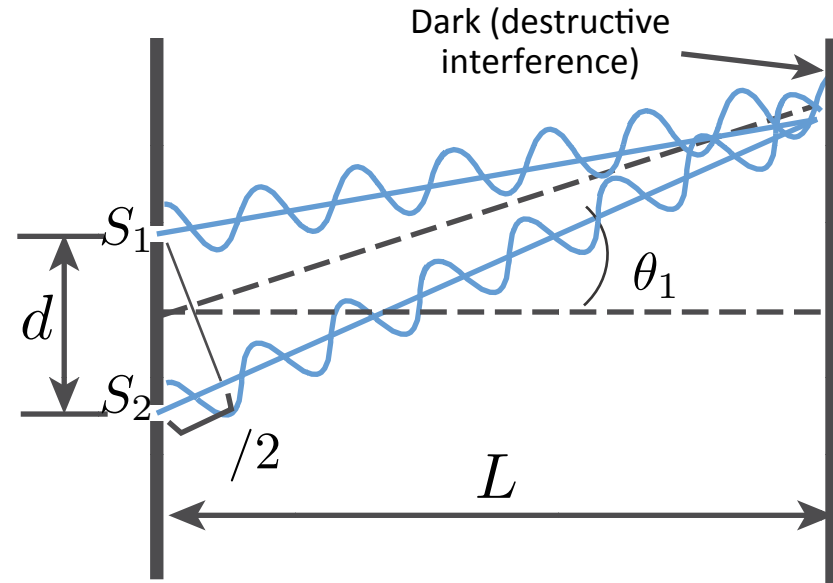
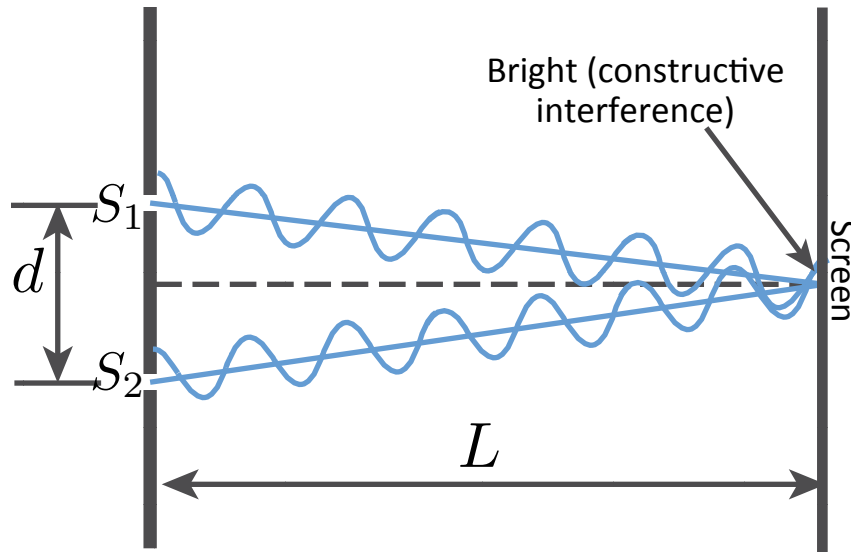


Thomas Young's Double Slit Experiment



Adopted from [6.007](#), Lecture 27

Interference



Waves at slits have to be *coherent* for interference to occur!

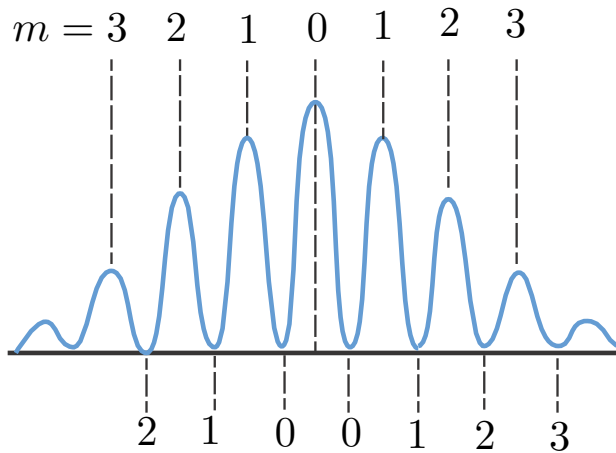
Two different light bulbs in front of each slit will not give interference pattern.

Interference Fringes

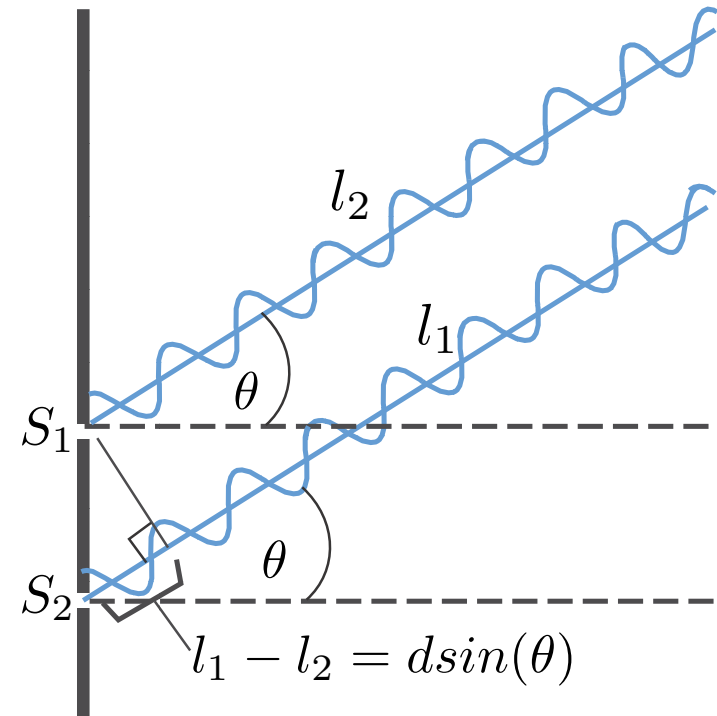
$d \sin(\theta) = m\lambda,$	$m = 0, \pm 1, \pm 2, \dots$	Constructive
$d \sin(\theta) = (m + 1/2)\lambda,$	$m = 0, \pm 1, \pm 2, \dots$	Destructive

m is the **order** of an interference fringe

constructive interference



destructive interference



Interference Preconditions

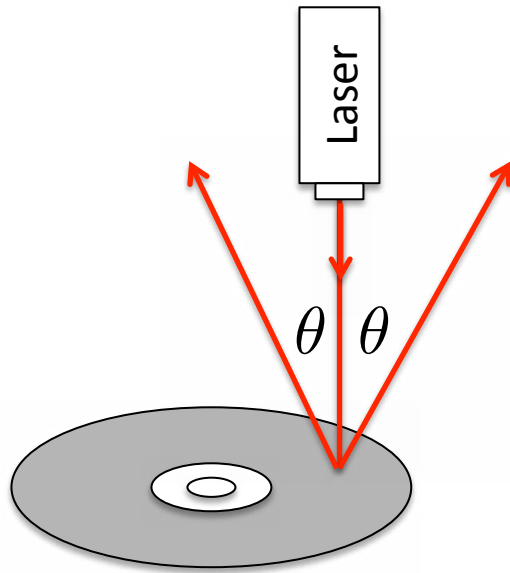
1. Light must be monochromatic, i.e., involve just a single frequency (single wavelength).
2. Light sources must be coherent, the relative phase is always the same.
3. Light sources must have the same amplitudes.

If these conditions do not hold, one still gets constructive and destructive interference but the interference pattern can change with time or not be complete (destructive interference leads to a decrease in amplitude but not to zero amplitude).

Activity

Do you know which one is CD, DVD, and Blue-ray?

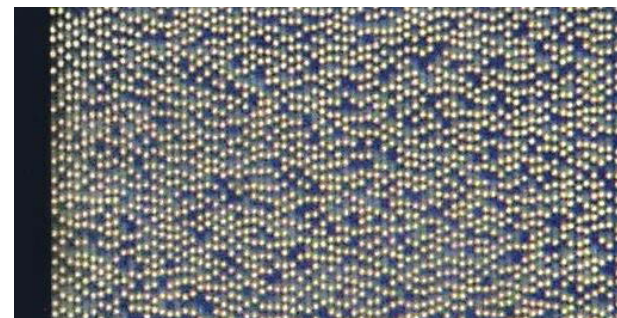
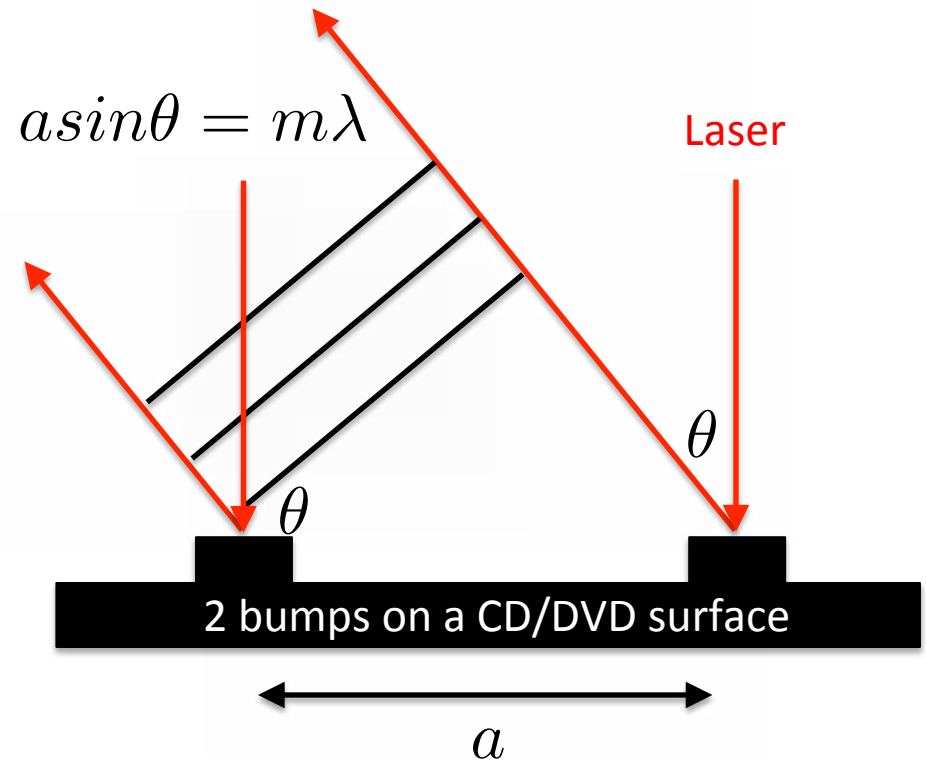
Diffraction of Light From CD/DVD



CD/DVD surface acts like a diffraction grating
How much information can the CD store?



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This image is in the public domain.

Particles or Waves
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Thin Film Interference

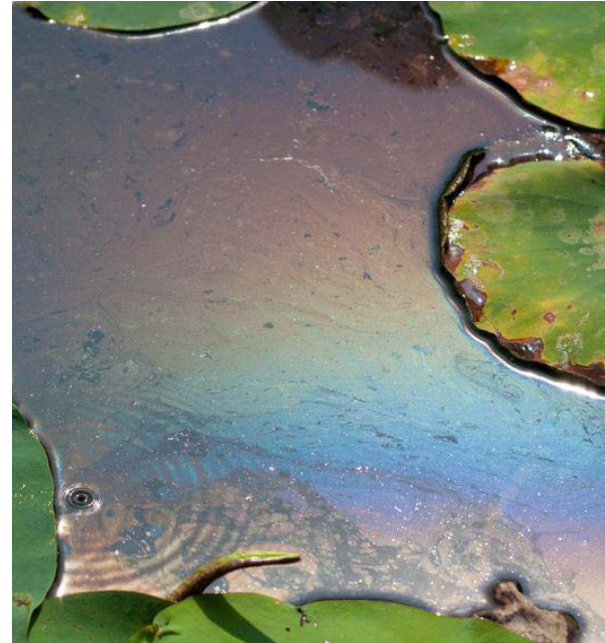
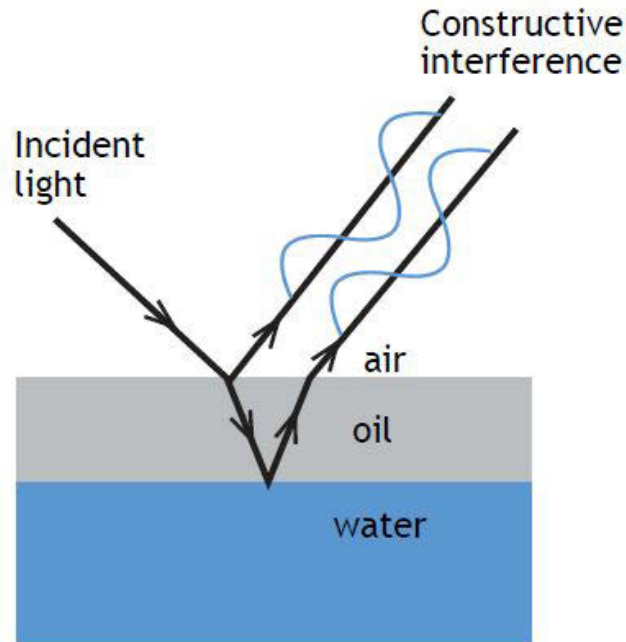


Photo courtesy of [Yoko Nekonomania](#) on Flickr.

Light reflected from the upper and lower surfaces of the film comes together in the eye and undergoes interference.

Some colors interfere constructively and others destructively, creating the color bands we see.

Thin Film Interference

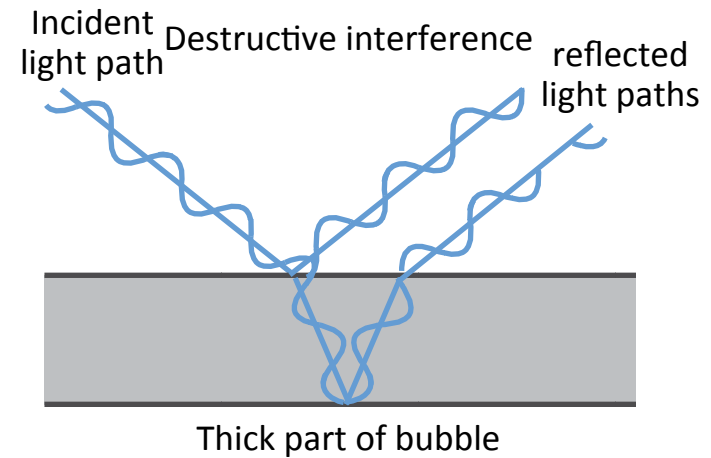
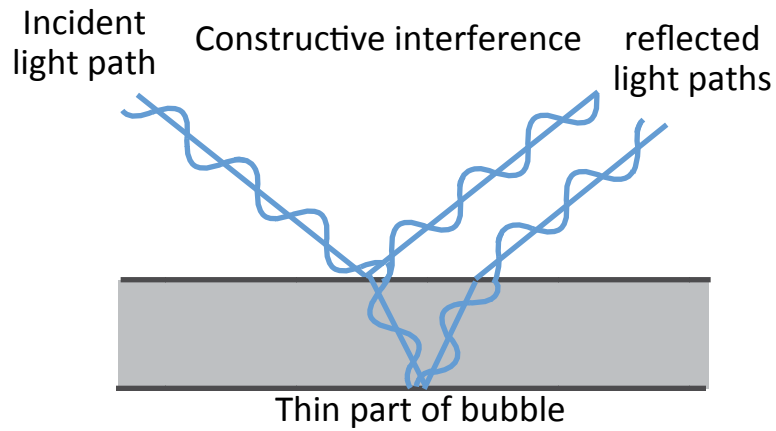
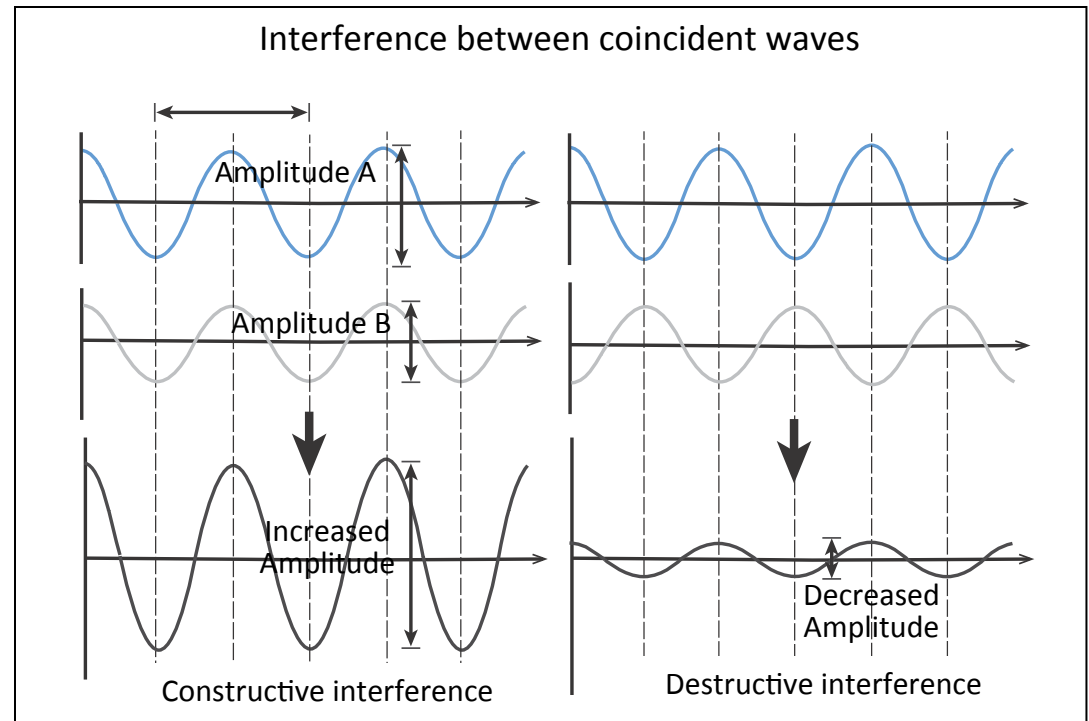


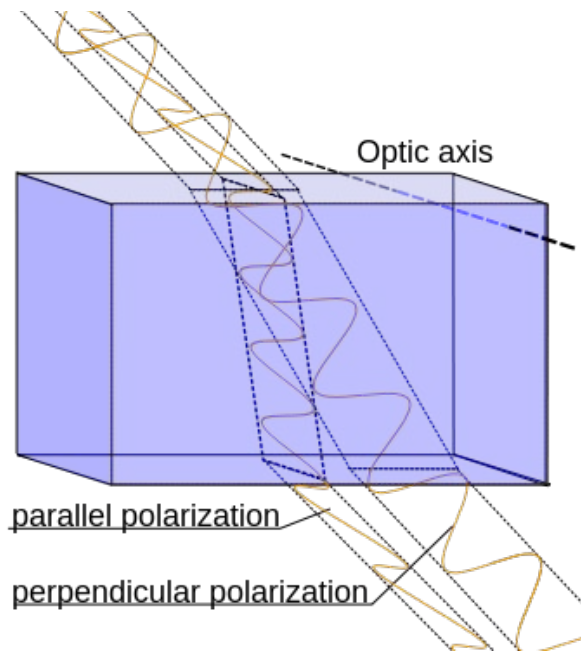
Photo courtesy of [Ali T](#) on Flickr.



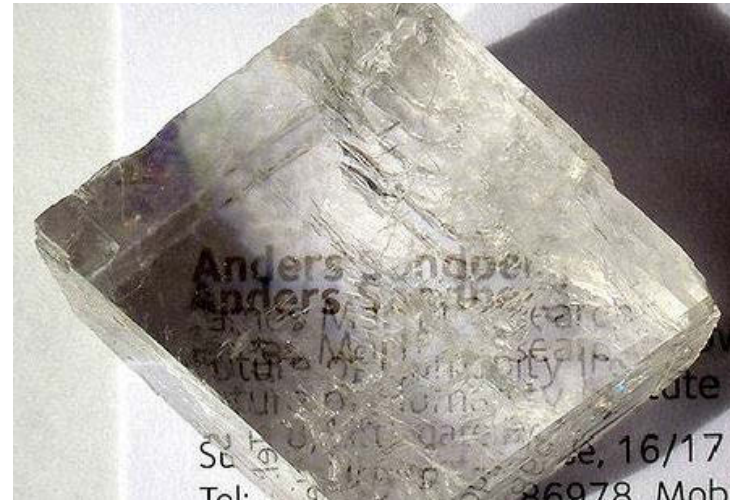
Adopted from [6.007](#), Lecture 27

Particles or Waves
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Birefringence



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A calcite crystal laid upon a paper with all letters showing the double refraction

Photo courtesy of [Anders Sandberg](#) on Flickr.

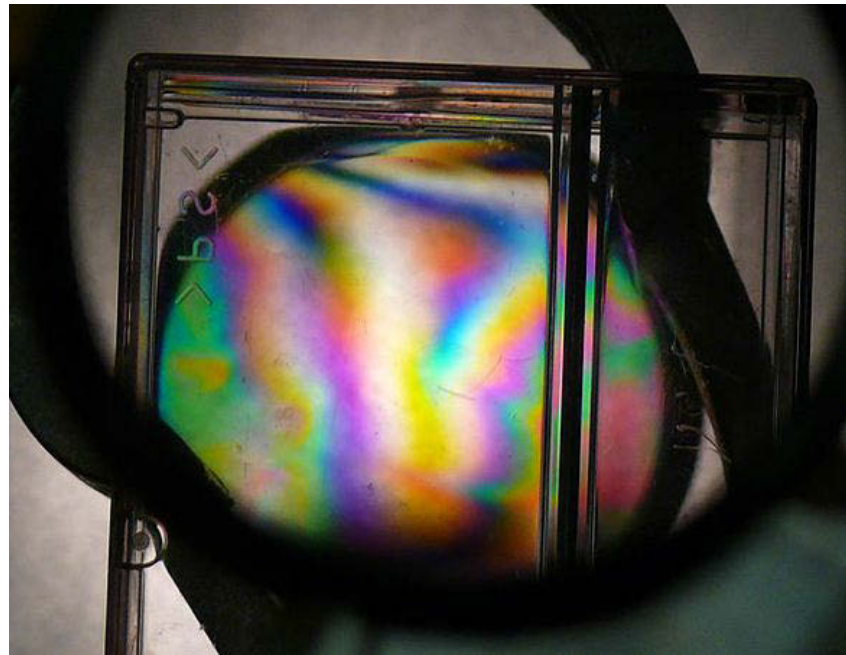
Birefringence, or double refraction, is the decomposition of a ray of light into two rays when it passes through certain **anisotropic materials**.

Rays passing through a positively birefringent material. The optical axis is perpendicular to the direction of the perpendicular component of incident ray, so the ray polarized parallel to the optic axis has a greater refractive index than the ray polarized perpendicular to it.

Stress-Induced Birefringence

When isotropic solids are under mechanical stress, color patterns can be observed when placed between two crossed polarizers.

It is because polarization of a light ray is rotated after passing through the stressed material and the amount of rotation is dependent on wavelength.



This image is in the public domain.

Color pattern of a plastic box with "frozen in" mechanical stress placed between two crossed polarizers.

Activity



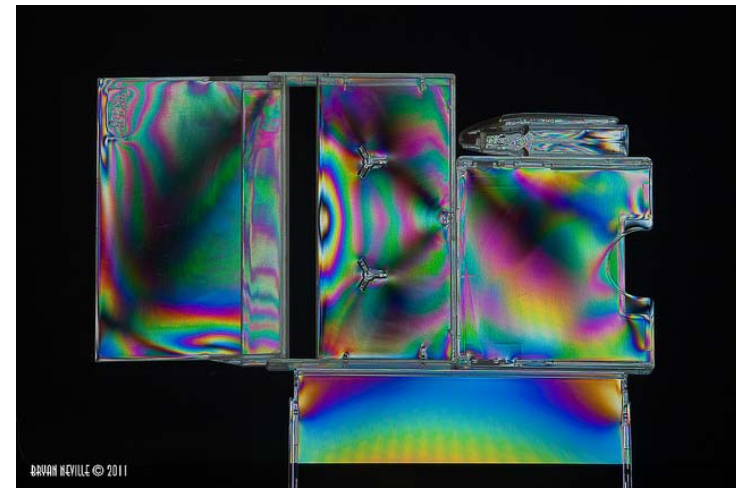
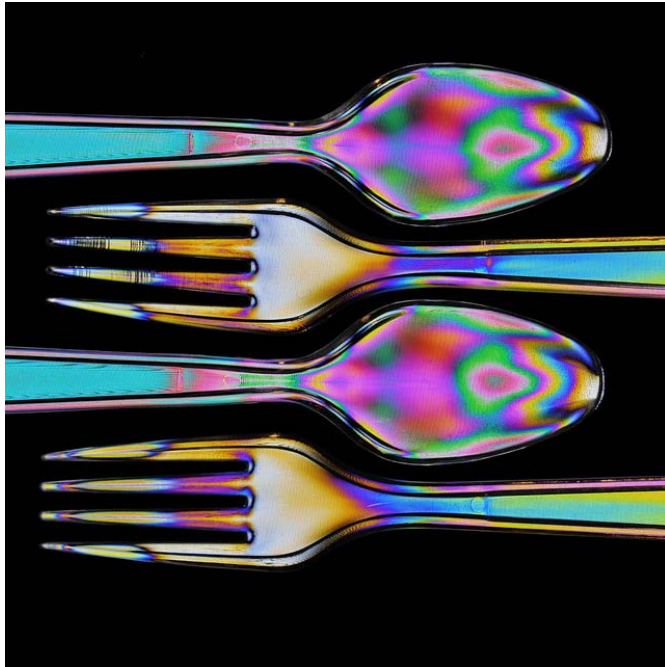
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Image courtesy of [Kris Mendoza](#) on Wikimedia Commons.

How do you see Birefringence Interference?

Photoelasticity



Courtesy of Photoextremist.com. Used with permission.

When a ray of plane polarized light is passed through a photoelastic material, it gets resolved along the two principal stress directions and each of these components experiences different refractive indices.

It leads to a relative phase retardation between the two component waves. The interference takes place and we get a fringe pattern, which depends on relative retardation.

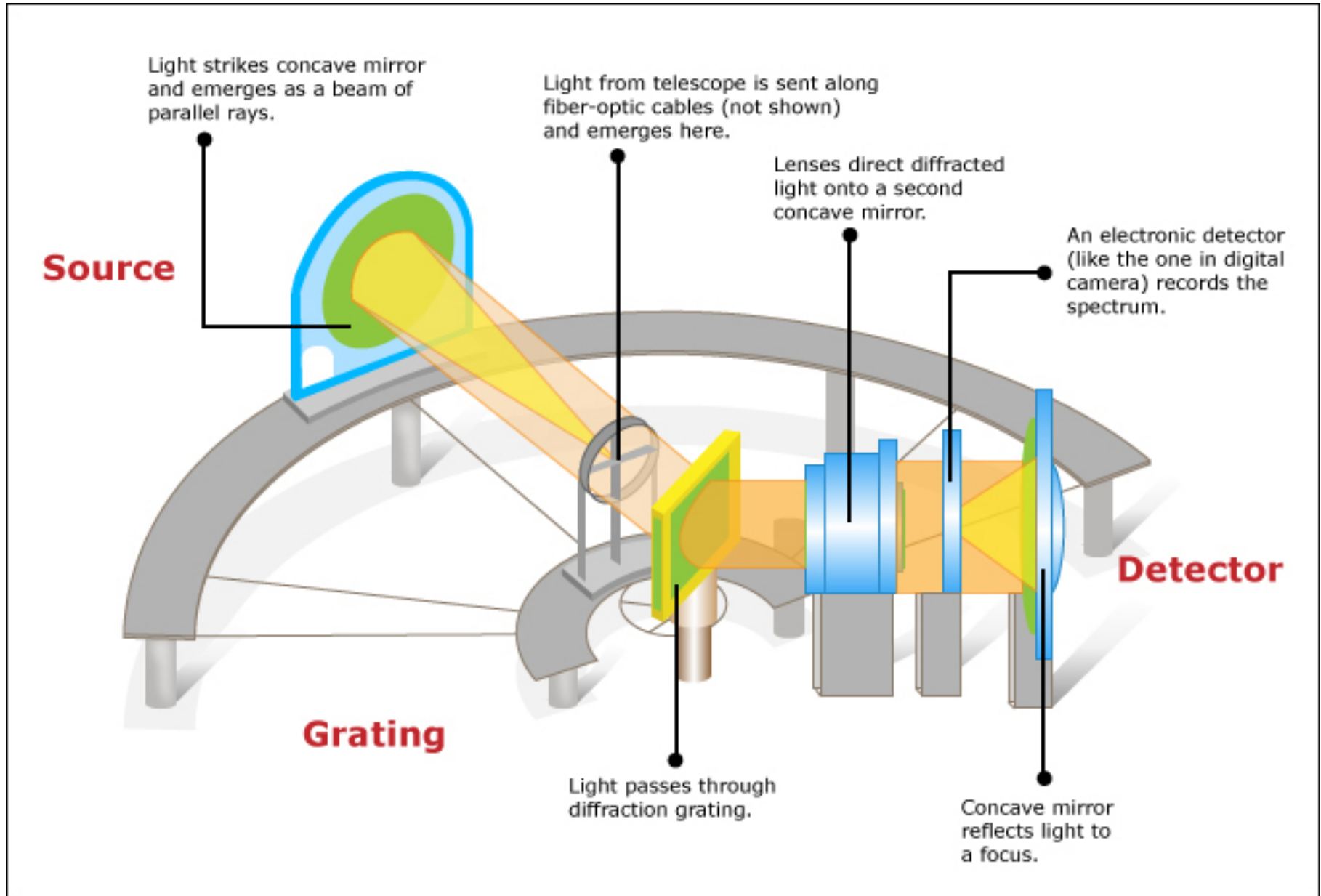
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X-Ray Crystallography

Illustrations of x-ray crystallography setup and angle calculations removed due to copyright restrictions.
Refer to: Figures from Young, Hugh D. "Interference and Diffraction." Chapter 26 in *College Physics with Mastering Physics*. 9th ed. Addison-Wesley, 2012. ISBN: 9780321749802.

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Spectrometer



Spectrometer

Photograph of handheld spectrometer removed due to copyright restrictions.

Handheld spectrometer



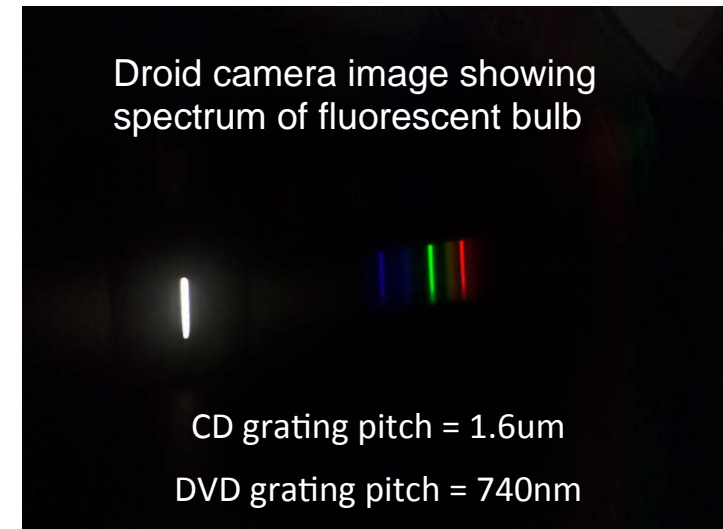
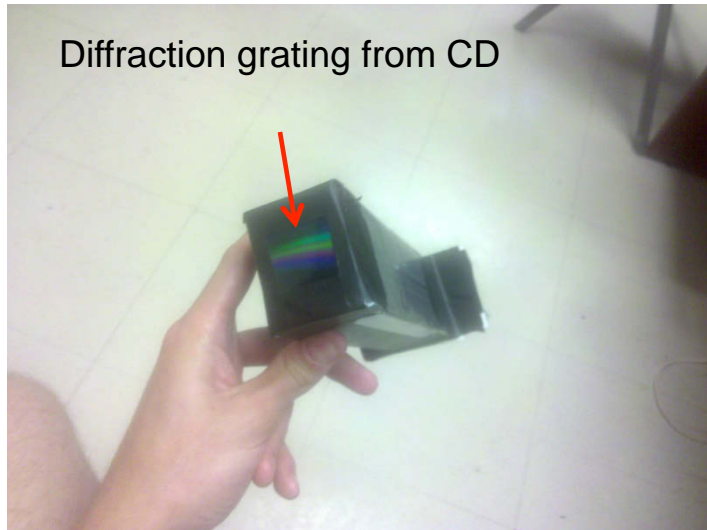
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Desktop spectrometer
\$2,000 and up

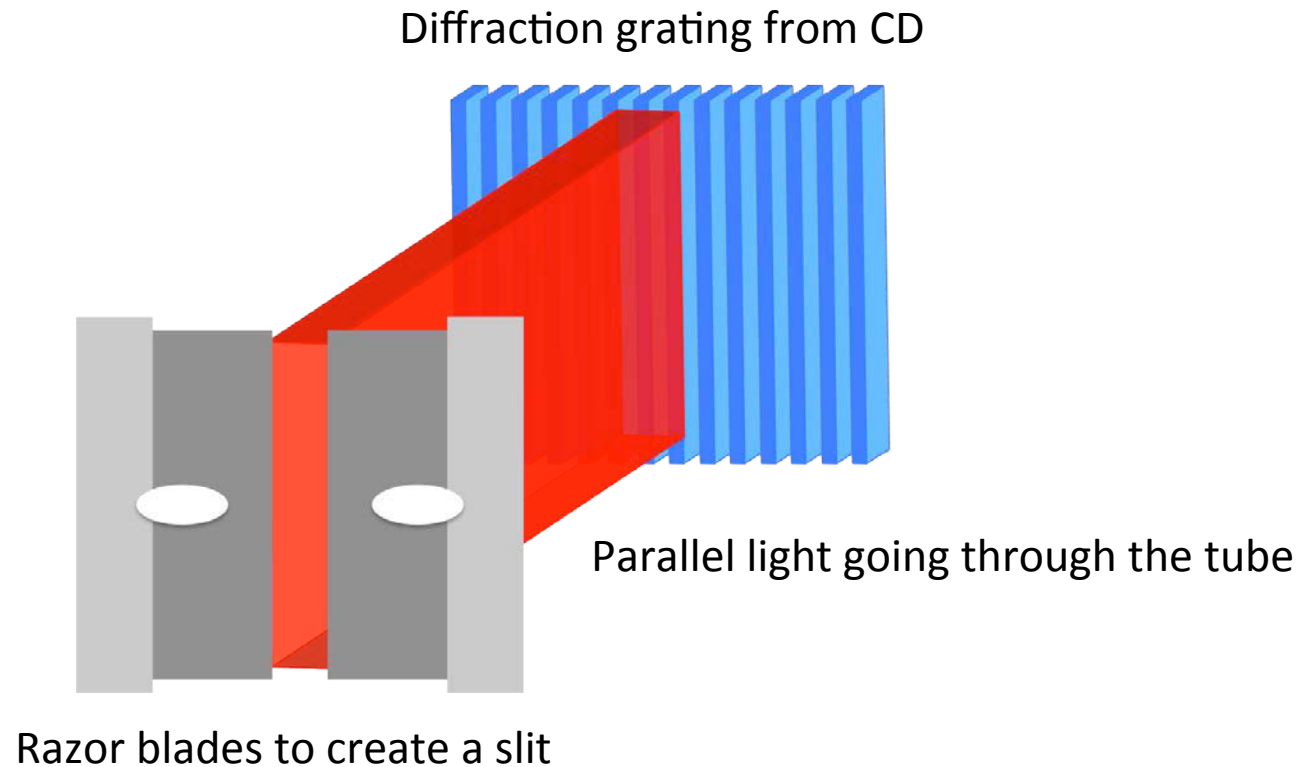
How to make a spectrometer for less than 2 dollars?

Sneak Peak (Lab #1 Spectrometer)

Homemade Spectrometer



Homemade Spectrometer



1. How does the slit width influence the resolution?
2. Why should the diffraction grating be in parallel with slit?
3. What do we need a tube in between?

Conclusions

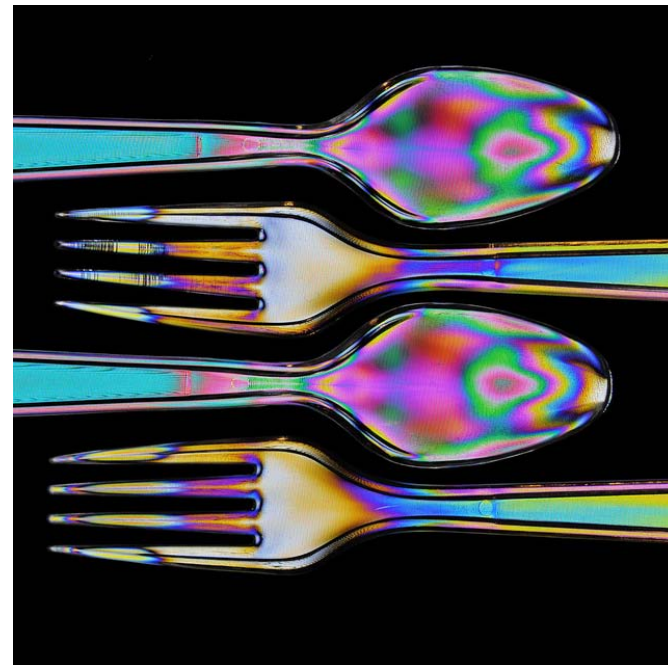
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$$d \sin(\theta) = (m + 1/2)\lambda, \quad m = 0, \pm 1, \pm 2, \dots \quad \text{Destructive}$$

Double-Slit Experiment



Photo courtesy of [Ali T](#) on Flickr.

Thin Film Interference



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Birefringence Interference

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