QUANTUM OPTICS INSTITUTE OF SOUTHERN CALIFORNIA

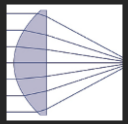
Intro to Optics

With mentions of Photonics Industry including Fiber Based & Integrated Photonics.

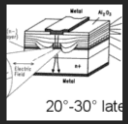
Instructor: Donn Silberman, Founder QOISC

www.qoisc.org

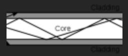
Lectures & Labs by Donn Silberman



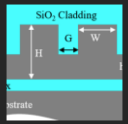
Introduction to Optics (1st lecture is today)



Photonics Industry & Technologies (2nd lecture, also today)



Fiber Based Photonics (3rd lecture on Monday)



Integrated Photonics (4th lecture also next Monday)

Labs – IPEK Demo Wed. 29th & Quantum Demos Fri. 31st

Topics:

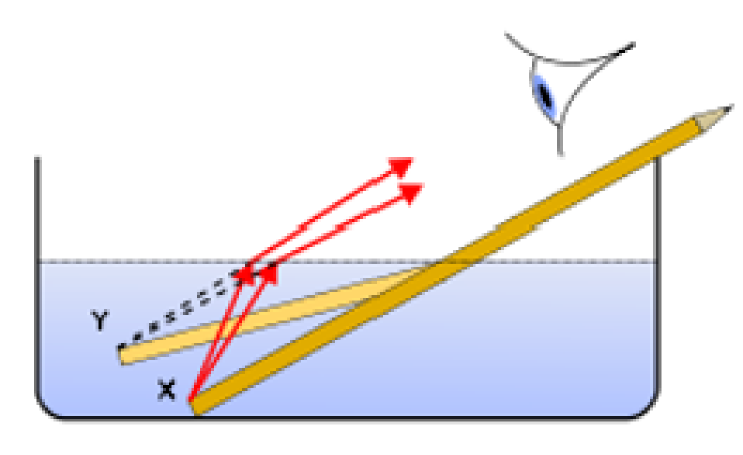
Geometric Optics
1. Reflection, Refraction with Plane & Curved Surfaces
2. Thin & Thick Lenses
3. Examples of Optical Systems
4. Aberrations & Ray Tracing
5. Non-Spherical Surfaces & Segmented optical surfaces

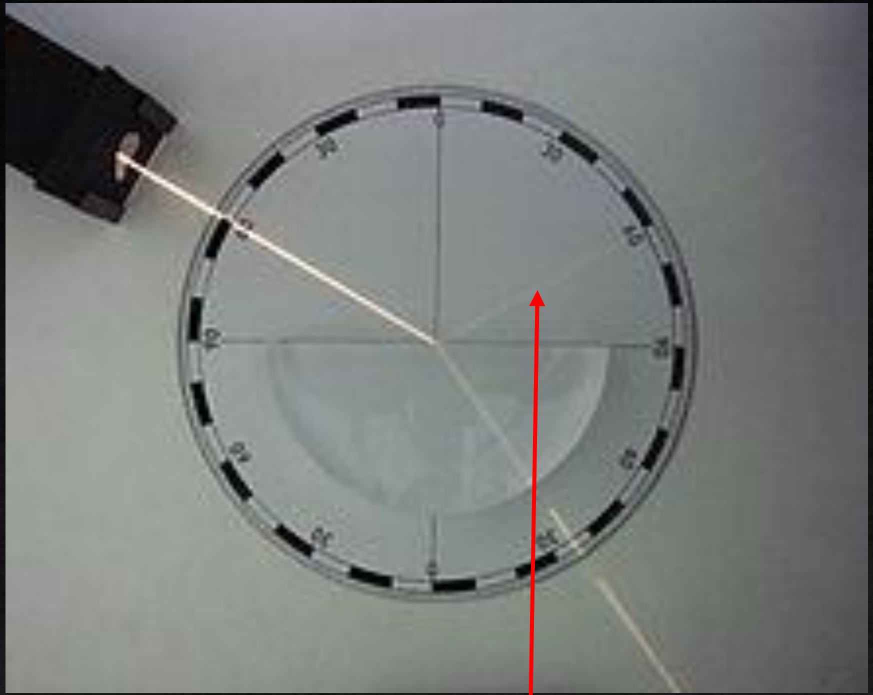
Physical Optics
1. The nature of light, light sources and detectors
2. Radiometry & photometry
3. Optical materials: light & matter interactions
4. Diffraction & Interference

Each of these topics would normally be a 1-hour lecture.

Intro to Geometrical & Physical Optics

Refraction





An object (in this case a pencil) part immersed in water looks bent due to refraction: the light waves from X change direction and so seem to originate at Y.

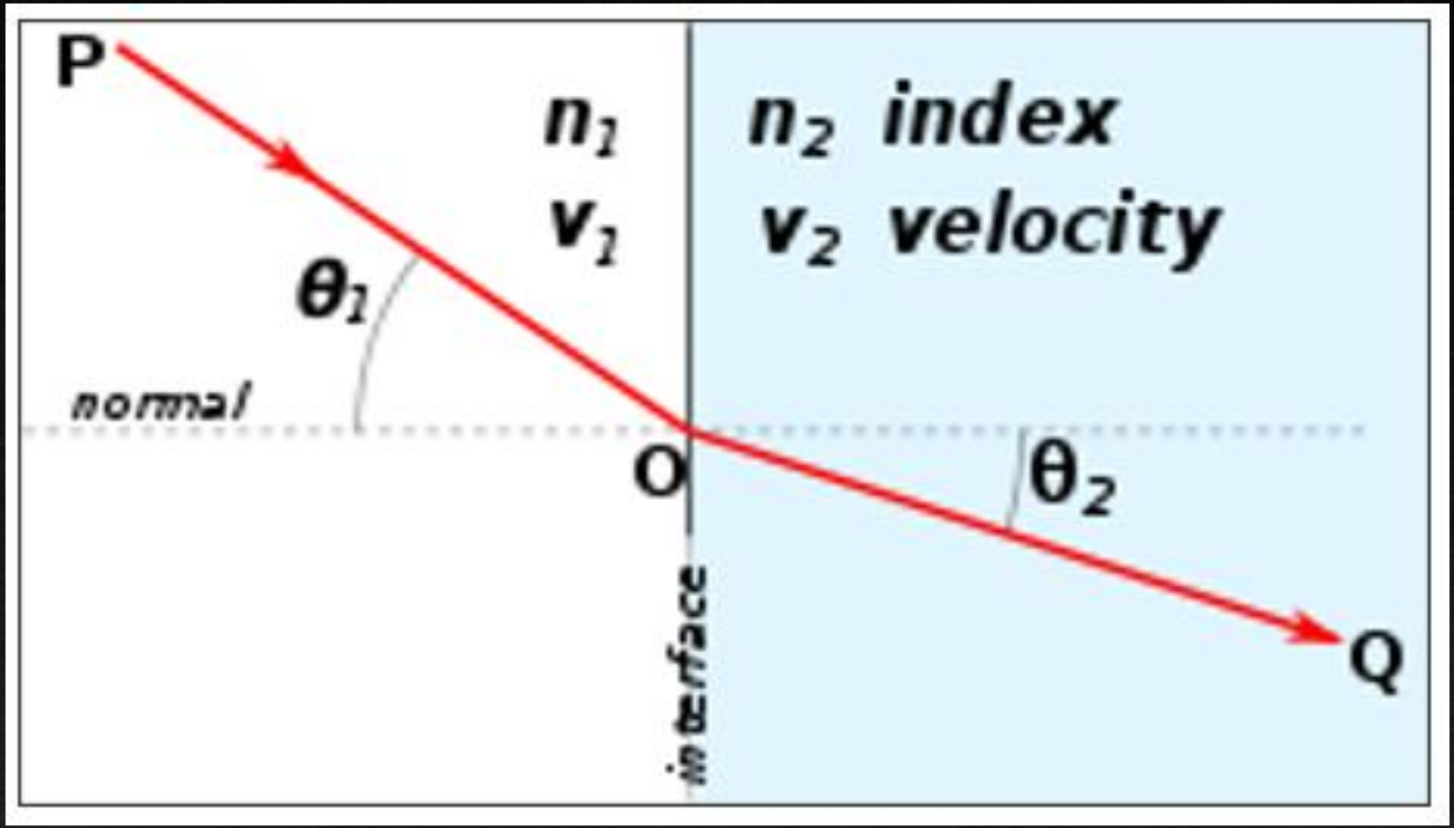
Light on air–plexi surface in this experiment mainly undergoes refraction (lower ray).

and to a lesser extent reflection (top ray).

Snell's Law of Refraction

n_x = Refractive index

(Remember this for later.)



$$\frac{\sin\theta_1}{\sin\theta_2} = \frac{v_1}{v_2} = \frac{n_2}{n_1}.$$

Reflection

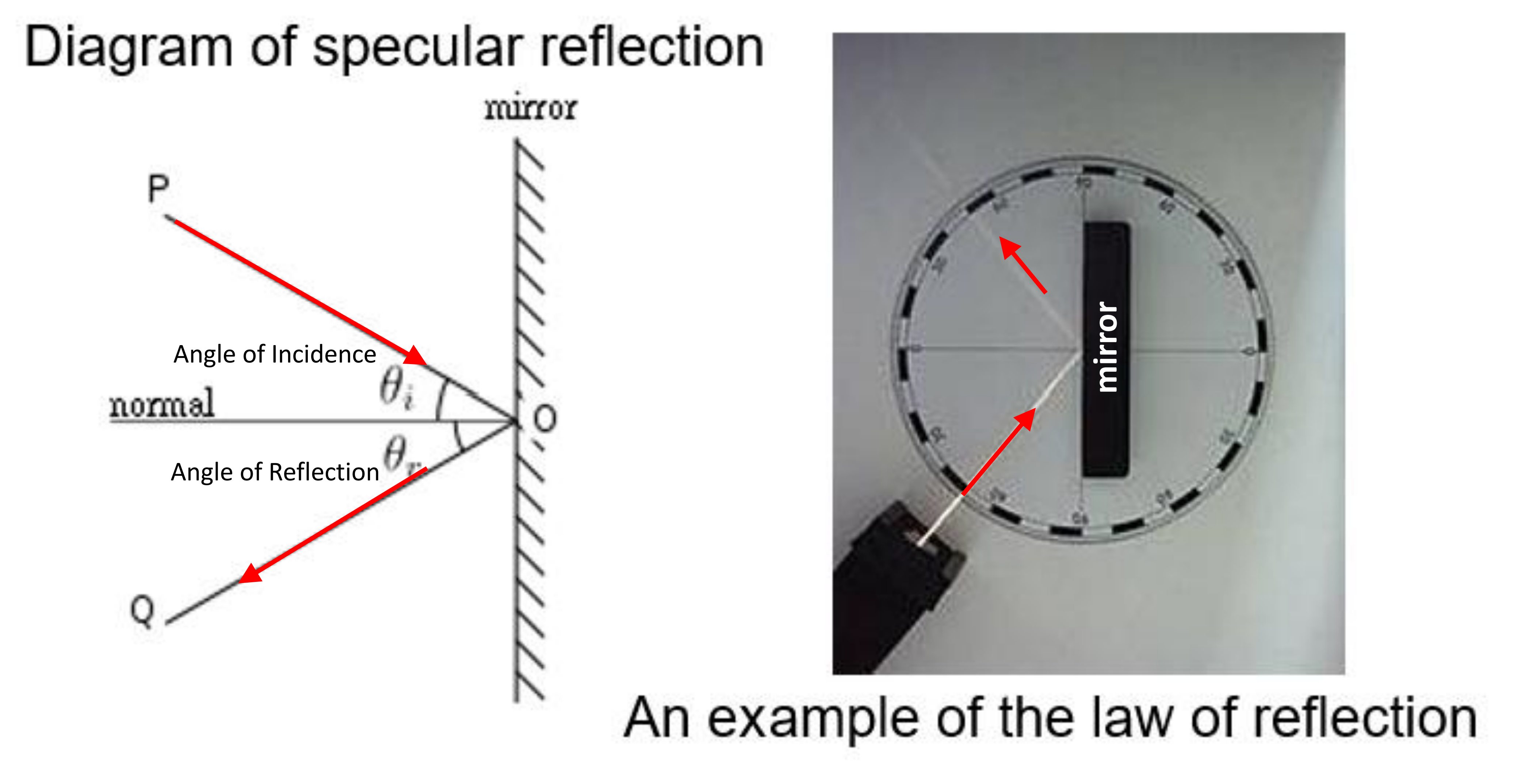


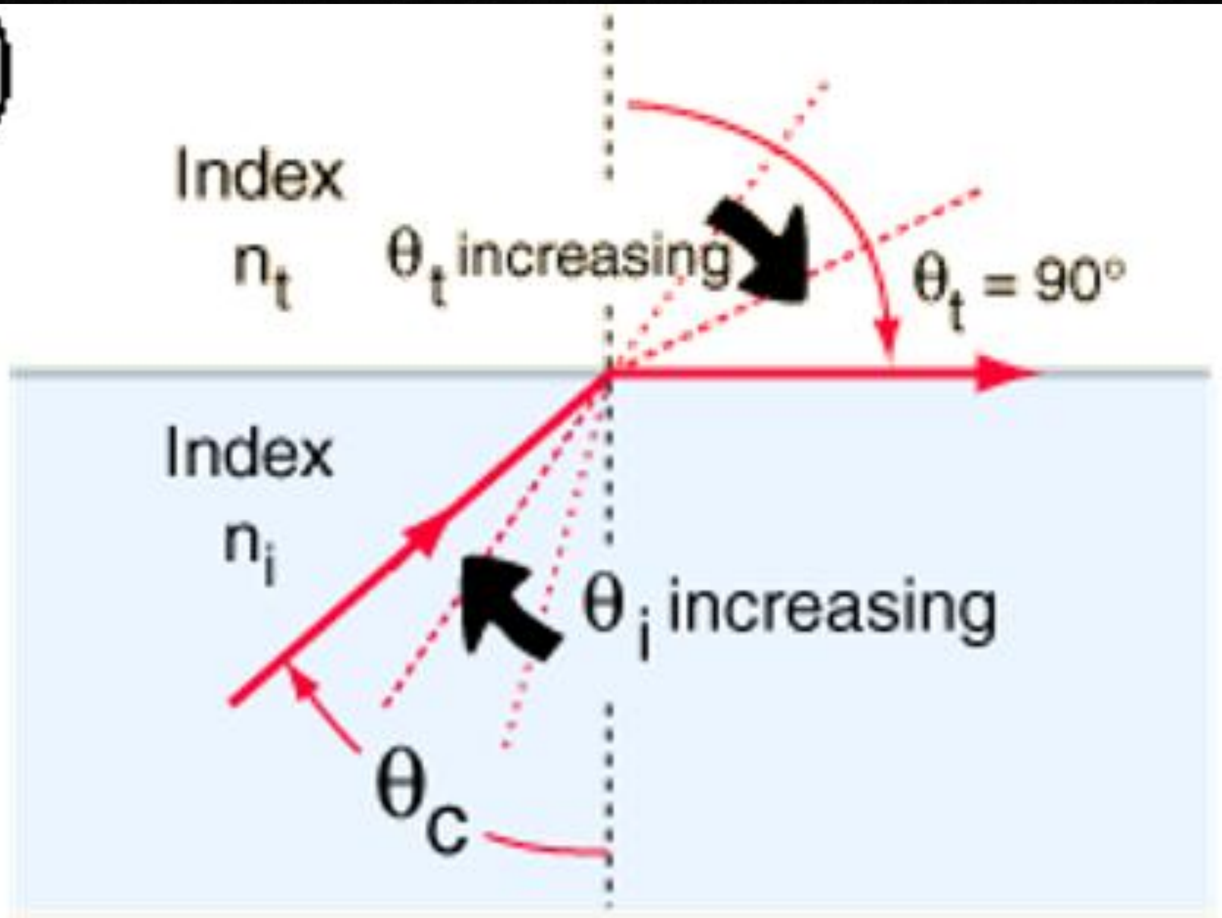
Diagram of specular reflection
mirror
P
Angle of Incidence
θ_i
normal
O
Angle of Reflection
θ_r
Q
mirror
An example of the law of reflection

Total Internal Reflection (TIR)

$$n_i \sin(\Theta_c) = n_t \sin(90^\circ)$$

$$n_i \sin(\Theta_c) = n_t \times 1$$

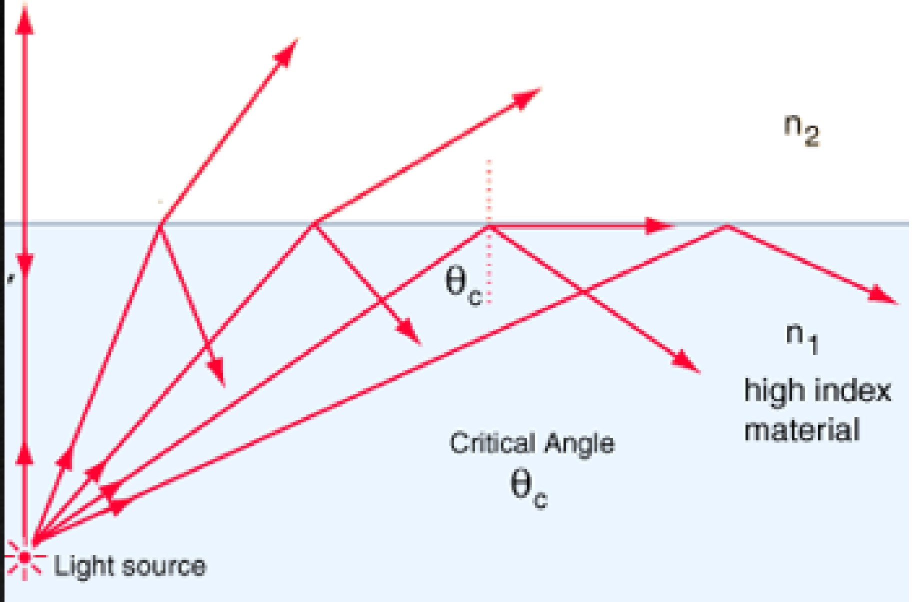
$$\Theta_c = \sin^{-1}\left(\frac{n_t}{n_i}\right)$$



The critical angle can be calculated from Snell's law by setting the refraction angle equal to 90° .

Threshold condition for total internal reflection.

Total Internal Reflection (TIR)



Condition for total reflection
Incident angle > Critical angle

Medium where light coming form must have higher index of refraction compared to second medium (ni > nt)

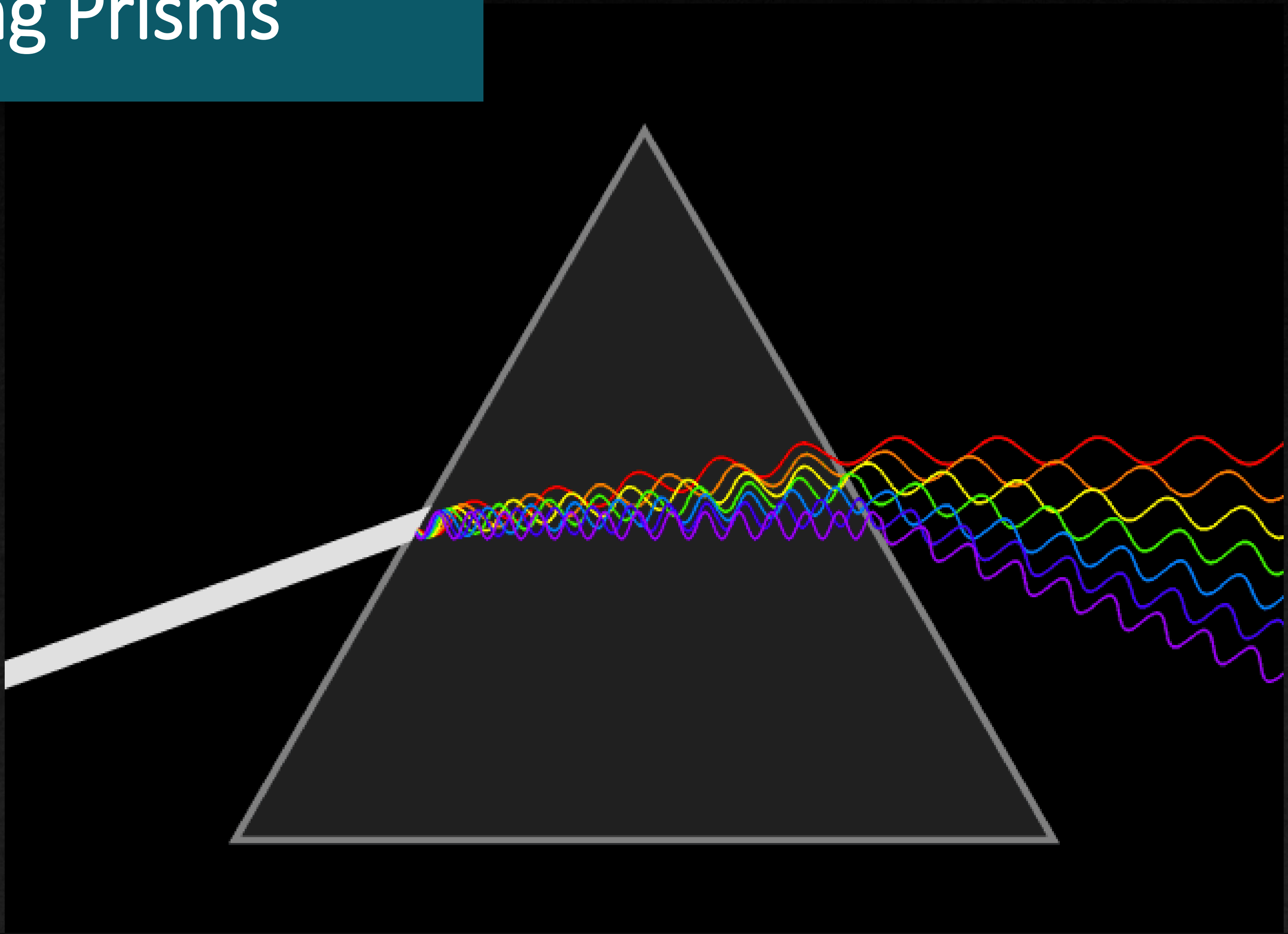
For any angle of incidence less than the critical angle, part of the incident light will be transmitted and part will be reflected.

Variable definitions used in this explanation
n1 = ni = index of refraction of medium where light coming from

n2 = nt = index of refraction of the second medium
Θc = Critical angle
Θi = Θ1 = Incident angle
Θt = Θ2 = Transmittance angle = Exit angle

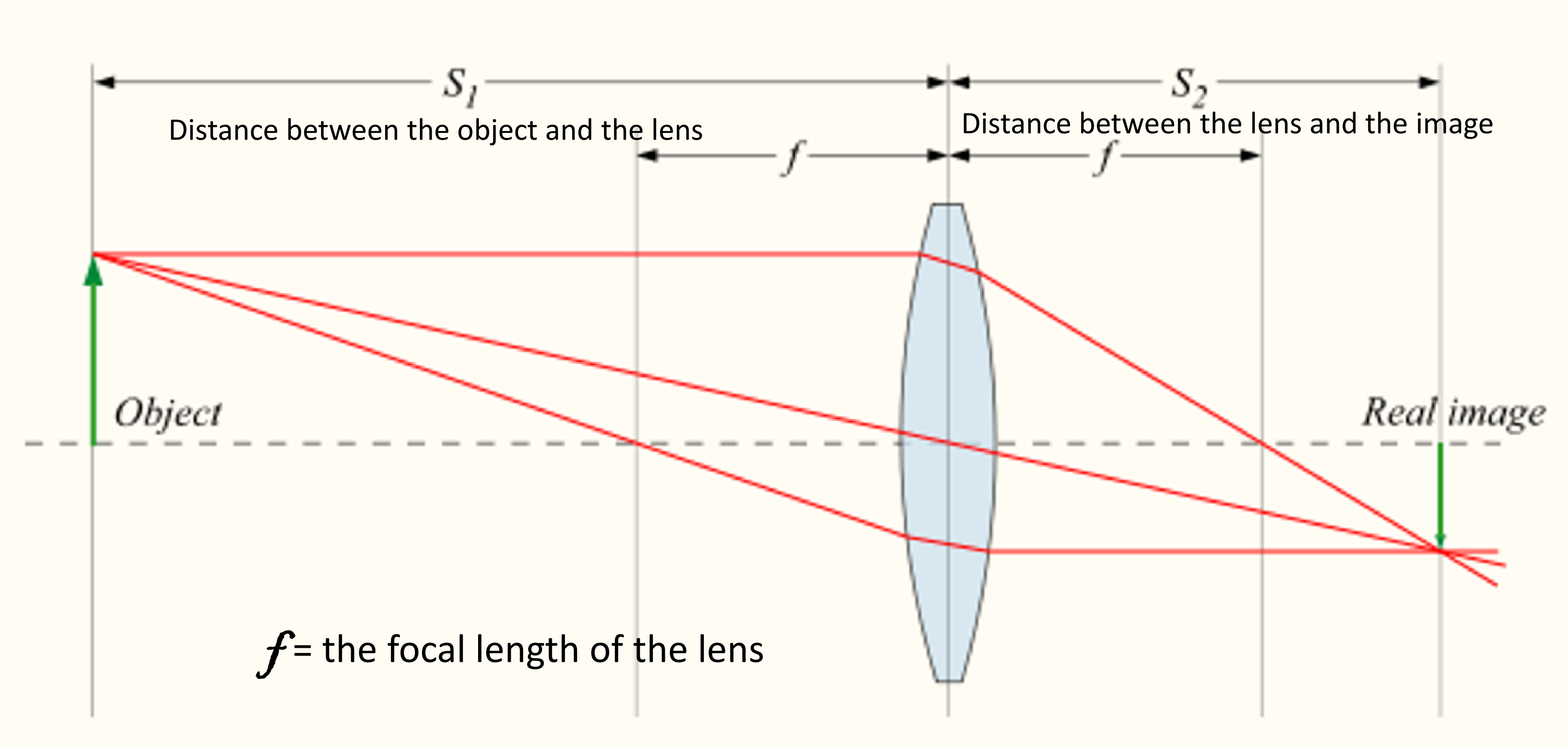
Critical angle and total internal refraction

Dispersing Prisms



A triangular prism, dispersing light; waves shown to illustrate the differing wavelengths of light.

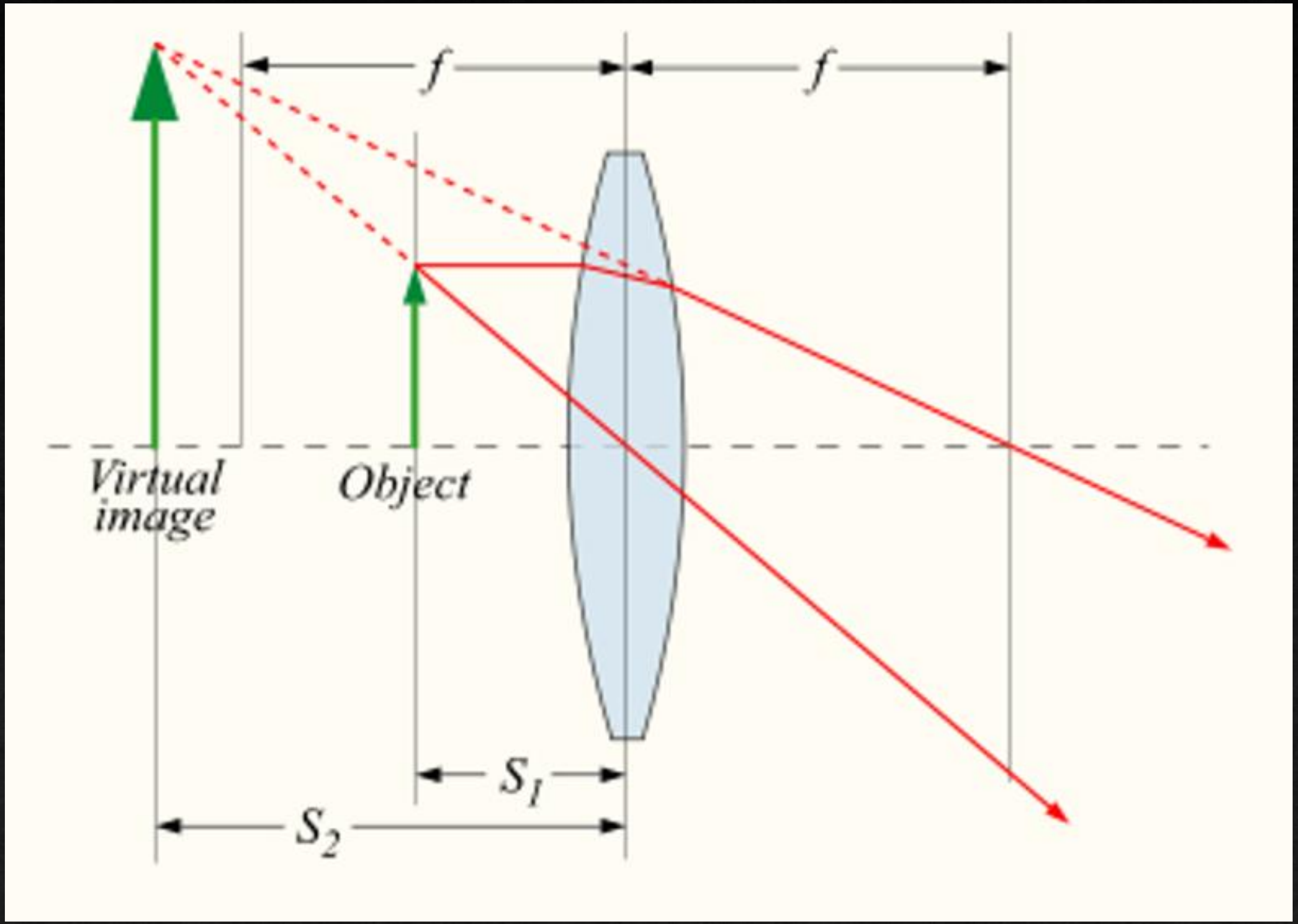
Imaging with thin lenses

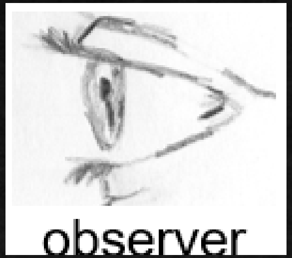


Thin lens formula

$$\frac{1}{S_1} + \frac{1}{S_2} = \frac{1}{f}$$

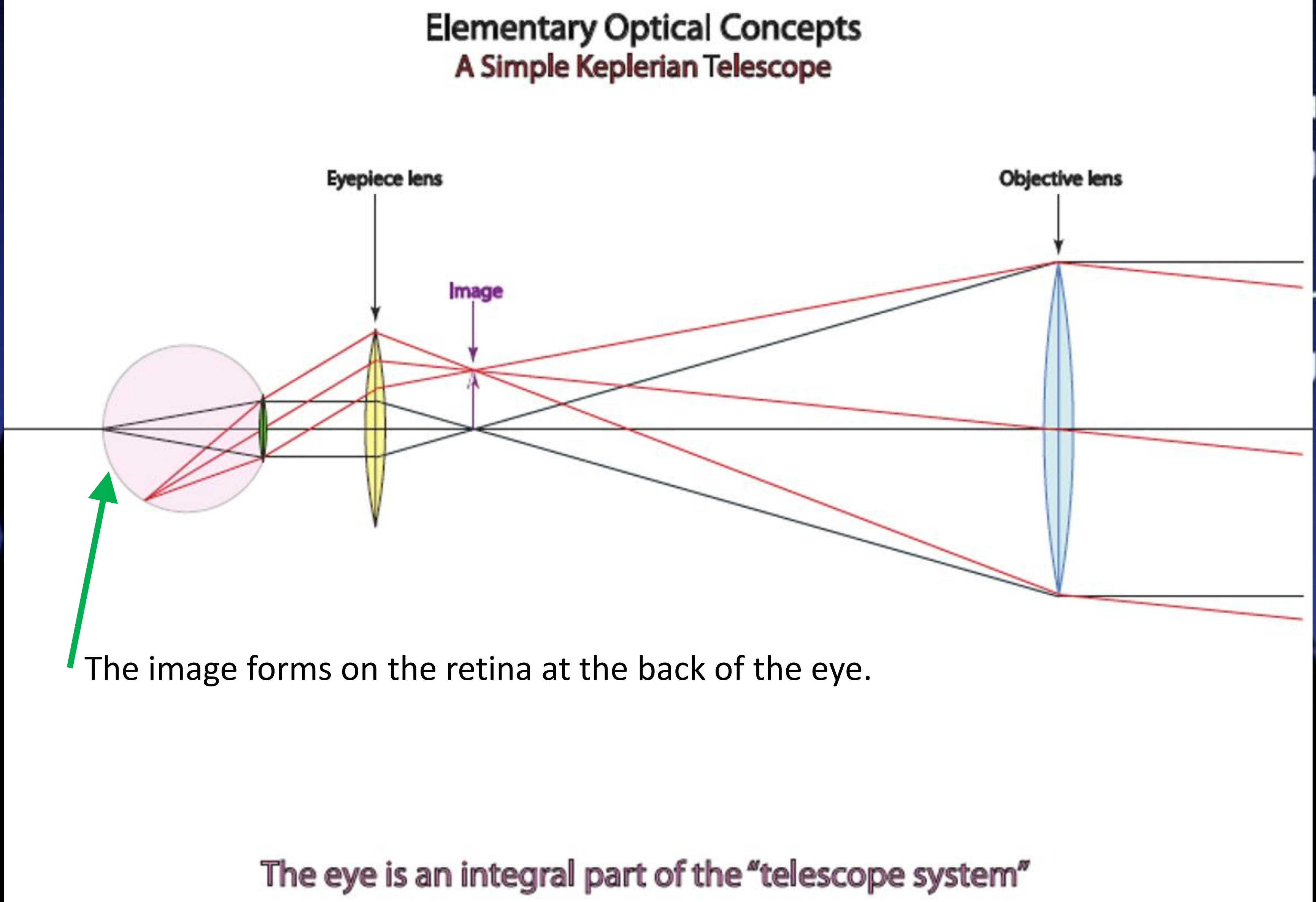
A Magnifying Glass





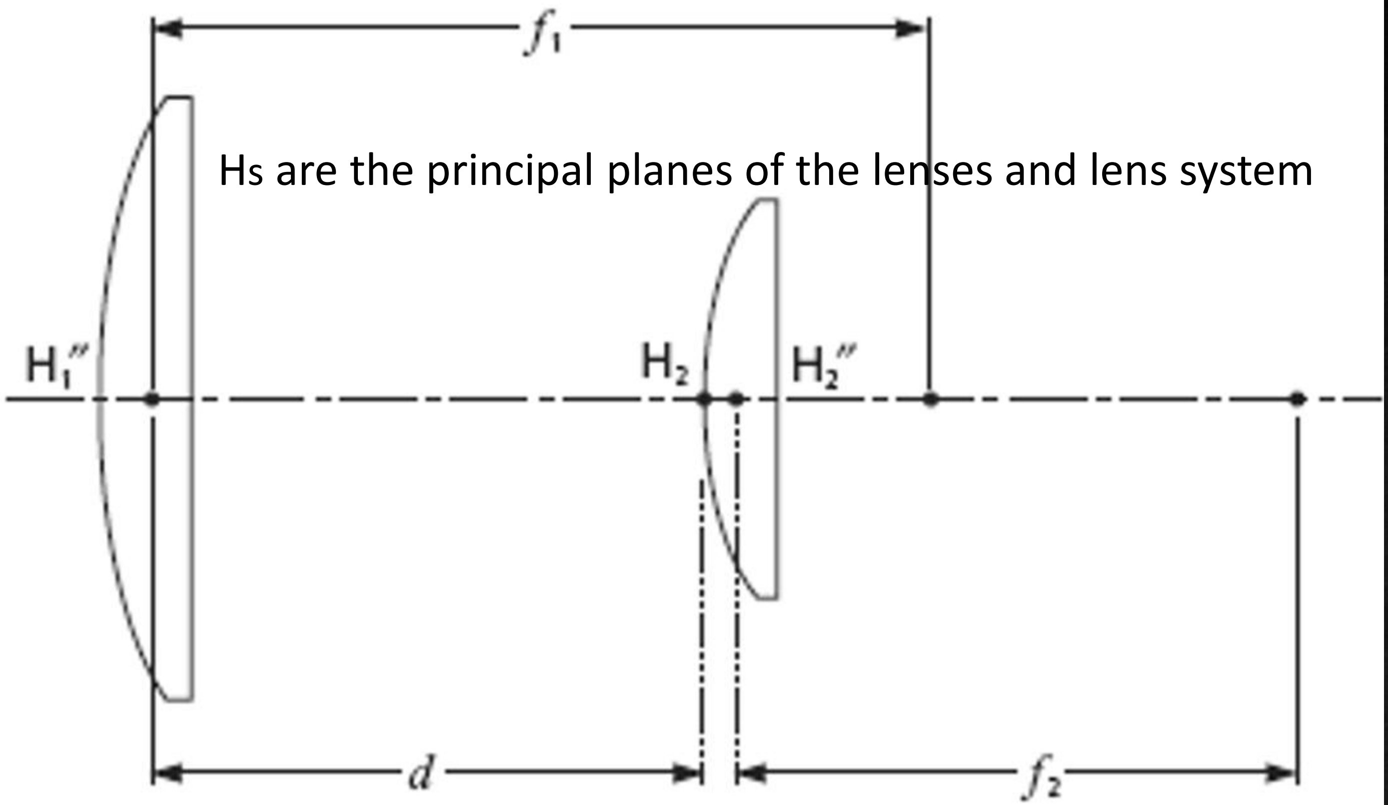
Magnification = $M = -\frac{S_2}{S_1} = \frac{f}{f - S_1}$

Multiple Thin Lenses



The image forms on the retina at the back of the eye.

Effective Focal Length & Power of Multiple Thin Lenses



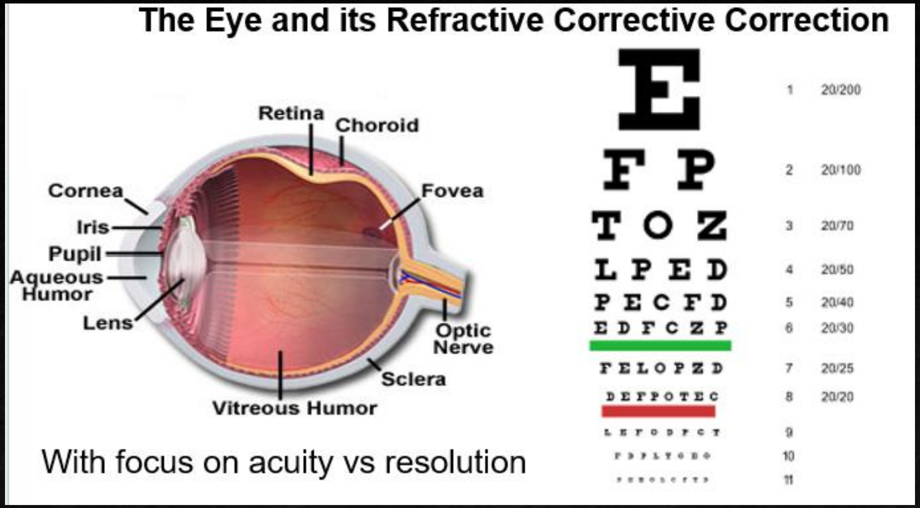
d = the distance between the lenses

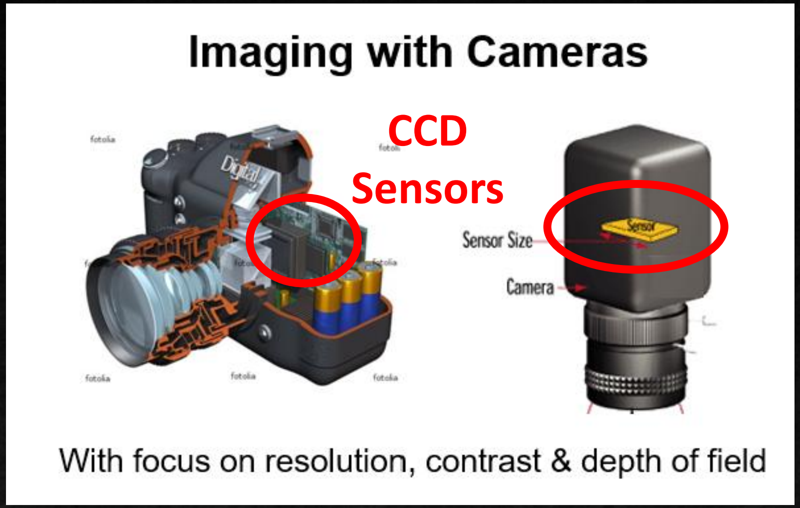
$$f = \frac{f_1 f_2}{f_1 + f_2 - d}.$$

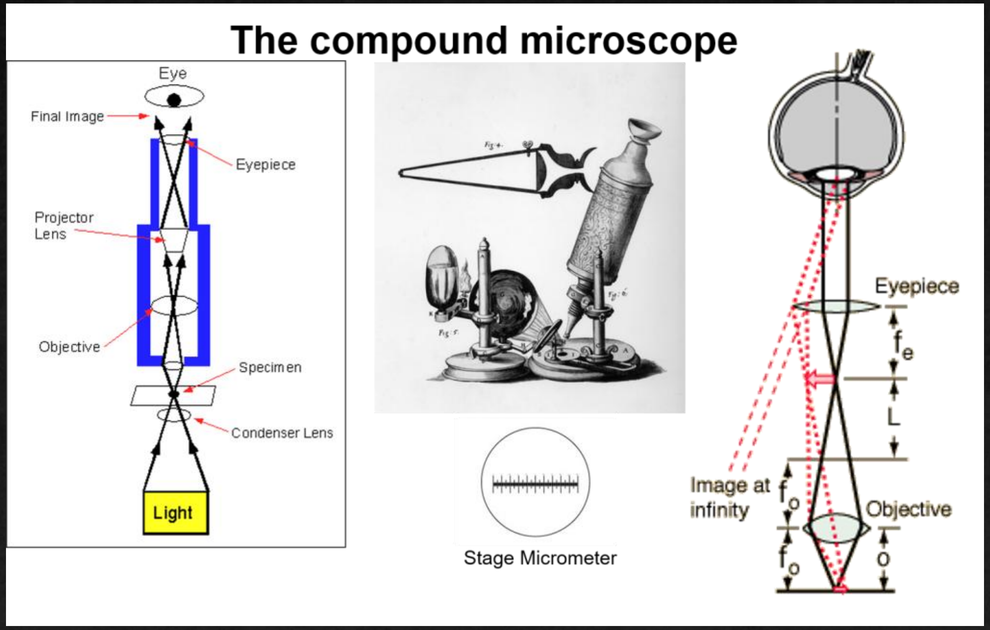
f = the focal length of the lens system

$$\frac{1}{f} = \frac{1}{f_1} + \frac{1}{f_2} - \frac{d}{f_1 f_2}.$$

Examples of Optical Systems



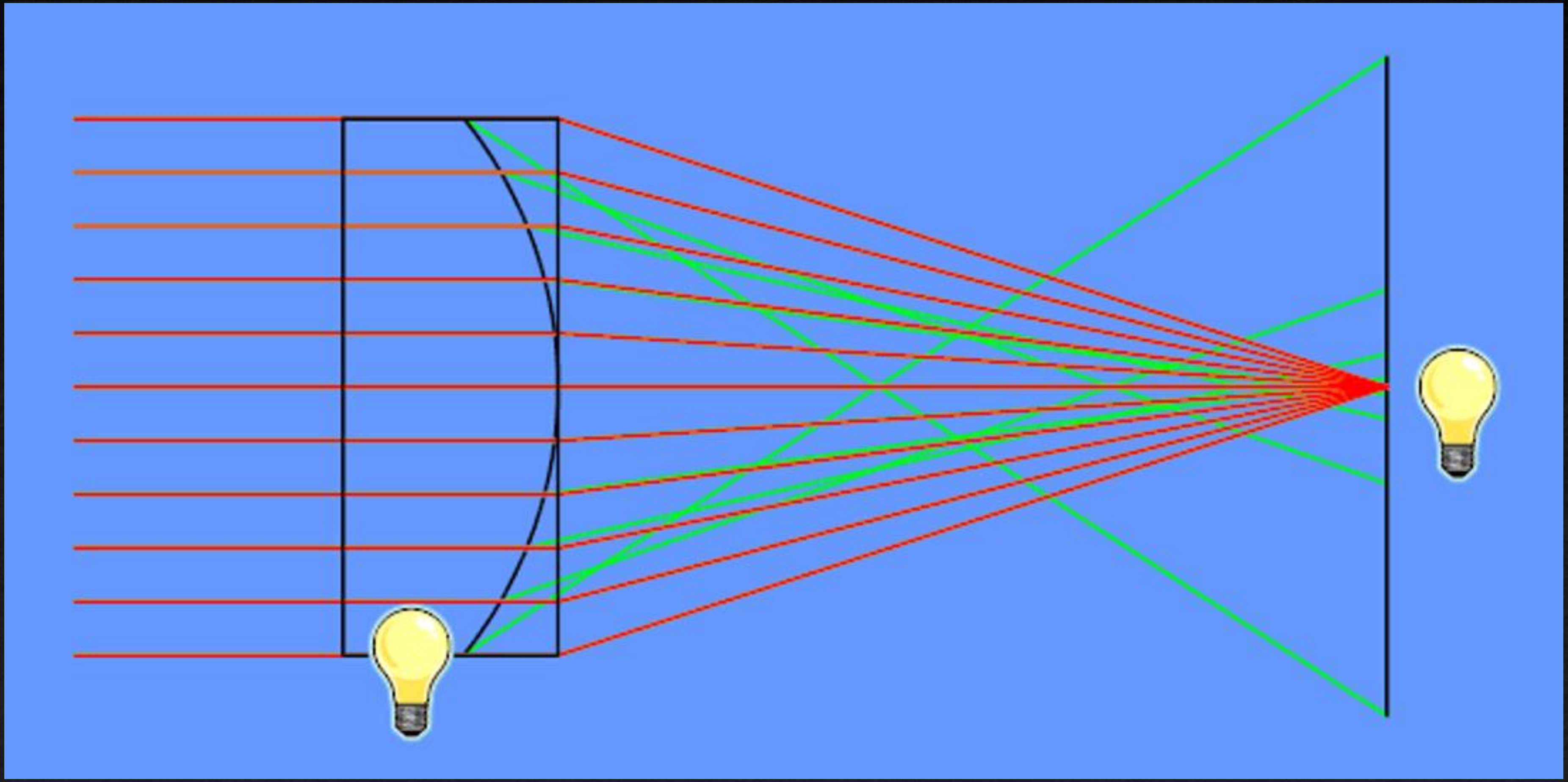




Aberrations & Ray Tracing

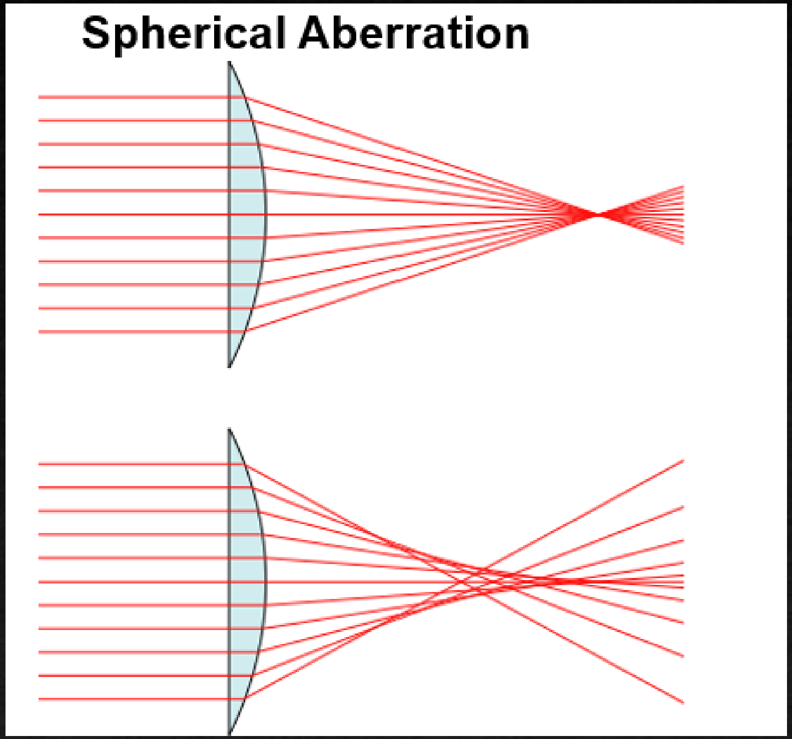
Usually taught to upper-level undergraduate physics & graduate level engineering students.

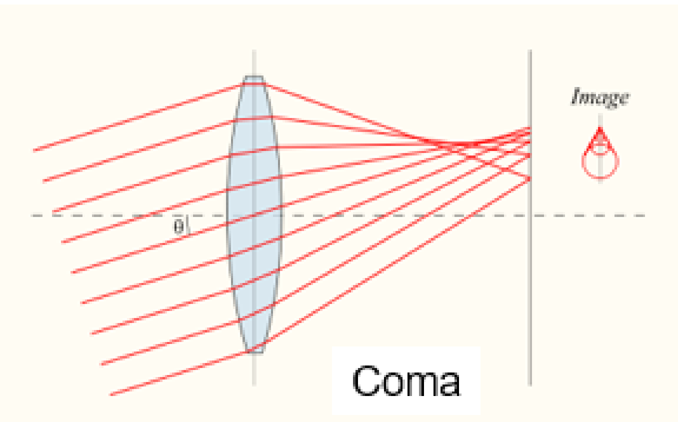
Out of the Paraxial >> Third-Order Theory

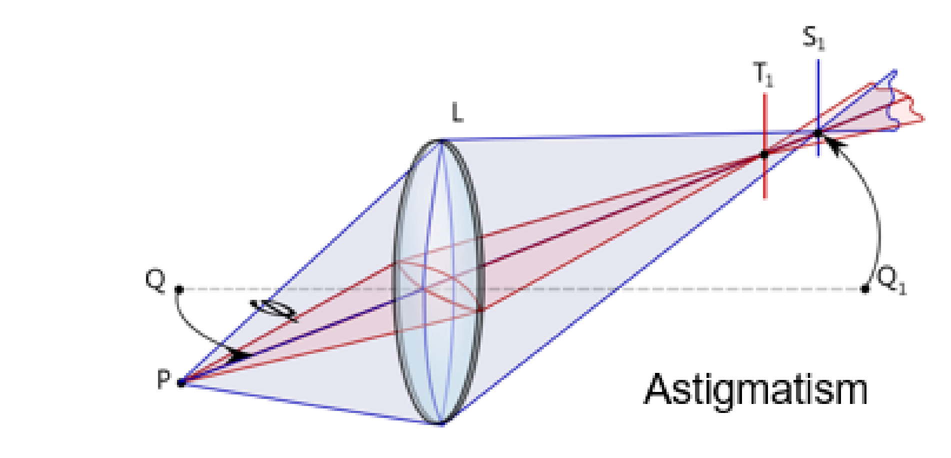


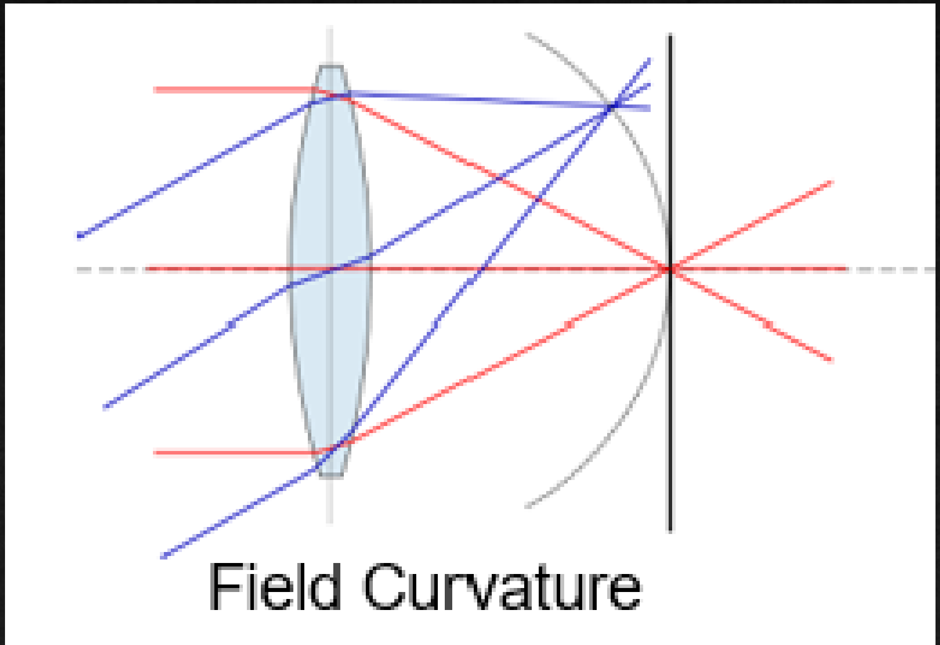
Paraxial Rays >>> Real Rays

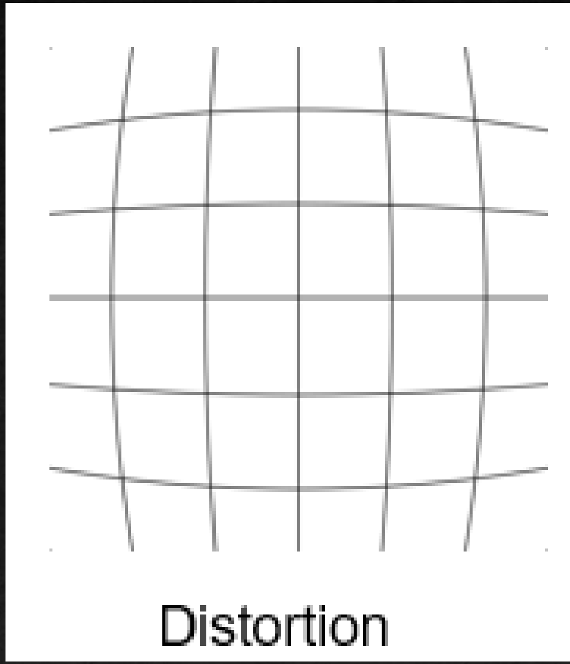
5 - Third Order Seidel Aberrations



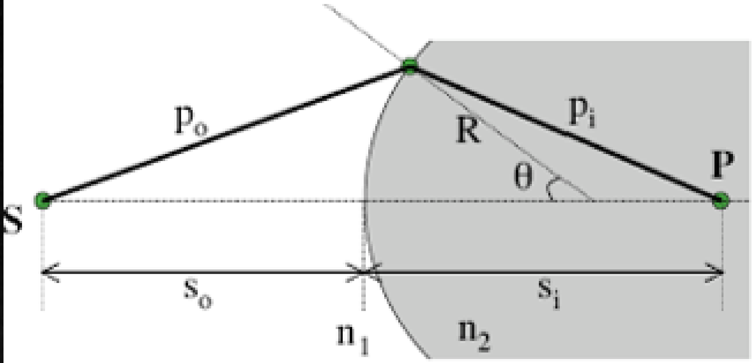








Third Order Aberration Theory



$$\frac{n_1 R(s_o + R)\sin\theta}{p_o} = \frac{n_2 R(s_i - R)\sin\theta}{p_i}$$

Approximation

$\sin\theta \approx \theta$

$$\sin\theta = \theta - \frac{\theta^3}{3!} + \frac{\theta^5}{5!} - \frac{\theta^7}{7!} + \cdots$$

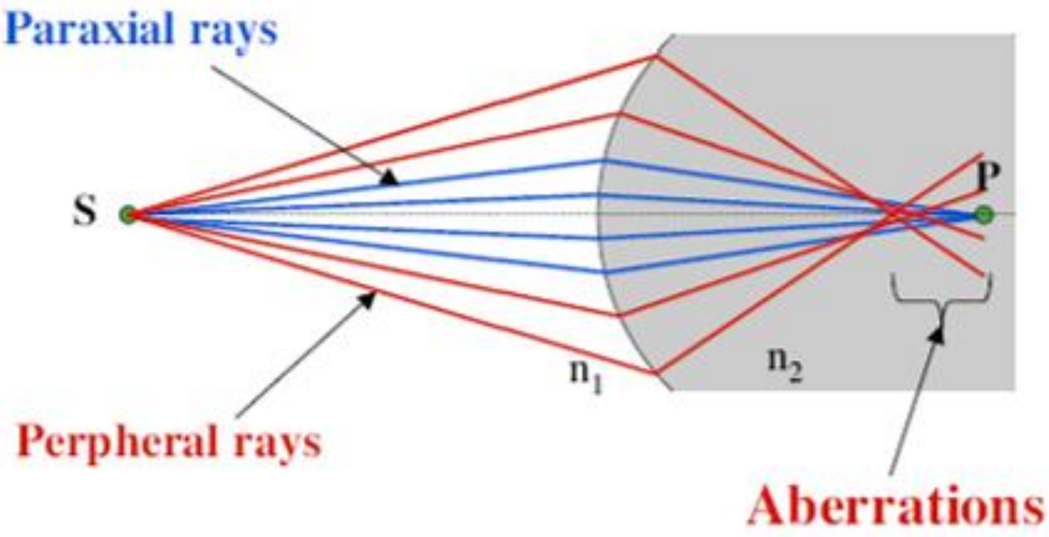
$$\frac{n_1}{s_o} + \frac{n_2}{s_i} = \frac{n_2 - n_1}{R}$$

Lens maker's formula

*"The paraxial approximation, **Sin θ ~ θ** is somewhat unsatisfactory if rays from the periphery of a lens are considered."*

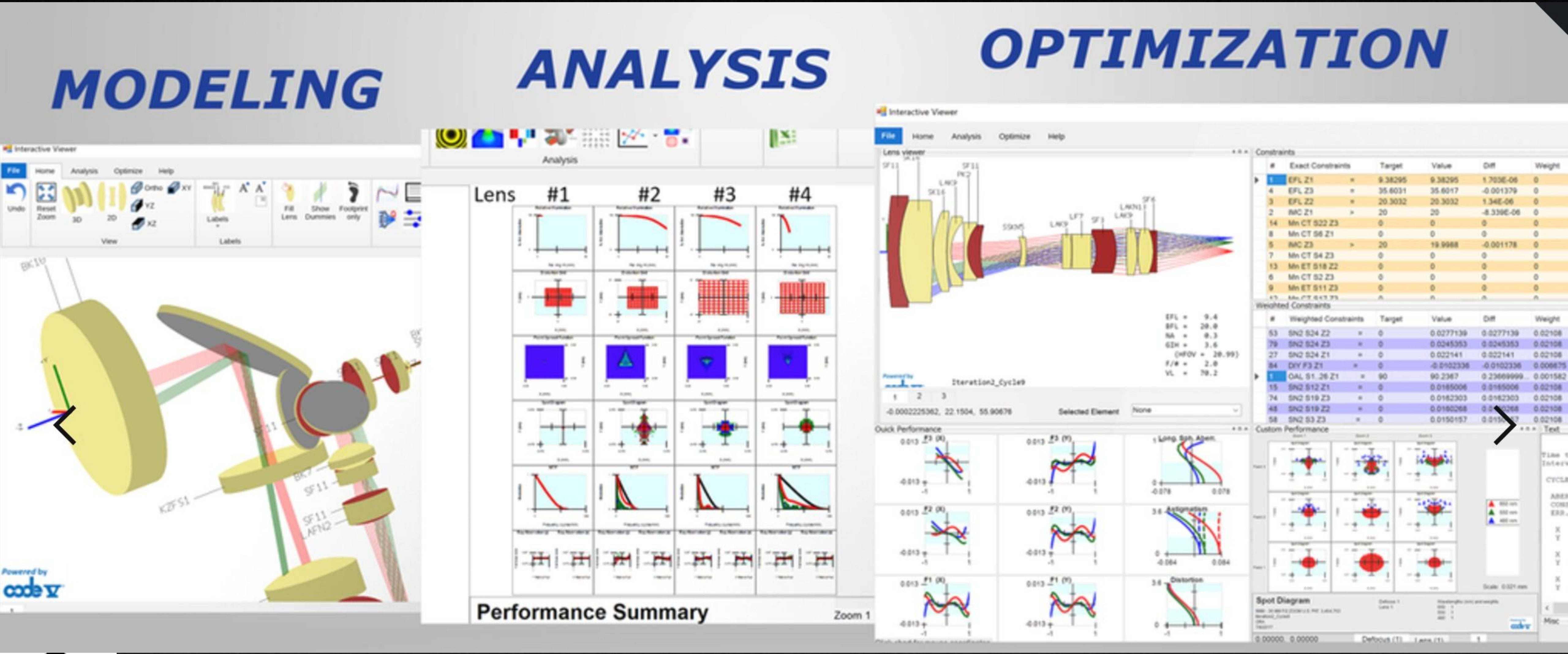
$$\sin\theta = \theta - \frac{\theta^3}{3!}$$

$$\frac{n_1}{s_o} + \frac{n_2}{s_i} = \frac{n_2 - n_1}{R} + h^2\left[\frac{n_1}{2s_o}\left(\frac{1}{s_o} + \frac{1}{R}\right)^2 + \frac{n_2}{2s_i}\left(\frac{1}{R} - \frac{1}{s_i}\right)^2\right]$$

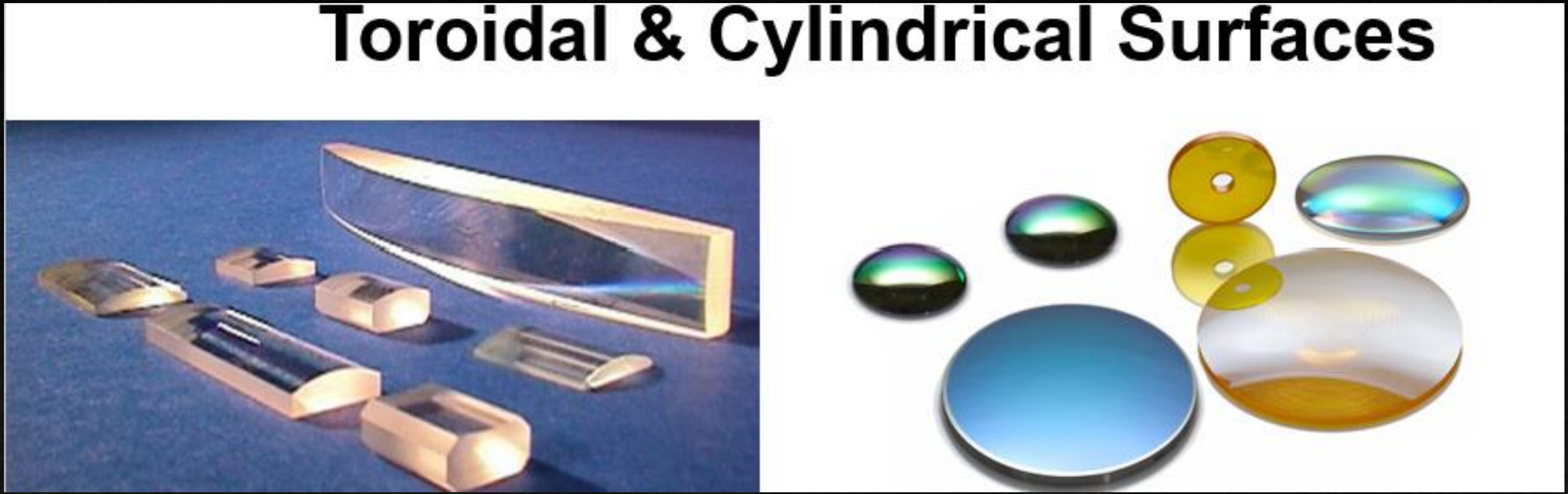


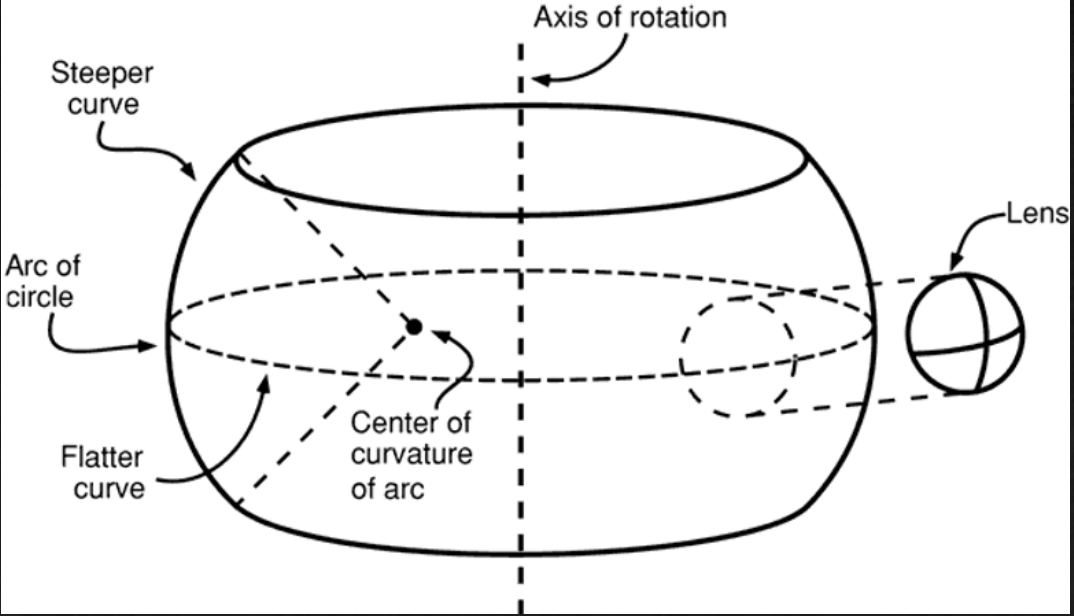
Ray Tracing

With modern raytracing software it is easy to do calculations.



Non-Spherical & Segmented Optical Surfaces

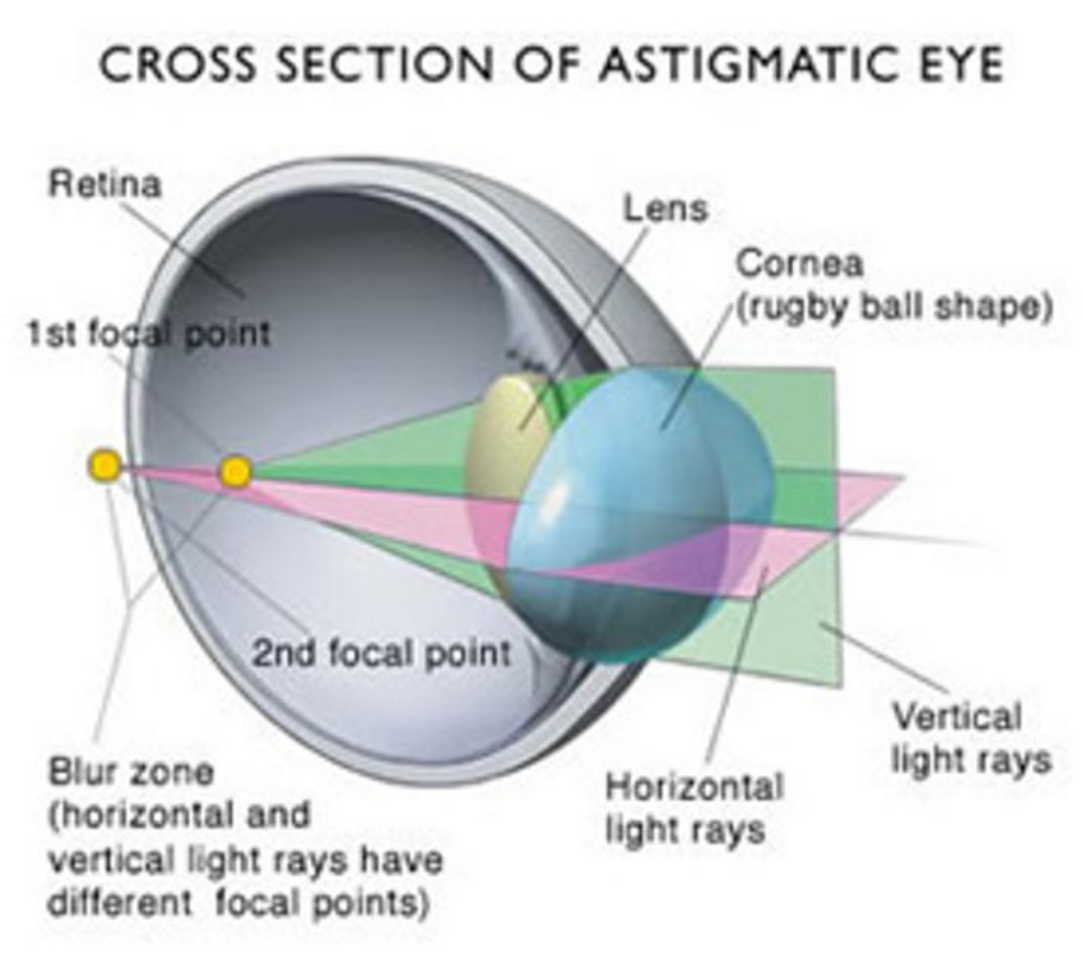


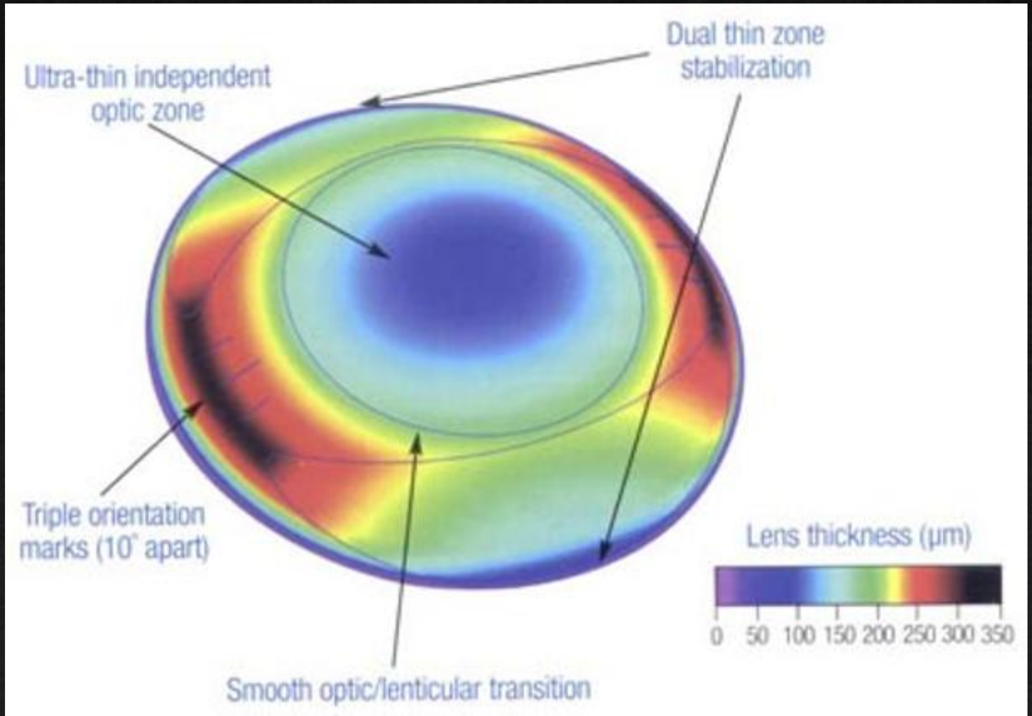


Like a section from a tire

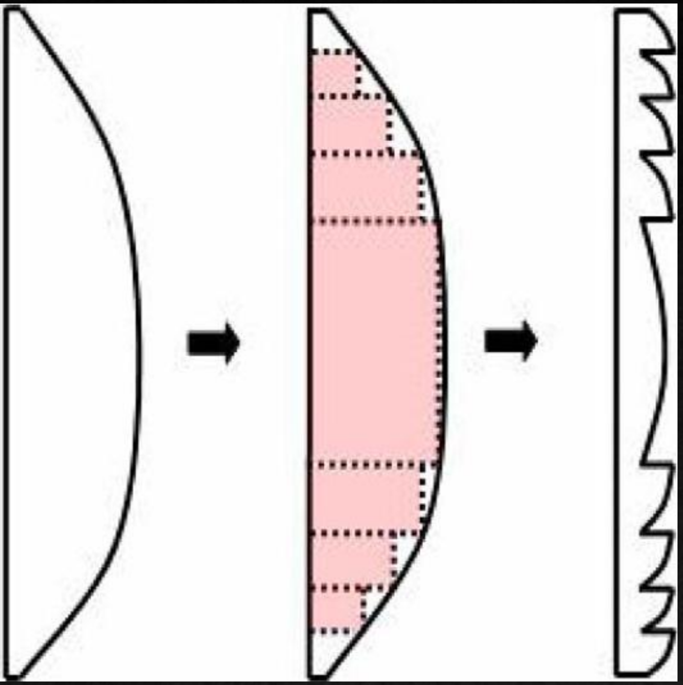
Non-Spherical & Segmented Optical Surfaces

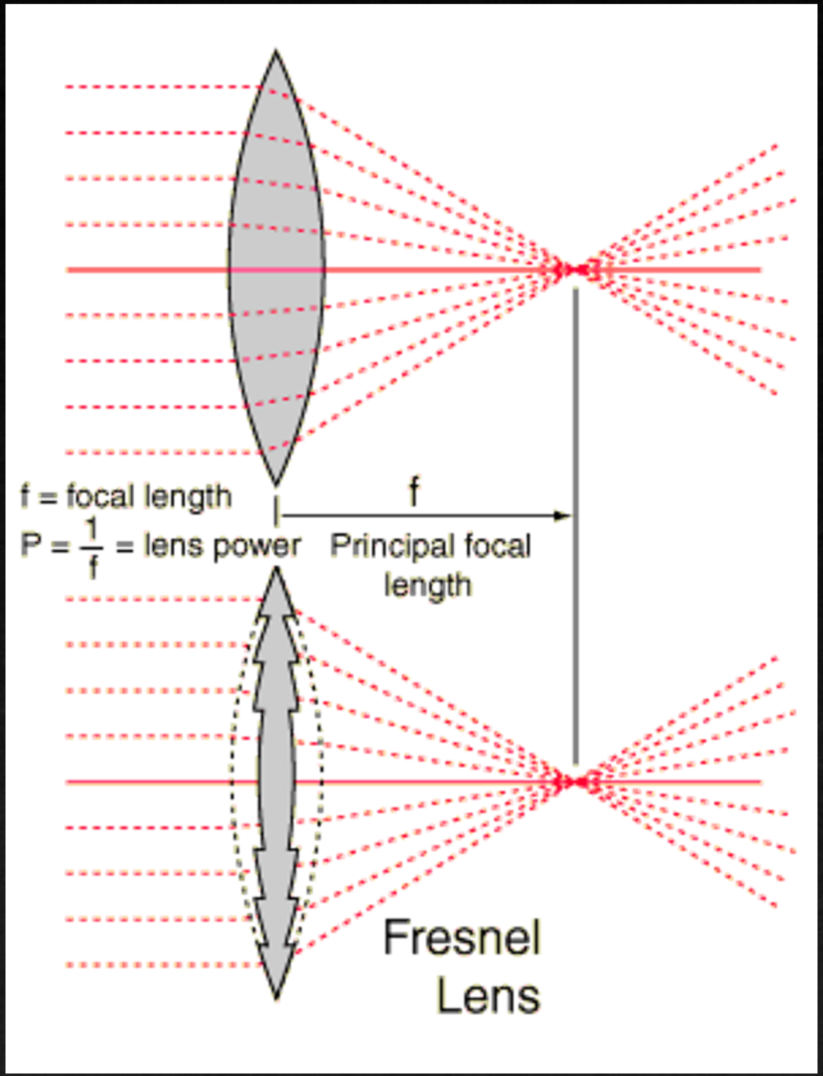
Ophthalmic Lenses with cylindrical power





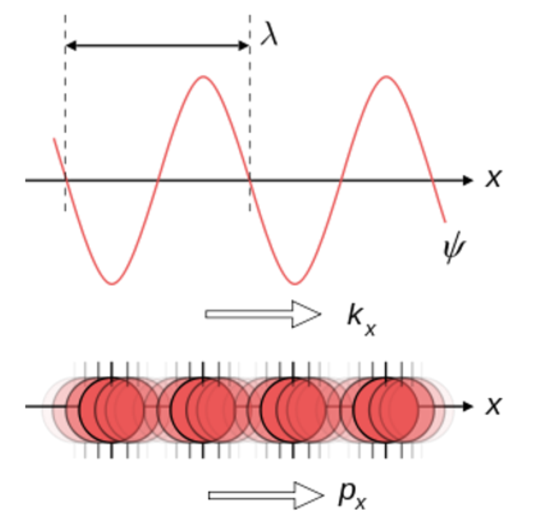
Segmented & Fresnel Lenses





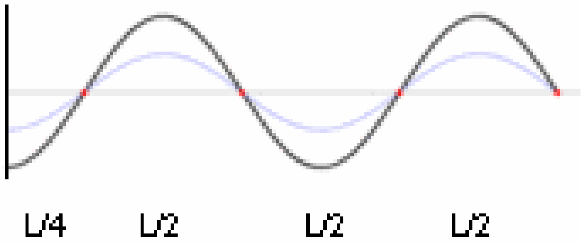
Physical Optics

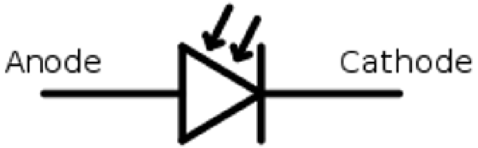
The nature of light, light sources & detectors



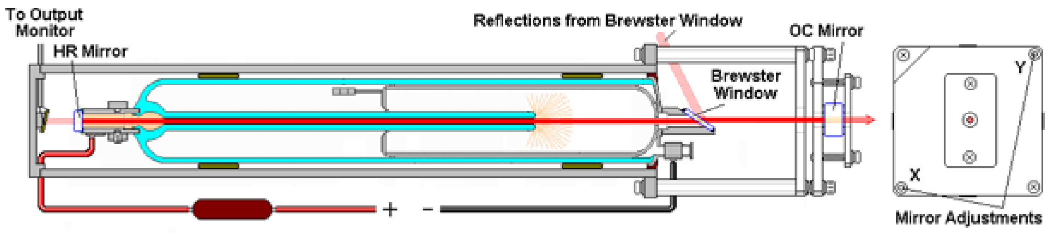
The dual nature of light

Wave motion and wave trains

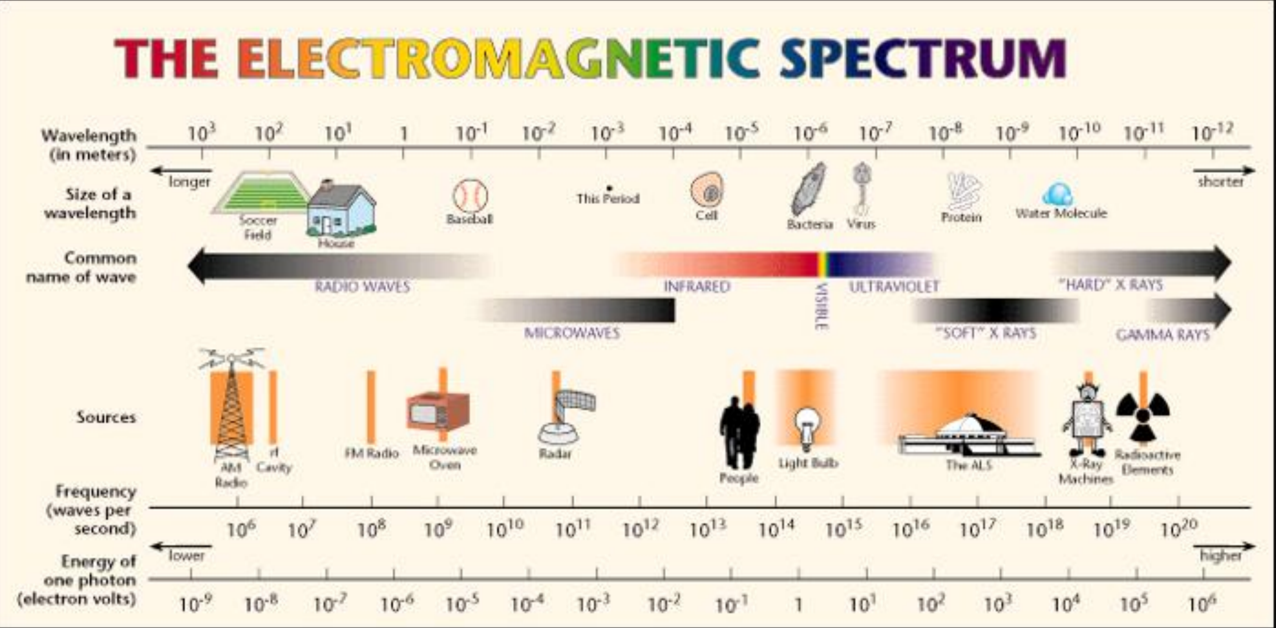




Detectors –photoelectric effect

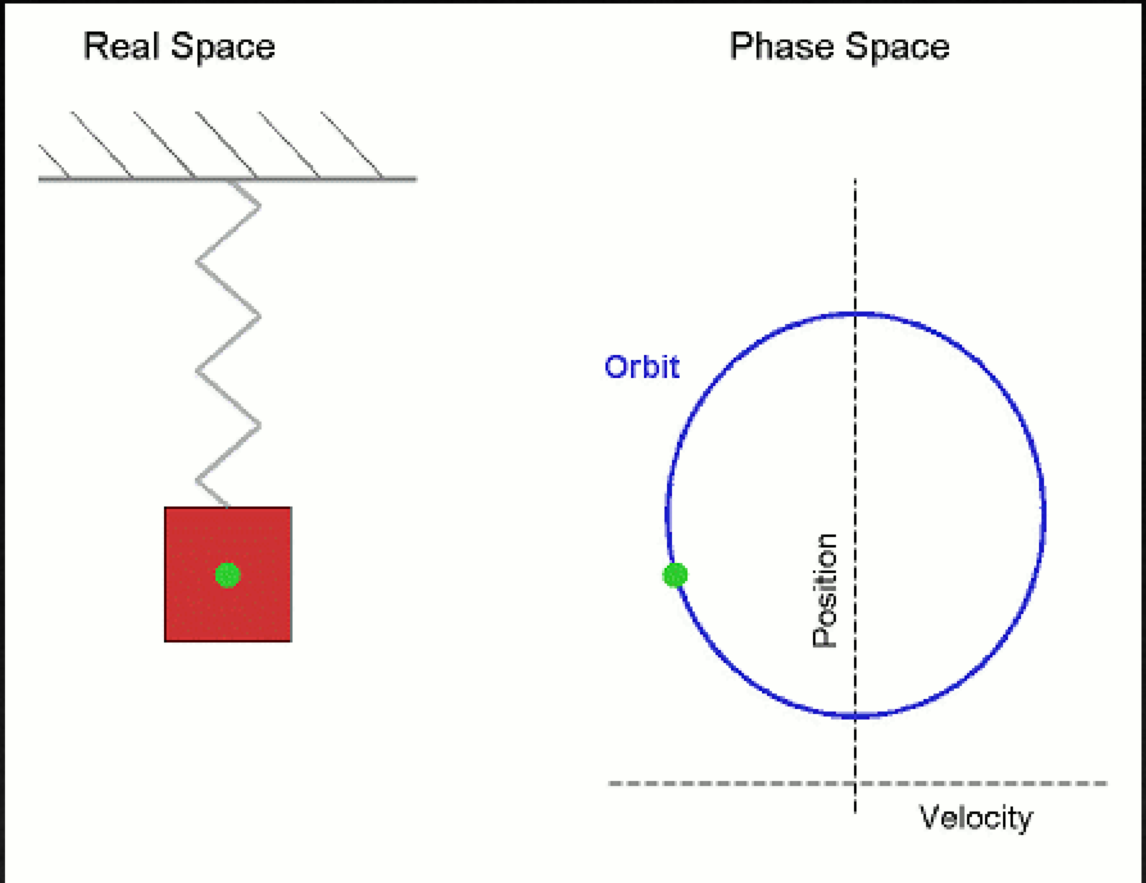


HeNe Laser Tube with Internal HR and Brewster Window with External OC



Simple harmonic motion

$$\mathbf{F} = -k\mathbf{x},$$

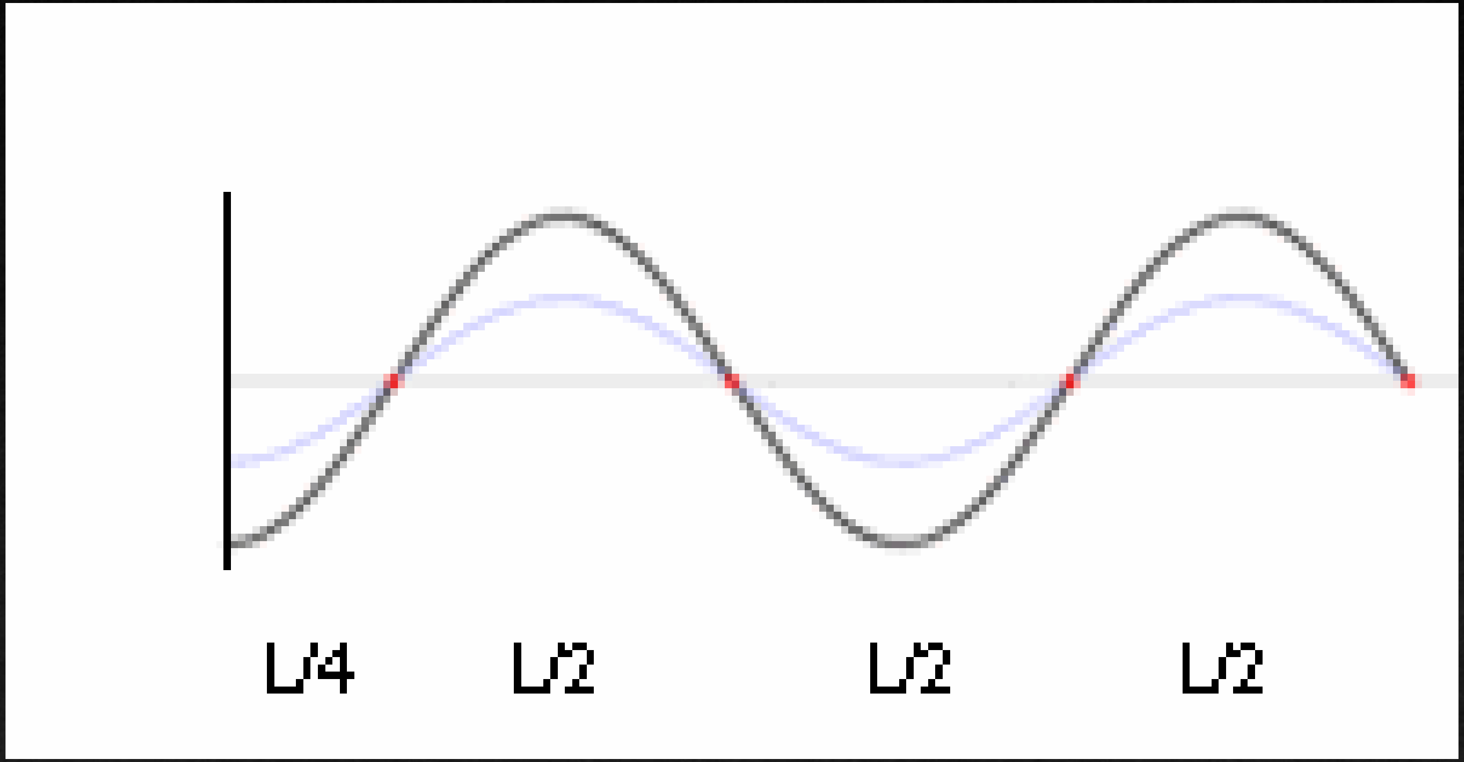


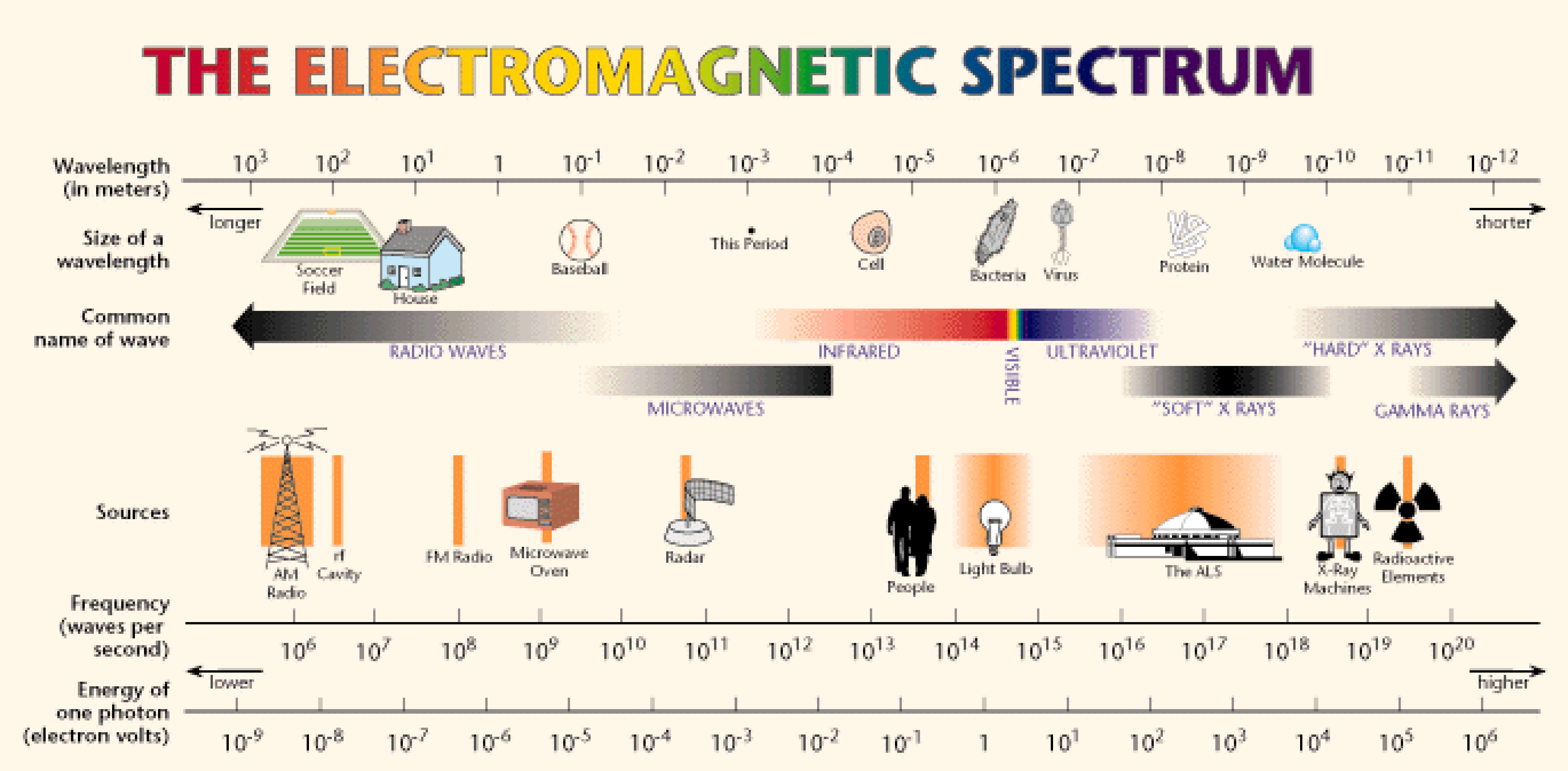
Simple harmonic motion shown both in real space and phase space. The orbit is periodic.

Animation demonstrating the simple harmonic motion of a mass on a spring in both real space and phase space.

Note that the phase space axes are switched from the standard convention in order to align the two diagrams

Wave motion and trains

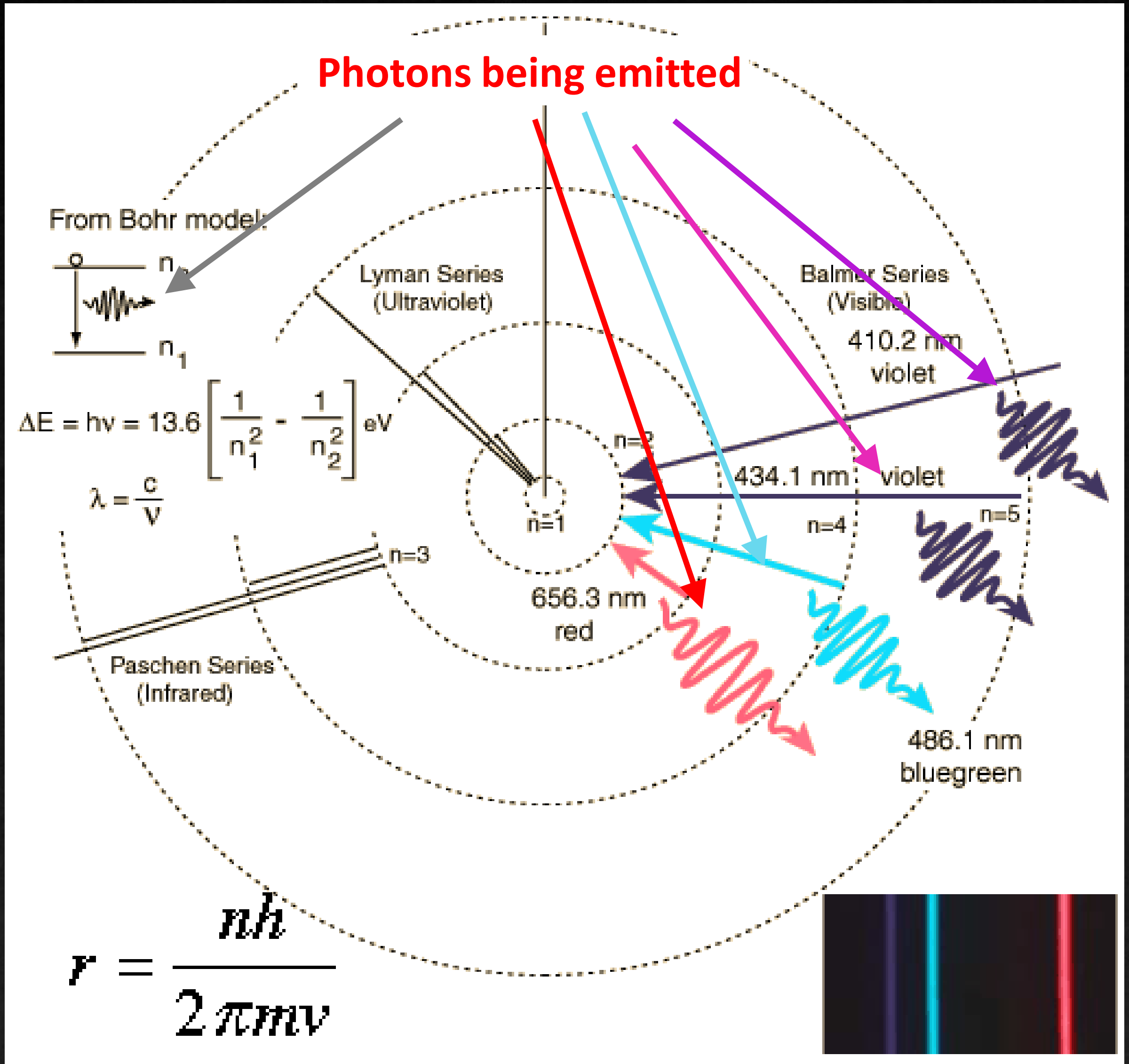



THE ELECTROMAGNETIC SPECTRUM
Wavelength (in meters)
10^3 10^2 10^1 1 10^{-1} 10^{-2} 10^{-3} 10^{-4} 10^{-5} 10^{-6} 10^{-7} 10^{-8} 10^{-9} 10^{-10} 10^{-11} 10^{-12}
longer
shorter
Size of a wavelength
Soccer Field
House
Baseball
This Period
Cell
Bacteria
Virus
Protein
Water Molecule
Common name of wave
RADIO WAVES
INFRARED
VISIBLE
ULTRAVIOLET
"HARD" X RAYS
MICROWAVES
"SOFT" X RAYS
GAMMA RAYS
Sources
AM Radio
rf Cavity
FM Radio
Microwave Oven
Radar
People
Light Bulb
The ALS
X-Ray Machines
Radioactive Elements
Frequency (waves per second)
10^6 10^7 10^8 10^9 10^{10} 10^{11} 10^{12} 10^{13} 10^{14} 10^{15} 10^{16} 10^{17} 10^{18} 10^{19} 10^{20}
lower
higher
Energy of one photon (electron volts)
10^{-9} 10^{-8} 10^{-7} 10^{-6} 10^{-5} 10^{-4} 10^{-3} 10^{-2} 10^{-1} 1 10^1 10^2 10^3 10^4 10^5 10^6

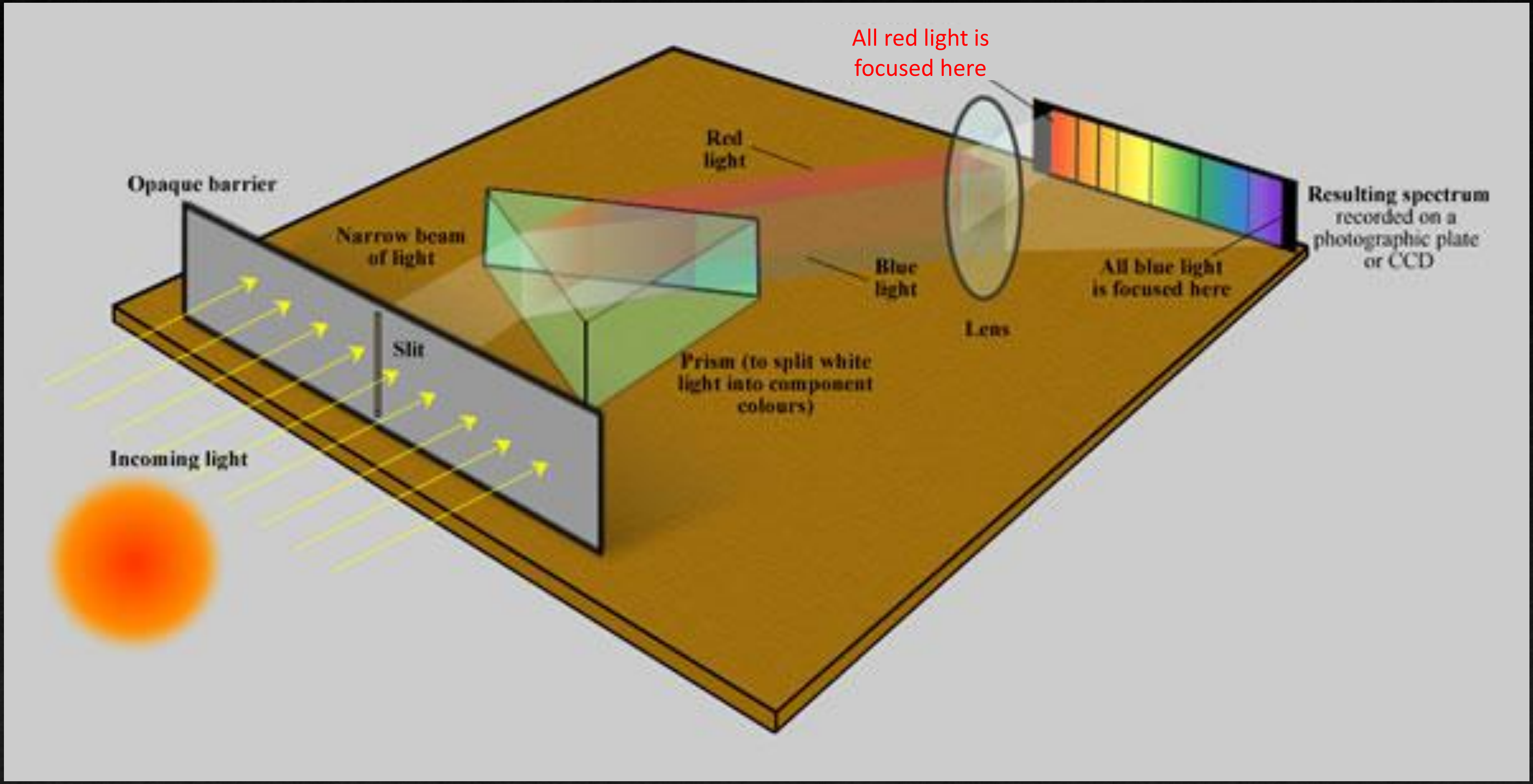
The Bohr Model of the Atom

E = energy
h = Plank's Constant
c = speed of light
r = Bohr radius
m = mass
λ = wavelength
υ = frequency
n = refractive index

$$v = \frac{c}{n(\lambda_0)},$$

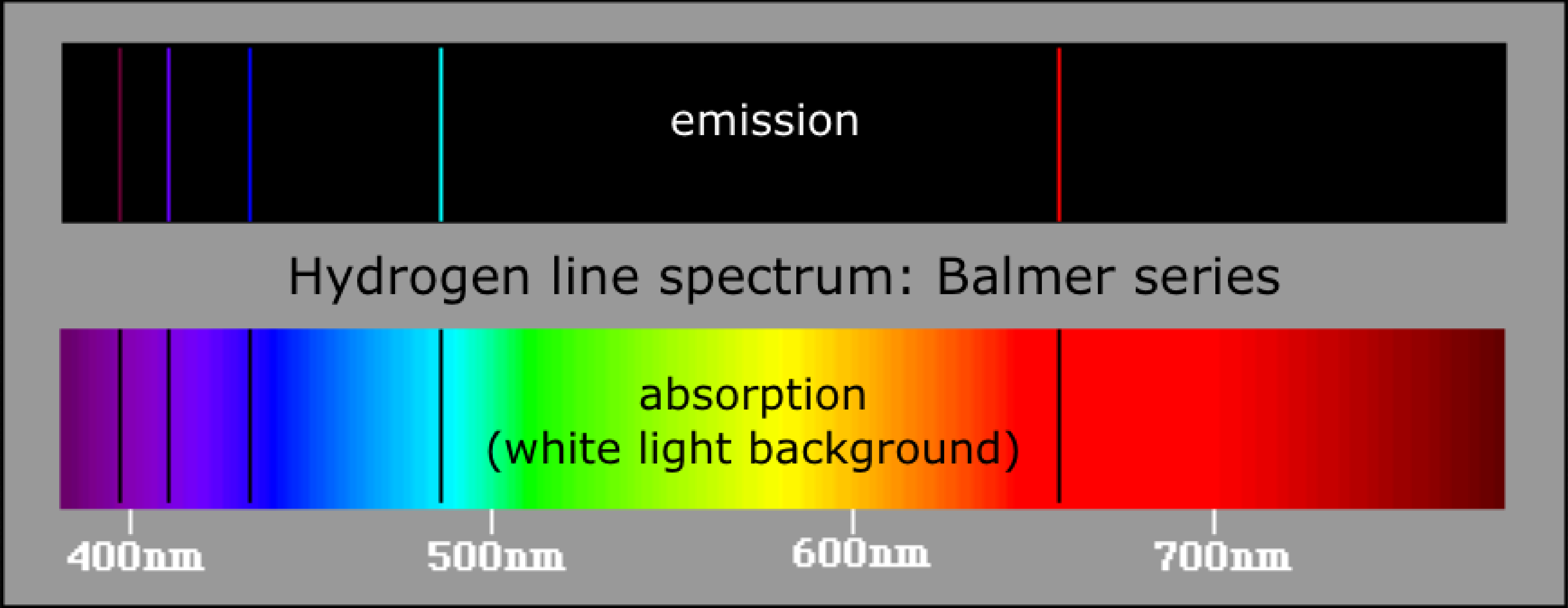


Prism Spectroscope



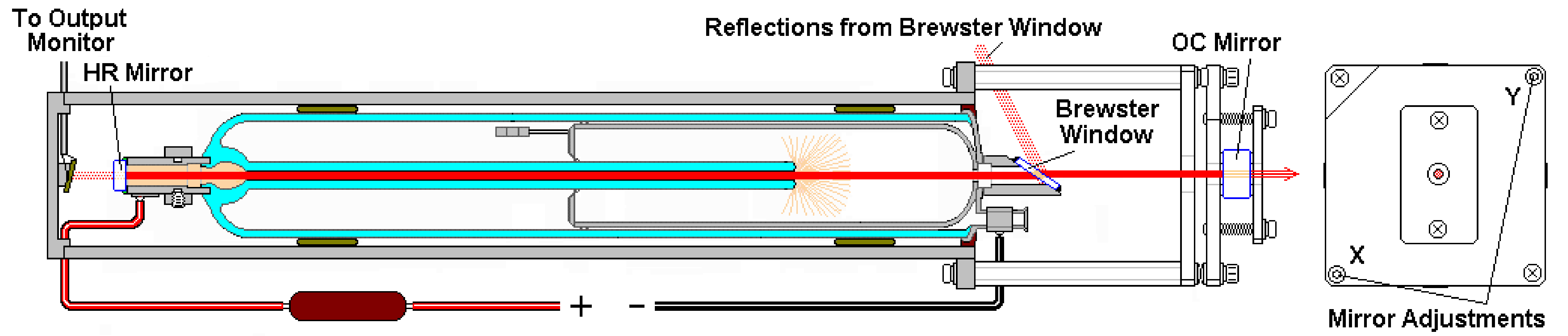
A spectrograph separates light into its constituent wavelengths. The spectroscopy of optical light produces the familiar rainbow.

Emission & Absorption Spectra



Emission and absorption spectra of the Balmer series of hydrogen

Various light sources and detectors

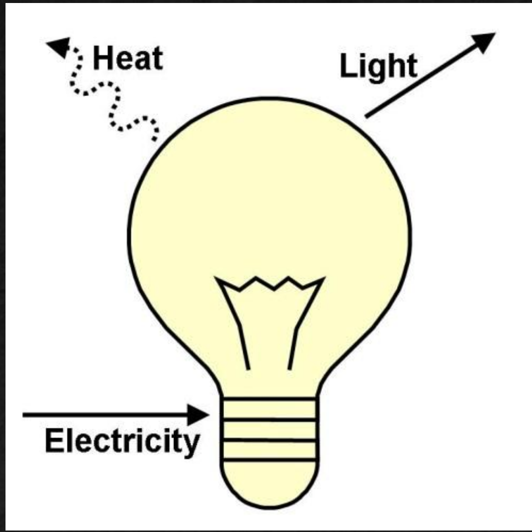


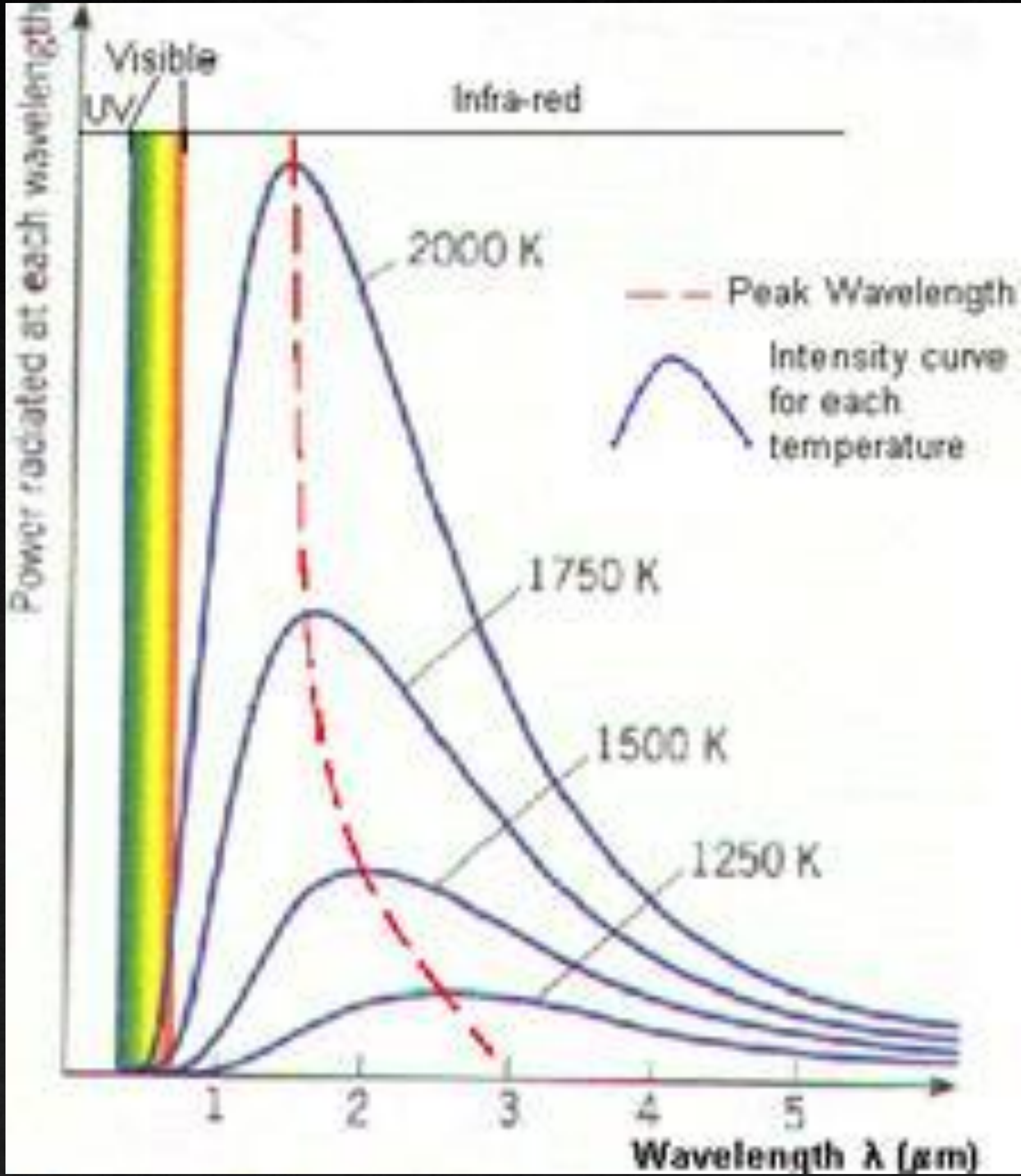
HeNe Laser Tube with Internal HR and Brewster Window with External OC

Detectors –photoelectric effect

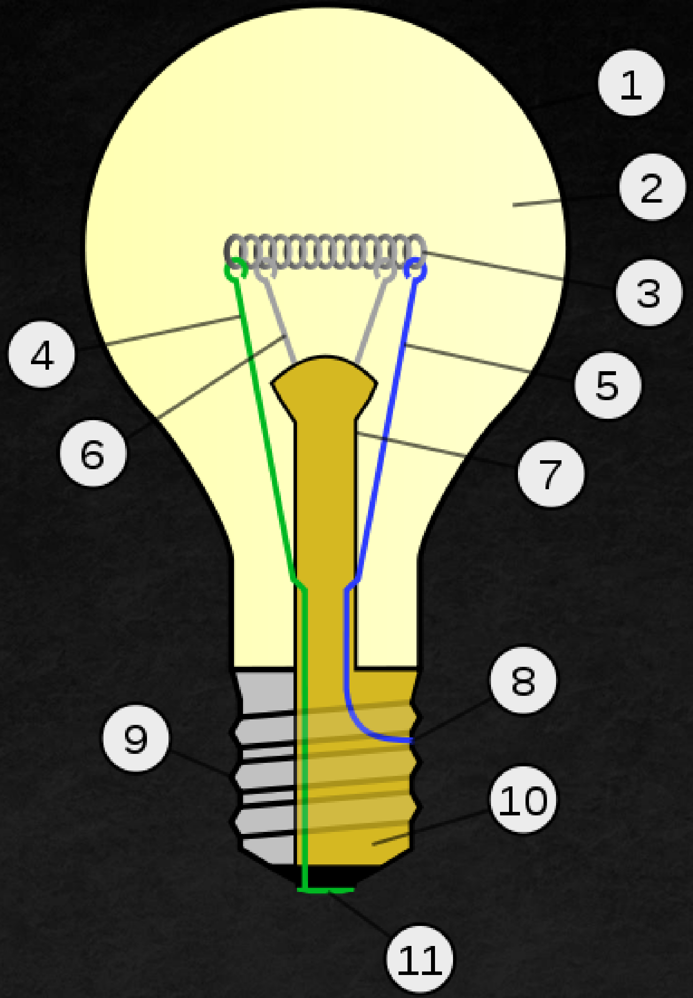
Thermal (incandescent) sources

Blackbody Radiators





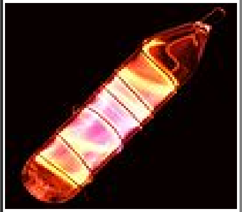
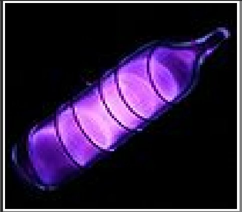
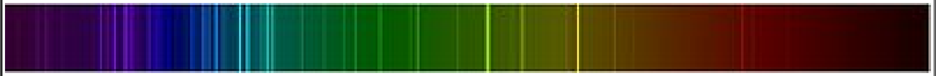
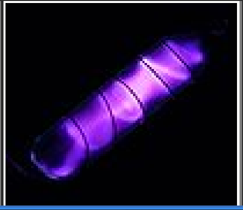
Tungsten Lamps



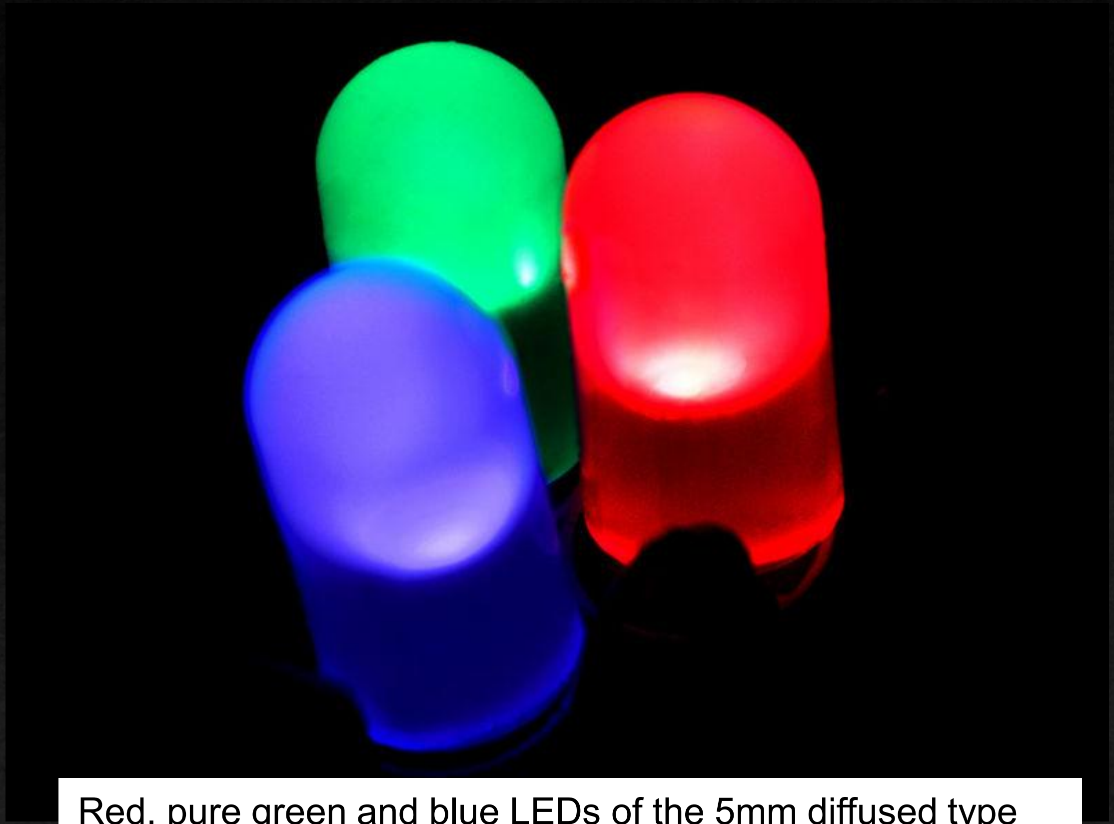
1. Outline of Glass bulb
2. Low pressure inert gas (argon, nitrogen, krypton, xenon)
3. Tungsten filament
4. Contact wire (goes out of stem)
5. Contact wire (goes into stem)
6. Support wires (one end embedded in stem; conduct no current)
7. Stem (glass mount)
8. Contact wire (goes out of stem)
9. Cap (sleeve)
10. Insulation (vitrite)
11. Electrical contact

Gas Discharge Lamps

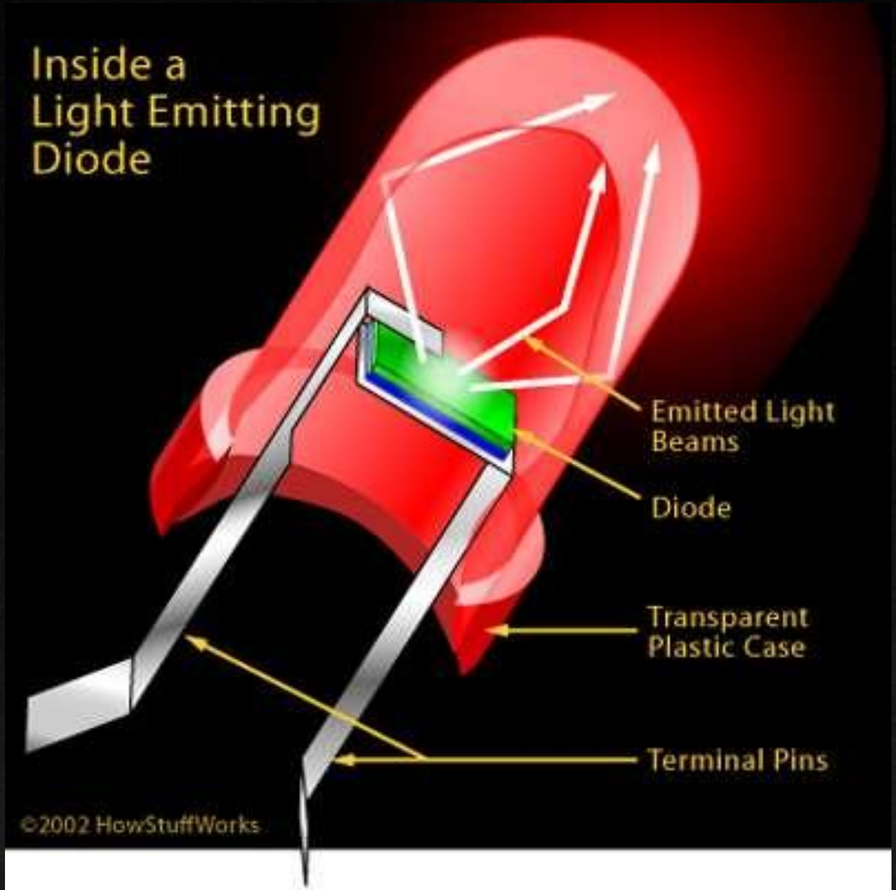
Germicidal lamps are simple low pressure mercury vapor discharges in a fused quartz envelope.

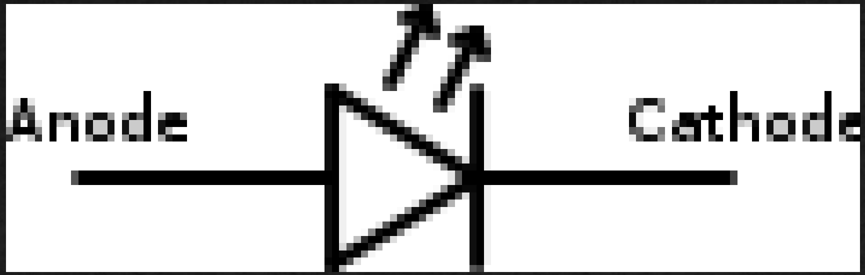
Gas	Color	Spectrum	Notes	Image
Helium	White to orange; under some conditions may be gray, blue, or green-blue.		Used by artists for special purpose lighting.	
Neon	Red-orange		Intense light. Used frequently in neon signs and neon lamps.	
Argon	Violet to pale lavender blue		Often used together with mercury vapor.	
Krypton	Gray off-white to green. At high peak currents, bright blue-white.		Used by artists for special purpose lighting.	
Xenon	Gray or blue-gray dim white. At high peak currents, very bright green-blue.		Used in flashbulbs, xenon HID headlamps, and xenon arc lamps.	
Nitrogen	Similar to argon but duller, more pink; at high peak currents bright blue-white.			

Light Emitting Diodes (LEDs)

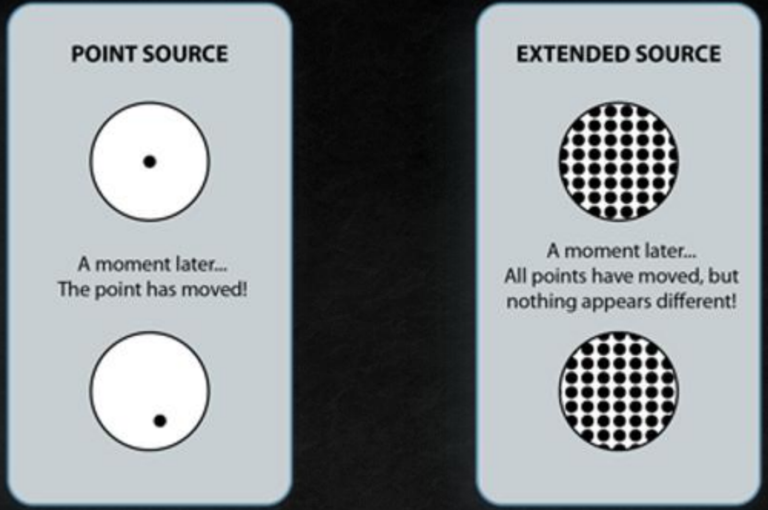


Red, pure green and blue LEDs of the 5mm diffused type





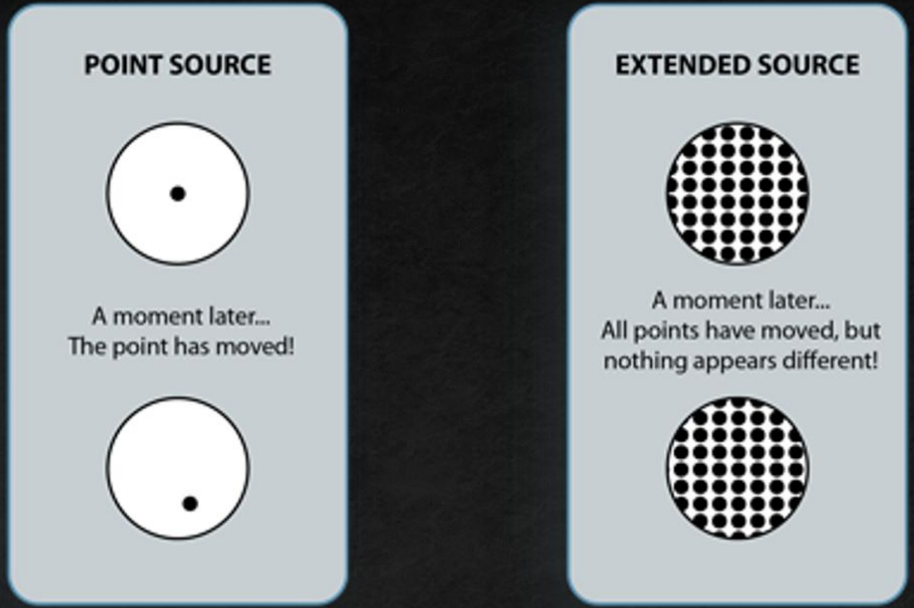
Radiometry & Photometry



Spectroradiometry & Spectrophotometry

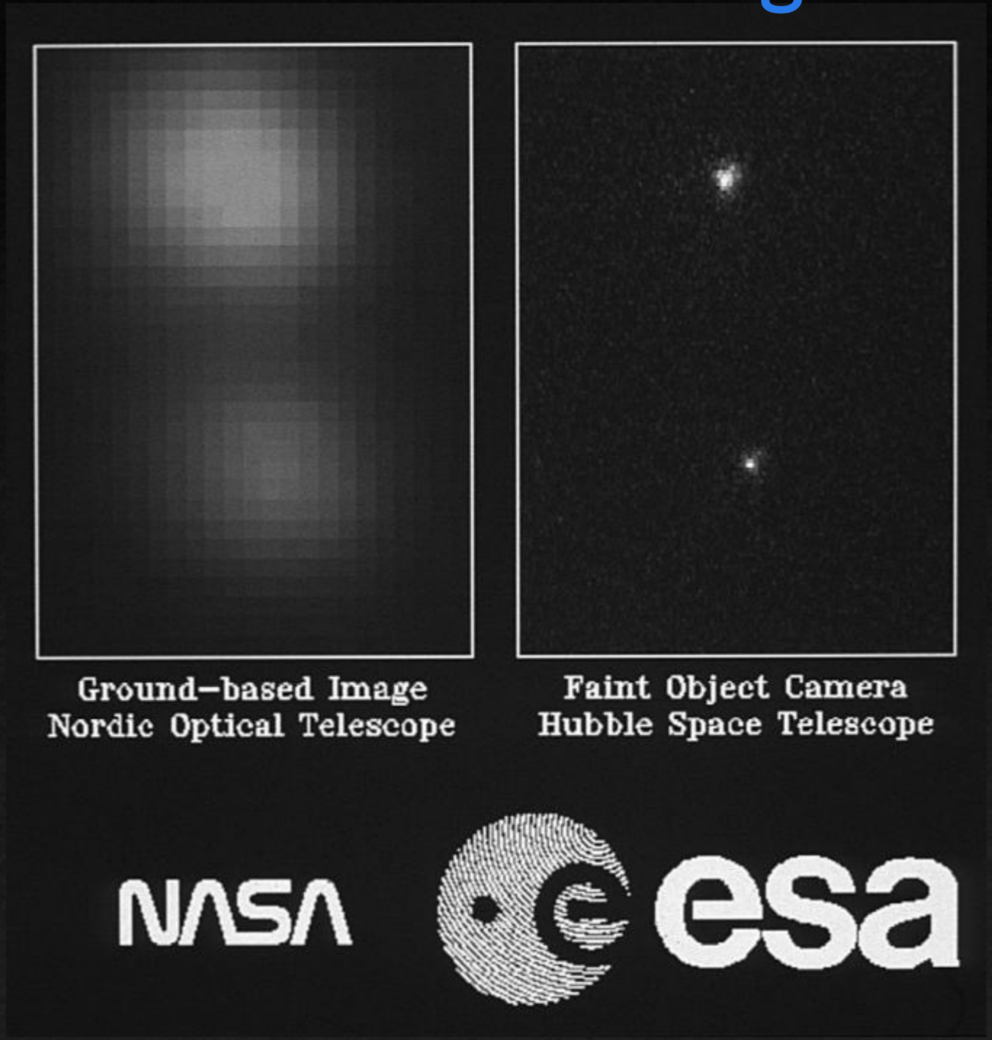
Radiometry & Photometry

Radiometry of point and extended sources



Why do stars twinkle and planets do not?

ESA's Faint Object Camera First Images



The Lambertian BRDF

Bidirectional reflectance distribution function

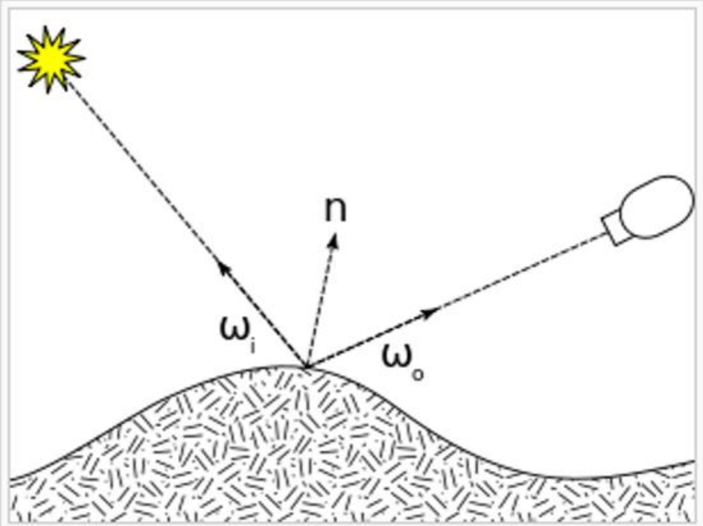
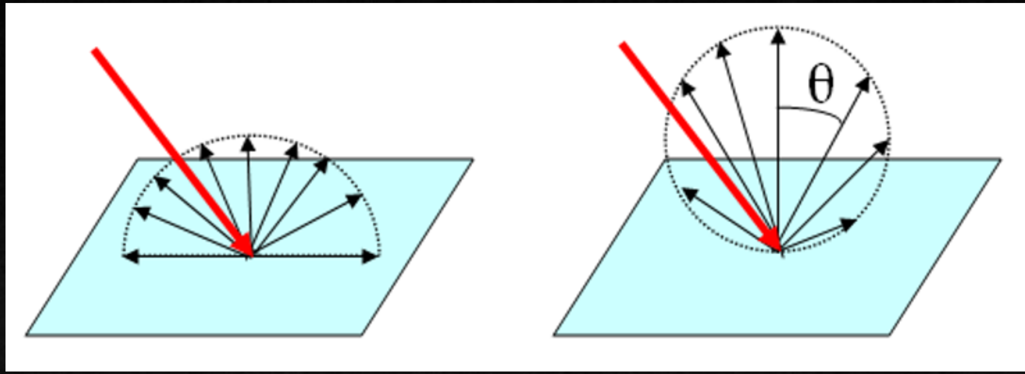


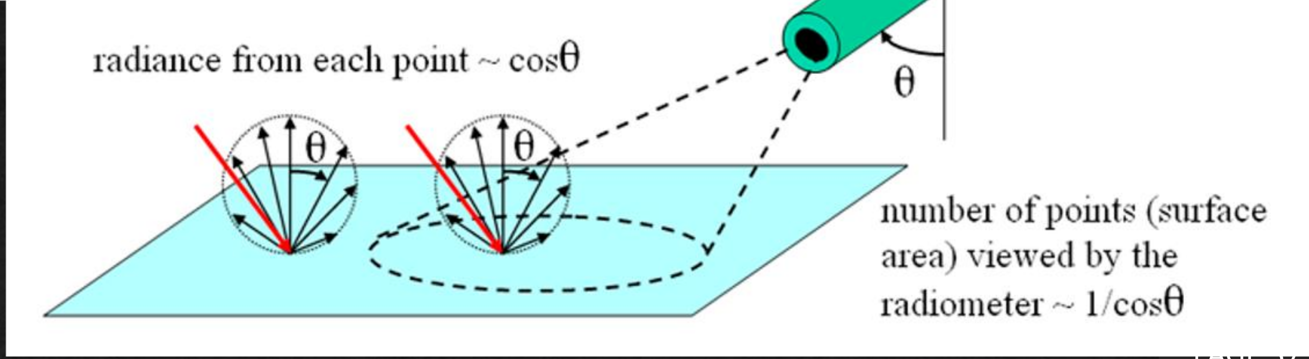
Diagram showing vectors used to define the BRDF. All vectors are unit length. ω_i points toward the light source. ω_o points toward the viewer (camera). n is the surface normal.



The mental images corresponding to the two descriptions of Lambertian surfaces.

$$BRDF_{\mathrm{Lamb}}(\theta_i, \phi_i, \theta_r, \phi_r) = \frac{\rho}{\pi},$$

$$BRDF_{\mathrm{Lamb}}(\theta_i, \phi_i, \theta_r, \phi_r) = \frac{\rho}{\pi},$$

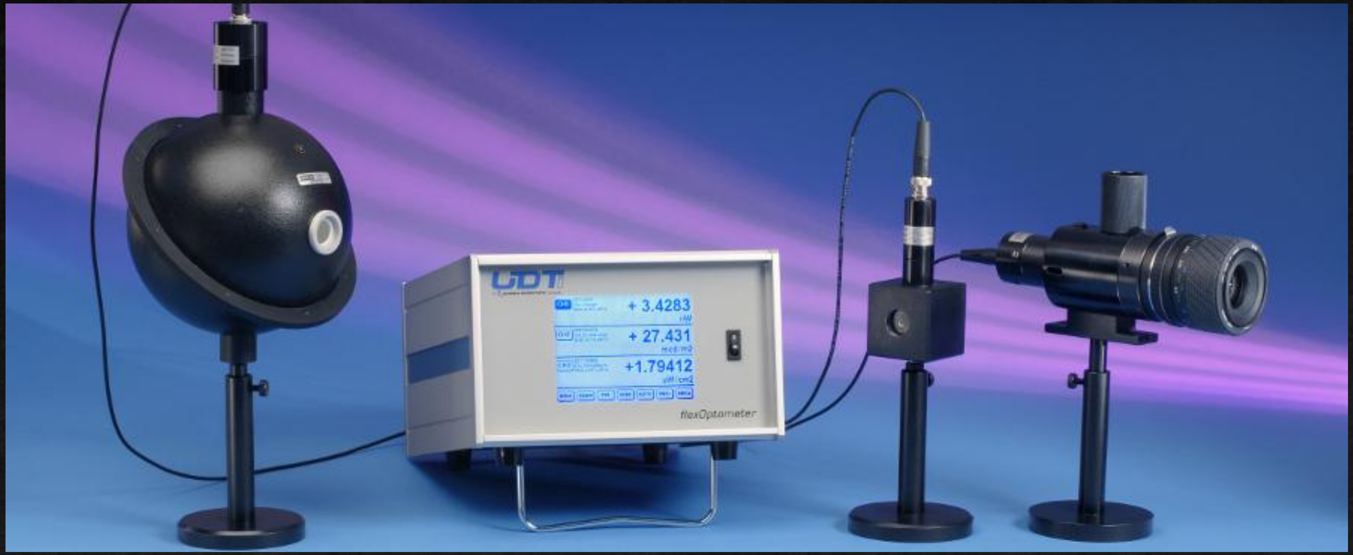


Crookes Radiometer

Radiometer. The Crookes radiometer, also known as the **light mill** or solar engine, consists of an airtight glass bulb, containing a partial vacuum. Inside are a set of vanes which are mounted on a spindle. The vanes rotate when exposed to light. The reason for the rotation has been the cause of much scientific debate.

Radiometry & Photometry

GAMMA SCIENTIFIC
Light Measurement Solutions



FlexOptometer Radiometer/Photometer

APPLICATIONS

- *Display Measurements*
- *LED Measurements*
- *Fiber-optic Measurements*
- *Laser Power Measurements*
- *Strobe & Signal Measurements*
- *Lamp Measurements*
- *Night-Vision Testing*
- *Customized optics for any application*

flexOpometer

Electronic	Integrator
Eight Photometric/Radiometric Ranges	Four Integrate Ranges
Range-to-Range Linearity <0.1% for most ranges (<0.25% for most sensitive range)	Range-to-Range Linearity <0.1% for most ranges (<0.25% for most sensitive range)
Sensitivity: 10^{-15} to 10^{-3} Amps	Sensitivity: 10^{-14} to 10^{-3} coulomb
Resolution: 1×10^{-15} Amps	Decay Error: analog-approx. 0.01% / sec
Dark Current Suppression: 50 nA Max	Digital-holds reading indefinitely
Noise: $<3\times10^{-15}$ Amps	
Frequency Roll-off: <10 Hz on most sensitive range	
A-to-D converter: 24-bit for each decade	

Radiometric/Photometric Ranges

Radiometric Units*	Range	Detector Configuration (see descriptions below)
Irradiance	0.000001 nanoWatts/cm² to 1000 microWatts/cm²	24600 or 24610 with 24960
Radiant Energy	0.00001 nanoJoules/cm² to 1 microJoules/cm²	24600 or 24610 with 24960
Radiance	0.00001 nanoWatts/cm²/steradian to 10 milliWatts/cm²/steradian	24600 or 24610 with 24960 and 54694
Photometric Units*		
Luminous Intensity	0.00001 mcandelas to 10000 candelas	24600 or 24610 with 24973-x
Illuminance	0.00001 milliLux to 10000 Lux	24600 or 24610 with 24606-x
Luminance	0.0001 millicandela/m² to 100000 candela/m²	24600 or 24610 with 24606-x and 54694
Illuminant Energy	0.00001 milliLux*seconds to 10 Lux*seconds	24600 or 24610 with 24973-x or 24606-x

*Ranges based on system configured with a 1 square centimeter silicon detector and corresponding accessories

Detectors & Accessories

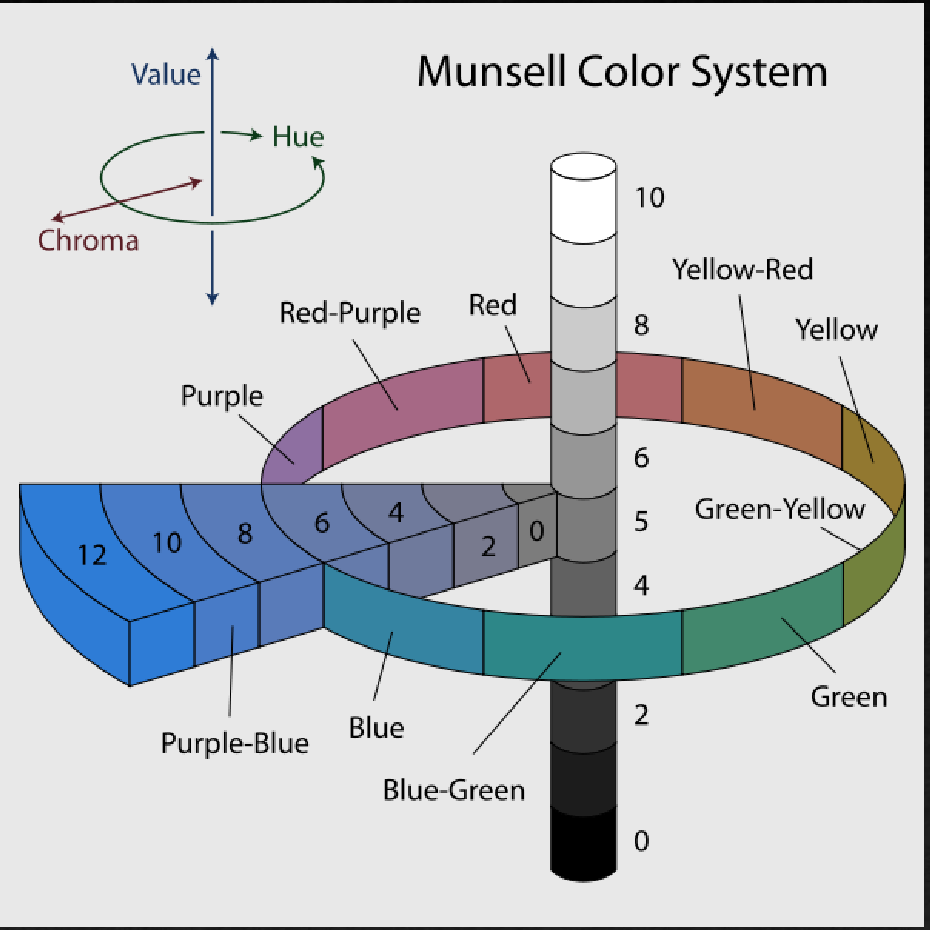
UV/Visible/near-IR		Filters	
24600	Silicon Detector (200-1100nm) 1cm² active area with rear-mounted BNC connector.	24606-x	Photometric Filter for 24600 and 24610
		24742-x	Photometric Cosine Receptor for 24600 and 24610
24610	Silicon Detector (200-1100nm) 1 cm² active area with side-mounted BNC connector.	24973-x	CIE127 Photometric Receptor for 24600 and 24610
		D-46-01	Photopic Correction Filter for D-46DQ
D-46DQ	Photomultiplier Detector (200-930 nm)	D-46-02	Scotopic Correction Filter for D-49DQ
D-49DQ	Photomultiplier Detector (200-1000 nm)	D-49-01	Photopic Correction Filter for D-46DQ
Infrared		D-49-02	Scotopic Correction Filter for D-49DQ
DR-2550-2I	InGaAs Detector (800-1800nm), 3mm² active area.	24642-1	Cosine Receptor, Flat Response for 24600 and 24610
D-100-2G	Germanium Detector (800-1800nm), 1.5mm² active area.	24659	CIE127 Flat Response for 24600 and 24610
D-100-2I	InGaAs Detector Head (800-1800nm), 3mm² active area.	24960	Flat Response Filter for 24600 and 24610
DC-200I	Cooled InGaAs Detector 3mm active area.	**Accessories**	
DC-200G	Cooled Germanium Detector 3mm active area.	54694	8.5° Field-of-view Lens for 24600 and 24610
		550-17-x	Neutral density filters 200-2000 nm (choose density)
		24792-1	Basic LED measurement tube (CIE127 Condition B)
		40044	Precision LED Alignment System (CIE127 Conditions A & B)

UNITS OF MEASURE MATTER

General

General
Automatic/Manual ranging
Microprocessor Controlled Functions
High Voltage circuit for photomultipliers (300-1500 Volts)
Thermo-electric coolers for detector and filter stabilization

Measuring color

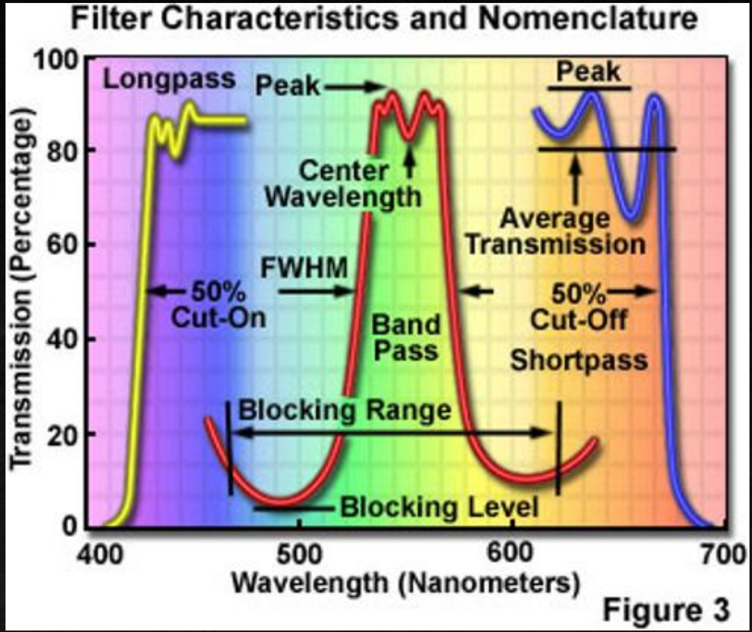


The Munsell color system, showing: a circle of hues at value 5 chroma 6; the neutral values from 0 to 10; and the chromas of purple-blue (5PB) at value 5

The VeriColor Spectro from X-Rite is a High spectral resolution—true 31-band spectrophotometer which provides absolute color data across the visible spectrum at 10 nm intervals

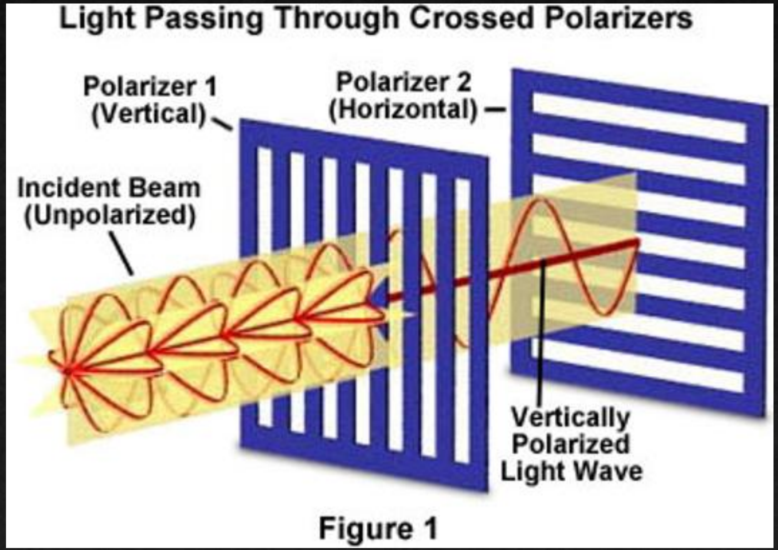
Optical Materials: interaction of light with matter.

Dispersion, spectrometers and refractometers



Transmission & absorption of optical materials

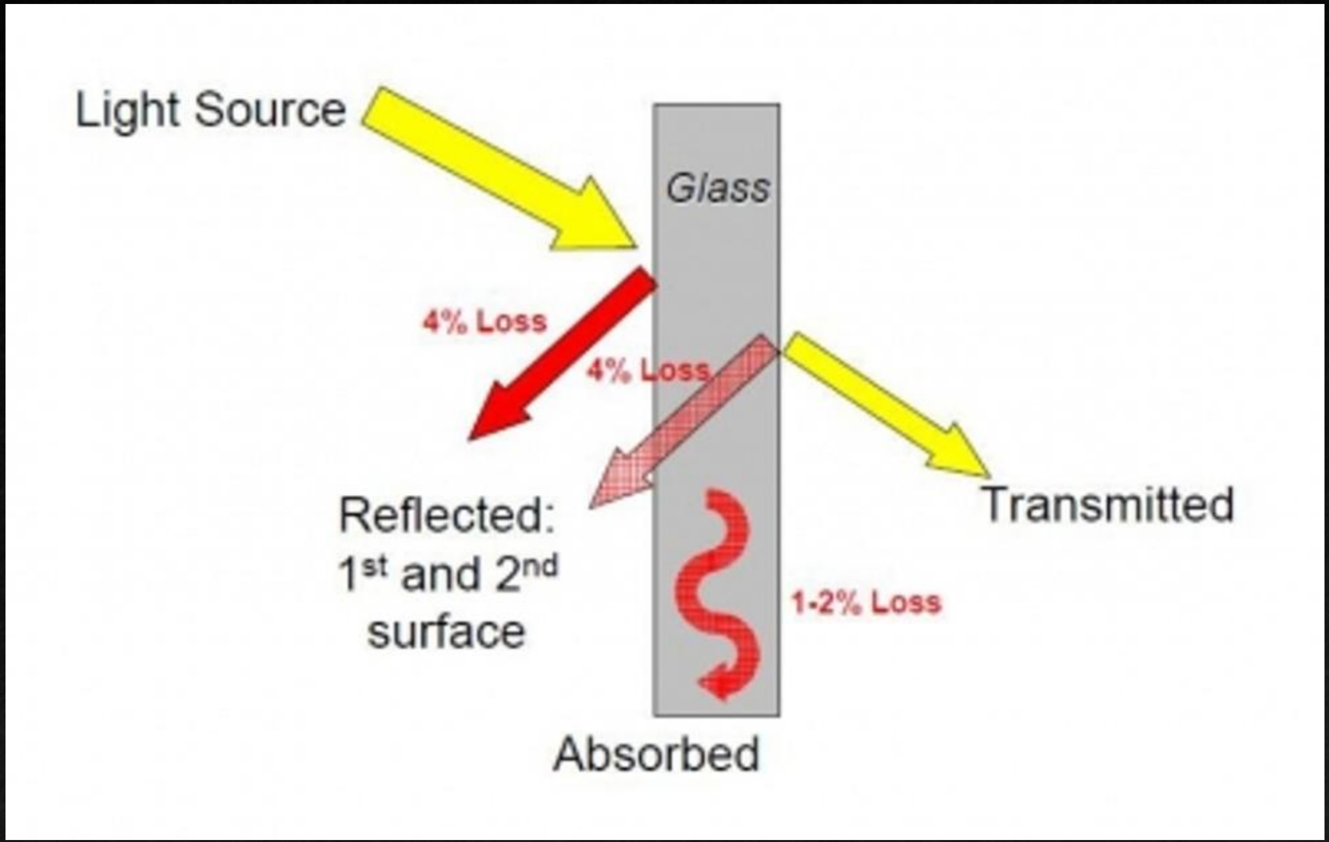
Practical filters, photochromic & inhomogeneous optical materials

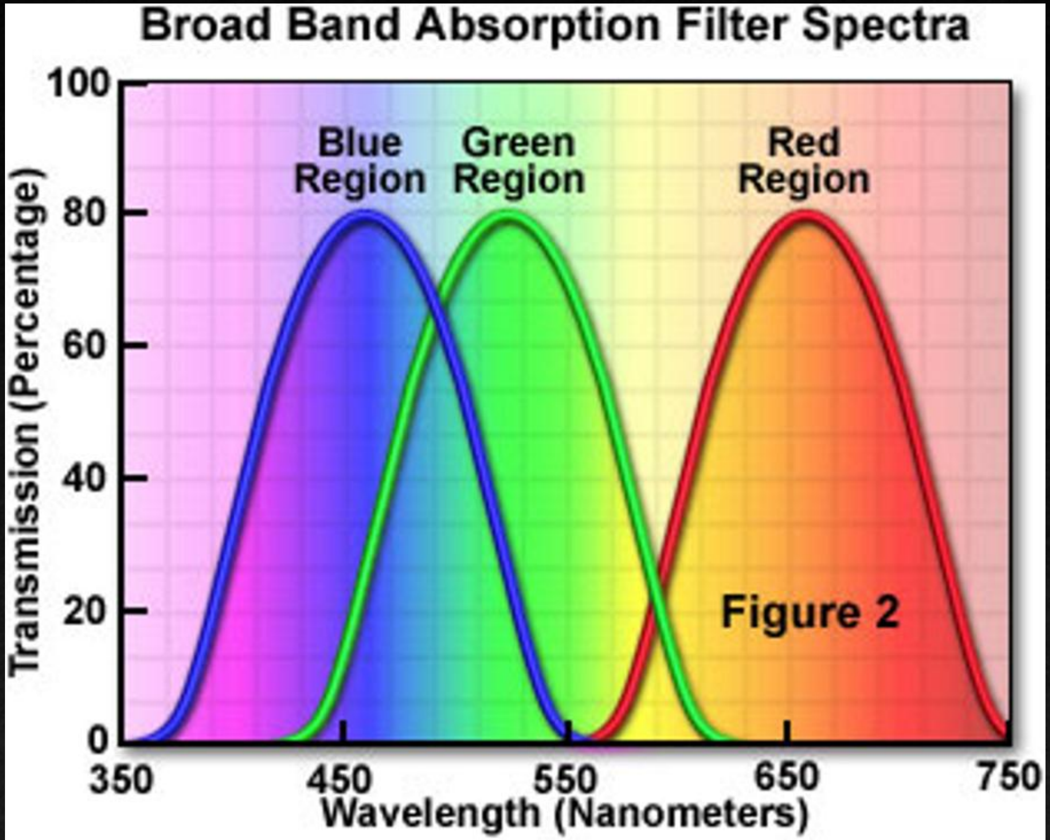


Polarization, scattering, reflections, definitions and applications

Optical Materials

Transmission, Reflection & Absorption of Optical Materials

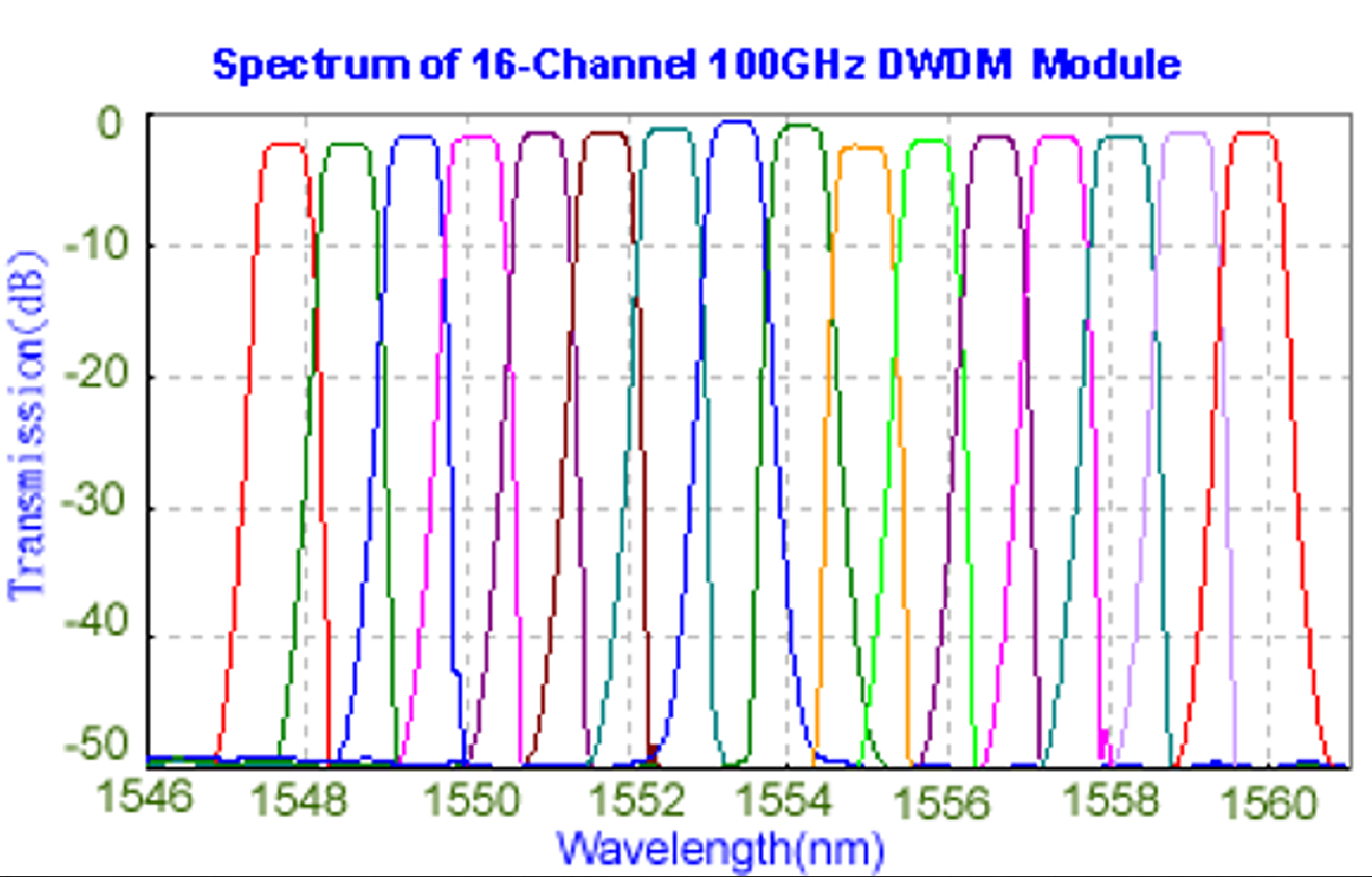




Use of Anti-Reflective Glass in Commercial Lighting Products

Explore how absorption filters, commonly made from dyed glass, polymers, or pigmented gelatin, operate by passing certain wavelengths of light while blocking others.

Dense Wavelength Division Multiplex



DWDM

Commercial DWDM

DESCRIPTION

Browave dense wavelength division multiplexer (DWDM) is based on thin film filter technology and high-reliability micro optics packaging. Browave provides high quality DWDM with flat channel bandwidth, flexible channel configuration, low insertion loss and high isolation. It is designed to upgrade capacity easily as the system grows. All Browave products are epoxy-free in the optical path and are used in high-power applications in DWDM systems.

FEATURES

- Telcordia GR-1221 and GR-1209 Compliance
- High Channel Isolation
- Low Insertion Loss
- Epoxy-Free Optical Path
- Customized Specifications Available

APPLICATIONS

- Dense WDM System
- Longhaul/Metro Communication Networks
- Fiber Amplifier System
- Fiber Optic Instruments

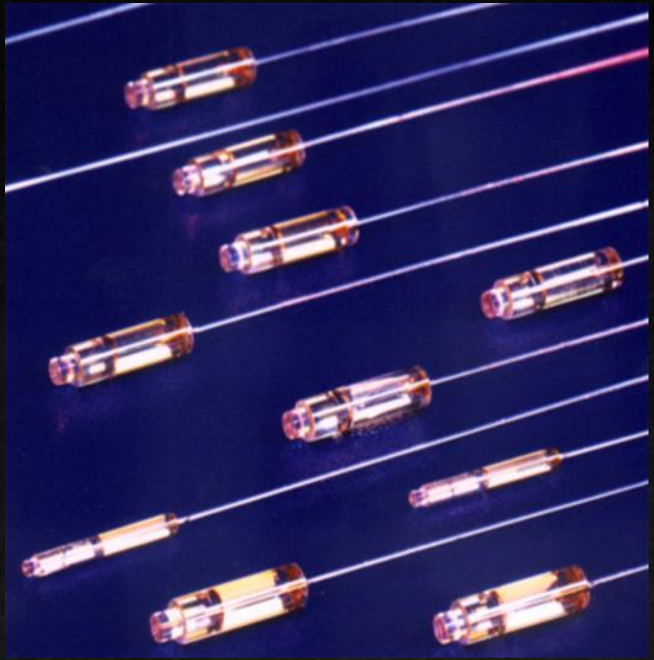
SPECIFICATIONS

Parameter	MUX	DEMUX	MUX	DEMUX
Operating Wavelength	C & L Bands			
Channel Spacing	100 GHz		200 GHz	
Channel Passband	ITU ± 0.11 nm		ITU ± 0.25 nm	
Maximum Insertion Loss (with connectors)	3.7 dB	4.0 dB	3.4 dB	3.7 dB
Minimum Adjacent Channel Isolation	12 dB	25 dB	12 dB	30 dB
Minimum Non-adjacent Channel Isolation	12 dB	40 dB	12 dB	40 dB
Minimum Directivity	50 dB	60 dB	50 dB	60 dB
Minimum Return Loss	45 dB			
Maximum Thermal Dependent Loss(relative to 23℃)	±0.25 dB			
Maximum Polarization Dependent Loss	0.15 dB		0.10 dB	
Maximum Polarization Mode Dispersion	0.20 ps		0.10 ps	
Maximum Channel Uniformity	1.5 dB			
Maximum Passband Ripple	0.5 dB			
Minimum Tensile Load	5 N			
Minimum Power Handling	300 mW			
Operating Temperature	-5℃ ~ 70℃			
Storage Temperature	-40℃ ~ 85℃			
Pigtail Type	900 um, 2 mm, 3 mm			
Connector Type	FC, SC, MU, LC			
Package Dimension(L x W x H)	120 x 80 x 14 mm (standard)			

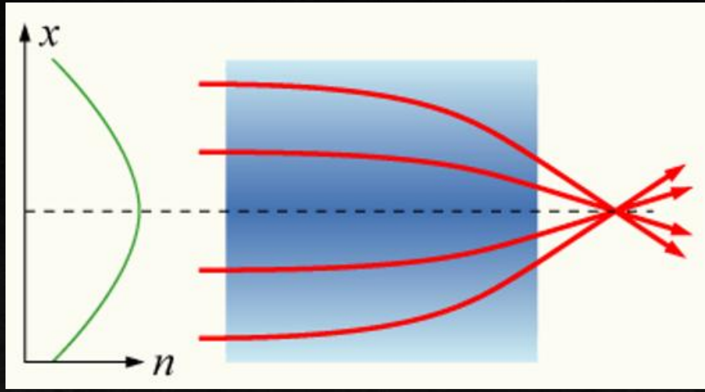
DWDM

Optical Materials

DWDM Optical Filters



GRIN lenses used for
Fiber optic collimators

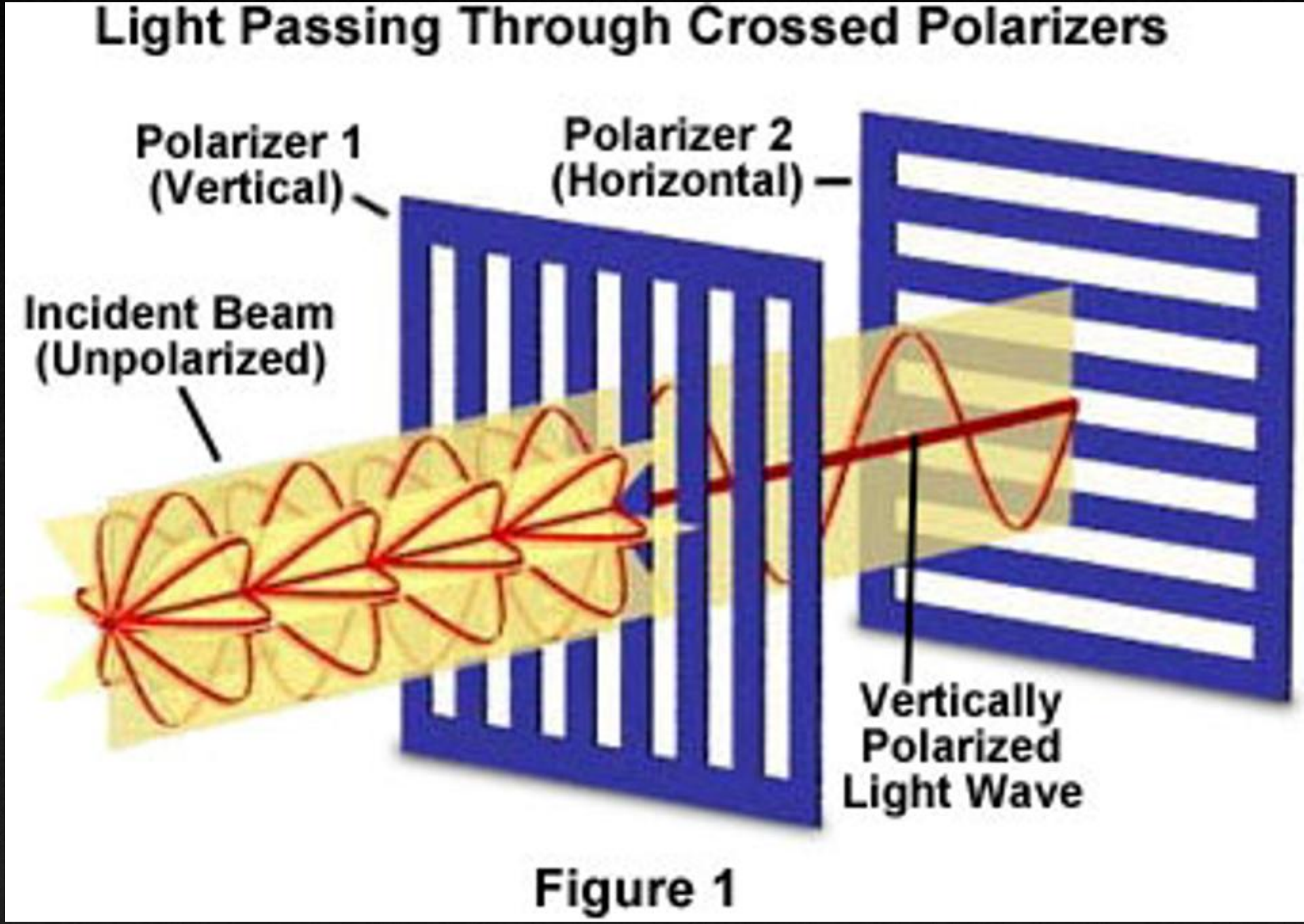


A gradient-index lens with a parabolic variation of refractive index (n) with radial distance (r). The lens focuses light in the same way as a conventional lens.

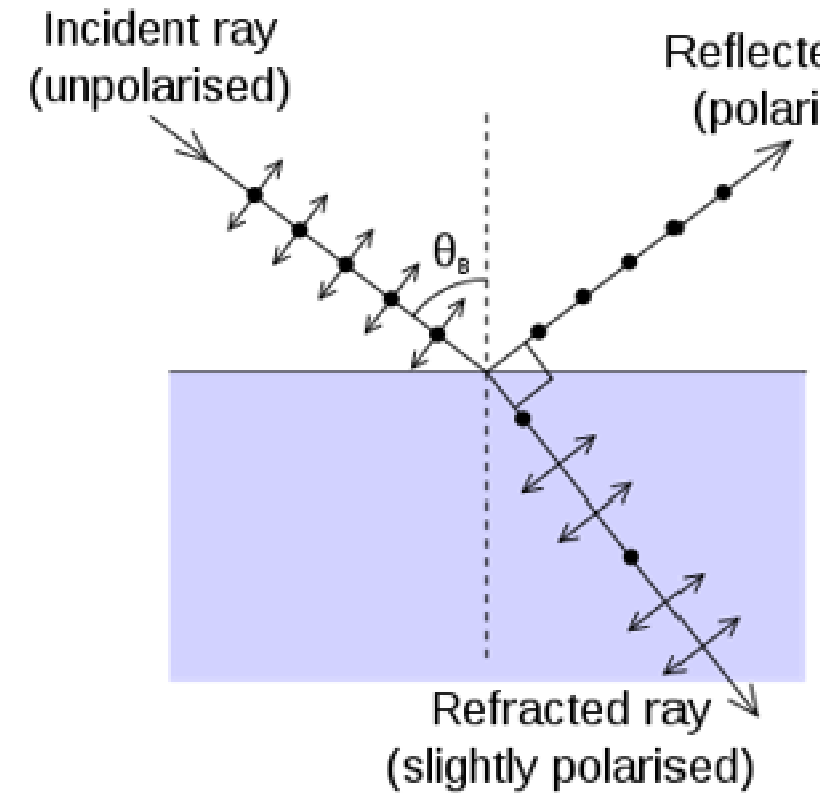
$$n_r = n_o \left(1 - \frac{Ar^2}{2}\right)$$

Lot of 144 pcs DWDM Filters WDM 200GHz
Made by Physical Optics Corporation
For sale on ebay

Anisotropic Materials - Polarization



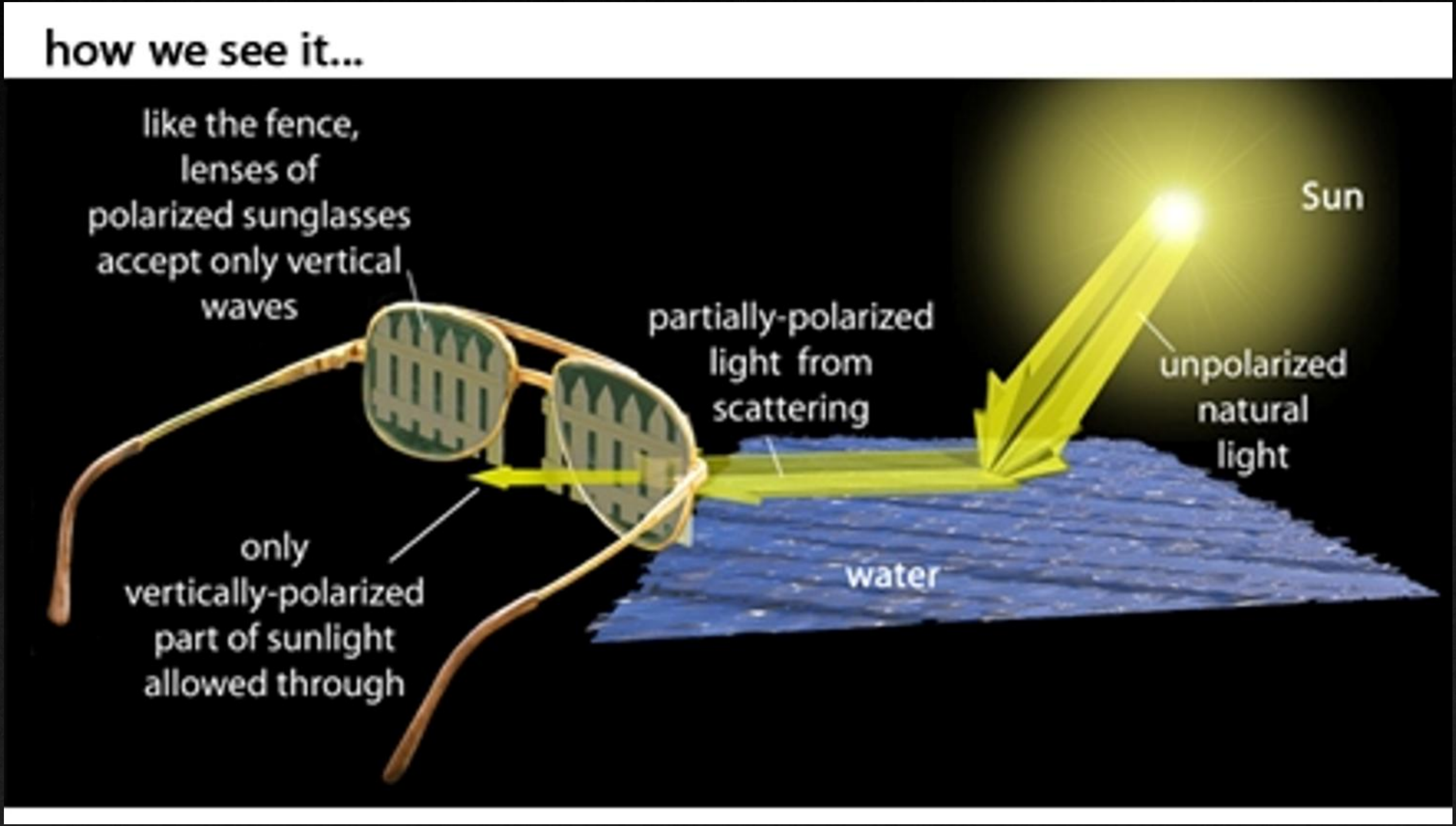
Brewster’s Angle



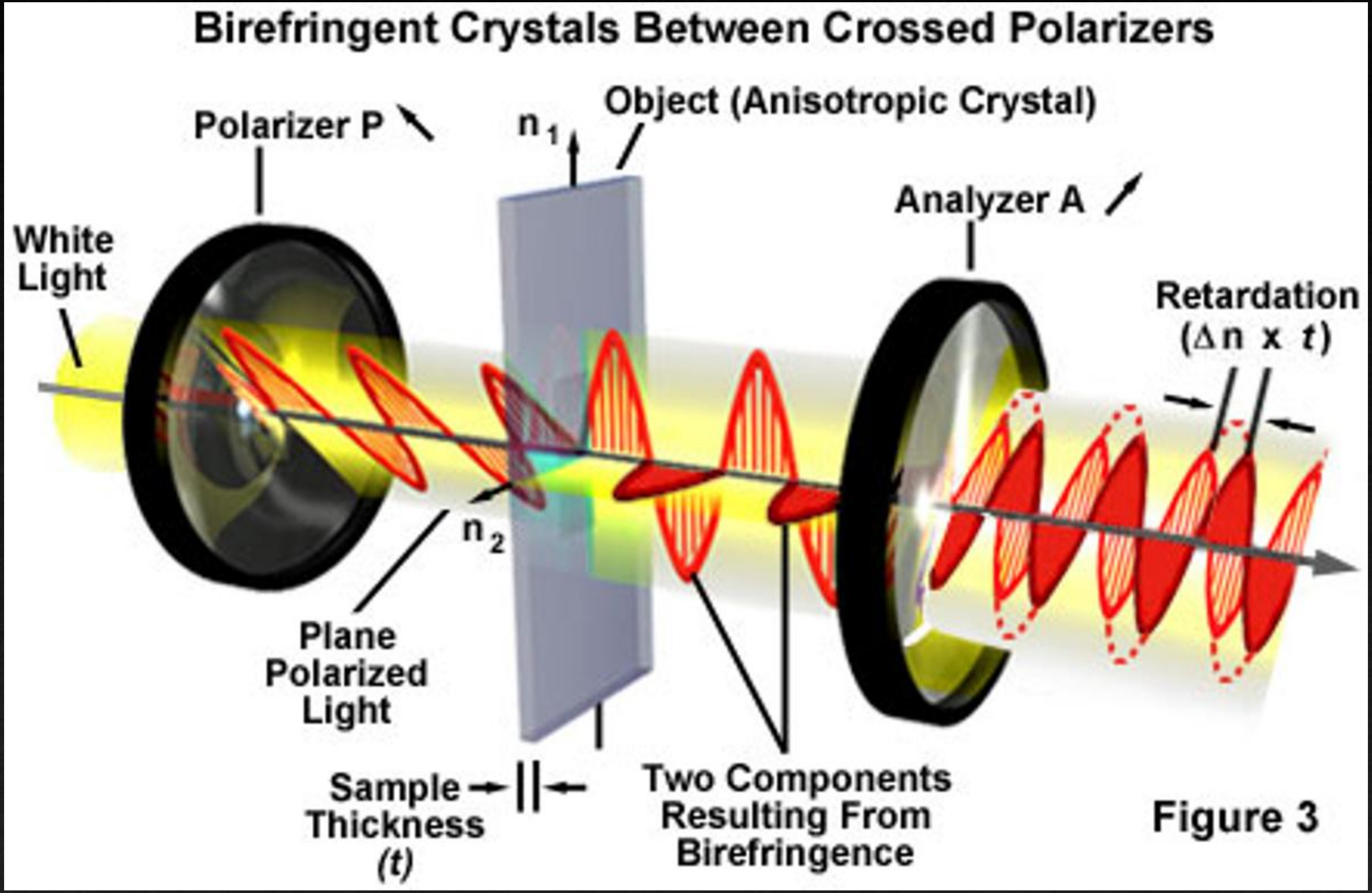
$$\theta_{\mathrm{B}} = \arctan\left(\frac{n_2}{n_1}\right)$$

An illustration of the polarization of light that is incident on an interface at Brewster's angle.

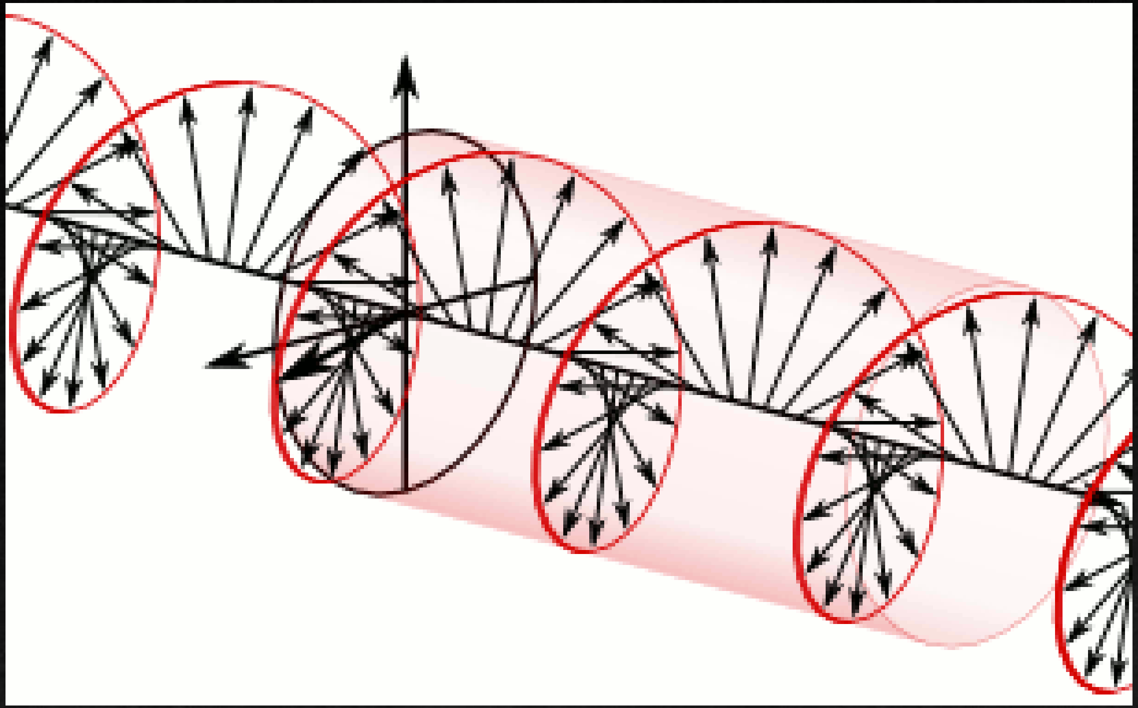
Polarized Light



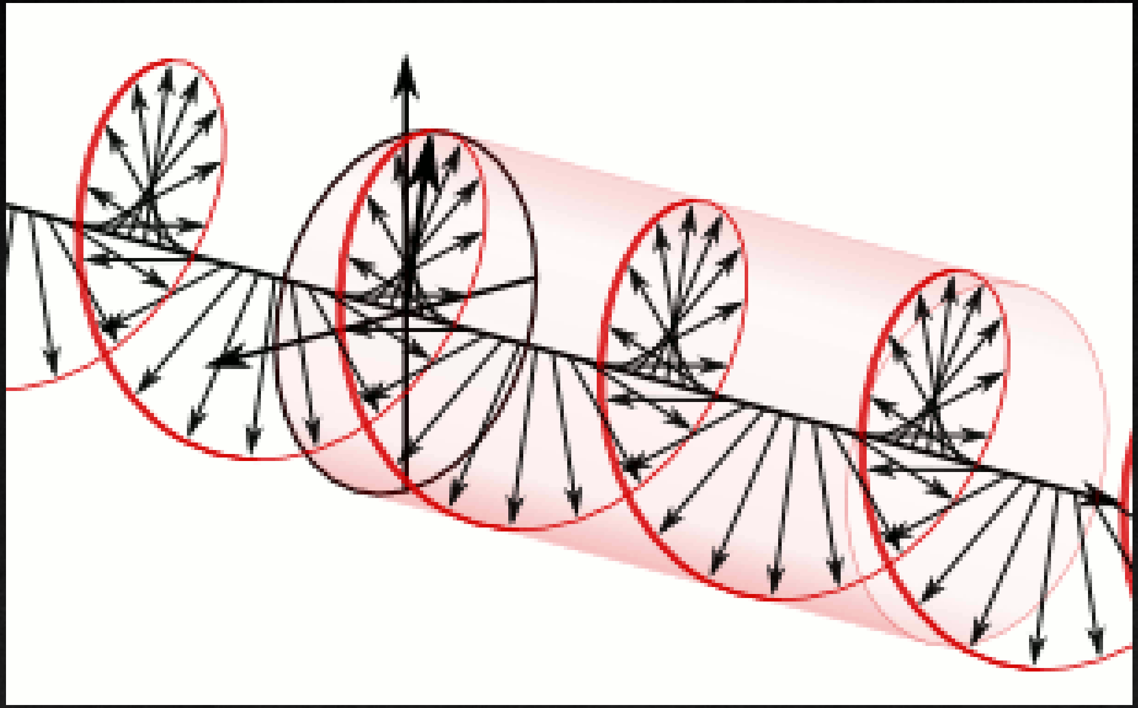
Optical Materials



Right & Left-Handed Polarization



A right-handed/clockwise circularly polarized wave as defined from the point of view of the source. It would be considered left-handed if defined from the point of view of the receiver.



A left-handed/counter-clockwise circularly polarized wave as defined from the point of view of the source. It would be considered right-handed if defined from the point of view of the receiver.

Laser Light Distribution Patterns

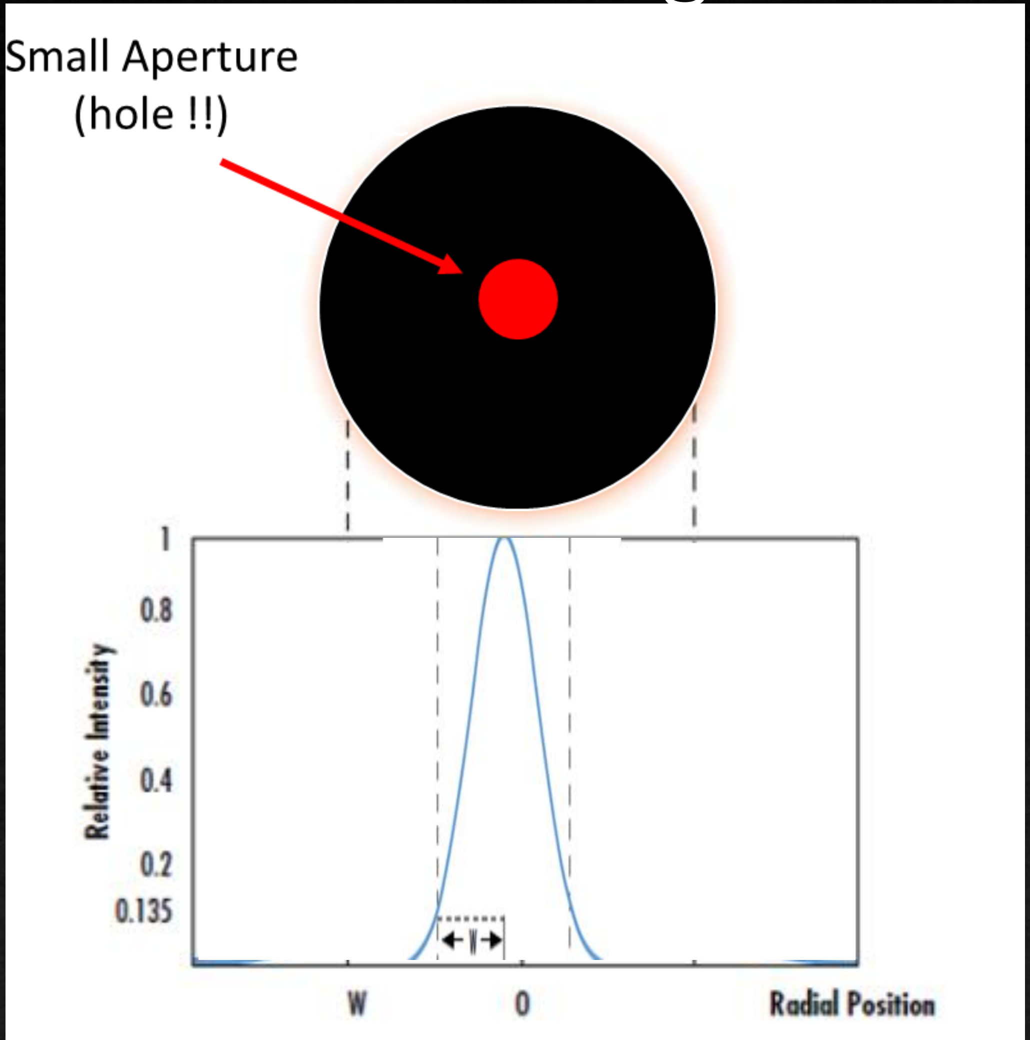
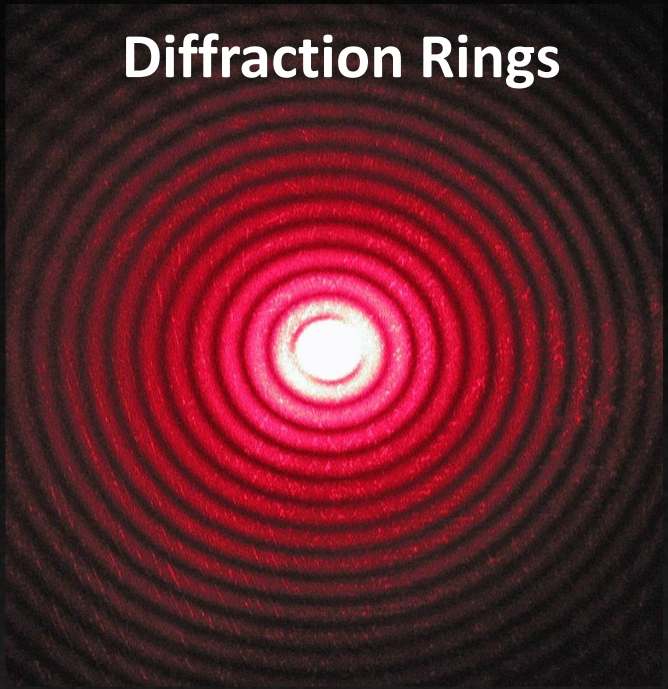


Figure 1: The waist of a Gaussian beam is defined as the location where the irradiance is $1/e^2$ (13.5%) of its maximum value

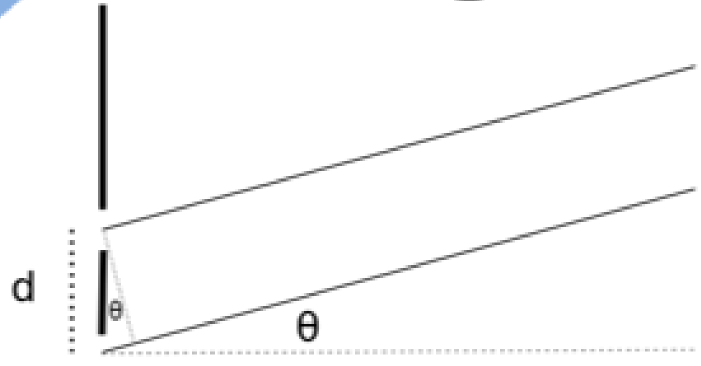
[Gaussian Beam Propagation | Edmund Optics]



A diffraction pattern of a red laser beam projected onto a plate after passing through a small circular aperture in another plate

[Laser Interference - Diffraction - Wikipedia]

Young's Double-slit experiment



$$d \sin\theta \approx d\theta$$

$$d\theta_n = n\lambda, \;\; n = 0, 1, 2, \ldots$$

$$\theta_f \approx \lambda / d$$

$$w = z\theta_f = z\lambda/d$$

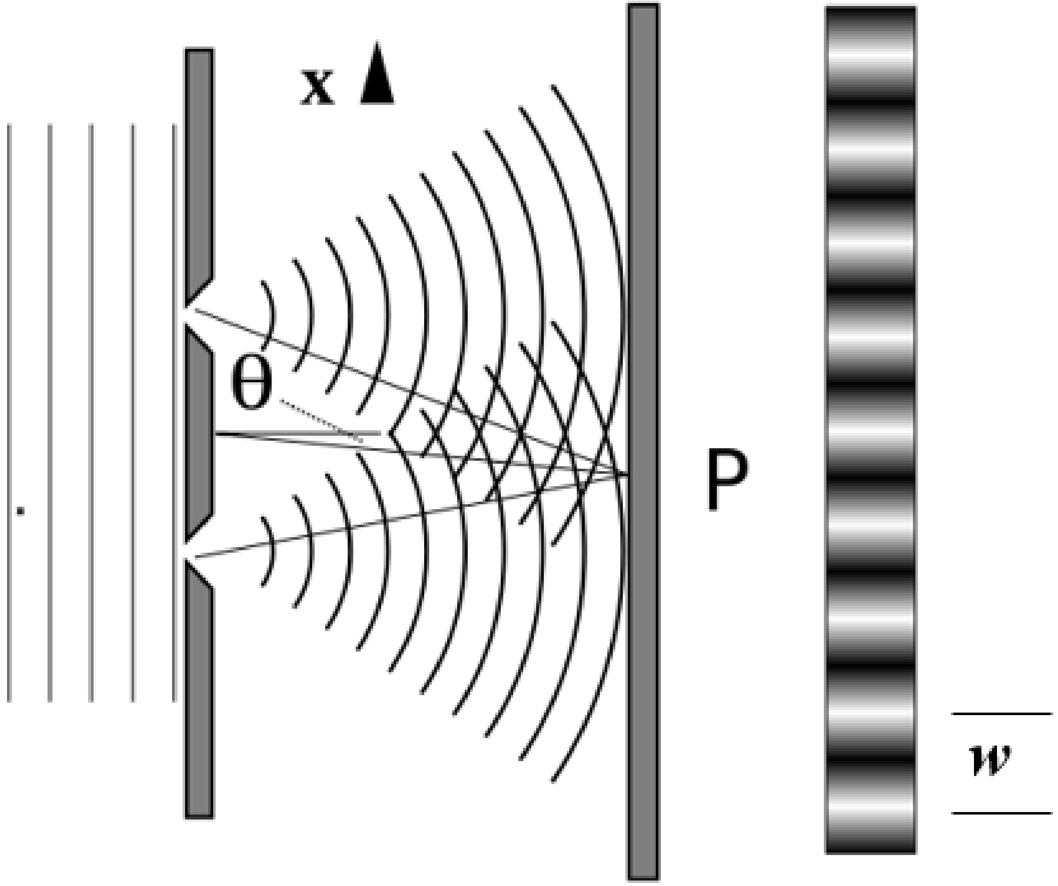
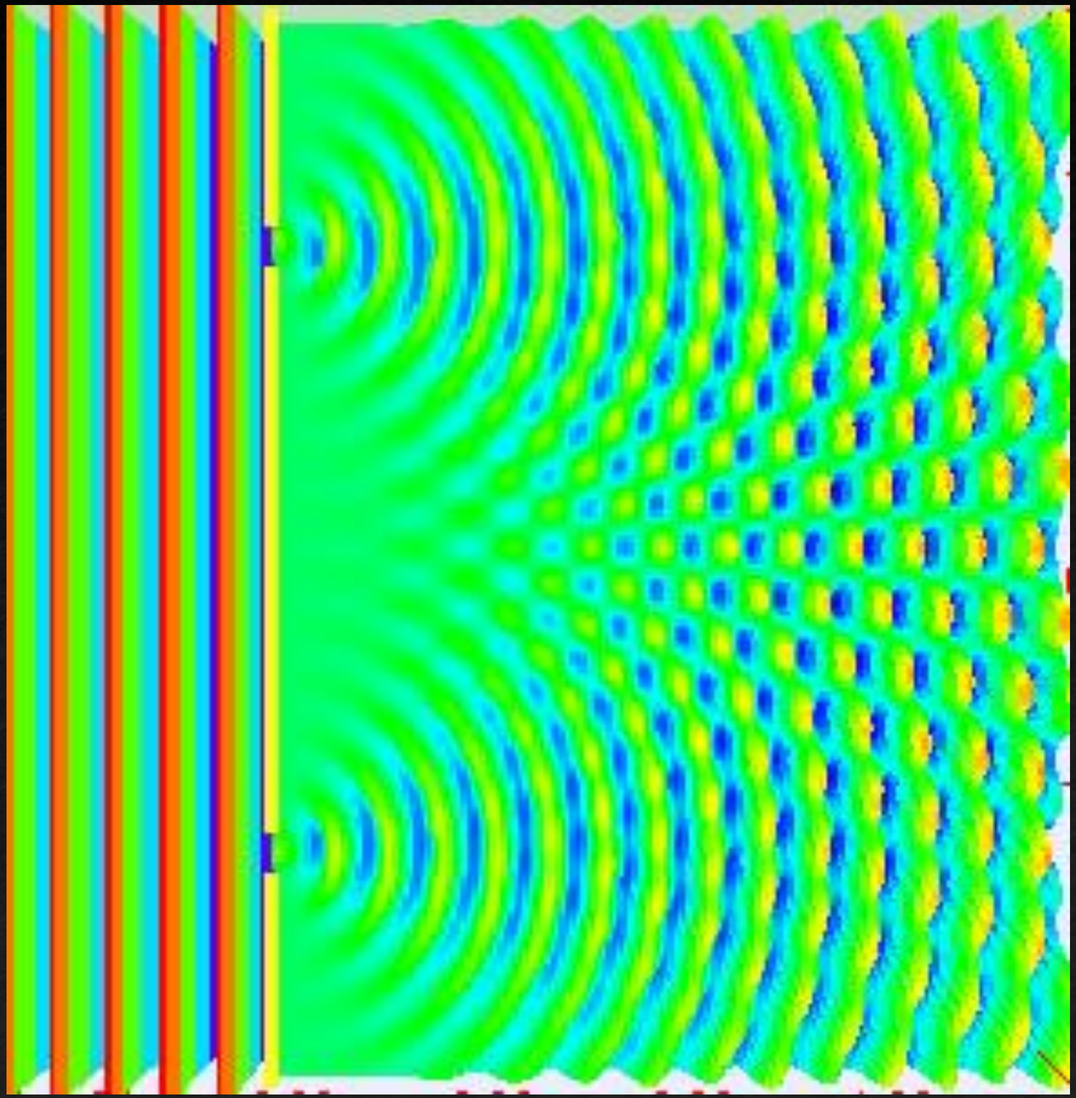
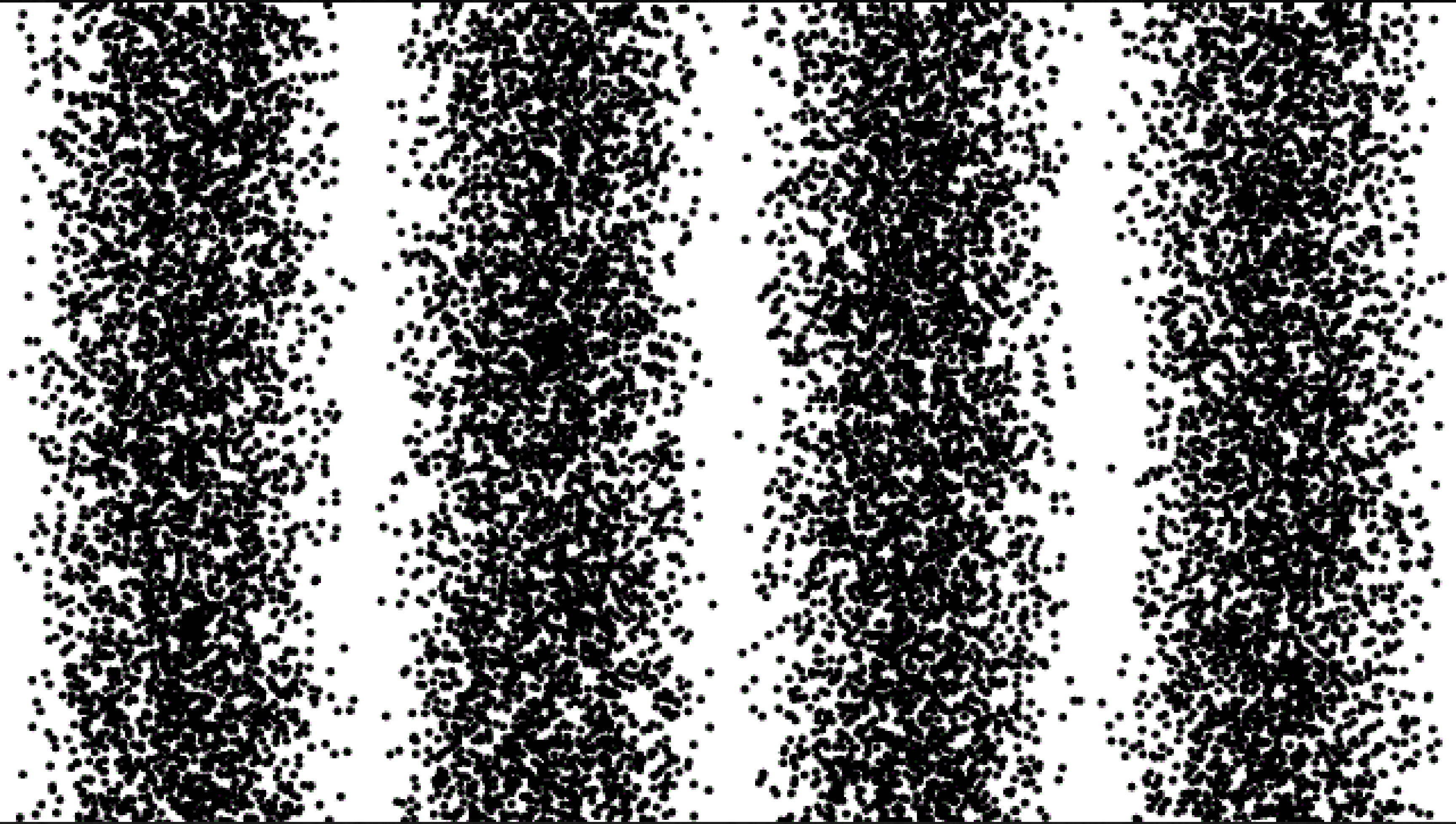


Diagram for the double-slit experiment

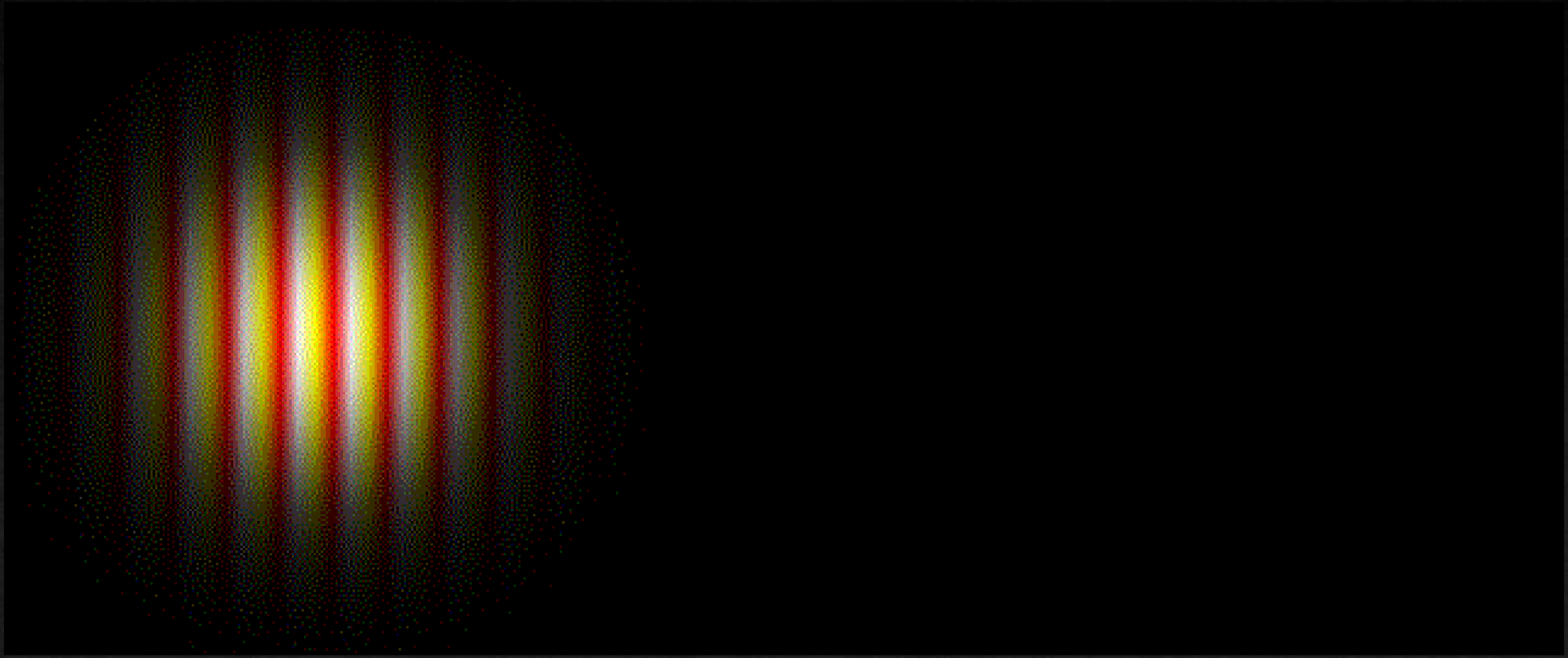
Two slits diffraction pattern by a plane wave



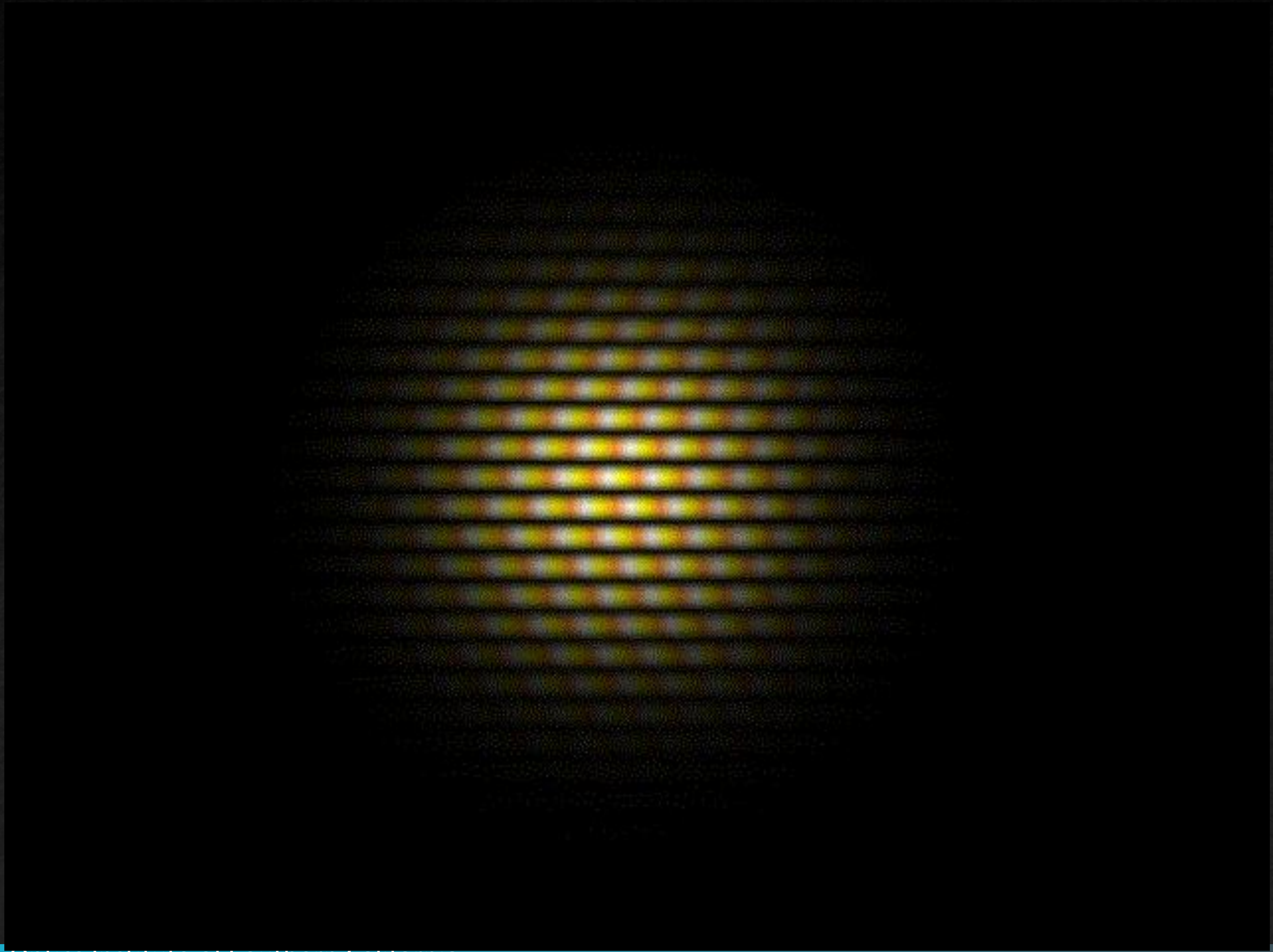
Particle impacts make visible the interference pattern of waves.



A quantum particle is represented by a wave packet.

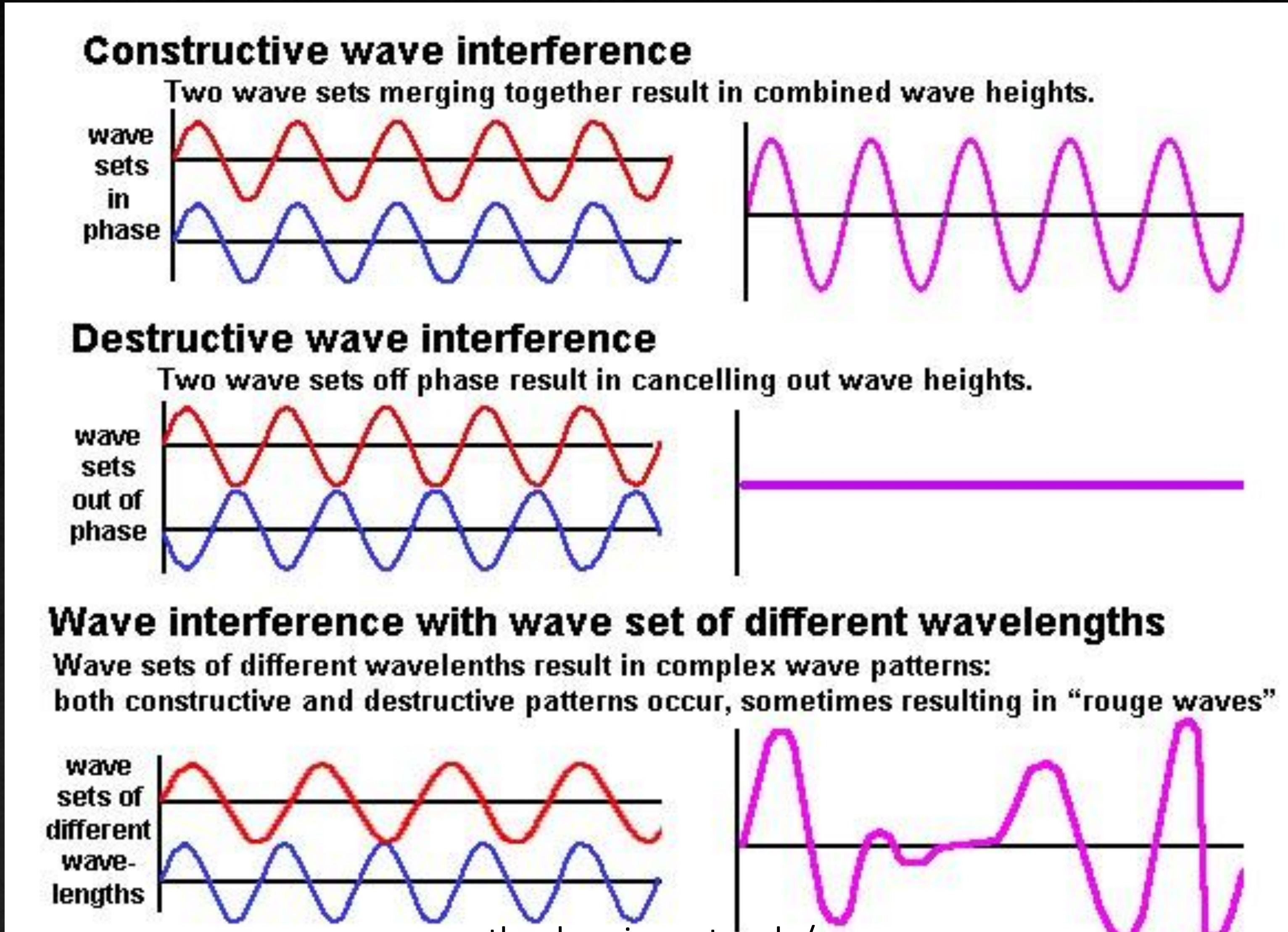


Interference of a quantum particle with itself



Superposition and Interference

Interference of two waves



gotbooks.miracosta.edu/oceans

Topics we just covered:

Geometric Optics
1. Reflection, Refraction with Plane & Curved Surfaces
2. Thin & Thick Lenses
3. Examples of Optical Systems
4. Aberrations & Ray Tracing
5. Non-Spherical Surfaces & Segmented optical surfaces

Physical Optics
1. The nature of light, light sources and detectors
2. Radiometry & photometry
3. Optical materials: light & matter interactions
4. Diffraction & Interference

These will be used in the following lectures & labs.