BOSTON UNIVERSITY

INTRODUCTION TO PHOTONICS

SUMMER 2019

BU Neurophotonics Center

BU Photonics Center

OVERVIEW

THE NATURE OF LIGHT

- AM I A PARTICLE OR A WAVE?
- REFLECTION AND REFRACTION
- POLARIZATION AND INTERFERENCE

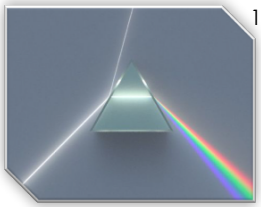
SHAPING AND MEASURING LIGHT

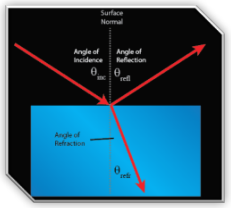
- THE SIMPLE LENS
- IMAGE FORMATION AND ABERRATIONS
- FILTERS AND GRATINGS
- SOURCES AND DETECTORS

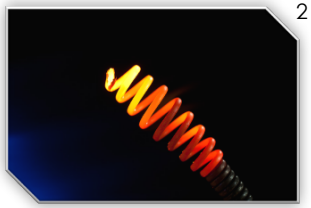
APPLICATIONS

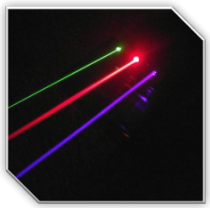
- TELESCOPES AND MICROSCOPES
- CAMERAS AND THE INTERNET
- MACHINING AND MANUFACTURING

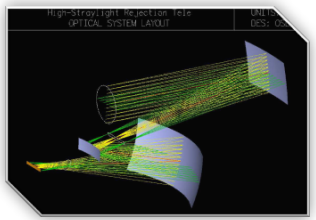
CONCLUDING REMARKS











[1]https://phys.org/news/2015-03-particle.html
[2]http://fancyfrindle.com/first-quantum-theory-black-body-radiation-max-planck/
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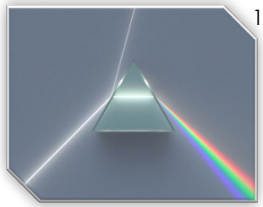
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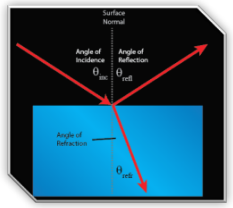

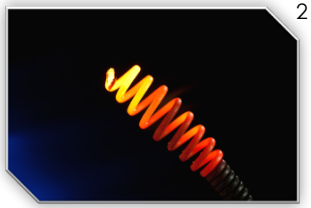
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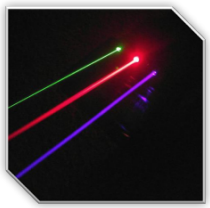

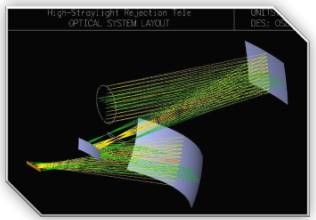

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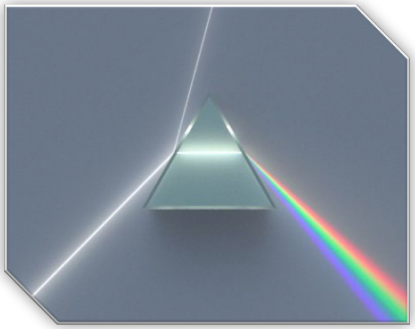
AM I A PARTICLE OR A WAVE?


Newton

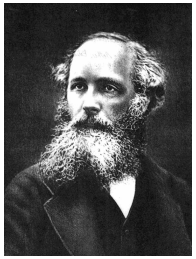
Light behaves as "particles"




Huygens

Light behaves as "waves"


Triple Rainbow -Bozeman, MT (06/19/2014)


Maxwell

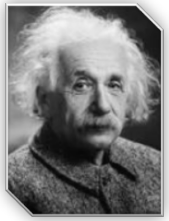
c = speed of light (3×10^8 m/s)
λ = wavelength of light
h = Planck's constant (6.63×10^{-34} m^2kg/s)

Light is both a "particle" and a "wave"

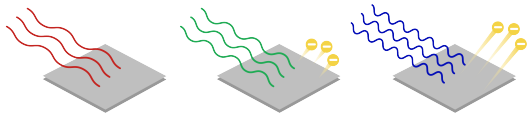

Planck

The Quanta (Photon)

$$E = {}^{hc}/_{\lambda}$$


Einstein

Photoelectric Effect




Schrödinger

Quantum Mechanics

https://www.khanacademy.org/science/physics/quantum-physics/photons/v/photoelectric-effect

AM I A PARTICLE OR A WAVE?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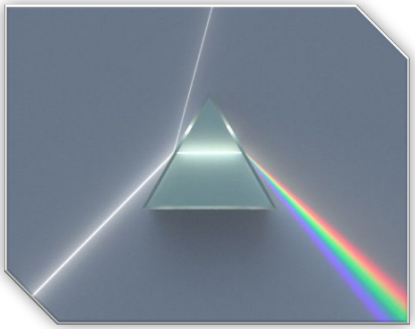


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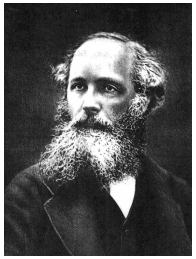
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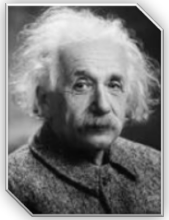
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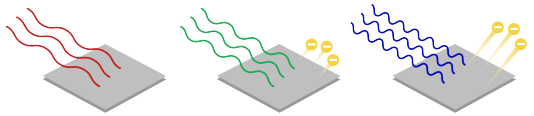



Schrödinger

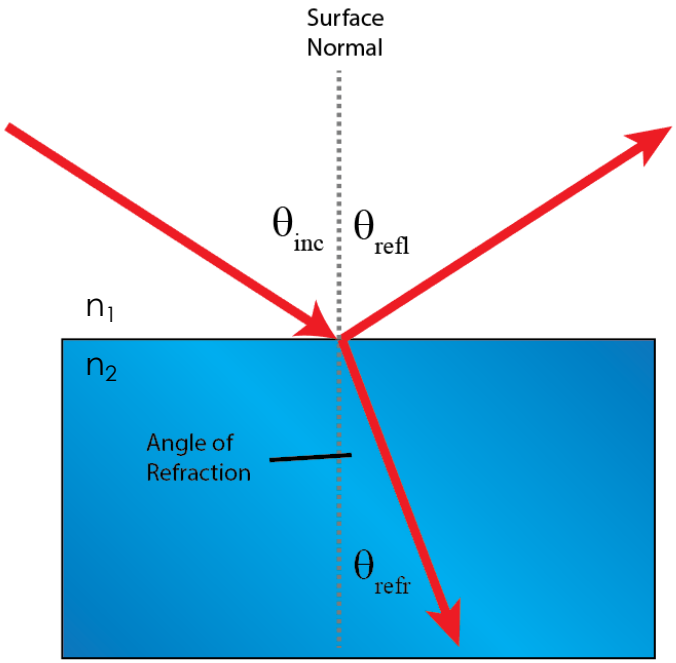
Quantum Mechanics

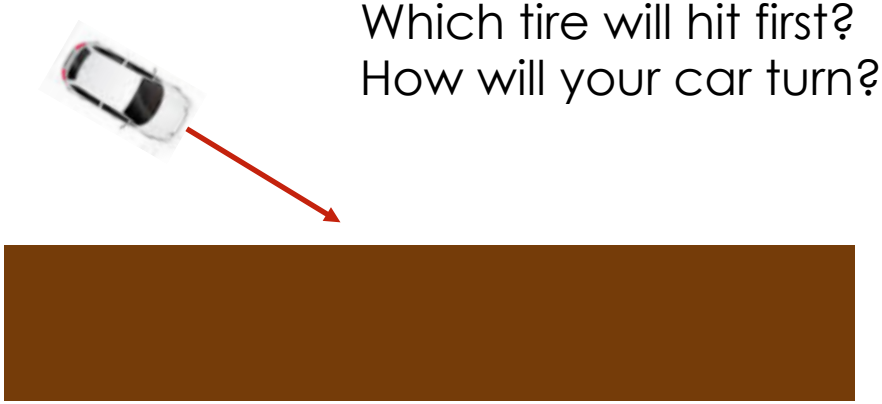
$$[\frac{-\hbar^2}{2m}\nabla^2 + V]\Psi = i\hbar\frac{\partial}{\partial t}\Psi$$

https://www.khanacademy.org/science/physics/quantum-physics/photons/v/photoelectric-effect

NEXT TOPIC:
Reflection and Refraction

REFLECTION AND REFRACTION





Which tire will hit first?
How will your car turn?

$$n_1 sin\theta_{inc} = n_2 sin\theta_{refr}$$

Snell's Law describes how light rays bend as they pass through a boundary between two different mediums.

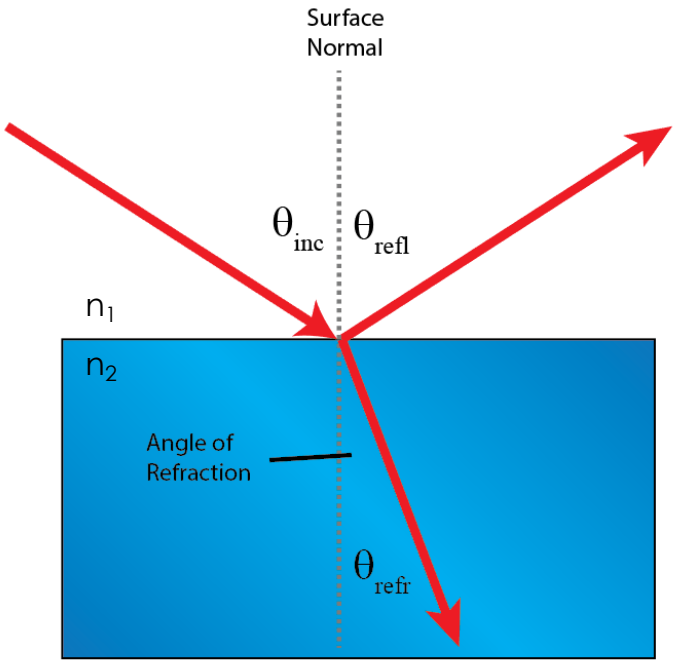
$$\theta_{inc} = \theta_{refl}$$

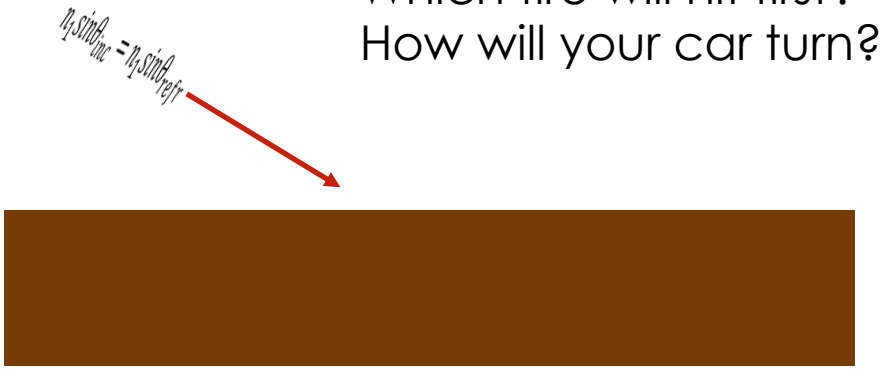
Law of Reflection describes how light rays reflect at a boundary between two different mediums.

KEY CONCEPTS

SNELL'S LAW
LAW OF REFLECTION
CAR MUD INTERFACE

REFLECTION AND REFRACTION





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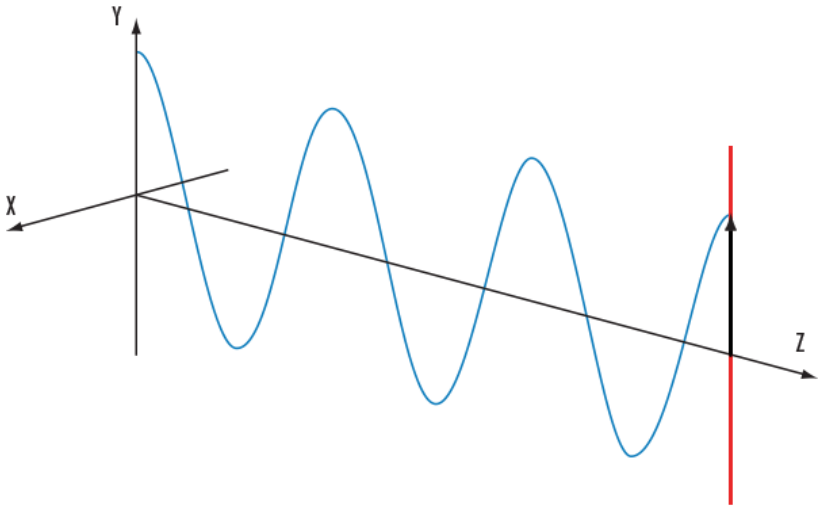
NEXT TOPIC:
Polarization and Interference

POLARIZATION AND INTERFERENCE

Other interesting properties of light…



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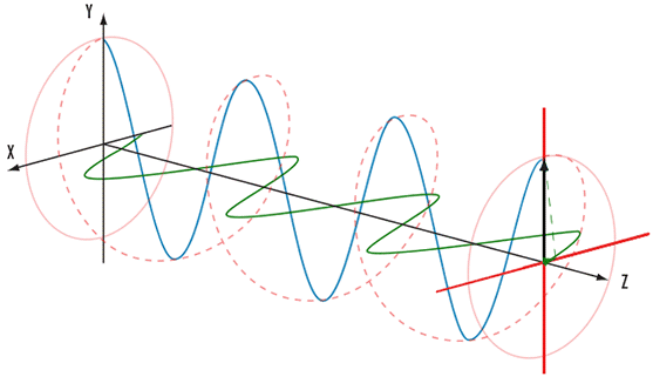
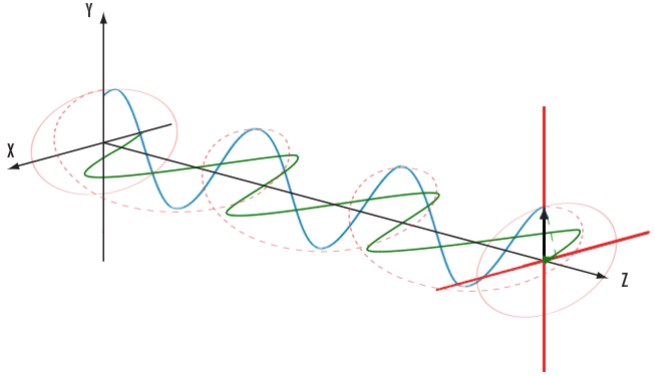




KEY CONCEPTS

ELECTRIC FIELD

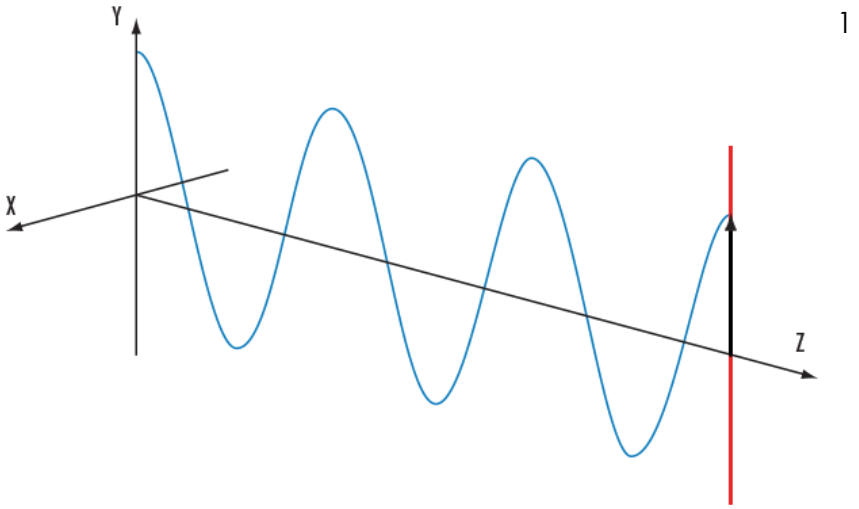
S AND P POLARIZATIONS

LINEAR, CIRCULAR (π/2) , ELLIPTICAL

[1]https://www.edmundoptics.com/resources/application-notes/optics/introduction-to-polarization/

POLARIZATION AND INTERFERENCE

Other interesting properties of light…



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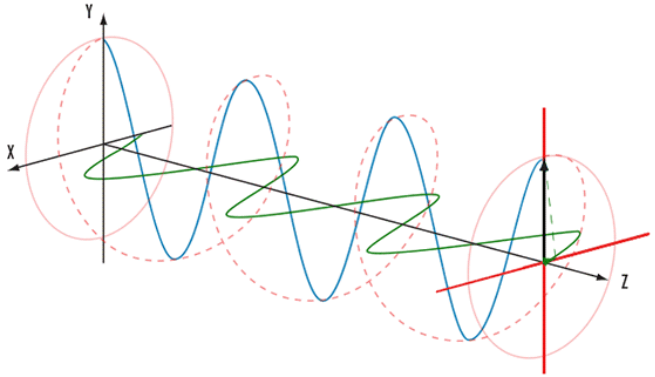

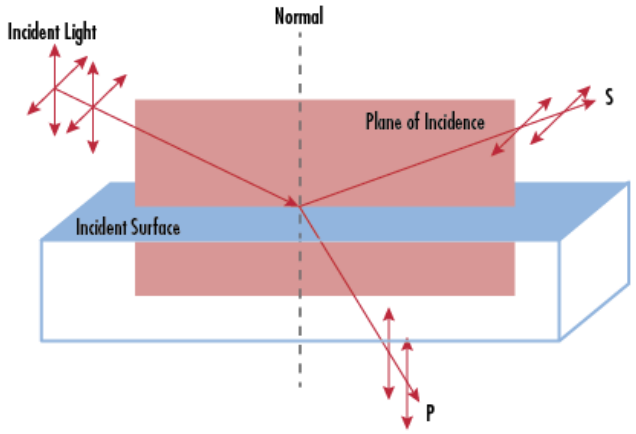

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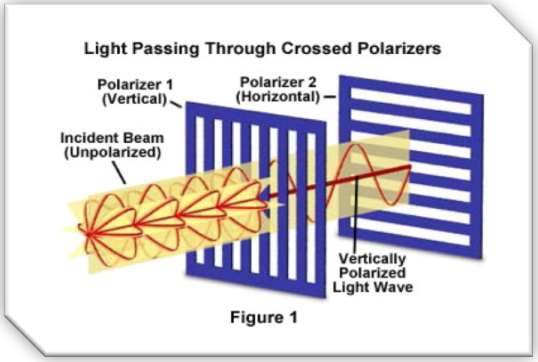
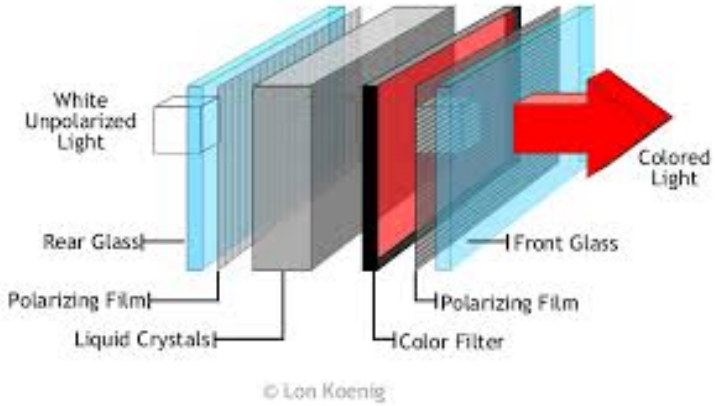
POLARIZATION AND INTERFERENCE

Other interesting properties of light…





KEY CONCEPTS

POLARIZERS AND POLARIZING UNPOLARIZED SOURCES
VARIABLE POLARIZATION RETARDERS
LCD DISPLAYS

[1]https://www.olympus-lifescience.com/en/microscope-resource/primer/lightandcolor/polarization/

POLARIZATION AND INTERFERENCE

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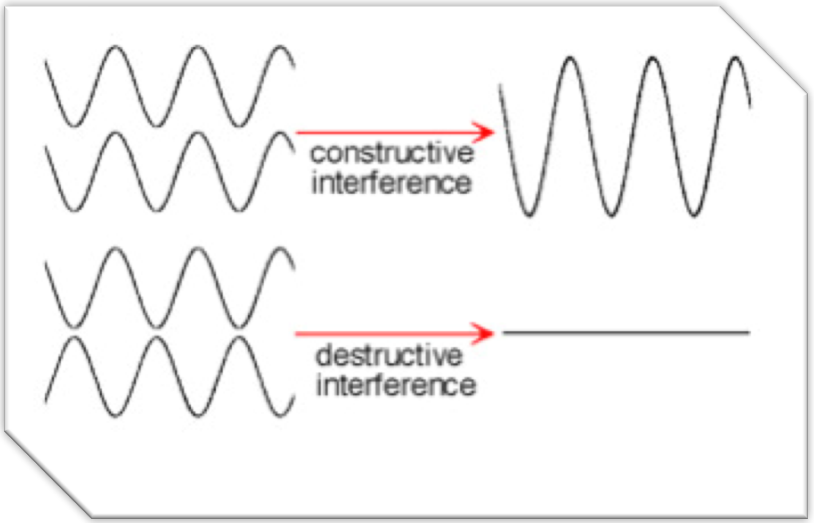

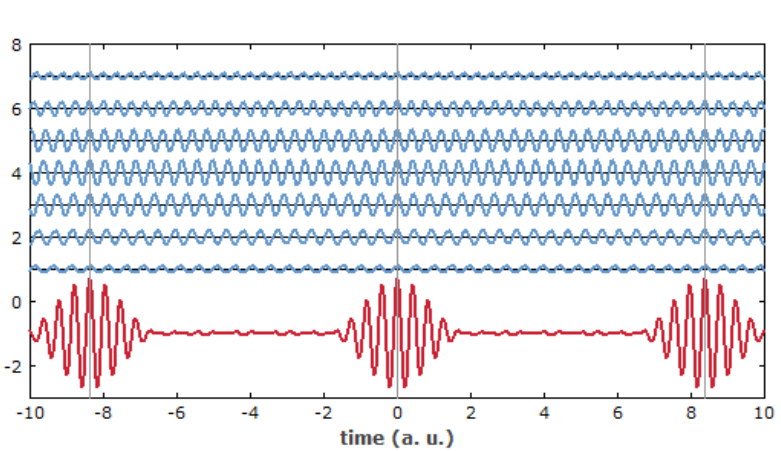

[1]

KEY CONCEPTS

CONSTRUCTIVE AND DESTRUCTIVE INTERFERENCE

IN PHASE (2π), OUT OF PHASE (π)

MANY WAVELENGTHS, SAME PHASE

[1]http://www.intellectualventureslab.com/invent/what-the-is-a-femtosecond-spectrometer

NEXT TOPIC:
Shaping and
Measuring Light

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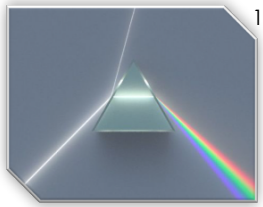
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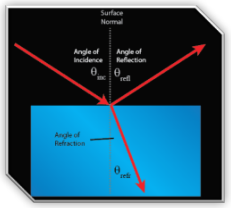

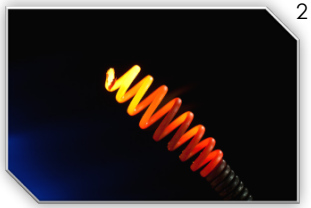
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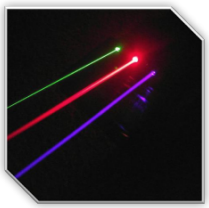

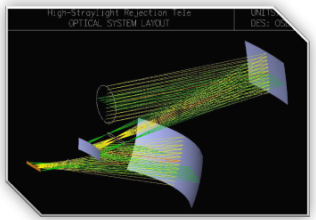

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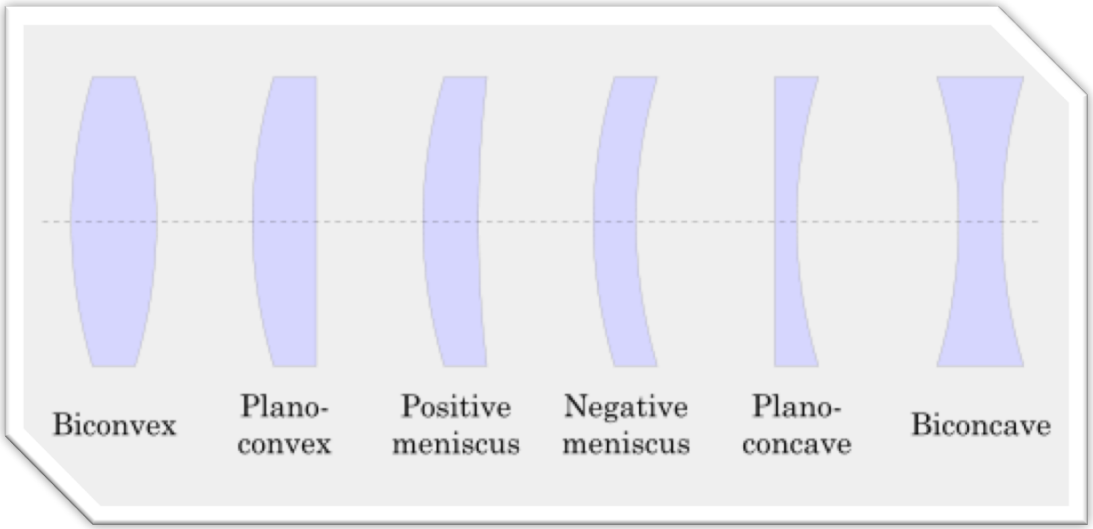
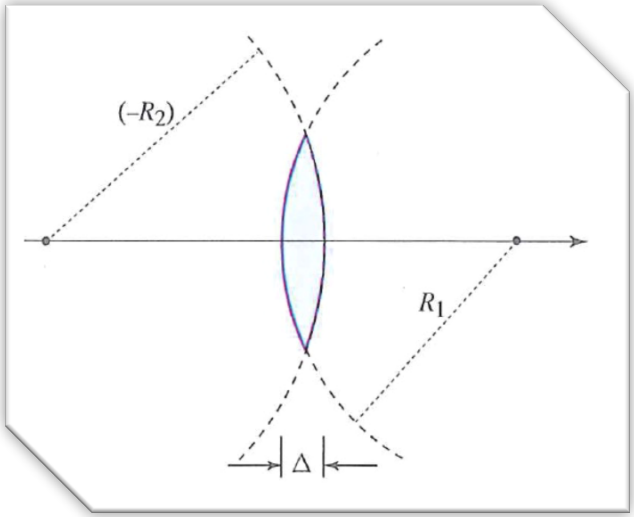
THE SIMPLE LENS



LENSMAKERS EQUATION

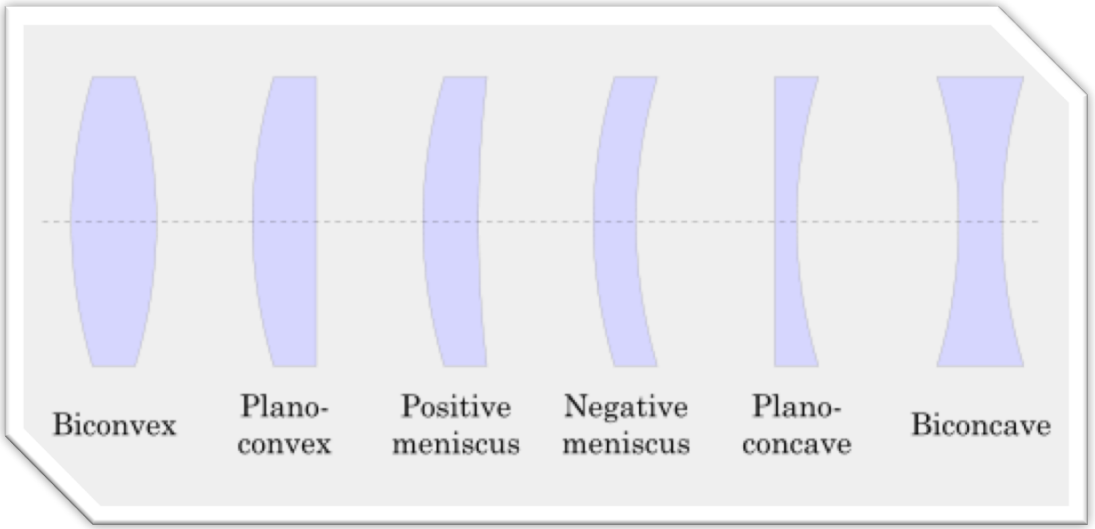
$$\frac{1}{f} = (n-1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$



KEY CONCEPTS

- THIN LENS EQUATION
- RADIUS OF CURVATURE
- SIGN CONVENSION

THE SIMPLE LENS



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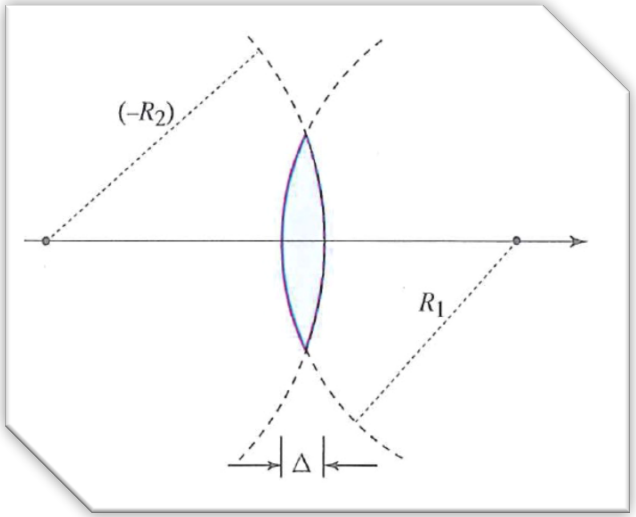

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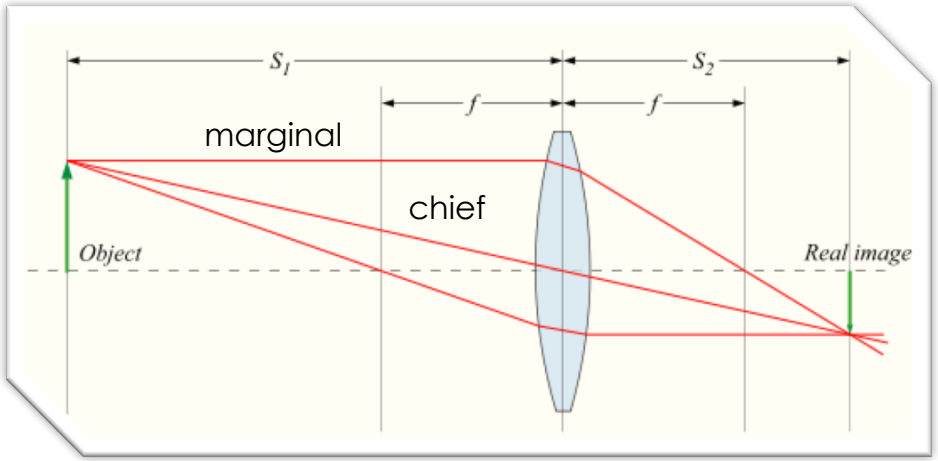
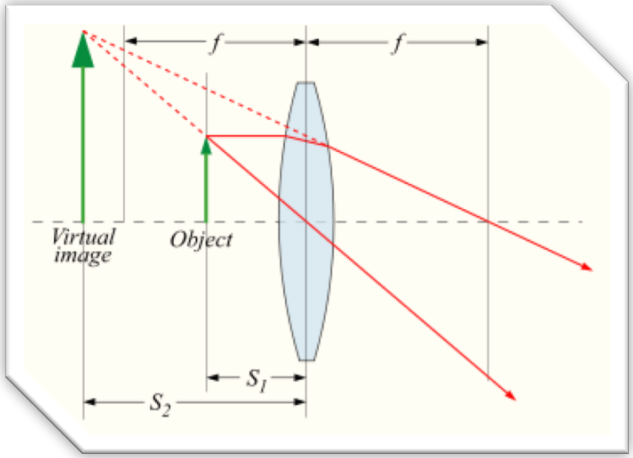
NEXT TOPIC:
Image formation and Aberrations

IMAGE FORMATION AND ABERRATIONS





KEY CONCEPTS

CHIEF/MARGINAL RAY

OBJECT/IMAGE HEIGHT

REAL/IMAGARY FOCUS

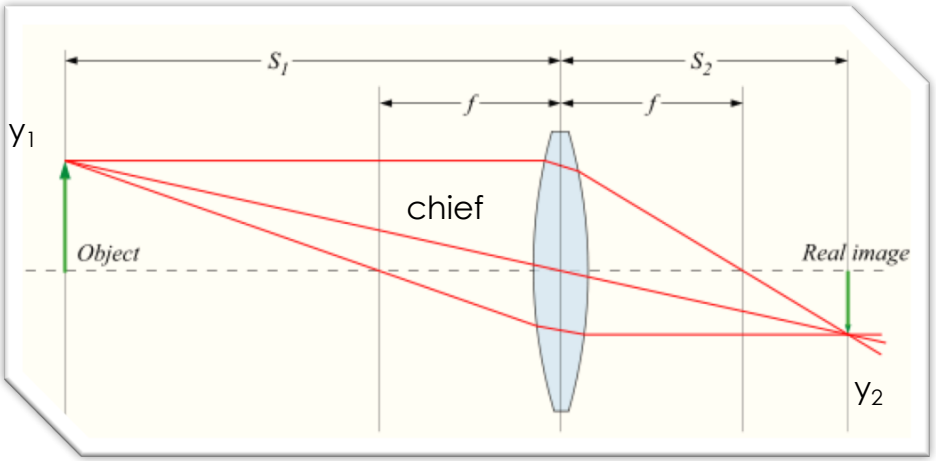
THIN LENS EQUATION

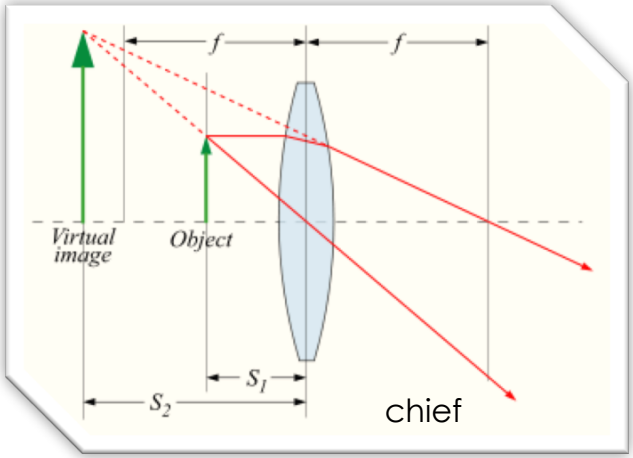
$$^1/_f = {}^1/_{S_1} + {}^1/_{S_2}$$

MAGNIFICATION

$$M = -{}^{S_2}/_{S_1} = {}^{y_2}/_{y_1}$$

IMAGE FORMATION AND ABERRATIONS





KEY CONCEPTS

CHIEF/MARGINAL RAY
OBJECT/IMAGE HEIGHT
REAL/IMAGINARY FOCUS
Diopter

THIN LENS EQUATION

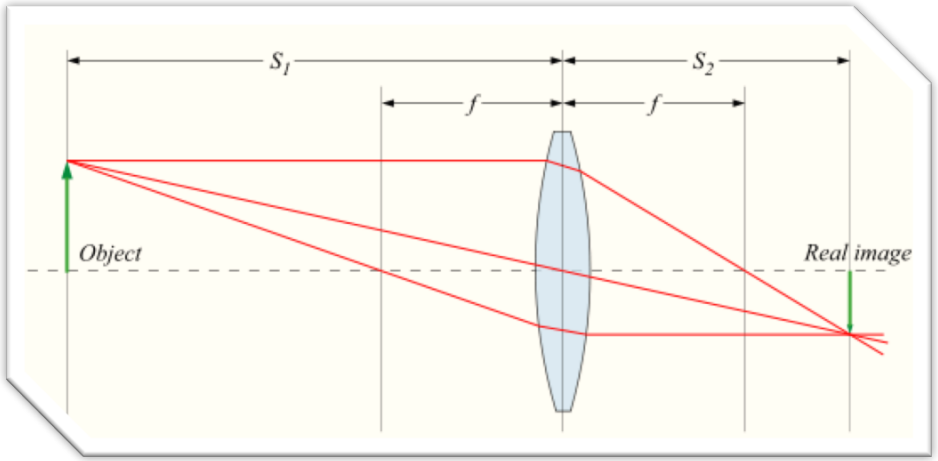
$$\boxed{1/f} = 1/S_1 + 1/S_2$$

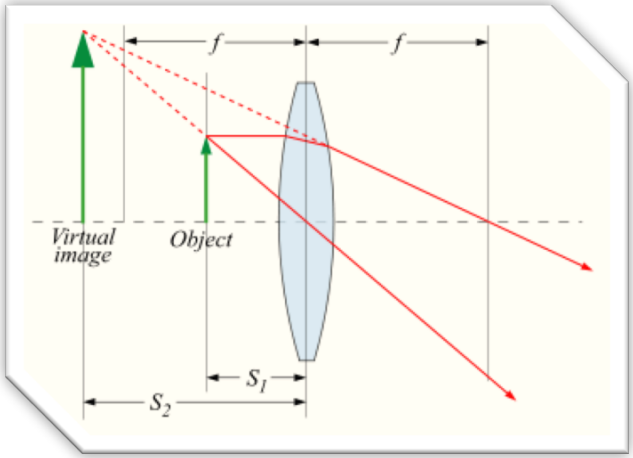
Diopter

MAGNIFICATION

$$M = -S_2/S_1 = y_2/y_1$$

IMAGE FORMATION AND ABERRATIONS





KEY CONCEPTS

CHIEF/MARGINAL RAY
OBJECT/IMAGE HEIGHT
REAL/IMAGARY FOCUS
Diopter

THIN LENS EQUATION

$$^1/_f = {}^1/_{S_1} + {}^1/_{S_2}$$

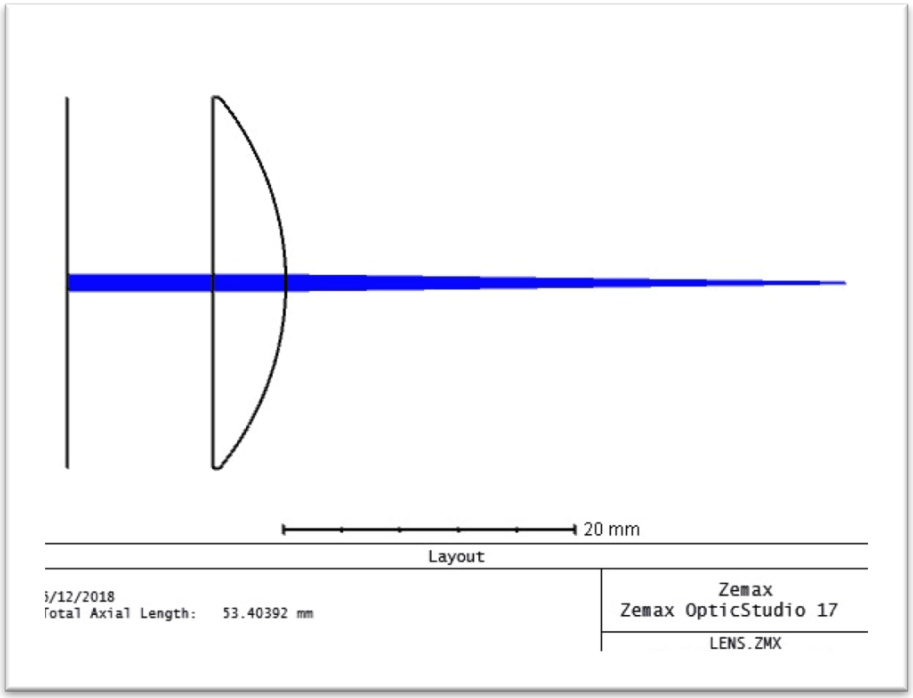
MAGNIFICATION

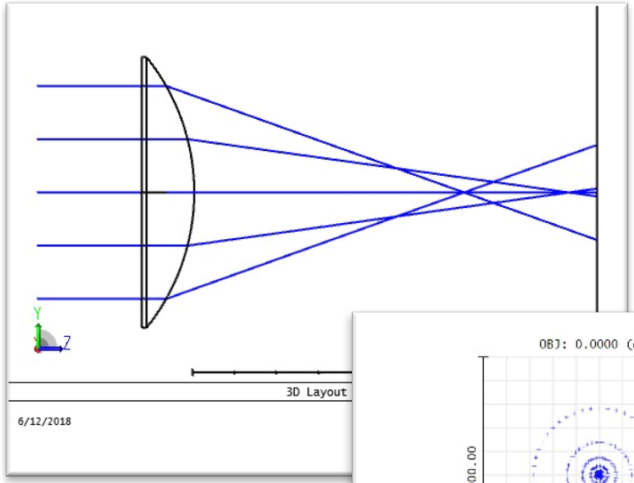
$$M = -{}^{S_2}/_{S_1} = {}^{y_2}/_{y_1}$$

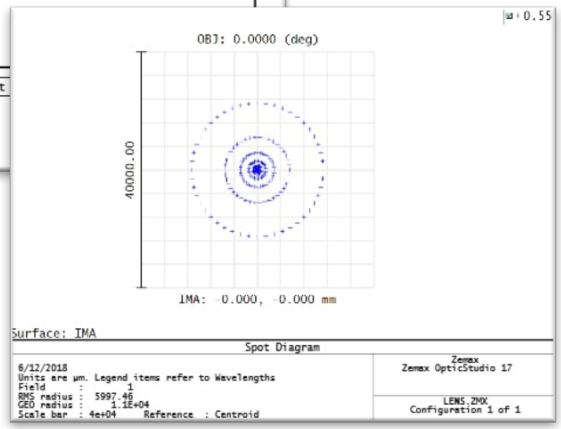
NEXT TOPIC: Spherical Aberration

IMAGE FORMATION AND ABERRATIONS

SPHERICAL ABERRATION





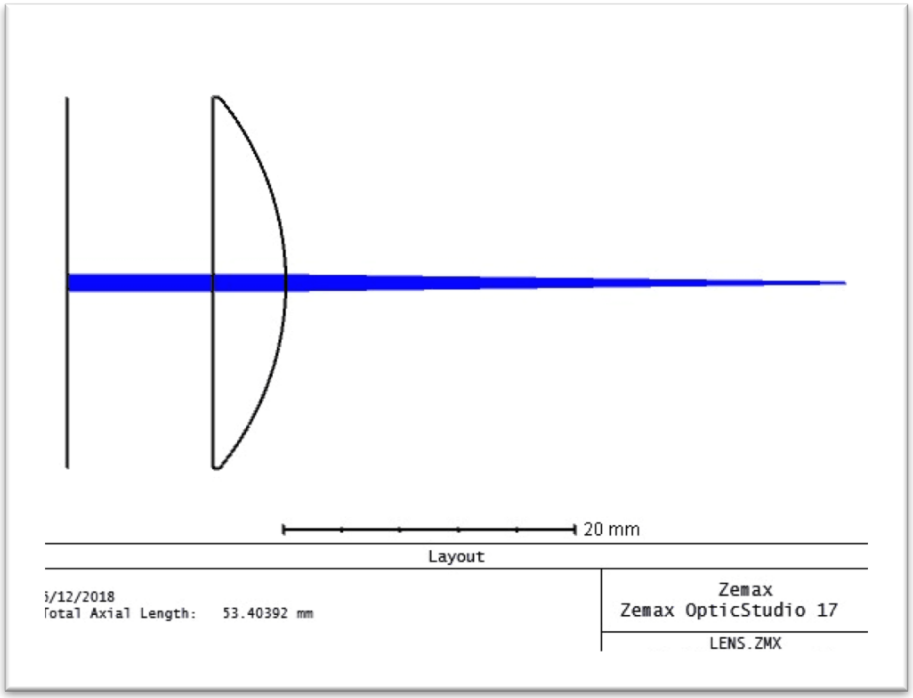


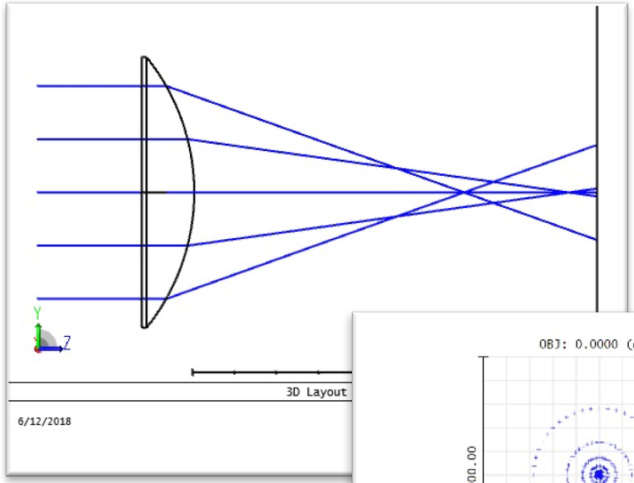
KEY CONCEPTS

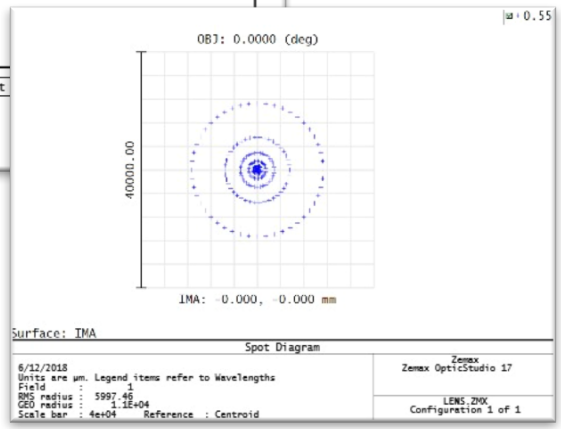
- PARAXIAL APPROXIMATION
- EFFECTS OF SPHERICAL ABERRATION
- ENLARGE FOCAL SPOT

IMAGE FORMATION AND ABERRATIONS

SPHERICAL ABERRATION







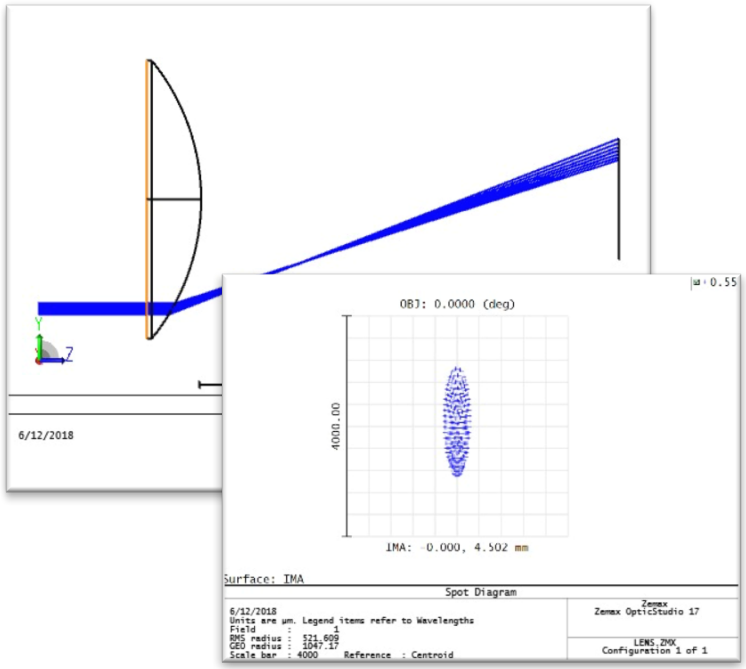
KEY CONCEPTS

- PARAXIAL APPROXIMATION
- EFFECTS OF SPHERICAL ABERRATION
- ENLARGE FOCAL SPOT

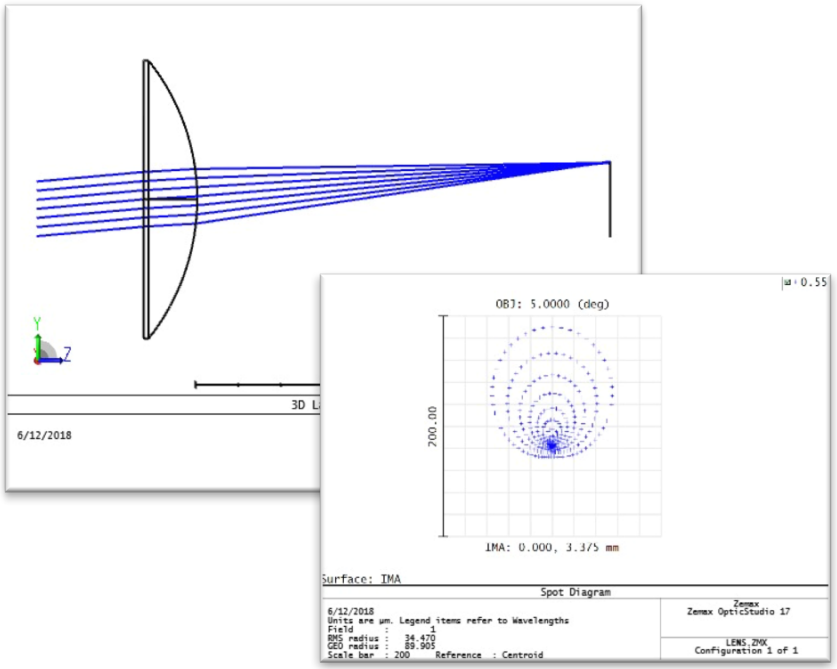
NEXT TOPIC:
Coma and Astigmatism

IMAGE FORMATION AND ABERRATIONS

ASTIGMATISM



COMA

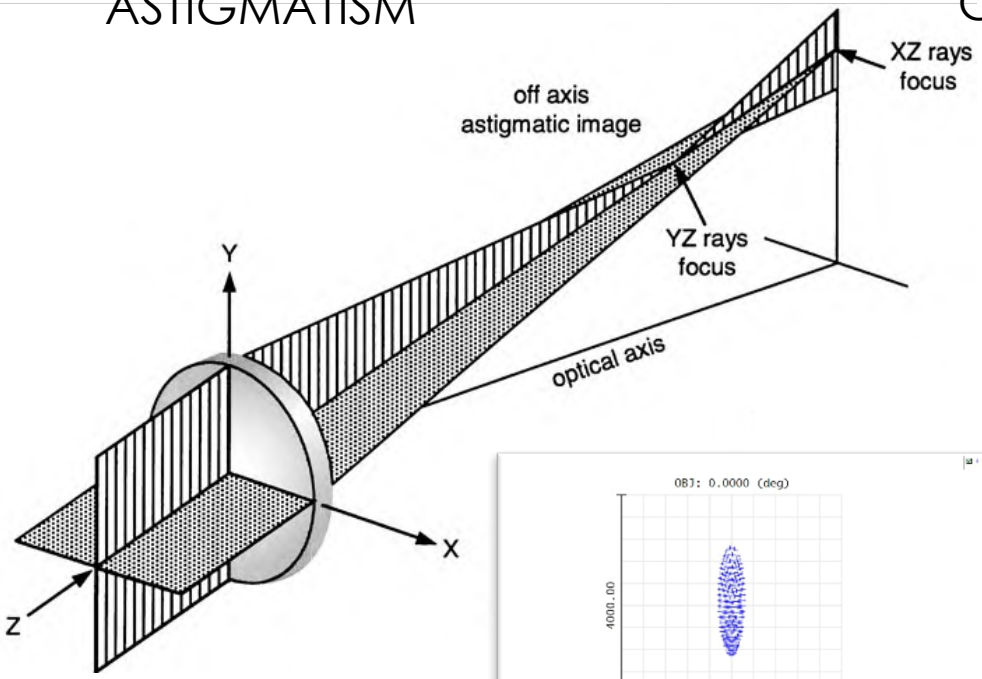


KEY CONCEPTS

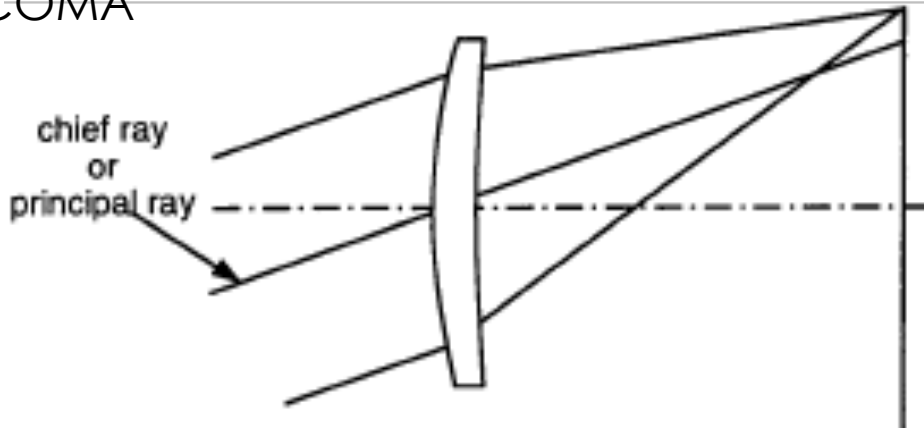
SOURCES OF COMA/ASTIGMATISM

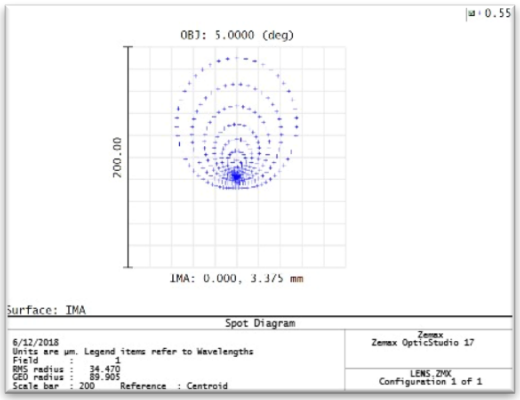
IMAGE FORMATION AND ABERRATIONS

ASTIGMATISM



COMA



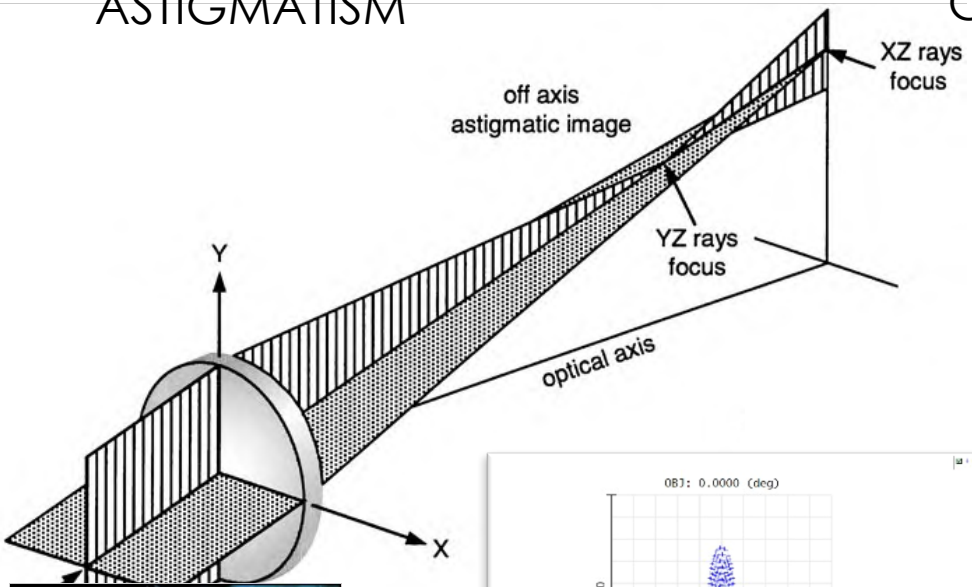


KEY CONCEPTS

SOURCES OF COMA/ASTIGMATISM

IMAGE FORMATION AND ABERRATIONS

ASTIGMATISM



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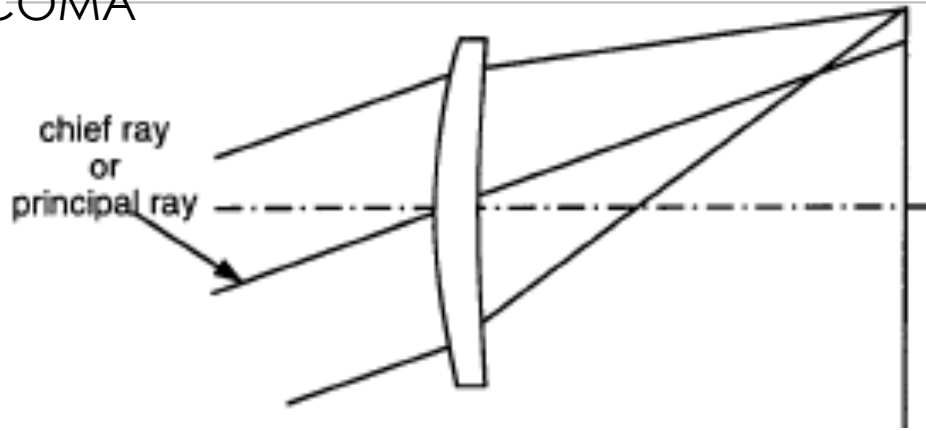
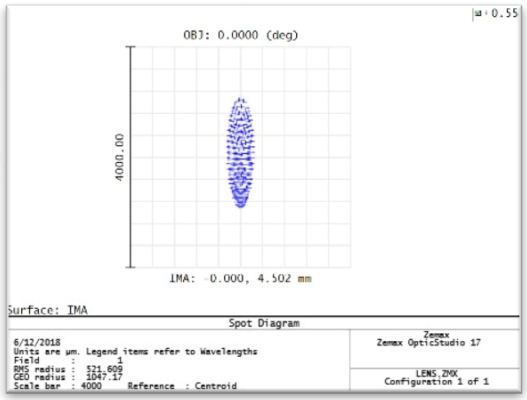
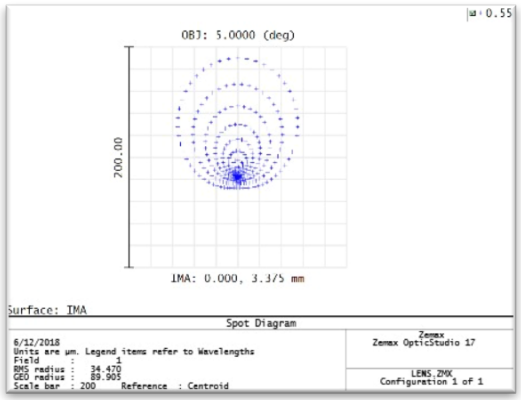
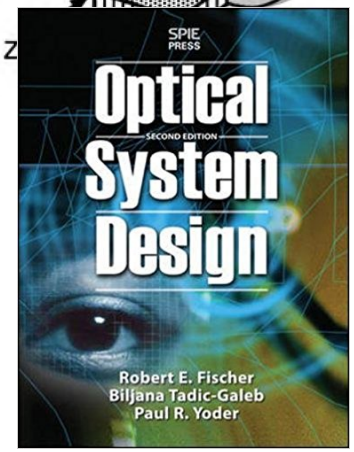






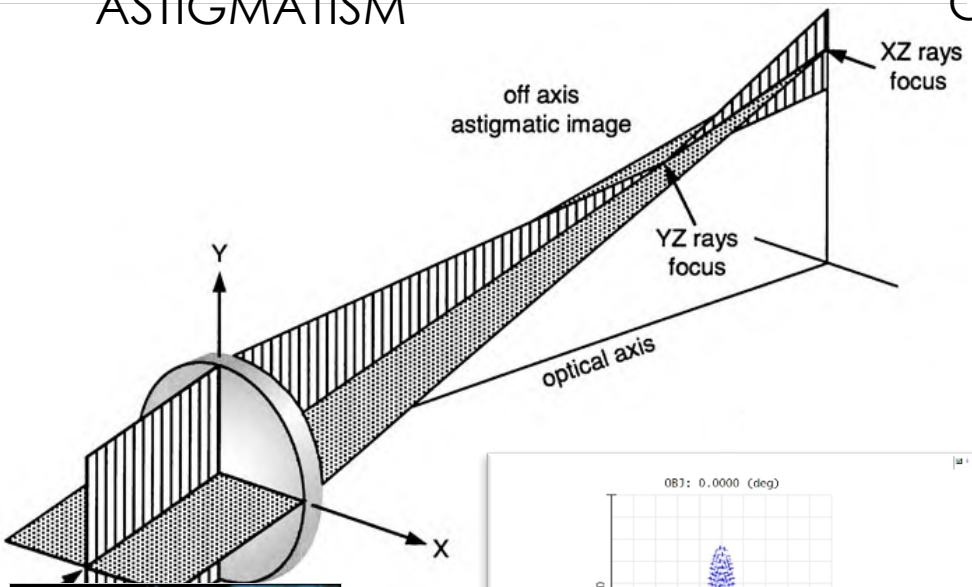


KEY CONCEPTS

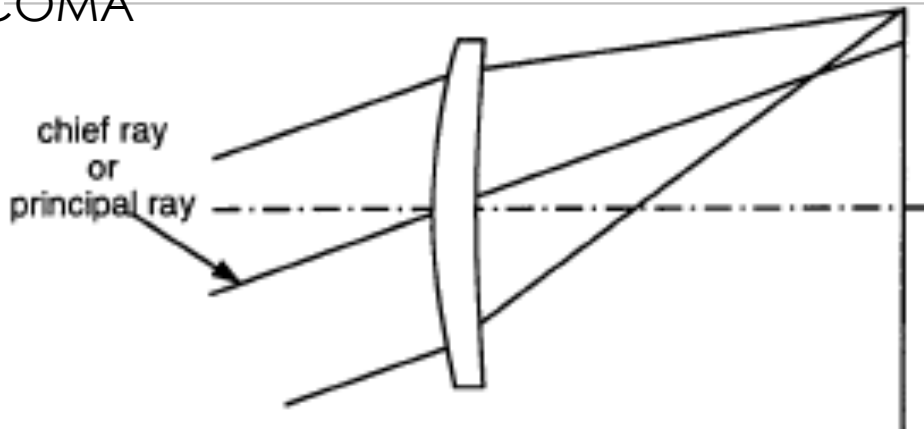
SOURCES OF COMA/ASTIGMATISM

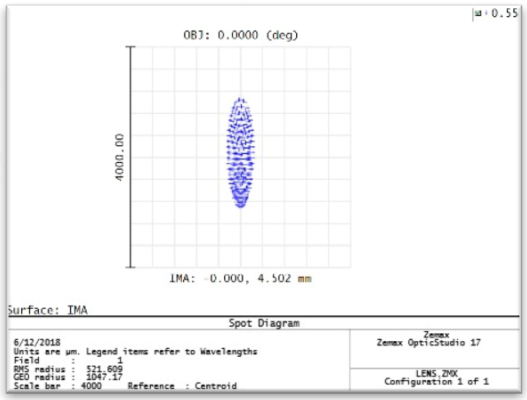
IMAGE FORMATION AND ABERRATIONS

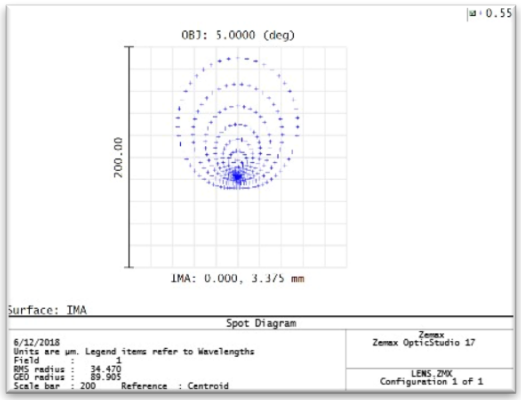
ASTIGMATISM

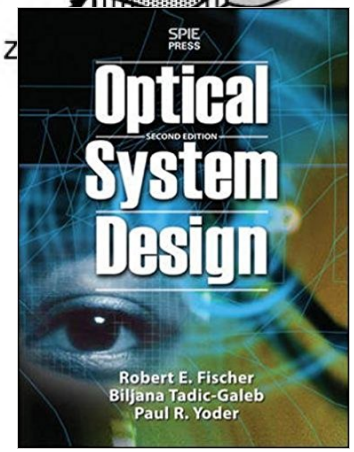


COMA







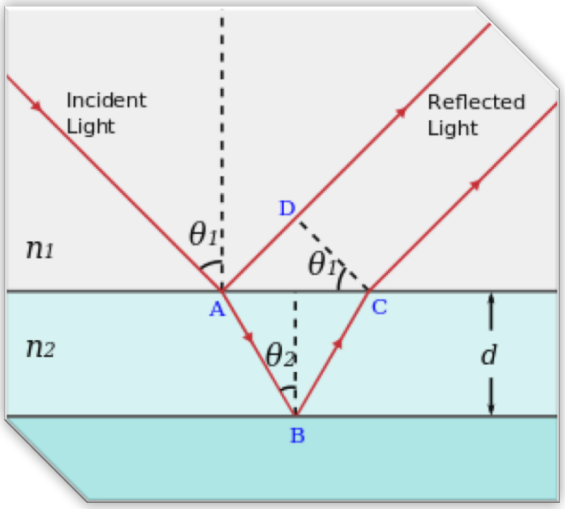


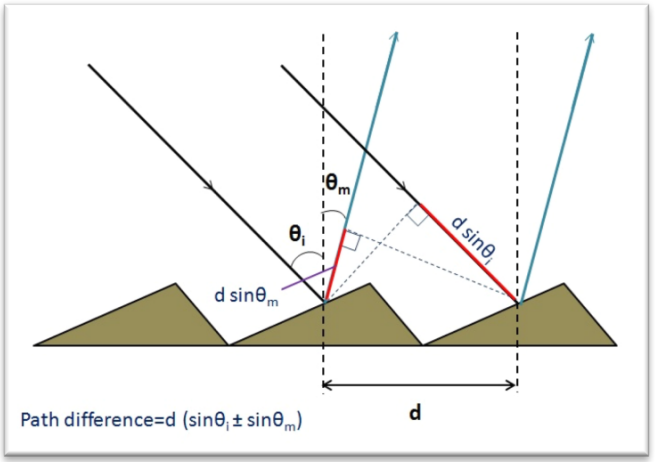
KEY CONCEPTS

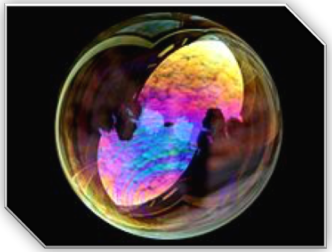
SOURCES OF COMA/ASTIGMATISM

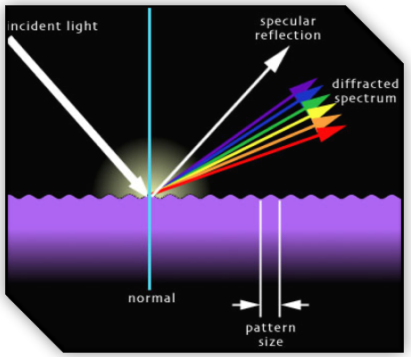
NEXT TOPIC:
Filters and Gratings

FILTERS AND GRATINGS









CONSTRUCTIVE INTERFERENCE

$$m\lambda = 2n_2 d\cos\theta_2$$

DESTRUCTIVE INTERFERENCE

$$(m - 1/2)\lambda = 2n_2 d\cos\theta_2$$

GRATING EQUATION

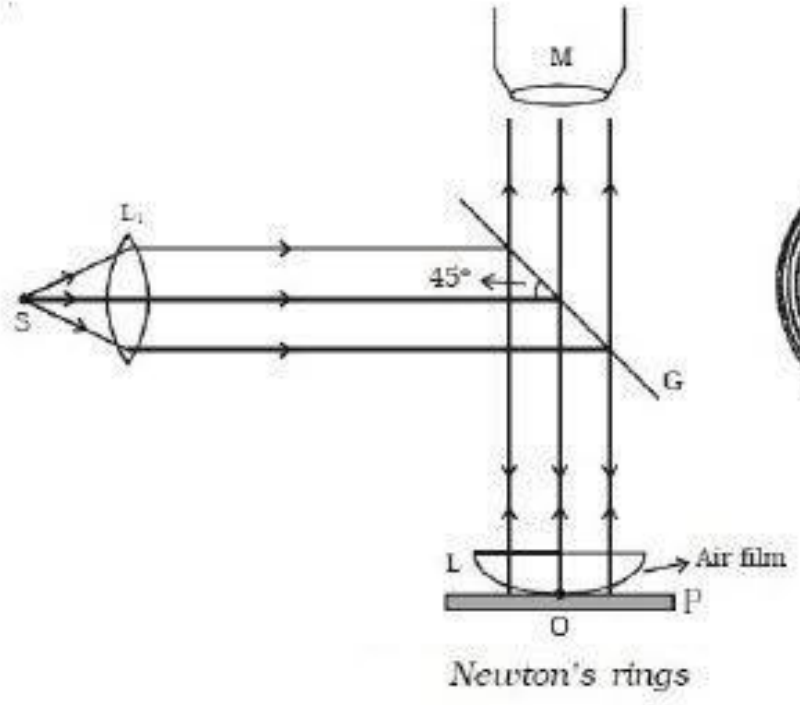
$$\mathrm{d}(sin\theta_i - sin\theta_m) = m\lambda$$

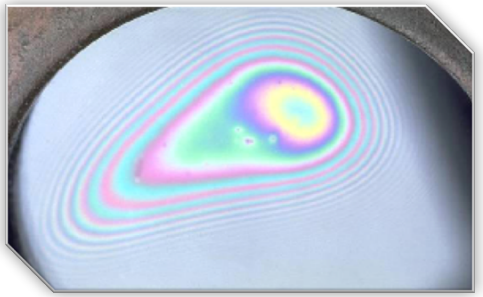
KEY CONCEPTS

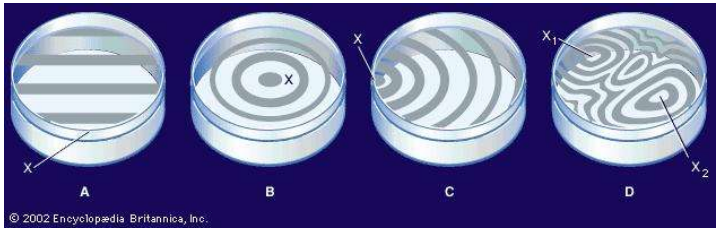
ANTI-REFLECTION DIELECTRIC COATINGS

TRANSMISSIVE AND REFLECTIVE GRATING

FILTERS AND GRATINGS







Newton Rings (Radius of dark rings/fringes)

$$r_n^2 = nR\lambda$$

R = radius of curvature
λ = wavelength of light
n = nth fringe

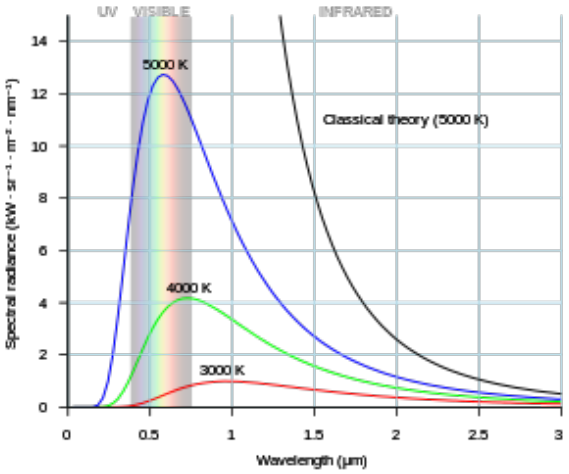
KEY CONCEPTS

INTERFERENCE FRINGES
MEASURE QUALITY OF LENS OR FILMS

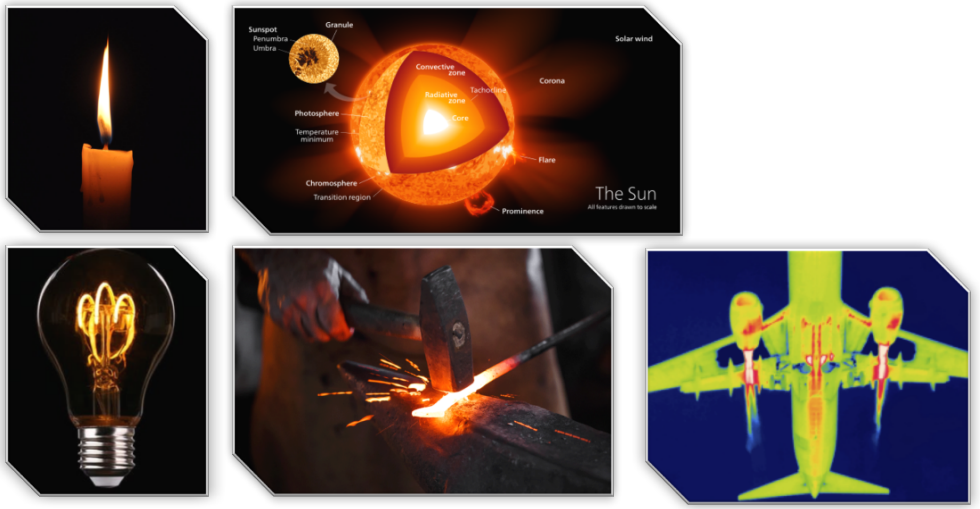
NEXT TOPIC:
Black Body
Radiators

SOURCES AND DETECTORS

BLACKBODY RADIATION



https://en.wikipedia.org/wiki/Black_body



https://en.wiktionary.org/wiki/candle
https://www.pexels.com/search/light%20bulbs/
https://www.cricketscove.net/forge-gallery-intro/

BLACK BODY EQUATION (Planck)

$$B_v(T) = \frac{2hv^3}{c^2}\frac{1}{e^{hv/kT} - 1}$$ W/sr m^2 Hz

Power density

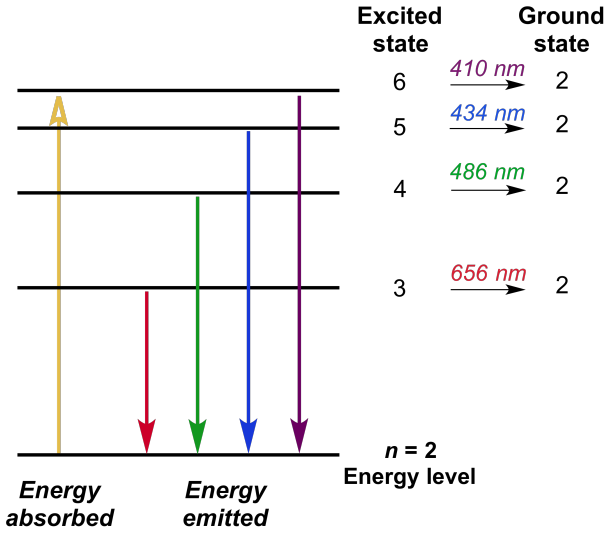
KEY CONCEPTS

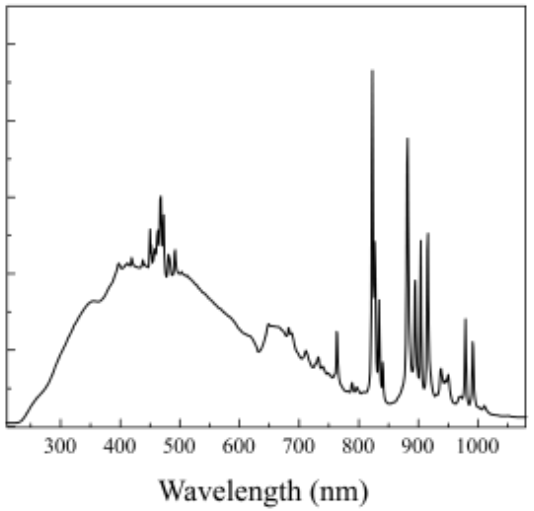
BLACK BODY TEMPERATURE
THE ULTRAVIOLET CATASTROPHE

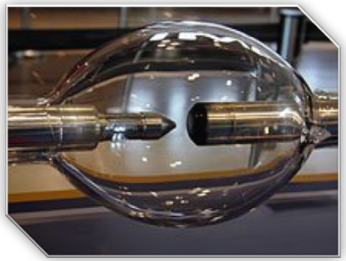
NEXT TOPIC:
Arc Lamps

SOURCES AND DETECTORS

Arc Discharge Lamps (Gas Discharge)







KEY CONCEPTS

SPECTRAL EMISSION LINES

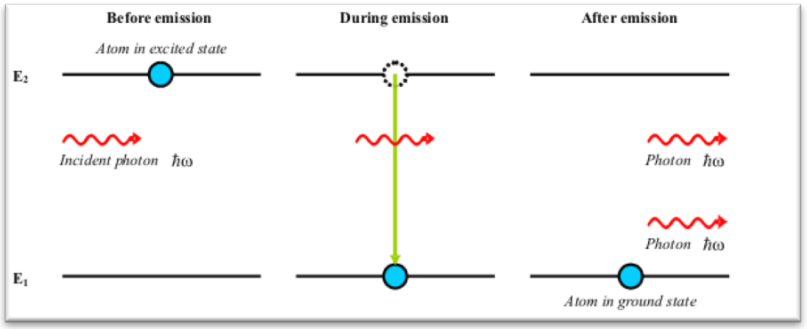
HIGH INTENSITY DISCHARGE

https://en.wikipedia.org/wiki/Xenon_arc_lamp
https://www.khanacademy.org/science/physics/quantum-physics/atoms-and-electrons/v/emission-spectrum-of-hydrogen

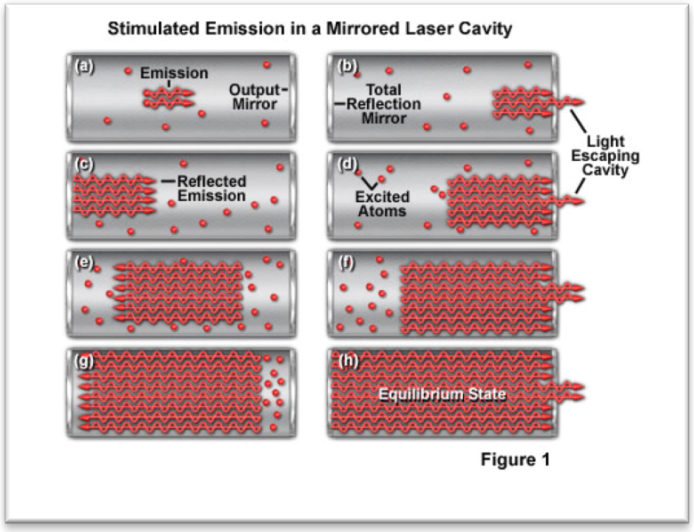
NEXT TOPIC:
Lasers

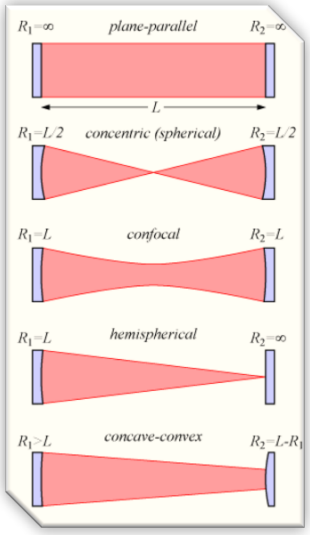
SOURCES AND DETECTORS

Light **A**mplification by **S**timulated **E**mission of **R**adiation



Various Types of Commercial Lasers
- Diode Lasers
- Gas Lasers
- Dye Lasers
- Diode Pumped Solid State Lasers
- Fiber Lasers





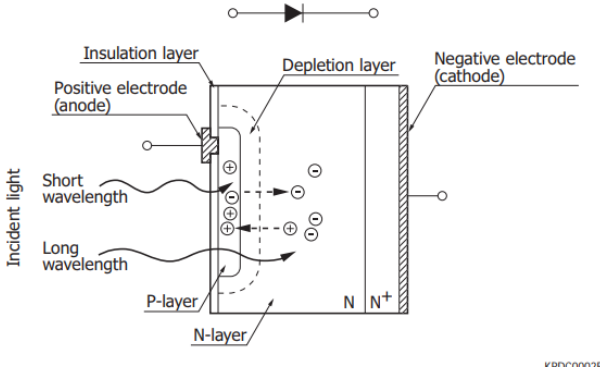
KEY CONCEPTS
- LIGHT AMPLIFICATION
- GAIN MEDIUM
- RESONATOR CAVITY

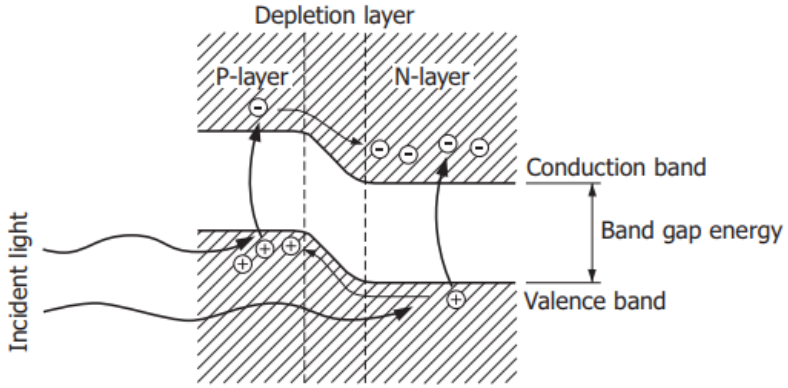
http://ffden-2.phys.uaf.edu/212_spring2011.web.dir/Thomas_Edwards/How%20Lasers%20Work.html
https://en.wikipedia.org/wiki/Optical_cavity

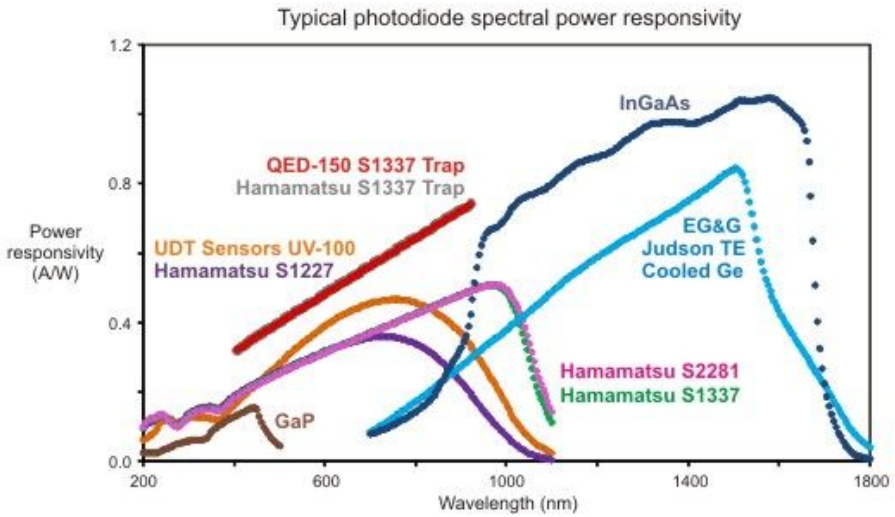
NEXT TOPIC:
Energy Band Gap Detectors

SOURCES AND DETECTORS

AND OF COURSE… we need to measure the light!







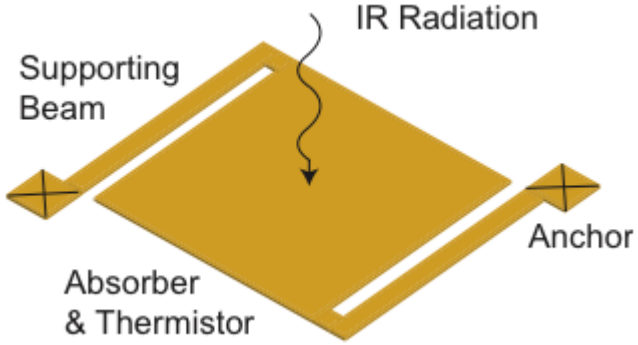
KEY CONCEPTS

DOPED MATERIALS
PHOTOCURRENT
BAND GAP ENERGY

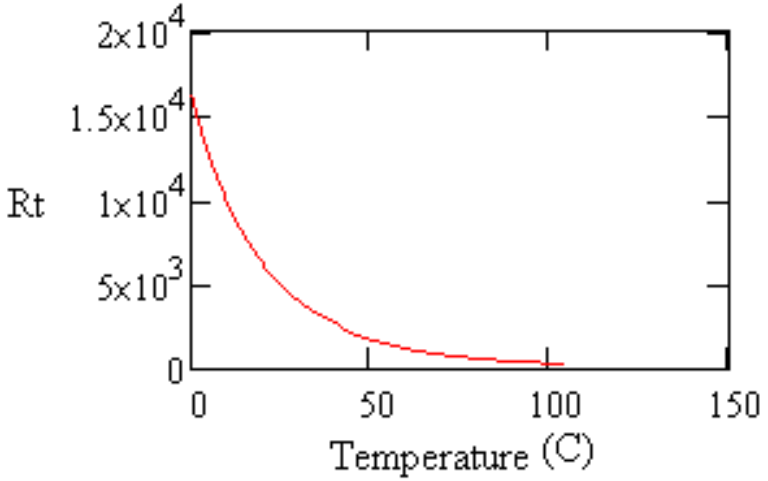
https://www.hamamatsu.com/resources/pdf/ssd/e02_handbook_si_photodiode.pdf

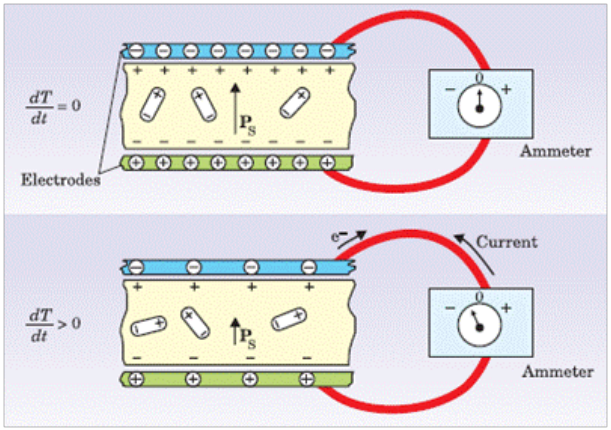
NEXT TOPIC:
Thermal Detectors

SOURCES AND DETECTORS



RESISTANCE VS TEMPERATURE





KEY CONCEPTS

THERMISTOR

PYROELECTRICITY & AC CURRENT

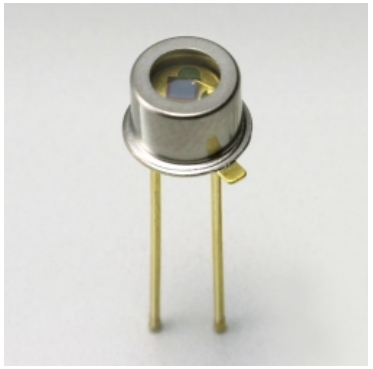
ABSORBER

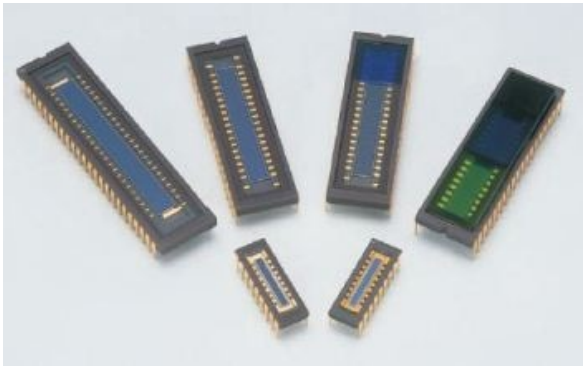
NEXT TOPIC:
Detector Arrays

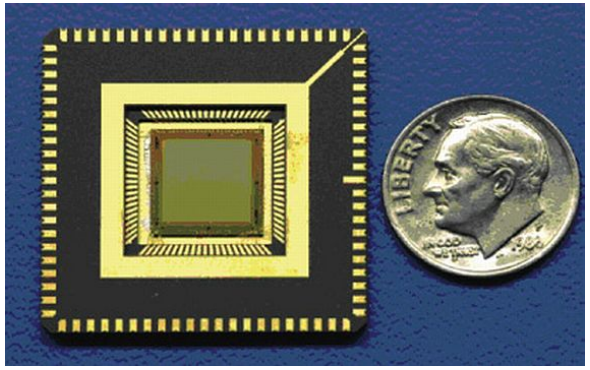
https://www.hamamatsu.com/resources/pdf/ssd/e02_handbook_si_photodiode.pdf

SOURCES AND DETECTORS

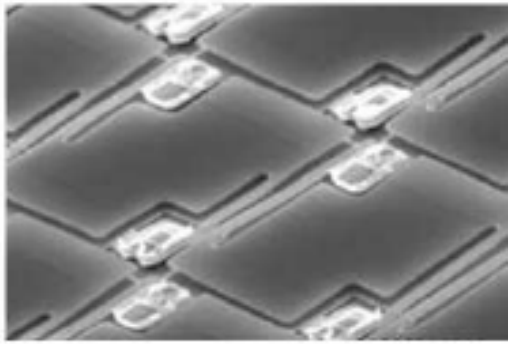
BANDGAP DETECTORS







THERMAL DETECTORS



KEY CONCEPTS

SINGLE ELEMENT
FOCAL PLANE ARRAY
COST VS PERFORMANCE

NEXT TOPIC:
Applications

OVERVIEW

THE NATURE OF LIGHT

- AM I A PARTICLE OR A WAVE?
- REFLECTION AND REFRACTION
- POLARIZATION AND INTERFERENCE

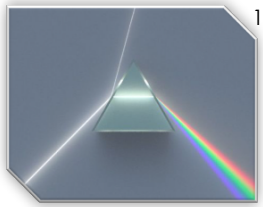
SHAPING AND MEASURING LIGHT

- THE SIMPLE LENS
- IMAGE FORMATION AND ABERRATIONS
- FILTERS AND GRATINGS
- SOURCES AND DETECTORS

APPLICATIONS

- TELESCOPES AND MICROSCOPES
- CAMERAS AND THE INTERNET
- MACHINING AND MANUFACTURING

CONCLUDING REMARKS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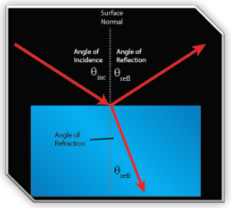

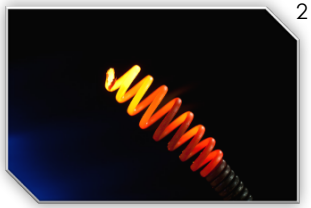
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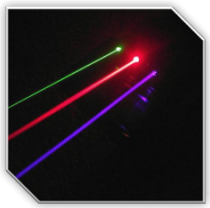
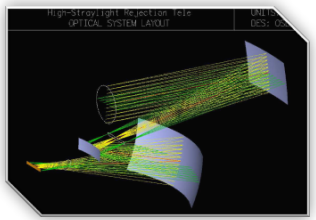
3

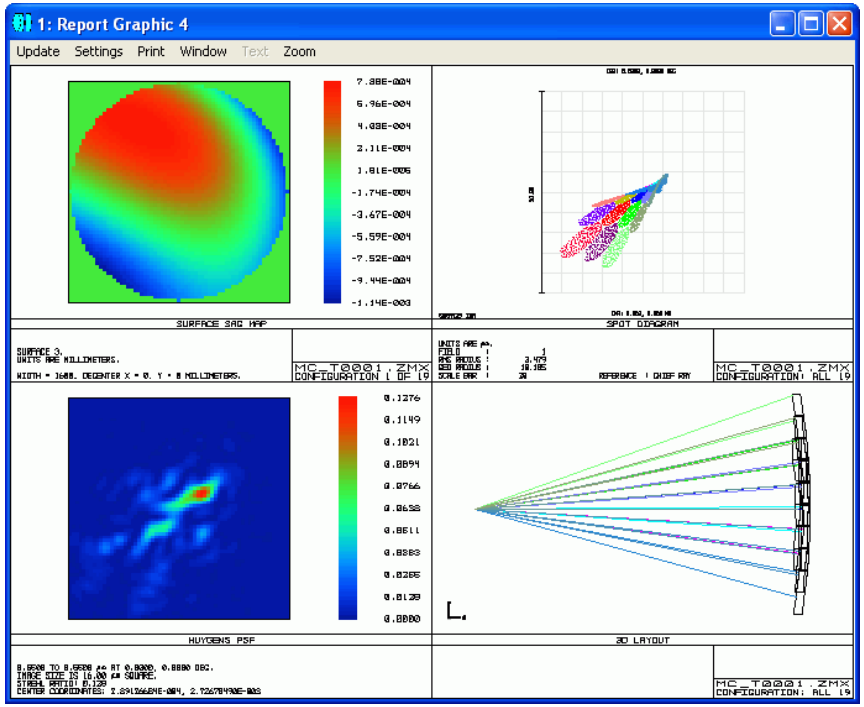


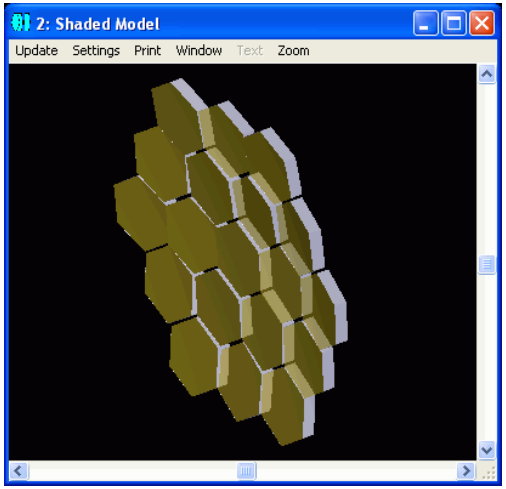


[1]https://phys.org/news/2015-03-particle.html
[2]http://fancyfrindle.com/first-quantum-theory-black-body-radiation-max-planck/
[3]https://lot-qd.de/en/products/light-lasers/light-sources-for-scientific-applications/product/arc-light-sources/

TELESCOPES AND MICROSCOPES

KECK OBSERVATORY



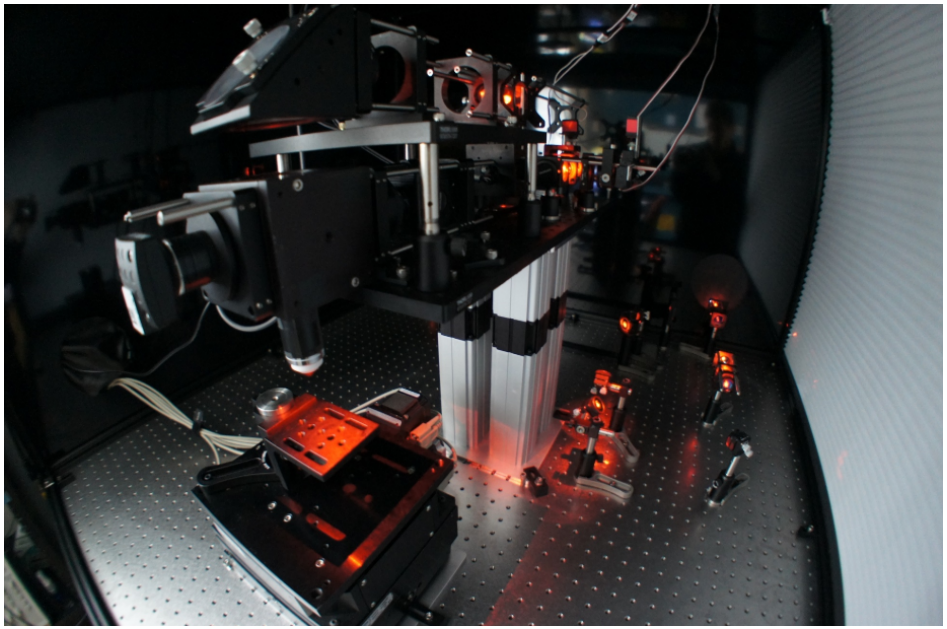


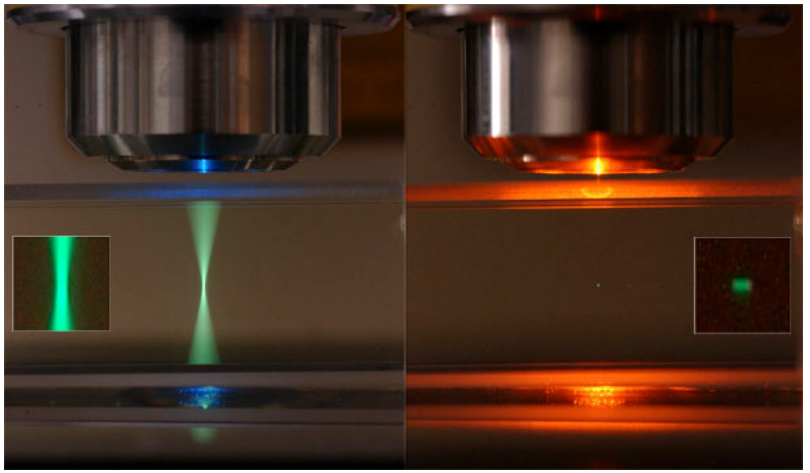
KEY CONCEPTS

ADAPTIVE OPTICS

NEXT TOPIC:
Laser Scanning Microscopes

TELESCOPES AND MICROSCOPES



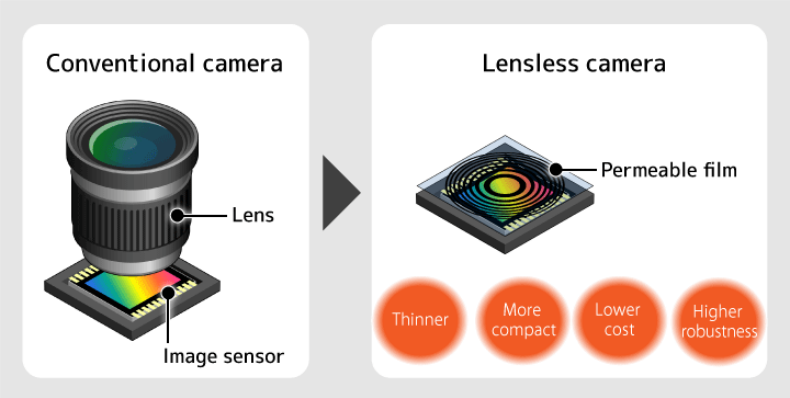


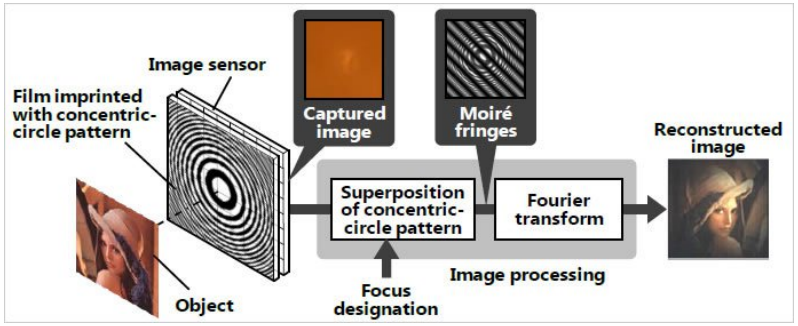
KEY CONCEPTS

FEMTOSECOND (10^{-15}) LASERS
CONFOCAL MICROSCOPES
MULTIPHOTON MICROSCOPES

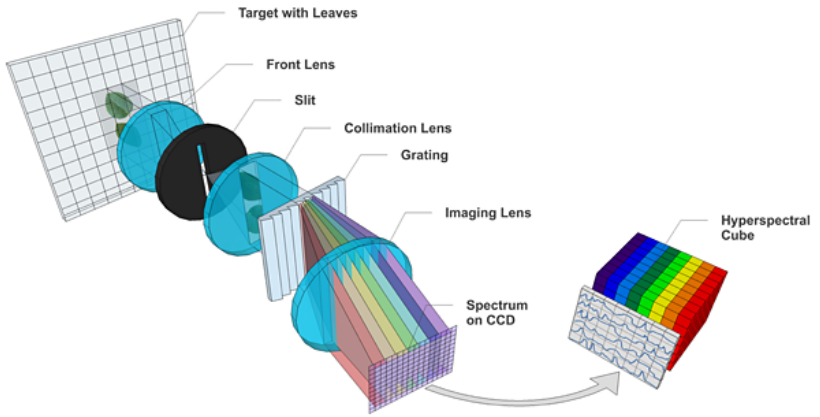
NEXT TOPIC:
Lensless Cameras and
Hyperspectral Imaging

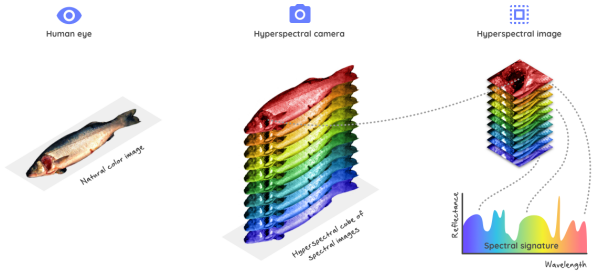
CAMERAS AND THE INTERNET





http://www.hitachi.com/rd/portal/contents/story/lensless/index.html





KEY CONCEPTS

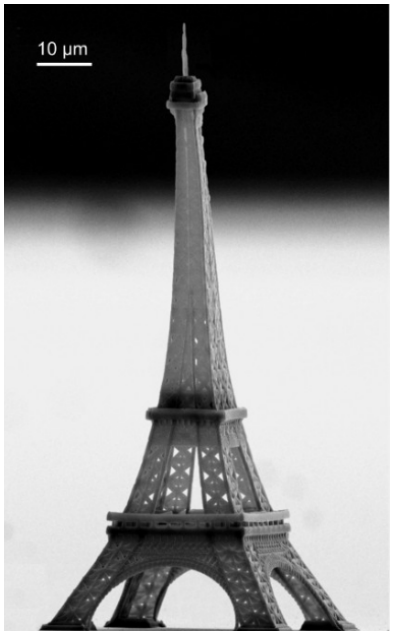
LENSLESS CAMERAS

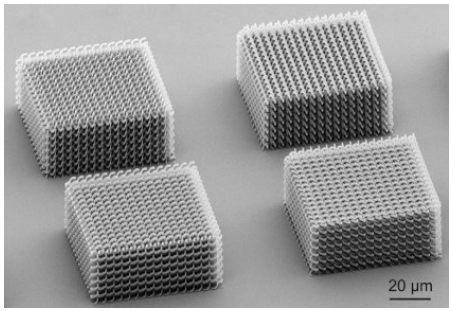
HYPERSPECTRAL CUBE

NEXT TOPIC:
Machining and Manufacturing

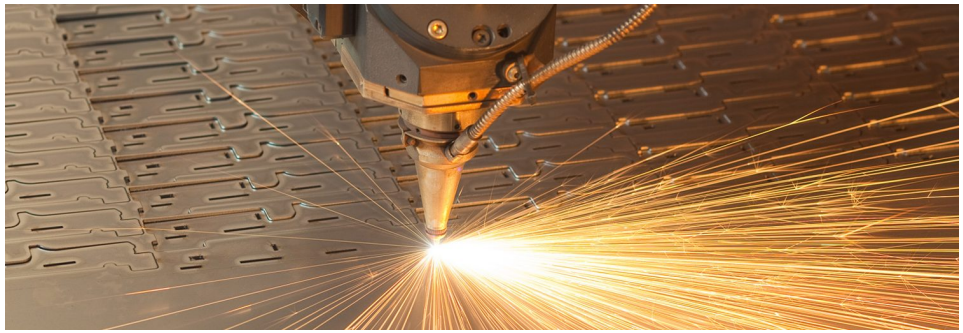
MACHINING AND MANUFACTURING

MICROMACHINING

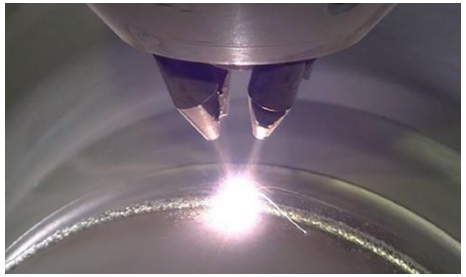


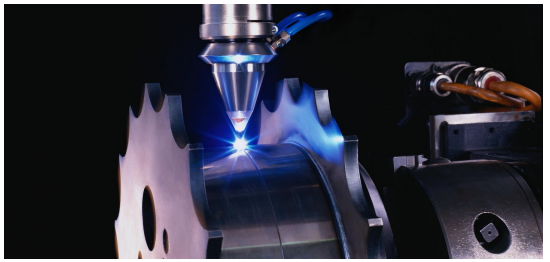


LASER CUTTING



3D LASER SINTERING/WELDING





http://www.viboon.org/2010/05/08/

NEXT TOPIC: Concluding Remarks

OVERVIEW

THE NATURE OF LIGHT

- AM I A PARTICLE OR A WAVE?
- REFLECTION AND REFRACTION
- POLARIZATION AND INTERFERENCE

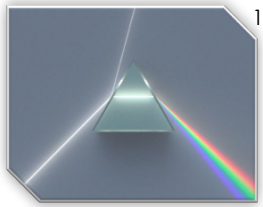
SHAPING AND MEASURING LIGHT

- THE SIMPLE LENS
- IMAGE FORMATION AND ABERRATIONS
- FILTERS AND GRATINGS
- SOURCES AND DETECTORS

APPLICATIONS

- TELESCOPES AND MICROSCOPES
- CAMERAS AND THE INTERNET
- MACHINING AND MANUFACTURING

CONCLUDING REMARKS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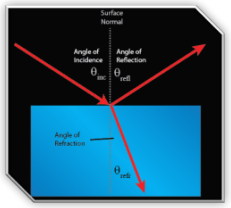

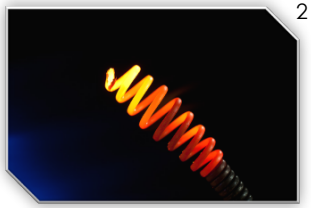
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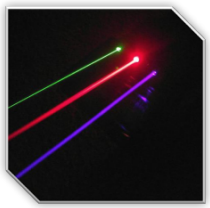

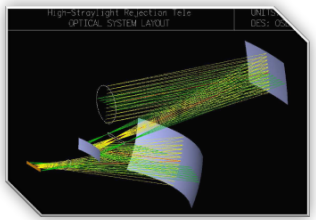

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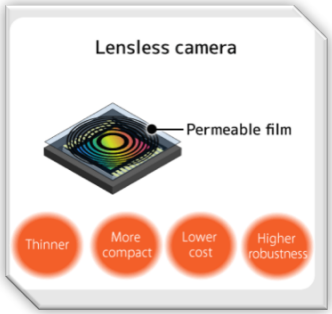
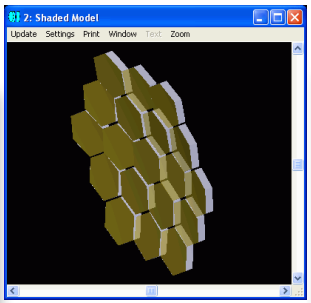
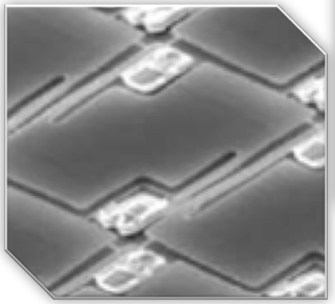
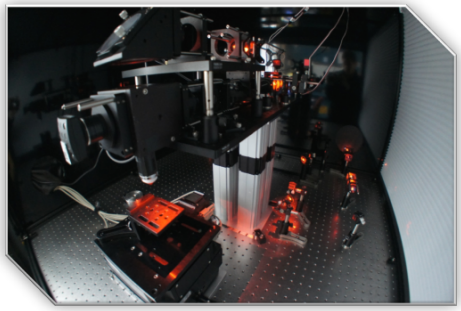
CONCLUDING REMARKS









"Ancient astronauts didn't build the pyramids. Human beings built the pyramids, because they're clever and they work hard."

Gene Roddenberry