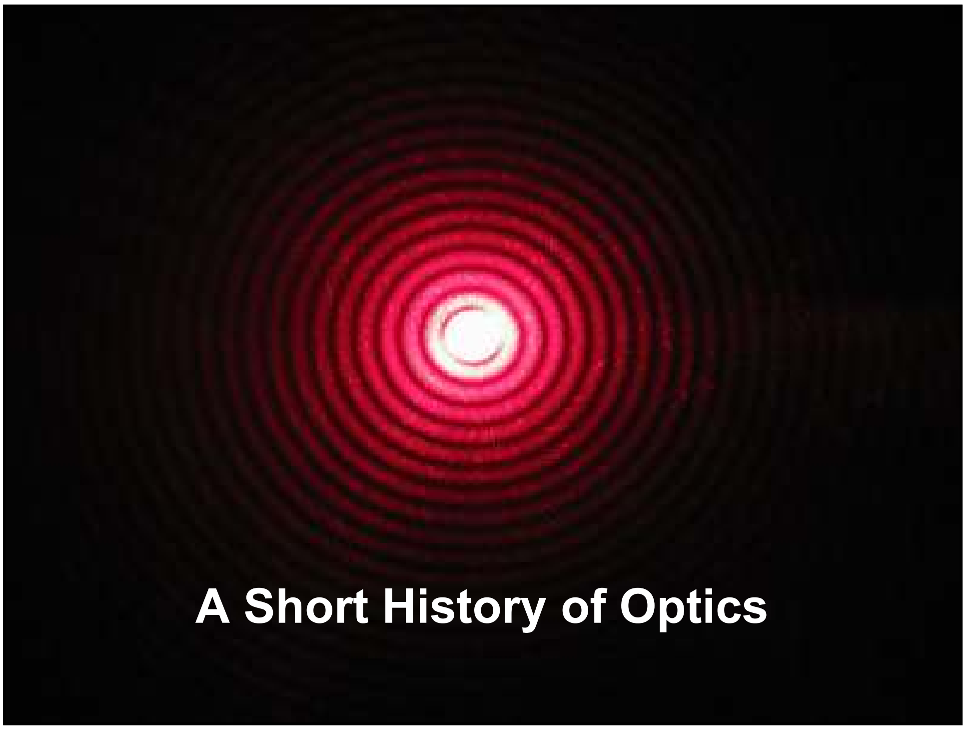
PY3101 Optics

Introduction: Overview

M.P. Vaughan

Overview

- A short history of optics
- Optical applications
- Course outline



A short history of optics

Optics: historically the study of visible light

Modern optics extends the spectrum to the near infrared and ultraviolet

Optics originates with **geometrical optics** – optics of lenses and mirrors

The Ancient Greeks

Euclid (c. 300 BC)

Optics

Views light as a cone of rays with the eye at the vertex.

Explains the phenomenon of perspective and unseen objects.

Raphael's The School of Athens

The Ancient Greeks

Hero of Alexandria

Catoptrica (c. 40 AD)

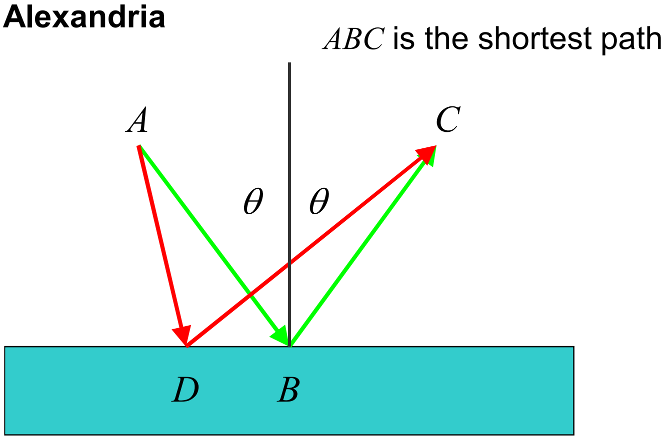
The path of a ray reflected from a plane to an observation point is the shortest possible path the light could have taken.

Related to Fermat's Principle. N.B. *variational principle*.

Hero of Alexandria

The Ancient Greeks

Hero of Alexandria

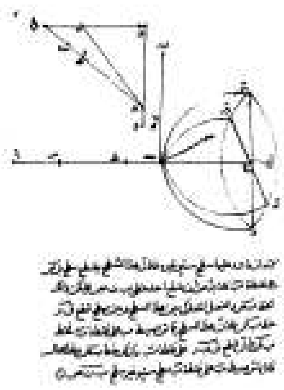


The Golden Age of Islam

Ibn Sahl (c. 940 – 1000)

On Burning Mirrors and Lenses (c. 984 AD)

First detailed formulation of *Snell's Law of refraction*



Excerpt from Ibn Sahl's treatise

The Golden Age of Islam

Alhazen (c. 965 - c. 1040)

Kitab al-Manazir (Book of Optics) (1011 – 1021)

Experiments on the rectilinear (straight line) propagation of light, reflection and refraction

Detailed description of the human eye

Alhazen

The Enlightenment

Galileo (1564 - 1642)

Improves Hans Lippershey's design of refracting telescope

Observes phases of Venus, sunspots and Galilean moons.

Galileo

The Enlightenment

René Descartes (1596 - 1650)

Derived Snell's Law in terms of sine functions

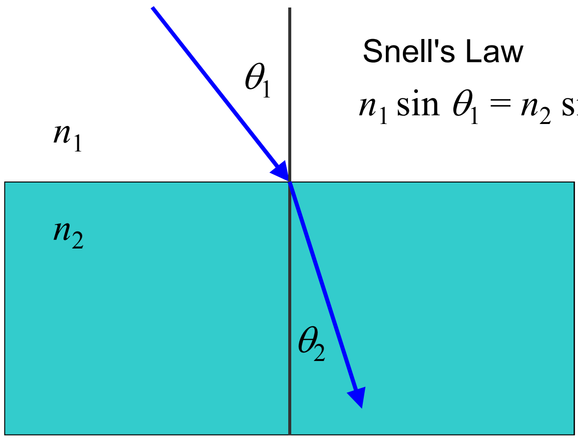
Showed that the angular radius of a rainbow from an observer is 42°

Advocate of the *wave theory of light*

René Descartes

The Enlightenment

René Descartes and Snell's Law

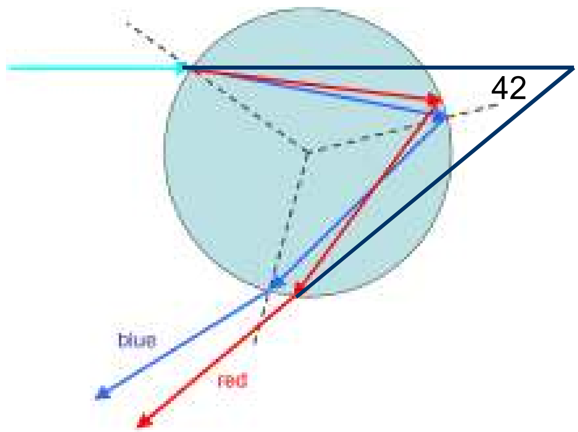


Snell's Law

$$n_1 \sin\,\theta_1 = n_2 \sin\,\theta_2$$

The Enlightenment

René Descartes and the rainbow



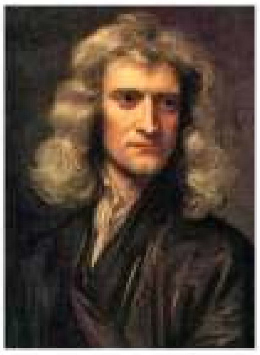
The Enlightenment

Isaac Newton (1642 - 1727)

Demonstrated decomposition of white light into the different colours of the rainbow via refraction through a prism

Built the first reflecting telescope

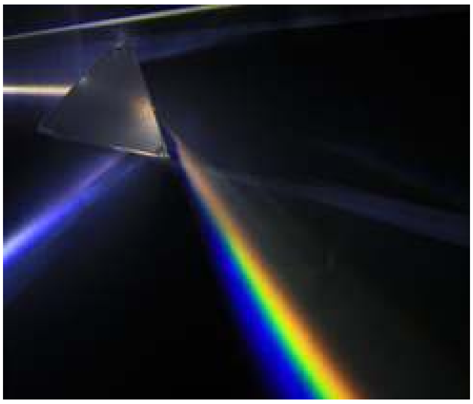
Advocate of the *corpuscular theory of light*



Isaac Newton

The Enlightenment

Isaac Newton and the prism



The Enlightenment

Pierre de Fermat (1607 - 1665)

Fermat's Principle:

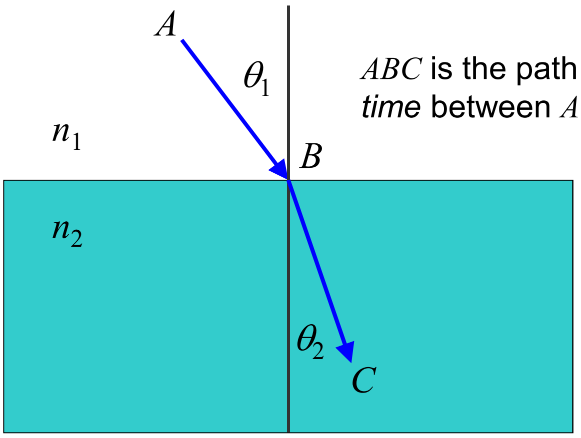
the path taken between two points by a ray of light is the path that can be traversed in the least time

N.B. *variational principle*.

Pierre de Fermat

The Enlightenment

Pierre de Fermat and Fermat's Principle.
Example: Snell's Law



ABC is the path of *least time* between A and C

Wave Optics

Christiaan Huygens (1629 - 1695)

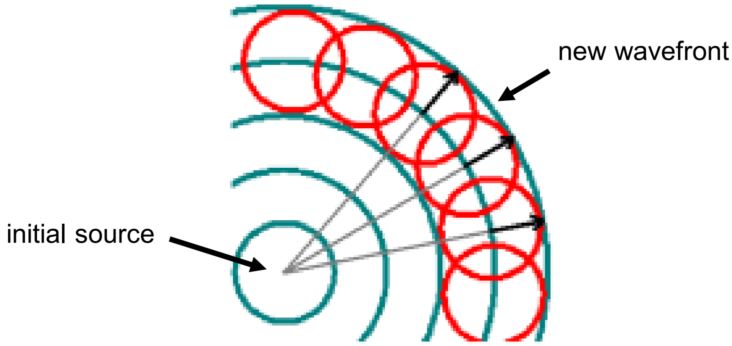
Huygens' Principle:

Each point on a wavefront acts as a source of secondary wavelets that, at some later time, adds up to give a new wavefront.

Christiaan Huygens

Wave Optics

Christiaan Huygens Huygens' Principle



Wave Optics

Thomas Young (1773 – 1829)

Double-slit experiment

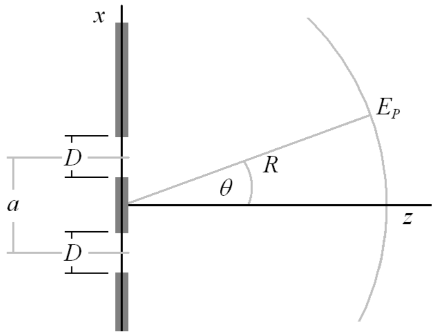
First conclusive evidence of the wave nature of light

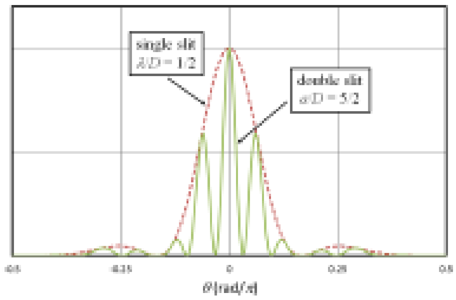
Early work on interference of light

Thomas Young

Wave Optics

Thomas Young double-slit experiment





Wave Optics

Augustin-Jean Fresnel (1788 – 1827)

Extensive work on interference and diffraction

Worked on polarisation of light

*Derived **Fresnels equations** for light propagation between different media*

Augustin-Jean Fresnel

Electromagnetism

James Clerk Maxwell (1831–1879)

Maxwell's Equations

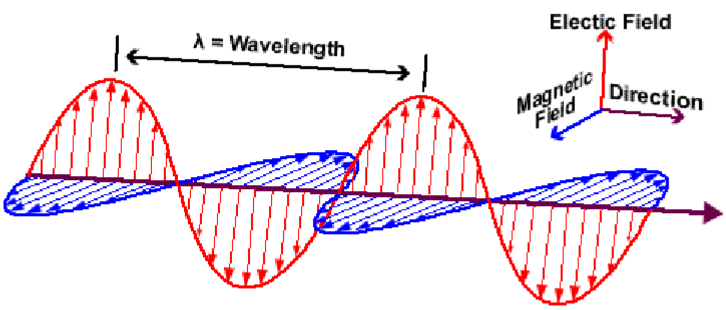
Predicted electromagnetic waves

Explained light as an electromagnetic wave and showed that the speed of light is a universal constant

James Clerk Maxwell

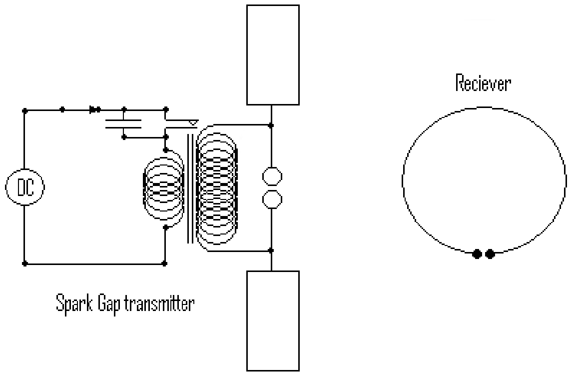
Electromagnetism

James Clerk Maxwell electromagnetic waves



Electromagnetism

Hertz generates radio waves in 1887



Heinrich Hertz

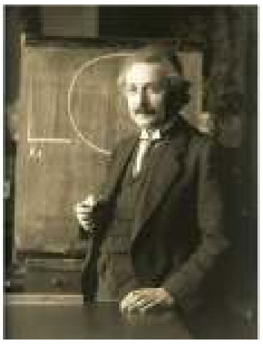
Electromagnetism

Albert Einstein (1879 – 1955)

Special Relativity Theory (1905)

Shows speed of light is the same for all observers

Does away with the need for the `luminous ether'



Albert Einstein

Quantum Mechanics

Max Planck (1858 – 1947)

*Explains **blackbody radiation** in 1894 by assuming light is emitted in quanta*

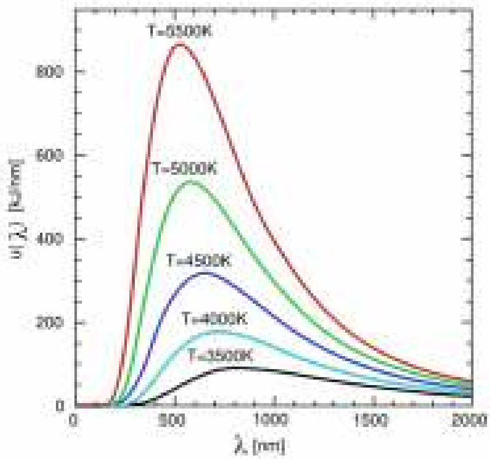
Energy of a quantum proportional to frequency

$$E = hf$$

Max Planck

Quantum Mechanics

Max Planck blackbody spectrum

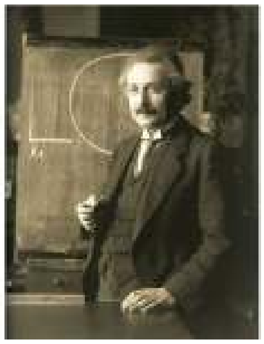


Quantum Mechanics

Albert Einstein (1879 – 1955)

*Explains the **photoelectric effect** in 1905 by assuming that the electromagnetic field itself is quantised*

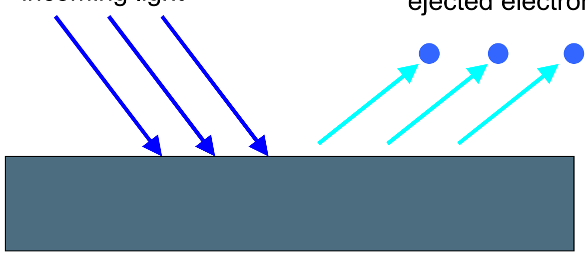
*Quanta later dubbed **photons***



Albert Einstein

Quantum Mechanics

Albert Einstein the photoelectric effect



- electron energy proportional to **frequency** of light
- number of electrons proportional to **intensity** of light
- electrons emitted immediately

Quantum Mechanics

Niels Bohr (1885 – 1962)

Explains stability of the atom in 1905 by assuming that the angular momentum of the electrons is quantised

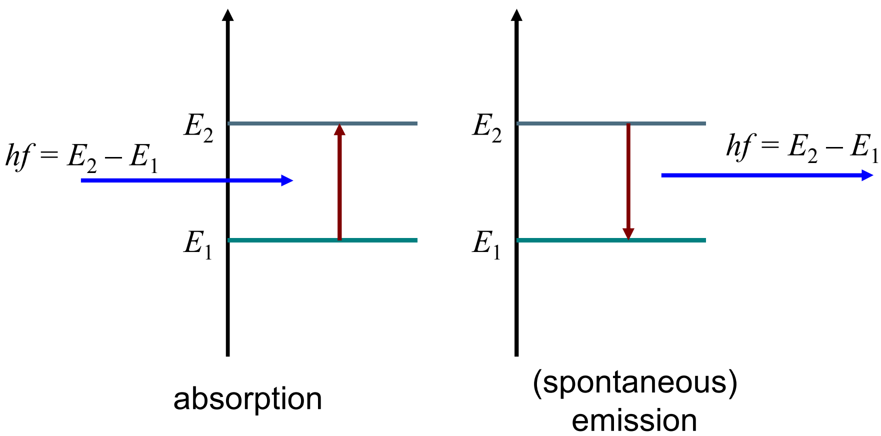
Implies ***discrete*** *electronic energy levels*

Transitions between levels via absorption or emission of photons

Niels Bohr

Quantum Mechanics

Niels Bohr model of the atom



Quantum Mechanics

Werner Heisenberg
(1901 - 1976)

Max Born
(1882 - 1970)

Pascual Jordan
(1902 - 1980)

Matrix mechanics

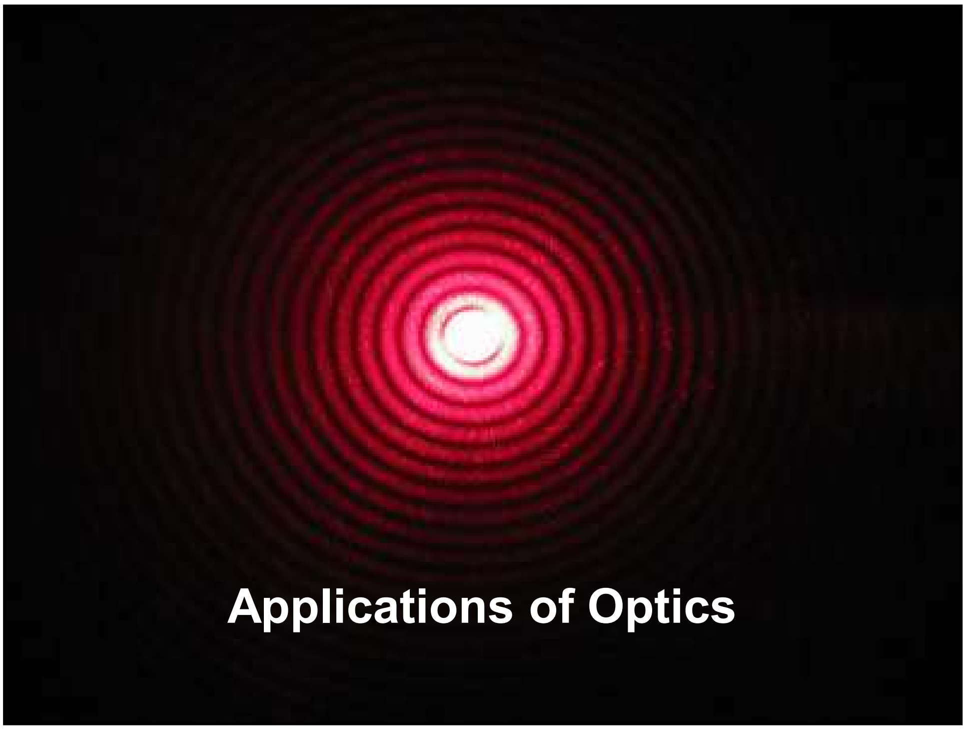
Involves derivation of **Heisenberg's Uncertainty Principle**. *This emerges from* ***wave mechanics*** *from the construction of* ***wave packets****.*

Quantum Mechanics

Louis de Broglie (1892 - 1987)

Gives relation between wavelength and momentum of particles (including photons), thus unifying wave and particle-like nature.

Louis de-Broglie



Some applications of optics

- Lenses and mirrors
- Spectroscopy
- Photonics
- Fibre optics
  - Waveguiding
  - Photonic devices
  - Nonlinear effects

Lenses and mirrors

Largely applications in **geometrical optics**

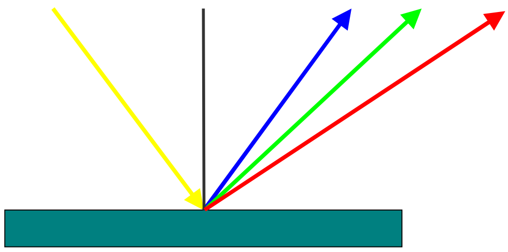
Ophthalmetry

Photography

Telescopes

Microscopes

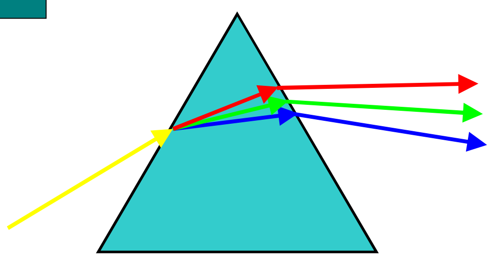
Spectroscopy



Diffraction grating

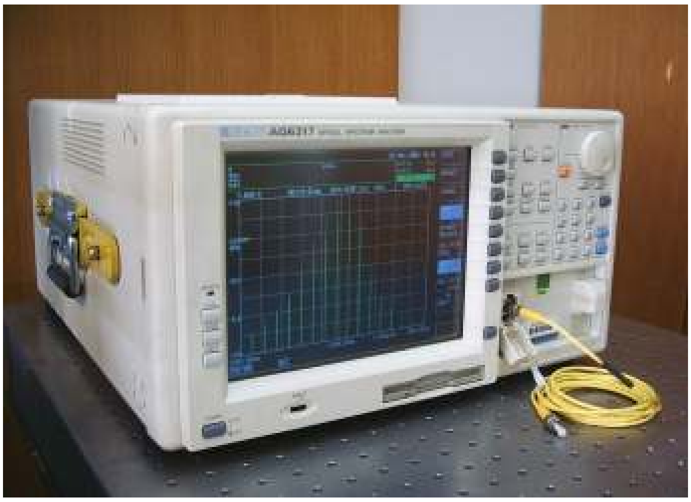
Analysis of light into spectral components

For example...



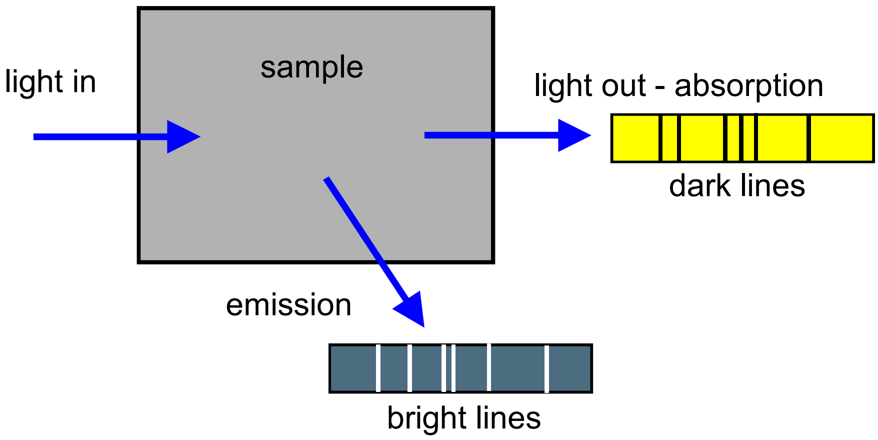
Prism

Spectroscopy



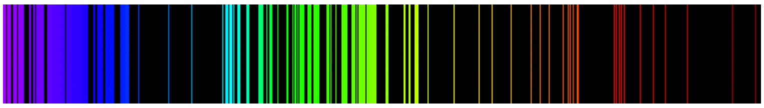
Optical spectrum analyser (OSA) based on diffraction gratings

Spectroscopy – emission and absorption lines



Spectroscopy – chemical analysis

Spectra provides `chemical fingerprint'



Emission spectrum of iron

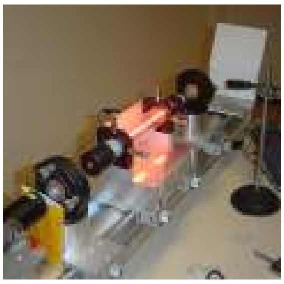
Many types of spectroscope techniques exist

Spectroscopy – astronomy

chemical composition of nebula

temperature of stars (blackbody radiators)

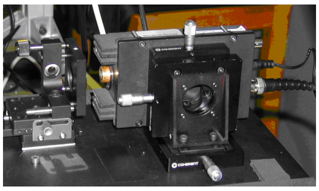
Photonics



HeNe laser

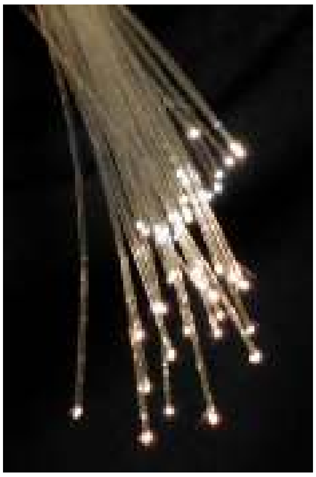
semiconductor laser

solar cell



avalanche photodetector

Fibre optics

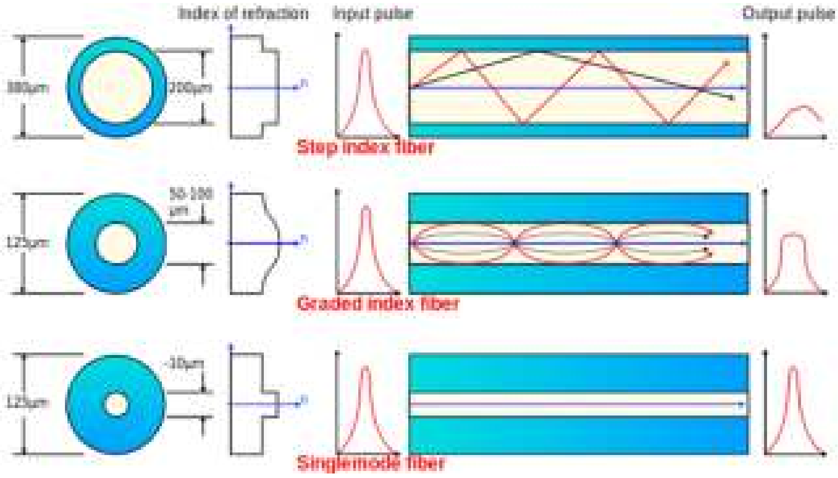


optical fibre guiding white light

laying optical communications fibre

Fibre optics – submarine network

Fibre optics – waveguiding



Fibre optics – photonic devices

- Lasers
- Detectors
- Amplifiers
  - Fibre amplifiers – e.g. erbium doped (EDFA)
  - Semiconductor optical amplifier (SOA)
- Modulators
- Wavelength converters

Fibre optics – nonlinear effects

- Four wave mixing

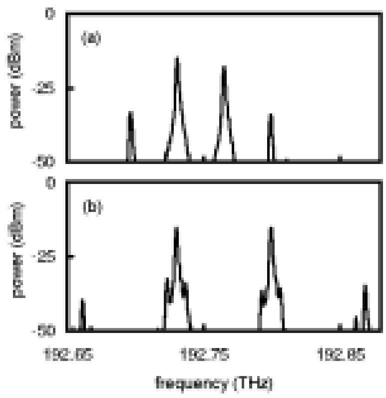


Fig. 6. OSA spectra with 80 mA (a) and 90 mA (b) SOA current.

[M.P. Vaughan, I. Henning, M.J. Adams, L.J. Rivers, P. Cannard and I.F. Lealman, *Mutual optical injection in coupled DBR laser pairs*, OPTICS EXPRESS 17, 2033 (2009)]

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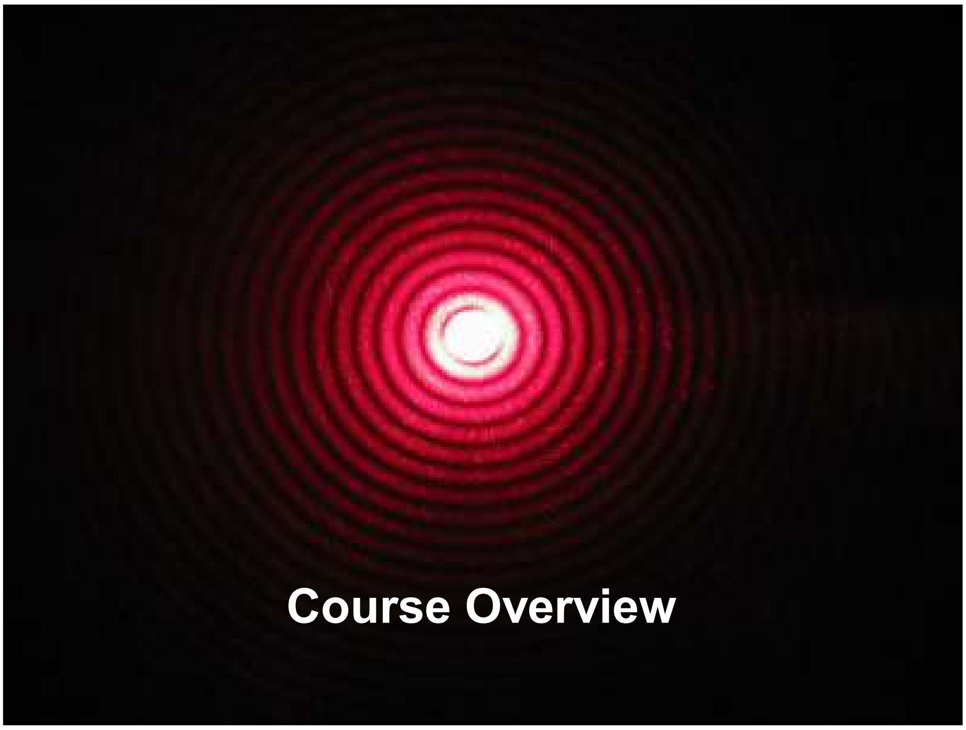
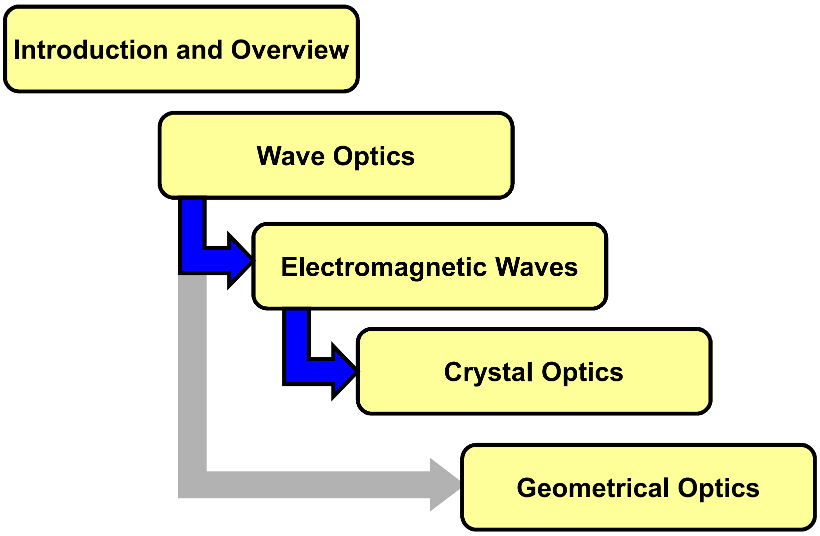


Course overview



Introduction and overview

- History and overview
- Waves and Photons
  - Discussion and comparison of the wave and photon theories of light
- Physics of Waves
  - Introduction to the general physics of waves with an emphasis on the universality of the concepts and mathematics

Wave Optics

- General physics of waves with application to optics
- Huygens-Fresnel Principle
- Derivation of Laws of Optical Propagation
  - Rectilinear motion
  - Reflection
  - Refraction
- Diffraction
- Diffraction gratings (use in spectroscopy)

Electromagnetic Waves

- Maxwell's Equations and the Wave Equation
- The susceptibility tensors (electric and magnetic)
  - Light propagation in isotropic media
  - Refractive index and dispersion
  - Optical loss
- Polarisation
  - Polarising optical elements (linear, retardation plates)
- Fresnel's Equations

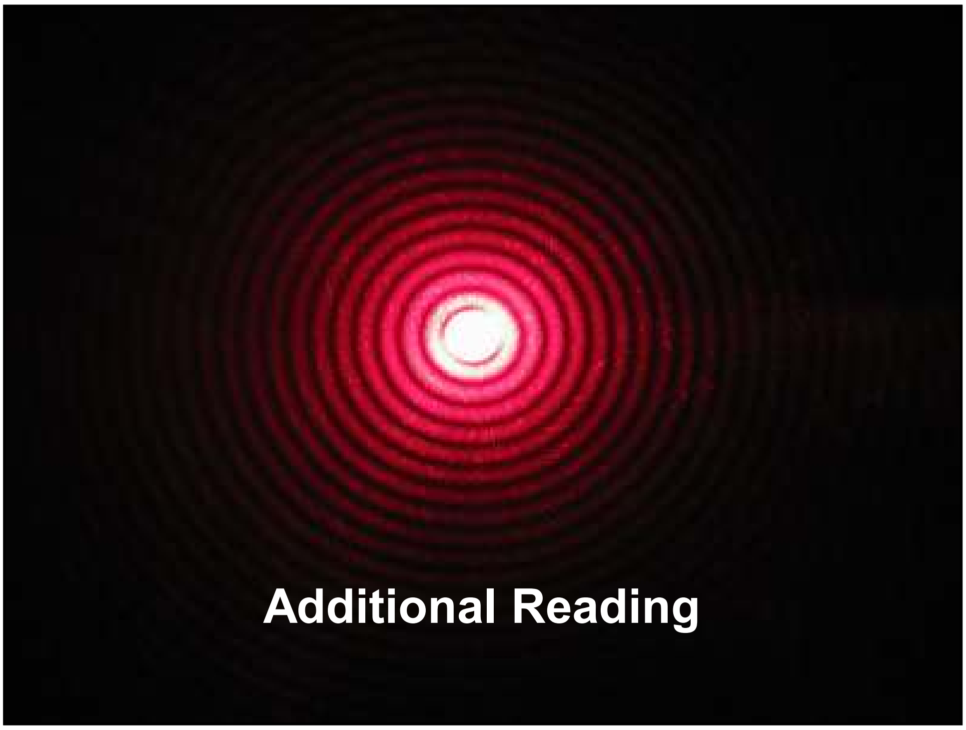
Crystal Optics

Crystal Optics – light propagation in *anisotropic* media

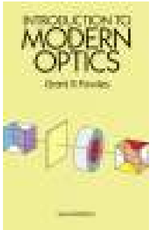
- Crystal symmetry
- The index ellipsoid
- Birefringence and pleochroism
- Interference figures
- Optical activity (Faraday rotation)

Geometrical Optics

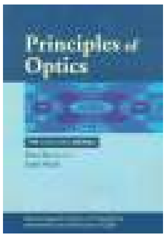
- Fermat’s Principle (least time)
- Derivation of Laws of Optical Propagation
- Imaging with lenses and mirrors
  - Perfect imaging
  - Spherical lenses and mirrors
  - Paraxial approximation
- Aberrations
- Systems of lenses and mirrors



Additional Reading

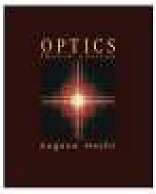


Grant R. Fowles, *Introduction to Modern Optics*, Dover Publications (1989)



Max Born and Emil Wolf, *Principles of Optics*, Cambridge University Press (1999)

(not for the faint-hearted!)



Eugene Hecht, *Optics*, Addison-Wesley (2001)

Assessment

	Lectures		Problem sets	
Week	**Session 1**	**Session 2**	**Set**	**Due**
1	*Intro*	*Waves Photons*		
2	*Physics of Waves*	*Huygens-Fresnel*		
3	*Diffraction*	*Diffraction*	03-Feb	
4	*EM waves*	*EM waves*		
5	*Polarisation*	*Polarisation*	17-Feb	17-Feb
6	*Fresenel Equations*	*Thin Film Interference*		
7	*Crystal Symmetry*	*The Index Ellipsoid*	03-Mar	03-Mar
8	*The Index Ellipsoid*	*Optical Activity*		
9	*Fermat's Principle*	*Perfect Imaging*	17-Mar	17-Mar
10	*Spherical Mirrors and Lenses*	*Spherical Mirrors and Lenses*		
11	*Problems and Exercises*	*Problems and Exercises*		31-Mar
12	*Problems and Exercises*	*Problems and Exercises*		
13	***Easter recess***	***Easter recess***		
14	***Easter recess***	***Easter recess***		
15	***Easter recess***	***Easter recess***		
16	***Easter recess***	***Study week***		

(subject to revision)