Optical and Laser Engineering Applications
ENSC 470-4 (Undergraduate) (3-0-2) 894-3 (Graduate) (3-0-0)

Professor

Glenn Chapman, Rm 8831; email glennc@cs.sfu.ca

Schedule for Fall 2017

Tuesday 17:00 - 18:20 Thursday 17:00 - 18:20, AQ5016
Tutorial: Tuesday or Thursday 16:30-17:00, AQ5016

Course Website

http://www.sfu.ca/~gchapman/e470out.html

Description

Optical Engineering is the study of the how optical elements can be applied to the design and construction of optical instruments, and their application to practical engineering problems. Lasers are increasingly moving from the laboratory into commercial products and industrial manufacturing. This course concentrates on the practical applications of optics/laser and less on the physics behind the behaviour. It starts with a basic explanation of the concepts of light then moves on to a concentrated understanding of optics, optical systems and optical design. Lasers operations, and interactions with optical systems (Gaussian optics) are covered, followed by the operational details and characteristics of the major laser types. The course then goes in detail of laser applications in engineering, an understanding of optical design and an introduction to fiber optics. In the lab the students will learn how use basic optical benches, lens setups, measurement tools and basic measurements with lasers and basic optical CAD concepts. Undergraduates (470) will do the three experimental labs while 894 Graduate students two labs and choose to do a minor or major project.

Prerequisites

Students need an introductory optics course (eg Phys 121), Math 310 and must be 3rd year or above. This course replaces 376 for the biophotonics stream.

Course Outline

Week 1: Introduction to light:
Spectrum, electromagnetic nature of light, black body radiation, optical interaction with materials, units of optical measurement, photometry and radiometry
Week 2: Basic Optical elements
Reflection, mirrors, refraction, lenses, human eye
Week 3: Geometric Optics
Geometric optics: reflective systems, refractive systems, matrix and ray tracing. Setting up optics in the lab
Week 4-6: Introduction to lasers & Laser Safety
Basic laser theory of operations, Gaussian optics; characteristics practical operations and care of major laser types:
Gas, Ion, Eximer, Solid State, Dye, Metal Vapour, Semiconductor, X-ray
Dangers in laser uses, potential damages, safety procedures
Week 7: Aberrations in optical systems
Aberrations from mirrors or lenses: beyond the first order approximations of geometric optics
Week 8: Polarization, Interferometry and interferometers
Polarization of light by materials: applications to the LCD display, interference and interferometers
Week 9: Diffraction & Spectrometers
Diffraction of light, Fraunhofer and Fresnel, optical resolution, diffraction gratings, spectrometers, nonlinear optical switches.
Week 9b: How optical elements are fabricated
Fabrication of mirrors and lenses; methods of measuring optical surfaces, lens/mirror quality
Week 10-11: Optical system Design & Zemax CAD
Design of multi-element optical systems; eyeglasses, achromatic optical elements, eyepieces, microscopes, reflecting and refracting telescopes, multi-element photographic lenses, digital cameras, optical CAD (Zemax).
Week 11-12: Laser Applications:
Laser heat treatment, laser heat flow calculations, surface melting, alloying, cladding, cutting, medical applications.
Week 12: Laser Consumer and Holography Applications
Compact disk, DVD operation/mastering, Applications in microelectronics, and holography
Week 13: Photonics, Fiber optics and Integrated Optics
Photodetectors, nonlinear optics, Guided light, integrated optics, Photonics. Laser Fusion, Laser flight, Course summery.

Laboratory

Labs will consist of demonstration labs and experimental project labs. Demonstrations will include the operation and use of laboratory bench optics devices and alignment. 3 Labs are planned for the course:
(1) Lens optics and aberrations measurements
(2) Spectrometer measurement of laser and light sources
(3) CW laser optical setup (beam expander) and beam measurements
(4) Laser dye bleaching
(5) Creation of Holograms lab.
Graduate students will do either a major or minor project in place of lab 4, which will be either from a list of projects or a project connected to their graduate studies.

Lab demos: LA01 Wednesday 17:30-19:20 ASB 10878
LA02 Thursday 14:30-16:20 ASB 10878
These times are for demos of labs. Students book time for their own lab in the same room

Laser Safety

Students must attend the Laser Safety lecture in the class in order to do the labs involving lasers. Students attending that class can take a test to get a Laser Safety certificate for SFU that is required for graduate or undergraduate research lab work with lasers.

Text Book

Full notes will be supplied to students on the web.
Suggested:
Jeff Hecht, "Understanding Lasers, an Entry Level Guide", Wiley/IEEE
Breck Hitz, J.J. Ewing, Jeff Hecht, "Introduction to laser technology, third edition"
Library electronic version available from the SFU library under the IEEE explore ebook section.

Assignments

Assignments will be given every 2-3 weeks after the second week of class. Assignments will be emailed to the students. Each student gets a separate assignment with the same questions but different parameters and solutions. If you used someone else's numbers you get zero on the question. If you do that twice within one assignment you get zero on the assignment. You will be emailed a solution set to your specific questions.

Tutorial/Problem Workshops

Tutorials will be held on an as announced basis (not every week but about every 2nd week) – typically in the hour before class (either day). These will involve workshops where a problem is assigned, worked through in groups, and then solutions given. Typically 2 problems per session. Post workshop problem solutions will be posted to web site.

Marking

Undergrads
Best of: 15% Weekly Assignments, 15% Midterm test, 40% Final Exam, 30% Project/Labs
25% Weekly Assignments, 50% Final Exam, 25% Project/Labs
Graduates
Best of: 15% Weekly Assignments, 15% Midterm test, 40% Final Exam, 30% Project/Labs
20% Weekly Assignments, 20% Midterm test, 20% Labs, 40% major project
Major projects are only for students working on their graduate thesis in the laser/optics fields. Projects are done in cooperation with their supervisor. They must use their own equipment and supplies for such project

Teaching Assistant

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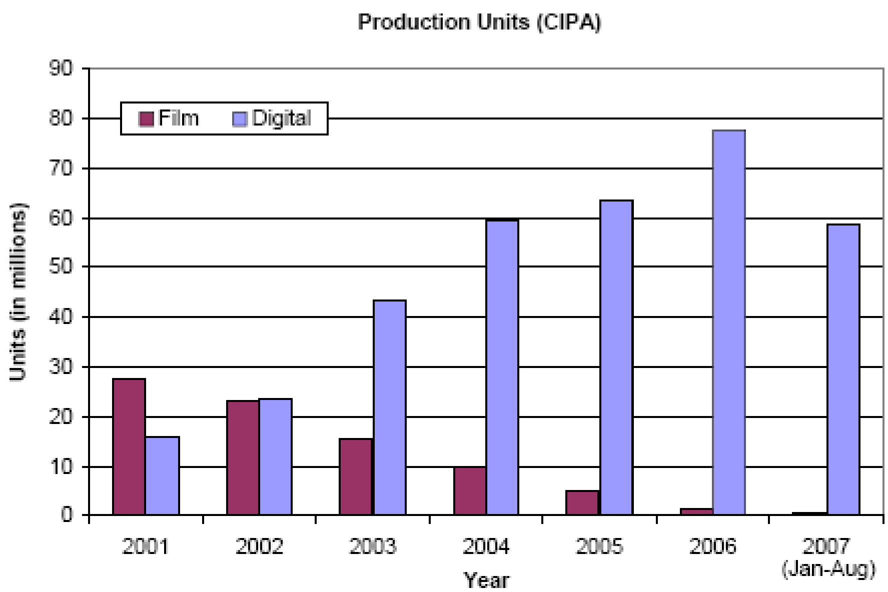
Class Email:

ensc-470, ensc894-g100

Why Study Optics?

- Optics one of the fastest growing technical fields
- Digital Cameras ~$24 Billion market
- High end digital cameras growing at 24% per year
- Lasers $9.7 Billion market
- Microchip Fabrication optical equipment ~$10Billion
- Optical Sensors now driving force in Microchip demand
- Light Emitting Diode lighting to replace traditional lightbulbs



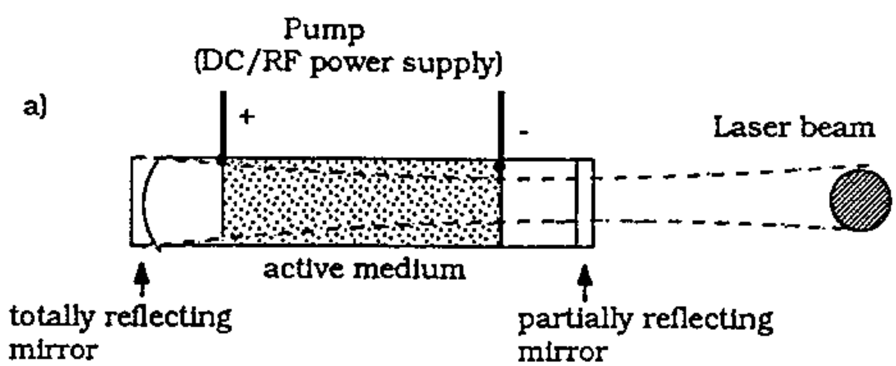
Statistics of Production of Film and Digital Cameras

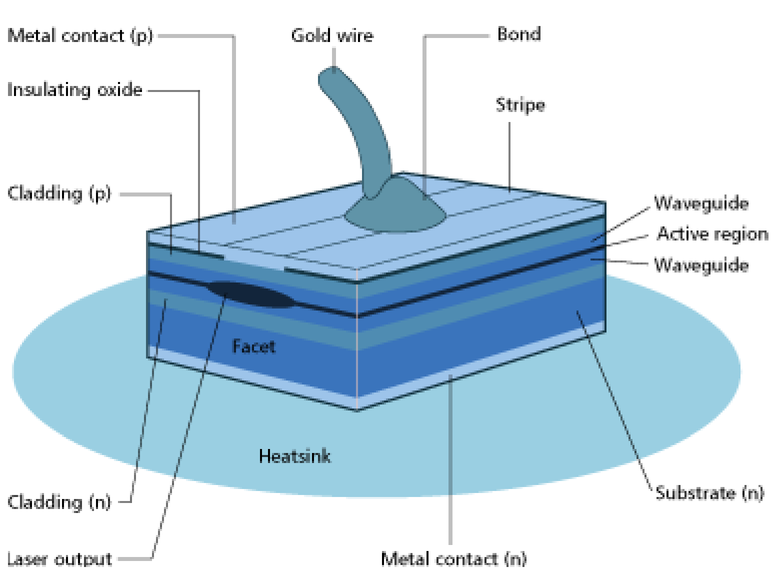
What are Lasers?

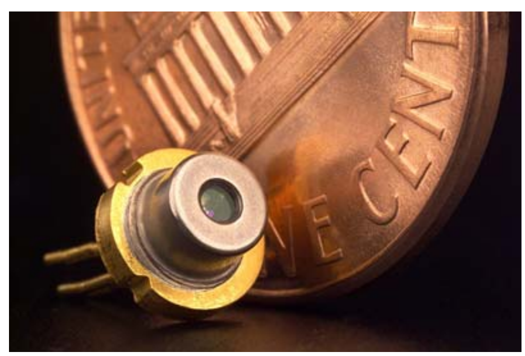
"Now you know the difference between a moon beam and a laser beam!"

What are Lasers?

- Light Amplification by Stimulated Emission of Radiation LASER
- Light emitted at very narrow wavelength bands (monochromatic)
- Light emitted in a directed beam
- Light is coherenent (in phase)
- Light often Polarized
- Diode lasers much smaller but operate on similar principals







Why Study Lasers: Market & Applications

- Market $11.1 billion (2016) (just lasers)

Major areas:

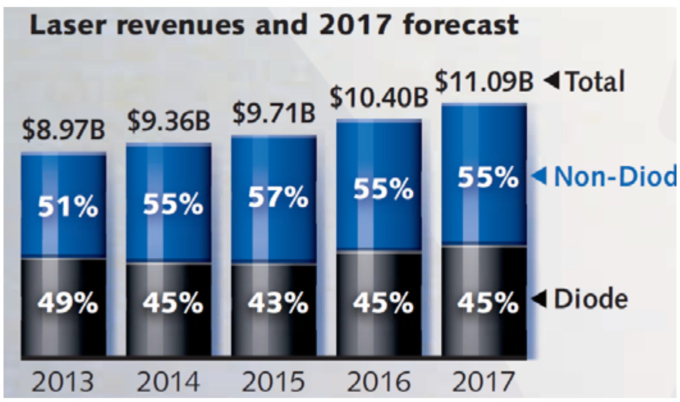
- Market Divided in laser Diodes (45%) & Non diode lasers (55%)

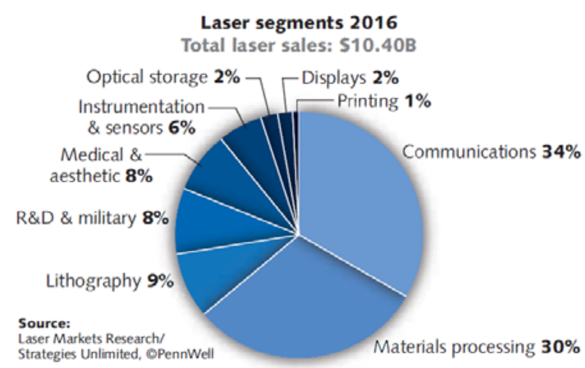
Traditional Non Diode Laser

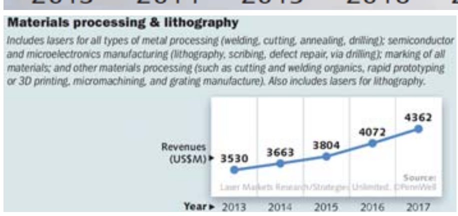
- Materials Processing (30%), Communications (34%)
- Medicine (8%), Scientific(8%)

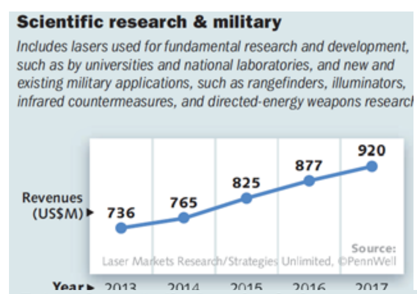
Diode Lasers

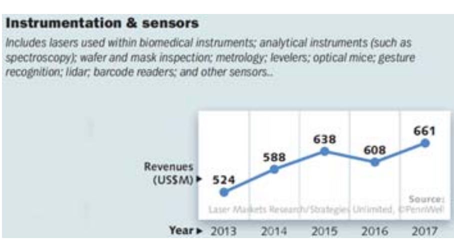
- Entertainment/CD/DVD/Printers (~22%)
- Telecommunications (31%) & Optical Storage (14%)

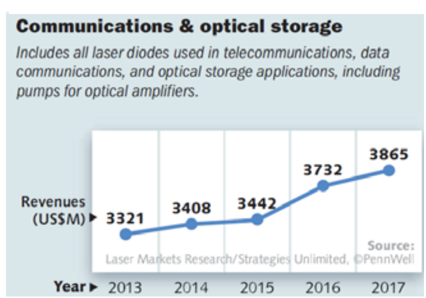


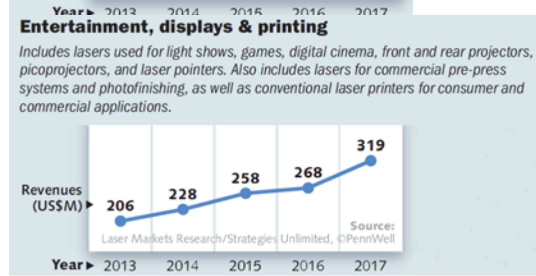


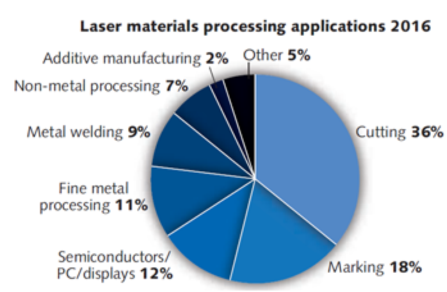












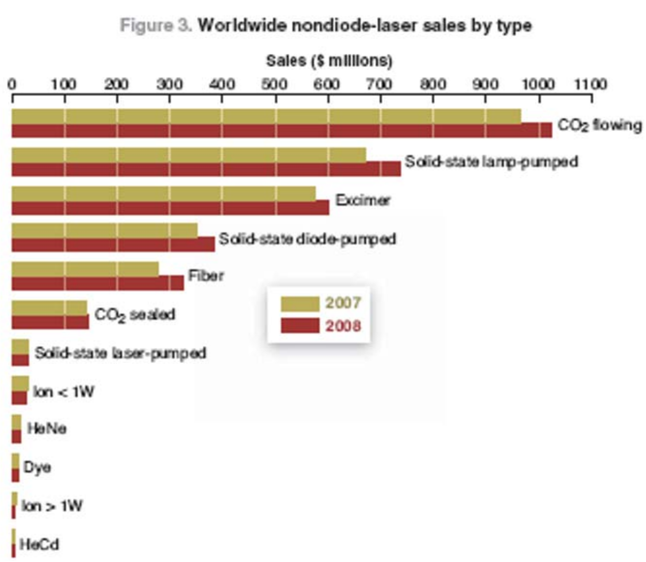
Why Study Lasers: Laser Types

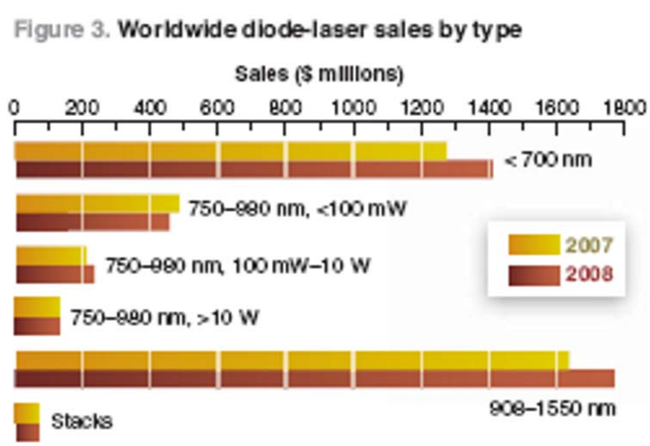
Traditional Lasers

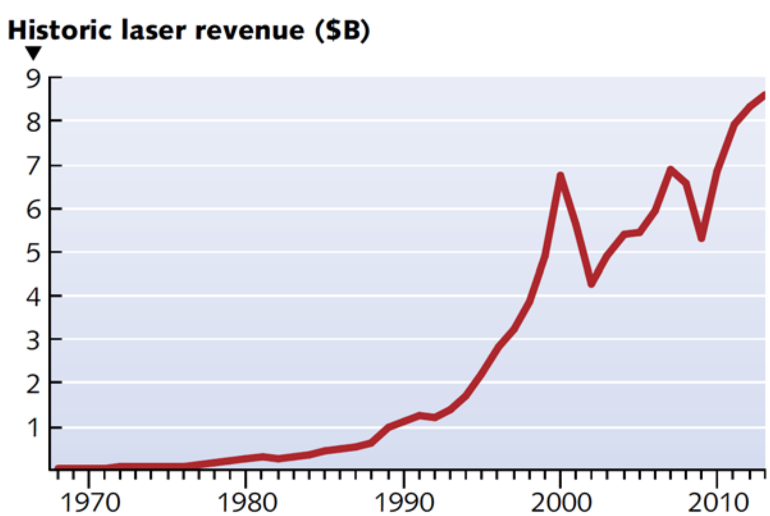
- Solid State laser (Infra Red to Visible)
- CO_2 Gas laser (Far Infra Red)
- Eximer Lasers (UV light)
- These mostly used in material processing

Diode Lasers

- Near Infra Red diodes dominate
- Mostly used in telecommunications and CD's
- Visible diode use is increasing
- DVD's driving this







History of the Laser

- 1917: Einstein's paper showing "**Stimulated Emission**"
- 1957: MASER discovered: Townes & Schawlow
- Demonstrates population inversion
- 1960: First laser using Ruby rods: Maiman
  first solid state laser
- 1961: gas laser
- 1962: GaAs semiconductor laser
- 1964: CO_2 laser
- 1972: Fiber optics really take off
- 1983: Laser CD introduced
- 1997: DVD laser video disks

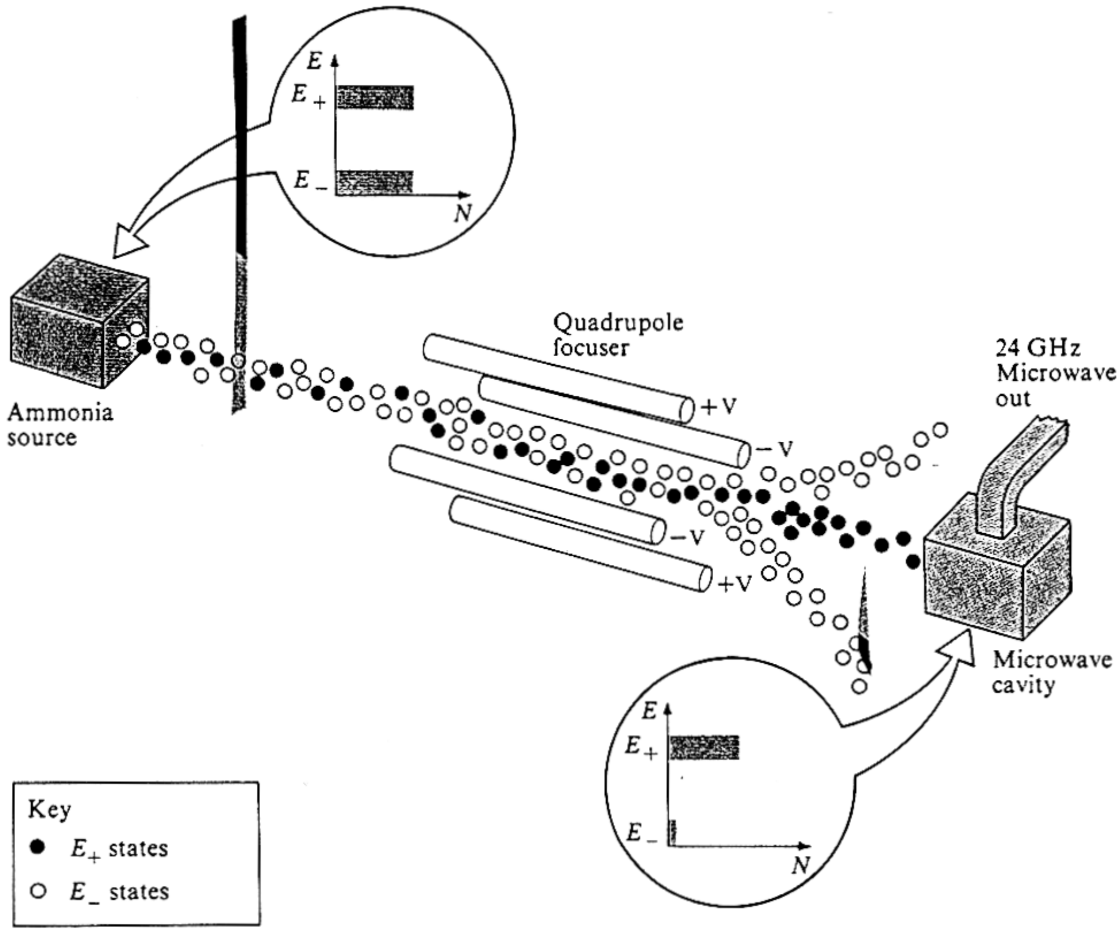
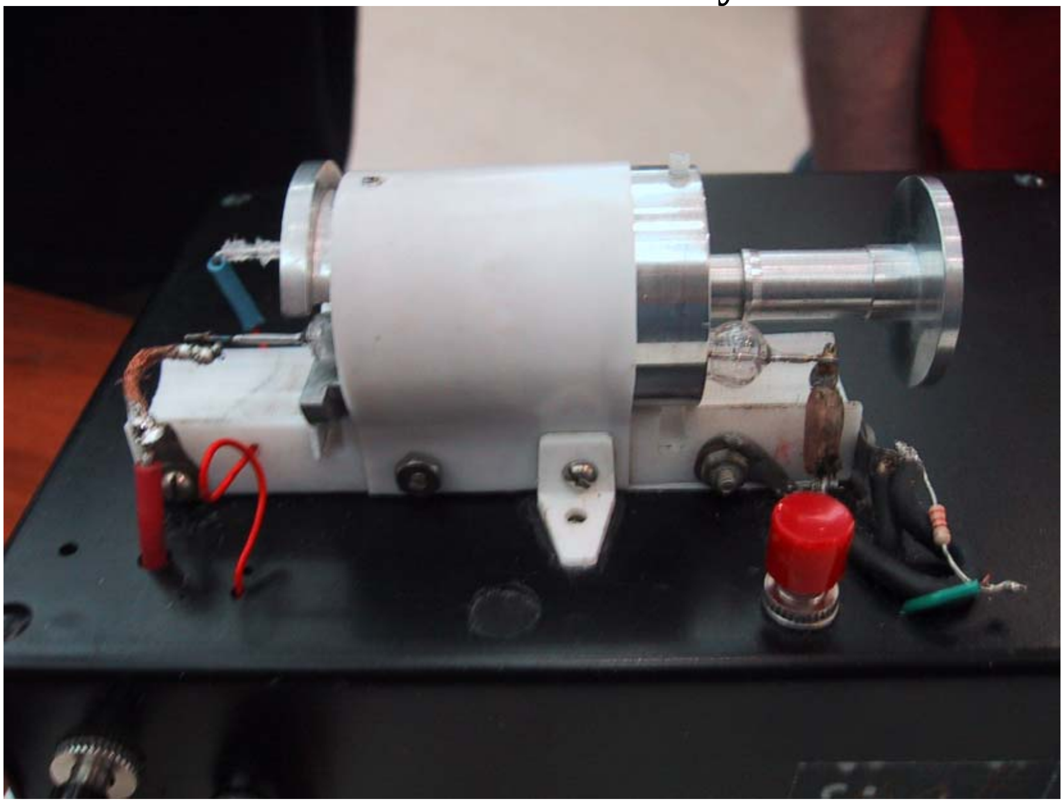


Fig. 3.4 Schematic of the ammonia-beam maser. Because the energy separation of the two states (● and ○) is small compared to the thermal energy of the system ($E_+ - E_- \ll kT$), the energy levels are nearly equally populated (top insert). By passing the atoms through an electric field gradient (quadrupole focuser), the higher-energy-state atoms (●) are directed into a microwave cavity resonant at $\nu = (E_+ - E_-)/h$. This physical separation creates a population inversion in this two-level system (bottom insert).

World’s First Laser: Ruby Laser

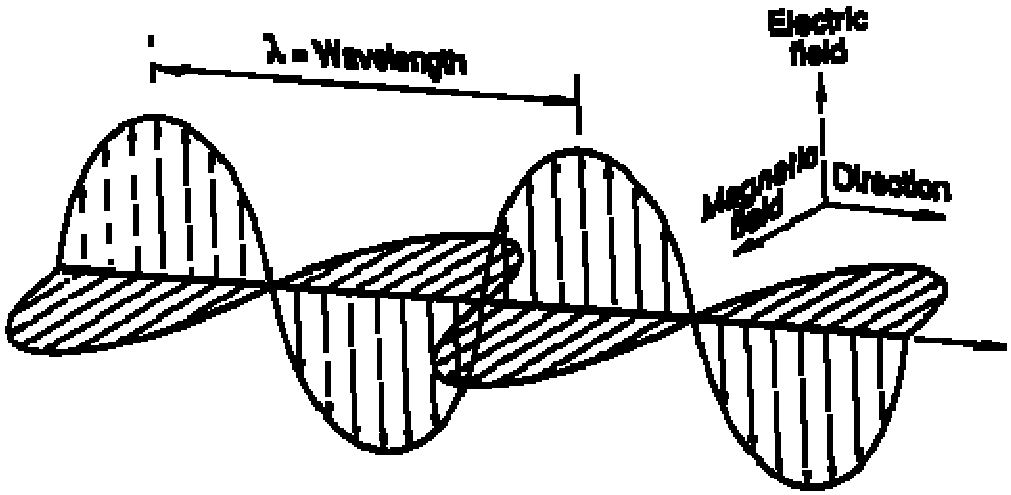


Dr. Maiman: Inventor of the World’s First Laser (on left)

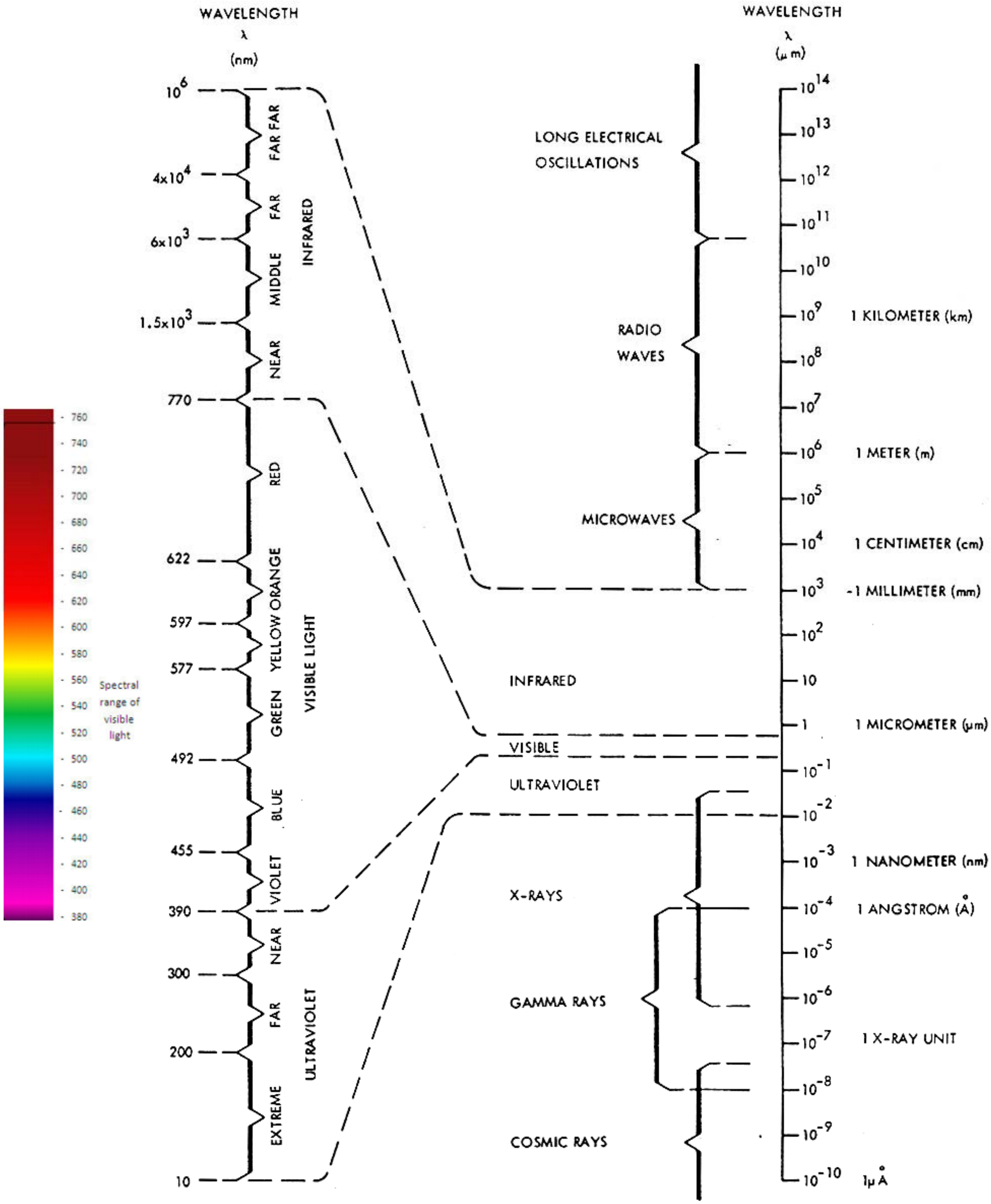
Light – Electro-Magnetic Radiation

- Light has both wave and quantum aspects
- Light as wave is Electro-Magnetic Radiation
- Important factors for the laser

λ = wavelength (for laser from mm to 10 nanometres (nm))
f = frequency (hertz)
τ= period (typically 10^{-15} sec)



Electromagnetic Spectrum



Light and Atoms

- Light: created by the transition between quantized energy states
- Creates wave packets – photons with an energy E

$$c = \nu\lambda$$

$$E = h\nu = \frac{hc}{\lambda}$$

c = speed of light
ν = frequency
hc = 1.24 x 10^{-6} eV m

- Energy is measured in electron volts
  1 eV = 1.602 x 10^{-19} J

- Atomic Energy levels have a variety of letter names (complicated)
- Energy levels also in molecules: Bending, stretching, rotation

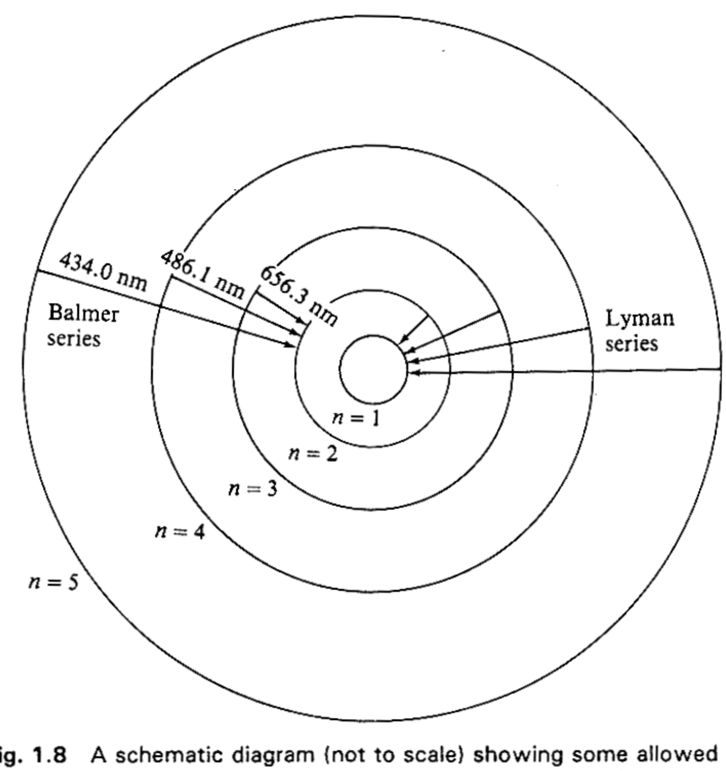
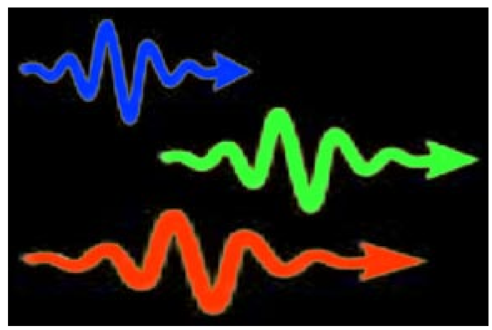


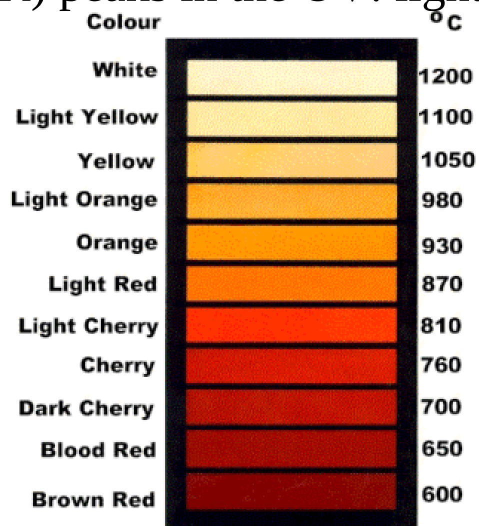
Fig. 1.8 A schematic diagram (not to scale) showing some allowed electron orbits in the Bohr model of the hydrogen atom. The electron transitions giving rise to some of the wavelengths in the line spectrum of hydrogen are also shown.

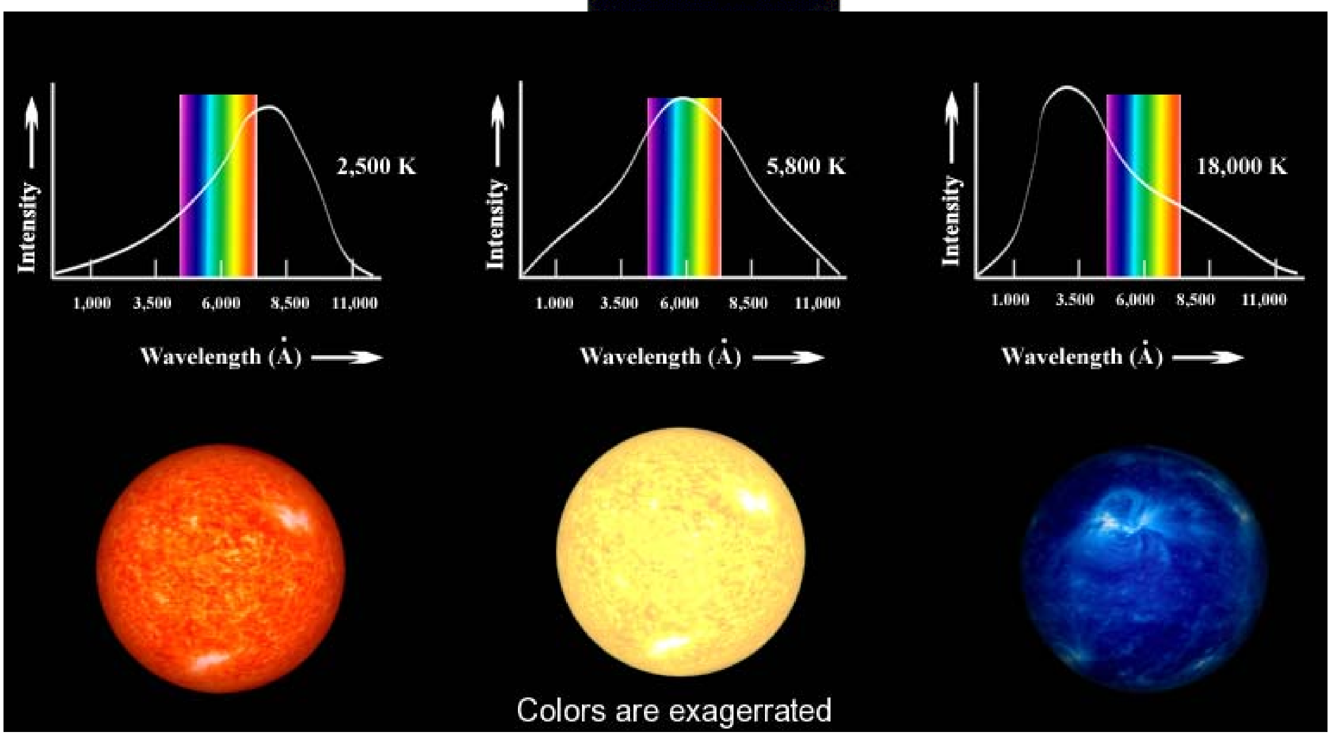


Photon wave packets

Black Body Emitters

- Most normal light emitted by hot "Black bodies"
- As temperature increases colour shifts from red to blue/white
- Just like a furnace goes from red to yellow to white
- Peak of emission of black body increase linearly with temperature
- Sun has a surface temperature of 6100 ^{o}K
- Peak colour in the green
- A cooler star (2500 ^{o}K) peaks in the infrared: light is reddish
- Hotter star (18,000 ^{o}K) peaks in the UV: light is bright blue/violet





Colors are exagerrated

Black Body Emitters

- Classical Black Body radiation follows Plank's Law

$$E(\lambda,T) = \frac{2\pi hc^2}{\lambda^5} \frac{1}{\left[\exp\left(\frac{hc}{\lambda KT}\right) - 1\right]} \quad W/m^3$$

h = Plank's constant = 6.63 x 10^{-34} J s
c = speed of light (m/s)
λ = wavelength (m)
T = Temperature (°K)
K = Boltzman constant 1.38 x 10^{-23} J/K = 8.62 x 10^{-5} eV/K

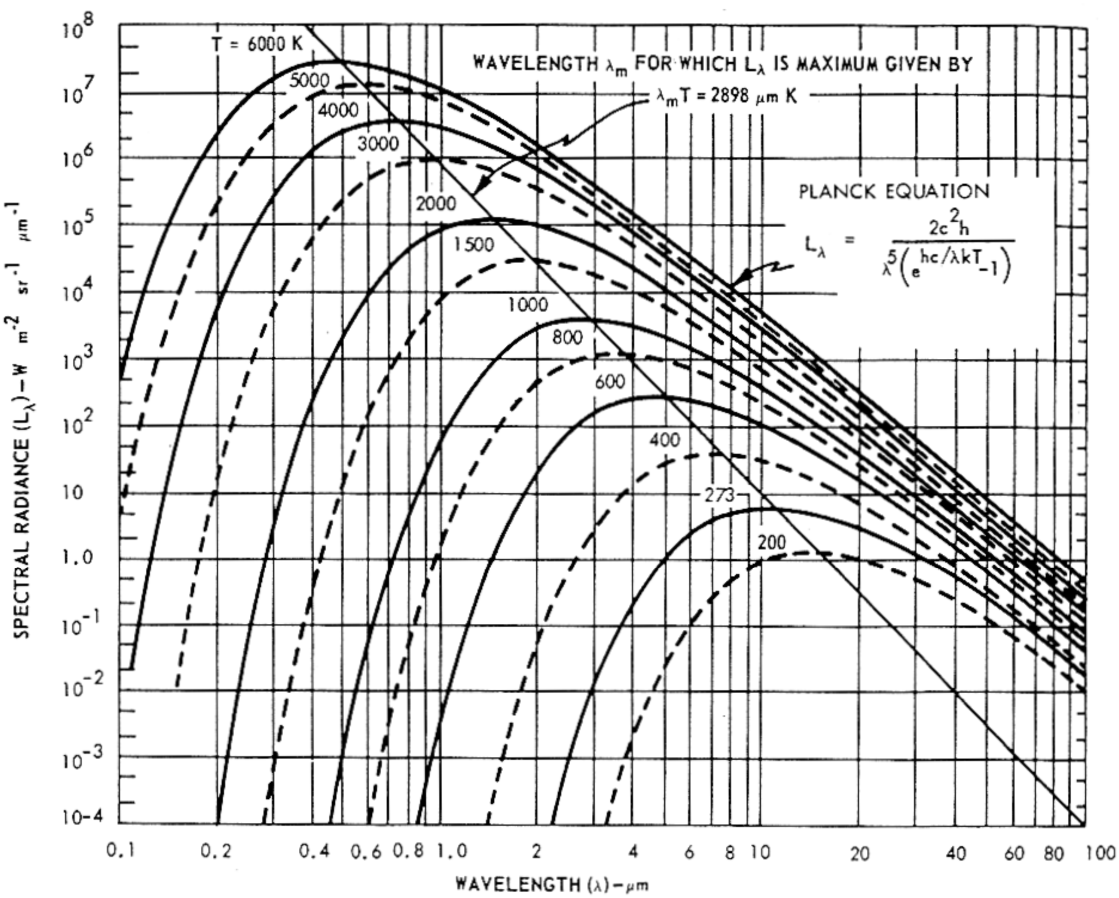


Fig. 4-1 Spectral radiance L_λ of a blackbody at the absolute temperature T shown on each curve. The diagonal line intersecting the curves at their maxima shows Wien's displacement law. Subdivisions of the ordinate scale are at 2 and 5.

Black Body Emitters: Peak Emission

- Peak of emission Wien's Law

$$\lambda_{max} = \frac{2897}{T} \quad \mu m$$

T = degrees K

- Total Radiation Stefan-Boltzman Law

$$E(T) = \sigma T^4 \quad W/m^2 = \int_0^\infty E(\lambda, T)\, d\lambda$$

σ = Stefan-Boltzman constant = 5.67 x 10^{-8} W m^{-2} K^{-4}

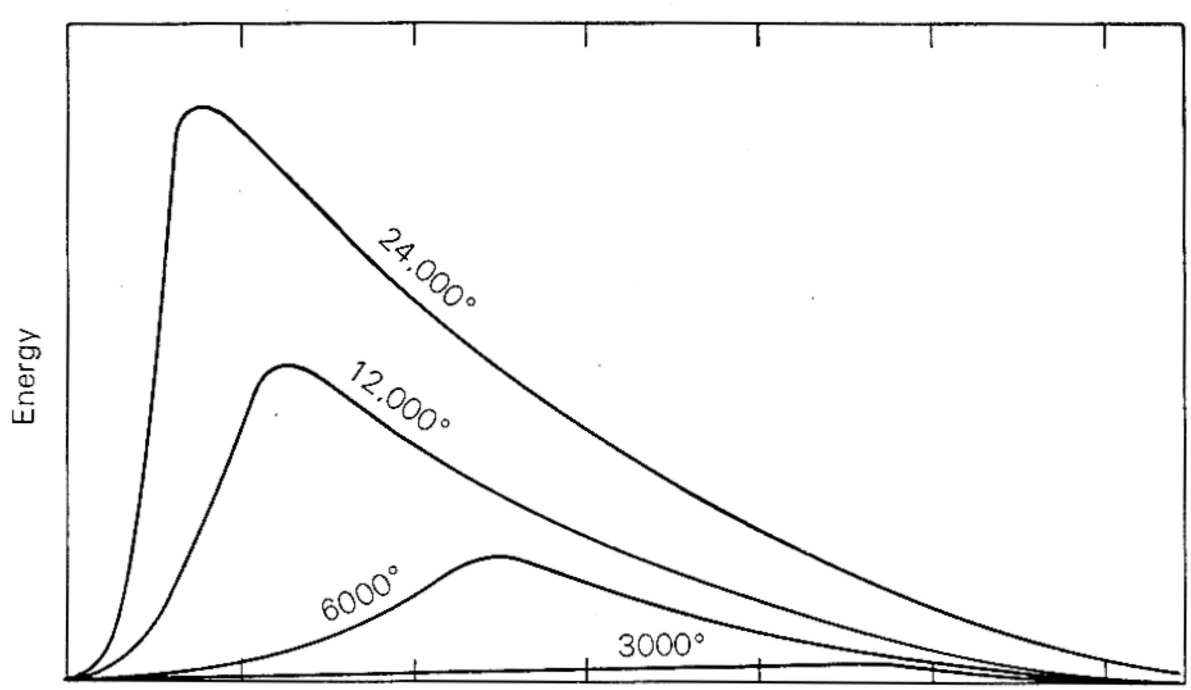


FIG. 10-17 Energy emitted at different wavelengths for black bodies at several temperatures.

Example of the Sun & Colour Temperature

- Sun has a surface colour temperature of 6100 ^{o}K
- What is its peak wavelength?

$$\lambda_{\max} = \frac{2897}{T} = \frac{2897}{5778} = 0.501 \mu m \text{ or Blue green}$$

- How much power is radiated from its surface

$$E(T) = \sigma T^{4} = 5.67x10^{-8}\, x\, 6100^{4} = 7.85x10^{7}\; W/m^{2}$$

- ie 78 MW/m^2 from the sun's surface
- In photography call T the colour temperature of the source
- Camera colour balance adjusts RGB ratios for a given T
- Human eye does much better than camera white balance

Model lit on left by Incandescent light, on right by sunlight
5600K balance (sunlight) 3200K (Tungstan)

Black Body, Gray Body and Emissivity

- Real materials are not perfectly Black – they reflect some light
- Called a Gray body
- Impact of this is to reduce the energy emitted
- Reason is reflection at the surface reduces the energy emitted
- Measure this as the Emissivity ε of a material

  ε = fraction energy emitted relative to prefect black body

$$\varepsilon = \frac{E_{material}}{E_{black\ body}}$$

- Thus for real materials energy radiated becomes

$$E(T) = \varepsilon\sigma T^4 \ W/m^2$$

- Emissivity is highly sensitive to material characteristics & T
- Ideal material has ε = 1 (perfect Black Body)
- Highly reflective materials are very poor emitters

Material	Total Emissivity	
Tungsten	500 K	0.05
	1000 K	0.11
	2000 K	0.26
	3000 K	0.33
	3500 K	0.35
Polished silver	650 K	0.03
Polished aluminum	300 K	0.03
Polished aluminum	1000 K	0.07
Polished copper		0.02–0.15
Polished iron		0.2
Polished brass	4–600 K	0.03
Oxidized iron		0.8
Black oxidized copper	500 K	0.78
Aluminum oxide	80–500 K	0.75
Water	320 K	0.94
Ice	273 K	0.96–0.985
Paper		0.92
Glass	293 K	0.94
Lampblack	273–373 K	0.95
Laboratory blackbody cavity		0.98–0.99

Figure 8.8 The *total* emissivity of a number of materials.

Light – Electro-Magnetic Radiation

- Light has both wave and quantum aspects
- Light as wave is Electro-Magnetic Radiation
- Uses typical wave equation

$$\Psi(x,t) = A\sin(kx - \omega t)$$

Where

Wave vector $k = \frac{2\pi}{\lambda}$

t = time (sec)

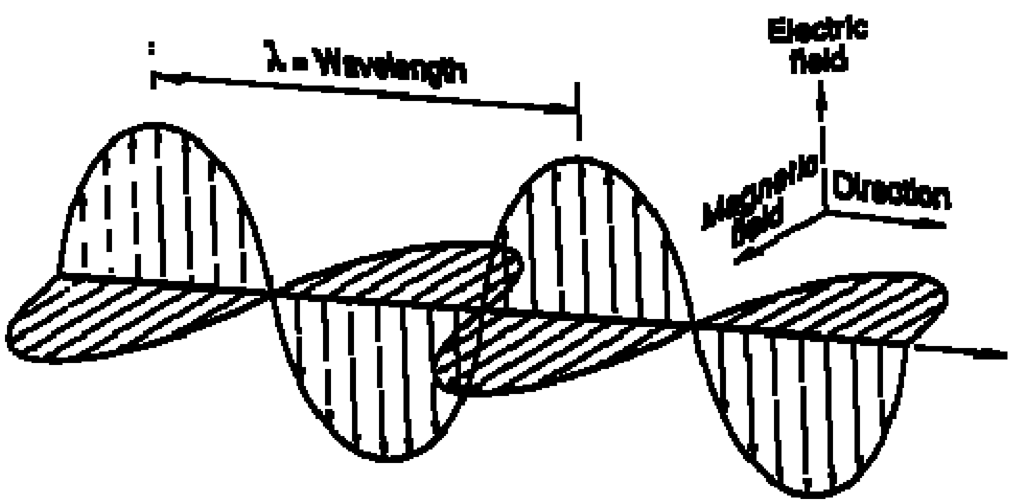
λ = wavelength

ω= angular frequency (radians/sec)

$\omega = 2\pi f = \frac{2\pi}{\tau}$

f = frequency (hertz)

τ= period (sec)



Light - Electro-Magnetic Radiation

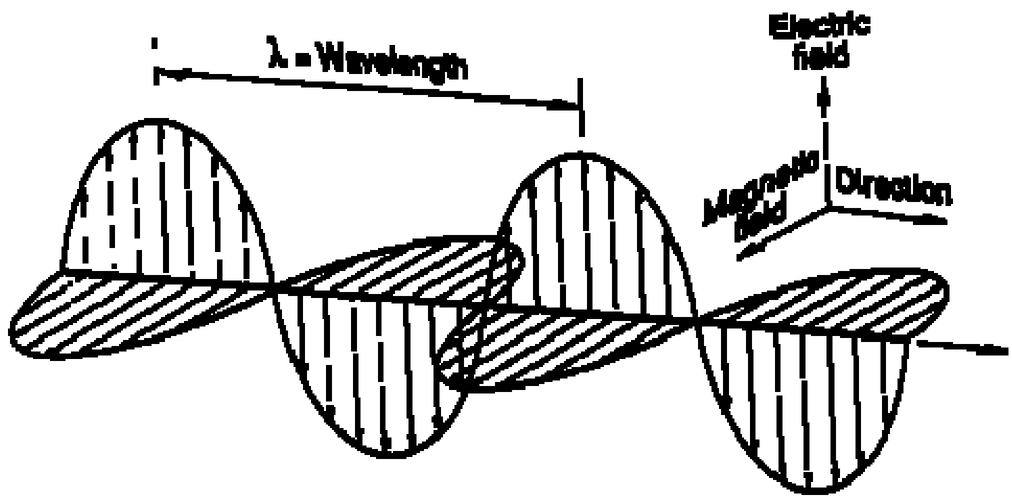
- Light in vacuum has Electric field and magnetic field at 90^o
- Obtained from Maxwell's Equations
- Electric wave

$$E_y(x,t) = E_0 \cos\left[\omega\left(t - \frac{x}{c}\right)\right]$$

Where c is the velocity of light

- Magnetic wave

$$B_z(x,t) = \frac{E_0}{c} \cos\left[\omega\left(t - \frac{x}{c}\right)\right]$$



Plane Waves

- Plane waves:
- Same E field intensity in a plane perpendicular to direction $\vec{r}$
- If $\vec{r}$ is in the x direction then E is constant in z, y planes

$$E(x,y,z,t) = E_0 \exp(i[\omega t - kx]) = E_0 \exp\left(i\left[\omega t - \frac{2\pi}{\lambda} x \right]\right)$$

- In general the wave equation for plane wave is

$$E(x,y,z,t) = E_0 \exp\left(i\left[\omega t - \vec{k} \bullet \vec{r}\right]\right)$$

- Where wave vector in direction of motion is $\left|\vec{k}\right| = \frac{2\pi}{\lambda}$

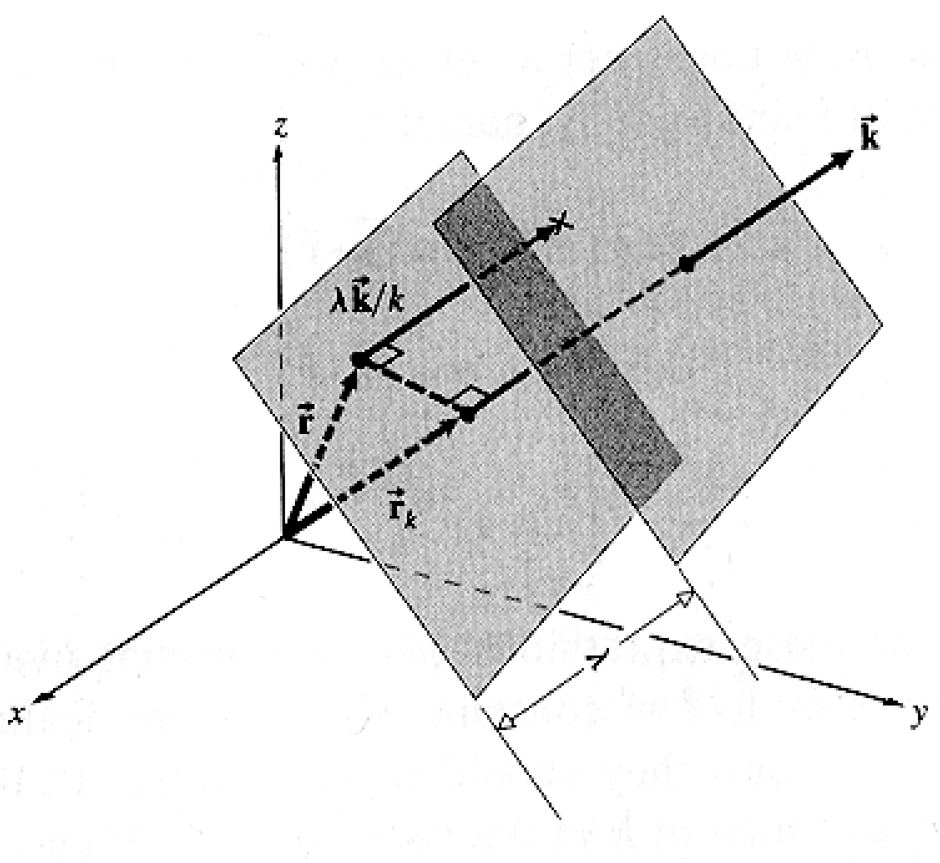


Figure 2.21 Plane waves.

Energy Flow and the Poynting Vector

- To get from E fields to light intensity talk about energy flows
- This occurs with the Poynting Vector S defined as

$$\vec{S} = \frac{1}{\mu_0}\left(\vec{E} \times \vec{B}\right) = c^2 \varepsilon_0 \left(\vec{E} \times \vec{B}\right)$$

- Where μ_0 is the magnetic permeability of free space
- When in a material replace by μ of the material
- This S represents the energy flowing past a point
- The energy lost in a material is dS/dx
- Occurs because the E and B field a nolonger perpendicular

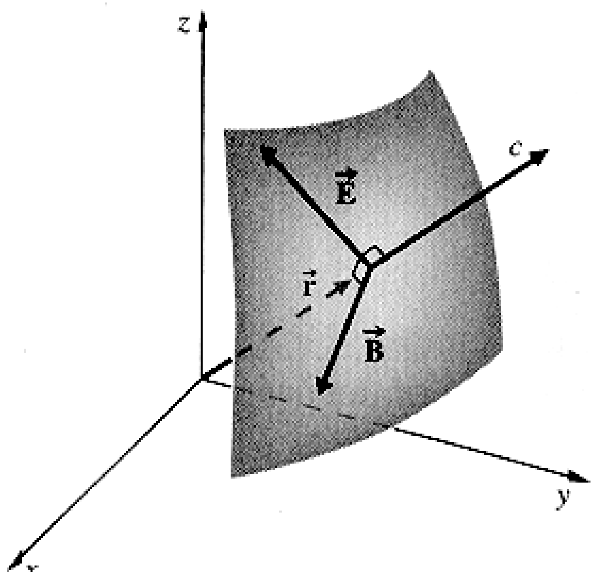


Figure 3.15 Portion of a spherical wavefront far from the source.

Gaussian Plane Waves

- Plane waves have flat emag field in x,y
- Tend to get distorted by diffraction into
  spherical plane waves and Gaussian Spherical Waves
- E field intensity follows:

$$u(x,y,R,t) = \frac{U_0}{R} exp\left(i\left[\omega t - Kr - \frac{\left(x^2 + y^2\right)}{2R} \right] \right)$$

where ω= angular frequency = 2πf

U_0 = max value of E field

R = radius from source

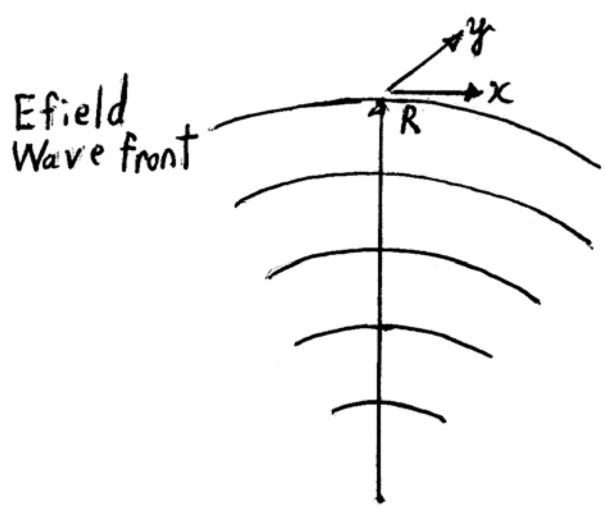
t = time

K= propagation vector in direction of motion

r = unite radial vector from source

x,y = plane positions perpendicular to R

- As R increases wave becomes Gaussian in phase
- R becomes the radius of curvature of the wave front
- These are really TEM_{00} mode emissions from laser



Irradiance or Light Intensity

- What we see is the time averaged energy of pointing vector

$$\langle S(t) \rangle = \int_{t-T/2}^{t+T/2} S(t)\,dt$$

- Where T is the period of the wave
- Called the irradiance I in Watts/unit area/unit time

$$I = \langle S \rangle = \varepsilon_0 c \langle E^2 \rangle = \frac{c}{\mu_0} \langle B^2 \rangle$$

- For sin waves this results in

$$I = \langle S \rangle = \varepsilon_0 c \langle E^2 \rangle = \frac{c\varepsilon_0}{2} E^2$$

- Not true in absorbing materials because
- E & B have different relationship & phase there