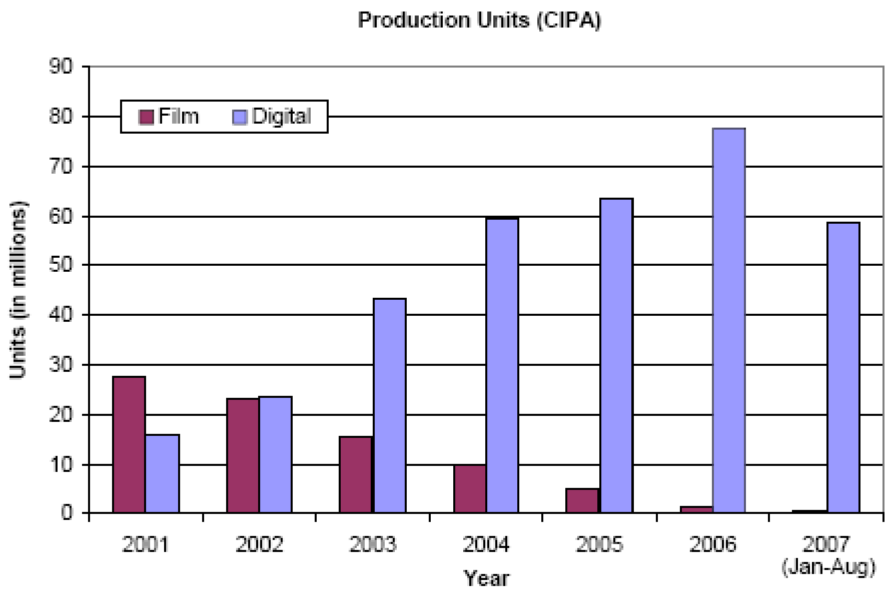
Why Study Optics?

- Optics one of the fastest growing technical fields
- Digital Cameras ~$24 Billion market
- High end digital cameras growing at 24% per year
- Lasers $4.9 Billion market
- Microchip Fabrication optical equipment ~$10Billion
- Optical Sensors now driving force in Microchip demand
- Light Emitting Diode lighting markets



Statistics of Production of Film and Digital Cameras

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)

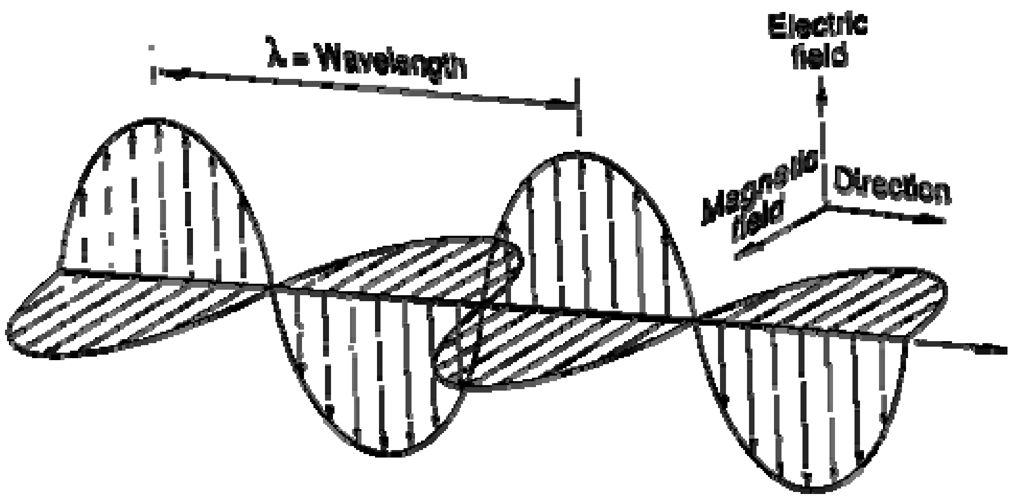
λ = wavelength

ω= angular frequency (radians/sec)

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

f = frequency (hertz)

τ= period (sec)



Light - Electro-Magnetic Radiation

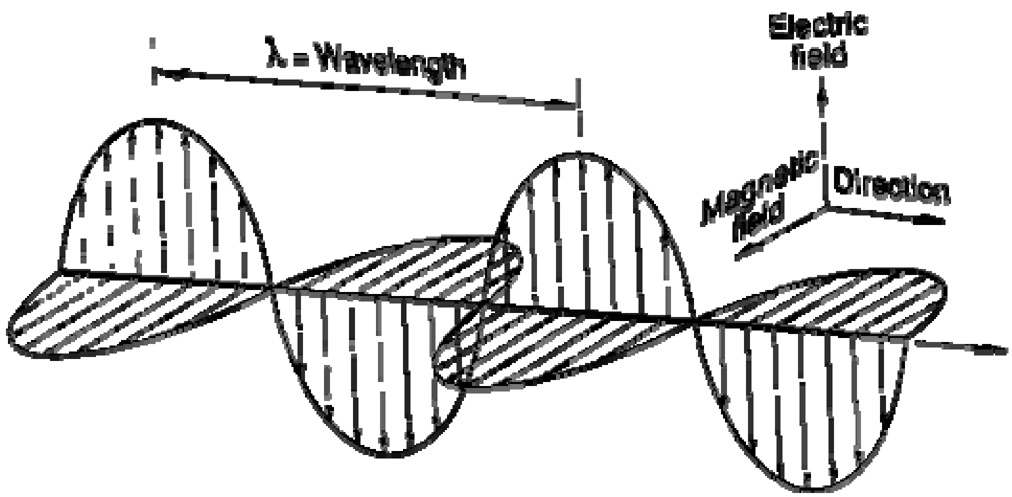
- Light in vacuum has Electric field and magnetic field at 90^o
- Obtained from Maxwell's Equations
- Electric wave

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

Where c is the velocity of light

- Magnetic wave

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



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

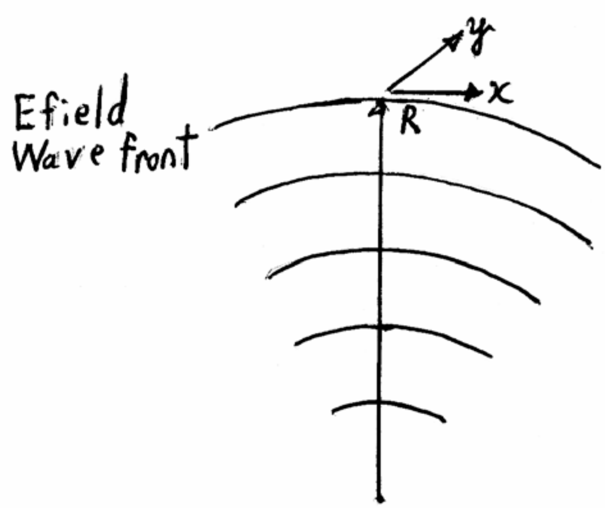
t = time

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



Black Body Emitters

- Most normal light emitted by hot "Black bodies"
- Classical 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 = 6.63×10^{-34} J s
c = speed of light (m/s)
λ = wavelength (m)
T = Temperature (^oK)
K = Boltzman constant 1.38×10^{-23} J/K = 8.62×10^{-5} eV/K

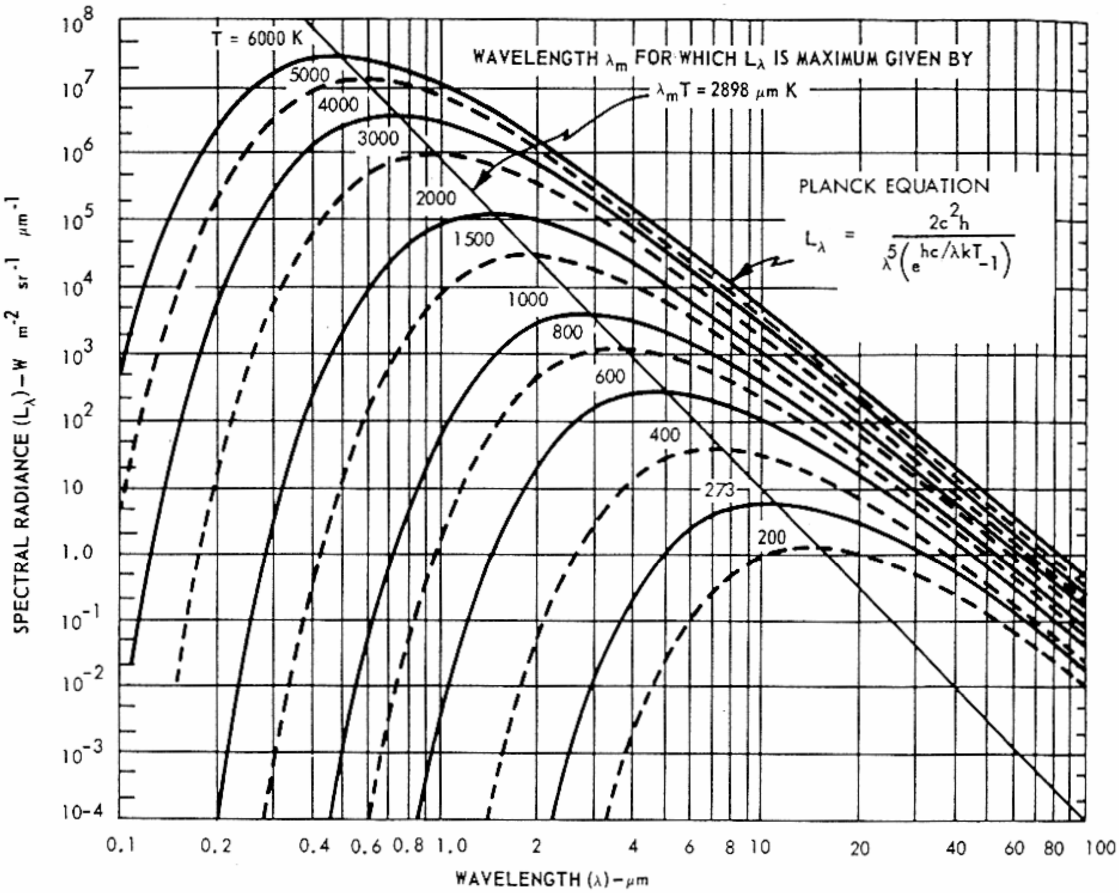


Fig. 4-1 Spectral radiance L_λ of a blackbody at the absolute temperature T shown on each curve. The diagonal line intersecting the curves at their maxima shows Wien's displacement law. Subdivisions of the ordinate scale are at 2 and 5.

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

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

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

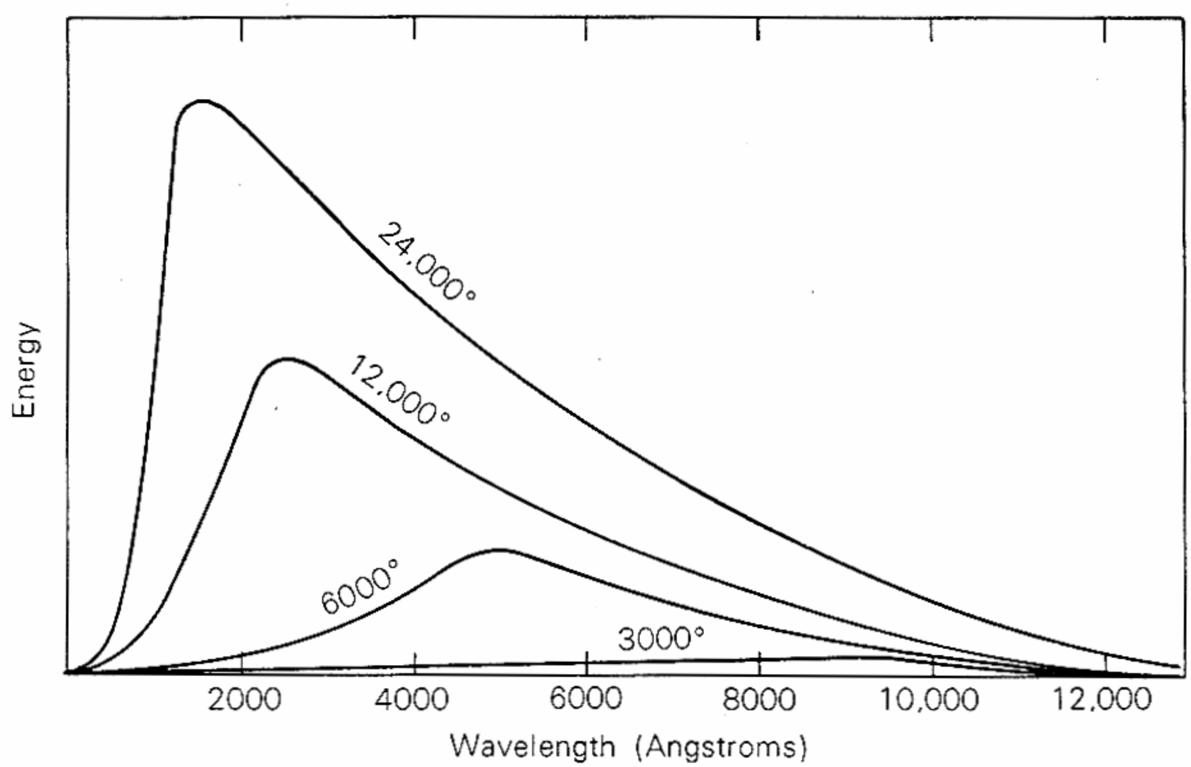


FIG. 10-17 Energy emitted at different wavelengths for black bodies at several temperatures.

Example of the Sun

- Sun has a surface temperature of 6100 ^{o}K
- What is its peak wavelength?
- How much power is radiated from its surface

$$\lambda_{\max} = \frac{2897}{T} = \frac{2897}{6100} = 0.475\,\mu m$$

- or Blue green colour

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

- ie 78 MW/m^2 from the sun's surface

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 and Atoms

- Light: created by the transition between quantized energy states

$$c = \nu\lambda$$

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

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

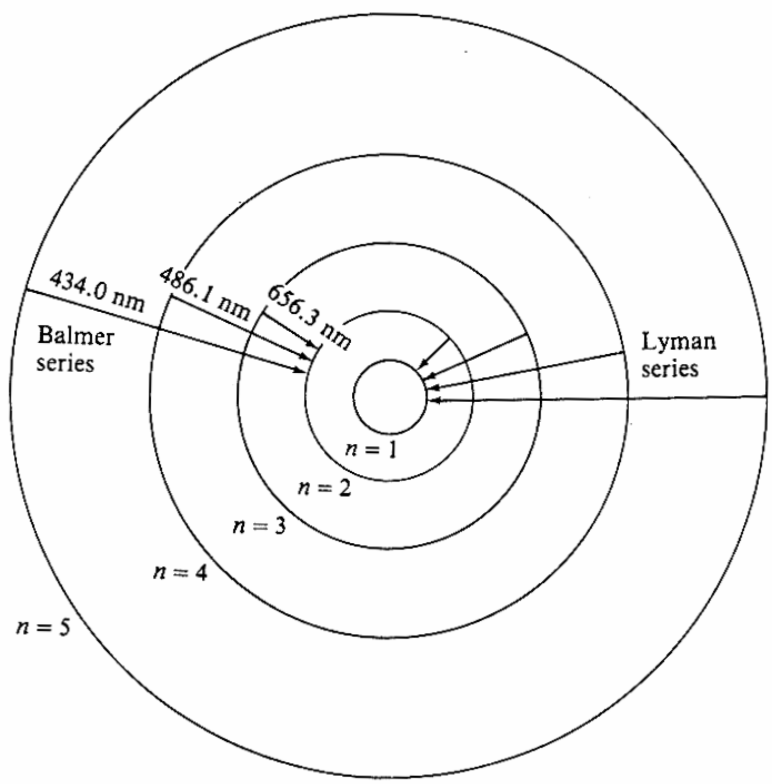


Fig. 1.8 A schematic diagram (not to scale) showing some allowed electron orbits in the Bohr model of the hydrogen atom. The electron transitions giving rise to some of the wavelengths in the line spectrum of hydrogen are also shown.