

Optics 2: Module 4 Summary

Spectrometry

Bohr Model of Atom

When electron moves from one energy level to another it absorbs or emits a specific amount (quantum) of energy.

Quantum: minimum amount of light that can be absorbed or emitted

Photon: a quantum (packet) of energy in the form of electromagnetic radiation.

Particle-like Properties of Light

Geometric shadows

Emission spectra

Wave-like Properties of Light

Refraction

Diffraction (bending around corners)

Interference

Absorption

An electron tends to stay in its ground state, but it can move to a higher energy level by absorbing a photon.

A photon can only be absorbed if its energy corresponds to exactly one of the energy levels of the atom.

Spontaneous Emission

When an electron in an excited state moves back to its ground state, it releases the energy in the form of a photon.

Electrons prefer to be in ground state, so this happens naturally.

Relationships of wavelength, frequency, and velocity

Velocity: $v = f\lambda$

Frequency does not change as light travels through various media.

Moving to a Denser Media

-frequency stays the same

-velocity is reduced

-wavelength is shorter

$v = c/n$ v : velocity c : 3×10^8 m/s n : index of material

$\lambda_{\text{medium}} = \lambda_{\text{vacuum}} / n_{\text{medium}}$

Wavelength for red light (633nm) in air is NOT the same wavelength at the retina due to index change in ocular media (1.336).

Example: $633\text{nm} / 1.336 = 474\text{nm}$

Energy of a Photon

Energy is directly proportional to the light wave's frequency (the higher the frequency, the more energy).

Energy is inversely proportional to wavelength

-the longer the wavelength, the less energy in the photon

-measured in electron volts (eV)

$\Delta E = hf$ h is Planck's constant = 4.136×10^{-15}

Energy of Photons Emitted from an Element

Each wavelength emitted is the result of an electron falling from a higher level to a lower level and emitting a photon.

Example Problem

What is the energy of a photon corresponding to 656.3nm?

$\Delta E = hf$

1. Convert from nm to meters

$$656.3\text{nm} = 656.3 \times 10^{-9}\text{m}$$

2. Convert from wavelength to frequency

$$c = f\lambda$$

$$3.0 \times 10^8 \text{ m/s} = f (656.3 \times 10^{-9})$$

$$f = 4.57 \times 10^{14} \text{ Hz}$$

3. Energy emitted per photon in electron volts (eV)

$$\Delta E = hf \quad \Delta E = (4.136 \times 10^{-15})(4.57 \times 10^{14}) = 1.89 \text{ eV per photon @ } 656.3\text{nm}$$

Emission vs Absorption Spectrum

Dispersion: separating a light source into component wavelengths

Refraction: uses a prism

Short wavelengths are deviated (refracted) more

Diffraction: uses a spectrometer

Long wavelengths are deviated (diffracted) more

Absorption Spectrum

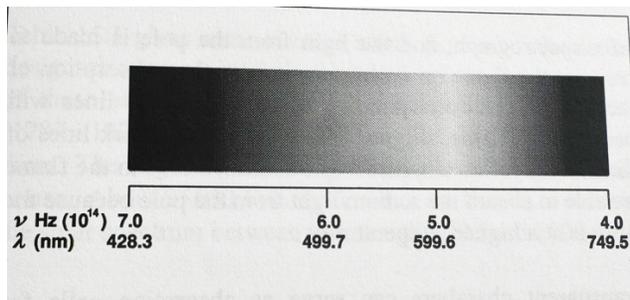
In an absorption spectrum black lines are wavelengths that are absorbed by the cold gas (non-excited).

Emission Line Spectrum

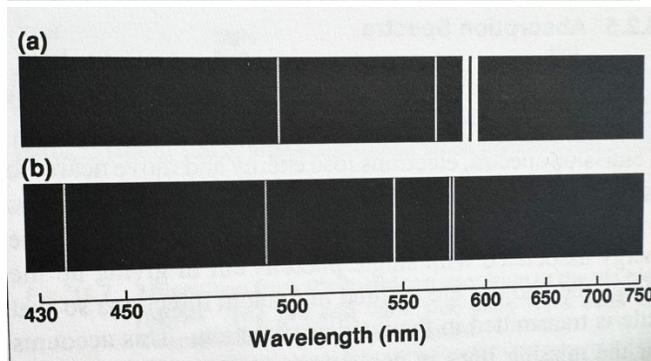
In an emission line spectrum, colored lines are wavelengths that are emitted by the excited gas.

When a gas is excited, it will emit the same wavelengths that it absorbs when it is in its cold state.

Continuous vs Line Spectrum



Continuous Spectrum



Line Spectrum

(both images: Tunnacliffe, 1996)

Sources of Optical Radiation

- Sunlight
- Incandescent Lamp
- Fluorescent
- LED (Light Emitting Diode)
- Discharge Tubes (gas-filled tubes)

Sodium Fluorescein

Absorbs higher frequency (shorter wavelength) “cobalt blue” and emits lower frequency (longer wavelength) yellow-green light.

Optical Radiation occurs when electrons fall back down to lower level and photons are released.

Blackbody Radiators

A blackbody is a theoretical “ideal absorber”

Absorbs all Electromagnetic Radiation (EMR) at particular temperatures.

Emits all wavelengths when heated.

Blackbody is an ideal emitter/radiator.

The peak intensity wavelength is inversely proportional to the temperature of the black body.

As temperature increases, peak intensity moves to lower wavelength.

Wien Displacement Law

The wavelength of peak intensity in black body emission decreases as temperature of blackbody increases.

Peak wavelength in nm = $\lambda_{\max} = b/T$

b: Wien's displacement constant = 2.898×10^6 nm-K

T: absolute temperature in Kelvin ($0^\circ\text{C} = +273.15\text{K}$)

As T gets larger, peak intensity is at lower wavelength

Total Radiant Exitance

Area (“M”) under / within blackbody radiation curve for a given temperature

$M = \sigma T^4$ (T in Kelvin) $\sigma = 5.67 \times 10^{-8}$ w/m²k⁴ (Stefan-Boltzmann constant)

Area M increases by a power of 4 with increased T

Graybodies and Emissivity

Graybodies emit a certain percentage “ ϵ ” of what a blackbody would emit at a certain temperature (peak wavelength does not change).

A graybody has similar distribution to that of a blackbody material except at a lower intensity.

Selective Radiator

Emissivity varies with wavelength.

Emissivity

$$M = \epsilon\sigma T^4$$

For blackbody: $\epsilon = 1$

For graybody: $\epsilon < 1$

LASERS

Light Amplification by Stimulated Emission of Radiation

Stimulated Emission

Incident photon passes by electron in excited state.

Energy of incident photon equals energy difference between excited and ground states for excited electron.

Characteristics for LASER Light

Monochromatic

Coherent (photons all in the same phase, frequency, and direction)

Directional

Powerful