

## 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  $c$ :  $3 \times 10^8$  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)

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

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

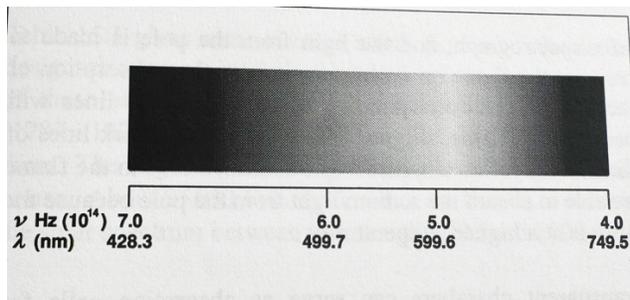
In an absorption spectrum black lines are wavelengths that are absorbed by the cold gas (non-excited).

### Emission Line Spectrum

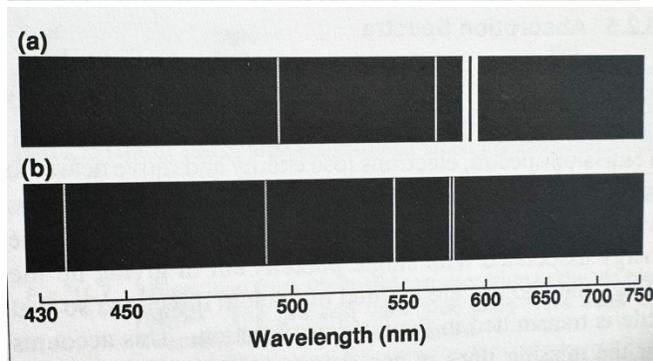
In an emission line spectrum, colored lines are wavelengths that are emitted by the excited gas.

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 =  $2.898 \times 10^6$  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/m<sup>2</sup>k<sup>4</sup> (Stefan-Boltzmann constant)

Area M increases by a power of 4 with increased T

### **Graybodies and Emissivity**

Graybodies emit a certain percentage “ $\epsilon$ ” 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